Direct testimony of Exxon witnesses before the State of Wisconsin Division of Hearings and Appeals. Volume 2

[Place of publication not identified]: Exxon Minerals Co., [s.d.]

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CRANDON PROJECT

DIRECT TESTIMONY OF
EXXON WITNESSES

BEFORE THE
STATE OF WISCONSIN
DIVISION OF HEARINGS AND APPEALS

APPLICATION OF EXXON CORPORATION FOR PERMITS TO BUILD AND OPERATE AN UNDERGROUND MINING AND ORE CONCENTRATING COMPLEX LOCATED IN FOREST COUNTY, WISCONSIN	) IH-86-18

VOLUME II

BEFORE THE
STATE OF WISCONSIN
DIVISION OF HEARINGS AND APPEALS

Application of Exxon Corporation for Permits to Build and Operate an Underground Mining and Ore Concentrating Complex Located in Forest County, Wisconsin	))))	IH-86-18

<u>TESTIMONY OF HOWARD S. LEWIS</u>

MINING PERMIT: RECLAMATION PLAN

Q. Please state your name and occupation and describe your education and experience.

A. My name is Howard S. Lewis. I have worked for Exxon on its Crandon Project since 1980 as an environmental specialist. I have a Bachelor's Degree in zoology from Utah State University granted in 1967 and a Master of Science Degree in wildlife ecology from the University of Wisconsin, Madison, granted in 1972. I am a member of the American Ornithologists' Union, the American Society for Surface Mining and Reclamation, the American Society of Mammologists, the Ecological Society of America and The Wildlife Society. A more complete description of my background can be found in my resume, which is EXHIBIT 274.

Q. What is a reclamation plan and how does it relate to the mining plan?

A. Wisconsin statutes require the applicant for a mining permit to submit a proposal for reclaiming the area to be physically or environmentally affected by the proposed mining. The area must be returned to its original state or, where that is not feasible or desirable, to a condition of long-term environmental stability.

Q. Has Exxon prepared and filed a reclamation proposal in connection with its mining plan?

A. Yes. The reclamation plan is found in EXHIBIT 111. It contains a description of the final land use of the reclaimed areas and of long-term monitoring and maintenance programs, states who will be legally and operationally responsible for maintenance, and projects reclamation costs.

Q. Explain your involvement in the development of the Reclamation Plan for the Crandon Project.

A. I have been involved in the environmental and regulatory aspects of the Project since August, 1980. I have worked specifically on the development of the Reclamation Plan since 1981. I have coordinated the work of consultants and Exxon staff in preparing the plan and written those plan sections relating to vegetation in the reclaimed areas. My assignment included consulting with the DNR's Mine Reclamation Section throughout the development of the Plan and addressing its questions, comments, and recommendations on the content and organization of the Plan.

Q. What qualified you to direct preparation of the Reclamation Plan for the Project?

A. I have had training and experience in botany, soils, wildlife ecology and natural resource interrelationships, all basic components of land reclamation. I am familiar with the biological and physical principles and concepts that are important in successful land rehabilitation. Since my involvement with the Crandon Project began in 1980, I have worked with other scientists to document environmental conditions in the site area. Therefore I am familiar with the specific soil, plant and wildlife interrelationships necessary to reestablish indigenous plants and animals after mine closure. I have conducted and directed sampling programs and inventories of plant communities, soils, and wildlife populations and have made recommendations for monitoring and managing areas affected by other developments like the Crandon Project. I also have field experience in establishing and maintaining agronomic plants and native grasses, legumes, shrubs and trees.

Q. How did the DNR participate in the development of the Reclamation Plan?

A. The DNR was involved throughout the development of the plan. DNR staff members met initially to discuss with Exxon the content and organization of the plan. They reviewed and commented on the first Reclamation Plan submitted in December, 1982 and on the revised plan submitted in February, 1985. DNR comments were used as the basis for revisions incorporated into the final proposed Reclamation Plan, which is Volume II of EXHIBIT 111.

Q. Describe the areas which will be reclaimed?

A. The project site comprises 735 acres, all of which - except for facilities which can be converted to alternate uses when mining ends - will be reclaimed during construction, during mining operation or at the time the mine closes. For convenience, the Reclamation Plan divides the project area into seven management units coincident with the Project's major facilities. Units 1-6 are shown on EXHIBIT 275. Unit 1 is the mine/mill site. The railroad spur is Unit 2, the access road is Unit 3. The Mine Waste Disposal Facility, which we abbreviate as MWDF, the Mine Refuse Disposal Facility (the MRDF), and the reclaim ponds comprise Unit 6. Unit 4 is the MWDF access road and tailings transport pipeline corridor. The discharge pipeline corridor and the discharge structure on Swamp Creek is Unit 5. The mitigation and contingency facilities constitute Unit 7.

Q. When does reclamation begin?

A. Reclamation begins almost as soon as construction begins and continues during construction and operation. Final reclamation will be completed after the mine closes. EXHIBIT 276 illustrates the five intensive reclamation development phases for the reclaim pond/MRDF/MWDF area. Partial reclamation of the mine/mill site, access road, railroad spur, reclaim ponds and tailing pond T1 will occur during the first five years of the Project. From Project year 6 through 32, partial reclamation of tailings ponds T2 and T4 will be completed and tailings ponds T1 and T3 will be fully reclaimed. Cells 1 and 2 of the MRDF will also be reclaimed during this period.

Surface facilities which cannot be converted to other uses will be removed during the four year period after the mine closes. All areas disturbed during removal of facilities and final grading and any previously unreclaimed areas will be reclaimed during this closure period. Monitoring and maintenance of the reclaimed areas will occur throughout the thirty year long-term care period following Project closure.

Q. Explain the procedures that will be followed in reclamation.

A. The detailed steps in the reclamation process for each unit are described in the Reclamation Plan in EXHIBIT 111. In general, reclamation plans are implemented as facilities are constructed. For example, topsoil will be salvaged and stored during construction. Erosion control measures will also be taken during construction. Areas disturbed during construction will be revegetated when construction is complete. When the mine has closed, surface facilities will be removed, underground shafts will be sealed and land form grades will be established to blend with the existing undisturbed topography.

Revegetation procedures will be carefully planned and followed to ensure a successful rehabilitation program. Topsoil which was salvaged and stored during construction will be applied and seedbeds will be prepared for the plant materials which are identified in the Reclamation Plan. After seeds and plants are put in place, mulch and fertilizer will be applied as needed.

Finally, steps will be taken to control erosion and to assure the growth of the plant materials.

Q How will topsoil be salvaged and stored?

A. Following clearing and grubbing of the sites, scrapers will be used to salvage topsoil to a depth of nine to twelve inches. That procedure will result in a blend of organic and mineral soils which will be stored at locations shown on EXHIBIT 275. Wetland soils will generally be blended with other organic and mineral soils and stored in common stockpiles. Some wetland organic soils may be stored temporarily adjacent to the excavations and then reapplied as topdressing on the regraded surface of the facilities being constructed, or used in landscaping.

Q. How will erosion be controlled from the time construction begins?

A. In the mine/mill site area, three surface drainage basins will be installed and used for runoff control. Those basin areas will be cleared and excavated first, and grading will then progress outward. Where necessary, other temporary siltation basins, hay or straw bale ditch retention checks or filter fabric will be used to control runoff and erosion. Graded areas not scheduled for immediate development will be revegetated with a temporary ground cover after rough grading. As an area is subsequently developed, it will be connected with the previously developed drainage system before other construction begins. Construction is thus staged to reduce the need for temporary erosion control measures.

In the access corridors, runoff and erosion control facilities will be installed concurrently with the earthwork activities. These include permanent culverts and a system of retention basins built into ditch bottoms. Rip-rap, filter fabric, hay matting and settling basins integrated into the ditch system will eliminate sediment flow into nearby streams and wetlands.

Erosion control facilities will be installed at the MWDF site before clearing and grubbing begins for each phase. A series of ditches, dikes and retention ponds will be used to control erosion. Surface runoff with potential for high suspended solids will be diverted through sedimentation ponds with overflow weirs.

Surface drainage basins in the mine/mill site are designed to contain runoff volumes from a 25 year, 24-hour rainfall. The temporary erosion control facilities in the MWDF area are sized for the 100 year, 24-hour rainfall.

Q. When will disturbed areas be revegetated?

A. Graded land surfaces will be revegetated as soon as practical after grading is completed. Areas not scheduled for immediate development will be seeded with a temporary ground cover. In the mine/mill site, graded areas not designated for Project facilities will be landscaped. Vegetation will be established on the embankments of the reclaim ponds, tailings ponds and MRDF cells upon completion of final grading. Under favorable plant growth conditions, revegetation will be initiated within a few days of seedbed preparation.

Q. What plants will be used in revegetating the disturbed areas?

A. The plant species to be used for revegetation are listed in Table 1 of my prefiled testimony. Both indigenous and introduced herbaceous plant species will be used. DNR approval will be obtained for seed mixtures before planting. Introduced species will predominate where immediate erosion control or soil stabilization for less than two growing seasons is the objective. Where indigenous plants are to be permanently established, a mixture of indigenous and introduced species

TABLE 1
INDIGENOUS AND INTRODUCED PLANT SPECIES
FOR USE IN TEMPORARY AND PERMANENT RECLAMATION

	Plant Species: Indigenous	Plant Species: Introduced
Grasses/Sedges		
	Big bluestem	Annual ryegrass
	Bluejoint grass	Barley
	Canada wildrye	Canda bluegrass
	Cord grass	Foxtail millet
	Indiangrass	Japanese millet
	Little bluestem	Oats
	Pennsylvania sedge	Perennial ryegrass
	Reed canary grass	Rye
		Smooth brome
		Timothy
		Winter wheat
Legumes		
	Leadplant	Alsike clover
	Lupine	Birdsfoot trefoil
	Roundheaded bushclover	Red clover
		Wagner flat pea
Forbs		
	Aster	
	Black-eyed Susan	
	Butterfly weed	
	Dotted mint	
	Evening primrose	
	Flowering spurge	
	Goldenrod	
	Smartweed	
Ferns		
	Bracken fern	
	Sweet fern	
Trees		
	Ash	
	Aspen	
	Basswood	
	Black spruce	
	Hemlock	
	Red maple	
	Red oak	
	Red pine	
	Sugar maple	
	Tamarack	
	White spruce	
	White birch	
	White cedar	
	White pine	
Shrubs		
	Dogwood	
	Hawthorn	
	Hazel	
	Highbush cranberry	
	Viburnum	

Note: This is a typical list of plants for use in site reclamation and is subject to modification.

indigenous and introduced species will be used. The seed mixtures selected will be depend upon soil, slope and moisture conditions at the various sites.

Trees and shrubs will be planted in the mine/mill site, the access road corridor, and the reclaim pond/MRDF/MWDF area. Plantings will be selected and located to promote community diversity, enhancement of aesthetic quality and to accelerate the successional process. EXHIBIT 277 illustrates plant development in the mine/mill site about fifteen years after installation. EXHIBIT 278 shows plant development about five years after the final reclamation of tailing pond T4.

Q. Why will non-native or introduced plant species be used at some locations?

A. The introduced species selected generally can be established more quickly than indigenous species, an important characteristic where vegetative cover is needed to stabilize the soil. Where the goal is permanent revegetation, the introduced species in the mixture will primarily consist of annuals that will serve as a nurse crop to provide a more suitable environment for the longer lived indigenous species.

Q. What role will invasion of plants from adjacent undisturbed areas play in establishing native plant species in the reclaimed areas?

A. Invasion of herbaceous and woody plant species from nearby seed sources will be allowed to occur in all reclaimed areas. Over time, these invading species will help fill in open areas with trees and shrubs like those in the adjacent undisturbed plant communities, and will augment the stock planted during the final reclamation phase. However, because the immediate reestablishment of native groundlayer and woody species is a primary goal, natural invasion is of secondary importance compared to the direct seeding and planting of native species.

Q. How will newly created slopes be stabilized?

A. The grades of newly created slopes have been designed to minimize erosion. Vegetative cover will be established as soon as possible to further control erosion, and mulches will be applied as temporary controls until the vegetation becomes established.

Q. Are terraces, benches or other slope reduction structures necessary for the outside slopes of the MWDF embankments?

A. No. Studies by Golder Associates, EXHIBIT 181, and Ayres Associates, EXHIBIT 163, showed that the expected water velocities during high intensity storms will not cause erosion on slopes like these with one foot of fall for every three feet of horizontal run. Surface runoff will be concentrated in the swales along the embankments between the ponds, and then will be directed down portions of the slopes protected with rip-rap facing. Moreover, the Monitoring Plan includes regular inspections of pond T1 after reclamation for evidence of soil erosion. If erosion proves to be a problem, corrective action such as rip-rap facing, slope drains or slope benches will be retrofitted as appropriate and similar corrections will be made in the design of the other ponds. Since there will be six years between the reclamation of ponds T1 and T2, there is adequate time to evaluate the need for additional erosion control measures.

Q. How will the quality and quantity of reestablished vegetation be monitored?

A. Representative segments of the reclaimed areas will be monitored closely during the first five years after final reclamation to insure the establishment of stable plant communities. Monitoring studies will be designed to determine plant species composition and diversity, relative frequency, percent cover, biomass, and vigor or condition of the plants. The results of the first five years studies will be evaluated to determine the scope and need for monitoring thereafter.

Q. Describe the final topography of the units being reclaimed.

A. EXHIBIT 279 illustrates the final landform grades in the mine/mill site area after all major surface facilities have been removed. EXHIBIT 267 shows the final topography in the MWDF area after closure and reclamation.

In the railroad spur, access road and pipeline corridors, the differences between the interim and final topography will be minor along the entire corridor lengths. Where agriculture was the premining land use, the corridor will be regraded to approximately the same elevation as the adjacent undisturbed agriculture land. The bridges along the access road and railroad corridors will be dismantled and removed. Roads maintained for monitoring purposes will be similar in appearance to logging roads in the area, which provide corridors for wildlife movement and improved but limited access for people. In general, the reclaimed topography of all areas except the MWDF and MRDF will approximate the original appearance of the site. In the MWDF area, the final grades and contours at the edges of those facilities will be blended into the surrounding undisturbed topography.

Q. What will be done with the facilities after the mine is closed?

A. The answer depends on whether alternative uses for some of the facilities are available at the time of closure. Alternative uses such as an industrial park, agriculture or intensive forestry have been identified. But the feasibility of such alternatives cannot be evaluated now, more than thirty years before a choice of alternatives can actually be made. If alternative uses would prove more beneficial than final reclamation at the time the mine is closed, an amended reclamation plan containing a description of the new proposed uses will be submitted to the DNR.

Q. What will be done if there are no alternative uses for the project facilities?

A. During the four year closure period, all major surface facilities will be dismantled and removed from the site. EXHIBIT 280 identifies the major surface facilities and the action that will be taken with each one at the time of closure. Broken concrete from the mine/mill site will be placed in low areas to assist in establishing the desired contours for the final site reclamation. The broken concrete used to fill those low areas will be mixed and covered with borrowed earth. Underground mining equipment with potential resale value will be salvaged. In the MWDF area, the following facilities will be maintained after closure: a fence around the MWDF, an access road to the MWDF from Deep Hole Lake Road, and roads necessary for inspecting and monitoring the MWDF during the thirty year long-term care period. Those roads will be left in place until a certificate of completion of the reclaimed land is issued by the DNR. Monitoring devices, such as stream and lake gauges and wells, will also remain at the end of the closure period.

Q. What will happen to the landscaping in the mine/mill site during final reclamation grading?

A. Regrading after the mine closes has been designed to minimize disturbance to existing forest and landscape plantings. However, turf and groundlayer vegetation adjacent to the buildings and the road corridors will be disturbed. Those areas will be seeded and planted in the same fashion as other areas disturbed during reclamation. Irregular clumps and strips of indigenous trees and shrubs will also be planted in portions of the regraded areas. Such plantings will accelerate the successional process and will be located to promote blending with the remaining landscape plantings and the adjacent undisturbed vegetation around the perimeter of the mine/mill site.

Q. How will the shafts leading to the underground mine be sealed?

A. A reinforced concrete plug designed to prevent the passage of ground water will be placed where each shaft enters the bedrock. All steel, service pipelines and utilities above the ground water isolation plugs will be removed and the shafts will be backfilled with overburden to within ten feet of the final surface grade after reclamation. All the surface structures, including the concrete shaft lining near the surface, will be demolished and combined with the final grade fill before the area is revegetated. Identification and security structures will be placed on the sites, and there will be provisions there for monitoring ground water.

Q. Describe the measures to be taken to prevent subsidence of the surface over the underground portions of the mine and of the tailings deposited in the MWDF.

A. During the course of normal mining operations, the stopes from which ore is removed will be backfilled with the course fraction of the mill tailings and crushed waste rock. The drifts, raises and shafts will not need to be filled because they are too small to experience stresses sufficient to cause rock failure which could lead in turn to surface subsidence. An evaluation by John D. Smith Engineering Associates in 1982, which is EXHIBIT 193 in the hearing records, showed that the proposed mining practices would cause negligible changes in surface topography. However, any subsidence that does occur will be reclaimed by regrading and revegetation. As described in the MWDF Feasibility Report, EXHIBIT 114, no subsidence of the tailings cover system is expected to occur.

Q. Will routine inspections and repairs of the MWDF be performed during the long-term care period?

A. Yes. As described in the MWDF Feasibility Report, EXHIBIT 114, there will be routine inspections of the MWDF. If a potentially defective condition is found during an inspection, corrective action will be taken at the earliest practical time.

Q. Does the Reclamation Plan for the Crandon Project meet all state requirements contained in NR 132 and NR 182 and Wis. Stat. §§ 144.80 et seq.?

A. Yes. The plan addresses all statutory and regulatory requirements.

Q. For how long will Exxon be responsible for the site after closure of the operations?

A. The long-term care period continues for 30 years after the closure requirements have been met. However, several sources of funding are available to continue long-term care functions at approved facilities, should they be required, after the site owner's responsibilities for long-term care have ceased. These include the Waste Management Fund (WMF), Environmental Repair Fund (ERF), and revenues set aside from the net proceeds tax. The purpose of the WMF is to provide a source of funds to continue long-term care functions at approved facilities after the owner's long-term care activities have ceased. The purpose of the ERF is primarily to fund remedial actions at abandoned sites without engineering and on improperly closed facilities; however, approved facilities requiring remedial action during site operations or after closure could be funded from the ERF. These funds are financed by "tippage" fees on all wastes disposed at approved disposal sites. In addition to these environmental funds, the state has provided that 10 percent of all net proceeds taxes paid by a mine operator are put into a revenue tax fund set aside solely for the municipalities within which a particular mine is located. This fund can be used for several purposes, including compensating municipalities for reclamation expenses.

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EXHIBIT 274

HOWARD S. LEWIS

EDUCATION: B.S. 1967 Utah State University, Zoology, Chemistry
M.S. 1972 University of Wisconisn-Madison, Wildlife Ecology, Botany

EXPERIENCE:

1980-Present <u>Environmental Engineer, Crandon Project, Exxon Minerals Company, Rhinelander, Wisconsin.</u>

Prepare permit applications and supporting technical reports to fulfill state and local regulatory requirements for the proposed Crandon Project. Direct contractors in the completion of aquatic ecology, terrestrial ecology, water quality, cultural resource, noise, reclamation and wetland studies in support of permit applications. Develop scopes of work for contracts and monitor and control contract budgets. Develop manpower requirements, schedules and budgets for completing project task. Organize and coordinate technical staff in completing permitting-related documents. Responsible for editing permit applications and supporting technical reports prior to submittal to state and local agencies. Communicate the status and results of project investigations to the public and governmental agencies. Interface with state regulatory personnel to resolve questions and comments on permit applications and reports and to monitor progress in preparing permits.

1974-1980 <u>Manager, Lincoln, Nebraska Regional Office, Hazleton Environmental Sciences Corporation.</u>

Project Manager of environmental studies associated with energy development projects. Responsible for preparing permitting documents for the construction and operation of nuclear, coal and pumped storage power plants and directing the technical staff in the completion of field and laboratory studies and reports. Performed administrative functions (budget development, cost control and hiring and evaluating staff) and managed a staff of professional biologists and water resources personnel. Edited and provided direction in the completion of all permit applications and project reports. Published the results of the biological and water quality investigations in a book on the Missouri River. Interacted with federal and state natural resources and pollution control personnel and project engineers. Responsible for planning, quality control and management of personnel and projects.

HOWARD S. LEWIS (Experience continued)

1972-1974 Section Head, Terrestrial Ecology, Industrial Bio-Test Laboratories, Northbrook, Illinois.

Supervised and directed personnel in the Wildlife Ecology and Plant Sciences Groups in completing studies to fulfill federal and state regulatory requirements for construction and operation of nuclear and coal fueled power plants and coal gasification facility. Responsible for the design, execution and completion of field and laboratory studies and reports. Served as Project Manager for environmental assessments. Evaluated potential project sites, developed scopes of work, and manpower requirements for environmental evaluations. Communicated the results of the investigations to clients and regulatory personnel.

1971-1972 Associate Biologist, Industrial Bio-Test Laboratories, Northbrook, Illinois.

Planned and implemented wildlife and vegetation field surveys to fulfill federal and state regulatory requirements for a proposed refinery and nuclear power plant. Met with federal and state resource personnel to discuss siting, construction and potential impact of industrial facilities. Prepared environmental impact reports.

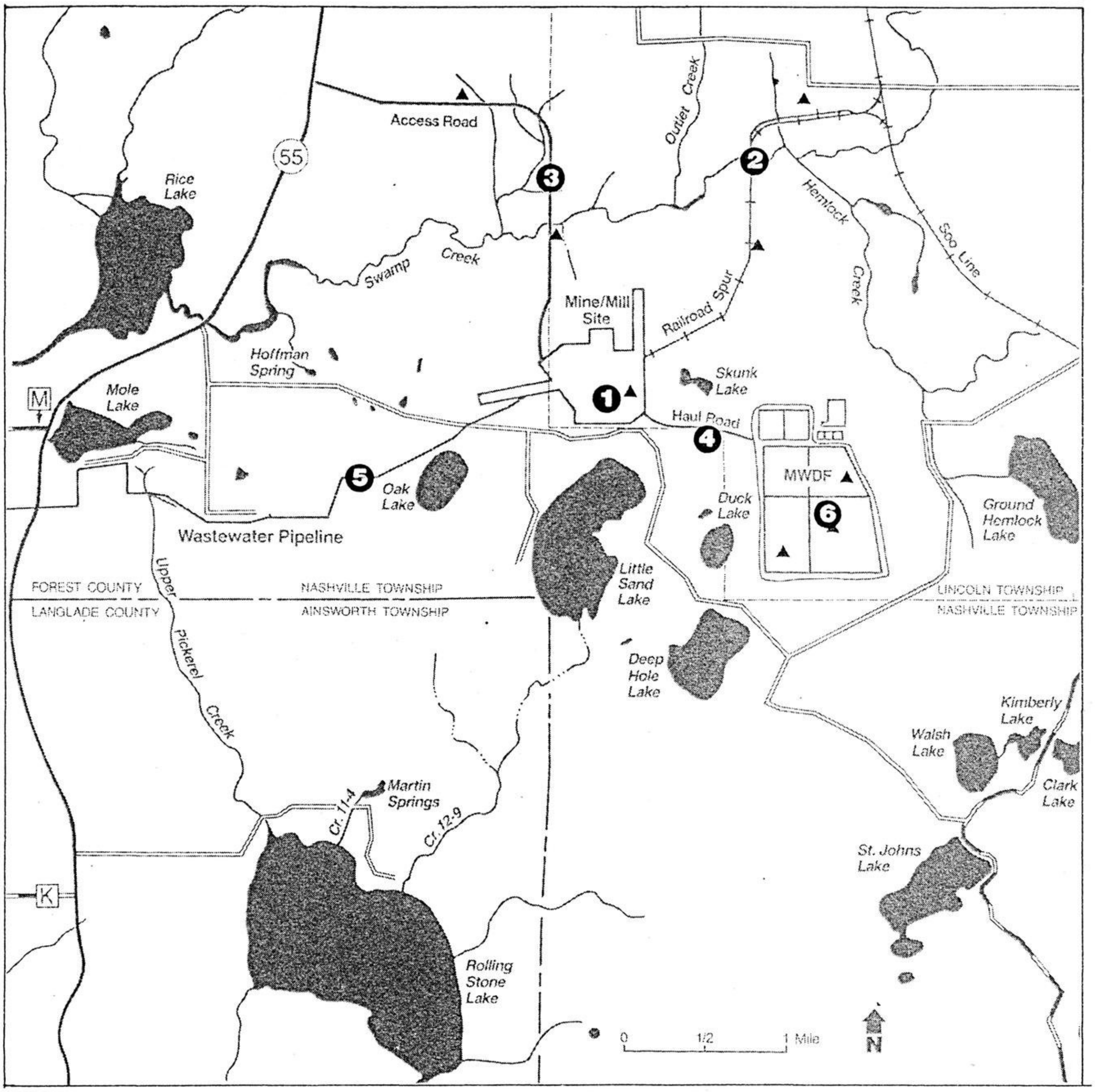
1969-1971 Research Assistant, University of Wisconsin, Madison, Wisconsin.

Designed and initiated a wildlife research study in Wisconsin. Determined population densities, habitat use and mortality factors of wildlife. Published a portion of the results in a professional technical journal.

Affiliations:

American Ornithologists' Union
American Society of Mammalogists
Ecological Society of America
The Wildlife Society

Crandon Project Facilities

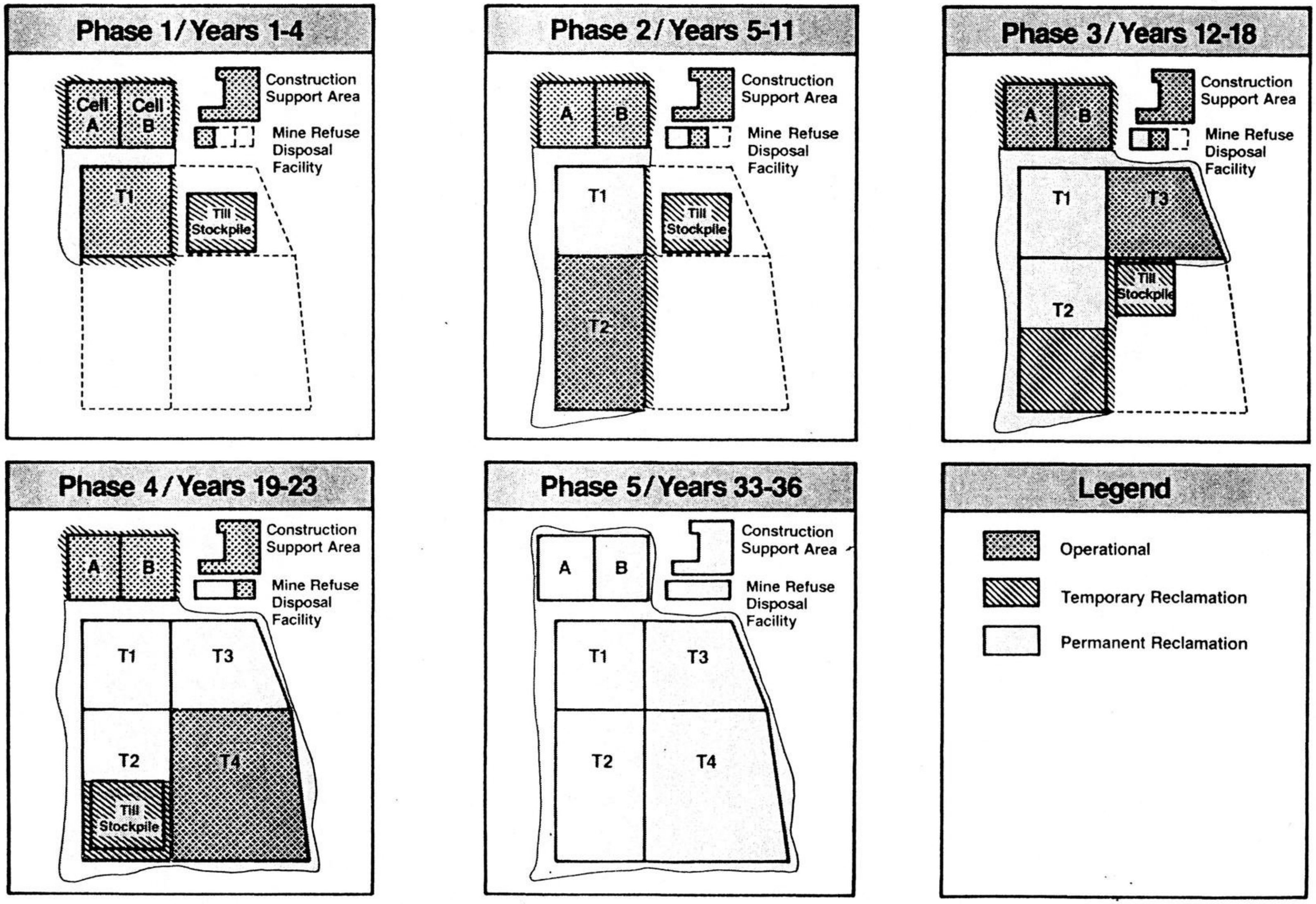


Legend

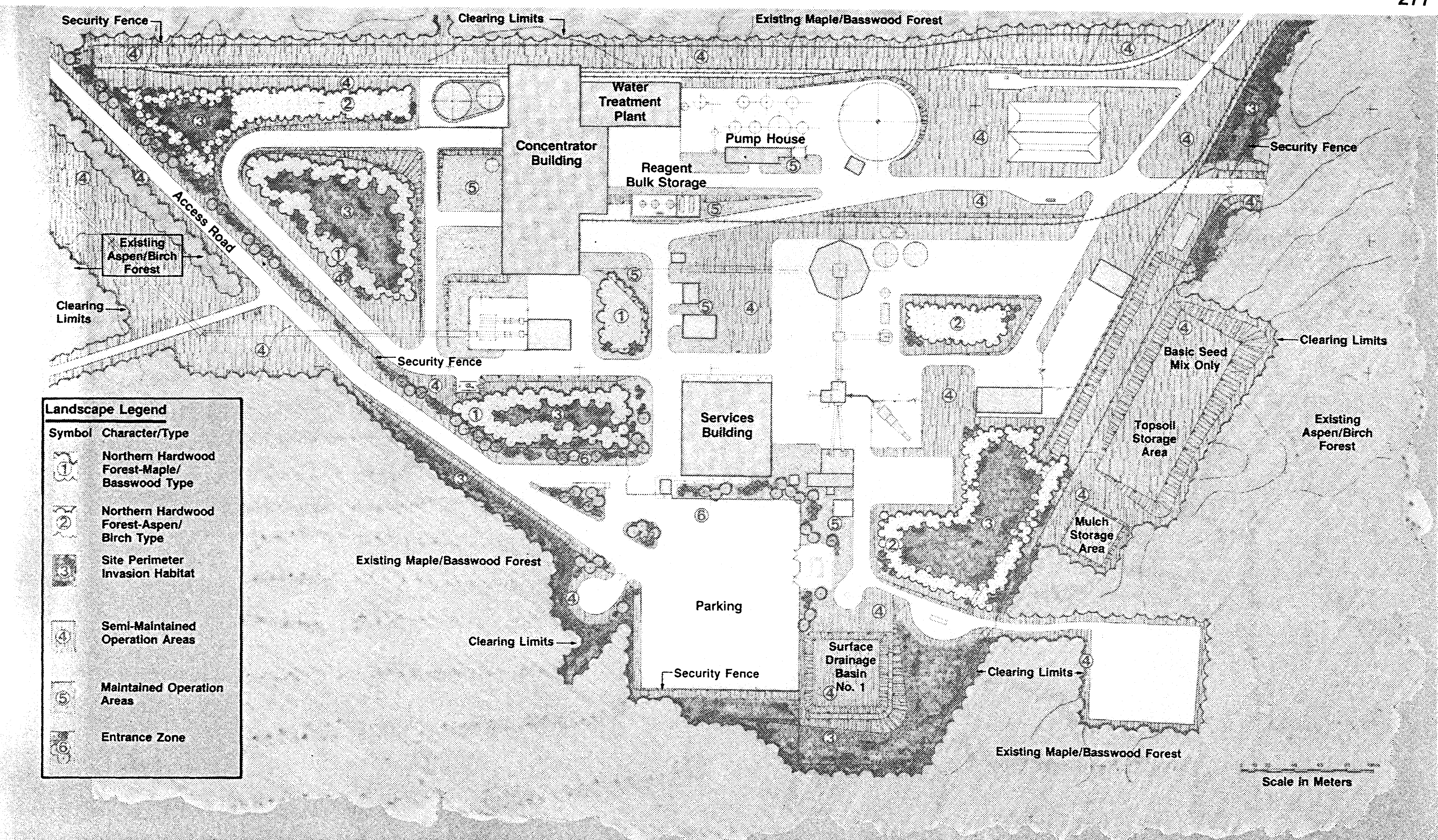
▲ Topsoil stockpile area

❶ Management unit

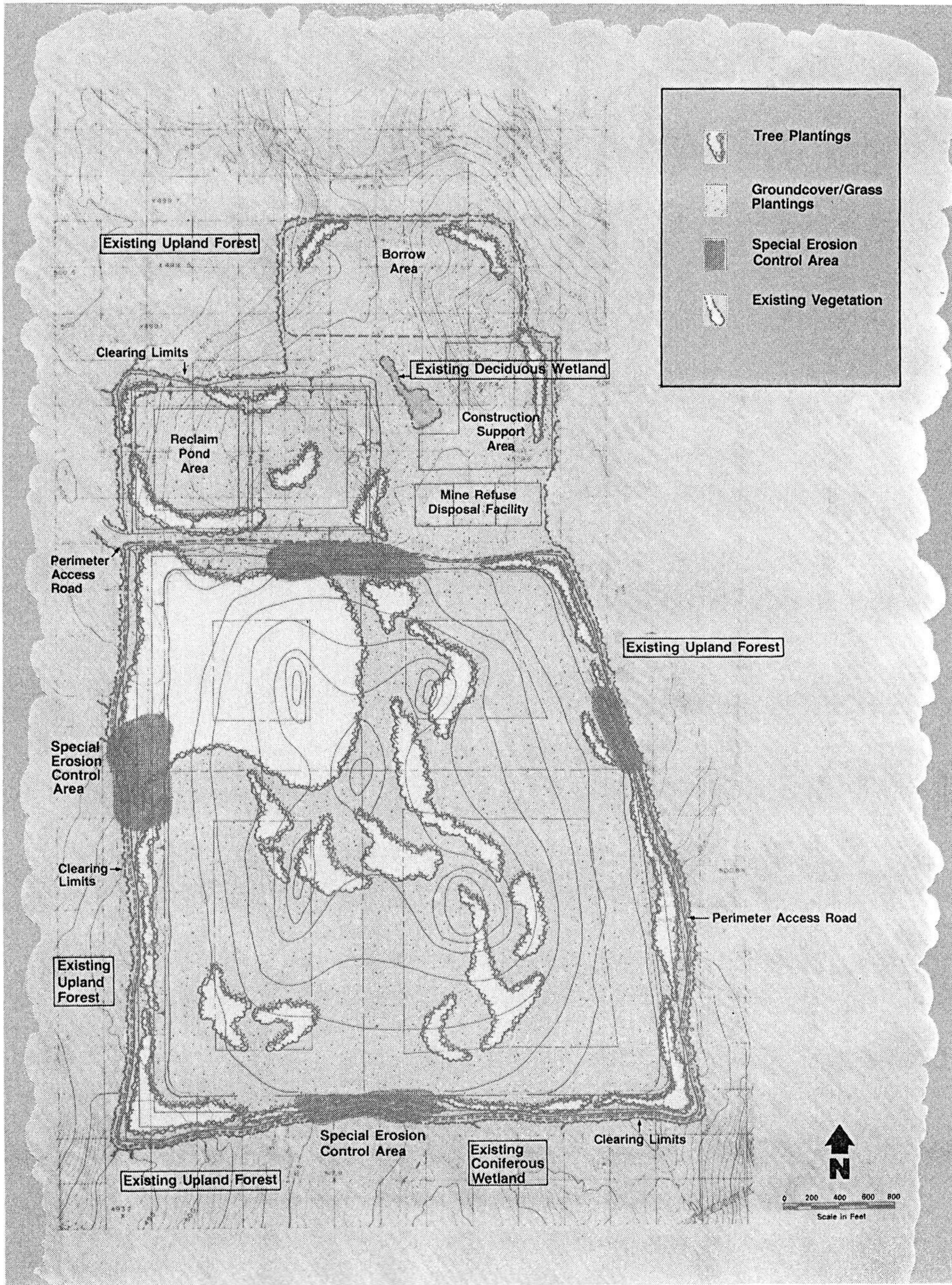
MWDF Area Reclamation



Mine/Mill Site Landscape Plan

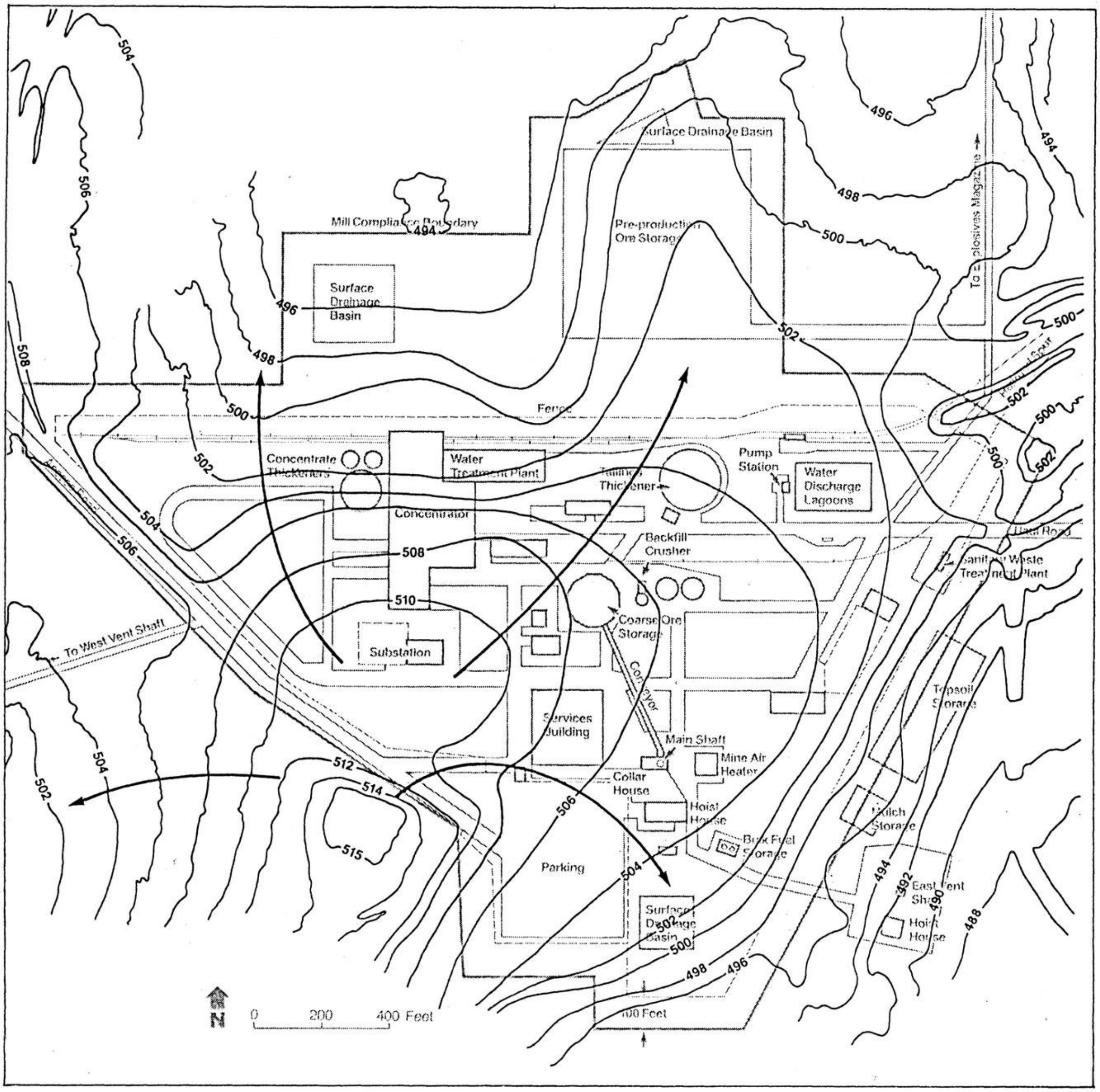


MWDF Area Reclamation Plan



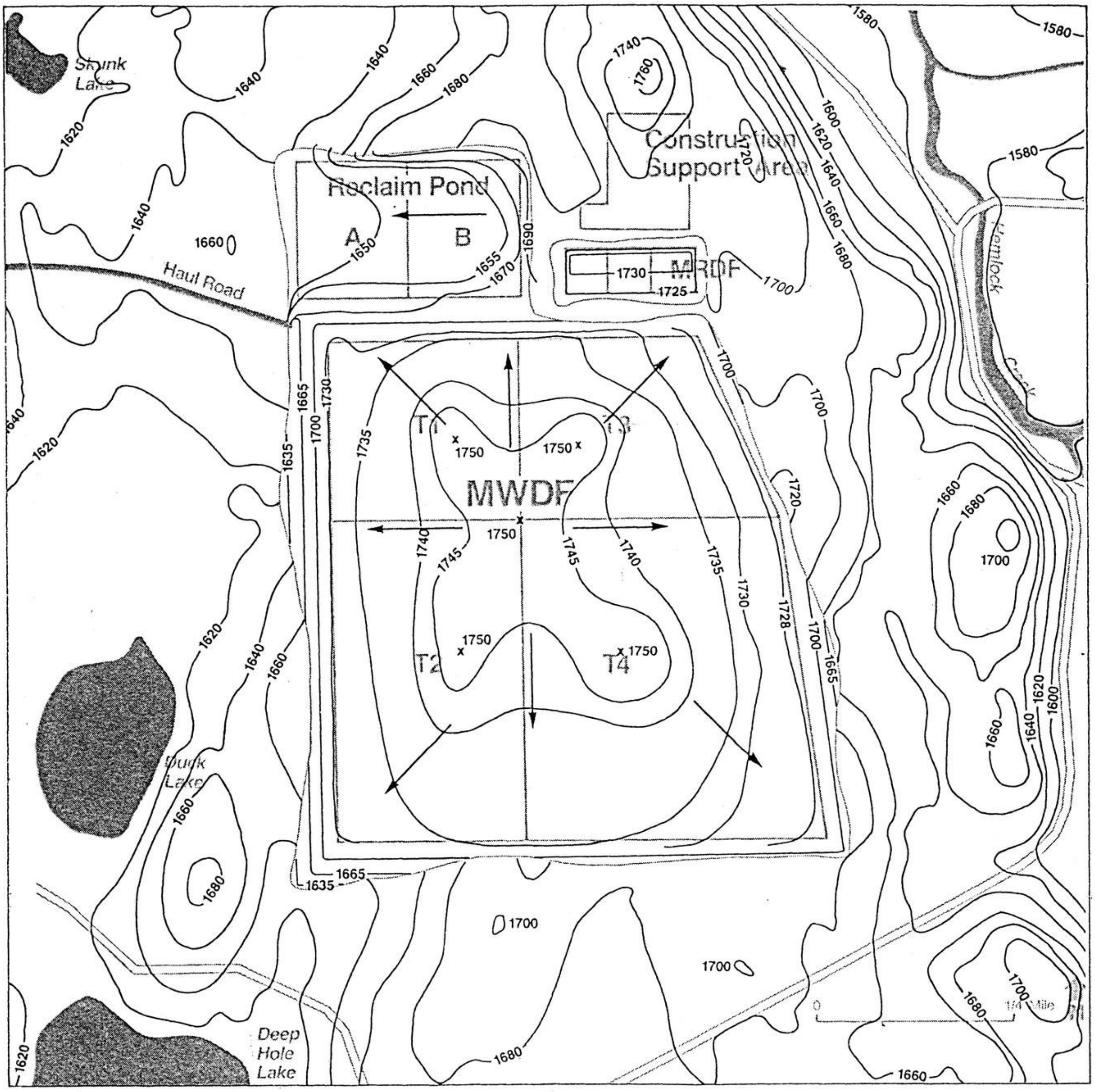
Final Landform Grades

Mine/Mill Site



Reclaimed Surfaces

MWDF Area



Summary of Project Area Final Reclamation

Mine/Mill Site	Dismantle and Regrade.
Railroad Spur	Remove Rails, Ties, Ballast and Subballast. Replace Topsoil and Final Grade.
Access Road	Remove Pavement and Base. Replace Topsoil and Final Grade.
Haul Road and Tailings Transport Corridor	Cover Base with Soil Layer. Plug Pipe Ends and Leave Pipeline in Place.
Water Discharge System	Remove Discharge Structure at Swamp Creek, Plug Pipe Ends, and Leave Pipeline in Place.
MWDF and MRDF	Remain in Place, Covered and Capped.
Reclaim Pond	Remove Liner System and Embankments. Replace Topsoil and Final Grade.

BEFORE THE
STATE OF WISCONSIN
DIVISION OF HEARINGS AND APPEALS

Application of Exxon Corporation for Permits to Build and Operate an Underground Mining and Ore Concentrating Complex Located in Forest County, Wisconsin	))) IH-86-18)

TESTIMONY OF DR. RICHARD P. HERBST

AIR PERMIT APPLICATION

Q. Would you please state your name?

A. My name is Dr. Richard P. Herbst.

Q. What is your occupation and by whom are you employed?

A. I am currently an Engineering Associate with Exxon Chemical Americas, in Baytown, Texas and was previously assigned to the Exxon Minerals Company. I have been employed by Exxon since 1979.

Q. Would you please briefly discuss your educational background and your work experience?

A. I received my undergraduate training at the University of Wisconsin (B.S.) and completed graduate programs at the University of Wisconsin (M.S.) and the University of Pittsburgh, culminating with receipt of my Ph.D degree from the latter in 1969. I then taught for seven years in the University of Wisconsin system. I taught courses and directed student research in the areas of botany, biology, ecology, aquatic biology, microbiology and limnology. My studies and research have included work on the structural and functional relationships of both aquatic and terrestrial ecosystems. Several papers have been published on this research.

I have also served as Associate Director of Environmental Research for Limnetics/CDM (Camp Dresser and McKee), an environmental consulting firm located in Milwaukee, Wisconsin, and as Manager of the Environmental Sciences Division at Environmental Research & Technology, Inc. (ERT), headquartered in Concord, Massachusetts.

I was elected Chairman of the Town of Palmyra, Wisconsin, and in this capacity, represented my constituents in many matters, including environmental concerns, before county and state government. As a member of the Wisconsin Towns Association, I was instrumental in advising state government on farm, inland lake restoration, wetland and tax issues with frequent testimony on various legislation before assembly and senate committees. I was an environmental policy advisor to Governor Lucey and have been a principal author of several major sections of WDNR regulations, including the mining rules.

Q. Do you have a curriculum vita with further details concerning your educational and employment background?

A. Yes. I have attached a copy of it to my prefiled written testimony as EXHIBIT 283.

Q. What will be the focus of your testimony today?

A. I will present testimony in support of Exxon's air permit application, and will be discussing the predicted effects of the Crandon Project on air quality.

Q. What has been the history of your involvement with the air permit application for the Crandon Project?

A. The Revised Air Quality Permit Application Report for the Crandon Project, which appears as EXHIBIT 116 in the record, was completed by me and by personnel under my direction from within and outside Exxon. That document constitutes Exxon's formal application to the Wisconson Department of Natural Resources for the necessary Crandon Project air permit. It includes baseline data, emission factors and estimated air contaminant emission rates, predicted air quality, and evaluation of current and projected air constituent concentrations.

All of this information is set forth in Exxon's application in great detail and, because of its extremely technical nature, it is not easily presented or summarized in oral testimony. Moreover, because of the pollution control equipment incorporated in the Project design and the resulting reduced quantity of air emissions, the regulatory and permitting requirements are relatively straightforward. For these reasons, I would propose to keep my testimony relatively short and focused on a general level.

Q. Let me begin, Dr. Herbst, with a few general questions. First, what are the various sources of air emissions associated with the Crandon Project?

A. Referring to EXHIBIT 201, the various emission sources will be located within the mine/mill site and the MWDF area. They include drilling and blasting activities and air heating in the underground mine, the effects of which will be discharged from the exhaust raises. Mill surface facilities and activities that will constitute emissions sources include ore transport and crushing, the concrete batch plant, concentrate handling and shipping, building heating, fuel transfer and storage, and emergency diesel generators. Construction activities associated with the Mine Waste and Mine Refuse Disposal Facilities will also produce emissions.

Q. What will be the nature and amount of the emissions from these sources?

A. Project air emissions will include total suspended particulates (TSP), sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO), hydrocarbons (HC), and lead (Pb). The total for each of these parameters from all the stationary sources will be below 250 tons (st) per year, and Exxon will, therefore, not be required to obtain a PSD (Prevention of Significant Deterioration) permit pursuant to state and federal law. Under governing law, the Crandon Project will be classified as a new minor stationary source.

Q. You indicated that the total emission of each of these parameters will be "below" the 250 ton/year PSD threshold. How far below?

A. Specifically, we estimate emissions from stationary sources of TSP will be 39.2 tons/year; for sulphur dioxide, 27.9 tons/year; for nitrogen oxides, 57.9 tons/year; for carbon monoxide, 94.2 tons/year; for hydrocarbons, 7.3 tons/year; and for lead, 0.18 tons/year.

Q. What impact will these emissions have on the ambient air quality of the surrounding area?

A. As set forth in great detail in the Revised Air Quality Permit Application Report, the predicted ambient air quality at the Project boundary will meet all federal and state standards. The net air quality effects predicted for the construction, operation and reclamation phases of the Project are minimal. As a result, no deleterious effects are projected to occur to either the soil, vegetation, or animals. Because federal and state standards will be attained, the Project will maintain the air quality for the area.

Q. Let me now turn to some more specific questions about your work. Dr. Herbst, what was the overall framework you followed in evaluating the emissions associated with the Crandon Project and their compliance with federal and state regulations?

A. Basically there were four major activities included in the Crandon Project air permit report submittal. First, all of the Project sources and the type and quantity of the emissions were identified. Second, a model was used to determine how those emissions might affect ambient air quality. Third, any predicted changes in ambient air quality were compared with the regulatory limits. Finally, even though we found that the estimated concentrations were well below standards, we evaluated their effect on the environment.

Q. Let me ask you some specific questions on the air permit application and how it addresses the requirements of Wisconsin's laws and regulations. To begin with, what are the general application requirements for the air permit application?

A. The implementing portion of Wisconsin law is section 144.391, Wis. Stats. This section provides for major and minor source permits. An application is required for a construction or new operation permit. In addition, the Wisconsin Department of

Natural Resources (DNR) reviews the air permit application for consistency with federal regulations, such as the New Source Performance Standards (NSPS) for metallic mineral processing plants (set forth at 40 CFR Part 60, Subpart LL).

The Wisconsin Air Quality Program requires owners of all non-exempt stationary sources of potential air pollution to apply for a construction permit from the DNR. Several factors must be considered in determining what must be addressed in the permit application, including source type (major or minor); source location (attainment or non-attainment area); and whether the source is new or existing.

The governing regulations implementing sec. 144.391, Wis. Stats., are found in Chapter NR 154 of the Wisconsin Administrative Code. These rules require the submittal of a permit application referred to as a Notice of Intent (NOI) prior to permitting the construction of a new stationary source.

Exxon submitted its application, which is EXHIBIT 116 in the record, in December 1985. This application contains all of the information required by the regulations, including corporate information, the sources and locations of emissions, construction and operations timelines, process descriptions, the composition and amounts of raw materials and fuel to be used, pollution control equipment information, stack dimensions and parameters, and emission rates.

Q. Please summarize the information contained in these submittals?

A. In summary, the Project will be a new minor stationary source since each of its potential air contaminant emissions will total less than 250 tons per year and is not a source type listed under Section 169(1) of the Federal Clean Air Act. Analysis of the estimated air contaminant emission rates and their predicted effect on the environment as shown in the air permit report indicate that Project sources will not violate (or exacerbate violation of) air quality standards or ambient air increments as promulgated under sec. 144.375, Wis. Stats. Further, although Wisconsin has not yet adopted the U. S. Environmental Protection Agency's (EPA) standards of performance for metallic mineral processing plants, Exxon has designed its facilities (and the DNR has reviewed the air permit report) to ensure compliance with these federal standards.

The Project will comply with all requirements for sources related to prohibited emissions (NR 154.09), open burning limitations (NR 154.10), particulates (NR 154.11), sulfur (NR 154.12), organic compounds (NR 154.13), carbon monoxide (NR

154.14), lead (NR 154.145), nitrogen compounds (NR 154.15), malodorous emissions (NR 154.18) and hazardous pollutants (NR 154.19). These requirements of NR 154 have all been discussed in Section 4 of the Revised Air Quality Permit Application Report and Chapters 1 and 4 of Exxon's Environmental Impact Report (EIR) (EXHIBIT 158).

Forest County is an attainment area for all of the air contaminants estimated for the Crandon Project. Therefore, Forest County does not currently have air pollution alert, warning or emergency periods to maintain its air quality. However, a Malfunction Prevention and Abatement Plan will be developed in accordance with NR 154 to ensure proper maintenance and operation of the Project's air pollution control equipment. Adherence to this Plan will maintain consistency with the good industrial practice and safe operating procedures required by NR 154.20.

Wisconsin has adopted primary and secondary standards for TSP, sulfur dioxide, nitrogen oxides, carbon monoxide, hydrocarbons, and lead. It has also promulgated air increment concentrations for TSP and sulfur dioxide. The 3- and 24-hour air increment concentrations can be exceeded once per year, whereas the maximum allowable concentration of any air contaminant in any attainment area cannot exceed the maximum concentrations permitted under the primary or secondary air standards.

NR 404 requires that the air quality impact of a proposed stationary source(s) be determined "... at such locations where people might reasonably be exposed for time periods consistent with the ambient air quality standards for the pollutants...." As shown in the Revised Air Quality Permit Application Report and the EIR, the proposed Project has been analyzed for all of its sources and is predicted to meet all ambient air quality standards. Further, the data and analyses in these reports demonstrate that the estimated emissions will not impact the air quality at any locations where people might reasonably be exposed.

Q. What will the company do to minimize the emissions of the air contaminants that you've mentioned?

A. Some of the specific control techniques for TSP emissions include periodic use of water or chemicals for control of dust, the paving of frequently traveled plant roads and the parking lot, the installation of baghouse and insertable collectors to retain over 99% of the dust generated by various processes, and chemical spraying or covering of materials being transported within the Project boundary and in the transportation of materials to shipping locations. Documentation of these control methods and their efficiencies are found in Appendix B and Section 2 of the Revised Air Quality Permit Application Report.

These portions of the air permit report also present information indicating the specific control techniques for sulfur dioxide, nitrogen oxides, carbon monoxide, visible, and organic compound emissions.

Although mobile sources are not included in the emission estimates used to determine the PSD designation of the Project, NR 154 does contain regulations limiting the air contaminant emissions from these sources. In particular, NR 154.17 limits emissions of TSP, sulfur dioxide, nitrogen oxides, carbon monoxide, and hydrocarbons, as well as any odors or visible concentrations of contaminants except for uncombined water. The Project will meet these requirements, as shown in Sections 2 and 4 of the Revised Air Quality Permit Application Report.

Q. How did you go about determining the amount of emissions from Project facilities?

A. First, all potential emitting sources of the Project were identified and their component air emissions determined from the current design of the facilities. Next, the operating mode and process rate was estimated for the sources. Once this was known, an EPA source book was used to provide the current air emission rates for each potential source of the Project. Finally, estimates of Project air emissions were calculated and totalled. The methodology, calculations and results of this effort are presented at length in the Revised Air Quality Permit Application Report.

Q. How did Exxon go about making the impact determinations?

A. The ambient air quality impact of the Project operations was assessed by performing a dispersion modelling analysis for TSP, sulfur dioxide, and nitrogen oxides concentrations. The impact of estimated carbon monoxide, hydrocarbon and lead emissions were analyzed by interpolation to the modelling results. The objective of the modelling analysis was to determine compliance with the federal and state ambient air quality standards. The EPA's Industrial Source Complex (ISC) model was used to predict the potential air quality effects, and is recommended by the EPA for assessing fugitive particulate (TSP) emissions.

The model calculations for annual mean and short-term (3-hour and 24-hour) ground level air pollutant concentrations were performed with the ISC model using one year of meteorological data. These data are conservative because they are based on stronger easterly wind direction and speed components than we actually measured at the site area through the monitoring program. As a result, the modeled ambient concentrations for all the air quality parameters are higher than what we expect will actually occur. In other words, our modelling is based on conservative assumptions and the actual concentrations should be even lower than those predicted by the model. Actual input of Crandon Project air emission rates used the annual and 24-hour estimates for TSP, sulfur dioxide, and nitrogen oxides.

As illustrated by EXHIBIT 284, a dense receptor grid was selected, and the maximum air quality impact from the Project was predicted for each of the 123 locations shown on the exhibit. These modelling points, or receptors, were located along the modelling boundary and beyond, including the locations of the air quality monitors used for the Project in 1978. The estimated air emissions are from sources that have short stacks with release heights below building roof levels, and from area sources of fugitive dust emissions, all of which are near ground surface. For these reasons, maximum air emission concentrations from Project sources will occur in close proximity to their point of origin with minimal concentrations beyond the modelling boundary.

Q. What were the results of the modelling analysis from the standpoint of TSP emissions?

A. EXHIBIT 284 shows the predicted annual average TSP concentrations beyond the modelling boundary which we attribute to the Project. The maximum annual average TSP concentration predicted from all sources was 4.29 ug/m^3 at receptor 80. This predicted TSP concentration is less than 6 percent of the primary federal and state standard of 75 ug/m^3. As can also be seen from EXHIBIT 284, the predicted TSP concentrations beyond the modelling boundary are even lower, generally less than 1 ug/m^3, (i.e., 2% of the standard).

The second highest 24-hour TSP concentration predicted was 22.65 ug/m^3 at receptor 46. The highest 24-hour average TSP concentration from stationary sources (excluding the access and haul roads, and the MWDF) was 2.8 ug/m^3 at receptor No. 32, which has no additive effect on any other receptors. This concentration was attributable to the diesel generators and the west exhaust raise (WER), which have their release locations immediately southeast and south of this receptor. This maximum predicted 24-hour average TSP concentration for the stationary sources is less than 1 and 2 percent of the primary and secondary standards (260 and 150 ug/m^3, respectively).

Q. What were the modelling results for estimated sulfur dioxide and nitrogen oxides emissions?

A. The predicted maximum annual sulfur dioxide concentration was 2.1 ug/m^3, which occurred at receptor No. 52. The second highest, 24-hour and 3-hour predicted concentrations were 25.0 and 186.0 ug/m^3, respectively, which also occurred at receptor No. 52.

These predicted sulfur dioxide concentrations resulted from mobile source air emissions during construction activities being conducted at the MWDF. However, because the model assumed such activities were being performed for a full day, and the 3-hour second highest concentration occurred during Period 8 (9:00 pm to midnight), a time period during which no actual MWDF construction activity will be conducted, this predicted value represents an unrealistic condition.

The highest predicted annual nitrogen oxides ground level concentration was 3.8 ug/m^3 at receptor No. 52. The principle source of this low concentration appears to be mobile vehicles at the MWDF.

Q. What analysis procedure was used to estimate carbon monoxide, hydrocarbons, and lead emissions, and what were the results?

A. Carbon monoxide concentrations were interpolated from the sulfur dioxide modelling results with appropriate conversion factors as is explained in detail in the air permit report. The highest estimated carbon monoxide concentrations were 2025.3 and 1802.5 ug/m^3 on a 1-hour and 8-hour basis, respectively.

Hydrocarbon and lead concentrations were estimated by interpolation from the nitrogen oxides and TSP results, respectively, as is also discussed in detail in the air permit report. Hydrocarbon emissions are approximately 14 percent of nitrogen oxides concentrations. The calculated maximum average 3-hour hydrocarbon concentration is 47.1 ug/m^3.

Lead emissions from the Project will be released as small particles and, as a result, the estimated ambient concentrations can be conservatively calculated from modeled TSP quantities. Estimated lead emissions are approximately 0.0047 percent of TSP concentrations. The estimated maximum 3-month average lead concentration is 0.01 ug/m^3.

Q. Lead is not the only metal you analyzed. The DNR requested Exxon to examine the potential effects of air emissions for other metals. Although there are currently no standards for these potential air emissions, would you please describe the evaluation you completed for other metals and what the results are?

A. Extremely low ambient concentrations can be predicted for other metals which might originate with Project activities. For example, the highest 24-hour average TSP concentration predicted by the ISC model at the property boundary for all sources is approximately 28.9 ug/m^3. Most of these particles will originate from the soil because of construction activities (i.e., excavation and embankment development), and it is estimated that approximately 6 percent of the particles might actually be wind-blown tailings from the disposal pond then currently in operation. Therefore, only a small percentage of the particles will have metal concentrations similar to that of the impounded tailings.

As explained in detail in the air permit report, we analyzed potential concentrations of aluminum, arsenic, cadmium, copper, mercury, and zinc. Even using the unrealistic "worst case" assumption that all particulates were wind-blown tailings (rather than being primarily soils), the projected concentrations would still be far below the guidelines established by the American Conference of Governmental Industrial Hygienists (ACGIH) for worker health. Specifically, these predicted metal concentrations would be 0.02 percent or less of the ACGIH guidelines.

Q. How do the results compare with regulatory limits set by the federal and state governments?

A. As seen on EXHIBIT 285, the predicted ambient air quality parameter concentrations are added to the background concentrations to provide the estimated Project impact on ambient air quality standards. These are compared on the exhibit with the National Ambient Air Quality Primary and Secondary Standards. As indicated, the combined background and estimated Project air emissions maintain all state and federal ambient air quality standards during all phases of the Project.

Q. In summary, has the Project evaluation indicated compliance with Wisconsin air quality laws and regulations and is Exxon requesting any exemptions from established standards?

A. In my professional opinion, Exxon has fully satisfied all legal requirements, and its modelling predictions demonstrate that the Project will meet all applicable federal and state standards. Therefore, there will be no need for any type of conditional permit or any other variance from the regulations.

Q. Dr. Herbst, moving beyond the question of compliance with various regulations, what will be the effect of Crandon Project emissions on the surrounding environment?

A. The net air quality effects predicted for the construction, operation, and reclamation phases of the Project will be minimal. Some dusting will occur to vegetation species nearest the major construction, operation, and reclamation activities of the Project. However, since the vegetation acts as a filter, no harmful effects are expected and rainfall will wash the vegetation regularly. Air emissions other than dust are of such minor concentrations that no effects on the vegetation or soils is predicted.

No deleterious effects are projected to occur to animal populations. Moreover, since the vegetation and soils are also expected to be unaffected by the Project air emissions, no animal food sources or habitats should be altered. Therefore, no deleterious effects are projected to occur to animal populations of the site area because of Project related air emissions.

Some emissions from activities performed as part of the Project construction and operation will be visible from off-site locations. The emissions visible from the Project are expected to be in the air vented from the mine exhaust shafts, especially immediately following explosive detonations. These blasting occurrences will be short duration (15 minutes) and on an infrequent basis.

The mine air exhausted during periods of extremely cold weather will also be visible beyond the property boundary. The primary visible component will be water vapor resulting from the saturated air leaving the mine. In all cases, the vented air should not have an objectionable color or odor, and its visibility will be restricted to the immediate areas surrounding the property boundary.

The general public will be protected because ambient air quality will meet all federal and state standards for public health and welfare. In addition, to ensure maximum protection to the health and safety of employees, all applicable work related regulations of the state and federal agencies will be attained by the Project.

Q. Thank you, Dr. Herbst.

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EXHIBIT 283

Curriculum Vita

Richard P. Herbst

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Baytown, TX 77522

Phone: (713) 425-2358

Professional Experience: Exxon Minerals and Chemical Companies, 1979-Present. Senior Environmental Associate - Environmental & Regulatory Affairs.

Responsible for interfacing with domestic and international project staff for developing permitting strategy, schedules, and planning and implementing necessary environmental studies and quality reports. Participated in the development and completion of all major documents submitted in support of permit applications for the Crandon Project in Wisconsin. I was the principal author of state regulations dealing with hazardous wastes and mine waste disposal, ground water standards for disposal facilities, wetlands use and surface water discharges. Also responsible for coordinating permitting activities and negotiations with agencies as well as developing workable regulations with agencies. Staff of the Nuclear Regulatory Commission (NRC) cited the ground water monitoring and statistical analysis program I developed for a uranium tailings disposal facility as the model for the United States.

Manager, Environmental Sciences, ERT, 1975 - 1979. Responsible for managing five departments (Ecology, Industrial Hygiene and Safety, Chemistry Labs, Water Quality Engineers, and Water Treatment Design Engineers) conducting projects throughout the USA and internationally. Developed the business plan, staffing requirements and initiation of the Company's new venture into marine sciences and local project management for many activities of the energy companies. Also established the central support staff for hazardous waste disposal and mining projects in the southwest. Personally responsible for the total management for the client in permitting several offshore and onshore drilling rigs and production platforms, two "grassroots" refineries and coal and nuclear fueled power plants.

Developed quality assurance/control and environmental audit capabilities for internal and external corporate activities. This division conducted and completed studies on over 100 projects ranging from original design to trouble-shooting and all aspects, including the socioeconomics, of facility permitting. Personally responsible for the original development and implementation of water quality regulations for the Kingdom of Saudi Arabia and several aspects of the Massachusetts Energy Facility Siting Law. Several large studies were conducted under my direction for waste disposal, nuclear power plant siting, and permitting.

Associate Director, Environmental Research Division, CDM/Limnetics, Inc., 1972 - 1975 Organized, staffed and managed all aspects of the Company other than employee relations and finance. Was responsible for the completion of over 50 projects and directly managing the complete licensing of three nuclear power plants in the Midwest and the establishment of NRC required QA/QC programs. Also represented industrial clients in writing Wisconsin DNR environmental regulatory Codes 102-105 and the 1972 revisions to the Clean Water Act.

Professor, University of Wisconsin System. Was on the faculty and taught various courses at four different campuses of the University of Wisconsin. Was elected to the Faculty Senate and served on state of Wisconsin's panel for environmental policy reporting to Governor Lucey.

Teaching. Was an assistant instructor at the University of Wisconsin and University of Pittsburgh as well as Nicelot High School in Fox Point, Wisconsin.

Administrative Experience:

Management Training and Development Courses
- American Electronic Media Training
- Political Education Seminar
- The Fundamentals of Ground Water Quality Protection
- Groundwater Quality Protection
- Elements of Profitability Course - Exxon
- Exxon Corp. Conference on Assessment of Environment Impact
- Interpersonal Management Skills
- Business Writing
- Time Management
- Seminar on Data Base III and ECOTRAC software

Chairman, Town of Palmyra, Wisconsin. Was elected (twice) chairman of this southeastern Wisconsin town of over 2,000 people and was responsible for overall town government as well as cooperative government actions with the closely associated Village of Palmyra (joint Fire, Police, School governance) of over 4000 people and the county government of Jefferson, Wisconsin.

Community Services:

Chairman, Town of Palmyra,
Palmyra, Wisconsin

Environmental Policy Advisor
Gov. Lucey, State of Wisconsin

Board of Directors (President),
Blue Spring Lake Association.

Advisor to Wisconsin Organization of Lake Associations.

Advisor Wisconsin DNR on rehabilitation of inland lakes.

Horticultural Society of Wisconsin Presentation on Effects of Air Pollutants.

Publications. Have been the major author of over 30 publications from both the private and academic environments and contributing authorship on over 150 reports for domestic and international projects. Have presented several papers at technical seminars, professional meetings, and major universities throughout the United States. Am currently on the editorial board of a major professional technical journal, and in 1984 was elected Secretary of the International Society of Petroleum Industry Biologists.

Education:

B.S. 1964 University of Wisconsin-Milwaukee
M.S. 1966 University of Wisconsin-Milwaukee
Ph.D. 1969 University of Pittsburgh

Currently enrolled in MBA program at the University of Houston, University Park.

Society Memberships:

Air Pollution Control Association
American Association for the Advancement of Science
American Men and Women of Science - 1976-1986
American Society of Limnology and Oceanography
Associate Member of Sigma Xi
Ecological Society of America
Environmental Science and Technology
(American Chemical Society)
International Society of Petroleum Industry Biologists
Pollution Control Engineering
Solid and Hazardous Waste Disposal Engineering
Toastmasters International

2402R

Project Area Map

Predicted TSP Concentrations

Comparison of Ambient Air Quality Standards With Predicted Concentrations

	Concentration			Standards		
	Predicted	Background	Summed	Primary NAAQS	Secondary NAAQS	Air Increments
Sulfur Dioxide (SO_2)						
Annual	0.1[b] (2.1)[c]	25.0	25.1 (27.1)	80	—	20
24-Hour	1.8 (25.0)	25.0	26.8 (50.0)	365	—	91
3-Hour	7.1 (186.0)	25.0	32.1 (211.0)	—	1,300	512
Particulate Matter (TSP)						
Annual	4.3	17.9	22.2	75	60	19
24-Hour	28.9	77.0	105.9	260	150	37
Nitrogen Dioxide (NO_x)						
Annual	3.8	19.4	23.2	100	100	
Carbon Monoxide (CO)						
8-Hour	1802.5	N/A[d]	1802.5	10,000	10,000	
1-Hour	2025.3	N/A	2025.3	40,000	40,000	
Hydrocarbons (HC)						
3-Hour	47.1	N/A	47.1	160	160	
Lead (Pb)						
3-Month Average	0.01	N/A	0.01	1.5	1.5	
All concentrations in $\upsilon g/m^3$						

a. All short-term limits (24-hour and less) can be exceeded once a year.
b. Stationary sources only.
c. Includes temporary mobile source emissions.
d. N/A = Not applicable.

BEFORE THE
STATE OF WISCONSIN
DIVISION OF HEARINGS AND APPEALS

Application of Exxon Corporation for Permits to Build and Operate an Underground Mining and Ore Concentrating Complex Located in Forest County, Wisconsin	) IH-86-18

TESTIMONY OF MICHAEL R. HARRIS

Q. Please state your name, affiliation and title.

A. My name is Michael R. Harris. I am employed by the consulting engineering firm of CH2M HILL and hold the position of District Discipline Director. In this position, I oversee all industrial water and wastewater treatment work by the firm in the central district of the U. S., which includes a total of 21 states.

Q. Would you please state your educational and professional experiences.

A. I have attached as EXHIBIT 288 my resume showing my educational and professional background. As shown in EXHIBIT 288, I have worked for CH2M HILL for 14 years. During this period I have managed a variety of water and wastewater treatment projects for industrial clients. My mining and milling project experience includes zero discharge studies for Anaconda Copper Company's mine and concentrator in Butte, Montana, Anaconda's smelter Anaconda, Montana, and my involvement with the Crandon Project. I have a Bachelor of Science degree in Civil Engineering from Oregon State University and a Master of Science degree in Sanitary Engineering also from Oregon State.

Q. What aspects of the Crandon Project will be included in your testimony?

A. I will describe the water management system for the project and discuss the collection, treatment, and discharge of water. This testimony covers the conclusions reached in a number of studies completed by CH2M HILL for Exxon over the past 7 years.

Q. What has been your involvement with the Crandon Project?

A. I was project manager for numerous assignments completed by CH2M HILL for Exxon. In this capacity I have managed all of CH2M HILL's work efforts which have resulted in the proposed design of the water treatment system for the Crandon Project. Under my direction, over 100 CH2M HILL staff members contributed to our work for the Crandon Project, including our most senior specialists in industrial water treatment. As project manager, it has been my responsibility to coordinate the work of all CH2M HILL staff, ensure that appropriate technical experts were called in when needed, and to supervise the preparation of all work products. It should be noted that CH2M HILL is the fifth largest architectural/engineering consulting firm in the U.S. We are the largest such firm specializing in environmental engineering work. CH2M HILL has completed literally thousands of projects dealing with the treatment of both municipal and industrial water and wastewater.

Q. Can you briefly describe the history of water management studies for the Crandon Project?

A. The analysis of water management for the Crandon Project has paralleled Exxon's overall development of the project. As the design of the mine and mill evolved from preliminary concepts to progressively more refined plans, the water management plans were likewise updated and refined.

In 1979, Exxon retained CH2M HILL to prepare a Phase II Water Management Study which was completed in January 1981. During this assignment, we reviewed the Preliminary Water Management Study by Kilbourn, a consultant retained by Exxon. This preliminary study by Kilbourn laid the groundwork for analysis of water sources, uses, and losses from the Crandon Project. Using this data as a base, a water balance for the overall Crandon Project was refined by our staff and prediction of water chemistry in the mill water circuit was begun by developing a preliminary computer model of the mill water system. In this study, a broad range of potential water treatment technologies were screened and preliminary treatment concepts were developed. As the Phase II work neared completion, we revised and refined our predictions of water chemistry and flow rates to reflect the new information received from others.

In mid 1981, CH2M HILL began a Phase III water management study. Using information from the Phase II study as a base, we further refined the water balance, computer model, and predictions of water chemistry in the mill water circuit. The Phase III report (EXHIBIT 164) contains all information developed in Phase II which was used in subsequent work. Our evaluation of potential water treatment technologies for the Crandon Project was also expanded. The Phase III report was completed in December 1982, prior to the time effluent limitations were proposed for the Crandon Project. The primary outcome of the Phase III study was identification of treatment technology which would permit use of 100 percent recycle water in the mill.

Q. After completion of the Phase III report, what happened next?

A. In 1983, the Wisconsin Department of Natural Resources provided Exxon with preliminary effluent limitations which would be applied to discharges from the Crandon Project. Receipt of these preliminary limitations allowed Exxon, for the first time, to evaluate specific effluent treatment requirements and to define appropriate treatment systems for both recycle and discharge treatment.

In late 1983 and 1984, CH2M HILL completed process flowsheets, preliminary building layouts, cost estimates, and a preliminary engineering report describing the proposed treatment system for the Crandon Project. This report was updated in 1985 based on further refinements by Exxon to the proposed mining and milling processes. Subsequently, in 1986, the Wastewater Treatment Facility Final Plans and Specifications report was prepared and submitted by Exxon to the Wisconsin DNR in support of its application for a WPDES discharge permit for the Crandon Project. The final report is EXHIBIT 118 in the hearing record.

Q. Can you describe how water will be used in the Crandon mine and mill?

A. The use of water will be an integral part of the Crandon mill process. Water is used to transport ore, concentrates, and tailings through the various processing steps in the mill and tailings ponds. When backfill is returned to the mine, water is used to pump material back into the mine. Water used in the process picks up dissolved and suspended metals and salts, suspended solids, and trace concentrations of organic chemicals used in the mill.

Utility water will be used throughout the mill for miscellaneous cleanup activities and in the mine for drilling operations.

Potable drinking water will be required in both the mill and mine for employees and visitors.

High quality water (water without scale forming compounds or high levels of suspended solids) will be required throughout the surface facilities to supply pump gland seal water and to provide makeup water for mixing reagents (chemical solutions) used in mill processes.

Q. Can you describe the sources of water in the Crandon Water Management System?

A. There will be three sources of water which will enter the Crandon water management system. The first source, potable drinking water, will total about 15 gallons per minute in the surface facilities. In addition, about 25 gallons per minute of potable quality water will be required in the laboratory, shops, and mine. Potable water will be supplied from an onsite well and will be the only source of fresh water used by the Crandon Project, a total of about 40 gallons per minute.

Since the orebody is located below the level of local groundwater, water will seep into the underground workings of the mine, providing the second source. I am aware that a number of studies have been completed by other consultants to predict the volume of seepage water anticipated. Mr. Thomas Prickett and Dr. Djafari will summarize these studies in later testimony.

Mine seepage from above the ore body, intercepted before it contacts mineralized rock, will be pumped directly to the surface. Intercepted groundwater pumped from the mine is expected to average 350 gallons per minute.

Groundwater which seeps into the workings of the mine will contact mineralized rock and will contain higher concentrations of dissolved metals and salts than intercepted groundwater. It is anticipated that approximately 870 gallons per minute of such mine water seepage will be collected at various locations in the mine and pumped to the surface. An additional 50 gpm of contaminated water will be contained in ore hoisted to the surface.

The third and last source of water which will enter into the Crandon water management system is precipitation which falls on the surface facilities. The majority of the precipitation, that which falls on the pond system, mill site, equipment lay down area, and preproduction ore storage area, will be collected and incorporated into the mill process water recycle system. On an annual average basis, this represents about 265 gallons per minute. A small amount of rainfall that falls onto parking lots, roadways, and other similar surface areas will be collected in a settling pond and discharged directly.

Q. Will there be any discharge of water from the Crandon Project?

A. Yes. As I mentioned previously, there are three sources of water to the water management system: Potable water at 40 gpm;

mine seepage water consisting of 350 gpm of intercepted water above the mine, 870 gpm seepage into the mine, and 50 gpm in ore; and precipitation at 265 gallons per minute, on an annual average. These are shown in EXHIBIT 289.

Balanced against these inflows, there are only a limited number of ways to get water out of the system and bring the water system into balance.

Q. Would you describe the outflows from the water management system?

A. Sanitary wastewater will be treated and discharged at a maximum flow rate of about 15 gallons per minute.

Solids which settle in the tailings pond and solids backfilled into the mine will retain some water. This retention is estimated to be about 215 gallons per minute, on a long-term average.

Ore concentrates will be shipped from the Crandon Project in damp form. Approximately 15 gallons of water per minute will leave in the concentrates.

The water surfaces of the tailings and reclaim ponds will be subject to water losses through evaporation. Since rainfall exceeds evaporation in the Crandon area, evaporative water losses will be less than the gains from precipitation. The water losses from evaporation will be about 150 gallons per minute on an annual average basis.

It is my understanding that a sophisticated pond liner system will be used in the tailings and reclaim ponds so only a very limited amount of seepage will occur from the ponds. This has already been discussed by Mr. Don Moe.

To maintain an overall water balance, approximately 1,175 additional gallons per minute must be treated and discharged. Zero discharge is simply not possible for the Crandon Project. The constant inflow of mine seepage water and the excess of rainfall over evaporation is not that much different from a bathtub with the faucet turned on continuously. Unless some water is let out of the tub, it will overflow.

Q. Did you evaluate alternative technologies to treat the water which must be discharged from the Crandon Project?

A. Yes. We conducted a literature search of technologies potentially applicable to this project. Over 40 technologies were screened and about 20 were evaluated in detail. The technologies selected for in-depth evaluation ranged from state-of-the-art treatment technologies in common use in the mining industry to more complex processes which are not in common use in the mining industry, but which are used in other industries.

Q. Can you discuss the criteria established by Exxon for selection of treatment technologies for this project?

A. The criteria for selection of treatment processes were established in the very early phases of CH2M HILL's work with Exxon and were emphasized throughout all of our studies. These criteria were as follows:

1. Meet all applicable effluent limitations set for the Crandon Project.

2. Permit the use of directly recycled or treated recycled water to provide 100 percent of the water requirements for the mill.

3. Use proven technology.

4. Provide cost-effective treatment.

5. Provide enough flexibility in the system design to allow for uncertainties in predictions of influent water quality and flow rates.

6. Provide enough flexibility in the system design to allow the operating staff to modify operations once the plant is started up and operational.

7. Produce environmentally acceptable sludges from treatment.

8. If possible, produce a useable by-product from the treatment process.

The treatment processes ultimately selected for the Crandon Project meet all eight of these criteria.

Q. How were the alternate technologies evaluated?

A. For each of the technologies evaluated in detail, we conducted an extensive literature searches to determine the capabilities of the process to remove contaminants from water. For each of these technologies, we prepared a computer program to predict the performance of the process. If these programs "receive" the flow rate and water quality of an influent stream, the computer will predict the flow rate and water quality of the treated effluent and any byproduct (sludge) streams generated by the process. These programs are quite complex. They are designed to perform a mass balance of 64 soluble and nonsoluble chemical species through each treatment process.

Q. How were these computer programs used in your evaluation of water management systems?

A. One of the major tasks assigned to CH2M HILL was to develop and refine a computer model of the entire water management system. As our work progressed, flexibility was added to the model to permit the evaluation of alternative water management plans. As I mentioned earlier, there were a number of other engineering studies being conducted in parallel with the water management studies. As each of these studies reached a conclusion, the model permitted us to quickly incorporate new information into our water management evaluation.

The model consists of a series of "links" which connect "nodes." Each link represents a potential pipeline which could transport water from one location to another. Each node represents a process or operation which could change the quality of water.

For each potential process or operation, we prepared a computer subroutine to predict changes in water quality if water were to pass through such a process. These subroutines range from relatively simple programs to blend two or more streams to very complex subroutines to predict the impact of the mill on water quality during the milling process.

Once the model is set up in a given configuration, it can be run and will estimate the steady state quality of water at all locations throughout the entire mine and mill.

Q. How was this model used to test different water management alternatives?

A. A great deal of flexibility was built into the model to allow us to look at options. There are a great number of links which can model the transport of water from one location to a variety of other locations. As the model user sets up a model run, he can specify where he wants to route water and how much water goes to each place. This feature permitted an evaluation of a wide range of water management alternatives and to evaluate the impact of those alternatives on water quality in the mill water circuit.

In addition, there are a number of locations in the model where the user can specify that a particular treatment system be modelled. In each of these locations, the user can model an entire treatment process consisting of several of the treatment technologies I described earlier. Once the configuration is entered, the computer then calculates steady state water chemistry in the entire water system.

To further add flexibility to the model, and to allow us to update model results as other engineering studies were completed, the user of the model can also specify a wide range of user-defined variables, including such things as:

- Type of ore to be processed
- The number of tons per day of ore to be processed
- Water requirements in the mill
- Rainfall and evaporation rates
- Summer versus winter conditions
- The amount of water retained in solids in the tailings pond or mine

- The acreage of each of the ponds
- The flow rate of seepage from each pond
- The flow rate of various qualities of water required for mill operations

Throughout the life of our work with Exxon, several hundred runs of the model were completed to test alternative water management flow patterns, evaluate the impacts of different treatment processes, and test the sensitivity of the water system to changes in various operations. The model allowed us to look at a number of alternatives that would otherwise have been too time consuming to consider.

Q. Are models such as the one you've just described common in the mining and milling industry?

A. To my knowledge, this is the most comprehensive model of its kind ever developed for a facility like the Crandon Project. In developing the programs to predict impacts on water quality, Exxon had to acquire a lot of unique information which had seldom, if ever, been necessary in the mining industry. The Crandon water use model is one of a kind, developed especially for this project.

Q. How accurate is the model in predicting water chemistry?

A. The model was verified by carefully checking each subroutine to ensure that the model does what we want it to do.

The model was calibrated by checking the predicted impacts on water quality against measured impacts at similar full-scale operating facilities.

Q. Can you elaborate on the calibration procedure?

A. The subroutines describing the impact the Crandon Mill will have on water quality are based on a series of pilot scale tests of the milling process by Lakefield Research of Canada.

To check the accuracy of the computer subroutine developed for the Crandon Mill, Exxon obtained and analyzed samples of water from various locations around Noranda's mine/mill complex at their Matagami mine in Quebec, Canada. It is my understanding that the Matagami ore body is similar to that at Crandon. The measured changes in water quality around the Matagami mill should be similar, therefore, to those predicted at Crandon.

In addition, I was involved in a zero discharge study for the Butte Operations at the Anaconda Copper Company. Analysis of water quality in the effluent from the tailings pond at this facility was added to the data base from Matagami to validate the computer predictions for tailings pond performance at Crandon.

A comparison of the predicted impacts of the Crandon facility with measured impacts at these two facilities showed that the predictions are reasonably close to what can be expected.

Q. How confident are you in the computer predictions of water quality in the water management system at Crandon?

A. Model predictions of water chemistry in the mill water circuit are as accurate as we can make them at this time. As with any complex model, however, the computer prints out very precise numbers which are approximate in nature. This fact was recognized throughout the water management studies and we were careful to make sure that the treatment systems selected will work even if the model results have inaccuracies.

Q. Were there special circumstances which justified all these detailed evaluations of water management for the Crandon Project?

A. Very definitely. The vast majority of water treatment work in the mining and milling industry has been done on actual effluents from operating facilities. Since plant processes are different at each plant and the chemical characteristics of ore are different at each plant, the quality of effluent, as you might expect, is different at each plant. Since the Crandon mill is not yet built, prediction of effluent quality had to be done very carefully and allowances had to be made to ensure acceptable performance of treatment systems even if our predictions of effluent quality are off.

Next, it has always been Exxon's goal to supply 100 percent of the mill water requirements with water recycled directly from the reclaim pond or with treated recycle water. No fresh water use other than potable water is contemplated. In a closed loop system like this, dissolved material builds up in concentration as the water is recycled through the system. Unless part of the water is treated to remove dissolved material, problems can develop with the formation of scale in the piping system. If you've ever lived in a house with very hard water, you've probably experienced a buildup of white scale around your faucets from time to time. In a closed loop industrial water system, the same kind of thing can be a very serious problem unless scale-forming compounds are removed. Removal of these compounds, such as calcium sulfate (gypsum), is a complex and expensive problem worthy of significant study.

Finally, as I discussed before, the water balance for the Crandon Project does not permit a zero discharge of water. Even though the mill uses 100 percent recycled water, it will still be necessary to treat and discharge some water to the environment. Because the proposed limitations on the effluent from the Crandon Project are very stringent, the water treatment system will have to treat water to a level of purity much higher than similar facilities around the U.S.

Q. What is the basis for your comment that the effluent limitations are very stringent?

A. The U.S. Environmental Protection Agency has set national effluent standards which must be met by various industries throughout the country. For facilities such as the Crandon Project, the category of regulations which apply are called "New Source Performance Standards (NSPS)." The effluent standards applicable to the Crandon Project are those NSPS standards applicable to copper, lead, and zinc mines and mills.

A comparison of NSPS standards to some of the projected Crandon Project effluent limitations is shown in EXHIBIT 290. This comparison demonstrates the stringency of the limitations. Table 1 of my prefiled testimony shows all of the proposed effluent limitations.

Q. How were the proposed effluent limitations derived?

A. The Wisconsin Department of Natural Resources developed the proposed limitations. In very simple terms, the daily maximum values shown in Table 1 were developed to protect against acute toxicity problems in Swamp Creek and the monthly average values to protect against chronic toxicity problems. The proposed monthly average limitations vary with the flow rate of the effluent stream because, at different flow rates, the impact on water quality in Swamp Creek would change.

Q. Now that you've described the background of your studies, can you describe the water management system proposed for the Crandon Project?

Table 1
Proposed Effluent Limitations and Projected Effluent Quality for Surface Water Discharge to Swamp Creek (from WPDES permit)

Parameter	Daily Maximum[1]	Monthly average limits[2] based on effluent flows of[9] <1300 gpm	1301-2000 gpm	Projected[10] Effluent Quality (Daily Ave.)
Arsenic	1.48	0.626/0.663[3]	0.508/0.533[3]	0.05
Cadmium	0.073	0.0045/0.0048	0.0037/0.0039	0.0006
Chromium^{+6}	0.058	0.051/0.053	0.042/0.043	0.012
Chromium^{+3}	11.0	0.27/0.28	0.22/0.23	0.06
Copper	0.025	0.025/0.025	0.021/0.022	0.01
Cyanide	0.093	0.010/0.011	0.010/0.011	0.006
Lead	0.6[4]	0.118/0.125	0.096/0.10	0.04
Mercury	0.002[4]	0.0002[5]	0.0002[5]	0.00017
Selenium	1.0	0.165/0.174	0.134/0.140	0.06
Silver	0.007	No recommended value	No recommended value	0.003
Zinc	0.44	0.14/0.14	0.11/0.12	0.06
BOD		20 (summer)[6]	15 (summer)[6]	<20[11]
		40 (winter)[6]	30 (winter)[6]	<20
Total Suspended Solids	30[4]	20[4]	20[4]	10
pH(S.U.)	6-9			6-9
Barium		10.8/11.4	8.8/9.2	0.03
Fluoride		14.6/15.5	11.9/12.4	2.0
Iron		1.8/1.9	1.5/1.6	0.4
Total Dissolved Solids(TDS)[7]	1210/1000[8]			700

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(1) For most of the toxic pollutants (except lead), the maximum limits were derived from the available acute toxicity information for resident Wisconsin aquatic species. All units are in parts per million unless otherwise specified.

(2) The monthly average limits were calculated using mass balance equations.

(3) The water quality criterion for arsenic to protect human health is being reviewed. The above limits are based on the acute and chronic toxicity effects to resident Wisconsin aquatic species.

(4) Categorical limits (New Source Performance Standards) apply because they are more stringent than the water quality numbers.

(5) The monthly average water quality criterion necessary to prevent exceedance of FDA action limits in fish and thus protect human health is 0.0002 mg/l. This criterion value is near the detection limit of most current analytical techniques.

(6) BOD limits are applied as weekly rather than monthly averages.

(7) Limits for chlorides and sulfates are regulated as part of the TDS number.

(8) The maximum limit for TDS is 1210 mg/l when Q_E <1300 gpm and 1000 mg/l when Q_E is between 1301 and 2000 gpm.

(9) Two scenarios were assumed in determining the monthly average effluent limits. The first set of numbers (before the slash) were calculated based on an upstream $Q_{7,10}$ of 13.5 cfs (assuming no flow mitigation for Upper Swamp Creek). The second set of numbers were calculated based an upstream $Q_{7,10}$ of 15 cfs (assuming that there will be flow mitigation to Upper Swamp Creek).

(10) WPDES Permit Application values (Dec. 1985).

(11) This value applies at the <1300 gpm only.

A. Certainly. EXHIBIT 291 is a greatly simplified schematic of the Crandon Project Water Management System, showing only major or significant features. CH2M HILL's final report (EXHIBIT 118) contains a more detailed discussion and a water balance for the entire system.

As I mentioned earlier, the total flow rate of fresh, potable water will be about 40 gallons per minute. Of this total, 15 gallons per minute will be used for domestic or sanitary purposes throughout the surface facilities. This water will be collected, treated, and discharged. About 20 gallons per minute of potable water will be needed in the mill's laboratory and shops and about 5 gallons per minute will be used in the underground workings of the mine. These are the only locations where use of fresh water is planned.

Rainfall collected around the surface facilities where it could potentially become contaminated will be incorporated into the mill water circuit. On an annual basis, this runoff will average about 30 gallons per minute.

Approximately 3,630 gallons of water per minute are required to supply water needs in the mill. An additional 50 gallons per minute enters in ore hoisted from the mine.

Water is discharged from the mill and surface facilities in four primary streams:

- o Ore concentrates produced by the Crandon Mill will contain about 15 gallons per minute of water;
- o Thickened tailings pumped to the tailings pond will contain about 315 gallons per minute of water;
- o Clarified water overflowing the tailings thickener and miscellaneous other low-solids streams, totalling about 3,100 gallons per minute, will be pumped directly to the reclaim pond; and
- o Sands (coarse residual materials after the milling process) will be pumped back to the mine to backfill mined-out underground voids. This stream will contain about 270 gallons per minute

Thickened tailings and sludges from the water treatment system will be pumped to the tailings pond and allowed to further thicken by gravity. Water which is released after the solids compact is then routed on to the reclaim pond. Even after compacting, about 105 gallons per minute will be trapped within the settled tailings. The tailings ponds will collect about 175 gallons per minute of rainfall and will lose about 105 gallons per minute to evaporation and another 5 gallons per minute to seepage.

All of the water in the mill water circuit eventually reaches the reclaim pond, which is a large lagoon with a retention time of about 1 month. The reclaim pond will collect about 60 gallons per minute of rainfall and lose 45 gallons per minute to evaporation. The seepage flow rate from this pond will be negligible. The reclaim pond, as I will describe later, is also an important process in the treatment of water for recycle. Effluent from the reclaim pond is pumped back to the mill for reuse.

The mine is the last major element of the Crandon operating facilities. The sources of water entering the mine will be intercepted groundwater, seepage water, the backfill water pumped to the mine, and potable water. After backfilled material drains, about 110 gallons per minute will remain trapped within the compacted material. Three streams of water will exit the mine. Fifty gallons per minute will be hoisted to the surface with ore. 1,035 gallons per minute will be collected in sumps in the mine workings and pumped to the surface. 350 gallons per minute will be intercepted at the top of the mine and pumped directly to the surface before it ever encounters mineralized rock.

In addition to all these facilities, there will be a small amount of rainfall collected from roadways, parking lots, and other surface areas on the south side of the mill. The runoff from these areas will be similar to existing runoff from the site except for minor impurities and solids picked up from paved surfaces. On an annual average basis, this flow will average about 65 gallons per minute.

At this point in the water balance, there are five streams left to discuss. These are the five streams requiring treatment.

Q. Before you get into the treatment processes, can you briefly discuss these five streams, explaining the quality of water in each and the reason you say they require treatment?

A. The first of the five streams is the effluent from the reclaim pond which is recycled back to the mill. Each time this water passes through the mill, it picks up additional dissolved salts; the two major concerns being calcium and sulfate. Unless a portion of this stream is treated to remove these dissolved salts, severe scaling problems could be encountered in the mill piping system. A second reason for treating this stream is that the mill has need for treated water to mix reagents and for pump gland seal water. Unless a portion of the recycle water is treated to meet this need, a fresh water source would be required and a portion of the recycled water would have to be discharged to maintain a water balance.

The second stream requiring treatment is the contaminated mine water stream collected in the sumps of the mine. This water will contain suspended solids and dissolved metals. To maintain an overall water balance in the mill water circuit, 190 gallons per minute of this water will be treated for recycle and about 845 gallons per minute will be treated for discharge. Treatment of this water will be necessary to achieve compliance with the effluent limitations for the project.

It is worthy of note at this point that these first two streams are the only sources of water used for operation of the mill. Other than an insignificant amount of potable water used in the laboratory and shops, 100 percent of the mill's water requirements are met through direct recycle or through treated recycle water.

The third stream is the intercepted ground water collected from above the ore body. It is expected that this will be essentially the same quality as area ground water with, perhaps, some trace concentrations of impurities picked up as it enters the collection system. A treatment system will be installed to treat this water, but it is simply too close to call at this time whether this water will actually require treatment. The ground water in the area meets all primary drinking water standards, but may not meet the effluent limitations set for the discharge of treated water to Swamp Creek.

The quality of intercepted ground water will be monitored as it comes from the mine and, if it meets the effluent limitations, will be discharged directly to Swamp Creek or used to supplement the level or flows of nearby streams and lakes. This will be discussed further by Mr. Schroeder. If the intercepted ground water does not meet the limitations, it will be treated to remove trace metal concentrations prior to discharge.

Sanitary wastewater from the project will be similar in quality to sanitary wastewater generated at any industrial facility. It will require treatment for removal of Biochemical Oxygen Demand (organic materials), suspended solids, and fecal coliforms.

The last of the five streams to be considered is runoff from general facilities on the south side of the mill. This runoff will be similar in quality to runoff from any roadways, parking lots, or grassy areas. This water may contain suspended solids which require removal prior to discharge.

Q. Can you now describe the treatment processes to be used?

A. The treatment of water actually starts in some of the processes within the mill water system, so I'll start there.

Almost all of the water leaving the mill passes through the tailings thickener before it goes out to the pond system. The thickener is simply a settling tank designed to separate settleable solids from the water. Before the tailings stream enters the thickener, lime will be added to flocculate solids and enhance settling. This will also remove soluble metals by forming insoluble metal hydroxides which will settle out with the tailings. In addition to its metallurgical process function, therefore, the tailings thickener acts as a water treatment device to reduce the concentration of metals in the recycle stream.

All of the water from the mill passes through the reclaim pond before it is recycled back to the mill. The reclaim pond is an important part of the water management system. Under normal operations, the reclaim pond will contain about 158 million gallons of water, providing a one-month retention time. The pond also has a freeboard volume (i.e., unused volume between the pond water surface and the top of the dikes) of 117 million gallons. In the event of a severe rainstorm, a very wet year, emergencies requiring outages at the treatment plant, or other similar conditions, the freeboard volume in the reclaim pond provides a place to store water until it can be treated for discharge.

In addition to providing excess water storage volume, the reclaim pond provides the following treatment functions:

1. Most particulates (suspended solids) will be removed by the tailings thickener and tailings pond, but influent to the reclaim pond will still contain some solids. The majority of these residual solids will settle out in the reclaim pond, providing cleaner water for recycle.

2. Due to the type of ore and the processes employed at the Crandon Project, water in the mill water circuit will contain a compound called thiosulfate (chemical formula is $S_2O_3^=$) and similar compounds called polythionates. If these compounds are not removed, they can adversely affect the mill processes. In the reclaim pond, thiosulfates and polythionates will be biologically

degraded to sulfate. In the summer, this reaction occurs quickly and it slows down in the winter months. Because the process increases acidity, lime will be added at the reclaim pond for neutralization.

3. A small amount of cyanide will be used in the mill process. Most of the cyanide used will end up as insoluble solids in the coarse and fine tailings. The concentrations of cyanide will be reduced by about 80 percent across the reclaim pond. Factors causing natural degradation of cyanide in the reclaim pond include photodecomposition by sunlight, acidification, oxidation by oxygen in the air, and biological action. These processes will continue in the winter especially where there are open areas of the pond.

4. Organic compounds will be present in the water from the chemicals used in the flotation process. Natural processes of evaporation and oxidation will reduce the concentrations of these compounds by 90 percent or more. These processes will continue throughout the year.

Q. Can you now describe the water treatment processes designed to treat effluent streams from the Crandon Project?

A. The Water Treatment Facility building contains three completely independent treatment systems. I'd like to discuss each of the systems separately and explain each of the technologies used.

The engineering report submitted with Exxon's WPDES permit application describes the treatment systems in great detail, so I'll go through the systems, fairly quickly at this time. The report is labelled Exhibit 118 in this proceeding.

Q. Can you describe the system designed to treat intercepted groundwater?

A. This system is shown in EXHIBIT 292. Under average inflow of water to the mine, 350 gallons per minute of water from this source are expected. Under absolutely worst case predictions, this flow rate could rise to as high as 850 gallons per minute. The entire intercepted groundwater treatment system is sized to treat 1,000 gallons per minute, which provides a 20-percent safety factor over the highest anticipated flow rate.

Water collected in the interceptor system will be pumped to the surface where its quality will be monitored. If this water meets effluent limitations, it will be pumped directly to the discharge lagoons or be used to supplement lakes and streams in accordance with Exxon's contingency plan; if not, it will be routed to the Intercepted Groundwater Treatment System. The processes that will be used in this system are:

Mixing, Neutralization, Aeration

The first step in the treatment process will be to mix recycle sludge with lime. The contact between recycle sludge and lime will enhance the sludge settling rate and will cause the final settled sludge to be more dense.

Lime and recycle sludge will enter the neutralization reactor where intercepted groundwater will be introduced. This will begin the process of precipitation of soluble metals as metal hydroxide. Ferric sulfate will be added to the reactor if needed as a coagulent. Compressed air will be introduced through a diffuser at the bottom of the reactor to ensure than any ferrous iron will be oxidized to ferric iron so it will be removed.

Lime/Sulfide Precipitation and Clarification

The purpose of this process will be to settle out solids contained in the water and remove soluble metals through precipitation as metal hydroxides and metal sulfides.

Effluent from the neutralization reactor will flow to a solids contact type reactor clarifier. Polymer solution will be added to the flocculating centerwell of the clarifier to promote the growth of settleable floc in the clarifier.

A solution of sodium sulfide will also be added to the flocculating centerwell of the clarifier to form metal sulfides, thereby precipitating additional metals which will still be in a soluble state after equilibration with lime in the neutralization reactor.

Metal hydroxide and metal sulfide sludge generated in the treatment process will settle to the bottom of the clarifier. The majority of the settled sludge will be returned to the neutralization reactor. The remaining sludge will be pumped to the tailings pond for disposal.

Mixed Media Filtration

Effluent from the clarifier will overflow to a pH adjustment tank and, from there, will flow to mixed media gravity filters which will remove residual solids. The filters will consist of a dual media bed of anthracite and silica sand.

Neutralization

The pH of effluent from the filters will be adjusted with acid to reduce the pH to within WPDES permit limits. This process will provide final effluent neutralization prior to discharge to the Excess Water Discharge Lagoon System.

Effluent from the Excess Water Discharge Lagoon System will be pumped to Swamp Creek, or used to supplement lakes and streams in accordance with Exxon's contingency plan.

Q. Can you now describe the system which will treat the contaminated mine water stream?

A. Certainly. EXHIBIT 293 shows a flow diagram of the Contaminated Mine Water Treatment System. Under normal operating conditions and average inflow of water to the mine, 1,035 gallons per minute of water are expected from this source. Of this total, 190 gallons per minute must be bypassed to the mill water circuit to maintain a long-term water balance within the system, leaving 845 gallons per minute to be treated in the Contaminated Mine Water Treatment System.

Under absolutely worst case predictions, the flow rate of contaminated mine water could rise to as high as 1,265 gallons per minute. The Contaminated Mine Water Treatment System has been sized to treat 1,550 gallons per minute, providing a 20-percent safety factor over the highest anticipated flow rate of Contaminated Minewater. (This safety factor is even larger when you consider that, on a long-term basis, 190 gallons per minute from this source must be routed to the mill water circuit.)

Except for sizing, this system will be identical to the Intercepted Groundwater Treatment System.

Q. Are the two systems you have described similar to other systems in the mining and milling industry?

A. The proposed treatment systems for intercepted groundwater and contaminated mine water are similar to the "model" system used by EPA to develop NSPS limitations for copper, lead, and zinc mines. The system will differ from the "model" system in three significant respects.

1. The NSPS "model" system does not use ferric sulfate for promotion of the floc formation nor sodium sulfide for

removal of trace concentrations of metals. The proposed Crandon Project treatment process, through use of these two additional chemicals, will achieve better removal of metals than the EPA's "model" system.

2. The NSPS "model" system does not contain a filtration process after lime precipitation and clarification. The filters proposed for the Crandon Project treatment system will remove virtually all metal hydroxide/sulfide precipitates in the overflow from the lime-sulfide precipitation clarifier, thereby achieving better effluent quality than the "model" system.

3. NSPS allows treatment and discharge of all water pumped from the mine. The proposed Crandon Project water management plan allows for the use of roughly one-fifth of the water pumped from the mine as mill makeup water. The proposed Crandon Project system, therefore, will result in a lower discharge volume than allowed by EPA.

Q. Can you describe the treatment system which will be used to treat water for recycle to the mill.

A. EXHIBIT 294 is a simplified flow diagram of the Recycle Water Treatment System, which is by far the most complex (and expensive) of the systems proposed for the Crandon Project.

This system has been sized with two main goals in mind:

1. Provide enough high quality water to fill needs for pump gland seal water, reagent preparation, and similar treated water uses in the mill.

2. Remove enough dissolved salts from the mill water circuit to reduce scaling potential in the water.

A minimum of 780 gallons per minute of high quality water is required to fulfill mill operating needs. This need can be met by treating 610 gallons per minute from the reclaim pond and 190 gallons per minute of contaminated mine water. The water use model predicts this level of treatment will also eliminate scaling conditions during winter months.

During the summer, the model predicts that slightly more reclaim water will have to be treated to eliminate scaling (more thiosulfate is degraded to sulfate in the reclaim pond in the summer). Under summer conditions, the computer predicts that 810 gallons per minute of reclaim pond water must be treated. With the 190 gallons per minute of contaminated mine water, this leads to a total flow rate of 1,000 gallons per minute to be treated. (In full scale operations, it may be possible to reduce this by using scale inhibiting chemicals in the water system).

The Recycle Water Treatment System will be designed to treat 1,200 gallons per minute. This sizing provides a 20 percent safety factor over the maximum volume of water we predict may actually have to be treated.

Reclaim pond water and contaminated mine water will be blended and treated in this system. The processes to be used in this system are:

Mixing, Neutralization, and Aeration

This process will provide for mixing of recycled sludge with milk-of-lime, oxidation of ferrous iron, and adjustment of the pH of influent water. The design and operation of this process will be identical to that I described earlier for the same operation in the other two systems.

Lime/Soda Softening

The purpose of this process will be to remove solids from the water routed to this system from the mine, remove soluble metals as metal hydroxides, and remove calcium through precipitation as $CaCO_3$. (Calcium removal will be important to downstream processes because it will reduce $CaSO_4$ scaling potential in the reverse osmosis system). A solids recycle system will be used, similar to that I described for the other two systems.

In the lime/soda softening process, lime will be added to raise the reaction pH, precipitating metals in the same reactions I described earlier. In addition, soda ash will be added to the system to precipitate calcium as calcium carbonate.

Effluent from the neutralization reactor will flow to a solids contact type reactor clarifier. Polymer solution and soda-ash solution will be added to the flocculating centerwell of the clarifier.

Metal hydroxide and calcium carbonate sludge generated in the process will settle to the bottom of the clarifier. The majority of the settled sludge will be recycled and the rest will be pumped to the tailings pond.

Mixed Media Filtration

Effluent from the lime/soda precipitation reactor clarifier will flow to mixed media gravity filters to remove residual solids which overflow the clarifier. (Solids removal will also be an important pretreatment step to reduce fouling problems in the downstream reverse osmosis system.)

The design and operation of this process will be identical to that I described earlier for the same operation in the other two systems.

Neutralization

The pH of effluent from the filters will be reduced by adding sulfuric acid.

The design and operation of this neutralization process will be identical to that I described earlier for the same operation in the other two systems, except that effluent from the neutralization system will be pumped to the reverse osmosis (RO) system rather than to discharge.

Reverse Osmosis (RO)

The purpose of this process will be to recover water with low concentrations of dissolved solids for recycle to the mill. The dissolved solids present in the influent to the process (primarily sodium sulfate) will be concentrated in the brine stream which will be routed to the vapor compression evaporator.

In a reverse osmosis system, shown schematically on EXHIBIT 295 feed water is pumped at high pressure through a series of semi-permeable membranes. The pressure will force water through the membranes. Most soluble substances will be "rejected" by (i.e., will not pass through) the membranes and will be concentrated in a brine stream from the RO system. An RO membrane is comparable to an extremely fine screen which allows water to pass through but captures water contaminants.

The clean water stream which passes through the RO membranes will be recycled to the mill.

Vapor Compression Evaporator (VCE)

The brine (high solids) stream from the RO system will be pumped into the vapor compression evaporator.

In a vapor compression evaporator, clean condensate water is produced in a vertical tube falling-film-type evaporator. Compressed evaporator product stream is used to vaporize evaporator contents.

The VCE will concentrate dissolved solids in the reverse osmosis brine to near the limit imposed by readily soluble salts (primarily Na_2SO_4) while crystallizing out readily insoluble calcium salt ($CaSO_4$). The clean water condensate stream (approximately 95 percent of the feed brine volume) will be recycled to the mill.

Lime/Soda Softening of VCE Brine

Concentrated brine (at approximately 20 percent solids) from the VCE will be pumped to a solids-contact-type reactor clarifier. In the centerwell of the clarifier, lime, soda-ash solution and polymer will be added.

This process will be included in the treatment process to precipitate additional gypsum, metal hydroxides, and calcium carbonate from the VCE brine to produce a relatively pure solution of sodium sulfate.

The design and operation of this softening process is similar to that I described earlier for the lime/soda softener used to treat the influent to this system.

Sludge produced in the softener will be pumped to the tailings thickener underflow sump for disposal in the tailings pond.

Crystallizing Evaporator

This final process will concentrate residual brine which overflows the brine softener to a high purity solidified form of sodium sulfate, which may potentially be a saleable byproduct, and to produce clean water condensate for recycle to the mill.

The overflow from the brine softener will be pumped to a crystallizing evaporator. The crystallizing evaporator will be a forced-circulation vertical tube evaporator. In the crystallizer, VCE brine will be further evaporated to produce a 55-percent solids slurry consisting primarily of sodium sulfate (Na_2SO_4) and sodium thiosulfate ($Na_2S_2O_3$).

Clean condensate from the crystallizer will be recycled to the mill.

The brine slurry from the crystallizer will be dewatered to a concentration of about 80 to 95 percent solids. After the concentrated slurry cools it will solidify and form a solid with no free water.

Once the water treatment system is started up, it is hoped that this material can be sold. The solidified brine will be essentially sodium sulfate, which is used in both the Kraft pulp and paper process and in the glass making industry. However, as a market for this material may be unavailable, the permits for the Crandon Project are being sought for the disposal of this solidified brine in a separate cell of the tailings ponds.

Effluent

Effluent from the Recycle Water Treatment System will be pumped to the mill for use in locations which require high purity water. This stream will represent the only fresh water makeup to the mill processes.

Q. Have any safeguards been provided to prevent discharge of effluent from the Crandon Project if it does not meet the effluent limitations?

A. Before water is discharged from the treatment systems to the environment, there will be one additional safety feature to ensure compliance with all effluent limitations.

As shown in EXHIBIT 296, effluent from the water treatment systems will be pumped to a set of Excess Water Discharge Lagoons which under maximum flow rate conditions have a 24-hour retention time. A sampler will collect daily composite samples of water entering the lagoon. By the time water passes through these lagoons, testing results from the previous day's operation will be available. If the effluent meets all limitations, it will be pumped to Swamp Creek or will be used in conjunction with Exxon's mitigation plan. If it does not meet the limitations, the water will be pumped either to the reclaim pond or back through the treatment system.

The Excess Water Discharge Lagoons will be equipped for either series or parallel operation. If only one of the treatment systems is having operating problems, the effluent from one system can be discharged through one lagoon while effluent from the other system can be recycled back through treatment system.

Q. How will sanitary wastewater be treated prior to its discharge?

A. Sanitary wastewater will be collected from all locations and will be routed to a biological wastewater treatment plant. Because of the small flow rate of sanitary wastewater, the most economical way to treat the water will be a prefabricated package-type system available from a number of manufacturers. After evaluating several alternatives, an extended aeration type system was selected as most appropriate for the Crandon Project.

This type of treatment process, shown in EXHIBIT 297, is basically the same type of process used in municipal wastewater treatment plants. The sanitary wastewater is mixed and aerated in a tank containing high concentrations of bacteria which degrade organic material present in the water. Effluent from the aeration tank is passed through a clarifier to separate out the solids for return to the aeration tank. Effluent from the clarifier is chlorinated for disinfection and then pumped to Swamp Creek along with the effluent from the water treatment systems.

The treated sanitary wastewater will be of about the same quality as treated effluent from a typical municipal wastewater treatment plant.

Q. Can you now describe how runoff from the roadways and parking lots on the south side of the mill will be handled?

A. Rainwater which falls onto roadways and parking lots on the south side of the surface facilities will resemble typical runoff from roads, streets, and parking lots. Other than a minor amount of suspended solids, it will be similar to runoff from the existing site. This water, which will only average about 65 gallons per minute annually, will be routed to a one acre retention pond, with capacity for over 2 million gallons, where solids will be allowed to settle out. Overflow water will then flow to nearby wetlands and will eventually reach Little Sand Lake.

Q. What is the expected volume of sludges to be generated by the water treatment systems at the Crandon Project?

A. Approximately 40 gallons per minute of sludges will be generated from the lime/sulfide and lime/soda softeners at the treatment plant. These sludges will be pumped to the tailings pond and will be comingled with the tailings. In the tailing pond, the sludge will slowly compact to a small fraction of its original volume.

In addition to these sludges, the crystallizing evaporator will produce on the order of 160 to 180 cubic feet of material per day.

Q. How will the sludges generated in the treatment process be handled?

A. As I stated previously, all of the lime/sulfide and lime/soda softening sludges will be stored with tailings in the tailings pond. Mr. Moe has already testified on the design features of these ponds.

The solidified brine from the crystallizing evaporator (Recycle Water Treatment System) will also be stored in the tailings pond in an isolated cell to keep it segregated from the main water system. It is possible that this material could eventually be sold as a useable byproduct, but that cannot be determined until the plant is started up and a product is available for testing.

All of the sludges generated from water treatment will be isolated from the surrounding environment and disposed in the tailings pond.

Biological sludge generated in the treatment of sanitary wastes will be hauled offsite by a licensed waste hauler.

Q. You mentioned earlier that the design of the water treatment facilities would incorporate a certain amount of engineering judgment to compensate for potential inaccuracies in your prediction of water quality in the water system. Can you describe how this engineering judgment was applied?

A. Engineering judgment was used to provide both flexibility in system operation and in developing contingency plans to overcome foreseeable problems:

1. The water treatment system piping will be arranged to provide for alternate modes of operation. For example, the system can be lined up to discharge a portion of the effluent from the Recycle Water Treatment System. This would be necessary during particularly wet years when the reclaim pond starts to fill up. Another operating alternative would allow direct use of intercepted groundwater in the mill. This mode could potentially save operating costs by reducing the amount of water treated with reverse osmosis and evaporator or, alternatively, could be used during equipment repairs in the Recycle Water Treatment System.

2. Excess capacity is built into the design of each water treatment system. The water treatment plant is capable of treating at least 20 percent more than the maximum predicted flows.

3. Pilot testing by Exxon indicates that the proposed processes will meet the limitations. The water treatment building, however, has been designed with enough extra space to add additional water treatment capacity if the proposed system must be supplemented.

4. In the treatment of water for recycling, the reverse osmosis process is probably the single unit operation most sensitive to influent water chemistry. The system design incorporates a number of features to protect this system:

   a. If organics are not degraded as projected, activated carbon could be added at the neutralization reactor to reduce this problem.

   b. Computer predictions of influent water chemistry indicate that in excess of 85 percent of the RO feed water could be recovered as permeate before scaling of the membranes becomes a problem. Although the RO system design will be such that high recoveries can be accomplished, the evaporator has been sized to treat all brine resulting from a design recovery rate of only 80 percent.

c. The design of the reverse osmosis system includes three operating RO modules and one standby module. This standby module represents an installed 33-percent safety factor over and above the design basis for the system.

5. All systems are designed with installed spares for critical items of equipment. Even if individual items of equipment must be taken out of service for repairs, the plant will still be able to operate.

6. In the event of a failure in one of the treatment processes, the freeboard volume in the reclaim pond could hold the untreated water while repairs are made.

In addition to design contingencies such as these, the operators of the plant will have considerable flexibility to adjust chemical dosages or to change chemicals added to the processes to compensate for unforeseen differences in influent water chemistry. Water can also be recycled back through treatment from the discharge lagoons if effluent quality does not meet limitations.

The treatment system will be operational for more than 1 year before it is truly necessary. During that time period, the performance of the treatment processes can be thoroughly tested. If proposed effluent limitations cannot be achieved, different reagent addition rates can be tested, different reagents can be added, alternate filter media can be tested, and pretreatment techniques can be evaluated.

Q. You've alluded to pilot testing done by Exxon to test the ability of the proposed system to meet effluent limitations. Can you describe this testing?

A. The key to compliance with the proposed limitations is the removal of soluble metals in the lime/sulfide precipitation process. Exxon tested this process both in batch and continuous flow-through tests using influent water which had been formulated to resemble the predicted water quality of influent to the Crandon Water Treatment System.

In both types of tests, effluent from the test equipment consistently met the proposed effluent limitations.

Q. If the bench and pilot scale tests showed that the proposed system can meet effluent limitations, can you explain why the treatment building has been laid out with room for additional water treatment capacity?

A. Certainly. As I've testified previously, Exxon's number one goal in selection of a treatment system was to ensure that effluent limitations will be met. Long-term operation of the overall mine and mill depends on compliance with the effluent limitations. As I also mentioned, engineering judgment was applied to the configuration of the treatment system to ensure compliance even if our predictions of influent quality are in error.

Leaving space in the treatment building for future addition of more water treatment capacity is the ultimate "insurance policy" against a number of unlikely events happening all together.

Q. Can you elaborate on that?

A. To the best of my knowledge, the system proposed for initial installation will meet the proposed limitations. Although we deliberately attempted to be conservative in prediction of water chemistry and in sizing the treatment plant, there still could be unexpected differences between prediction and real life conditions.

Q. If any of these differences occur, would the additional water treatment capacity be installed?

A. It's possible, but there are other alternative revisions to the processes which would be evaluated and tried before the additional water treatment equipment would have to be installed.

Q. Wouldn't it be too late by then to prevent the discharge of water which does not meet effluent limitations?

A. Not at all. The RO and VCE units installed initially have the capacity to treat all the water which must ultimately be discharged from the Project. It could be used to treat mine water while other water treatment equipment is ordered and installed. In addition to the treatment system operational period prior to startup of the mill, there will be about a year of mill operation before the quality of recycle water reaches equilibrium and treatment of that stream becomes mandatory.

Q. What is the likelihood that the future water treatment equipment, such as an additional RO and VCE will be necessary?

A. It is very difficult to quantify that precisely. The possibility of having to add future units is certainly much less than 50 percent. They would only be necessary in the case of improbabilities built onto improbabilities. It is far more likely that process modifications can compensate for unanticipated events.

Q. How will the day-to-day performance of the system be controlled?

A. The water treatment plant will be a state-of-the-art facility, designed to operate with minimum operator attention. It is currently planned that the control room will be equipped with a computer console for monitoring the performance of the system. Key instrument readings and alarms will also be displayed in the main control room of the mill.

The plant will have an extensive instrumentation and control system to monitor the performance of each process and to permit operators to make adjustment from the control room. If upset conditions occur, alarms will be sounded in the control room alerting the operators that their attention is required.

The water treatment plant will be manned round-the-clock, 7 days per week. Operation of the plant will be under the control of a state certified operator. There will always be a trained operator in the building to respond to the needs of the system.

It would be too time consuming to discuss all of the control features of the water treatment plant in my testimony today. This is discussed in detail in the final plans and specifications report submitted, which is EXHIBIT 118.

Q. How will the quality of water discharged from the Crandon Project be monitored?

A. Performance of the water treatment system should be relatively stable. There will be seasonal fluctuations in water temperatures and quality, but very little day-to-day change in quality is expected. Any changes in quality should happen slowly once the system stabilizes.

Automatic composite samplers (EXHIBIT 298) will collect flow proportional samples of intercepted groundwater, contaminated mine water, and reclaim pond water. Samples collected at these locations will be used to monitor the quality of influent to each of the three water treatment systems.

Flow proportional composite samplers will also be installed to collect effluent samples from each of the three treatment systems on a daily basis. A final sampler will be installed at the outlet from the Excess Water Discharge Lagoons to measure effluent quality immediately before it is discharged to Swamp Creek or used as water to supplement lakes and streams pursuant to the contingency/mitigation plan. Effluent samples will be collected daily and analyzed for all parameters required by the WPDES permit.

Effluent from each of the three systems and the lagoons will also be analyzed continuously for pH, specific conductance, and turbidity to alert operators of any short-term fluctuations in effluent quality.

A composite sampler will also be installed at the discharge point of the sanitary wastewater package treatment. Samples will be analyzed for parameters specified in the WPDES permit.

Uncontaminated runoff collected in the runoff sedimentation basin will be manually sampled and water will be analyzed as described in the Monitoring Plan (part of EXHIBIT 111)when water is being discharged to adjacent wetlands.

This monitoring strategy will result in a record of the quality of all water discharged from the Crandon Project.

Q. What is the expected range of water temperature in effluent from the water treatment system?

A. Effluent from the intercepted groundwater and contaminated mine water treatment systems should remain relatively constant at about 48^{o} F year round, which is the approximate temperature of area groundwater. During winter months, the water will cool down in the Excess Water Discharge Lagoons to a cooler temperature, depending on ambient weather conditions.

Q. Where will effluent from the Crandon Project be discharged?

A. All water leaving the site and not used in the contingency/mitigation plan will be pumped through a 6-mile-long pipeline and be discharged to Swamp Creek downstream from the bridge on County Trunk Highway M as shown on EXHIBIT 101.

Q. Does Exxon plan to do any special monitoring to determine whether compliance with its effluent limitations does, in fact, result in acceptable pollutant concentrations in Swamp Creek?

A. Yes. Exxon has submitted a Monitoring and Quality Assurance Plan as part of their Mine Permit Application, EXHIBIT 111, to the Wisconsin DNR. This plan describes the sampling and analysis program designed to monitor the impact of the Crandon Project on the environment. I will discuss only those elements of the plan that relate directly to the water treatment systems I have described.

At the outfall to Swamp Creek, combined effluent from the water treatment systems and the sanitary wastewater treatment system will be continuously monitored for dissolved oxygen, flow rate, pH, and specific conductance. A daily composite sample will be tested for total dissolved solids and total suspended solids.

Water samples from Swamp Creek will be collected regularly and tested to determine the in-stream concentration of a wide range of compounds as described in the Monitoring Plan. These samples will be collected quarterly at a point upstream from the outfall and monthly at both a point within the mixing zone in the creek and a point well downstream.

In addition to the stream water sampling program, duplicate sediment samples will be collected annually upstream from, downstream from, and within the mixing zone and tested for various compounds as described in the Monitoring Plan.

Fish and benthos sampling and analysis will also be conducted on an annual basis. Samples obtained will be analyzed as described in the Monitoring Plan.

Discharge from the runoff sedimentation pond (actually several ponds during construction) will be intermittent. When they are discharging water to nearby wetlands, water samples from the sedimentation basin outlets will be collected and tested in accordance with the Monitoring Plan.

Information collected in this monitoring program will be assessed regularly by Exxon's environmental staff to determine whether the discharges have any potential for adverse impact on the environment. In addition, it is my understanding that information from the monitoring program will be reported to the DNR on a regular basis.

Q. When will the water treatment facilities be constructed?

A. EXHIBIT 270 shows the approximate construction schedule for the water treatment system in relation to the remainder of the mine and surface facilities. It will be operational by about month 19 of the overall construction of the Crandon Mine and Mill.

The package plant for treatment of sanitary wastewater will be installed and operational by about month 6 of construction.

Q. Mine construction is scheduled to start 19 months before the water treatment plant is operational. What will happen to all the mine water during those first 19 months?

A. There will be very little flow from the mine during the first few months of construction. When water is encountered, it will be pumped to the reclaim pond. I understand that projections of mine water flow are such that the reclaim pond could hold all of the water pumped from the mine between start of construction and startup of the mill in month 36.

It is projected that the water treatment system will be completely installed and operational one year before it is really required.

During this period, each of the treatment systems can be started up and the performance can be tested and optimized. If any modifications to the process are required, changes can be made before operation of the plant becomes critical to operation of the mill or compliance with effluent limitations.

During start up of the systems, effluent from the discharge lagoons can simply be routed back to the reclaim pond. No water will be discharged unless it complies with effluent limitations.

Q. The whole water treatment plant sounds very complex. Are the processes you've described used elsewhere?

A. Every technology to be used in the Crandon Project treatment system represents proven technology in use in numerous places throughout the country. To my knowledge, however, the Crandon Water Treatment Plant will be the first of its kind in the mining and milling industry.

Q. How big will the water treatment system be?

A. From end-to-end, including the evaporator, the building will be about 340 feet long, will be about 110 feet wide, and will be 30 feet high inside. In other words, it will be a three story building as long as a football field (including the end zones) and about two-thirds as wide.

Q. Are you confident then, to a reasonable degree of engineering certainty, that the proposed treatment system, including the contingency planning inherent to the design, can provide effluent for discharge that meets the Wisconsin DNR's proposed effluent limitations?

A. Yes.

Q. Will effluent discharged from the Crandon Project to surface waters comply with the surface water quality standards?

A. Yes. It is my understanding that the effluent limitations calculated by the Wisconsin DNR were formulated to protect against violation of surface water quality standards. Compliance with the limitations, therefore, ensures that surface water quality standards will be met.

Q. In your professional opinion and to a reasonable degree of engineering certainty, will the water management facilities of the Crandon Project be located, designed, constructed, and operated in such a manner as to prevent any surface discharge into navigable waters that would cause a violation of any state toxic discharge standard for compounds for which effluent limitations have not already been computed?

A. To the best of my knowledge, all toxic compounds which may be present in the discharge from the Crandon Project have been considered in CH2M HILL's studies and are included in the list of compounds for which DNR has computed effluent limitations. As I have already testified, the proposed treatment system, in my professional opinion, is capable of meeting those limitations. I am not aware of any regulation which will not be met by the proposed system if it is constructed and operated as described in the engineering report.

Q. In your professional opinion, will the facility comply with all applicable regulations for point source discharges into navigable waters?

A. Effluent from the proposed system will comply with all state point source pollution control requirements and the treatment processes selected will prevent the discharge of any substance into surface waters at concentrations which will violate any state law.

Q. Will there by any discharges from the Crandon Project to a publically-owned treatment works?

A. No, and because there are no such discharges, pretreatment standards do not apply.

Q. Can you quickly summarize the facts you've presented today?

A. The water management plan for the Crandon Project is based on extensive studies, during which numerous overall water management options and water treatment technologies were evaluated.

The water treatment systems ultimately selected are very sophisticated and will ensure compliance with effluent limitations established by the Wisconsin DNR.

Although the treatment system will be one of, if not the most sophisticated treatment systems in the U.S. mining and milling industry, all of the technologies used are state-of-the-art processes which have been used elsewhere.
Predictions of system performance are based on proven performance of similar installations and on pilot testing using simulated water from the Crandon Project.

The water treatment systems selected are flexible with respect to influent water chemistry. Even if our predictions of water quality are off what is actually encountered, the processes will still work. Excess capacity has been designed into the system to account for unknowns. Contingency plans have been developed for all foreseeable problems which might develop.

From my experience with similar types of projects, it is my professional opinion that Exxon has left no stone unturned in completing its evaluation of water management options. At Exxon's request, we have evaluated almost every conceivable option in great detail. The proposed treatment systems have been very well thought out. As I mentioned early in my testimony, Exxon's number one goal was to end up with a system that meets effluent limitations established for the Crandon Project. It is my professional opinion that Exxon has met that goal and that the water treatment system will meet all of the applicable effluent limitations.

5023R

Exhibit 288

MICHAEL R. HARRIS
Industrial Processes Engineer

Education

M. S. Sanitary Engineering, Oregon State University
B. S. Civil Engineering, Oregon State University

Experience

Mr. Harris is a senior project manager in CH2M HILL's Industrial Processes Division. He has managed a wide variety of projects involving both biological and physical-chemistry treatment of water and wastewater for industrial clients. He has overseen all of CH2M HILL's Midwestern solid and hazardous waste remedial planning work under the superfund program and, in addition, has personally managed several private-sector remedial planning projects.

Mr. Harris' industrial experience includes clients in base metals mining and milling, pulp and paper, industrial chemicals, food processing, and chemical products formulation. He is a recognized firmwide consultant in biological kinetics, sludge dewatering, pilot plant data analysis and scaleup, remedial planning for hazardous waste sites, and similar, related fields. He was coauthor of CH2M HILL's in-house computer program for analysis of biological pilot plant data.

Representative examples of Mr. Harris's experience with the mining and milling industry are his projects for Anaconda and Exxon Minerals Company. He managed zero-discharge evaluations for both the Anaconda reduction works and for Anaconda's Butte Operations. For Exxon, he managed a series of projects for a grass roots copper, lead, and zinc mine/mill near Crandon, Wisconsin. These projects included development of a water balance for the facility, preparation of a computer model to predict water quality under a number of operating scenarios, and preparation of conceptual designs for process and domestic water treatment systems. Special project considerations necessitated the use of lime-soda softening, dual media filtration, reverse osmosis, vapor compression evaporation, and a crystallizing evaporator for the final brine product.

Mr. Harris has assisted a number of clients in dealing with the public and with agencies. He has appeared at public meetings and has assisted with permit negotiations with local, state, and federal agencies.

MICHAEL R. HARRIS

He has served as a management consultant and process troubleshooter for a number of industrial treatment systems. He has provided services during construction, prepared O&M manuals, and provided operator training and assistance during startup of a number of wastewater treatment systems.

Mr. Harris has served in numerous capacities on both biological and physical-chemical pilot plants. He has been onsite pilot plant operator, project manager, project consultant, and supervisor of data analysis.

For the Minnesota Pollution Control Agency, Mr. Harris managed CH2M HILL's evaluation of groundwater treatment technologies and water supply alternatives for the City of St. Louis Park, Minnesota. The City's water supply aquifer is contaminated with polynuclear aromatic hydrocarbons emanating from the Reilly Tar and Chemical Superfund site. CH2M HILL's work on this project included quantification of PAH removals at the low nanogram per liter (part per trillion) levels. Technologies evaluated included chlorine, chlorine dioxide, hydrogen peroxide, ozone, peroxide/UV, ozone/UV, macroreticular resins, and granular activated carbon. Based on the results of bench and pilot scale tests and an economic comparison with other water supply alternatives, CH2M HILL recommended treatment of contaminated groundwater with activated carbon and use of treated water in St. Louis Park's potable water system.

In the area of industrial chemicals, Mr. Harris was a project manager for the study and/or design of physical-chemical and biological wastewater treatment facilities at General American Transportation Corporation's (GATX) railroad tank car cleaning facilities in Masury, Ohio, East Chicago, Indiana, and Hearne, Texas; and for the study and design of industrial wastewater pretreatment facilities for all miscellaneous wastes generated at the Trident Support Site, U.S. Navy, Bangor, Washington.

His project experience includes pilot scale evaluation and/or design of the following biological treatment processes: aerated lagoon, activated sludge, pure oxygen activated sludge, rotating biological contractors, anaerobic filter, upflow anaerobic sludge blanket, powdered activated carbon treatment, and a variety of land application techniques.

MICHAEL R. HARRIS

Similar project experience with physical-chemical treatment processes includes lime, lime-soda, and lime-sodium sulfide softening, dual and mixed-media filtration, reverse osmosis, chemical oxidation, granular activated carbon, ion exchange, evaporation, and crystallization.

Prior to his employment with CH2M HILL, Mr. Harris served as a plant engineer at a major oil refinery in Anacortes, Washington.

Professional Registration

Professional Engineer, Texas, Oregon, Washington, Wisconsin, Michigan, Minnesota, Indiana, Ohio, Texas

Membership in Professional Organizations

Water Pollution Control Federation - Program Committee
American Society of Mining Engineers

Publications and Presentations

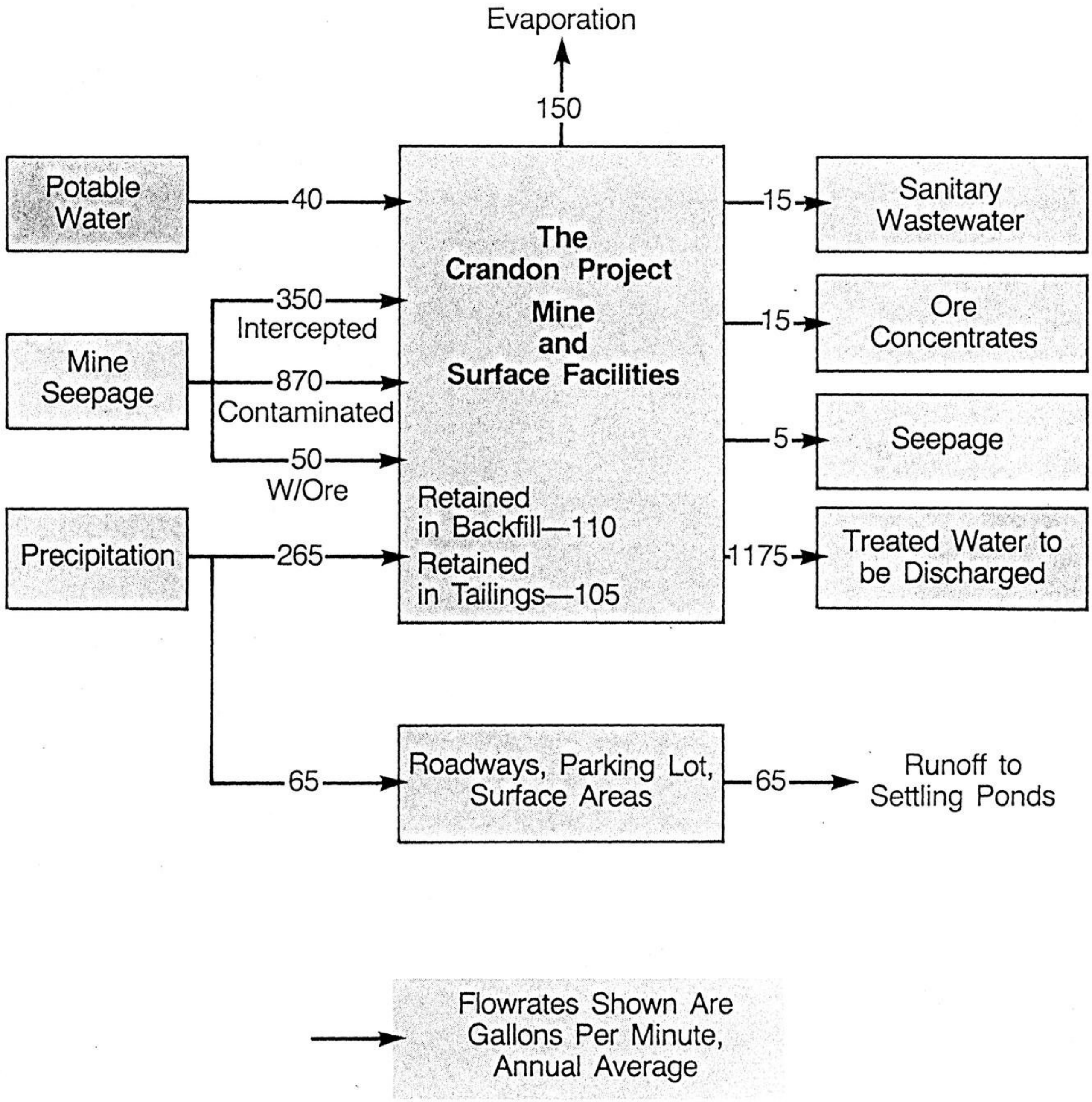
"Removal of Polynuclear Aromatic Hydrocarbons from Contaminated Groundwater," coauthored with Michael J. Hansel. Presented at the 4th National Conference of Management of Uncontrolled Hazardous Waste Sites, November 1983.

"Integrated Water Reuse in Mineral Processing Facilities," presented at AIME Annual Meeting. Atlanta, Georgia. March 8, 1983.

"CM - The Fast Track for Minimizing Inflation," Pollution Engineering, June 1980.

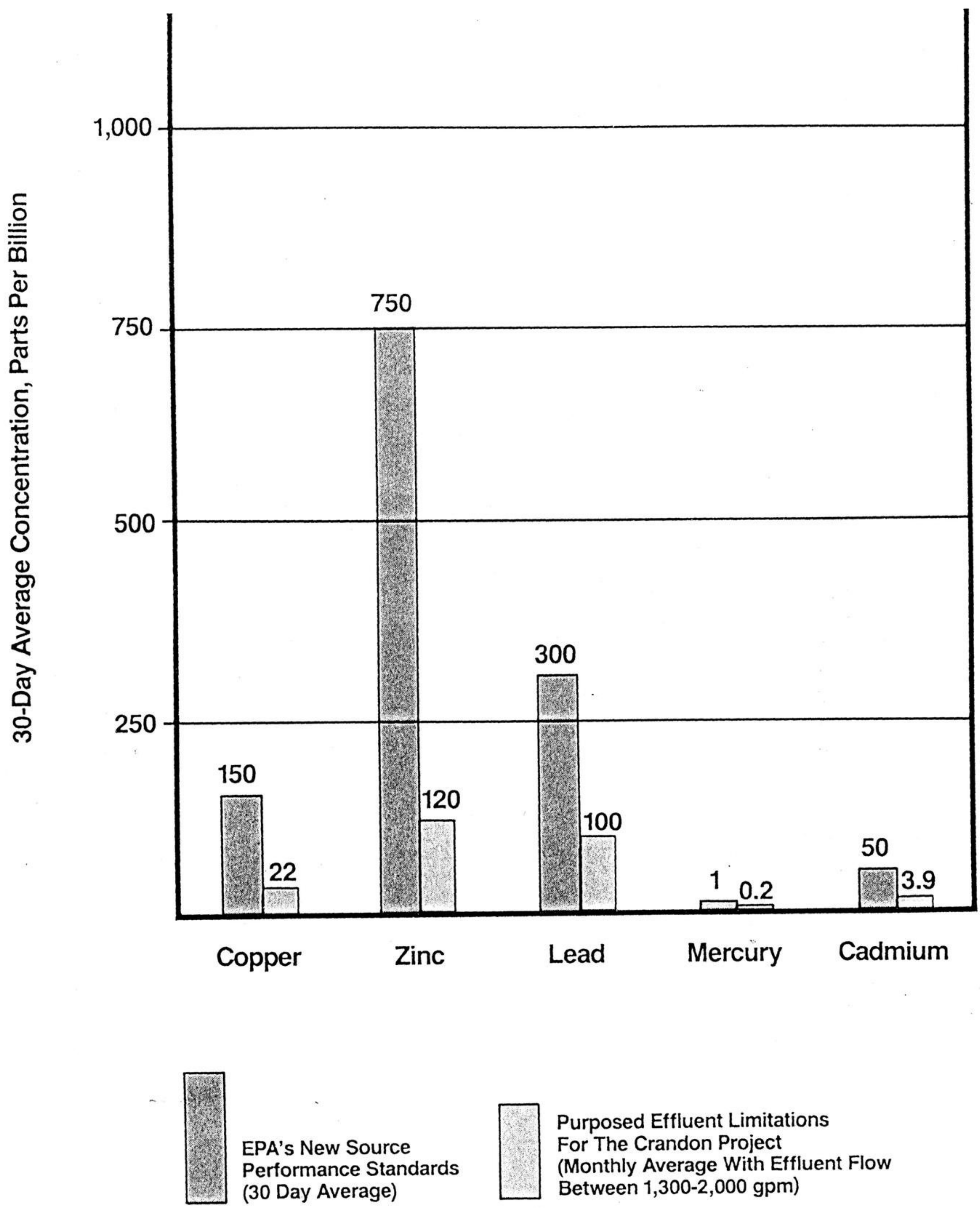
"Joint Treatment of Municipal and Fruit Processing Wastewaters in an ABF-Activated Sludge Treatment System," Paper presented at the PNPCA annual meeting, 1977.

Water Sources and Losses

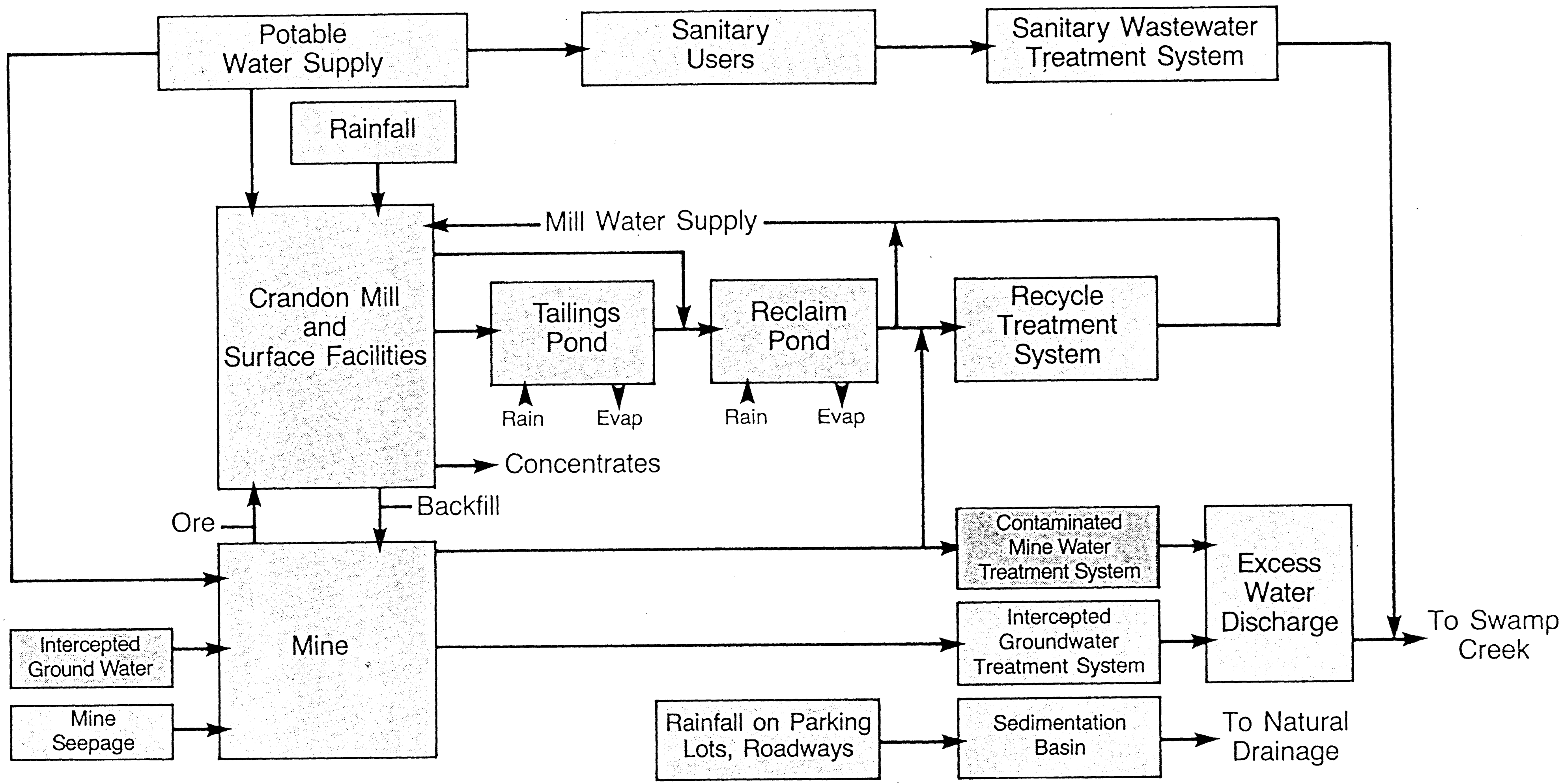


Effluent Limitations

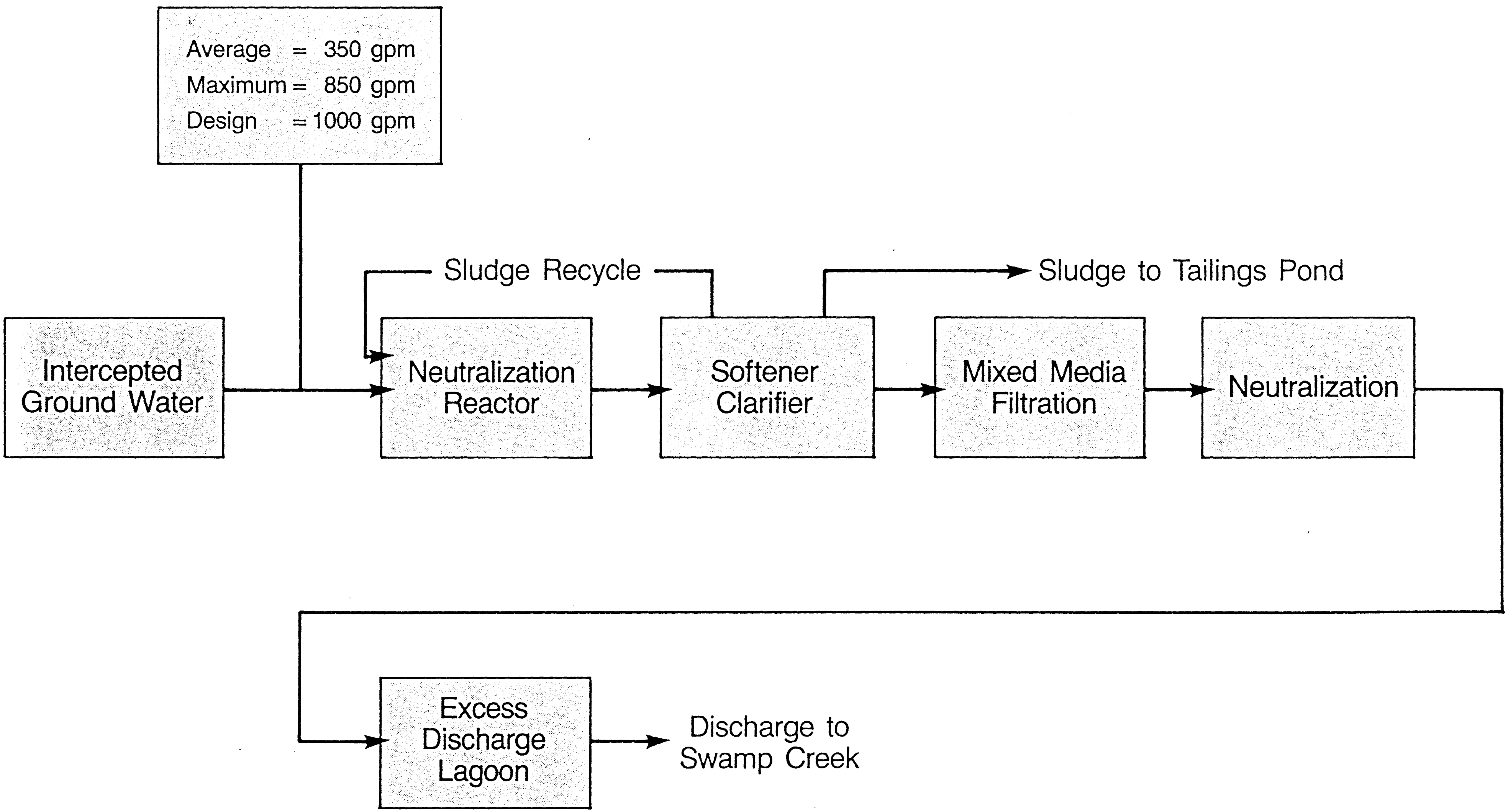
Comparison to EPA's NSPS



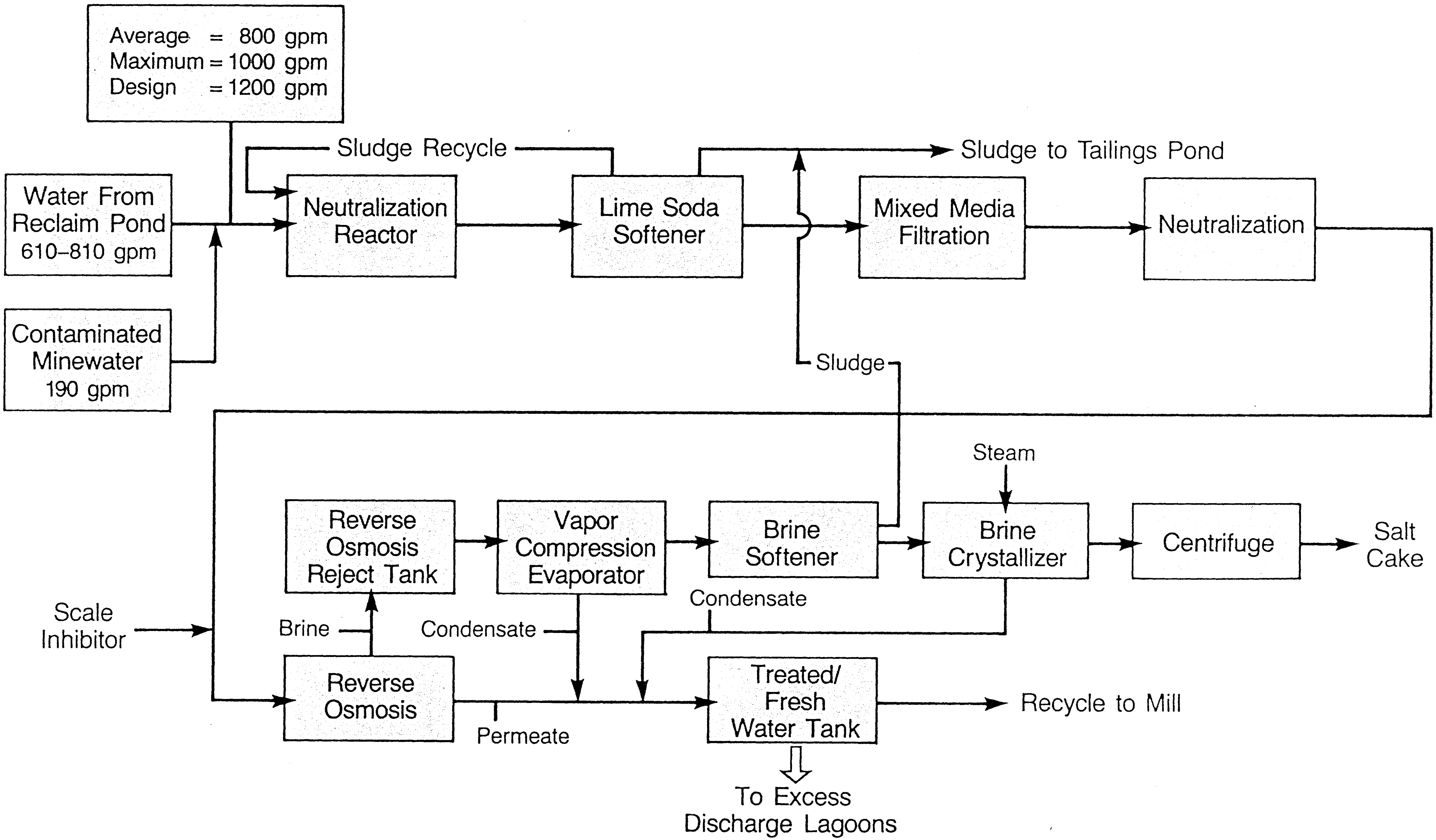
Water System
Crandon Project



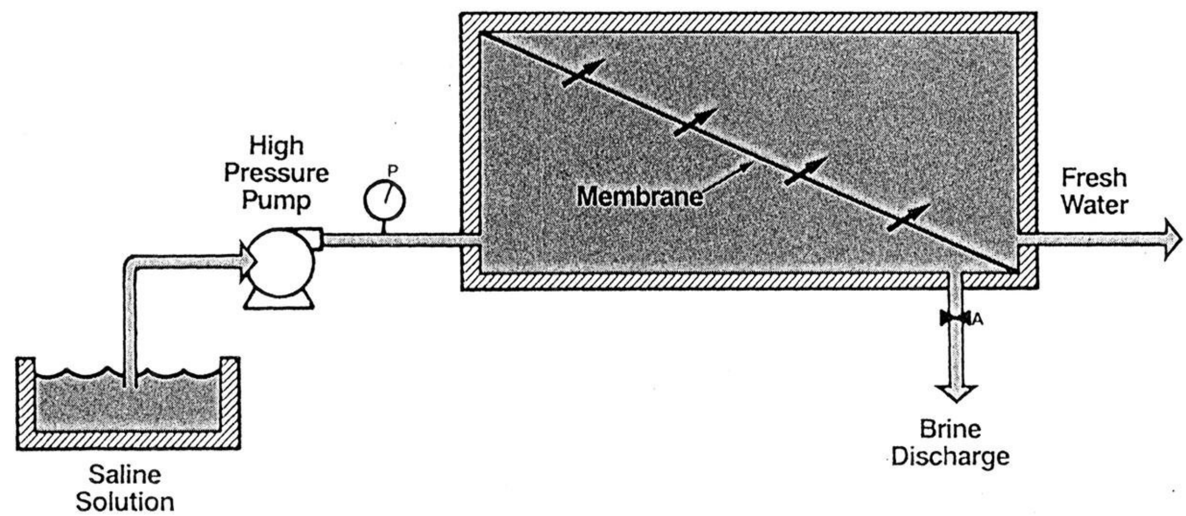
Intercepted Ground Water Treatment



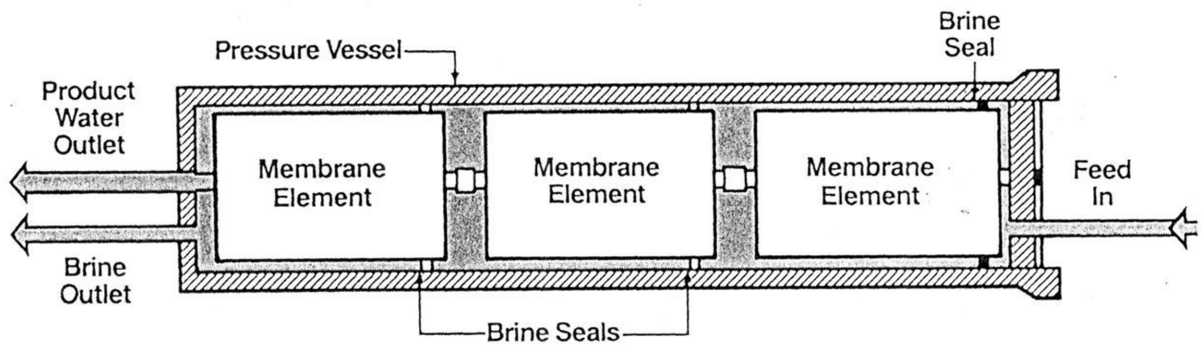
Recycle Water Treatment



Reverse Osmosis System



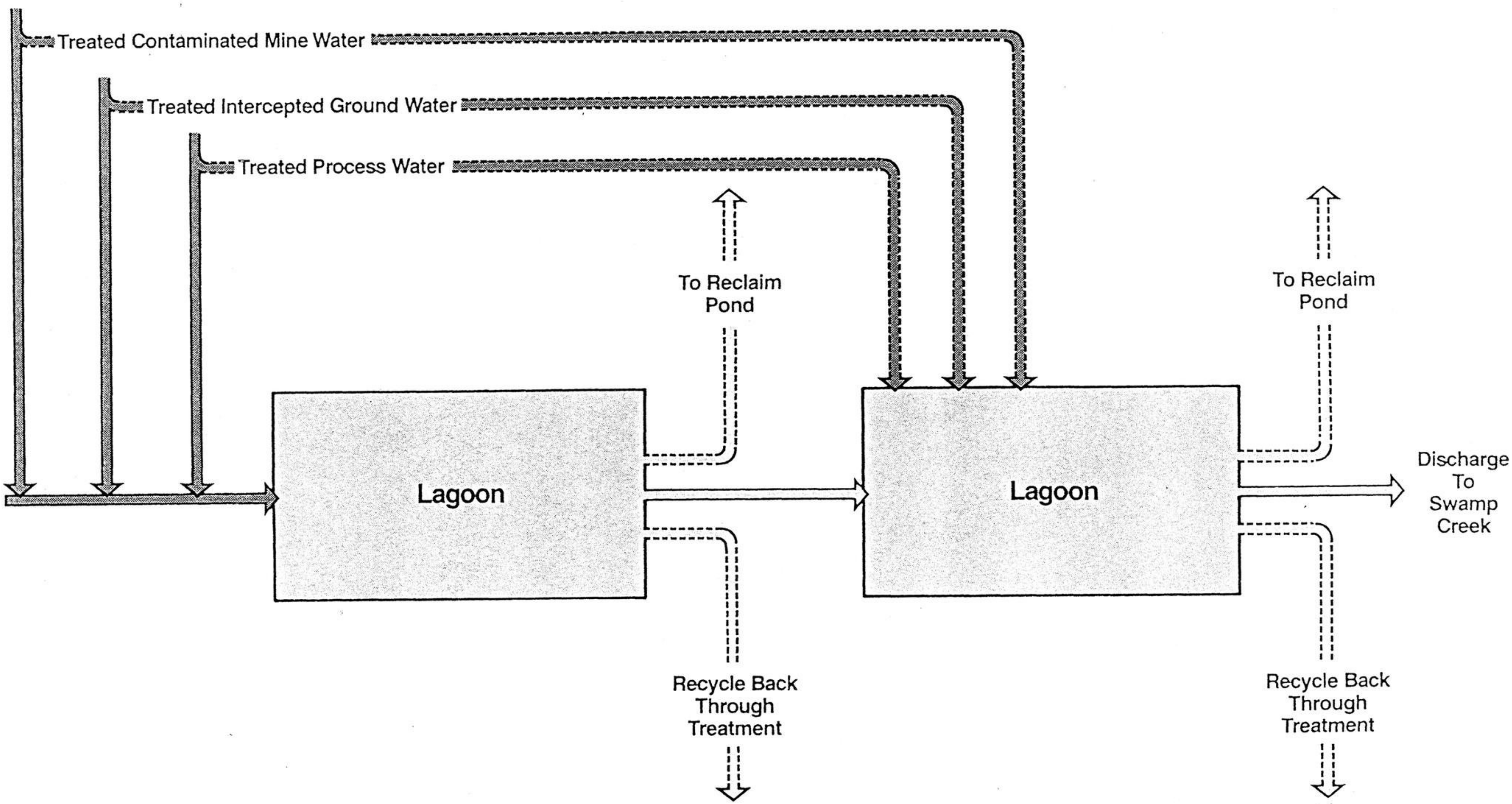
Elements of a Reverse Osmosis System



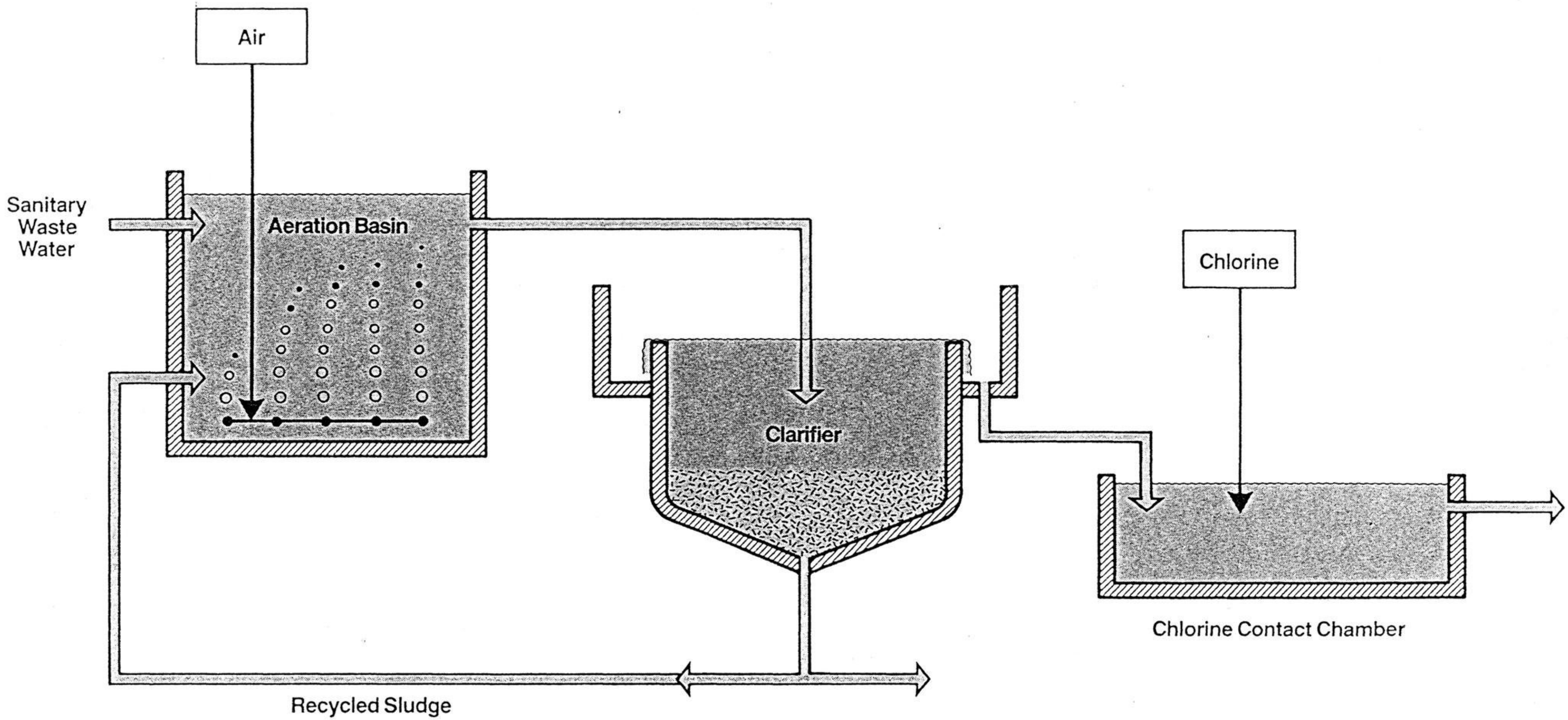
Conceptual Equipment Arrangement

Excess Water Discharge

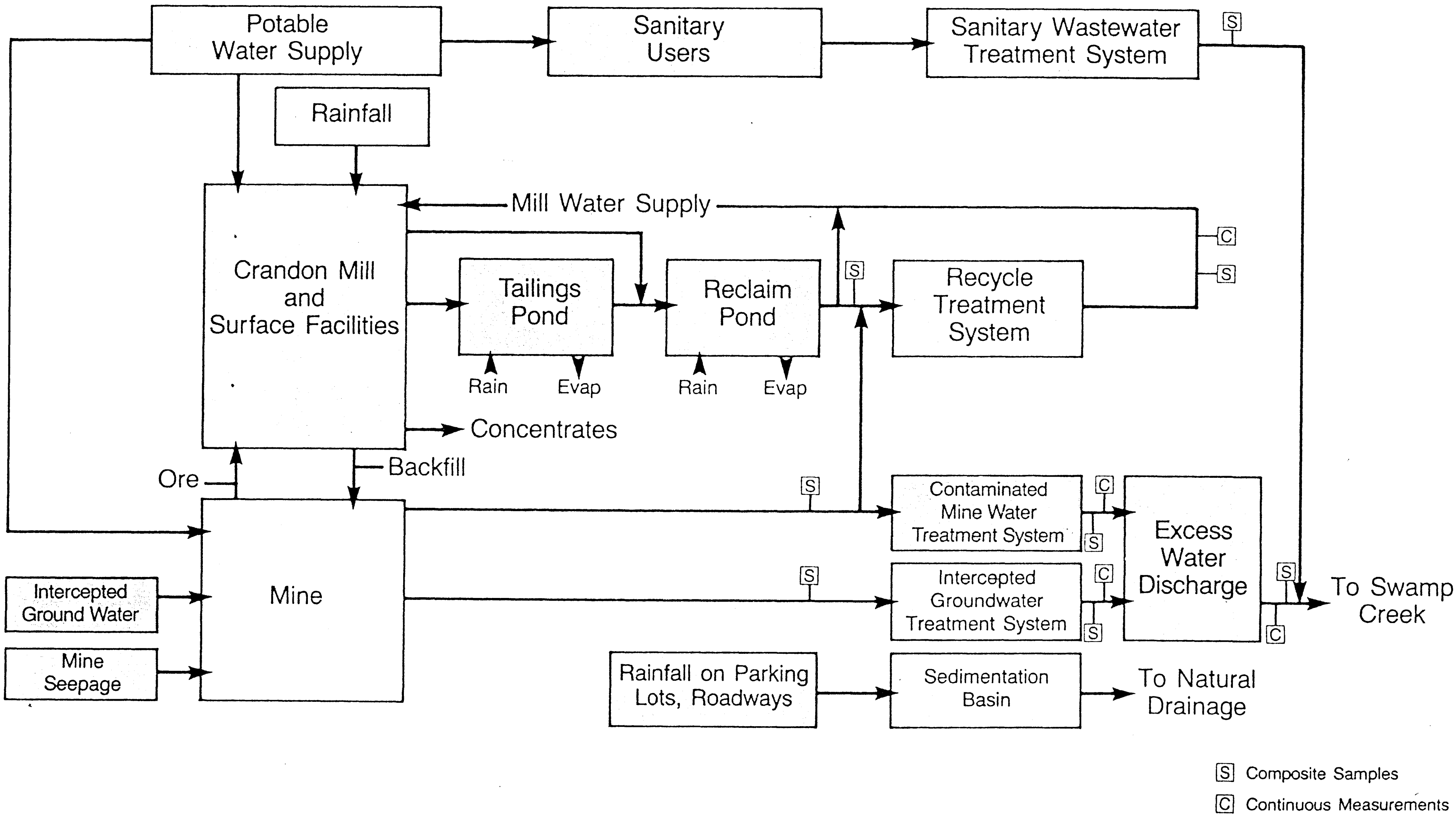
Lagoons System



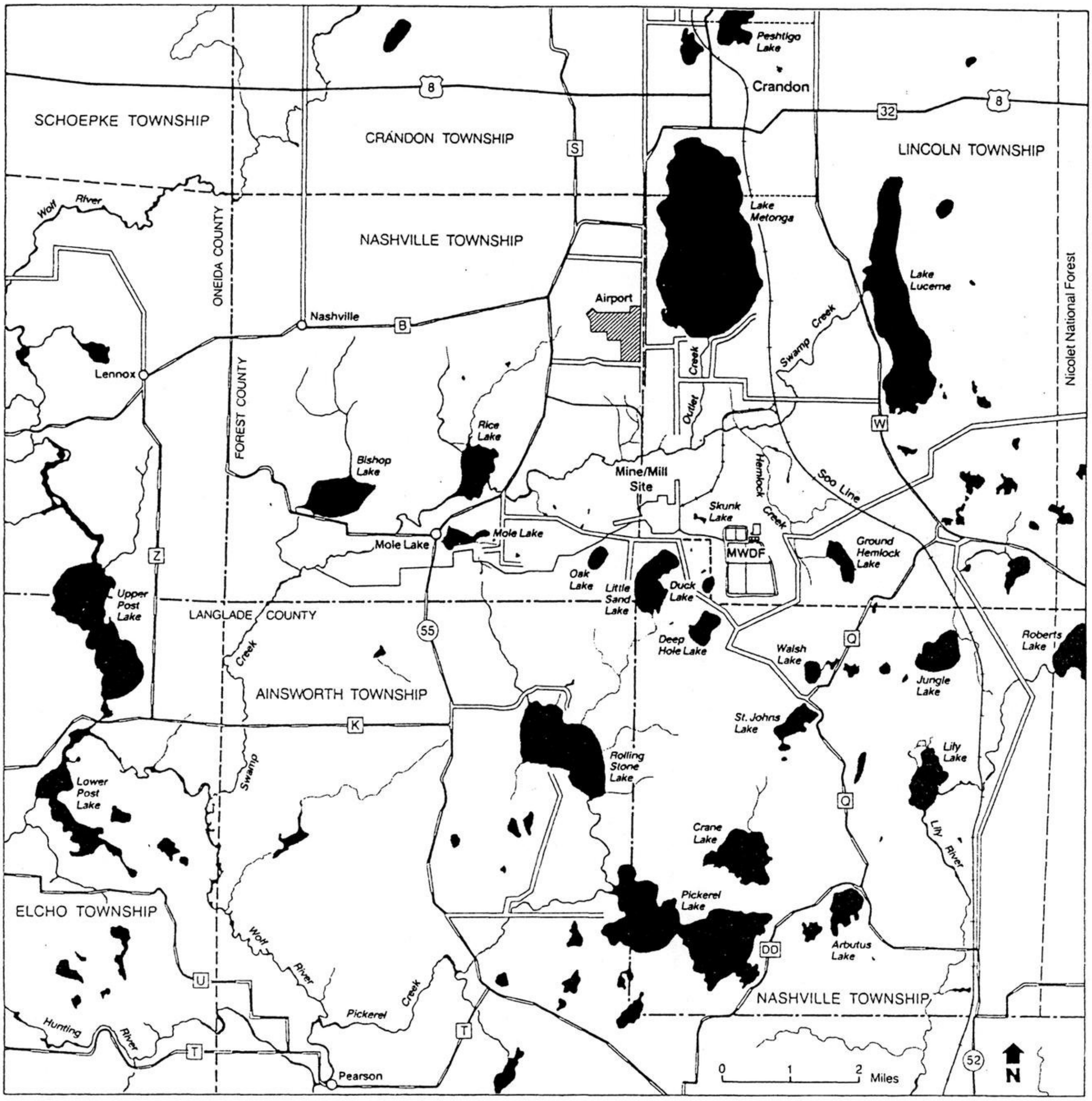
Sanitary Wastewater Treatment System



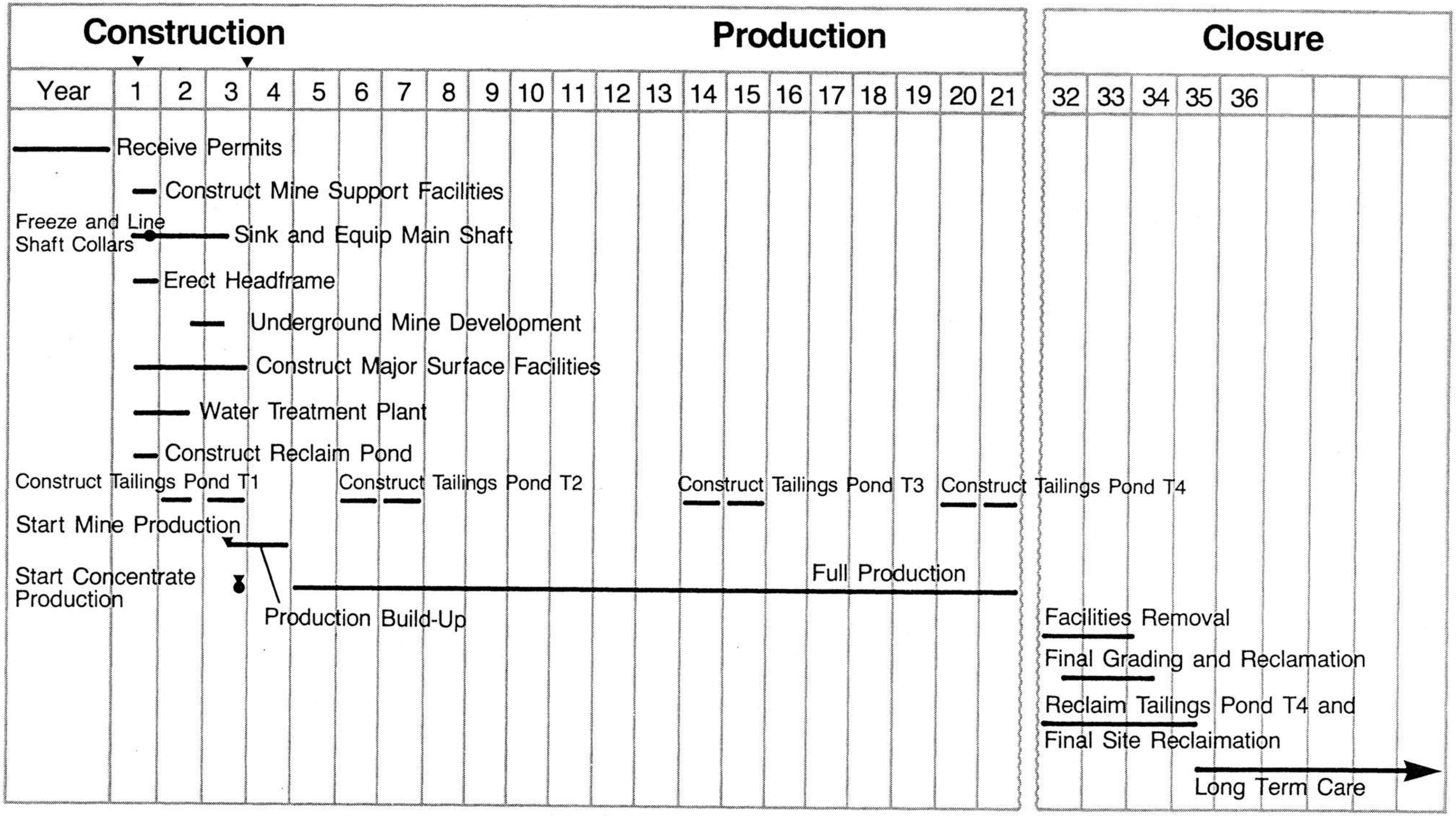
Sample Collection Points
Crandon Project



Regional Base Map



Project Schedule



BEFORE THE
STATE OF WISCONSIN
DIVISION OF HEARINGS AND APPEALS

Application of Exxon Corporation for Permits to Build and Operate an Underground Mining and Ore Concentrating Complex Located in Forest County, Wisconsin	))))	IH-86-18

TESTIMONY OF CARLTON C. SCHROEDER

HIGH CAPACITY WELL AND CHAPTER 30/31 PERMITS

Q. What is your name?

A. My name is Carlton C. Schroeder.

Q. By whom are you employed?

A. I am employed by Exxon Coal and Minerals Company, a division of Exxon Corporation.

Q. How long have you been employed by Exxon?

A. I have been employed approximately seven years by Exxon.

Q. What is your educational background?

A. My training is in civil engineering. I have a Bachelor of Science and Master of Science in Civil Engineering. I also have a Master of Business Administration. A resume of my background is attached as EXHIBIT 302.

Q. What has been your involvement with the Crandon Project?

A. I have been involved in the study, planning, and design of most of the surface facilities for the Project.

Q. What will be the scope of your testimony today?

A. I will be testifying in support of Exxon's High Capacity Well Approval Applications, which include our plans for mitigating surface water impacts caused by mine dewatering. I will also testify about all aspects of the Project which require permits under Chapters 30 and 31 of the Wisconsin statutes.

Q. Let us focus first on the High Capacity Well Approval Applications. What wells are included in those applications?

A. EXHIBIT 303 shows all the locations where we have wells. These include wells to meet Project water needs and to supplement area streams, springs and lakes if they are affected by mine dewatering. And the mine itself has been included as a high capacity well because ground water flows into the mine and then it is removed by pumping.

Q. What specific materials have been prepared and submitted to the DNR for these applications?

A. EXHIBITS 112 and 113 are the High Capacity Well Approval Applications. EXHIBIT 112 covers the underground mine and its ground water inflow control and drainage systems. As part of that application, we have also included the Hydrologic Impact Contingency Plan, which describes the supplements that will be made to the area waterbodies in the event that mine dewatering affects them. The other application, EXHIBIT 113, covers the potable, construction and mitigation and contingency supplement water wells and transmission systems.

Q. NR 112.26(1)(d) requires a significant amount of information, including the location, design, and operation of each well.

Has all that information been included in each application?

A. Yes. We have followed the regulation in completing the applications.

Q. Will the water from any of Exxon's wells be used as drinking water for people?

A. Yes. Exxon plans a public, non-community drinking water system supplying less than 50 gallons per minute for human consumption, sanitation and laboratory use at the Project site. The potable water will be supplied from well WS1.

Q. NR Chapter 109 creates quality monitoring, testing and record keeping requirements for potable water supplies. Has Exxon planned for meeting these requirements?

A. Yes. Water monitoring, testing, and record keeping will be performed as required by the regulations. The required information also will be reported to the appropriate state agencies.

Q. Mr. Schroeder, you mentioned earlier the mine ground water inflow control and drainage systems. What are they?

A. There are two components of the mine drainage system. The Ground Water Intercept System, which I will discuss in more detail later, is used to intercept and remove ground water before it reaches the mine workings and before the water has any chance of being contaminated.

The other component of the mine drainage system is the underground mine drain system that collects and removes mine water. This mine water consists primarily of ground water that seeps into the mine workings and that may be contaminated as a result of its contact with the orebody. The mine water also includes water entering the mine with the backfill that fills the mined zones. As the backfill water drains it is also collected in the underground mine drainage system.

Q. Why can't Exxon simply seal up the entire mine so that no water flows into it?

A. Studies have been conducted to determine the feasiblity of sealing the mine area and there is still a possibility that we might be able to seal at least some of the higher inflow areas at the orebody subcrop. A bentonite slurry was considered for this application, but this type of seal is not economically feasible on an area-wide basis. Also, because of the uncertainty associated with the effectiveness of the seal, some sort of mine water drainage system would still be required. In addition, a water handling system to collect and remove backfill drainage water would be required regardless of how effective a mine seal might be. Within the mine area cement rock grouting will be practiced to control local inflows. This grouting will not significantly reduce total mine seepage but it will divert or redirect the seepage water to minimize water handling operations in the mine.

Q. Did Exxon consider any other alternatives for eliminating or reducing ground water inflow to the mine?

A. Yes. A number of alternatives have been studied including the intercept system I have already discussed, overburden grout curtains, chemical or cement grouting, and many variations. With the exception of the intercept system and the selective bentonite grouting, these alternatives were either ineffective, economically not feasible, or had a high level of uncertainty of success.

I should add here that we believe an important objective is to reduce the amount of mine inflow to the maximum extent reasonably possible. This objective is in Exxon's interest because it leads to overall lower impacts, reduced water treatment costs, and reduced mitigation. In addition, for the water that does enter the mine area, we have the further objective of maximizing the portion of uncontaminated seepage water collected and minimizing the contaminated water portion. This objective also is in Exxon's interest because it leads to lower water treatment costs, less excess water discharge and provides maximum water available for mitigation.

Q. How will Exxon get the water out of the mine?

A. For the variation of the Ground Water Intercept System where water is removed from the glacial overburden material in the area of the mine, as shown in EXHIBIT 304, a series of surface wells would be used. These wells would be linked by a transmission line so all the water could be pumped back to the mine/mill area.

For the Ground Water Intercept System, if the entire system is underground as shown in EXHIBIT 260, the intercepted water will be transferred by pipe to a clean water sump planned on the 230 mine level. Pumps will then be utilized to remove the water from the sumps and transfer it out of the mine.

For the water that does seep into the mine and may be contaminated, a separate collection and removal system similar to the intercept system shown in EXHIBIT 260 is planned. This mine drainage system utilizes collection facilities on each level and transfer systems to direct the water to the main mine drainage sump on the 470 level. Pumps are utilized at this main mine drainage sump to transfer the water from the mine.

Q. Where will the water go?

A. All of the water will go back to the mine/mill area where it will be temporarily held and monitored. The clean ground water from the intercept system will either be discharged or reused as mitigation or contingency supplement water. The mine drainage water will go to the water treatment facilities for treatment and reuse in the process.

Q. Mr. Schroeder, are you familiar with the projected ground water cone of depression and its potential impacts to lakes and streams?

A. Yes. As Mr. Prickett and Dr. Djafari will testify later, the inflow of ground water to the mine and the process of pumping this water out of the mine will lower the levels of the ground water table in the immediate vicinity of the mine. This phenomenon is sometimes referred to as a ground water "cone of depression." This lowering of the ground water surface creates the potential for reducing the levels of several lakes and reducing the flows of several creeks in the immediate vicinity of the mine. The precise extent of potential impacts was determined through the modeling work of Mr. Prickett and Dr. Djafari.

Q. Have you had any involvement in the modeling work of Mr. Prickett and Dr. Djafari?

A. Yes I have. My colleagues and I have worked closely with these experts and with the Department of Natural Resources in attempting to predict the potential range of impacts caused by mine dewatering. We assisted these experts in developing and calibrating their models, made suggestions to them for additional modeling work, and consulted them as we developed our Contingency Plan.

Q. Mr. Schroeder, are you familiar with the "Revised Hydrologic Impact Contingency Plan," Volume II of EXHIBIT 112?

A. Yes, I was actively involved in its preparation.

Q. What is the purpose of the Hydrologic Impact Contingency Plan?

A. The Contingency Plan is a commitment by Exxon to provide a means of eliminating or minimizing unacceptable impacts to the Project area lakes streams that are caused by the mine dewatering. The waterbodies that are included in the Hydrologic Impact Contingency Plan are shown in EXHIBIT 304. They include Hoffman Spring and Creek, Martin Spring and Creek 11-4, Upper Pickerel Creek, Creek 12-9, Swamp Creek, Hemlock Creek, and Skunk, Little Sand, Duck, Deep Hole, Rolling Stone and Rice lakes.

Q. You mentioned the "commitment" that Exxon has made in this plan. What is that commitment?

A. We have committed in this plan to mitigate any declines in the levels or flow rates of area lakes, streams, creeks, or springs caused by Project dewatering activities that would, in the absence of mitigation, result in the unreasonable detriment of public rights in the waters of the state.

Q. What is your understanding of the phrase "unreasonable detriment of public rights"?

A. The definition of that phrase in relation to the Project has been provided by the Wisconsin Department of Natural Resources. More specifically, the DNR has set lake levels and stream flow rates at which Exxon must begin taking mitigation actions. The DNR believes that if stream flows or lake levels dropped below these points, adverse impacts to the animals and vegetation dependent on these waterbodies and to the various public uses of these waterbodies might begin to occur. Although Exxon believes that some of these points could be reasonably set at lower levels, we have adopted the DNR's levels as trigger points in implementing contingency measures.

Q. Why hasn't Exxon proposed contingency measures for other area waterbodies?

A. We have not done so because neither Exxon nor the DNR has predicted any potential for significant impacts to these other waterbodies. For example, Oak Lake is a perched lake and will therefore not experience any increased seepage or lake level declines as a result of the ground water drawdown from mine inflow. Other lakes are outside of the zone of influence created by mine dewatering. As Dr. Djafari will testify, any decline in the levels of these lakes would be on the order of fractions of an inch. I should note that Rolling Stone and Rice lakes fall into this category, but we have included them in the plan because contingency actions are included for the main streams that flow into these lakes.

Let me also add that, even though we have named specific waterbodies in the plan, the commitment set forth in the plan extends to <u>all</u> area waterbodies. If, notwithstanding the predictions of all of the experts who have been involved with this Project over the years, another waterbody is affected by mine dewatering, Exxon will ensure that mitigation measures are taken to protect the public's rights.

Q. What if the flow rate of a stream declines as a result of factors other than mine dewatering -- such as an extreme drought or beaver activity? Is Exxon still responsible for mitigating the decline?

A. We do not believe that Exxon should be responsible for mitigating any declines in the levels or flow rates of lakes, streams, creeks, or springs that are not caused by Crandon Project dewatering activities. There are a number of other factors that might cause the flow of a stream or the level of a lake to decline. Drought conditions, for example, obviously can have a substantial impact on a waterbody. Moreover, persons other than Exxon may operate wells or dams in this area that would affect these waterbodies. And beaver presently play a major role in controlling the hydrology of many area waterbodies. All of these conditions would not be Exxon's fault, and we therefore believe that Exxon should not be responsible for off-setting them.

Having said that, however, we also recognize that there may be a large "gray area" in which one cannot immediately be certain whether a decline in a waterbody is caused by one factor or another. As discussed in the Contingency Plan, Exxon will bear the burden of these uncertainties. In other words, once the flow of a stream or the level of a lake declines to the point specified in the plan, we will take action whether or not we believe Exxon is the cause of that decline. If we believe we are not the cause of the decline, we retain the right to go to the DNR and attempt to demonstrate that the decline is entirely or partially attributable to some factor other than mine dewatering. If we can show this, we will ask the Department to modify our obligations to the extent that the decline has not been caused by our own activities. Unless and until Exxon can make this demonstration and obtain the DNR's approval, we will take the actions set forth in the Contingency Plan. In other words, we would not be able unilaterally to suspend or modify any actions required by the Plan.

Q. Mr. Schroeder, you have referred to "mitigation actions" and to "contingency actions." What is the difference between the two?

A. Mitigation actions are specific water supplement actions that will be undertaken before Exxon begins Project dewatering activities. The mitigation actions are planned for Hoffman Spring and Creek, Martin Spring and Creek 11-4, Upper Pickerel Creek, and Skunk Lake. Except for Skunk Lake these mitigation actions cover creeks that are primarily ground water supplied.

Contingency actions are also specific actions but they are not undertaken until triggered by reaching a certain flow rate or water level in a stream or lake. The contingency actions cover the remaining waterbodies identified in the Contingency Plan. These actions mainly consist of water supplements to the waterbody. However, the Plan also includes options for placing outlet control structures on the lakes to maintain water levels. The outlet control structures may be used in addition to the supplements.

Q. Where will the water supplements come from?

A. EXHIBIT 304 shows all of the water supply facilities proposed for mitigation and contingency purposes. With these facilities a number of alternative sources of supply are available. Wells

WS1 and WS2 not only can supply potable and construction water, but depending upon actual mitigation and contingency supplementation requirements they may supply a significant portion of that need.

Wells C1, C5 and C6 have been planned specifically for the mitigation actions for the streams that are primarily ground water supplied--Hoffman Spring and Creek, Martin Spring and Creek 11-4, and Upper Pickerel Creek. Depending upon actual mitigation needs for supplement volume and duration these wells may meet all or most of the need.

Wells C2, C3 and C4 are planned specifically for contingency actions at Creek 12-9 and Swamp Creek. These creeks have a larger surface flow component and contingency supplements are expected only for shorter durations. These wells are expected to be satisfactory for their anticipated need. I should note here that there may be minor location adjustments as detailed plans are finalized.

The Mine Ground Water Intercept System will also be available to supplement lakes and streams.

Q. Although you have already briefly described the Mine Ground Water Intercept System, would you give us some additional details on how it will fit into Exxon's Contingency Plan?

A. The Mine Ground Water Intercept System is an underground water withdrawal system used to intercept ground water before it enters the mine working areas and has any chance of being contaminated. The system shown in EXHIBIT 304 consists of 18 wells extended to the top of bedrock connected by a manifold for transfer of the water back to the mine/mill area and then for redistribution as supplement water for mitigation and contingency purposes.

EXHIBIT 260 shows an alternative intercept system that is located entirely underground and has also been described in the Mine High Capacity Well Approval Application. This intercept system utilizes ground water interceptor holes drilled from the mine workings to collect ground water before it enters the mine workings. This water is transferred underground to sumps where it is then pumped to the surface for redistribution as supplement water.

Both of these alternatives are capable of intercepting and collecting ground water before it enters the mine. They both collect ground water that can be used for other purposes such as mitigation and contingency supplementation activities and they both reduce the volume of ground water that would otherwise enter the mine workings and be removed by the main mine drainage system.

Q. Why have you proposed all of these alternatives?

A. First, we want operating flexibility. Second, our modeling work has shown that pumping too much water from any given well might cause unacceptable secondary impacts. That is, at some point such pumping might begin to increase the existing ground water cone of depression rather than mitigating its effects on surface waters. Having alternative sources of supply will enable Exxon to provide sufficient amounts of water to lakes and streams if needed without producing unreasonable secondary impacts.

Q. Is Exxon seeking permits for all of these alternatives at this point?

A. Yes, we want to obtain authorization for all of the water supplementation alternatives at this time so that we will be able to respond promptly in the best way possible as conditions arise. Thus, as I have earlier indicated, we have included all of the contingency wells, the water supply wells, and the wells associated with the Mine Ground Water Intercept System in the High Capacity Well Approval Application. Similarly, we have requested permit approval for all pipelines and discharge structures that might be necessary.

Q. Has Exxon designed the Contingency Plan simply to meet its own impact projections?

A. No. The Plan has been designed with the flexibility to ensure that we could meet the worst projected impacts. Those impacts we based on the Department of Natural Resources' worst-case set of conditions. Although we disagree with those conditions, the Contingency Plan will be able to mitigate them. The numbers I will be giving you later are based on the DNR's worst-case conditions.

Q. Mr. Schroeder, I would like to review with you Exxon's proposals on a waterbody by waterbody basis. First, what are Exxon's proposals with respect to Hoffman Spring and Hoffman Creek?

A. EXHIBIT 304 shows a plan view of well C1 showing the proposed location of the well and the water discharge line from the well to Hoffman Spring and the location of the discharge point at the spring area. If the level of Hoffman Spring drops down to the DNR's "trigger point", we will turn on the pump and add up to 130 gallons per minute of ground water to the spring.

Q. What will the well look like, and how will it be operated?

A. The well will be drilled and cased and use a submersible pump. In appearance it will be similar to a residential well only larger. The design is based on our understanding and description of the geohydrologic system at that location. The operation of the pump will be governed by the trigger levels agreed to for flow rates for Hoffman Stream. We believe pump operation should initially be controlled manually and then later automated if that proves to be advantageous.

Q. You mention that a discharge structure will be built. What is the purpose of that discharge structure?

A. EXHIBIT 305 shows the typical discharge structure planned for all the discharge points. Structures similar to this are very common and provide stability for the pipe and protect the soils from erosion by the discharge water.

Q. Will Exxon aerate the ground water supplement prior to its discharge into Hoffman Spring?

A. Yes. The aeration will raise the dissolved oxygen level in the water and should be beneficial to the spring and creek. I should note here that we will be aerating all water supplements going into lakes, streams, creeks, and springs.

Q. What if the 130 gallon-per-minute supplement is not enough to maintain Hoffman Creek's flow?

A. We have a high level of confidence in the modeling estimates. However, the alternative Mine Ground Water Intercept Systems previously described offer the flexibility to provide larger supplements and assurance that they could be satisfactorily supplied without creating unacceptable secondary impacts.

Q. How quickly would Exxon install this additional capacity if needed?

A. Using the well field or ring of wells alternative as an example, we would install one or more of the wells of the system to meet any additional supplement requirements. With proper plans and approvals already in place the well construction could be completed in approximately two weeks. We have agreed to have the systems for the larger contingency supplements operational within 20 days. However, we may utilize temporary surface discharge lines to meet that objective.

Q. What are Exxon's proposals with respect to Martin Spring and Creek 11-4?

A. EXHIBIT 304 shows the layout of the well and discharge system. The proposed well design for Martin Spring and Creek 11-4 is similar to the one described earlier for Hoffman Spring. A 30 gpm supplement is planned from this well which has been designated as well C5.

Q. What if the 30 gallon-per-minute supplement does not maintain the flow rate of Creek 11-4?

A. Martin Spring and Creek 11-4 is the one waterbody that is so remote from the mine/mill area and that has such a low supplement that it is not reasonable to supply water from the Mine Ground Water Intercept System. If for some reason a higher supplement were justified at Martin Spring a larger pump would be installed in the well or a second well and pump would be installed.

Q. What are Exxon's proposals with respect to Upper Pickerel Creek?

A. EXHIBIT 304 also shows the layout of well C6 which has been planned for the supplement to Upper Pickerel Creek. Well C6 and its pump are similar in design to the Hoffman Spring well and are sized to provide a 110 gallon-per-minute supplement to Upper Pickerel Creek.

Q. What if the 110 gallon-per-minute supplement does not maintain the creek's flow rate?

A. The alternatives planned for Upper Pickerel Creek are the same as those for Hoffman Spring and Creek. If our planned mitigation action is not adequate, we will utilize the mine ground water intercept system to meet additional supplement requirements.

Q. Are any other waterbodies included in the category of "mitigation actions"?

A. Yes. Skunk Lake is in that category.

Q. What will Exxon's mitigation actions consist of?

A. We have agreed to provide a mitigation water supplement ranging up to 216 gallons-per-minute for Skunk Lake.

Q. Where will the water come from?

A. Based on the water quality requirements, the supplement will be a blend of ground water and the excess treated discharge water from the plant. The ground water will come from either well WS1 or the mine ground water intercept system. A portion of the excess discharge water normally discharged to Swamp Creek will be used for the other supplement component.

Q. What if the 216 gallon-per-minute supplement is not sufficient to replace lake water lost due to mine dewatering?

A. We have confidence in the estimates of the supplements and believe the 216 gallon-per-minute estimate will be more than sufficient. However, there is additional excess treated discharge water and ground water from the intercept system available if a larger supplement is justified.

Q. Let us now turn to creeks and streams included in the "contingency" category. What are Exxon's proposals with respect to Creek 12-9?

A. A 355 gallon-per-minute well and pump designated as well C2 has been planned for Creek 12-9. EXHIBIT 304 shows the layout of the well and discharge system. The proposed well design is similar to the wells described earlier.

Q. What are Exxon's proposal with respect to Swamp Creek?

A. Two well and discharge systems have been planned for Swamp Creek. Well C4 is sized at 140 gpm and located near where Hemlock Creek enters Swamp Creek. Well C3 is located downstream from well C4 between our proposed access road and Highway 55. Well C3 is sized at 120 gpm. The designs for wells C3 and C4 are similar to the other wells.

Q. What are Exxon's proposals with respect to Hemlock Creek?

A. Our plans are to use well WS2 to provide the supplement for Hemlock Creek if a supplement is required. Well WS2 will be installed to supply construction water for the MWDF and will have adequate capacity to meet the projected 345 gallons-per-minute intermittent requirement for Hemlock Creek. EXHIBIT 304 shows the location of well WS2 and the discharge line route. The preliminary well design of WS2 is similar to the other wells except that a surface located pump drive is planned for WS2.

Q. Let me now turn to lakes included in the "contingency" category. What are Exxon's proposals with respect to Little Sand Lake?

A. EXHIBIT 304 shows the water supplement line and discharge location for Little Sand Lake. The exhibit also shows an additional option for installing an outlet control structure on the lake. An outlet control structure is simply a low-head dam. The control structure would reduce the outflow from the lake and thereby offset seepage increases from mine inflow and ground water drawdown. The water supplement to the lake is the planned contingency action, but the outlet control structure may also be employed to reduce the supplement amount.

If the supplement alone is used, we have indicated in our plan a supplement in the range of 190 gallons-per-minute to 680 gallons-per-minute will be provided. The supplement would be triggered when the lake level lowered to an elevation of 1591.5 or 1591.0 feet above Mean Sea Level depending upon the time of year. These elevations were established by the DNR and are 0.5 to 1.0 feet below Little Sand Lake's Ordinary High Water Mark elevation of 1592.0 feet above Mean Sea Level.

Q. You have indicated a range of possible supplementation volumes. How will the actual volume at any given time be determined?

A. The range is indicated because there has been a range in the estimates of seepage increase between work Exxon has performed and work done by Exxon for the DNR using the DNR's different set of input data. While we have confidence in our estimates, we have designed our contingency facilities to make sure that we can respond even to the DNR's worst-case set of conditions if that is required. If the requirement is low the outlet control structure may provide most of the mitigation, or a small supplement originating with well WS1 may be adequate; if a larger supplement is necessary the Ground Water Intercept System would be utilized. Even though the trigger elevations are very specific, water balance monitoring of the lake will be required to establish the proper supplement volume. I might add that availability of alternatives for mitigation ensures that the most efficient system is developed. Because the increase in lake seepage will progress slowly there is adequate time to develop the best alternative.

Q. What are Exxon's proposals with respect to Duck Lake?

A. EXHIBIT 304 also shows the alternatives available for Duck Lake. They are the same as for Little Sand Lake and include the water supplement and the additional outlet control option. As the exhibit shows, the same supplement distribution system originating in the mine/mill area would serve Little Sand, Duck, and Deep Hole lakes. For the supplement alternative, a range of supplement from 6 gpm to 12 gpm is provided in the plan with a lake trigger elevation of 1610.59 feet MSL as recommended by the DNR.

Q. Here again, you have mentioned a range of possible supplementation volumes. How will the amount of water pumped into Duck Lake be determined at any given period in time?

A. The answer here is similar to the one for Little Sand Lake although the supplement volume is much less and the range is smaller. Again the alternatives proposed ensure that Exxon's commitment can be met and that the most efficient mitigation system will be developed.

Q. What are Exxon's proposals with respect to Deep Hole Lake?

A. The alternatives for Deep Hole Lake also include the water supplement system and the additional outlet control structure option as shown by EXHIBIT 304. The systems are similar to those described for Little Sand and Duck lakes although the supplement range is from 30 gpm to 100 gpm and the trigger elevation ranges from 1605.0 to 1605.25 feet MSL depending upon the time of year.

Q. How will the precise volume of supplementation be determined?

A. As with the other lakes, the system proposed can handle the range of supplements indicated. The precise volume will be determined through continued monitoring of the lake water balance.

Q. You have indicated that lake outlet control structures might be used in addition to the lake supplements. How do they fit into the Plan?

A. As I indicated, lake outlet control structures could be used to regulate the levels of lakes affected by the ground water drawdown. They would be in addition, and not an alternative, to the use of ground water supplements. Exxon has not requested permits for such structures at this time because we believe it best to wait to see what actually develops and to determine at that time with the Department whether such control structures would be useful. The water supplementation program we have proposed will be fully adequate to meet any mitigation needs for these lakes, and the control structures would simply give us even greater flexibility in operating the Contingency Plan.

Q. I noticed that Exxon has included Rolling Stone Lake and Rice Lake within this Contingency Plan. Do you predict any changes in the levels of these lakes as a result of dewatering activities?

A. No, not any noticeable effect. As Dr. Djafari will discuss, any changes caused by mine dewatering would be on the order of fractions of an inch. However, Rolling Stone and Rice Lakes are heavily populated and it is appropriate that we pay close attention to those lakes.

Q. What are Exxon's proposals with respect to Rolling Stone Lake?

A. Because Rolling Stone Lake lies on the periphery of the area affected by Exxon dewatering activities, any significant mine-related changes in its level would result from a reduction of inflow of its tributaries -- Martin Spring/Creek 11-4, Upper Pickerel Creek, and Creek 12-9. Our mitigation and contingency actions for these tributaries accordingly will serve as our contingency actions for Rolling Stone Lake. We will also monitor the level of Rolling Stone Lake at a lake gauge. If there are any further mine-related impacts to Rolling Stone Lake -- and I should emphasize again that no one is predicting any noticeable impacts -- Exxon in consultation with the DNR will take further mitigation steps.

Q. What about Exxon's Contingency Plan as it relates to Rice Lake?

A. Like Rolling Stone Lake, Rice Lake lies on the periphery of the area affected by Project dewatering activities. Any significant mine-related changes in its level would therefore result from a reduction in flow of its tributary, Swamp Creek, and Swamp Creek's tributaries, Hoffman Creek and Hemlock Creek. Exxon's mitigation and contingency actions for these creeks will accordingly serve as our contingency actions for Rice Lake. We will also monitor the level of Rice Lake with a staff gauge. If any mine-related changes in the level of Rice Lake do occur notwithstanding everyone's predictions, Exxon in consultation with the DNR will immediately take further mitigation measures.

Q. Will the intercept system provide sufficient water so that secondary impacts caused by pumping from the contingency wells can be avoided?

A. We have analyzed the Mine Ground Water Intercept System with the ground water computer model that will be described to you by Dr. Djafari. We have determined overall impacts for mitigating for the DNR's expected impact conditions, which are higher than our predictions, and have determined there are no significant impact increases over our original impact predictions as reported in Appendix 4.1A of our Environmental Impact Report which appears in the record as EXHIBIT 158. This was accomplished by withdrawing all necessary supplement water for the lakes and primary stream systems from the Ground Water Intercept System and not utilizing any of the specific wells designated for each of the waterbodies. We have also successfully analyzed a mitigation system for the DNR's worst-case conditions. In the worst-case analysis, sufficient ground water was withdrawn in the mine area to meet the entire supplement needs for all the lakes and the primary stream systems on a continuous basis.

We also modeled the intermittent wells for Hemlock and Swamp creeks and Creek 12-9 for both DNR cases. These results showed the intermittent wells to be effective provided they are not used for extended continuous periods.

Q. What will happen to all of the contingency facilities you have discussed once the project is completed and the mine is closed?

A. After the ground water system has recovered and there is no need for the mitigation systems they will be reclaimed and abandoned in accordance with the Reclamation Plan, which is Volume II of EXHIBIT 111 in the record, unless some alternate use is determined for some of the wells. Similar to other facilities, the discharge pipes will be plugged and remain in place, the discharge structures will be removed, and the wells will be grouted and abandoned according to regulation.

Q. What about private water wells in the area of the Crandon Project mine? Won't the ground water cone of depression dry up some of those wells?

A. We conducted a private water well inventory in the area surrounding the proposed Project. That inventory is set forth as Volume 2 of our High Capacity Well Approval Application presented as EXHIBIT 113. Let me here refer you to EXHIBIT 306, which shows all of the existing wells in the project vicinity. Of the 56 existing wells, 5 are test or water supply wells installed by Exxon, 21 are former residential wells purchased by Exxon, and the remaining 30 are private residential wells. These wells are within the areas that Exxon expects may experience a reduction of the ground water table as a result of mine dewatering.

Q. What will you do with the former residential wells that are now owned by Exxon?

A. These wells will be abandoned according to DNR regulation during the construction period of the Project.

Q. What about the remaining privately owned residential wells?

A. We assume that the owners will wish to continue to use these wells. Exxon has committed to each well owner that it will mitigate any impacts caused by dewatering activities. We have also prepared a suggested mitigation plan for each and every privately owned residential well that may be adversely affected by dewatering activities, included as part of EXHIBIT 307. As you can see, Exxon would propose to deepen many of the existing wells and to replace others outright. If the Department of Natural Resources approves these suggestions, Exxon will make formal commitments to the individual well owners as to the specific mitigation steps to be taken for each and every well. All of these actions, of course, would be entirely at Exxon's expense.

Q. So there would be no cutoff of residential water supplies?

A. No. Residential water supplies are of primary concern to Exxon, and we will ensure that water supplies are not adversely diminished in quantity as a result of our operations. As I just discussed, we will take those actions necessary to ensure that there is no interruption in anyone's water supply as a result of our mining activities.

Q. Let me turn now to the Chapter 30/31 permits. Have you been personally involved in the planning of the structures which require Chapter 30/31 permits and in preparing the applications for them?

A. Yes, with the assistance of other Exxon staff members. I also had the assistance of Foth & Van Dyke & Associates, who prepared the preliminary engineering reports for the access road and the railroad spur, each of which involves Chapter 30/31 permits.

Q. Exxon, then, has filed written applications for the permits you have listed?

A. Yes. EXHIBITS 120 through 126 are the permit applications for the structures regulated by Chapters 30 and 31 of the Wisconsin Statutes. Together, those permits deal with all the Chapter 30/31 approvals required for the bridges, culverts and discharge structures to be constructed as part of the Crandon Project.

Q. Please identify the locations of the structures for which Chapter 30/31 permits are required.

A. All of the structures are identified on EXHIBIT 308. Locations A and B are the sites of the access road and railroad spur bridges over Swamp Creek. At locations C and D, the railroad spur culverts carry small streams which the DNR has identified as navigable. Access road culverts at locations E, F, G and H are on water courses identified as non-navigable by the DNR. The letters I through T locate discharge structures adjacent to navigable streams or lakes for excess water discharge and mitigation and contingency plan supplements which may be needed.

Q. Does Exxon control all the property on which these structures will be built?

A. Yes, except for two sites. Negotiations are in progress at Site L for Upper Pickerel Creek where the land is owned by Langlade County and at Site K for Martin Spring and Creek 11-4 where the land is owned by the State of Wisconsin. The complete status of land ownership and control at each site is described in the applications presented as EXHIBITS 120 through 126.

Q. Which of the structures will require removal of materials from stream or lake beds?

A. Small amounts of bottom materials will be removed at each site. The waterbodies affected are listed in Table 1 of my prefiled testimony. In the exhibit each location as shown on the map is designated and the associated waterbody is indicated.

Q. The removal of materials from the beds of lakes and streams is regulated by Wis. Stat. § 30.20 and by NR Chapters 340 and 345-347. Have you determined whether Exxon's applications meet those requirements?

A. Yes. These facilities will not have an adverse environmental effect, and the proposed structures are consistent with the public interest in the water involved. Plans for each of these structures have been prepared in consultation with the DNR. The applications, presented as EXHIBITS 120 through 126, provide all of the required information.

Q. Do your plans call for removing any stream or lake bed material for the primary purpose of extracting merchantable sand, gravel or rock for sale or use by Exxon, or to create an artificial waterway or to change the course of a navigable stream as regulated by NR Chapter 340?

TABLE 1

Location	Water Body	Facility	Disturbed Area[1] (Acres)	Total Excavated Material (Cubic Yards)	Fill Volume[2] (Cubic Yards)	Lake Bed & Stream Bed Excavated Material[3] (Cubic Yards)	Riprap Area (Square Yards)
A	Swamp Creek	Access Road Bridge	1.80	8,700	24,000	43[7]	500
B	Swamp Creek	Railroad Bridge	2.12	10,300	30,700	20[7]	240
C	Unnamed Swamp Creek Tributary	Railroad Culvert	0.05	200	800	20[8]	--
D	Creek 20-8	Railroad Culvert	0.05	200	800	20[8]	--
E	Creek 24-14	Access Road Culvert	0.23	700	2,000	20[8]	--
F	Creek 24-13	Access Road Culvert	0.62	3,000	8,000	20[8]	--
G	Creek 24-4	Access Road Culvert	0.25	800	4,000	20[8]	--
H	Unnamed Swamp Creek Tributary	Access Road Culvert	0.33	1,100	6,000	20[8]	--
I	Swamp Creek	Excess Water Discharge	0.57	1,200	1,200[4]	2	35
J	Hoffman Spring	Mitigation Supplement	0.10	700	700[4]	2	104
K	Martin Spring/ Creek 11-4	Mitigation Supplement	0.23	1,500	1,500[4]	7	40
L	Upper Pickerel Creek	Mitigation Supplement	0.60	3,700	3,700[4]	1	5
M	Hemlock Creek	Contingency Supplement	0.09	600	600[4]	1	52
N	Swamp Creek (Upstream)	Contingency Supplement	0.30	1,900	1,900[4]	1	102
O	Swamp Creek (Downstream)	Contingency Supplement	1.26	8,100	8,100[4]	1	72
P	Creek 12-9	Contingency Supplement	0.06	400	400[4]	1	42
Q	Skunk Lake	Mitigation Supplement	0.05[5]	100[6]	100[4]	9	30
R	Little Sand Lake	Contingency Supplement	0.05[5]	100[6]	100[4]	2	13
S	Duck Lake	Contingency Supplement	0.20	2,700	2,700[4]	3	30
T	Deep Hole Lake	Contingency Supplement	0.05[5]	100[6]	100[4]	2	13

(1) Wetland Area Removed at the Location.
(2) Total Fill Placed in Wetland at the Location.
(3) Approximate Volume Within the Ordinary High Water Mark Elevation Using 1' Depth for Excavation.
(4) Majority of Excavated Material Reused as Backfill.
(5) No Wetlands Identified at Location; Minimal Disturbed Area Assumed.
(6) 1' Excavation Depth Used.
(7) Stream Bed Excavation Taken as 25% of Riprap Area at 1' Depth.
(8) Stream Bed Excavation Based on Approximate Size of 100' x 5' at 1' Depth.

5011R

A. No.

Q. Describe the volume of materials to be removed for each of these structures.

A. The volume of material to be removed at each location is shown in Table 1. Typically, very small amounts will be removed for each discharge structure. These materials will be removed only to the extent necessary to provide a stable base for the placement of rip-rap. For all the facilities, removal ranges from approximately 40 cubic yards at location A to approximately 1 cubic yard at locations L through P. The applications, presented as EXHIBITS 120 through 126, show stream bed, lake bed and shore configurations, contain drawings of the proposed structures and describe construction methods for each location.

Q. What will be done with the dredged materials?

A. The wetland materials will be applied as top dressing on the final graded slopes either at the particular site involved or at other construction locations in the project area. Dredged or excavated materials which are too wet to be used immediately will be stored temporarily for drying behind silt retention barriers adjacent to the excavation site. There will be no long term storage of these excavated materials.

Q. Do these excavation or dredging materials contain hazardous materials?

A. No. The materials to be excavated consist primarily of organic soils with a smaller component of mineralized soil, all of it deposited by natural processes. There have been no human activities in these areas which would lead us to expect to find hazardous contaminants in these stream bed and wetland soils. We have found no evidence of hazardous contaminants in similar soils which have been sampled and analyzed throughout the Crandon Project area.

Q. NR 345.05(7) forbids the exercise of dredging permits until all necessary permits and approvals have been issued by local, state or federal government agencies having jurisdiction over the proposed project. Has Exxon obtained all of those approvals?

A. I believe all necessary permits have been applied for. Exxon will not begin construction until all necessary local, state and federal permits have been granted.

Q. NR Chapter 346 requires a contract with the State of Wisconsin for the removal of materials from the beds of natural lakes. Does Exxon intend to obtain such contracts before proceeding with dredging or excavation at all lake locations?

A. Yes, Exxon will enter into the necessary contracts at the noncommercial removal fee before proceeding with construction at any of the lake locations.

Q. Which of the structures we have been discussing involve the placing of structures or deposits in navigable waters as regulated by Wis. Stat. § 30.12?

A. Four culverts on the access road, locations E, F, G and H, carry water courses which the DNR has identified as non-navigable. All the other locations - the access road bridge over Swamp Creek, the railroad bridge over Swamp Creek, two culverts along the railroad spur, and all of the water discharge structures - are located on navigable streams or lakes.

Q. Please describe the nature of the filling that will occur at each location.

A. Construction of the access road and railroad bridges and culverts requires filling. In addition, rip-rap will be placed at the bridge sites to control erosion. Very small amounts of fill will be required at the excess water discharge structure at Swamp Creek and at the locations associated with the mitigation and contingency facilities. At the discharge locations, rip-rap will also be put in place to control erosion. A more detailed description of the filling and rip-rapping is contained in the applications presented as EXHIBITS 120 through 126. The area disturbed at each location and the volume of fill required are presented in Table 1.

Q. Wis. Stat. § 30.12 provides that the Department of Natural Resources may permit filling and the placement of structures in stream and lake beds provided that "the structure does not materially obstruct navigation or reduce the effective flood flow capacity of a stream and is not detrimental to the public interest." Have you determined that the structures covered by Exxon's Chapter 30/31 permit applications meet those requirements?

A. Yes. Hydrologic analyses were performed to determine the potential flood flows at the access road and railroad bridges and culverts. Those studies employed Soil

Conservation Service and United States Army Corps of Engineers analysis procedures. The bridges were designed to accommodate the 100-year flood volume in Swamp Creek. The culverts along the railroad spur were designed to accommodate the 25-year flood flow. The bridges are high enough to permit uninterrupted movement of canoes and wildlife along Swamp Creek even under 100-year flood conditions. These structures have been designed and will be constructed to meet the standards used by the Department of Transportation for state highways in Wisconsin.

Q. Will the placement of rip-rap or similar materials on the bed or bank of navigable waters interfere with navigation, reduce the effective flood flow capacity of a stream or harm the public interest?

A. No. At each location the rip-rap will be located between the structure, which will be located above the stream ordinary high water mark and the lowest water level at which the stream ordinarily flows. It is used to protect the stream bank from erosion caused by the discharge of water or from surface water flows near the bridges and culverts. It will have no effect on navigation or stream capacity and will serve the public interest by controlling erosion.

Q. At what locations do the access road or the railroad spur cross navigable streams?

A. The access road and the railroad spur each have a bridge across Swamp Creek identified as locations A and B. In addition, culverts at locations C and D will carry the railroad spur across minor Swamp Creek tributaries which the DNR has identified as navigable. Access road culverts at locations E, F, G and H are not located on navigable streams.

Q. The construction of bridges and culverts on navigable streams is regulated by Wis. Stat. § 31.23 and by NR Chapter 320. Have you provided all the information required and determined that the proposed bridges and culverts meet the statutory and regulatory requirements?

A. Yes. All the legal requirements are addressed in detail in the applications included as EXHIBITS 120 through 126.

Q. Please describe the construction of the bridges and culverts.

A. Drawings of the bridges and railroad spur culverts are contained in the applications, EXHIBITS 120 through 126, where each is described in detail. Each bridge consists of a single span constructed of pre-stressed concrete girders supported by concrete abutments. Stream banks near the bridges will be protected by rip-rap. Both bridges are designed to meet Wisconsin Department of Transportation standards.

Q. What is the planned clearance for the two bridges and the railroad spur culverts?

A. When Swamp Creek is at its ordinary high water mark elevation, clearance at both bridges is more than five feet as required by NR § 320.04(1). Even at 100-year flood flow conditions, the clearance of the access road bridge is 5.6 feet and the clearance at the railroad bridge is 4.5 feet. There are lesser clearances at the culverts which carry the railroad spur over the minor Swamp Creek tributaries. Each of the minor waterways is narrow and shallow. An adult can readily step across them under ordinary flow conditions near the railroad spur crossing. As a result, each waterway is known to have little or no navigation or snowmobile use, and thus may have a clearance of less than five feet under NR § 320.04(3). If it were necessary, these culverts could be portaged, although it would be necessary to walk across the railroad.

Q. How will the bridges and culverts affect the capacity of the navigable streams on which they are located?

A. The bridges and culverts were sized so that the increase in backwater from the structures during a 100-year flood flow would be less than 0.1 foot. Detailed bridge profiles, cross-sections and hydraulic calculations are included in the permit applications.

Q. Will construction of these projects require grading of the banks of navigable waters as regulated by Wis. Stat. § 30.19(a)?

A. Yes. The aggregate total of the construction will expose an area greater than 10,000 square feet, and is therefore regulated by Wis. Stat. § 30.19(c).

Q. How much area will be graded at each of these locations?

A. The area affected by grading at all the 30/31 locations is shown in Table 1. The area affected ranges from approximately 2.0 acres at location B to approximately 0.05 acres at locations C, D, Q and T.

Q. In order to grant a permit for the grading of the banks of navigable waters, the Department must find that the project will not impair public rights or interests, including fish and game habitat, will not cause environmental pollution, conforms to the requirements of laws for the platting of land and for sanitation, and that no material injury to the rights of any riparian owners on any body of water affected by the project will result. Have you determined that these applications meet these standards?

A. Yes. The areas graded will be left exposed for only a short time, and measures will be taken to control erosion and siltation. The Chapter 30/31 applications presented as EXHIBITS 120 through 126 cover in detail the requirements for grading. Disturbed areas will be reclaimed immediately following construction.

Q. What is the schedule of construction for the bridges, culverts and discharge structures which are the subject of the Chapter 30/31 permits?

A. The railroad spur and access road, with their bridges, culverts and associated drainage structures, will be constructed early in the construction period. The work associated with the water discharge facilities will be performed later in the three year construction period. Since these discharge facilities are not needed immediately, construction can be accomplished when conditions are most favorable for construction.

Q. What type of equipment will be used in the dredging, filling, grading and crossings construction?

A. Construction of the access road and railroad spur involves equipment which is typical for highway construction, including dump trucks, back hoes, small dozers and possibly a small bucket crane.

Q. What precautions have you planned to minimize erosion or other adverse impacts during construction?

A. In the case of the bridges, sheet piling or a similar barricade would be used between the stream and the construction area to prevent any siltation of Swamp Creek. At the other locations where there is a potential for erosion, silt fences, straw bale barriers or other similar temporary facilities would be used to control siltation and erosion. A detailed description of Exxon's erosion control planning is found in EXHIBIT 111.

Q. How will these areas be reclaimed?

A. Reclamation begins almost as soon as construction begins. Materials removed from the stream beds and from elsewhere on these construction sites will be used as top dressing in the final phase of construction of these facilities. Materials excavated from the beds of waterways will consist mostly of organic soils with small volumes of mineral soils. These materials will be used in landscaping and reclamation during the construction period. At each excavation site, the temporary stock pile will be contained by silt retention barriers. More detailed descriptions of the final grading and revegetation of each of these sites is contained in Volume II of EXHIBIT 111, the Reclamation Plan, which Howard Lewis has already told you about.

Q. Thank you, Mr. Schroeder.

0787R

EXHIBIT 302

CARLTON C. SCHROEDER

EDUCATION:	B.S.	1966, University of Toledo, Civil Engineering
	M.S.	1967, University of Toledo, Civil Engineering
	MBA.	1978, Baldwin-Wallace, Management

EXPERIENCE:

1979-Date

Project Engineer, Crandon Project, Exxon Minerals Company, Rhinelander, Wisconsin.

Plan and manage civil related in-house and contractor Project development work, including field geotechnical studies, waste disposal facilities, roads, railroad, water supply, sanitary disposal and reclamation work. Manage ground water hydrogeological studies and impact modeling work. Prepare EIR and permit documents and interface with DNR and public throughout verification and permitting process.

1975-1979

Principal Engineer-Facilities and Civil/Structural Engineer, H.K. Ferguson Co., Cleveland, Ohio.

Responsible for planning and management of the engineering design of the civil, structural, and architectural portions of industrial facilities, including heavy manufacturing complexes, breweries, and chemical plants.

1973-1975

Project Engineer Land Development, Sea Pines Company, Hilton Head Island, South Carolina.

Responsible for the planning and management of civil related improvements projects (subdivisions, roads, water, sewage, drainage) and planning and management of company surveying and land mapping programs.

1967-1973

Consultant and Design Engineer, McDonnell Douglas Automation (MCAUTO) and Astronautics Company, St. Louis, Missouri.

Responsible for assisting clients in use of civil-oriented computer analysis and design programs. Participated in development of civil related computer programs. Responsible for design of spacecraft structural components and hardware.

1961-1967

Field Engineer, Ohio Department of Highways; Teaching Assistant (Basic Civil Courses), University of Toledo; Draftsman, Scholz Homes.

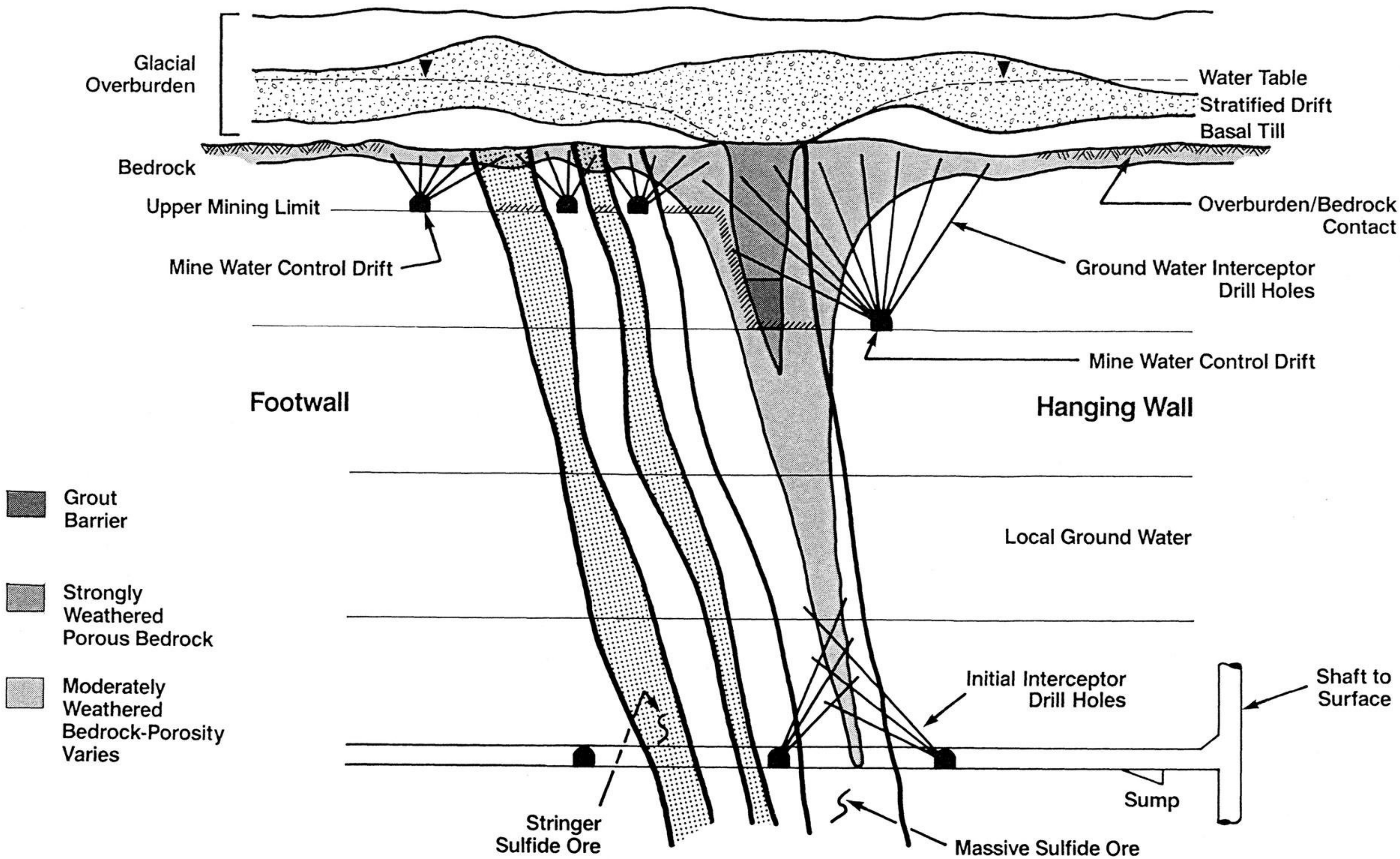
Work while in school.

High Capacity Well Locations

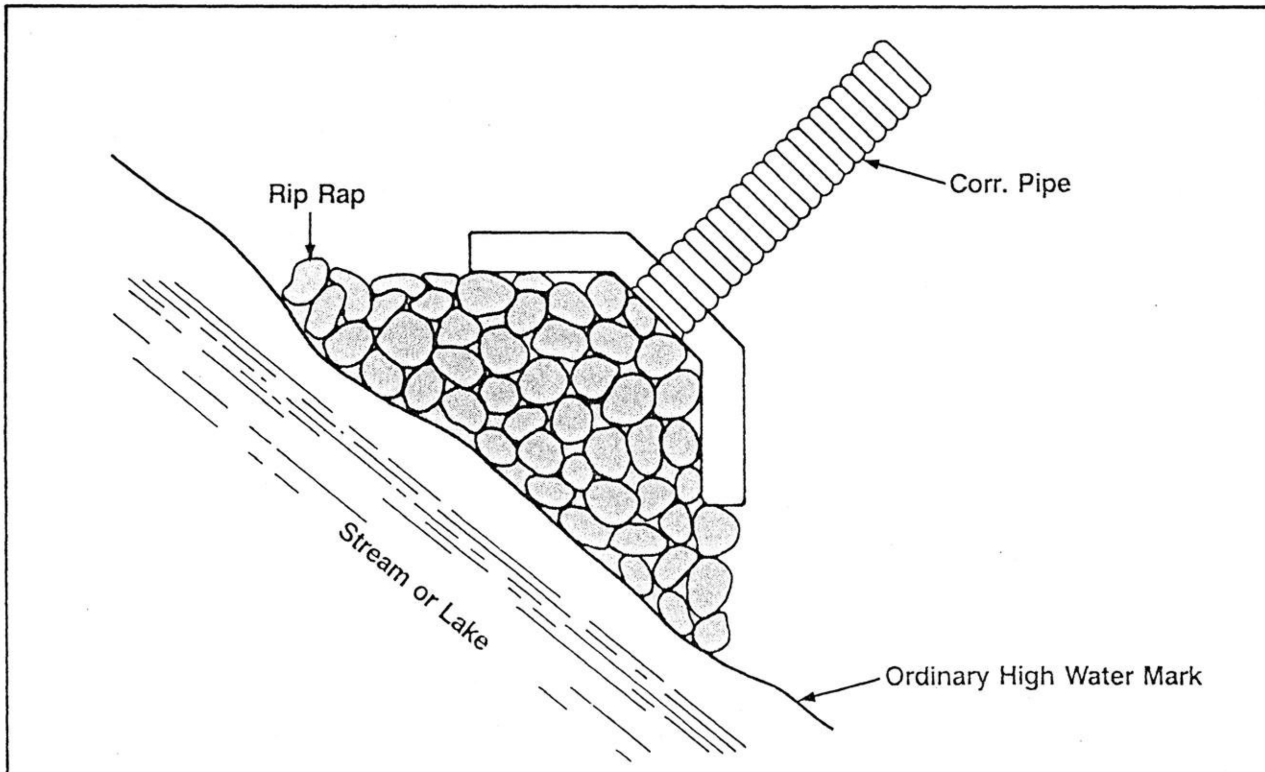
Mitigation/Contingency
Facilities

Legend
● Wells
▲ Outlet control structures

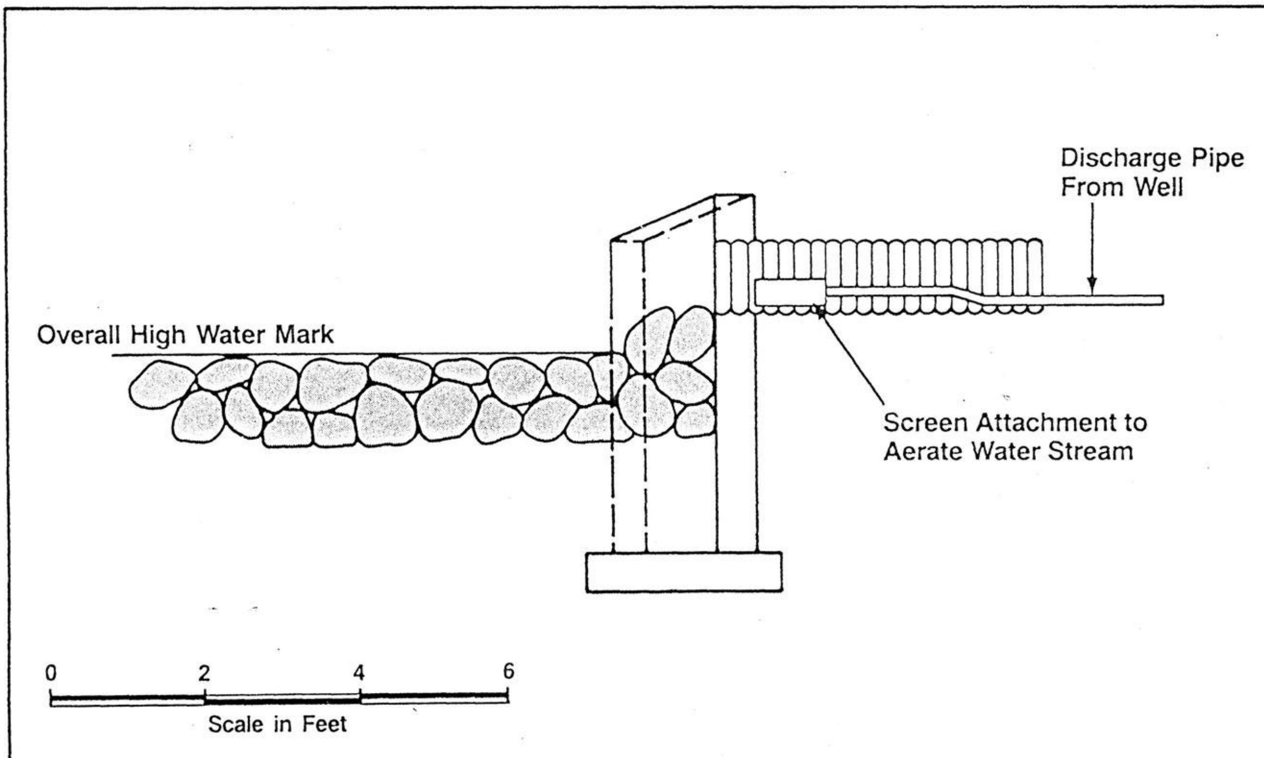
Ground Water Interceptor System



Typical Discharge Structure

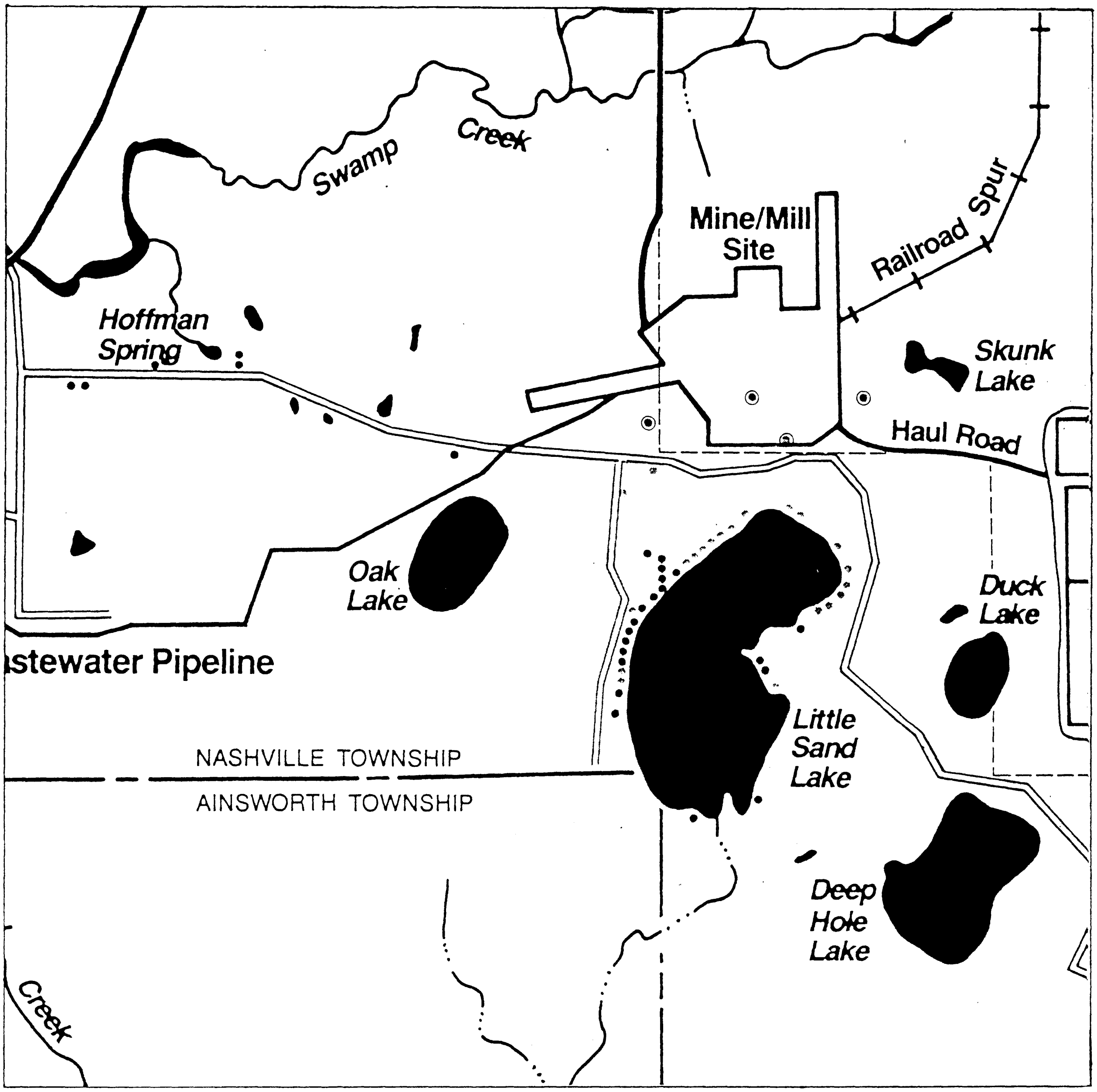


Typical Headwall Plan View



Typical Headwall Section

Water Wells In Mine Area



Legend

- Privately owned water wells
- Residential water wells owned by Exxon
- Exxon test and water supply wells

EXAMPLE OF EXXON INDEMNIFICATION LETTER TO WELL OWNERS

Note: Provided to all owners of private wells in the area where the ground water table will be influenced by Project activities.

August 23, 1983

Dear

As you may be aware, Exxon Minerals Company (Exxon) submitted the Environmental Impact Report for our proposed Crandon zinc-copper mine to the Wisconsin Department of Natural resources last December.

During the preparation of our Environmental Impact Report, it was determined that geologic conditions in the vicinity of our deposit may allow an inflow of ground water to the mine of up to 2000 gallons per minute. Based on this maximum inflow rate, our hydrologic consultants have determined that, while the inflow will not affect the quality of the ground water in the area or the water level of Little Sand Lake, there may be a drawdown in the ground water level in a limited area around Little Sand Lake.

We understand that there is currently a well on your property which could be affected by a significant drawdown of the ground water table. Accordingly, Exxon Minerals Company wants to reconfirm that, as provided by law, Exxon will assume responsibility for any unreasonable adverse change in quantity of the water you have due to our operations.

You can be assured that the water supply to your residence is a primary concern to Exxon, and you can be confident that your water supply will not be adversely diminished in quantity by Exxon's operations. Our planning efforts will include those actions necessary to see that there is no interruption in your water supply as a result of our mining activities.

If you have any questions or specific concerns about the Project or its affect on your water well, please contact Frank Sonderman, our Coordinator of Community Planning (715/369-2800), who I have asked to respond on my behalf.

Sincerely,

EXXON MINERALS COMPANY

Robert L. Russell
Manager, Crandon Project

0832R

SUGGESTED MITIGATION PLANS FOR PRIVATELY OWNED WATER WELLS

(Plans will be implemented if water wells are adversely affected by Project activities)

WELL NUMBER	WELL OWNER	WELL TYPE	STATIC WATER LEVEL	ESTIMATED DRAWDOWN FROM MINE INFLOW	WATER LEVEL DURING MINING OPERATIONS	WELL DEPTH	COMMENTS/ PLANS
87	Chchogz	Driven	15' (est.)	1'	16' (est.)	–	Decision to replace awaiting field survey data.
88	Mushell	–	15' (est.)	1'	16' (est.)	–	Decision to replace awaiting field survey data.
89	L. Hoffman	Driven	20'	1'	21'	20'	Decision to replace will be based on field measurements.
89A	L. Hoffman	Driven	20'	1'	21	20	Should be abandoned.
90	R. Hoffman	Driven	21'	4'	25'	27'	To be replaced.
91	R. Hoffman	Driven	22'	4'	26'	28'	To be replaced.
98	Chappy	4" Drilled	75'	19'	94'	93'	To be deepened.[1]
102	Webb	4" Drilled	25'	19'	44'	58'	To be deepened.
105	Kelchner	6" Drilled	21'	23'	44'	54'	To be deepened.
105A	Kelchner	Driven	–	22'	–	22'	To be replaced.
106*	Haferman	Driven	5'	24'	29'	17'	To be replaced.
107	Fritstche	Driven	14'	25'	39'	20'	To be replaced.
108*	Becker	Driven	15'	26'	41'	35'	To be replaced.
111*	Matulis	Driven	8'	28'	36'	24'	To be replaced.
115	Dietzler	Driven	8'	32'	40'	30'	To be replaced.
116	Pallen	Driven	6'	31'	37'	23'	To be replaced.
117	Karol	Driven	6'	31'	37'	23'	To be replaced.
118	Betters	Driven	6'	30'	36'	25'	To be replaced.
119	Walentowski	3" Drilled	11'	30'	41'	30'	To be deepened.
120	R. Yeagher	Driven	25'	32'	57'	30'	To be replaced.
121	Mantey, et al.	Driven	12'	33'	45'	24'	To be replaced.
140*	Tomczyk	Driven	–	26'	–	–	To be replaced.
143	Parker	5" Drilled	23'	23'	46'	64'	To be deepened.
144	Lijewski	5" Drilled	23'	22'	45'	58'	To be deepened.
166	Dhuey	Driven	25'	12'	37'	32'	To be replaced.
167	Laux	5" Drilled	26'	12'	38'	57'	To be deepened.
168	Griffith	4" Drilled	23'	18'	41'	38'	To be deepened.

WELL NUMBER	WELL OWNER	WELL TYPE	STATIC WATER LEVEL	ESTIMATED DRAWDOWN FROM MINE INFLOW	WATER LEVEL DURING MINING OPERATIONS	WELL DEPTH	COMMENTS/ PLANS
11	Lyons	Driven	--	1'(2)	--	20'	Modifications will be based on effect of well C-4.
12	Bradley	Driven	14'	1'(2)	15'	20'	Modifications will be based on effect of well C-4.
67	Mihalko	Drilled	41'	1'(2)	42'	89'	Modifications will be based on effect of well C-3.

*Property under option to purchase by Exxon Corp.

[1] Deepened wells may require new pump, tank, etc.
[2] Minimal drawdown expected from pumping of contingency wells C-3 and C-4.

0832R

Chapter 30/31 Permit Structures

Legend

- Bridge A,B
- Culvert C-H
- Excess water discharge structure I
- Mitigation/Contingency discharge structure J-T

BEFORE THE
STATE OF WISCONSIN
DIVISION OF HEARINGS AND APPEALS

Application of Exxon Corporation for Permits to Build and Operate an Underground Mining and Ore Concentrating Complex Located in Forest County, Wisconsin	))))	IH-86-18

TESTIMONY OF THOMAS A. PRICKETT

MINE INFLOW

Q. Please state your name, address, and occupation.

A. My name is Thomas A. Prickett. I live in Urbana, Illinois. I am the President of Thomas A. Prickett and Associates, Inc. which is a groundwater resources engineering consulting firm.

Q. Would you give me a brief history of your background in groundwater evaluations?

A. I graduated from the University of Illinois in General Engineering in 1960. I then spent 17 years doing groundwater research with the Illinois State Water Survey on the campus of the University of Illinois. In 1977, I joined the environmental consulting firm of Camp Dresser & McKee as a Vice President in charge of the midwestern water resources division located in Champaign, Illinois. Since the first of 1980 I have had my own water resources consulting firm. Further details on my career are set forth in my resume, which appears as Exhibit 312 in the record.

Q. Would you describe what some of your experience has been during your career?

A. Briefly, I did considerable research in the physics of basic groundwater flow while at the Water Survey. While I was at the Survey, I wrote or published about 50 reports, journal articles, part of a book, and numerous in-house compilations of basic groundwater information and technical procedures. I wrote some of the first computer programs for modeling groundwater flow during my tenure at the Survey. Presently, some of these models are among the standards of the groundwater industry. I have taught groundwater analysis and modeling techniques at the University of Illinois, have given numerous seminars and workshops throughout the United States, and have been invited to lecture on computer analysis of groundwater problems in several foreign countries including Spain, India, Turkey, Denmark, Costa Rica, El Salvador, and France.

Q. What are the major activities of your consulting firm?

A. I am primarily engaged in the analysis of water flow beneath the ground. The major items comprising my work have to do with design of water wells and well fields, evaluation and cleanup of hazardous waste sites, development of digital computer programs for solving groundwater problems, and evaluating the impacts of mining activities.

Q. You mention that you have been involved in studying impacts of mining on groundwater resources. Would you please elaborate on this?

A. Yes. Both as part of my work with Camp Dresser & McKee and within my own corporation, I have been in direct charge of or have played a prime role in evaluating impacts due to strip mining of coal at two mines owned by Carter Mining Company in Wyoming. As further examples, I have worked as the primary engineer on predictions of the impacts of a proposed shaft mine and in situ leaching of uranium reserves owned by Mobil Oil Corporation in New Mexico, pumping and injection of natural gas in a shallow groundwater reservoir owned by Shell Oil Company near Jackson, Mississippi, surface pit mining of iron in Southern Spain, and this Exxon project having to do with mining of zinc and copper here in Wisconsin.

Q. Would you describe your involvement in the Exxon Crandon project here in Wisconsin?

A. I began my involvement with the project in 1976 when I helped the consulting firm of Dames & Moore in constructing a groundwater model of the area to help predict the rate of water inflow to the mine which would result from an open pit mining scheme. That involvement only amounted to about 40 hours of my time as Dames and Moore had the primary responsibility for water flow analysis. In 1981, I became involved again as a subcontractor to Camp Dresser & McKee. My responsibility during 1981 was to predict mine inflow given specific basic data on hydrologic conditions and a set of Exxon underground mining plans. Based upon this initial set of data, and the related uncertainties in mine inflow details, further field work was carried out by other consultants during 1982. My firm was then again retained to update my mine inflow analysis. That was done and I produced a revised report dated December 1982 on expected mine inflows. Subsequent to this study, further field work was initiated and carried out in 1983 and 1984 to clarify the remaining questions concerning mine inflow. In finalizing the mine inflow estimates in 1984, I worked hand in hand with Warzyn Engineers of Madison, Wisconsin and D'Appolonia Corporation hydrologists of Pittsburgh, Pennsylvania, which was later acquired by IT Corporation. The final estimates of mine inflow were given to D'Appolonia hydrologists for their analysis of impacts to the groundwaters and surface waters of the area in the vicinity of the orebody.

Q. Mr. Prickett, would you explain how your work in connection with the project relates to the work that was done by others in connection with the geological base line and the expected cone of depression that may be created as the result of the mine?

A. Yes, I can explain that. There were essentially two objectives in all of this work. The first was to determine how much water could be expected to flow into the mine, water which would have to be removed to permit mining of the ore body. The second objective, which is related to the first, is to predict the impact on the levels of ground water and surface water that may result from water flowing into the mine. My studies begin with information given me by geologists about the sub-surface conditions present at the mine site.

Q. Would you explain that please?

A. As I will explain in somewhat greater detail later in my testimony, the nature of the soil, rock, gravel, whatever one finds present beneath the surface at the mine site is important for me to determine the extent to which there are permeable pathways for the water to flow into the mine when the mine is constructed. I depend upon the geologists to tell me what they believe the conditions are at the site of the mine that bear upon the degree to which water that is in the area may find its way into the mine. There are also experts who analyze what I might describe as the surface conditions in order that we may know how much surface water -- that is water in lakes, in streams, in marshes, and water that falls to the earth as rain, all of which supply those surface bodies -- how much of that water will percolate into the ground water system and therefore be available to flow into the mine.

Q. Can you tie that together for us, Mr. Prickett?

A. I take the information from the geologists regarding the conditions that permit water to flow into the mine or, on the other hand, impede the flow of water into the mine. I then ask the question, suppose that the conditions are such that in my view X amount of water can flow into the mine. Where is that water going to come from -- is it available? I then take the information that has been developed by consultants such as D'Appolonia, Camp Dresser & McKee, Dames & Moore, and the results of the modeling work done by Dr. D'Jafari. Those studies separately and in combination will answer the question, if the mine will accept 1,000 gallons per minute, are there 1,000 gallons per minute available to flow into the mine?

Q. Is it important that these various studies and analyses be balanced or related to each other?

A. By all means. Obviously, simply estimating mine inflow is irrelevant unless conditions are present that produce the water that can flow into the mine. On the other hand, if the studies show that there is plenty of water one cannot assume that that water will flow into the mine simply because it is available. An important part of our work as a team here was to relate the studies one to another to achieve a set of conclusions that we as experts believed were correct. One of the problems with some of the analysis that has been done by the Department of Natural Resources is the apparent absence of an effort to balance or correlate the results of various studies to achieve an overall rational result.

Q. You mentioned that you estimated mine inflows. How did you go about doing that?

A. The mine inflow estimating process required organizing all of the known hydrologic data in the area and then putting these data into a groundwater model for analysis.

Q. It appears that most of what you have to tell us will depend upon understanding just exactly what a groundwater model is. Why don't you first explain to us generally what a model is and how that relates to anything a layman might be aware of? When that matter is explained, we'll discuss the particular Crandon mine inflow model.

A. Let me start first by offering a general definition of a model and then follow up with several examples. A model is anything that helps you organize your thoughts concerning a particular situation or problem. The worth of the model, whatever it is, is usually judged by comparing model results with the real world. If the model compares closely to the real world, then within limits, the model can be used to predict the future.

Let me offer you some examples of what a model is. Please refer to EXHIBIT 313 where I have listed several examples. The models that I have listed here are the Scale Model, the ordinary Road Map Model, the Checkbook Mathematical Model, the Water Distribution System Model, and finally, the Groundwater

Model. Let me proceed through each of these and bring you up to speed as to the vocabulary, operation, and understanding of models and what they can do for you. Once you have gone through an explanation of these examples, you should have a reasonable idea as to what a model is, and in particular, how modeling can be used to predict the future.

First consider the Scale Model. Many of us have built and flown model airplanes. Here, we use a scaled-down version of the real world airplane to experience many aspects of flying. Many historians have remarked that the success of the Wright brothers was probably due to their experiments with scale models, such as using a model of an airplane wing in a wind tunnel. A scale model of an airplane can be changed and tested for response without actually building the airplane.

Second, let us go on to the familiar Road Map Model. Here, the ordinary road map can be considered a model of the actual road system. In this case, you should realize that the road map doesn't even look like a road. However, you might ask who would travel, for example, from here to the west coast without such a model? So, this is an example of a model that works well but doesn't look anything like the actual system that you are working with. I should also mention here with the road map model the important idea about model scale.

Road maps come in all different sizes and scales. If you are driving from coast to coast, you would first look at, for example, a map of the interstate road system. It isn't until you get to the state that you would start referring to a state road system map. And finally, as you get closer and closer to your destination, you would seek road information on a city and street basis. It is important to realize that in the above cases, each of the maps is accurate for their intended purposes. The details, however, are different from map to map, as the map size varies.

Let me now go on to a more complex idea having to do with balancing your checkbook with a so-called Mathematical Model. In this sense what I will be explaining is how you reconcile your bank balance with your checkbook balance at the time the bank statement arrives in the mail. Please refer to EXHIBIT 314.

What is shown here represents how you view your checkbook balance compared with the bank's view of your balance. To save time and space in writing, I'm abbreviating this balance concept by the letter YV equals BV. Your view must equal the bank's view. The use of the abbreviations and the symbol representing "equals" is what modelers call a mathematical model. This is a very simple mathematical model which states there must be a balance between these two items, otherwise, somebody has made a mistake. I think we've all been through experiences of this imbalance situation.

Let's go on here as to how we justify the balance by taking into account such items as outstanding checks, bank service charges, deposits, and so forth. As most know, we proceed with the balancing analysis by adding or subtracting transactions from either view depending upon who did what to whom. For example, your outstanding checks are subtracted from the bank's balance. Furthermore, any recent deposit made by you has to be added to the bank's balance. On your side of the story, the bank's service charges must be subtracted from your checkbook balance.

Note that I have abbreviated these items and their additions or subtractions into the cryptic expression at the bottom of EXHIBIT 314. This expression is an abbreviation, or short hand, version of the subtractions and additions necessary to balance your account. If all goes well, and if you've kept track of your checks, the bank balance and your checkbook balance will be the same. The first important idea in this explanation is that we have set up a Mathematical Model here as shown at the bottom of EXHIBIT 314. The model here is an abbreviation of the amounts involved, all organized to help you and the bank understand the condition of your checking account. The balance between your two views should be equal.

If they aren't, then somebody has made a mistake or left something out of the equation.

You should also be aware, as in the Road Map example above, that this checking account equation, or Mathematical Model, doesn't look anything like money any more than the road map looks like a road. Thus one can realize that "models" can take on several forms such as scale models, drawings on maps, or abstract processes expressed as organized and balanced transactions such as the mathematical model of a checkbook.

Where things begin to become difficult is when the number of items to be handled in your model becomes large. For example, in the checkbook model, consider what happens when your spouse and children all have checkbooks themselves, and each of them can draw money out of your account. At the end of the month, the problem of balancing the bank's view and your view becomes more difficult. The mathematical model of EXHIBIT 314 is the same, but you need additional transaction information from all check writers as input to the equation. The problems in balancing an account under this situation become more and more difficult as more and more people get their hands on your checkbook.

Incidentally, the bank, in a little more complex way, must also balance all of its accounts in the same manner individuals do.

Again, the mathematical model remains generally the same. However, with all of the money going into and out of many accounts in various amounts, it is the total bank view that must equal the sum of the individual accounts.

The only modern way of keeping track of balancing accounts when you are dealing with large numbers of them, like thousands upon thousands of accounts, is to use computers. The individual account models are simple as in EXHIBIT 314 but the computer does all of the work for you. The computer is given the check, deposit, and service charge information from all accounts and then does all of the additions, subtractions, and balancing for you. When the accounts don't balance because of errors in information or overdrawn accounts, the computer then prints out a message telling where the trouble is.

Let me go ahead and talk about an ordinary water distribution system made up of pipes, valves, pumps, and elevated water storage tanks. Most people are familiar with the operation of this type of system. However, let me explain in some detail how a distribution system works.

The first item of concern here is to describe how the individual parts of the system work, and second, figure out how all of the parts work hand in hand with each other. This is very similar to analyzing the individual parts of a checking account and then seeing how the bank handles the balancing of everyone's account as a total. In the checking account system, everything must balance. Otherwise someone runs out of money. In the distribution system example, too, everything must balance. Otherwise someone runs out of water.

Let me start by discussing four individual parts of a water distribution system. The four parts are the pipe, valve, pump, and elevated storage tank. I'll explain how these parts fit together later.

EXHIBIT 315 shows a simple pipe as a fundamental part of a water distribution system. Engineers have known for centuries that if you force water into one end of the pipe, the water will come out the other end at a lower pressure. That pressure drop depends on how long the pipe is, what is the pipe diameter, how rough the inside of the pipe is, the characteristics of the water itself, and how fast you force the water through the pipe.

The mathematical model of the pipe flow is shown at the bottom of the EXHIBIT. That particular mathematical model is an equation that is similar to the checking account type of mathematical model, except the pipe model involves its own characteristic data, multiplication, and division operations and the checkbook example involved its own data and additions and subtractions.

As long as you know or measure the characteristics of the pipe in the field and how much water you want to force through it, the mathematical model of EXHIBIT 315 will tell you what the pressure drop will be.

The second part of a water distribution system that I want to describe is a storage tank as shown in EXHIBIT 316. If I assume that the tank takes on the shape of a cylinder, then the mathematical model for the volume of water in storage in the tank is shown at the bottom of EXHIBIT 316. The calculation of how much water is in storage in the tank is no mystery: it depends on the diameter of the tank and the height and weight of the water in the tank. The height of the water in this tank is indicated by the pressure gage.

The last two parts of the water distribution system I want to describe are the valve and pump as shown in EXHIBIT 317. Pumps are used to deliver water at increased pressure. Valves are used to restrict water flow and to regulate pressures. The individual mathematical models of pumps and valves are as numerous as the individual pump and valve manufacturers that make them. There are big and little pumps, pumps that deliver little water but at very high pressures, and pumps that deliver large amounts of water at very low pressures. Individual manufactures of pumps and valves build their products according to the buyer specifications.

Therefore, the mathematical models or characteristics of the pumps and valves are derived from the manufacturers themselves. The individual models of pump and valve operations are thus found in manufacturer catalogues.

In summary, the pipe, tank, pump, and valve are the individual parts of the water distribution system. At this point, it should be clear just how the individual parts of the water distribution system work. The general rule is that as the water flows into one end of the part, it is either stored, as in the tank, or passed along to another part according to its individual mathematical model. It is very similar to the checkbook modeling concept. That is, money goes into and out of the account, the difference showing up as either a decrease or increase in the amount of money in the account. In the case of the checkbook, you are dealing with flow of money. In the case of the water distribution system, you are dealing with flow of water. Once again, everything must balance in the water system, otherwise the pipes go dry in the same manner as you would be in trouble with the checkbook if your cash flow out, in the long run, were to exceed your deposits.

So, realize here that I am emphasizing another model concept with the checkbook and water distribution system. The concept with these models is that flow in minus flow out always causes a change in storage--whether it relates to water in a distribution system or to money in the bank.

Q. How do you keep track of all of the interactions of the water distribution system?

A. Again, as in the checkbook example, the complications with the water distribution system come when you start connecting several parts together and give a large number of people access to the flow of water in the system. Although the individual mathematical models of the water distribution system are easily understood, it is the combination and interaction of the group of parts that requires a more complicated accounting procedure to figure out where all of the water is or is going.

What is needed here, and in fact what is done today, is to get a computer involved in keeping track of all of the water flowing in the system and in doing all of the algebra necessary with the component part mathematical models. Don't forget, the overriding rule that holds everything together is that flow in minus flow out equals the change in storage. The rest is a huge bookkeeping problem. The computer does the bookkeeping and prints out status reports as to where the water is or has gone.

Q. You've enlightened us about models in general, mathematical models of checking accounts, the banking system, and mathematical models of water distribution systems. How does this relate to groundwater models?

A. I am going to follow the same procedure with groundwater flow as I did with the checkbook and water distribution system examples. First I will describe individual mathematical models of a groundwater flow and storage system and then discuss how these are analyzed in combination with one another with a computer. The analogies among these ideas are almost one for one. If you can understand the checkbook and water distribution system analysis, you can get a good idea of what is happening in a groundwater system.

Please refer to EXHIBIT 318 which will start a discussion of the first basic part of a groundwater system. EXHIBIT 318 involves the downward flow of water through a block of porous materials. The rate of flow through this porous block of materials depends upon how permeable the materials are to water, what the water level force is behind the flow, how thick the materials are, and finally, how large is the area of the block. The mathematical model of groundwater flow here is shown at the bottom of EXHIBIT 318 and is known as Darcy's law, named in honor of the Frenchman who discovered it in his study of sand filters over one hundred years ago.

Darcy's law is one of the basic laws, or mathematical models, of groundwater flow. Not only does Darcy's law apply to vertical flow as shown here in EXHIBIT 318 but it also applies to horizontal flow as shown in EXHIBIT 319.

Here again, the flow rate through the block of porous materials depends upon the permeability of the materials, the driving force of the water levels across the block, and the cross-sectional area of flow. You might think of the permeability of the block here as being similar to the roughness of the pipe in the water distribution system. The mathematical model for the horizontal flow of groundwater here is given at the bottom of EXHIBIT 319. The permeability in this model is obtained by data measurements in the field somewhat like one would obtain the roughness coefficients of a pipe from field measurements. For example, in the Crandon Mine model, tests conducted by Camp Dresser & McKee, Dames & Moore and others supplied these data.

EXHIBITS 318 and 319 show the component parts for steady flow of groundwater when there is no consideration of water being stored in the ground. Therefore, let me next consider what the parts of a groundwater system have to do with storing water.

Consideration of individual mathematical models for accounting for water in and out of storage requires discussions of two separate mechanisms. First, EXHIBIT 320 illustrates how water can be released from groundwater storage by the process of actual drainage of the permeable materials. In this case, the saturated thickness of the materials thins as water is drained from the ground. The amount of water released from storage in this case is proportional to the volume of the block drained and the drainage characteristics of the soils. The mathematical model here is as shown at the bottom of EXHIBIT 320.

There is a second way in which water can be stored and released from a groundwater reservoir. Water may be stored under pressure--in this case we call it "artesian" pressure. If some circumstance occurs which relieves the pressure on such a reservoir, water will be released but the reservoir will not be drained. The releases of water from a reservoir when pressure is reduced are very much smaller than releases that result from draining a reservoir. These releases must, however, be accounted for in the model if we are to get an accurate prediction. The important thing to note in connection with water released from a reservoir under artesian pressure is that after the water is released the reservoir remains saturated but under reduced artesian pressure. The amount of water released as shown in EXHIBIT 321 will depend upon the size of the block of materials, the artesian type of storage coefficient of the porous materials, and of course, the magnitude of artesian pressure change being considered.

The final group of individual groundwater components have to do with how water gets into or out of the system. For example, water wells are devices that can be used to take water out of the groundwater system. Other examples of groundwater flow into or out of the system would be via such means as downward percolation of rainfall into the water table and runoff to or from streams, lakes, rivers, ditches, or springs. Of course, man made devices such as constructed pits, lagoons, and mine shafts beneath the water table are other examples of how water can come and go in the groundwater reservoir.

Q. Would you describe how the individual components of the groundwater system you just explained fit together?

A. The entire groundwater system, with all of the above mentioned individual components or mathematical models, works together by the same general rule as the previously explained checkbook and water distribution system. Here again the rule is there must be an overall balance between flow in and flow out, otherwise there will be a change in storage. For example in the groundwater situation, if more water comes out of the ground than goes into the ground over a period of time, there will be a lowering of the water levels. And vice versa, if more water goes into the groundwater reservoir over a period of time than comes out of the ground, then water levels rise. Finally, as with the checkbook, banking system, and water distribution system analyses, a computer is used to help do the bookkeeping in the case of analyzing the status of a groundwater reservoir.

Q. Please explain how you use a computer in organizing all of the individual groundwater mathematical models within this general rule of flow in, flow out, and change in storage concept.

A. The first step is to realize that the computer can handle only discrete bits of information. Because of this computer characteristic, the overall continuous groundwater formation is first broken up into a large number of discrete parts. These parts look like the blocks that I've talked about in the previous EXHIBITS 318 through 321. This process is an approximation to the real world situation, but works out to be a reasonable representation of the groundwater reservoir if the number of blocks is made large in comparison with the overall size of the groundwater system being studied.

An example of a discrete set of blocks representing a continuous groundwater reservoir is shown in EXHIBIT 322. In the applications to the real world situation, each of the blocks shown in EXHIBIT 322 is given the field values of the permeability and storage coefficients of the mathematical models spoken of earlier. Groundwater modelers refer to the grid-like network of blocks in EXHIBIT 322 as a finite-difference grid. This is because the block models involve specifications of groundwater parameters which are applicable to finite differences in values of water levels measured between finite differences in lengths, widths, and thicknesses of the blocks.

As I have mentioned before, what we have here is a huge bookkeeping problem as it is related to the balancing of all of the flows in and out of each block, the transfer of water from one block to the next, and the overall interaction of the demands and sources of water within the total groundwater system. As explained earlier, the individual mathematical models for each block are known. It is the sharing, transferring, and balancing of ins and outs that make up the computer aided bookkeeping problem. To begin with, each block of the overall model of EXHIBIT 322 is given some initial amount of water from field measurements expressed by a water table map. Next, one assumes certain demands upon the system, like pumping from one block, and then the bookkeeping problem is solved to reveal the status of the water balance shared by all blocks of the system in relation to the individual mathematical models connected to the pumped block. In this case, the output of the computer bookkeeping system might be water level changes due to the pumping.

Q. Would you tell us something about the computer system that is necessary in doing the bookkeeping that you've just described?

A. The computer that was used in most of the groundwater modeling we're talking about in my work was located at the Champaign-Urbana campus of the University of Illinois. The computer was manufactured by Control Data Corporation and is called a Cyber 175 system. This is a very large, fast and accurate computer system.

The instruction set that allows the computer to solve the set of interacting mathematical models of the groundwater flow was written by me and one of my colleagues at the Illinois State Water Survey. This computer program, or computer instruction set, is well known in the groundwater industry. The code has acquired the name PLASM which is an abbreviation of the Prickett Lonnquist Aquifer Simulation Model. Mr. Lonnquist is a computer programmer presently with the Water Survey. This model has been widely used throughout the world and has proven itself through many applications. I should mention here that I worked with Dr. Michael Voorhees of Warzyn Engineers in Madison, Wisconsin, who was a subcontractor to me, in the application of this model to the mine inflow project here.

Q. Mr. Prickett, before we discuss the modeling that was done here, the results of that modeling, and your opinion with respect to mine inflow, would you address two preliminary subjects. First, how does a person such as yourself use the results of modeling to arrive at an opinion or judgment and, second, how do you test the results of the model to determine whether the model is a useful tool?

A. Those are two very important questions, the answers to which must be understood if my testimony and opinions and the opinions offered by others in this proceeding are to be understood. First we must understand that a model is a tool. The model alone does not produce the opinion upon which we may rely. What it does produce is an answer that an expert in the science which is involved may use to enhance his ability to predict what will occur in the real world when changes are made in the environment. It would be a serious mistake to assume that we can take the answer produced by a mathematical model and use it without expert judgment and without verification of the model. In attempting to predict what the impact of the Crandon mine will be on the environment in and about the mine it would be a mistake to assume that any model or sets of models has the capacity to predict, with no margin of error, precisely what will occur in the real world. If we have a good model, if we have tested the model and are satisfied that it will materially assist us in predicting what will occur in the environment, and if we bring our experience, judgment and learning to the task of prediction, we may have a high degree of confidence that our opinion of what will occur is essentially correct. In this case I have a high degree of confidence that the inflow to the mine that I predict will not be exceeded, but of course, I will explain that in greater detail in a few minutes.

The second concept you asked me to explain is model verification. Quite simply, by verification we mean that we endeavor to test our model against the real world. The model tells us to expect a certain field response if certain conditions are changed. If it is possible, we then undertake an experiment where those conditions are in fact changed and compare the actual response that occurs in the field with the model's prediction. If we undertake that exercise a number of times in varying field circumstances and the model results are reasonably close to the field results, we may conclude that we have a good model. Verification of a model is, of course, complicated by the fact that the model is predicting the future and we may not be able to create field conditions that correspond exactly with what will occur in the future. There are, however, a number of ways that models such as the one we have here can be verified, and out of the process of verification we are able to arrive at a judgment on the quality of the model and the reliability of its predictions.

It is also important to consider the predictions of several related models. By way of example in this case, suppose that we developed a model of several of the lakes in this region to tell us how much "leakage" we could expect from those lakes if the water table below the lakes declined for whatever reason. Further suppose that that model told us that the levels of those lakes would decline in a given amount. From that we could derive the amount of water that would be "leaking" out of the lakes into the system below. But if we know that the system below cannot accept or take all of the water that the model tells us will leak out of the lakes, we have learned through verification that our "lake leakage" model requires more work. As I have said at the beginning of my testimony, in a complicated study such as we have here it is important that the results of the various models that are employed to analyze the effects of the Crandon mine are consistent and rational. In this case the mine will accept only so much water. If our lake model tells us that more water will leave the lake than can be accepted by the mine, it is obviously necessary to examine the accuracy of one or both of the models.

Here I am pleased to say the modeling work done by the firms and individuals whose names I listed at the beginning of my testimony, and my modeling work, are reasonably consistent. The results can be rationalized and my model and the models employed by the other experts have been verified. Accordingly, I can and do have a high degree of confidence in my opinions regarding what will occur when construction of the mine has been completed and the system is in steady state.

Q. How do you know whether this total modeling exercise is working or not?

A. One of the critical ideas in modeling, of course, is how the model generates status reports compared with what someone has actually measured in the real world. Therefore, the relevance of the model must be checked against something in the real world. The comparative analysis of real world versus model responses is called model verification. Model verification is an essential part of any serious modeling effort.

The difference between the model and field response is usually a good measure of the difference to be expected between a model prediction in the future and what can actually be expected.

Q. Mr. Prickett, would you now explain how you assembled the groundwater model of the Exxon Crandon Project orebody and thus how you analyzed the expected mine water inflows?

A. To expand and clarify some of my earlier testimony, let me say that my assignment from Exxon was to predict mine inflows, whereas it was the responsibility of others to gather field data and analyze related impacts due to these flows. In accordance with this division of responsibility, Exxon hired as I have mentioned before, various contractors to provide field measured parameters of the geology, formation thicknesses, permeabilities, groundwater storage properties, and water levels of the region. Considerable data were thus collected on both the near surface groundwater reservoir and the characteristics of the underlying orebody.

Q. I understand. Now would you please briefly describe how you went about constructing your groundwater model to predict mine inflows?

A. The design of the groundwater flow model for the orebody began with the two-dimensional regional flow model developed by D'Appolonia Engineers. Their model included the basic permeabilities, boundary conditions, recharge rates, and formation thicknesses of the groundwater reservoir that would be impacted by the mining scheme. To this set of model parameters was connected a three-dimensional model which represented the vertical distribution of the underlying orebody itself. Let me expand on this description as follows.

EXHIBIT 323 shows a representation of the chosen grid and node locations for the two-dimensional plan view groundwater model. The position of the underlying orebody is shown in EXHIBIT 323 as being just north of Little Sand Lake. Most of the blocks of the grid in the area of the orebody measure 100 meters on a side. Variable sized grids are used elsewhere. To this extent, the grid of EXHIBIT 323 provides enough grid blocks that a three-dimensional flow model of the underlying orebody may be attached.

EXHIBIT 324 shows a close up of the orebody area indicating the model blocks, or nodes, that are shared between the overburden aquifer model on top and the orebody model below. EXHIBIT 325 shows the grid and block configuration for the orebody section of the overall flow model.

In summary, the overall mine model then consists of two linked models. The first model was the overburden of the main aquifer represented by EXHIBIT 323 and the second was the orebody represented by the orebody model of EXHIBIT 325. The linkage between the two was accomplished at the orebody-overburden interface represented by EXHIBIT 324.

Q. Would you please expand on your explanation of the orebody part of the model?

A. Yes, EXHIBIT 325 illustrates the node or block network selected for the orebody flow model. The mathematical models of each of these blocks follows the same form as those mathematical models of the groundwater model explained at the beginning of my testimony. The plan view grid intervals were squares 100 meters on each side. This grid interval was selected because all the weathering and mining plan maps had coordinates which matched these intervals, and because of computer storage, computational speed, and well location considerations. The cross-section view of the orebody grid is composed of 100 meter plan view blocks with variable thicknesses defined by the various mining level elevation activities. Note in EXHIBIT 325 that the vertical grid intervals for the three-dimensional orebody model are made variable to aid in the data input for the defined blocks.

EXHIBIT 326 shows, first, the East and North coordinates which define the orebody node network in plan (top) view, and then second, a typical cross-sectional (side) view of the layers involved. As indicated by the studies done by the Exxon geologists testified to by Roger Rowe, below an elevation of 350 meters there is negligible permeability. This information was used in connection with the inputs to the model as was other information respecting permeability at various places and elevations at the site of the ore body. The detailed information with respect to these matters is contained in the testimony of Mr. Rowe and reports of the Exxon geologists.

Q. I understand that the grid blocks of your EXHIBITS are there to represent the mathematical models of permeable materials spoken of before. But, how do you now account for the mining plans?

A. The three-dimensional part of the model as shown in EXHIBIT 325 is capable of simulating any desired mine plan by specifying the orebody blocks and respective simulation times at which these blocks become open to direct mine drainage. When the mining plan calls for the particular block to be penetrated or to be mined out, then the water level at that block is set to its base elevation. Thus, at the assigned mining time, the model blocks become a sink for the removal of groundwater at the mine level of concern.

Implementation of the mine plan then simply involves the specification of the orebody block coordinates and the simulation time at which the block becomes effectively mined. Each level of the mine model has its own mining plan and time sequencing.

The total mine inflow rate can be calculated by summing up the individual contributions to all blocks being mined.

I should mention that individual flow rates anywhere in the model can be calculated by a form of Darcy's law that I described in my previous testimony. As a matter of fact, several water balance calculations can be made anywhere in the model to give information concerning flow rates of interest. Of course, the computer is used to make these computations and print out the results where desired.

Q. You mentioned that the worth of any model depends upon how well it compares with the real world. How did you check your mine inflow model?

A. The model verification process took place by first assigning estimated groundwater parameters to all blocks that were not directly calibrated by D'Appolonia modeling. Information concerning orebody weathering, permeabilities, and thicknesses were estimated from orebody pumping test data and geohydrologic studies made by Exxon and outside consultants, which I believe to be reasonable. These data are referred to in my reports and, I am informed, are introduced in this record.

The model was then run by using two sets of actual orebody pumping test data supplied by Camp Dresser & McKee, Inc., in 1981, as tests on the validity of the model to predict orebody response. Finally, the model parameters such as orebody and subcrop permeabilities, orebody storage coefficients, and the geometry of the overburden and orebody model connections at the subcrop were adjusted until the response of the computer model water level changes reasonably matched the water level changes measured in the field pumping tests. When the model and field data reasonably matched, the orebody model was considered calibrated, verified, and ready for predicting the mine inflow rates in question.

Q. After having completed the verification process, did you arrive at an opinion regarding the ability of your model to predict mine inflow?

A. Yes. In my professional opinion, I believe the model can reasonably be depended upon to produce accurate mine inflow estimates. The upper and lower bounds of model credibility, because of uncertainties in the parameters, will be discussed later as a part of my testimony regarding the model inflow rate sensitivity analysis.

Q. Would you please describe the main results of mine inflow rates estimated and the general procedures that you went through to arrive at your estimates?

A. First, EXHIBIT 203 shows the initial conditions that exist in the overlying glacial aquifer of the study area. Please note where the mine area is just north of Little Sand Lake. The potentiometric surface shown in EXHIBIT 203 agrees with that produced by my plan view glacial drift model and by D'Appolonia in their model.

Focus your memory for the moment on the water level contours near the mine area, as they are going to change as a result of the mining. Notice the positions and shapes of the 478, 480, 482, and 484 meter contours. Now, let's go to EXHIBIT 327 which shows the minimum potentiometric surface that the aquifer takes on when the mine is in full operation.

Notice in EXHIBIT 327 how the contours have distorted and deepened, particularly around the mine area. This has happened as a result of opening the mine deep within the orebody and as a result of pumping the drainage water from the mine works.

By application of Darcy's law to the conditions illustrated in EXHIBIT 327, the maximum steady rate of mine inflow was estimated to be 1270 gallons per minute. The change in potentiometric surface, or the so-called drawdown of the water table, is obtained by subtracting this EXHIBIT 327 map from the previous intitial condition EXHIBIT 203 potentiometric map. The resulting drawdown made for this mine inflow calculation is thus produced and shown in the next EXHIBIT 328.

Dr. D'Jafari will discuss the details of this type of groundwater-level decline in his more detailed discussions of impacts of mine inflows later. For now, EXHIBIT 328 illustrates the general view of the expected drawdowns in the Crandon project area for a typical set of realistic conditions. Drawdowns in the neighborhood of 20 meters, or approximately 66 feet, are to be expected right at the orebody subcrop with the glacial aquifer.

Q. Would you give us some details of what is happening right in the area of the orebody subcrop with the glacial drift?

A. Water is mainly draining vertically downward in the area of the orebody subcrop.

What is interesting here is that the application of Darcy's law here to mine inflow is very close to the original Darcy experiments done over one hundred years ago. The water here is flowing downward through materials of varying permeability and thickness in response to water level pressures between the water table above and the open mine works below. The application of Darcy's law here in his original vertical flow form shows where the water is flowing downward into the mine areas and at what rates.

The downward flow of groundwater is greatest in the south, and least in the north. Again, the application of Darcy's law to the total area indicates the 1,270 gallon per minute of mine inflow.

Q. You've stated that more water is flowing down towards the mine in the south. What proportions come from the other directions?

A. Separation of flows into the mine area by direction can be clarified by application of Darcy's law to the horizontal flow of groundwater. EXHIBIT 329 shows the directions from which the water is coming in the glacial aquifer. The majority of the water comes from the south, about 63 percent of the total. About 18 percent comes from the west, about 7 percent comes from the east, and the least, or about 4 percent of the mine inflow, comes from the north. The remaining 8 percent comes into the mine area by direct downward percolation of rainfall.

Q. You say that the flow of 1,270 gallons per minute is the steady rate of mine inflow. What do you mean by this?

A. Actually, the mine inflow will be insignificant until the first permeable material is penetrated by the mine. As the mine works increase in size and number, the flow will naturally increase. EXHIBIT 330 shows how a typical time variation of mine inflows results from an analysis of a typical mine plan.

As you will note in EXHIBIT 330, mine inflow, calculated as I just testified, is plotted on the vertical axis versus time, in days since mining started, being plotted along the horizontal axis. Substantial mine inflow begins when the first permeable material is penetrated and as mining areas increase the flow picks up significantly. However, when the mine has increased in size such that it covers most of the existing downward flow paths, then the mine flow peaks out at an approximate steady rate that remains until the mine is closed. It is this peak, or maximum, steady rate that I referring to.

Q. Earlier you mentioned a sensitivity analysis of mine inflows. What is that?

A. Due to a degree of uncertainty that always has to be dealt with in estimating the field parameters of a groundwater situation, one might question what the upper and lower limits on mine inflow rate might be? A sensitivity analysis is a study in which we statistically vary all of the important parameters involved in the inflow calculations to determine how sensitive our estimates are to variations in the parameters. Examples of the parameters varied were glacial aquifer and orebody subcrop permeabilities, and rates of groundwater recharge to the glacial aquifer.

On the basis of about 35 model runs, the results of this sensitivity analysis was that the most likely steady mine inflow rate would be about 1,342 gallons per minute. The analysis also indicated that within a 95 percent level of certainty, the ultimate mine inflow would be less than 1,761 gallons per minute. I should add that the difference between the initial inflow rate we predicted -- 1,270 gallons per minute -- and the rate as refined by the sensitivity analysis -- 1,342 gallons per minute -- is for all practical purposes insignificant. I therefore advised Exxon that, for planning purposes, it should assume a most likely mine inflow rate of 1,270 gallons per minute and provide sufficient capacity to handle a total inflow of 2,000 gallons per minute.

Q. Just a couple more questions here. What studies did you do to estimate the rate of flow through the undisturbed orebody materials?

A. Actually, I did a study to estimate both a before and an after mining flow through. Let me first describe the before condition flow through estimate.

I estimated the flow through the orebody materials on the basis of permeability measurements of the orebody itself, the calibration and verification permeabilities from the above analysis, and a simple cross-sectional flow model of uniform thickness and depth, values of which come from field data. This model calculation indicated the natural orebody flow through would be small or about 8 gallons per minute.

Q. What did you estimate the flow through would be after closure when the mined out orebody was abandoned?

A. Exxon described to me the expected condition of the mine and the permeability of the replaced materials in the abandoned mine. I used the same cross-sectional flow model as I used in determining the natural flow through situation above, but substituted the expected mine closure plan. The results of that study indicated that flow through would amount to about 25 gallons per minute. The difference is so small that it is my opinion that one would be hard pressed to even measure that flow rate change from a reasonable data collection system in the field.

Q. Mr. Prickett, in your professional judgement were sufficient studies undertaken here for you to arrive at a reliable opinion on the rate of mine inflow when the mine is constructed and reaches steady state?

A. Yes. There was an extraordinary amount of investigation and analysis involved in studying the impacts of this mine. Several interrelated modeling efforts were undertaken, many runs were taken, a great deal of empirical data was collected. I might say by way of summary that if ever a project was studied to an abundance of caution it was this project.

Q. Mr. Prickett, in a few sentences can you state your opinions respecting the rate of inflow to this mine that you expect to occur when the mine is constructed and reaches its maximum rate of inflow?

A. As I said early in my testimony, my opinion is the product of the development and verification of a model, collection of empirical data, and the exercise of my judgment developed through years of experience in this science. In my opinion, the most likely rate of mine inflow when the mine is in full operation, therefore in steady state, will be 1,270 gallons per minute. Further, it is my opinion that there is a 95% level of certainty that the mine inflow will not exceed 1,761 gallons per minute. Accordingly, I think it is appropriate to plan on mine inflow of approximately 1,270 gallons per minute, but to develop Contingency Plans for, and equipment to handle, inflow as high as 1,761 gallons per minute, and certainly no greater than 2,000 gallons per minute.

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EXHIBIT 312

RESUME OF QUALIFICATIONS OF Thomas A. Prickett

PERSONAL HISTORY

Born September 22, 1935, in Pekin, Illinois. Grew up in Pekin and attended public schools there, graduating from high school in 1953. In June 1958, married Alice Ann Weber, a scientific illustrator at the University of Illinois. Have two daughters, ages 25 and 21. Hobbies are music and weekend farming.

EDUCATION

Name of School	Address	Remarks
University of Illinois	Urbana, Illinois	Attended 1953-1957 in curriculum of Electrical Eng. Degree of Bachelor of Science in General Engineering in 1960.

EXPERIENCE

January 1, 1981 to present: President, Thomas A. Prickett and Associates, Incorporated, a water resources consulting firm, Number 6 G.H. Baker Drive, Urbana, Illinois 61801.

August 1977 to December 31, 1980: Vice President and General Manager, Water Resources Division of Camp Dresser & McKee, Champaign, Illinois. Responsible for a staff of 12 groundwater hydrologists.

July 1960 to August 1977: Engineer, Hydrology Section, Illinois State Water Survey, Urbana, Illinois. Conducted hydrologic investigations leading to the development and use of the groundwaters of Illinois. Analyzed the results of field hydraulic engineering investigations and prepared reports for publication.

MEMBERSHIP IN PROFESSIONAL SOCIETIES

National Water Well Association
American Society of Civil Engineers
The Society of the Sigma Xi

ACTIVITIES IN PROFESSIONAL SOCIETIES

ASCE: Past member of Task Force Committee on Low Flow, Total Runoff, Infiltration and Groundwater Recharge in the Urban Environment
Past member of Task Force Committee on Effects of Energy Development on Groundwater Resources
Past member (Past Chairman) Groundwater Hydrology Committee (Hydraulics Div.)
Past Corresponding member, Groundwater Committee of Irrigation and Drainage
Past Associate Contact member, University of Illinois Student Chapter
Corresponding member, Groundwater Committee of Hydraulics Divisions

NWWA: Exam Director of State water well drillers certification program
Editorial Board Member of Ground Water Journal
Board of Directors of Technical Division

ACTIVITY IN INTERNATIONAL COMMITTEE

Member, International SCOPE groundwater modeling steering committee, Holcomb Research Institute, Butler University, Indianapolis, Indiana.

PROFESSIONAL ENGINEERS LICENSE

Registered Professional Engineer in the State of Illinois #62-24605 obtained by written and oral examination.

AWARDS AND HONORS

National Water Well Association Scientist of the Year Award in 1977. Adjunct Professor of Geology, Oklahoma State University, Stillwater, Oklahoma 1983.

MILITARY ACTIVITIES

Member of the United States Marine Corps Reserve, infantryman and active reservist beginning 1957 until honorably discharged in September 1963.

ARTICLES & REPORTS

Sasman, R.T., Prickett, T.A., and R.R. Russel, 1961, Water level decline and pumpage during 1960 in deep wells in the Chicago Region, Illinois: Illinois State Water Survey, Circular 83.

Zeizel, A.J., Walton, W.C., Sasman, R.T., and T.A. Prickett, 1962 Ground-Water Resources of DuPage County, Illinois: Illinois State Water Survey and Illinois State Geological Survey Cooperative Ground-Water Report No. 2.

ARTICLES & REPORTS (continued)

Prickett, T.A., 1963, Methods used in evaluating the potential yield of shallow aquifers in the Chicago region: Illinois State Water Survey open file report to Northeastern Illinois Metropolitan Area Planning Commission.

Walton, W.C., and T.A. Prickett, 1963, Hydrogeologic electric analog computers: Journal of the Hydraulics Division, ASCE, Volume 89, No.HY6, November, Proceedings Paper 3695, pp. 67-91.

Prickett, T.A., Hoover, L.R., Baker, W.H., and R.T. Sasman, 1964, Ground-water development in several areas of northeastern Illinois: Illinois State Water Survey, Report of Investigation 47.

Prickett, T.A., 1965, Type-curve solution to aquifer tests under water table conditions: Ground Water, Technical Division Journal of NWWA, Volume 3, No. 3, July, pp. 5-14.

Prickett, T.A., 1966, Schemes of ground-water development in Zapotitan Valley, Repulbic of El Salvador: Supplemental report, Irrigation Plan for the Zapotitan Valley Project, Harza Engineering Company International, Chicago, IL, July.

Prickett, T.A., 1966, Curso breve sobre analisis hidrogeologico de sistema con computadores analogos electricos pasivos. Direccion de Grandes Obras de Riego, Ministry of Agriculture and Livestock, Republic of El Salvador.

Prickett, T.A., 1967, Designing pumped well characteristics into electric analog models: Ground Water, Technical Division Journal of NWWA, Volume 5, No. 4, October.

Prickett, T.A., and C.G. Lonnquist, 1968, Comparison between analog and digital simulation techniques for aquifer evaluation: Illinois State Water Survey, Reprint Series 114.

Prickett, T.A., 1972, Selected notes on the design of electric analog computers for groundwater resource evaluation: Publication of Investigation de Aguas Subterraneas Proyecto Hidrometeorologico Centroamericano, San Jose, Costa Rica, Publication No. 85.

Prickett, T.A., and C.G. Lonnquist, 1971, Selected digital computer techniques for groundwater resource evaluation: Illinois State water Survey, Bulletin 55.

Moench, Allen F. and T.A. Prickett, 1972, Radial flow in an infinite aquifer undergoing conversion from artesian to water table conditions: Illinois State Water Survey, Reprint Series 202.

ARTICLES & REPORTS (continued)

Prickett, T.A., and A.P. Visocky, 1972, Effects of spray irrigation of industrial waste water on ground water levels at Havana, Illinois: Illinois State Water Survey open file report.

Prickett, T.A., and C.G. Lonnquist, 1973, Aquifer simulation model for use on disk supported small computer systems: Illinois State Water Survey, Circular 114.

Prickett, T.A., 1973, Digital computer model for predicting quality of feedwater: in "Feasibility study on desalting brackish water from the Mt. Simon aquifer in northeastern Illinois," Publication 14-30-2924 with the Department of the Interior, Office of Saline Water.

Prickett, T.A., 1974, Water resources in Illinois for coal gasification: Proceedings of State-Wide Advisory Committee Conference of April 23, Water Resources Research Center, University of Illinois.

Prickett, T.A., 1974, Hazards of underground construction related to development of sand boils--a case history near Pekin, Illinois: Illinois State Water Survey open file report.

Prickett, T.A., Bhowmik, N.G., Visocky, A.P., and W.J. Roberts, 1974, Water resources of Illinois for coal gasification: Preliminary report leading to Illinois State Water and Geological Surveys Cooperative Report 4.

Prickett, T.A., 1974, Hydrologic conditions in Banner strip mine area, Fulton and Peoria Counties, Illinois: Illinois State Water Survey open file report.

Prickett, T.A., 1975, Modeling techniques for groundwater evaluation, in "Advances in Hydroscience," Academic Press, Volume 10, pages 1-143.

Prickett, T.A., Roberts, W.J., and Kothandaraman, V., 1976, Physical description and hydrology of Illinois; Report to Illinois Environmental Protection Agency: Illinois State Water Survey open file report. Also published by the Illinois Environmental Protection Agency.

Prickett, T.A., 1976, Advances in groundwater flow modeling, in Proceedings of the Twelfth Annual National Meeting of the AWRA.

ARTICLES & REPORTS (continued)

Prickett, T.A., and C.G. Lonnquist, 1976, Metodos de ordenador para evaluacion de recursos hidraulicos subterraneos: Ministerio de Obras Publicas Servicio Geologico, Boletin No. 41, Madrid, Spain. Bulletin 55 translated into Spanish and converted to metric units.

Prickett, T.A., and C.G. Lonnquist, 1977, A randon-walk mass transport model for selected groundwater quality evaluations: Illinois State Water Survey. Open file report.

Prickett, T.A., 1978, State-of-the-art of groundwater modeling, in Proceedings of the Symposium on Water Management in Arid Lands, by Pergamon Press.

Prickett, T.A., and C.D. Morris, 1978, Development of a hydrologic model of the Knife River Basin, North Dakota--A feasibility study: North Dakota State Water Commission Special Report.

Voorhees, M.L. and T.A. Prickett, 1978, Selected hand-held calculator codes for horizontal collector well analysis. Report to the Ranney Company of Worthington, Ohio.

Prickett, T.A. August 1978. Predicted Impacts of Groundwater Development, City of Lakeland, Florida. Report to Ross, Saarinen, Bolton, and Wilder, Inc. of Clearwater, Florida. 38 pages.

Prickett, T.A. and B.L. Herzog. October 1978. Aquifer Performance Test at Town of Highland Beach, Florida. Report to South Florida Water Management District, W. Palm Beach. 53 pages.

Prickett, T.A. and B.L. Herzog. December 1978. Results of Four Pumping Tests in Nye Area, near Evansville, Indiana. Report to Shell Oil Company. 63 pages.

Prickett, T.A. January 1979. Estimated Flow Rates into Proposed Nye Area Deep Coal Mine. Report to Shell Oil Company. 38 pages.

Prickett, T.A. February 1979. Practical Sustained Yield and Potential Yield of Henrico County Water Supply Authority Well Fields, Virginia. Report to Environmental Engineering Division of Camp Dresser and McKee, Inc. Suitland, Maryland. 40 pages.

Prickett, Thomas A. March 1979A. Ground-Water Computer Models State-of-the-Art. Ground Water, Journal of the NWWA, Volume 17, Number 2.

ARTICLES & REPORTS (continued)

Prickett, T.A. March 1979B. Results of Computer Model Analysis--see Well Field Evaluation Study of King Khalid Military City Kingdom of Saudi Arabia, Report to Leggette, Brashears, and Graham, Inc., of Westport,Connecticut. 88 pages.

Evenson, D.E., and T.A. Prickett, April 1979A. Processes and Parameters Involved in Modeling Radionuclide Transport from Bedded Salt Repositories. Report to Lawrence Livermore Laboratories, University of California. 61 pages.

Prickett, T.A. April 1979B. Geohydrologic Data Review and Pumping Test Possibilities--70th Street and Canterbury Mine Areas, Belleville, Illinois. Report to Illinois Geological Survey, University of Illinois. 8 pages.

Prickett, T.A. April 1979C. A Salt-Water Intrusion Monitoring and Management Program for the City of Boca Raton, Florida. Prepared in Compliance with the S. Florida Water Management District Directives. 93 pages.

Prickett, T.A. June 1979A. An Estimation of Leakage Rates from Proposed Ash Lagoons--Saskatchewan Power Corporation Electric Generating Plant near Coronach, Saskatchewan, Canada. Report to Saskatchewan Power Corporation, Regina. 52 pages.

Prickett, T.A. and B.L. Herzog. June 1979B. Results of the Water-Level Program, Computer Analysis of Mine Seepage Rates, and a Study of Desalination Processes related to the Proposed Nye Area Deep Coal Mine. Report to Shell Oil Company. 83 pages.

Voorhees, M.L. and T.A. Prickett. August 1979A. Selected Hand-Held Calculator Codes and Models for Aquifer Analyses. Camp Dresser & McKee Methods Report I. 82 pages.

Prickett, T.A. and R.C. Johnson. August 1979B. Mitigative Schemes and Monitoring Needs for Proposed Ash Lagoon Operation--Report to Saskatchewan Power Corporation (Coronach Generating Station). 65 pages.

Prickett, T.A., M.L. Voorhees, and B.L. Herzog. September 1979. Comparison of One-,two-, and Three-Dimensional Models for Mass Transport of Radionuclides. Report to Lawrence Livermore Laboratories, University of California. 87 pages.

Prickett, T.A. November 1979. Specification for Design of a Fully Three-Dimensional Mass Transport Model for Radionuclide Movement from Waste Repositories. Report to Lawrence Livermore Laboratories, University of California. 70 pages.

ARTICLES & REPORTS (continued)

Johnson, R.C., T.A. Prickett, and W.C. Walton. March 1980. Dixie Well Field Stress Analysis. Report to the City of Ft. Lauderdale, Florida. 56 pages, 37 Exhibits, and 8 Appendices.

Davis, P.R. and T.A. Prickett. April 1980. The Statement of the Results of Test Borings or Core Samplings for Comet Coal and Clay Company, Sullivan County, Dugger, Indiana. Report to Office of Surface Mining.

Walton, W.C., M.L. Voorhees, and T.A. Prickett. May 1980. Conceptual Model for regional radionuclide transport from a basalt repository Site. Report to Lawrence Livermore Laboratory. University of California. 63 pages.

Voorhees, M.L., T.A. Prickett, and W.C. Walton. June 1980. Selected hand-held calculator codes for aquifer analysis. Camp Dresser & McKee Manual of Aquifer Analysis. 160 pages. General sales to selected clients.

Walton, W.C. and T.A. Prickett. August 1980. An evaluation of the aquifer system /well field in the Haina River Valley, near Santo Domingo, Dominican Republic. Report to Dominican Republic Water Resources Department. 117 pages and 8 Appendices.

Walton, W.C. and T.A. Prickett. September 1980. Results of Pumping Tests at the Occidental Chemical Company Tank Farm, Lathrop, California. 69 pages.

Prickett, T.A., P.R. Davis, and W.C. Walton. September 1980. An evaluation of the long-term yield of a shallow sand and gravel aquifer near Clinton, Iowa. 24 pages and 3 Appendices.

Johnson, R.C., T.A. Prickett, and W.C. Walton. September 1980. Prospect well field impact analysis. Report to the City of Ft. Lauderdale, Florida for permitting purposes. 96 pages, 37 exhibits, and 15 Appendices.

Prickett, T.A. December 1980. An evaluation of future water-level declines in the sandstone aquifer in the Clinton, Iowa Area. 20 pages and 3 Appendices.

Prickett, T.A. and M.L. Voorhees. March 1981. Selected hand-held calculator codes for the Evaluation of cumulative strip-mining impacts on groundwater resources. Report prepared for the Office of Surface Mining Region V, Denver, Colorado. 75 pages.

ARTICLES & REPORTS (continued)

Prickett, Thomas A. June 1981. A comparative study of the impacts of uranium mining by the insitu versus shaft mining techniques on the groundwater resources of the Crownpoint, New Mexico region. Mobil Oil Corporation. 140 pages.

Neff, C.H. and T.A. Prickett. September 1981. Reliability and comparative analyses of the McGehee area water samples collected 2/21/81-6/10/81. Report prepared for Shell Oil Company, New Orleans, LA. 92 pages.

Prickett, T.A., C.H. Neff, and T.G. Naymik. December 1981. The hydrologic and water quality impacts of the McGehee Number 1 blowout and recommended future monitoring plan. Report prepared for the Shell Oil Company of New Orleans, Louisiana. 80 pages.

Prickett, T.A. and M.L. Voorhees. November 1981. The hydrologic impacts of the Crandon copper mine: A predictive model. Report prepared for the Exxon Minerals Division at Rhinelander, Wisconsin. 86 pages.

Prickett, T.A. and M.L. Voorhees. March 1982. The hydrologic impacts of strip mining near Gillette, Wyoming (Caballo and Rawhide Mines). Report Prepared for Carter Mining Company. 620 pages.

Prickett, T.A., T.G. Naymik, and C.G. Lonnquist. 1981. A random-walk solute transport model for selected groundwater quality evaluations. Illinois State Water Survey Bulletin 65, Champaign, Illinois. 103 pages.

Walton, W.C., P. Davis, and T.A. Prickett. June 1981. Hydrologic report and proposed plan of replacement Crownpoint and Monument projects. Report submitted to Mobil Oil Corporation Uranium/Minerals Division. Camp Dresser & McKee, Inc. and Thomas A. Prickett and Associates, Inc., both of Champaign-Urbana, Illinois. 86 pages.

Prickett, T.A. and M.L. Voorhees. January 1982. Groundwater flow model for Exxon ore body near Crandon, Wisconsin. Report submitted to Exxon Minerals Company, Rhinelander Wisconsin. Thomas A. Prickett & Associates, Urbana, Illinois. 153 pages.

Voorhees, M.L. and T.A. Prickett. May 1982. User's guide for an interactive groundwater flow management model. Computer code prepared for Vulcan Materials Company Chemical Division, Wichita, Kansas. 198 pages.

Prickett, T.A. and A.P. Visocky. May 1983. Analysis of south trend development area pumping test, August 16-18, 1982, Crownpoint, McKinley County, New Mexico. Report to Mobil Oil Corporation, Uranium Minerals Division.

ARTICLES & REPORTS (Concluded)

Voorhees, M.L. and T.A. Prickett. December 1982. Ground water inflow model for the proposed Crandon mine. Report submitted to Exxon Minerals Company, Rhinelander, Wisconsin. Thomas A. Prickett and Associates, Inc. of Urbana, Illinois. 90 pages and 17 appendices.

Prickett, T.A. and K.D. Goff. November 1984. Selected numerical flow and mass transport groundwater models for the Naval Air Engineering Center -- Lakehurst, New Jersey. Report to the United States Navy by Thomas A. Prickett & Associates of Urbana, Illinois. 495 pages.

Voorhees, M.L. and T.A. Prickett. October 1984. Predictive ground water inflow modeling and sensitivity analysis for the proposed Crandon mine. Report submitted to Exxon Minerals by Thomas A. Prickett and Associates of Urbana, Illinois.

PRIVATE CONSULTING EXPERIENCE
(Prior to joining CDM)

All such work listed was accomplished under private contract and was done on vacation leave, week-ends, and evenings. Dates indicate time within which work took place. Work is listed by date, work subject, location, and for whom work was done. The symbol * indicates I accomplished the work at the location listed.

February 1963: Safe yield of well field, Bracebridge, Ontario, Canada, W.C. Walton of Minneapolis, Minnesota.
March-June 1965: Design and analyze analog computer for well-field response, Estevan, Saskatchewan, Canada, W.c. Walton, Minneapolis.
October 1965: Evaluate well field irrigation scheme, San Miguel, Republic of El Salvador, W.C. Walton, Minneapolis.
*December 1965: Set up test drilling program, Zapotitan Valley, El Salvador, Harza Engineering of Chicago, Illinois.
*February 1966: Presented short course on analog model design, University of New Hampshire, Durham, New Hampshire, 10 lectures.
*March 1966: Review-recommendations of water supply, Port-au-Prince, Haiti, James F. MacLaren International of Toronto, Canada.
*April-December 1966: Hydrogeologic systems analysis irrigation project, Zapotitan Valley, El Salvador, Harza Engineering of Chicago (2 trips).
*September 1966: Short course on analog model design, San Salvador, El Salvador, Ministry of Agriculture and Livestock, 16 lectures.

PRIVATE CONSULTING EXPERIENCE (continued)
(Prior to joining CDM)

*March 1967-May 1970: Set up large analog model lab, arranged for all equipment, and gave one-month instruction course in use during May 1970, Proyecto Hydrometeorologico Centroamericano, San Jose, Costa Rica, and US A.I.D.
*January 1968: Short course on analog model design, University of Toledo, Ohio, given as Geology 495 special course, 10 lectures.
*June 1969: Short course on analog and digital model design, Pennsylvania State University, University Park, 16 lectures.
February 1970: Surface water lake depletion due nearby groundwater pumping, Lake Bronson, Minnesota, W.C. Walton of Minneapolis.
*March 1970: Led seminar in analog model design, University of Strasbourg, France, 20 lectures.
*April 1970: Short course in analog model design, Copenhagen, Denmark, Geological Survey of Denmark, 20 lectures.
*July 1971: Short course in digital modeling, Madison, Wisconsin, University of Wisconsin, 10 lectures.
*April 1972: Short course in digital modeling, Madrid, Spain, Servicio Geologico de Obras Publicas, 6 lectures.
May 1972-December 1973: Wrote book on modeling techniques, contract with Academic Press (see article listed in publications list).
August 1974-January 1975: Taught Civil Engineering 457, University of Illinois, Urbana, contract required half time leave from Water Survey.
*June 1975: Evaluated safe yield of Almonte-Marismas aquifer, Seville, Spain, Internacional de Ingenieria y Estudios Technicos, Madrid, Spain.
*December 1975: Trained United Nations personnel in groundwater quality modeling techniques, preliminary model of salt water wedge, Valencia, Spain.
February 1976: Lake--water augmentation by groundwater, Baraboo, Wisconsin, Harza Engineering Company, Chicago, Illinois.
June 1976: Seepage into coal mine, location confidential, Nye Metals of Indianapolis, Indiana.
*October 1976: Training in regional evaluations with computers, Water Technology Center, New Delhi, India, Indian Agricultural Research Institute.
April 1977: Designed numerical model for Exxon pit mine in Wisconsin, sub-contracted from Dames & Moore of Denver, Colorado.
June 1977: Designed numerical model for analyzing groundwater quantity and quality problems at strip mine sites near Gillette, Wyoming, Harza Engineering Company, Chicago, Illinois.
July 1977: Reviewed Exxon shaft, strip and insitu mining problems for Dames & Moore, Salt Lake City, Utah office.

CONSULTING EXPERIENCE AFTER JOINING CDM

Impact analysis of new well-fields of City of Lakeland, Florida. Ross, Saarinen, Bolton, and Wilder of Clearwater, Florida.

Analysis of saltwater encroachment potential for various well field production schemes for the City of North Miami Beach, Florida, Ross, Saarinen, Bolton, and Wilder of Clearwater.

Designed saltwater management and monitoring program for city of Boca Raton, Florida. Ross, Saarinen, Bolton, and Wilder of Ft. Lauderdale.

Designed program to meet South Florida Water Management District comsumptive use permit conditions for the city of Ft. Lauderdale, Florida. Ross, Saarinen, Bolton, and wilder.

Hydrologic impact analysis of new 45 mgd Cross Bar Ranch Well Field, for West Coast Regional Water Supply Authority.

Well-field site location and impact analysis for Government of Pakistan, for CDM Environmental Engineering Division.

Feasibility study of hydrologic modeling of Knife River Basin of North Dakota. North Dakota State Water Commission, Bismarck.

Developed a series of hand-held programmable calculator codes for studying horizontal collector well hydraulics and hydrology. Ranney Company of Worthington, Ohio.

Designed baseline data collection system for groundwater and surface water systems for a potash insitu mining development in Moab, Utah. Done for subcontract with Environmental Sciences Division of CDM.

Performed special aquifer tests for city of Highland Beach, Florida, Ross, Saarinen, Bolton & Wilder, Ft. Lauderdale.

Special consultant to Stone & Webster on disposal of high level radioactive wastes in salt domes.

Special consultant to Leggette, Brashears, & Graham, Inc. on modeling Wasai formation of King Khalid Military City Saudi Arabia.

Special consultant to Geraghty & Miller, Inc. on modeling groundwater reservoir in Puerto Rico.

Set up test drilling, pump testing, monitoring system, and digital model for analysis of deep mine seepage problems, southern Indiana for Shell Oil Company.

Special consultant to Holcomb Research Institute of Butler University, Indianapolis, Indiana on setting up worldwide clearinghouse on ground-water models.

Conducted Groundwater Modeling Course in cooperation with the Southwest Florida Water Management District, Brooksville, Florida.

Conducted Groundwater Modeling Short Course in cooperation with Holcomb Research Institute of Butler University, Indianapolis, Indiana.

Project manager for Consolidation Coal Company for surface strip mine and shaft mine in southern Indiana concerning groundwater impacts and permitting requirements.

CONSULTING EXPERIENCE AFTER JOINING CDM (continued)

Groundwater consultant to Saskatchewan Power Company, Regina concerning groundwater contamination potential and remedial actions for ash lagoon leachate pollution. Provided analysis and testimony for two international hearings in Montana and Regina.

Consultant for Lawrence Livermore Laboratories, University of California. Conducted research on mass transport of radioactive contaminants from deep repositories of high-level nuclear wastes.

Analyzed new well field for City of Clinton, Iowa, including test wells, pumping tests, surface water/groundwater relationships and safe yield.

Special consultant to Occidental Chemical Corporation concerning toxic wastes coming from ponds, lagoons, storage areas, and landfills. Work included predictive model development and pumping test design.

Special consultant to Mobil Oil preparing testimony for legal hearings regarding water consumptive use permit near Crownpoint, New Mexico.

Provided expert witness testimony for Broward County, Florida Engineering Department concerning a case against a dewatering contractor.

Presented modeling technique seminar to Arab conference of hydrologists in Cairo, Egypt.

Project director for Federal Office of Surface Mining concerning small operators permitting of a coal strip mine at Dugger, Indiana.

Provided guidance to City of Milwaukee, Wisconsin concerning preliminary siting of sanitary landfills and their groundwater pollution potential.

Consultant to Delaware River Basin Commission participating in evaluation of groundwater potential and setting up a basin-wide permitting system.

Design of numerical models and special aquifer tests for the government of the Commonwealth of Guam concerning groundwater development and salt water encroachment.

Main consultant to the Government of the Dominican Republic on rehabilitation of the Haina Valley well field---hurrican damage.

Experience and Present Clients
With T.A. Prickett and Associates

Shell Oil Company: Impacts of natural gas blowout situation near Jackson, Mississippi.

Exxon Oil Corporation: Development of computer program for evaluating groundwater impacts due to deep shaft mining of copper near Crandon, Wisconsin.

U.S. Office of Surface Mining: Developed calculator codes for evaluating the cumulative impacts of surface mining on groundwater resources (both quantity and quality of water).

Experience and Present Clients
With T.A. Prickett & Associates, Inc.

U.S. Environmental Protection Agency: Developed computer codes for ranking and evaluating future landfill sites throughout the United States.

Saskatchewan Power Corporation, Regina, Canada: Developed methodology for evaluating leachate rates and quality impacts on local groundwaters from coal ash lagoon site.

Geraghty & Miller of Syosett, New York: Special consultant in computer modeling of flow and mass transport groundwater models.

Mobil Oil Corporation: Providing expert testimony in uranium mining techniques by shaft or insitu leaching methods before New Mexico State Engineer.

West Coast Regional Water Supply Authority, Clearwater, Florida: Consultant directing development of groundwater resources in Tampa/St. Petersburg area.

Government of the Dominican Republic: Consultant overseeing groundwater development in the Nigua basin near Santo Domingo.

Vulcan Materials, Wichita, Kansas: Designed computer model for studying various cleanup procedures and impacts in multi-layered groundwater system contaminated with both organic and inorganic compounds.

Exxon Minerals, Inc. Providing expert testimony at public hearings in Wisconsin regarding impacts of groundwater development due to mining activities.

O'Brien & Gere, Inc. Provided expertise in groundwater modeling to staff of Syracuse, NY to bring groundwater group up to speed. In-house training, computer code implementation, and applications to two project situations were accomplished. PCB, 1,1,1,TCE pollutants

Prudential Insurance Company: Provided expert testimony and groundwater evaluations concerning large irrigation project in Northwestern Indiana.

Westinghouse: Provided basic modeling expertise and pretrial material development at landfill near Bloomington, Indiana. PCB

Donohue Associates, Sheboygan, Wisconsin: Provided mass transport model and evaluation techniques for groundwater staff to analyze TCE contamination situation at Delevan, Wisc.

Minnesota Pollution Control Agency, Minneapolis, Minnesota: Project Director for determining the responsibility for the largest TCE contamination plume in the United States. This is a half million dollar project for which the prime contractor is Camp Dresser & McKee of Detroit. (Plume covers approximately 18 square miles).

O.H. Material, Findlay, Ohio: Presently instructing main office hydrogeological staff in computer techniques for analyzing aquifer cleanup alternatives involving contaminated, polluted, and multi-fluid situations.

Stauffer Chemical Corp., Westport, CT: Reviewed Super Fund site situation at Mobile, Alabama and presented first design considerations for cleanup.

Morrison-Knudsen Engineers, Denver, Colorado: Presently working on modeling of numerous cleanup scenarios concerning the Rocky Mountain Arsenal. Involves one-, two-, and three-dimensional impact studies of contaminants under variable saturation conditions.

Blatchey Engineers, Denver, Colorado: Aiding in designing dewatering schemes for new east-west runways at Denver Stapleton airport.

Neyer, Tiseo, and Hindo, Detroit, Michigan: Directed groundwater flow and mass transport modeling study of 40-million gallon per day new well field for General Motors assembly plant at Kansas City, Kansas. Included hydrocarbon pollutant simulation.

National Water Well Association: Conducting numerous seminars in groundwater modeling techniques for NWWA. During the last two years, have presented seminars to over 1,000 participants.

Dyer, Riddle, Mills, & Precourt of Orlando, Florida: Designed fully three-dimensional mass transport model for analyzing salt-water barrier near Cocoa Beach well field for Deseret industries.

Burns & Mcdonnell of Kansas City, Missouri: Designed and applied surface water/groundwater interaction computer model to evaluate effects of river dredging on groundwater resources of Kansas River. Project for US Army Corps of Engineers.

Model Example

What is a Model?
Examples
1. Scale Model
2. Ordinary Road Map
3. Checkbook
4. Water Distribution System
5. Ground Water Model

Checkbook Example

Your View = Bank View
YV = BV

1. Adjustments to Bank's View:

Bank Balance Less Outstanding Checks Plus Deposits

$$BV = BB - OC + D$$

2. Adjustments to Your View:

Your Balance Less Bank Service Charges

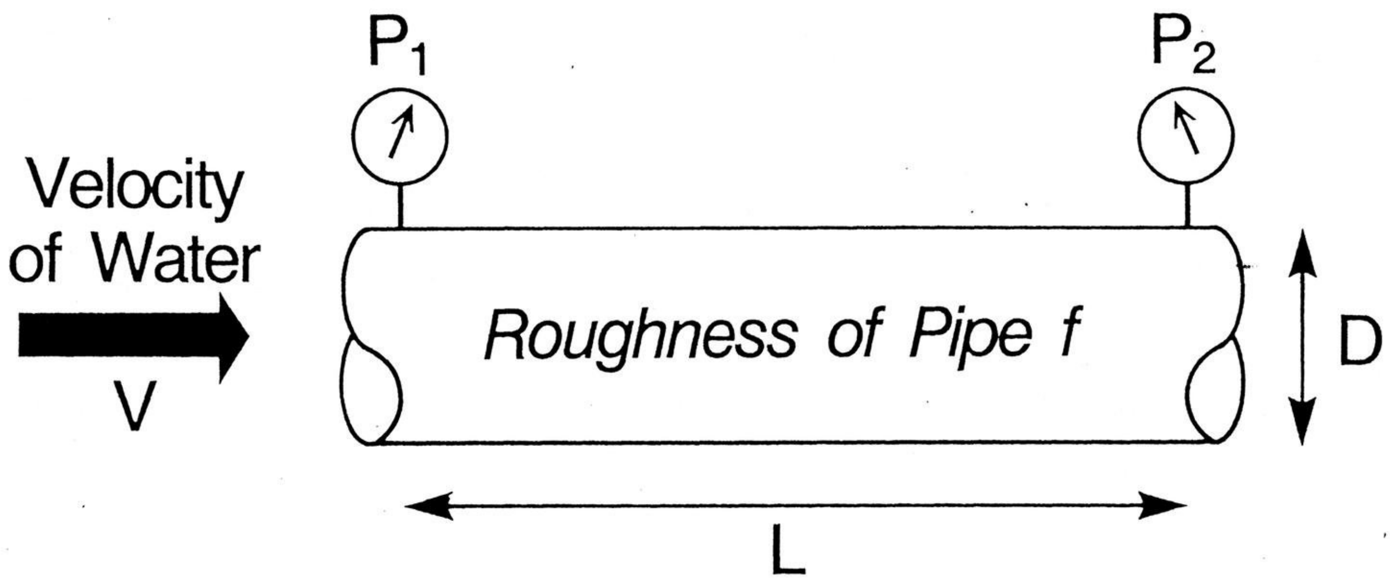
$$YV = YB - SC$$

Mathematical Model of Checkbook

$$YB - SC = BB - OC + D$$

Water Distribution System

Pipe

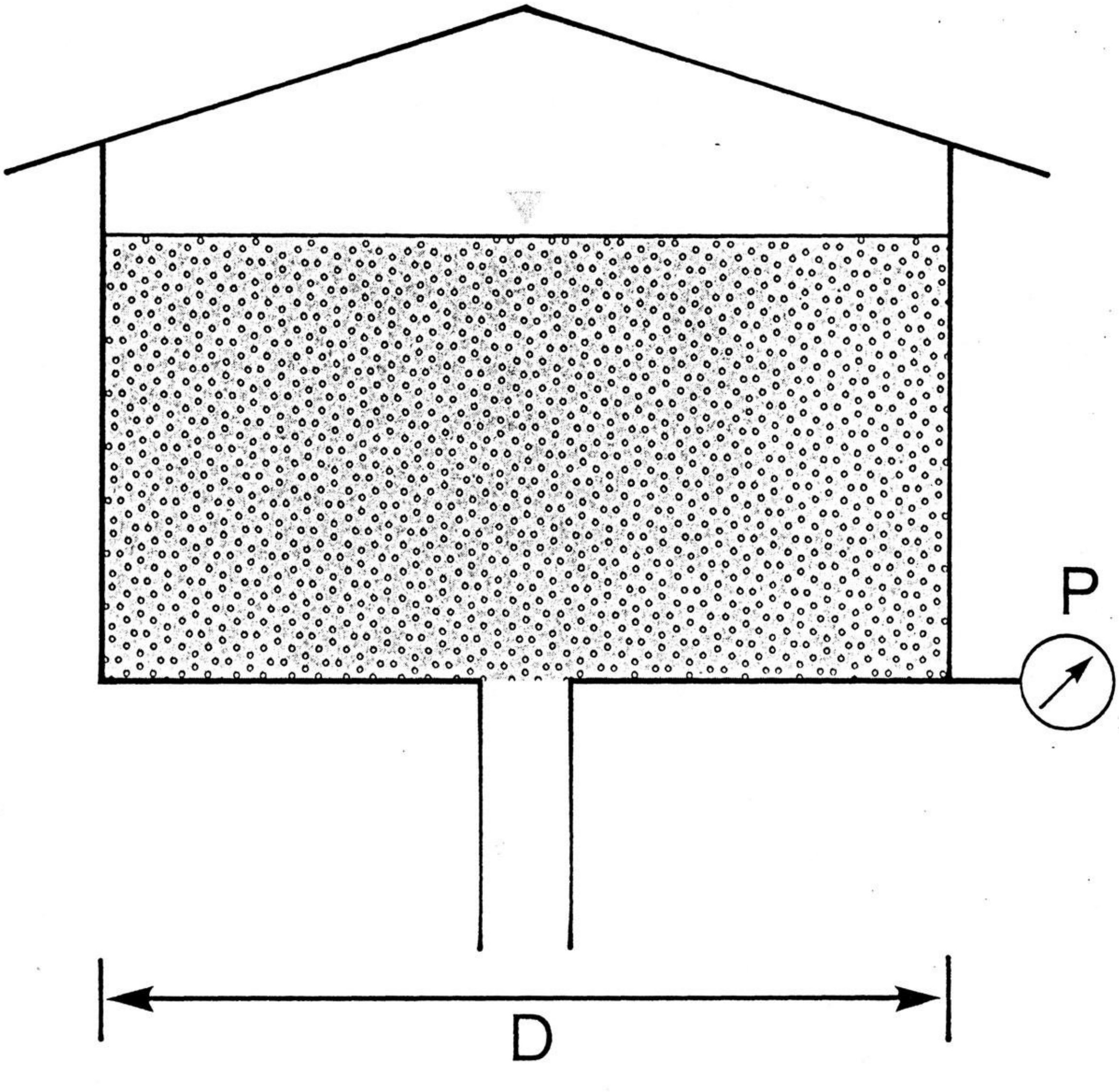


Mathematical Model of Pipe

$$P_1 - P_2 = f \frac{LV^2 w}{2\,Dg}$$

Water Distribution System

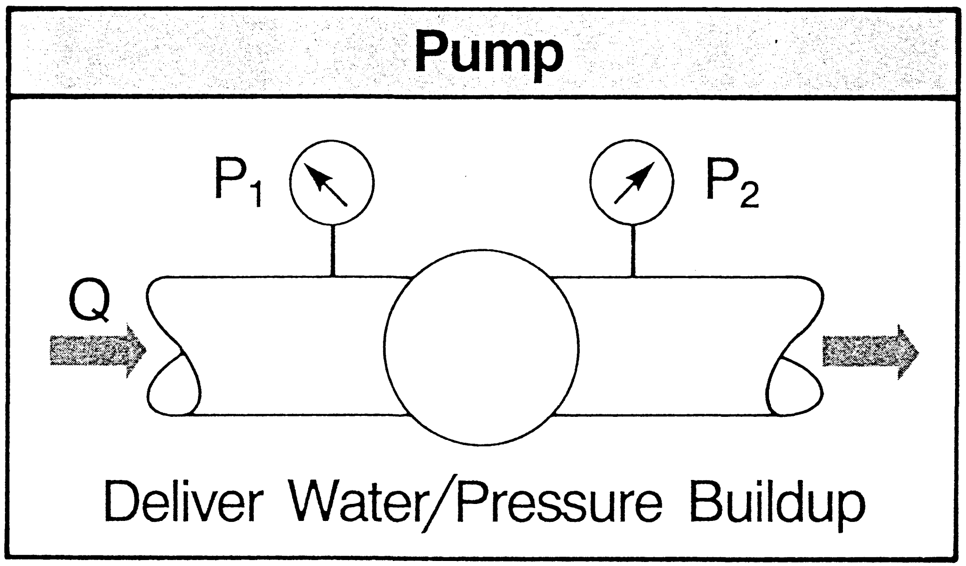
Storage Tank

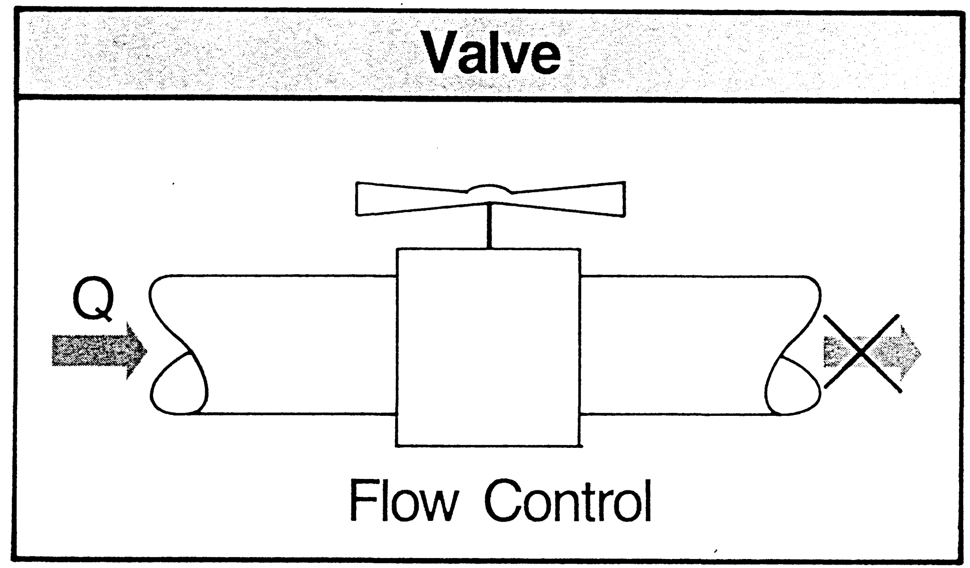


Mathematical Model of Volume of Water in Storage Tank

$$Volume = \frac{P \pi D^2}{4w}$$

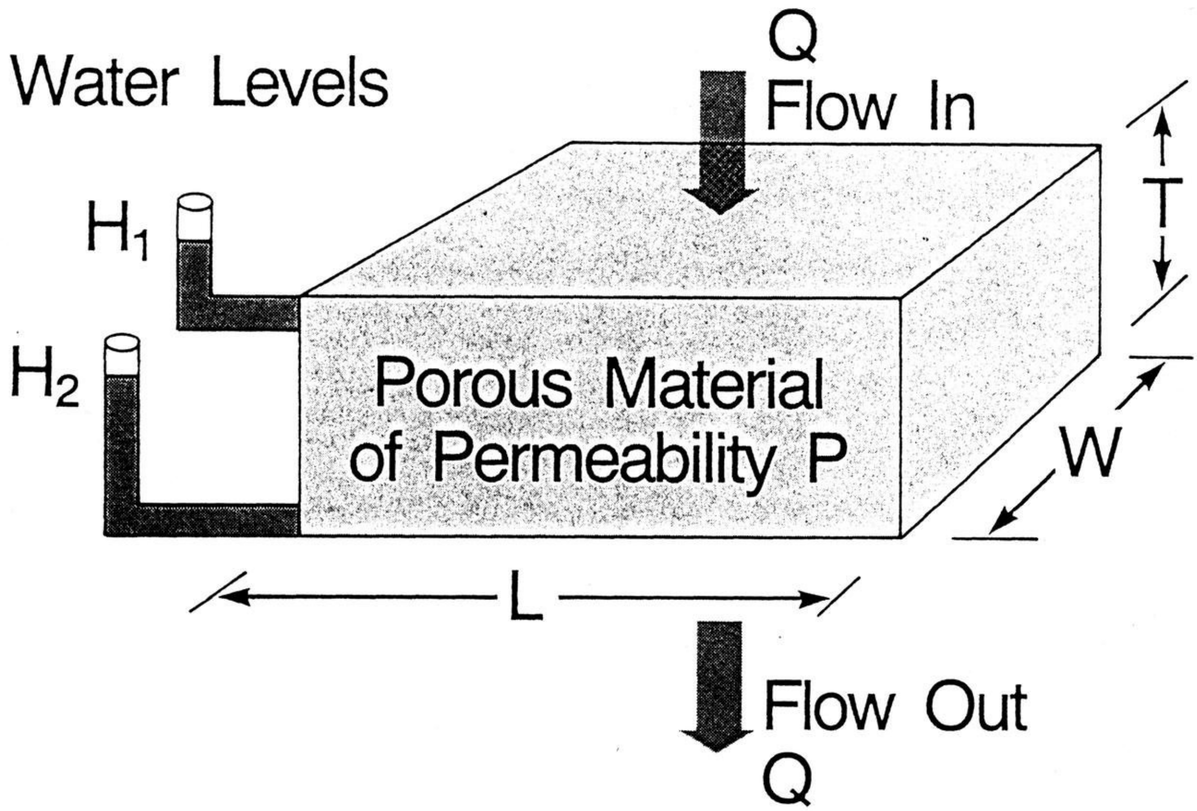
Water Distribution System





Ground Water Flow

Vertical



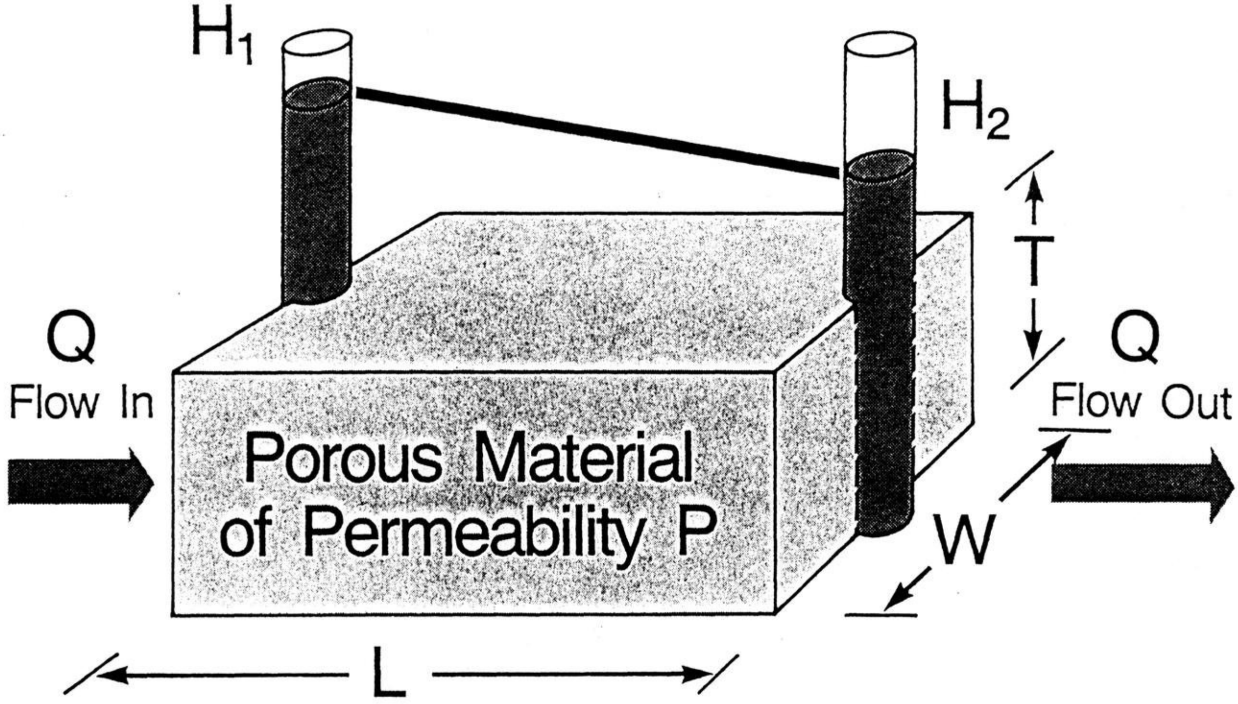
Mathematical Model of Vertical Ground Water Flow

$$Q = \frac{(H_1 - H_2) \times L \times W \times P}{T}$$

Darcy's Law

Ground Water Flow

Horizontal



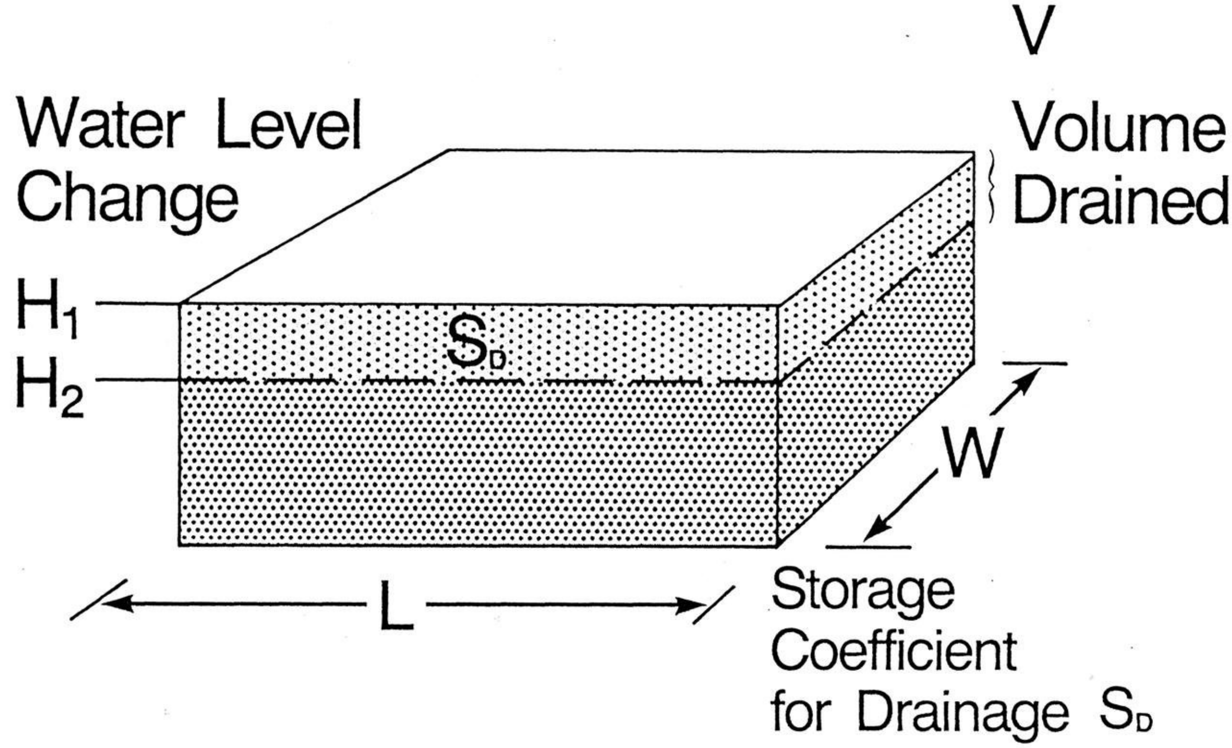
Mathematical Model of Horizontal Ground Water Flow

$$Q = \frac{(H_1 - H_2) \times W \times T x P}{L}$$

Darcy's Law

Ground Water Storage

Release by Drainage

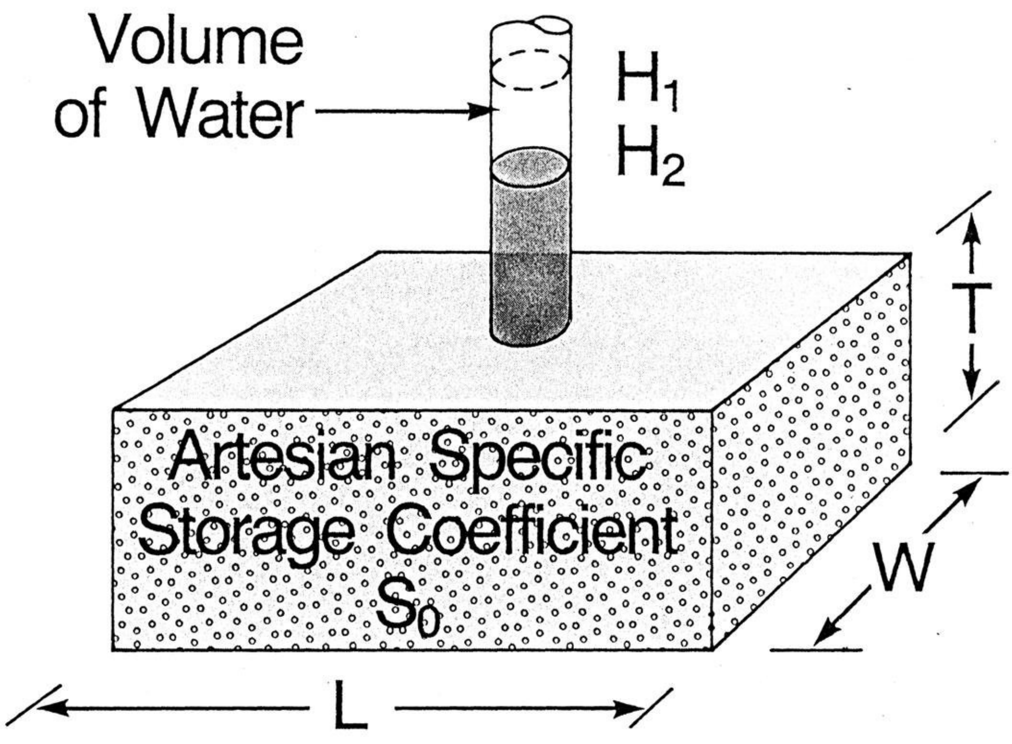


Mathematical Model for Drainage

$$V = (H_1 - H_2) \times L \times W \times S_D$$

Ground Water Storage

Release by Artesian Pressure

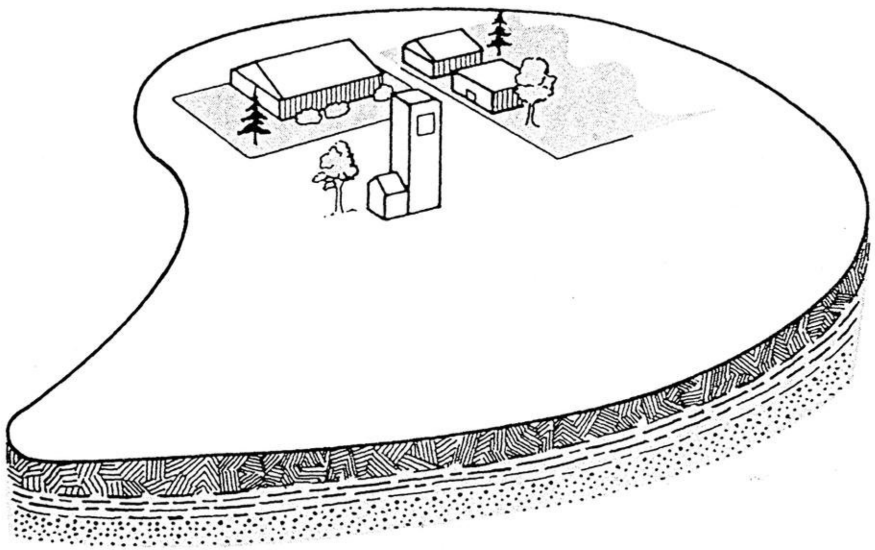


**Mathematical Model
for Artesian Pressure**

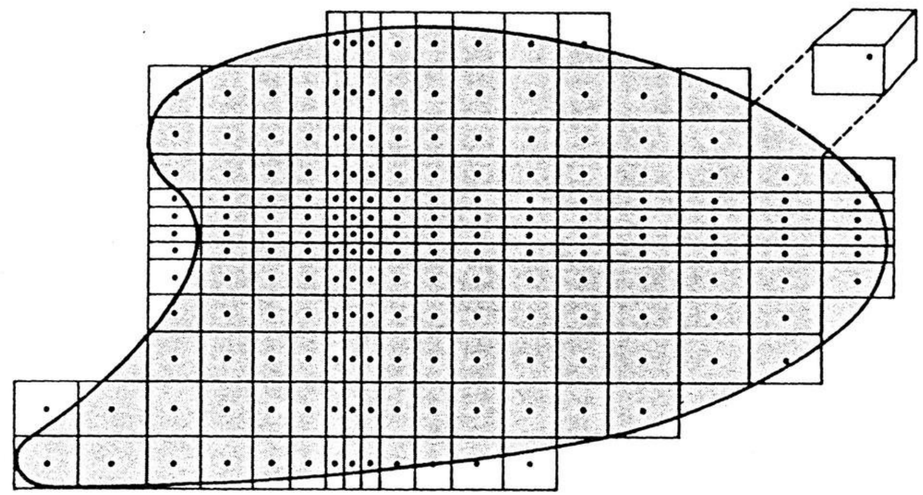
$$V = S_0 \times L \times W \times T \times (H_1 - H_2)$$

Modeling Example

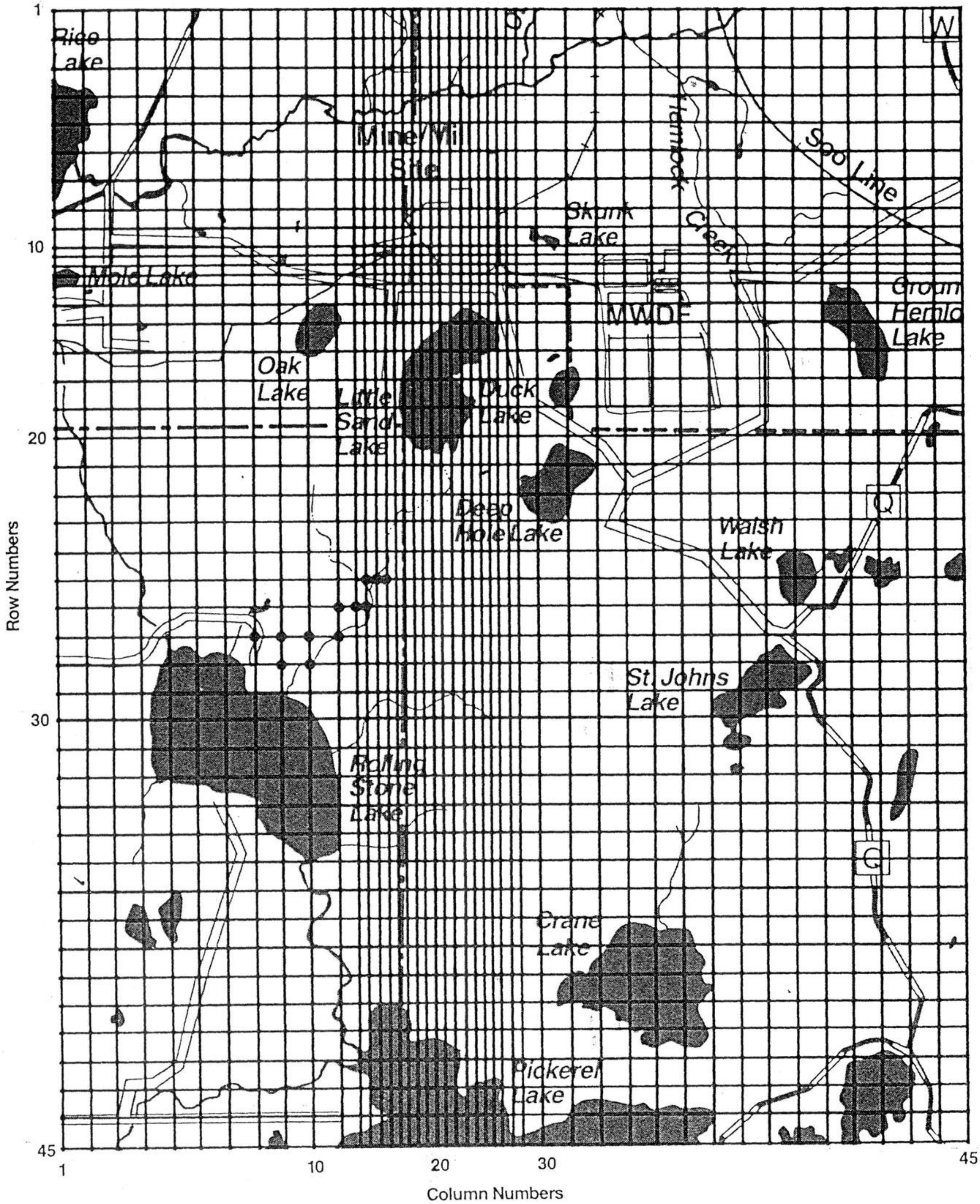
Continuous Ground Water System



Computer Model

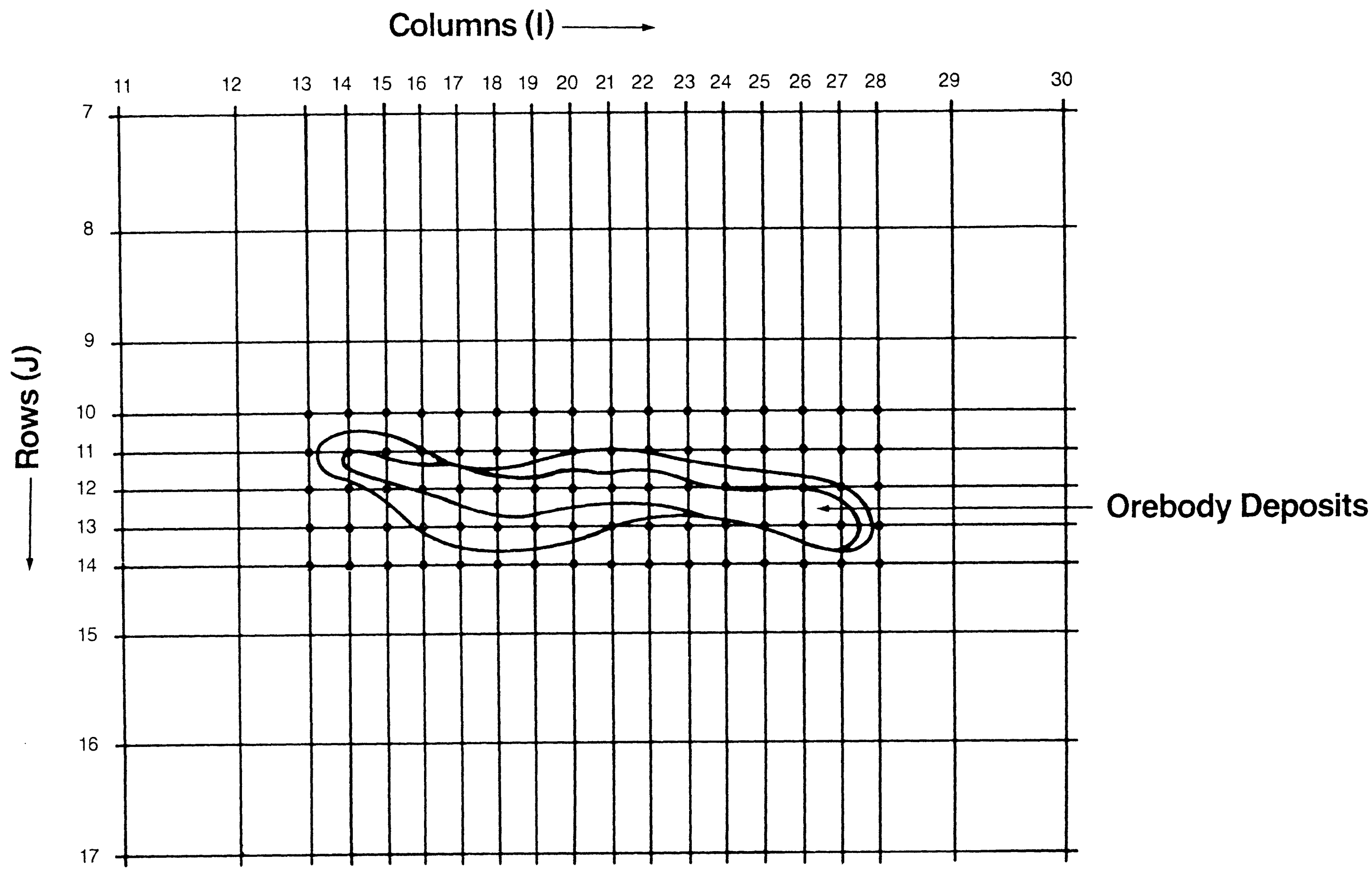


Model Grid Network



Common Grids

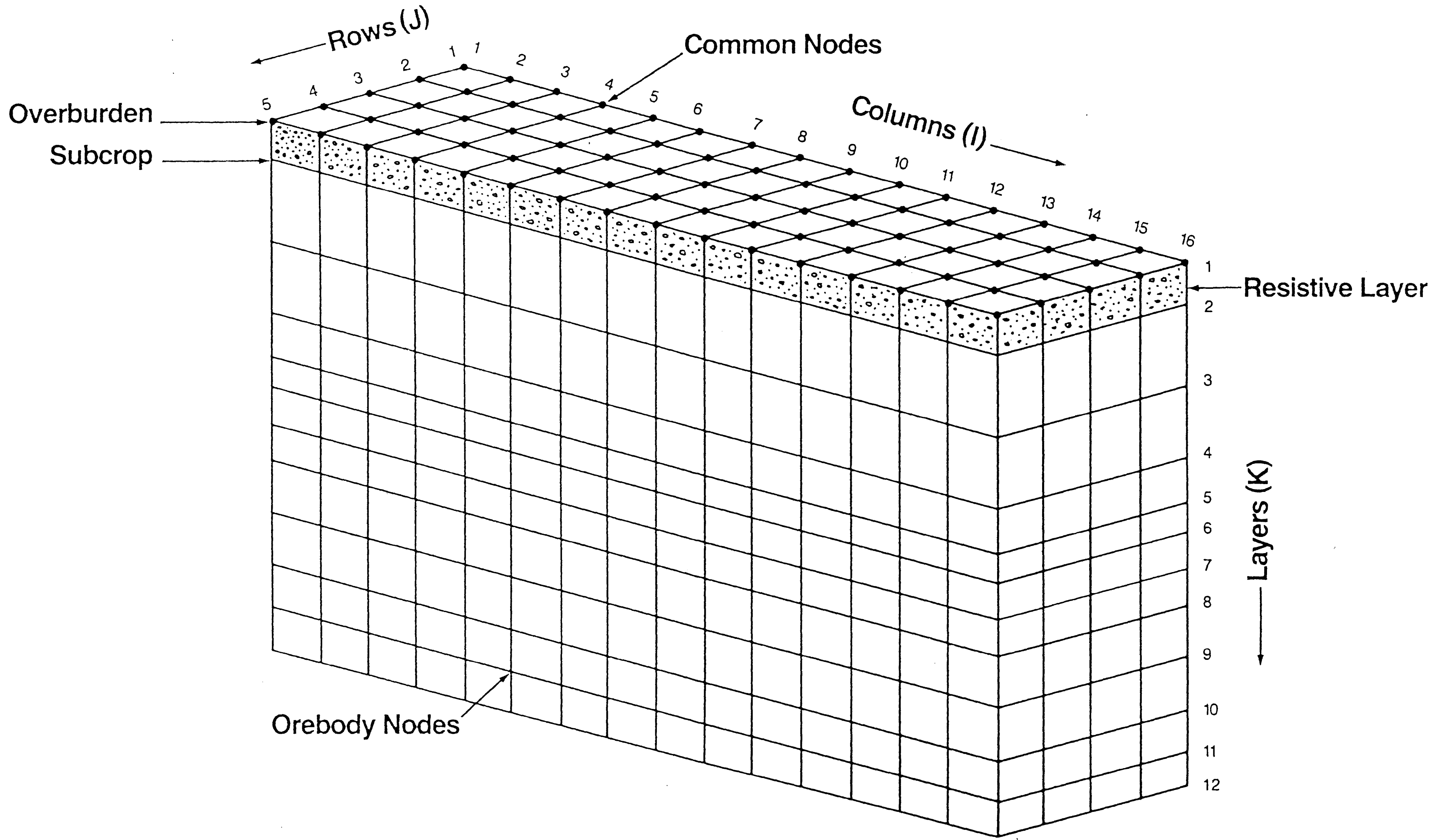
Overburden and Orebody Models



• Indicates Nodes Common Between Orebody and Overburden Model

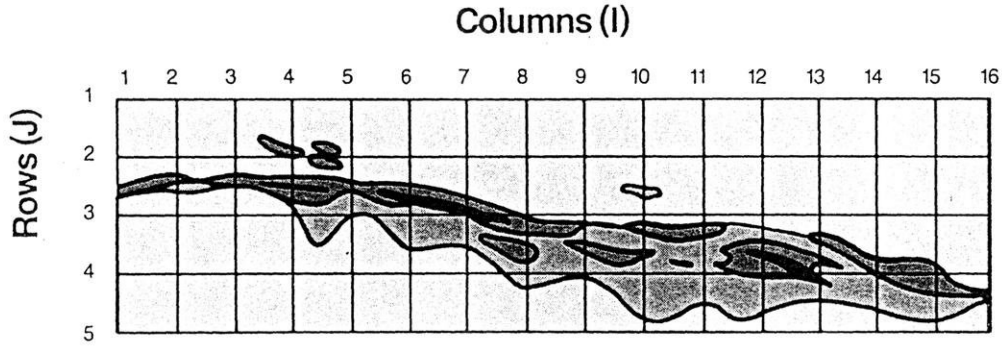
Orebody Model

Grid Configuration

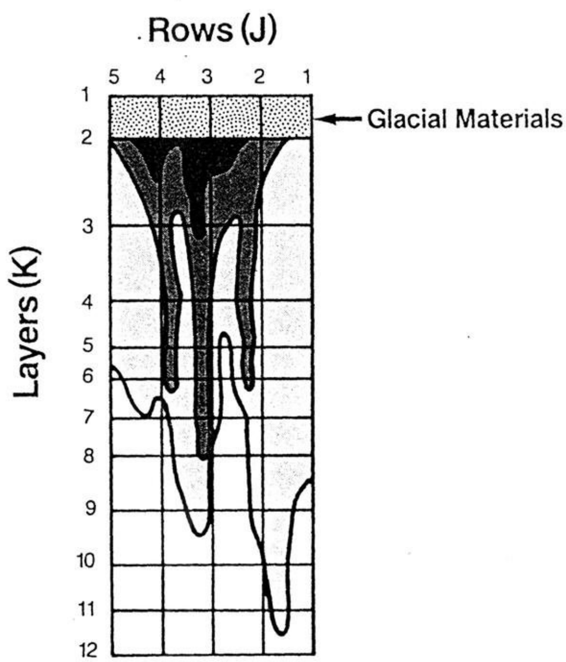


• Indicates Nodes Common Between Orebody and Overburden Model

Example Model Grids

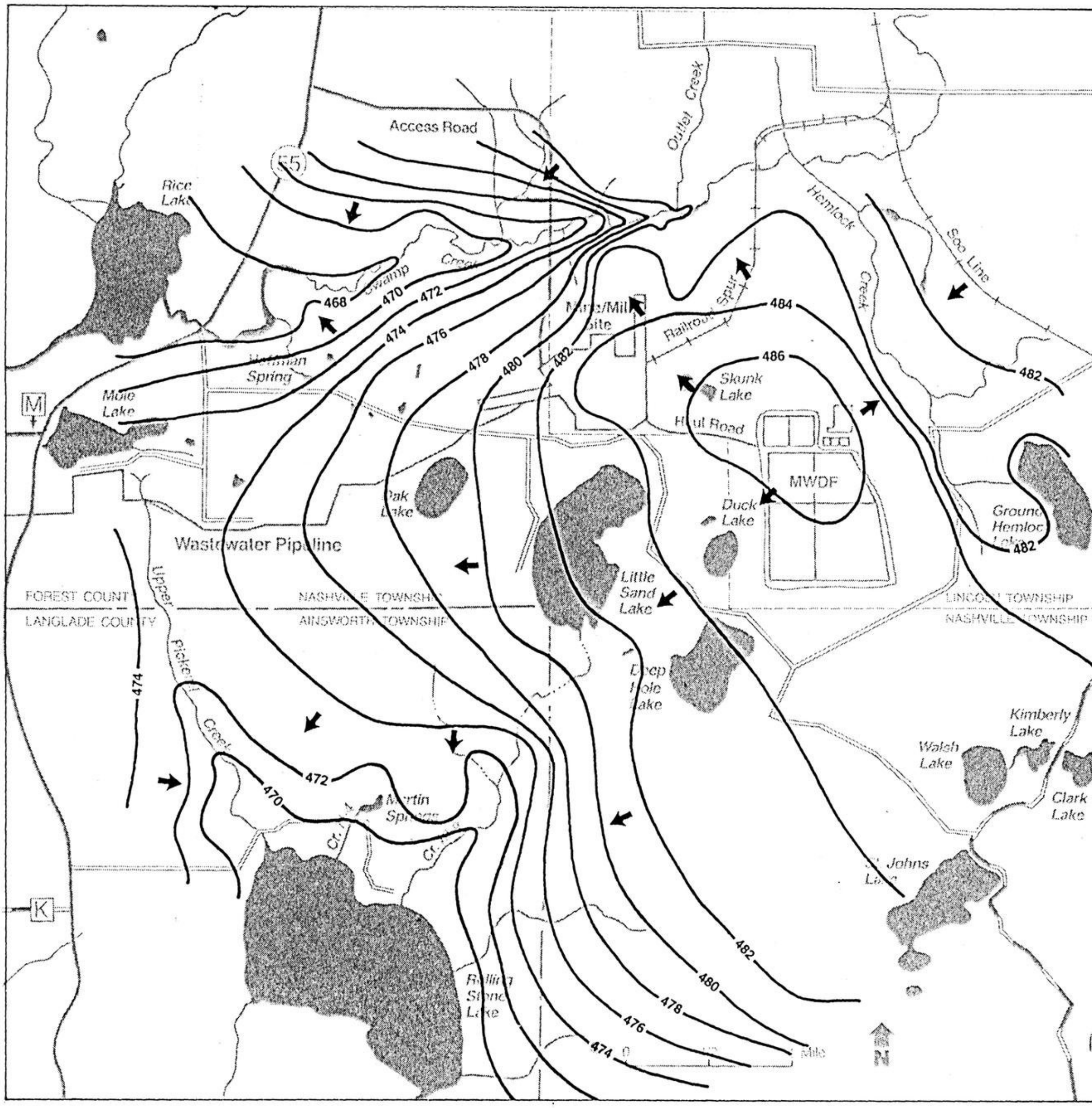


Plan View of Orebody (Level 140M (K=4))



Cross-Section View of Orebody (at 94,000 East)

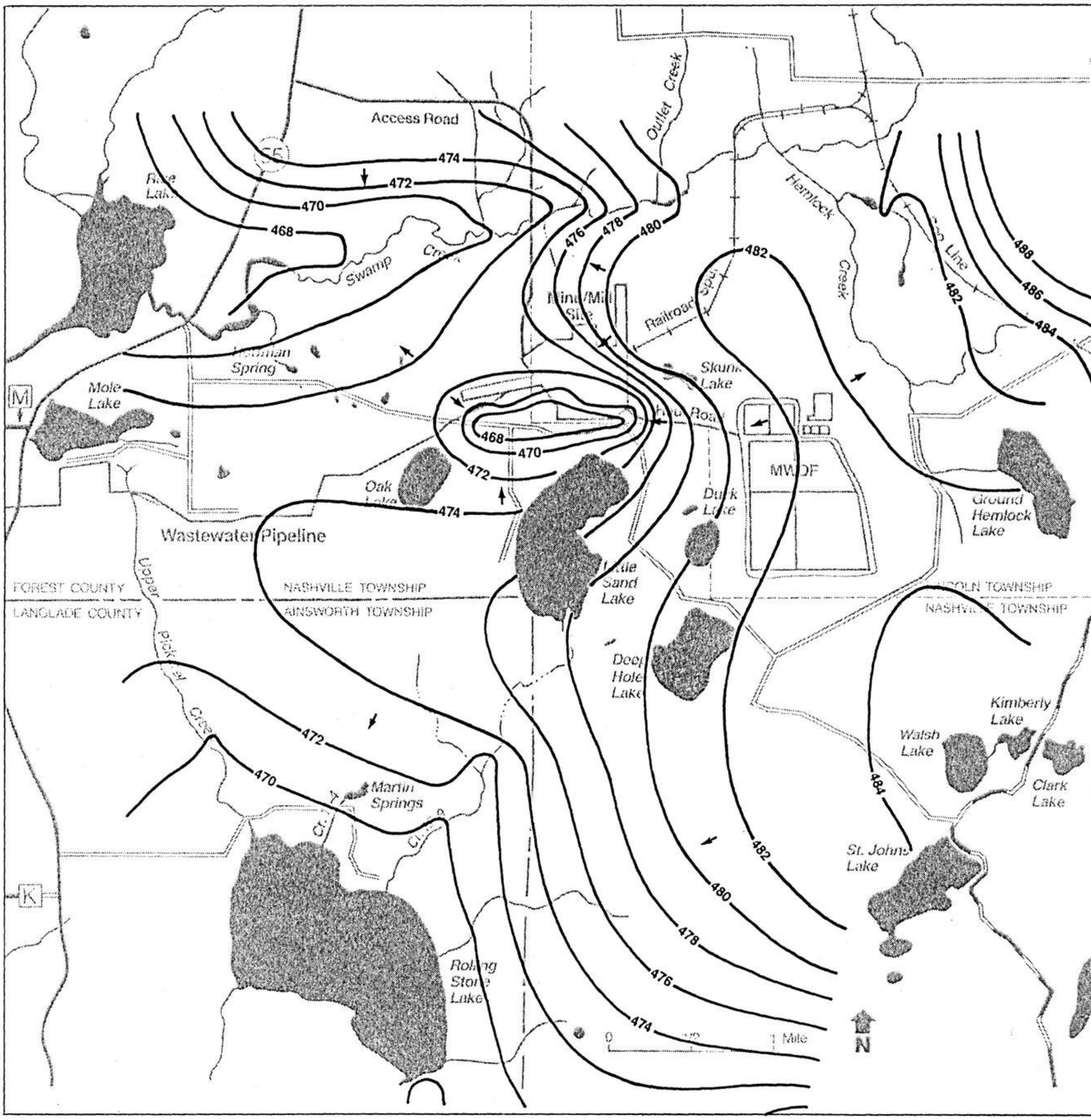
Potentiometric
Surface Contours



Legend
Ground water contours in meters above sea level
Ground water flow direction

Potentiometric Surface

Middle Recharge Case (Simulated)

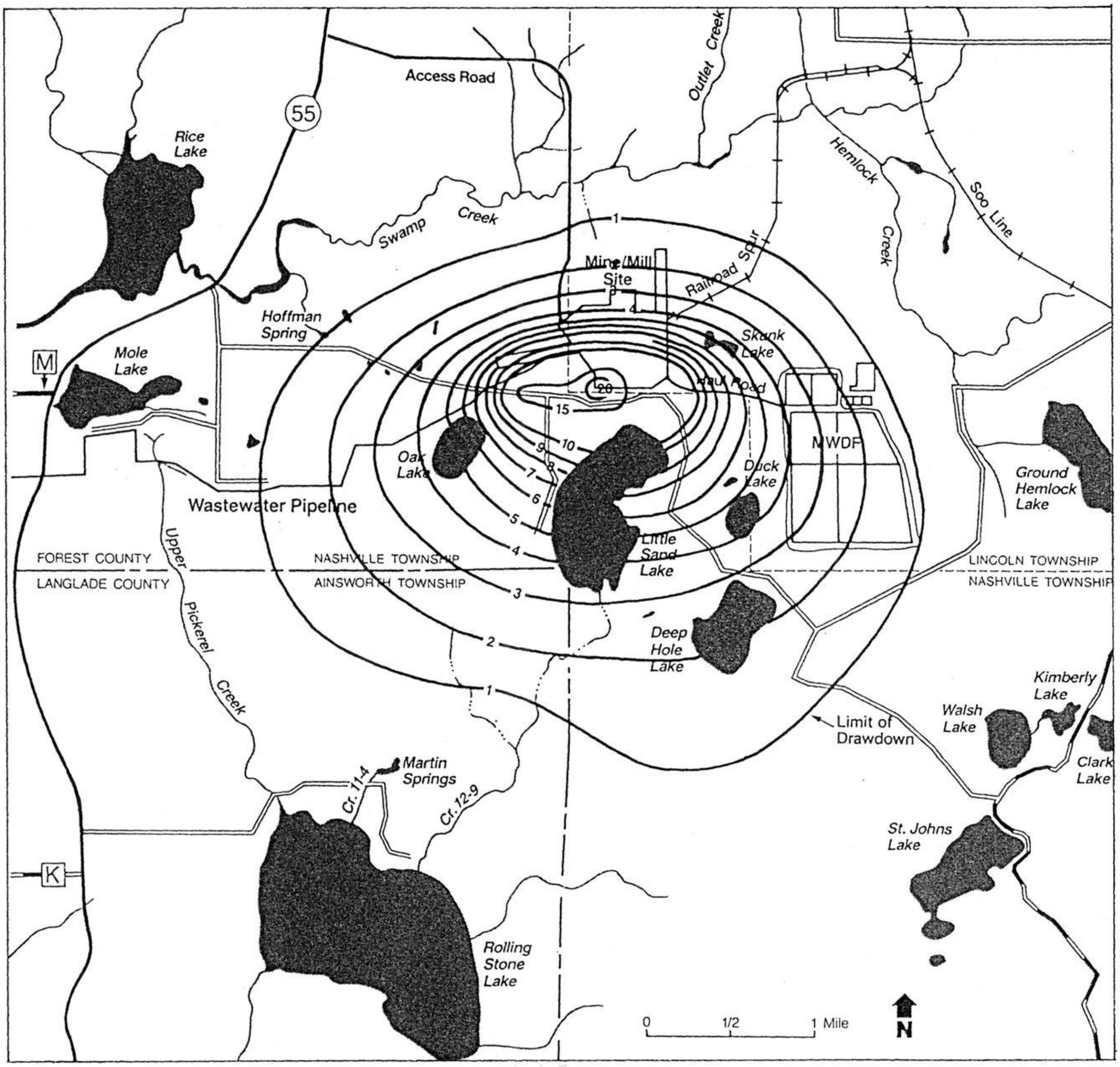


Legend

— Potentiometric Surface (Meters) above MSL

Simulated Drawdown

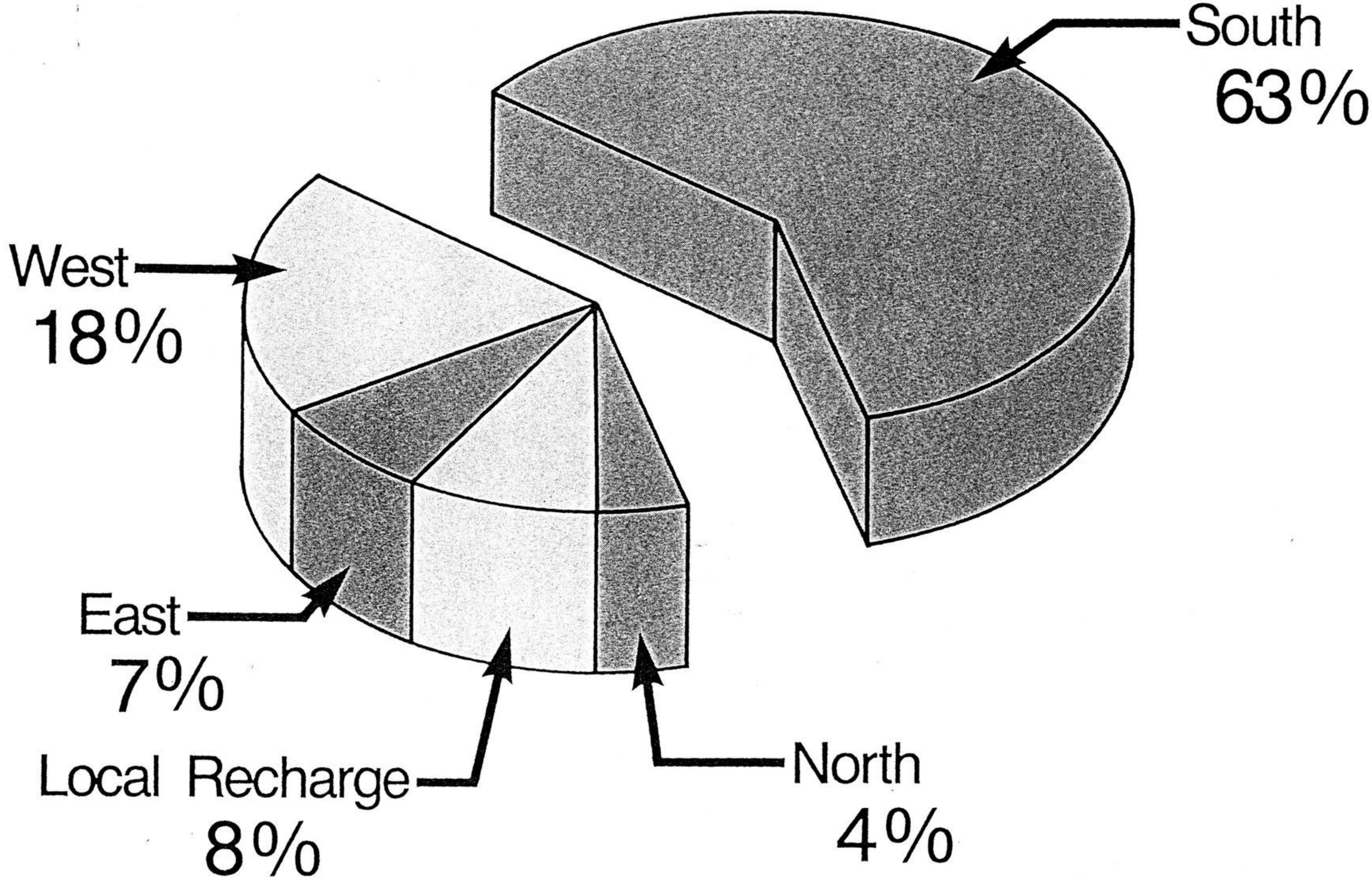
Middle Recharge Case



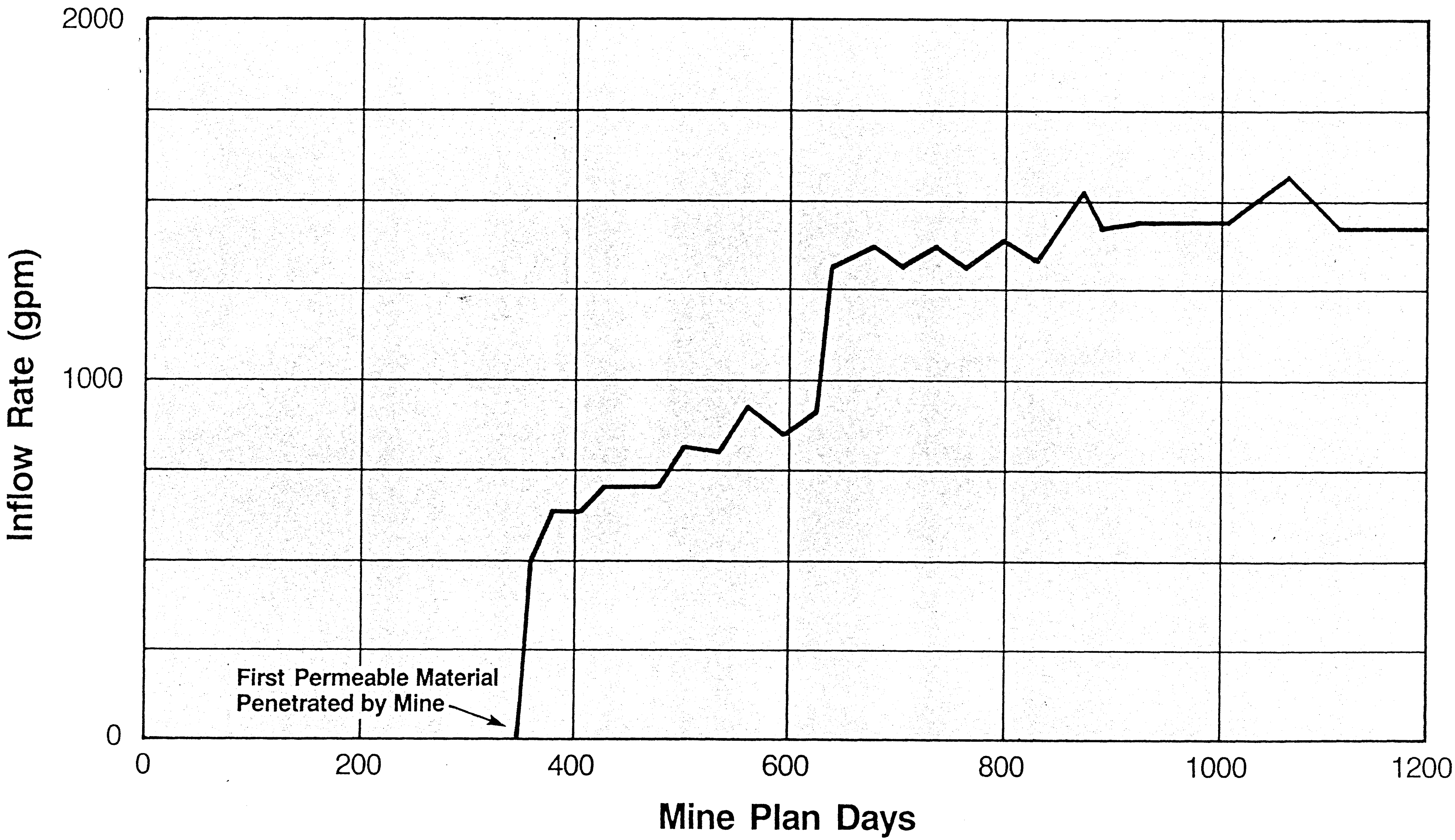
Legend
~ Drawdown (Meters)

Mine Inflow Distribution

329



Typical Mine Inflow Buildup



BEFORE THE
STATE OF WISCONSIN
DIVISION OF HEARINGS AND APPEALS

Application of Exxon Corporation for Permits to Build and Operate an Underground Mining and Ore Concentrating Complex Located in Forest County, Wisconsin	) IH-86-18

TESTIMONY OF DR. SIROUS HAJI-DJAFARI

SURFACE WATER AND GROUND WATER IMPACTS

Q. Please state your name.

A. Dr. Sirous Haji-Djafari.

Q. Where do you live, Dr. Djafari?

A. I live at 129 Wilmar Drive, Pittsburgh, Pennsylvania.

Q. What is your occupation?

A. I am General Manager of Engineering of International Technology (IT) Corporation.

Q. What is IT Corporation?

A. It is a company which engages in environmental management studies. The range of IT services includes environmental risk control, analytical analysis, engineering and remediation.

Q. Would you please briefly discuss your educational background and your work experience?

A. Yes sir. I have a Bachelor of Science and Master of Science in Agricultural Engineering and a Ph.D. in Civil Engineering. I have academic and practical experience in the field of ground water movement and solute transport. In the past 20 years, I have worked on numerous projects in different capacities from project engineer to project director. My responsibilities ranged from simple flow calculations to performance prediction of waste disposal facilities under different hydrological regimes and assessment of mitigative measures to minimize environmental impacts. I have written several computer programs for prediction of flow and solute transport. One of these programs is GEOFLOW, which has been extensively used in the last ten years in numerous projects for performance assessment of waste disposal facilities. Details of my work experience are included in my resume presented as EXHIBIT 333.

Q. Would you also please discuss the background and experience of IT Corporation?

A. IT Corporation is a publicly owned company in the business of environmental management services. IT has over 2,000 employees of which about 1,000 are professionals with different advanced degrees. IT acquired D'Appolonia Waste Management Services, Inc. in 1984.

IT has offices throughout the country, including Pittsburgh, Pennsylvania; Milwaukee, Wisconsin; Minneapolis, Minnesota; Chicago, Illinois; and Knoxville, Tennessee. The Exxon project has been managed by the Pittsburgh office. The Pittsburgh office has more than 50 professionals in different disciplines including geologists, hydrogeologists, geochemists, computer model experts, geotechnical and civil engineers, and process design engineers.

Q. What was your assignment from Exxon with respect to this project?

A. D'Appolonia and subsequently IT Corporation were retained to evaluate the potential effects of the Crandon project mine on the site hydrologic regime. Project facilities include an underground mine, mine and mill surface facilities, mine waste disposal facilities (MWDF), a water treatment plant, and water discharge structures. Our assignment was to evaluate the effect of these facilities on ground water quality and quantity and the resulting impacts on various hydrologic regimes including lakes, streams, creeks, and springs. The assessment included the geochemical analysis of site geologic units utilizing available tools including computer models.

Q. Would you please discuss the history of your involvement in this project?

A. I started working on the Crandon project in 1980 as an employee of D'Appolonia. Our initial assignment was to evaluate the geochemical characteristics of the various geological units such as till and stratified drift. The purpose of the geochemical analysis was to determine whether constituents in the waste disposal facility could alter the hydrological characteristics of the geologic units such as permeability, and how fast the constituents, such as sulfate, could move through this media as compared with water. Because of my expertise in this field, I was responsible for supervision of the program development and its implementation. A description of the evaluation procedure, which I co-authored, was published by the American Society of Testing Materials.

After this initial project, D'Appolonia was retained to evaluate the potential effects of the Crandon project mine and its operation on the site hydrologic regime. For this project, initially, I was principal investigator; subsequently, I became the project manager. Throughout the last several years, the assessment has been done under my direct supervision and numerous qualified staff such as hydrogeologists, geochemists, and computer modeling experts have worked on this project. I have personally reviewed the background data, assessment procedures, and conclusions.

Q. Dr. Djafari, would you please briefly explain and identify the studies and reports you have relied on in preparing this testimony and to which you will be referring today?

A. We have used numerous reports, documents, and references in assessing the impact of the Crandon mine and its operation on the hydrologic regimes. These references are identified in Appendix 4.1A of Exxon's revised Environmental Impact Report, entitled "Hydrologic Impact Assessment," presented as EXHIBIT 334. This report includes references, the data base, and conclusions I will be relying on in this testimony. In addition to this report, since December 1985 we have performed additional investigations at the request of the DNR which were ongoing at the time my direct testimony was originally filed.

Q. What is the purpose of your testimony?

A. My testimony will discuss the hydrologic impacts of the proposed mine in two respects. First, I will discuss impacts on water quantity associated with mine dewatering, and second, I will discuss impacts on the quality of ground waters associated with the disposal of waste from the mine.

Q. By the way, were your evaluations based on the 1984 mining plan or the new mining plan?

A. My evaluations were based on the 1984 mining plan. However, I have reviewed the new mining plan and have concluded that the potential impacts resulting from the new plan will be no greater than those resulting under the 1984 plan. My specific evaluation is presented in EXHIBIT 334.

Q. Before we begin discussing those subjects, Dr. Djafari, would you review for us the ground water and surface water hydrology of the site area?

A. The Crandon project site is shown on EXHIBIT 335. EXHIBIT 335 shows the location of the mine and the facilities associated with the mine, the waste disposal facility, and the boundary of the study area which is outlined by the blue lines. The site area, which became the model area and is highlighted in orange, was selected because it represents a bounded system; that means water entering the recharge areas flows through the system and discharges at points along the site area boundaries. No hydrological impacts will be experienced outside of the area shaded in orange. Additionally, our studies also indicate that not all the area shaded in orange will be impacted in a manner that will be subject to observation. In addition to the site area, I have identified a study area for evaluation of the surface water and base flow studies.

Q. Referring to EXHIBIT 335, will you show where the proposed mine is located?

A. The proposed mine is located just north of Little Sand Lake. As you can see, several other lakes and streams are located within the study area. An understanding of both the ground water and the surface water hydrology of the site area is essential to understanding the potential hydrological impacts of the project.

Q. Dr. Djafari, what is "ground water hydrology"?

A. Ground water hydrology is the science of ground water flow beneath the surface in geologic or earth materials. The properties of the geologic materials, such as gravel and sand, together with other parameters, such as ground water elevation and permeability, control the rate and direction of the ground water flow. In general, ground water flows from a higher elevation to a lower elevation and the rate of movement is proportional to hydrologic properties of the geological materials and the difference in elevation.

To illustrate, let me refer you to EXHIBIT 336. EXHIBIT 336 represents a schematic cross section, or cut-away view, of a generalized geological formation. In this illustration, the top surface is the ground surface. Beneath the surface, the ground water level is depicted by line AB. The elevation of the ground water at Point A is higher than Point B and, therefore, ground water moves from A to B. To measure the ground water, we drill and install observation wells. For example, if we drill one well in location C and another well in location D, we can read the ground water level at each well. In this example, in Well C, the ground water level is 1,520 feet. At Well D, the ground water level is 1,510 feet. Therefore, ground water will flow from Point C to Point D. To calculate the gradient, we measure the distance between two observation wells which, in my illustration, is 200 feet. If we calculate the head difference and divide by the distance, then we are able to determine the gradient, which, in this example, is 10 feet divided by 200 feet which is a 5 percent gradient. To determine how fast the water will move, we have to measure the properties of the geological unit, which is characterized as permeability. Permeability is a measure of the capability of the geologic material to transmit water. The unit of permeability is feet per day or centimeters per second. The higher the permeability of geological material, the faster the water would flow. Certain formations such as bedrock or shale have low permeability and do not readily transmit water. The permeability of a geologic media is comparable with the size of a pipe. The smaller the pipe, the less water will flow.

Velocity is the measure of the rate of movement of the ground water within the geologic material and it is calculated by multiplying the permeability by hydrologic gradient. The units of velocity are feet per day or centimeters per second. The velocity of ground water in general is very slow. For fast-moving ground water, usually we are talking about feet per day. For a slow-moving ground water, we are speaking in feet per year or sometimes inches per year.

Q. Dr. Djafari, would you extend this analysis to the Crandon project?

A. The same fundamentals discussed in the illustration are applicable to the Crandon project site. Let me refer you to EXHIBIT 227, which presents two cross sections, or cut-away views, representative of the geologic material at the project site. These cross sections show the geologic material from the surface to several hundred feet below the surface. As you see in this exhibit, the bedrock, which does not readily transmit water, represents the base of the main aquifer. The majority of the ground water flow which occurs in the area is in the saturated materials above the bedrock. These materials resulted from glaciers or ice sheets which covered the region several thousand years ago. The glacial deposits include till, which consists of a mixture of gravels, sand, silts, and clay deposited when the ice melted; saturated drift, which consists of layered deposits, primarily of sands deposited by flowing waters from the melting ice; and lacustrine deposits, which were created in the beds of the lakes or ponds that were created by the glaciers. The exhibit indicates how these deposits may vary over the site area.

On the table to my left is a fence diagram, EXHIBIT 356, which provides a three-dimensional view of the site geology and hydrology. It consists of nine cross-sectional diagrams similar to EXHIBIT 227 which are tied together so that one may see how the geology of the site differs in the various locations. Thus, it is possible to look at the changes in geology in any direction. The diagram shows lakes, streams, and ground water.

The water level, or potentiometric head, in this fence diagram represents the ground water elevation within the saturated geologic material. This water level is the level which would occur in a well drilled at any location. Using this information, we have constructed lines of equal potentiometric value. EXHIBIT 203 shows the contours of ground water elevations measured in the site area. Ground water elevations are highest in the eastern portion of the site, roughly around the mine waste disposal facility, and decrease gradually toward the south and west and more rapidly to the northwest.

Q. Do these differences in ground water elevations have any consequence?

A. Yes, they illustrate the direction of ground water flow. As indicated previously, the ground water moves from the high elevation to the low elevation, and because of these differences in elevation, ground water flow occurs in the direction indicated by the arrows on this exhibit. In general, ground water is recharged by precipitation and lake seepage and flows toward lower areas where it discharges into the streams, lakes, and wetlands.

Q. Can you explain how the ground water flows in the Crandon site area?

A. Let me refer you to EXHIBIT 233. On this exhibit, we see that the top portion of this cross section consists of material which we call till. A portion of this material is not saturated with water. Water will flow through it, however. The ground water level is shown on the exhibit. Below the ground water level, we have saturated till material. Below the till material, we have material which we call drift.

This area is charged with water either in the form of precipitation or in the form of surface water flowing into the area. On the average, there are approximately 30 inches per year of precipitation in the area, of which approximately eight inches recharge, that is, reach the ground water. This occurs as a result of the water on the surface percolating through the material below the surface. The balance evaporates or flows into streams. As the exhibit illustrates, the water on the surface in the form of precipitation will percolate through a level of till material which extends below the surface until it reaches the ground water.

Q. Dr. Djafari, will you please explain how the surface water actually gets to the ground water and then flows from one point to another?

A. As I've said, the ground water recharge in this area occurs at rates on the order of eight inches per year causing ground water elevation differences and driving the ground water from higher to lower elevations. Again referring to Exhibit 233, rain falls on the surface, percolates down through various layers until it reaches the ground water, and then in essence flows down gradient through that material which by its nature permits the greatest rate of flow. Ground water flow occurs at different rates in different materials depending upon the ability of the materials to transmit water. This characteristic, as I mentioned earlier, is called permeability.

More flow would occur in the drift material than in the till material because drift has greater permeability due to its sandy nature. The silts and clays in till impede ground water flow.

Q. How does one measure permeability?

A. Permeability values can be expressed in units of feet per day. It is measured in the field or laboratory depending on type of material and method of measurement. A representative permeability value for stratified drift is 37 feet per day, while till permeabilities are much lower, typically on the order of one foot per day. Therefore, the majority of ground water flow at the site occurs in the drift units.

Q. Dr. Djafari, earlier in your testimony you referred both to the ground water hydrology and to the surface water hydrology of the area. Would you now review the surface water hydrology of the area?

A. Let me refer you back to EXHIBIT 335. Surface water is present at the site area in the streams and lakes indicated in this exhibit, and can influence the ground water system, either as areas of ground water recharge or discharge.

Q. What is an "area of ground water recharge"?

A. This simply means that water from the surface water body seeps into the ground and finds its way to the ground water system. On EXHIBIT 335, I have shaded in blue the five lakes closest to the mine which recharge ground water in this fashion. They are Little Sand Lake, Skunk Lake, Duck Lake, Deep Hole Lake, and Oak Lake.

Q. What, then, is an "area of ground water discharge"?

A. That is simply the other side of the coin - the area in which water from the ground water system discharges into surface waters. On EXHIBIT 335, I have indicated in orange some of the surface waters that receive ground water. Ground water discharge occurs mainly in the low-lying topographic area. As you can see from the exhibit, these ground water discharge areas include Swamp Creek, Pickerel Creek, Hemlock Creek, Rice Lake, Crane Lake, Pickerel Lake, and Rolling Stone Lake.

Let me emphasize again, however, as I will discuss later, that not all of these surface waters will be affected by a reduction in ground water levels.

Q. What Crandon Project activities will have an impact on the ground water and surface water systems in this area?

A. EXHIBIT 335 shows the location of the project facilities and the 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.

Q. What will the major site hydrologic impacts be?

A. The major potential site hydrologic impacts result from two activities. First, ground water will flow into the underground mine and will have to be pumped out during construction and operation of the mine. This ground water flow and consequent pumping will result in a lowering of the ground water table in the area - with the greatest reduction occurring at the immediate mine area itself, and with the effects gradually tapering off further from the mine. This lowering of the ground water table will result in the lowering of the levels and flow rates of some surface water bodies in the immediate vicinity of the mine.

The second potential source of impact is from seepage from the tailings ponds, the MWDF, into the ground water. As Mr. Moe has testified, after the tailings ponds are reclaimed the reclamation caps are designed to prevent infiltration of water into the ponds and, thus, there should be virtually no seepage from the ponds into the ground water. Small amounts of seepage will occur before the ponds are capped.

Other hydrologic actions will have much less impact, such as redirected surface infiltration and water supply wells at the mine, and reduced infiltration at the reclaim pond area.

Q. When will these various impacts occur?

A. I have summarized the projected schedule for the major hydrologic actions on EXHIBIT 337. As you can see, mine dewatering will commence approximately two years after the project begins, and will continue through the life of the project. After the project is completed, the ground water regime will quickly return to its preconstruction conditions and the potential for further impact on surface water bodies will end.

Seepage from the tailings ponds will begin shortly after the ponds are put into use, and will also continue through the life of the project. Following reclamation, seepage from the tailing area should essentially end because the reclamation cap is designed to prevent infiltration of the water into the MWDF.

Q. Before moving on to the details of your analyses, Dr. Djafari, would you briefly summarize your major conclusions both as to the extent of the effects caused by mine dewatering and as to the extent of the effects caused by seepage from the Mine Waste Disposal Facility?

A. Mine dewatering will reduce the ground water level at the mine area approximately 17 meters, or 58 feet. The drawdown will decrease away from the mine area. This drawdown will increase seepage from some of the lakes and will decrease ground water discharge to some of the site area creeks. I will discuss the effect on specific lakes and streams in more detail later. As I will also explain, Exxon's Contingency Plan will mitigate any reasonably possible impacts.

The MWDF will cause changes in ground water quality beneath and adjacent to the facility during the operation period, but these changes will be well within regulatory standards at the compliance boundary and beyond. As Mr. Moe has testified, after the MWDF is reclaimed there should be virtually no seepage because of the reclamation cap and, thus, no continued impacts to ground water quality. Exxon asked me to predict what impacts to ground water would occur if there were a partial failure of the reclamation cap. As Mr. Moe has testified, with no membrane, most seepage would be 0.66 inches per year. For partial failure, we took 10 percent of this number, or 0.066 inches/year, as shown in EXHIBIT 337. As I will discuss in more detail later, I found that, even with such a cap failure and even if no remedial steps were taken, regulatory standards at the compliance boundary and beyond would still be fully met.

Q. Dr. Djafari, how is it possible to predict how the Crandon project facilities will affect ground water and surface water in the site area?

A. To predict these impacts we need a technique to incorporate the various interactions among the ground water system, surface water bodies, and the project facilities and their operations. The most powerful and convenient technique for making this evaluation is to use computer programs, or ground water models, which calculate ground water elevations based on geologic conditions, interactions with surface water bodies, and mine dewatering. By calculating ground water elevations for various conditions, the model results can be used to evaluate ground water flow rates and directions, and to assess the impacts associated with different hydrologic actions, such as pumping water out of the mine.

Q. What model did you use?

A. We used GEOFLOW, a computer program capable of predicting flow and solute transport in a ground water regime. This program was initially developed by me and improved by other engineers.

Q. How does the model work?

A. I'm afraid that a complete answer to your question would take several days of testimony and would involve a level of detail that might strain the patience of everyone present. Details of the model as it was used for the Crandon Project are discussed in EXHIBIT 334. The modeling program involves various accepted mathematical formulas, the collection and input to the model of data collected from the field, and various verification and calibration measures. Before I explain all of these, let me suggest that I give a brief explanation of what the model looks like and what is has enabled us to do.

Let me refer here to EXHIBIT 338. This is an extremely simplified version of the diagrams that will follow. As it indicates, the site is divided into a series of blocks. Input parameters such as permeability and recharge rate are assigned to each block, or element, of the grid. The boundaries of the grid system represent boundaries of the ground water system, such as major streams. Pumping well locations and areas of seepage from lakes can be located on the grid. The ground water model uses the complete set of input data such as permeability and aquifer thickness to compute the resulting ground water elevations at each grid intersection, or node. Accordingly, we can predict ground water elevations and flow directions that result from conditions that are input to the model.

Q. You indicated that this exhibit represents a simplified view of the grid system used in your modeling efforts. Could you illustrate the grid which was actually used for the model?

A. EXHIBIT 339 illustrates the grid system which was developed for the Crandon site. The grid boundaries generally correspond to areas of ground water discharge to surface water bodies. The shapes of individual grid elements were adjusted to allow accurate representation of features such as the mine, the MWDF, and lakes. An additional zone was incorporated to represent areas where the major water-bearing unit, the stratified drift, is mixed with lower permeability till.

Q. Will you explain how the model works and the input data used?

A. To understand the ground water model that was developed for the Crandon project area, it is necessary for me to explain in somewhat greater detail the nature of ground water modeling. We start with the proposition that there are accepted mathematical equations, or formulas, that are used in ground water modeling. These equations have been used for a number of years by everyone in the field. They have been tested and they are accepted as appropriate by all of the experts in the field including in this case the United States Geological Survey and the Department of Natural Resources of the State of Wisconsin. In order to use these equations and the input data that I will explain in a moment, in a computer analysis, one must have a computer program -- in this instance the GEOFLOW computer program is likewise well known and accepted. It has been verified extensively and has been tested in a number of arenas including contested proceedings like this one. Its performance has been accepted by the DNR and the U.S. Geological Survey in this case.

The next step in developing the Crandon Project model is to feed to the computer program input data regarding the hydrological and geological conditions that are present at the Crandon mine site. That data was accumulated by various techniques used in the field. Wells were drilled, cores were taken to determine the nature of the material that exists beneath the surface, ground water levels were measured at various points and, by these and other techniques, a very large amount of data was collected regarding subsurface conditions, both geological and hydrological. I have examined the data that was collected to determine if it is adequate in quantity and quality and to ascertain whether it is inherently credible. I am satisfied that the data was both adequate in quantity and in quality. I should add that the data collection process went on for many years and indeed continued until the Draft Environmental Impact Statement was published and thereafter. I know that Exxon has worked closely with representatives of the Department of Natural Resources to develop a data base that was satisfactory to all parties, and in fact, in several instances, I know that additional data was collected at the request of the DNR. I know this because I participated in discussions with the DNR when it requested additional data. I used the additional data for model refinements and additional runs of the model.

When we have agreement on the equations to be used and agreement on the computer program to be used to load the input data into the computer, and when we have all of the input data that we believe are required to obtain appropriate modeling results, we are then in a position to calibrate the model.

Q. What do you mean by "calibrate the model"?

A. The word "calibrate" as used here can be somewhat confusing. Quite simply it means that we test the model to see whether the results that it produces are consistent with what we find in the real world. If the model results and the real world findings are in agreement, we know that we have constructed an appropriate model for our purposes.

A simple illustration of calibration here would be to take a particular area of the Crandon Project site and determine whether the ground water actually flows in that area as the model predicts it would flow on the basis of the data that has been fed to the model, for example, regarding permeability of the materials below the surface. If the model results do not correspond with the results that we measure at the site we can "fine tune" the model to make it predict the measured conditions. We may make a number of different tests or calibrations until we are satisfied that the model has in fact been "calibrated." When we have completed our calibration exercise, we are satisfied that the model is the best representation of the hydrological conditions which can reasonably be achieved. The model is then ready to be used to predict impacts on ground water levels and surface water flow and levels at the various streams and lakes at the site area when the mine is constructed and is in operation.

Once we have taken all of these steps, we are in a position to use the model to calculate the amount that the ground water table and area surface water bodies will be affected by dewatering of the mine and by any wells that are drilled in the area to supplement the flow of streams or lakes after the mine is in operation. Thus, we can predict the impact on any given lake, stream or creek.

Q. Before we move on to your modeling predictions, let me ask you some follow-up questions concerning matters you have already raised. First, you mentioned earlier that the rate of ground water flow into the mine is an important factor to consider in predicting potential impacts to area surface water bodies. Have you reviewed the work and testimony of Mr. Prickett, who preceded you on the stand?

A. Yes sir.

Q. Could you explain for us how your modeling work and projections relate to the work and projections that Mr. Prickett has discussed?

A. I worked very closely with Mr. Prickett when he was calculating mine inflow. Tom did a more detailed analysis of the hydrological conditions right at the mine site for purposes of determining mine inflow rates. He was concerned not only with the steady-state rate of inflow but with the peak inflow and with inflows that would occur during various phases of construction and operation as well. We provided Tom the results of our model calibration, including aquifer permeability and recharge. He also reviewed our work before completing his mine inflow calculations. I have studied Tom's work and reviewed that work with him, and believe it is eminently sound. Therefore, I am comfortable in using Prickett's mine inflow calculations in predicting potential surface water impacts caused by mine dewatering.

Q. Dr. Djafari, you also testified that various input data regarding the hydrological and geological conditions in the area were obtained through field work and then fed into the computer program. What type of data did you obtain and what led you to conclude it was appropriate for the model?

A. Let me here refer you to EXHIBIT 340, which summarizes the input data used in the model. I've already discussed the concept of permeability. The permeability values we chose were derived through analysis of field and laboratory test data and through various calibration runs of the model. This work enabled us to determine that we could best calibrate our model using permeability values for the stratified drift and till/drift mixture zones of 34.5 and 20.5 feet per day, respectively. Again, it is important to observe that permeability values measured in feet per day do not indicate the actual flow rate of ground water, inasmuch as ground water flow rate is the product of the gradient present where the flow is occurring as well as of permeability values. Note that permeability values assume a hydraulic gradient of one--one foot of drop over one foot of distance. In the site area the hydraulic gradient is a few percent.

The recharge rate was set at 8.5 inches per year over most of the area, with lake seepage recharge determined according to individual lake characteristics. As EXHIBIT 334 indicates, we tested other rates and values as well.

Q. What led you to select an 8.5 inch per year recharge rate as opposed to, say, a recharge rate of 6 or 11 inches per year?

A. We tested various recharge rates within the range of observed data and the results are shown in EXHIBIT 334. The 8.5 inch per year recharge rate gives us good calibration and the DNR recommended that we use that rate. From our analyses, I believe the actual recharge rate will be less than 8.5 inches per year.

Q. You mentioned that lake seepage was determined according to individual lake characteristics. How were these characteristics determined, and how do they affect the amount of lake seepage recharge?

A. Baseline lake seepage was calculated by Dames and Moore based on field measurements and literature values. We took these baseline data and we calculated lake bottom permeability using the seepage and the thickness of the lake sediments determined from field borings.

Q. EXHIBIT 340 also notes that the thickness of saturated materials was used as model input data.

A. The saturated aquifer is an important input parameter to the model. The ground water flows in saturated portions of the aquifer. The thickness of the water-bearing units was varied across the area according to the geologic information available from drilling programs. Under my direction, the drilling logs and geological cross-sections were reviewed by IT geologists. I am satisfied that the data furnished to me which I input to the model properly represent the hydrological conditions present at the project site. Using all of the input parameters discussed in EXHIBIT 340 enabled us to produce a very good representation of the existing site ground water conditions, and our calibration program has given us confidence that the model is capable of realistically predicting hydrologic impacts that will result from future changes to the hydrologic system.

Q. You just mentioned your confidence in the model. Precisely how confident are you?

A. With a model of this type, it is difficult to place a precise numerical value on the degree of confidence that one may have in the predictions of the model. However, on the basis of my experience in modelling hydrological conditions, comparing model predictions with subsequent field studies, and further, on the basis on the degree of effort that has been expended on this model and the quality of the data that has been input to the model, I am very confident that the model accurately predicts what the impact will be on any given lake level or stream flow when the mine is in full operation. I am also confident that the deviations from the model predictions will be minor.

Perhaps what is more important in this case is that I have an even higher degree of confidence with regard to the upper and lower bounds of the impact predictions. In other words, with the model, I am able to testify with confidence that when the mine is in full operation a specific lake will decline by only so many inches and any deviations will be minor. But I can testify with a higher degree of confidence that the decline in the elevation of that lake will be no greater than the upper-bound prediction of the model.

Q. I will be asking you more questions as we proceed about the way the model works and the manner in which various input data were selected. But with the background you have now given us, may we now move on to the question of what you predict the impact of mine dewatering will be on ground water levels and the levels and flow rates of area lakes and streams?

A. I will refer to EXHIBIT 341, which illustrates the computed ground water elevations and flow directions when full impact conditions are reached. This represents the maximum ground water decline. When mine dewatering is discontinued, ground water levels will gradually return to pre-mine construction conditions.

The predicted declines during full impact conditions are presented in EXHIBIT 342. The maximum decline in ground water elevations occurs in the glacial deposits directly overlying the mine and is approximately 17 meters, or 58 feet. The declines in ground water elevations decrease with distance from the mine. Declines are less than 1 meter, or about 3 feet, in areas outside the region termed the "zone of influence." The results indicate that the zone of influence of mine inflow will be limited to the site area.

Q. Why was the 1-meter drawdown figure used in defining the zone of influence?

A. There are two reasons. First, declines in the ground water table of less than one meter are so small that we cannot determine whether they are mine-related or the result of yearly fluctuations. The yearly fluctuation of ground water levels in the area is on the order of 3 feet per year. Second, these declines are so small that they will have at most an insignificant impact on surface water bodies outside of this boundary area and further will not noticeably affect well yields or lake seepage.

Q. How will these declines in ground water elevation affect surface water bodies in the area?

A. There are two ways in which the decline in ground water elevation will affect surface water bodies. First, the decline in ground water elevation means that ground water discharge to streams and receiving lakes in the area will be reduced. Second, the decline in ground water elevation will cause the seepage rates of the recharge lakes close to the mine to increase and could, therefore, cause some decline in their levels, unless some mitigation action is taken.

Q. Let me suggest that we take these issues one by one. Dr. Djafari, how will the reduction in ground water discharge affect streams and creeks in the area?

A. Let me refer here to EXHIBIT 343. Creeks and streams in the project area receive their water from two sources: surface water runoff and ground water discharge. The contribution from ground water is also referred to as the baseflow. The combination of these two flows constitute the total flow for the streams and creeks. For any given creek or stream in the area, the answer to your question depends on the amount of flow that is contributed by surface water runoff and the amount that is contributed by baseflow. Because the drawdown cone created by mine dewatering will only affect the baseflow component of these water bodies, the impacts will be greatest on those surface water bodies that have a relatively high baseflow component.

Q. Dr. Djafari, could you show for us on EXHIBIT 343 the surface water and ground water components for the various creeks and streams indicated on the map?

A. Yes sir. Referring to EXHIBIT 343, the surface runoff and ground water baseflow from Areas 1, 2, 3, and 4 feed the Swamp Creek area and produce its flow. Of these areas, Areas 1 and 3 are within the site area and Areas 2 and 4 are outside of the site area. Similarly, portions of Area 5 and all of Area 6 feed to Rolling Stone Lake. These areas and Area 7 constitute Pickerel Creek flow. Creeks 11-4 and 12-9 are spring fed, that is primarily fed by ground water.

Q. What will be the impacts on those creeks that are primarily fed by ground water?

A. Let me take Martin Spring and Creek 11-4 as examples. Our projected impact to Martin Spring is a reduction in flow of 30 gallons per minute (gpm).

Since Creek 11-4 is fed by Martin Spring, the impact on Creek 11-4 is the same. Obviously, that impact can be easily mitigated.

Q. Dr. Djafari, you described the impact at Creek 11-4 which could occur in the absence of any mitigation efforts. Are you familiar with Exxon's proposals respecting mitigation actions to offset these impacts?

A. Yes sir. Exxon has prepared a Hydrologic Impact Contingency Plan designed to mitigate the impacts that I am discussing in this testimony. For example, at Martin Spring and Creek 11-4, Exxon intends to construct a well near the spring and to pump ground water into the spring to offset the impacts I have just discussed. I believe that Carlton Schroeder has discussed this plan previously.

Q. So the impacts you are discussing in your testimony today are those that would take place in the absence of any efforts by Exxon to mitigate?

A. That is correct, sir. I have reviewed Exxon's Contingency Plan and am satisfied that, with that plan in place, the projected impacts I am discussing will be mitigated.

Q. You've discussed creeks that are primarily ground water fed. What about those creeks and streams that have a large surface water runoff component in addition to a ground water component?

A. If we can now refer to EXHIBIT 344, Hemlock and Swamp creeks are good examples. Our model predicts a 1.49 cubic feet per second (cfs) reduction in ground water discharge to Swamp Creek under full impact conditions. This would represent an 8 percent reduction in the baseflow of Swamp Creek as measured at point D. Swamp Creek has a very large surface water component, and when we take that into consideration, the reduction in the Swamp Creek flow rate would be just over 3 percent of the total flow under average-flow conditions. It will be seen that changes in precipitation can cause a much greater change in the flow rate of these creeks than will mine dewatering.

EXHIBIT 344 shows that the percentage reduction of flow through the Pickerel Creek/Rolling Stone lake system will be considerably less.

Q. What about the other creeks and streams in the area?

A. I used Creek 11-4 and Swamp Creek as examples of the two types of streams in the area. The other springs, creeks, and streams that may be affected by the drawdown cone are all discussed at length in EXHIBIT 334, especially Tables A-21 through A-31.

Q. Turning for the moment from creeks and streams, Dr. Djafari, how will the declines in ground water elevations affect the lakes in the area of the mine?

A. Let me give you a brief summary before discussing the details. Referring back to EXHIBIT 335, you will recall that I have marked some lakes in blue and some lakes in orange. The blue lakes -- Little Sand Lake, Skunk Lake, Duck Lake, Oak Lake, and Deep Hole Lake -- are referred to as recharge lakes because water from those lakes percolates to and recharges the aquifer. I predict that there will be no decline in the level of Oak Lake and there will be varying declines in the levels of the other 4 lakes. These declines range from less than 3 inches in Duck Lake to approximately 6 inches in Deep Hole Lake under average weather conditions. For Little Sand Lake the level decline is less than 4 inches. These are the declines that would occur without contingency measures being taken by Exxon.

For Skunk Lake, as Mr. Schroeder indicated earlier, mitigation is planned to offset impacts. If there were no mitigation for Skunk Lake, we predicted a higher lake level drop than for the other 4 lakes.

There is a second category of lakes in the area, which, you will recall, are referred to as receiving lakes. These lakes receive a portion of their water from ground water and include Rolling Stone, Rice, Pickerel, and Crane Lakes. These lakes lie on the periphery of the site area. Although there will be some reduction in ground water discharge flow to these lakes, there will be insignificant reductions in their levels.

Q. What do you mean by "insignificant?"

A. I mean fractions of an inch.

Q. Dr. Djafari, turning to the recharge lakes -- the lakes shaded in blue -- why do you predict different declines in the levels of these lakes as contrasted with Oak Lake?

A. The lowered ground water levels beneath the lakes may cause lake seepage rates to increase, which in turn may cause the levels of these lakes to decline somewhat. In the case of Oak Lake the ground water level is already below the bottom of the lake sediments. Any decline in ground water level will not cause the lake to seep at a greater rate.

Q. You've referred several times now to lake seepage rates. What are "lake seepage rates" and how will they be influenced by the ground water drawdown caused by mine dewatering?

A. Let us take Duck Lake as an example. Referring to EXHIBIT 345, you will note that Duck Lake lies upon relatively low-permeability lake deposits -- clays and fine-grained silt. These deposits maintain lake levels which are higher than the underlying ground water elevations, thereby creating slow downward seepage from the lake to the ground water. By lowering ground water elevations, the difference in water levels will increase and the rate of seepage from the lake will increase correspondingly. However, in certain areas, such as in the wetlands adjacent to Duck Lake, seepage is already occurring at its maximum rate because the wetland area is perched above the ground water with a partially saturated zone beneath it. Lowering ground water elevations will, therefore, not affect seepage in these areas.

Q. What do you mean by a "perched" area?

A. A perched area is an area where the surface water is separated from the ground water by a layer of material that has low permeability. In this area there are sediments at the bottom of each of the lakes that have relatively low permeability. As a result, the lakes can contain water even though the ground water level is below the lake level. If those sediments were not present, that is, if the lake was not perched, the lake level would be the same as the ground water level.

All of the lakes that we will discuss today are more or less perched. The difference between Oak Lake and Little Sand Lake for instance is not that one is perched and the other is not; they are both perched. The difference is that presently the ground water level under Oak Lake is lower than the bottom of the lake sediments. Consequently, if the ground water level further declines under Oak Lake there will be no increase in the seepage rate from Oak Lake. Accordingly, the mine dewatering will have no impact on Oak Lake.

In contrast, in the case of Little Sand Lake the ground water level presently is somewhat higher than the bottom of the lake bed sediments. The seepage from Little Sand Lake is therefore impeded by two factors: 1) the low permeability sediments in the bed of the lake and 2) the difference in head between the surface of the lake water and the surface of the ground water.

In the case of Little Sand Lake, if the ground water level declines below the bottom of the lake bed sediments there will be some greater seepage from Little Sand Lake and therefore some decline in the level of Little Sand Lake unless mitigation efforts are undertaken.

Q. How did you go about computing lake seepage rates?

A. Here again, we turned to computer modeling, collection of data from the field, and model calibration. Each lake within the projected zone of influence was divided into zones to permit calculations of seepage. Referring back to EXHIBIT 345, you can see, for example, that Duck Lake was divided into 15 zones. Each zone was assigned parameter values, and we computed seepage for each individual zone. Pertinent parameters assigned to each zone included lake and ground water elevations and lake sediment thickness and permeability. These input values led to the calculation of overall lake seepage rates for the predicted, lowered ground water elevations. Seepage rates were also calculated for lowered lake levels to determine how seepage will vary as lake levels decline. The procedure was performed individually for each of the five lakes within the projected zone of influence.

Q. How did you select lake sediment thickness and permeability?

A. Core samples were taken from each lake bed. Roger Rowe, who testified earlier, reviewed the field data and prepared a thickness map for each lake. Dames and Moore, consultant for Exxon, calculated baseline lake seepage for each lake. We took this information and calculated permeability for each lake sediment.

Q. Other than the lake seepage rates, what other factors did you consider in determining the change in lake levels?

A. Let me refer you to EXHIBIT 346, which illustrates the various components of a lake's water balance. Lake seepage to ground water will increase due to the lowered ground water elevations. Therefore, lake levels will decline until other water balance components compensate for the increased seepage. Those other components include evaporation and surface outflow. On the other hand, lakes are fed by precipitation and surface runoff. We determined these components based on the available site data or data from nearby areas using established methods. The difference between the amount of water gained by a lake over a period of time and the amount of water lost over the same period indicates how much the lake levels will change. We used this water balance method in computing new lake levels for each of the lakes using the previously computed seepage rates and average climatic conditions.

Q. What, then, are your predictions with respect to changes in lake levels as a result of mine dewatering?

A. Let me again refer you back to EXHIBIT 335. As I mentioned earlier, Oak Lake is fully perched and the other lakes within the drawdown cone are partially perched. Because Oak Lake is a fully perched lake, its level will not decline as a result of lowered ground water levels as I explained.

Q. What about the other four lakes within the projected cone of depression?

A. The other four lakes are also perched, but in each case the present ground water level is higher than the bottom of the sediment layer. Duck Lake will decline by an average of approximately 3 inches, Little Sand Lake by about 4 inches, and Deep Hole Lake will decline by about 6 inches. Skunk Lake would decline quite a bit further than the other lakes. I would like to mention that these predictions reflect yearly declines in lake levels. Except for Skunk Lake, our analysis shows during average climatological conditions there will be enough inflow to maintain lake water levels at preconstruction levels part of the year.

Q. Are these the declines that would occur with or without mitigation measures by Exxon?

A. As I indicated earlier, all of the model results I am discussing are premised on the absence of any mitigation efforts. As Carlton Schroeder has testified, Exxon's contingency plan will ensure that these declines are mitigated.

Q. What about the impacts on lakes outside of the projected cone of depression?

A. As I have discussed earlier, Rolling Stone Lake, Rice Lake, Crane Lake, and Pickerel Lake are receiving lakes -- that is, they receive a portion of their water from ground water discharge. As you can see on EXHIBIT 335, these lakes are positioned such that they lie beyond the zone of influence created by mine dewatering. There may be some minor reduction in ground water discharge to these lakes, but such reductions would translate into lake-level declines on the order of only fractions of an inch. These declines would be so small that, not only would they cause no adverse impacts, but it would also be difficult to determine whether they resulted from mine dewatering or from normal changes in lake levels related to the weather.

Q. Before we leave the question of the drawdown cone and move on to water quality issues associated with the MWDF, let me ask you a few questions relating to some of the matters you have thus far discussed. First, you have referred at several points to conditions that would occur under "average conditions." What do you mean by that?

A. In nature, there are some events which result in abnormal conditions. Except for such events we may predict a range of normal or expected conditions. In any given period, say a ten year period, we can expect a range of temperatures, snowfall and rainfall. The conditions in any single year will vary within that range. From these ranges, we select appropriate averages, which represent average conditions.

Q. Did you look at impacts that might occur during periods of extreme drought?

A. Yes sir, we looked at the impacts for extreme drought conditions. Our results are set forth in Appendix 4.1A of the EIR, which appears as EXHIBIT 158 in the record. As one would expect, during these conditions, if everything else stayed the same, reductions in lake levels and stream flows would be greater. In assessing extreme drought conditions in order to be conservative we did not change things like the mine inflow rate. However, our analysis concludes that, during a drought, mine inflow also would be decreased and less water would be pumped from the mine. Therefore, the predicted dry weather impacts would in reality be partially offset since mine dewatering, which is the main cause of the predicted impacts, would also be reduced.

Q. Let me also ask whether you are aware of any other work that has been done with respect to the possible impacts of mine dewatering?

A. Yes, the Department of Natural Resources has done its own modeling work to study lake impacts. In addition, we have performed some modeling work for the Department in this area using the input data given to us by the Department.

Q. Have you reviewed the methodology and conclusions of the DNR's lake water balance work?

A. Yes, and I have commented on some of this work in a letter report that appears in the record as EXHIBIT 199. As that letter report indicates, I disagree with the DNR's methodology and its use of input data. At the time this testimony was prepared, I had only recently received the second version of the DNR's lake water balance studies, and we understood that the DNR had not completed its work. Accordingly, I reserved my comments for my supplemental testimony.

Q. Recognizing your disagreement with the DNR's methodology and its use of input date, what if the Department is correct in its predictions? Would Exxon be able to mitigate impacts projected by the DNR?

A. Yes. At the DNR's request, we performed a worst-case lake seepage impact and mitigation analysis using their input parameters and the GEOFLOW model. This analysis included a study of secondary impacts from mitigation pumping. Although we disagree with the DNR's input data, we found that, even under such worst-case conditions, Exxon's Contingency Plan was able to successfully mitigate the impacts with either no or minimal secondary effects.

Q. One final question before moving on to the water-quality issues relating to the Mine Waste Disposal Facility. How long will the cone of depression continue and will the ground water table and surface water levels ever return to their pre-mine condition?

A. Yes sir. When mining is completed and mine dewatering is discontinued, ground water elevations will begin to recover and will ultimately regain their preoperation levels. Correspondingly, lake elevations will also return to their preoperation levels. Rapid recovery will occur within a short time period, less than one year, and complete recovery within several years after mine dewatering is discontinued. By this time, in other words, ground water flow in the site area will essentially have returned to its premining condition.

Q. You mentioned at the outset of your testimony that you would testify regarding the MWDF and contiguous facilities.

A. Yes. In addition to impacts on the amounts of ground and surface waters in the Crandon site area, the mine will also have some effects on the <u>quality</u> of the waters in the immediate proximity of the MWDF. I was asked by Exxon to analyze and discuss these effects.

Referring to EXHIBIT 201, you will see that the Mine Waste Disposal Facility consists of four tailings ponds at the locations shown in the exhibit.

Q. To refresh ourselves on this point, Dr. Djafari, what are "tailings" and what are "tailings ponds"?

A. As discussed earlier, the ore will be removed from the underground mine and milled to extract the minerals of interest. Finely ground rock segregated during ore processing is called tailings. The tailings will be disposed of in secure facilities called tailings ponds.

The ponds will be constructed with low permeable liners and underdrains to reduce seepage to the minimum. Seepage will occur at very low rates during operations and will have water quality characteristics different than the underlying ground water. The seepage will travel downward from the tailings ponds, through a partially saturated zone approximately 40-feet thick, where many of the materials in the seepage will be attenuated and their movement retarded by the soil. Eventually some of this seepage will reach the ground water. The chemical constituents, as they seep from the tailings ponds, will be diluted and their concentration will be reduced as the seepage is incorporated into the much larger volume of ground water and begins to move with ground water flow. As you can see on EXHIBIT 203, ground water flow in the vicinity of the MWDF is toward the northeast. State regulations require that a compliance boundary be established at which Exxon's compliance with water quality standards will be determined.

As Mr. Moe has testified, after the tailings ponds are reclaimed, the reclamation caps on the ponds are designed to prevent water from infiltrating into the tailings and, thus, should essentially eliminate seepage from the bottom of the ponds.

Q. What, then, was your assignment from Exxon?

A. My assignment was to analyze and predict, through the use of modeling, data collection, and verification techniques, what the concentrations of various constituents would be at the compliance boundary as a result of seepage from the tailings ponds and whether ground water quality would be in compliance with the maximum permissible limits specified by state and federal standards.

Let me emphasize an important point here. If the reclamation cap performs as designed, there will be essentially no seepage after the ponds are reclaimed and thus there will be no impact. The modeling I am about to discuss was based on the hypothetical scenario of a ten-percent failure in the reclamation cap that if unremedied, would allow continuous infiltration of water into the ponds and seepage from the bottoms. The modeling results I will discuss are thus based on that assumption.

Q. What are the parameters that you studied?

A. The long list of parameters of interest to us and to federal and state authorities is discussed in EXHIBIT 334. To simplify my testimony, I propose to focus on the five parameters of most direct relevance to this project. Let me refer to EXHIBIT 347, which presents the average concentrations of these parameters as they currently exist in the site area ground water. As the exhibit indicates, TDS, arsenic and sulfate are currently at levels below the maximum levels set by federal and state drinking water standards. As you can see, average iron and manganese concentrations currently exceed the maximum levels set under these drinking water standards. The exhibit also presents existing surface water quality for these parameters for Hemlock Creek.

Q. Let me interrupt with two questions at this point. First, what led you to include these five parameters in your discussion but to exclude the other parameters discussed in EXHIBIT 334?

A. For two reasons, I propose not to include those other parameters in my testimony today. First, some of the parameters would not even be contained in any seepage from the tailings and thus are not relevant. Second, the other parameters would be present in the tailings seepage in such minute quantities that there would be no possibility that their concentrations could exceed the allowable levels at the compliance boundary. For example, barium concentration in the tailings is less than 0.1 parts per million (ppm), which is at least 10 times lower than the U.S. EPA recommended primary drinking water standard, even without dilution and adsorption.

Q. You also mentioned that you have studied the existing surface water concentrations for these parameters at Hemlock Creek. Why are you focusing on Hemlock Creek?

A. Hemlock Creek is the closest surface water body where tailings seepage could affect water quality. The compliance boundary at the eastern portion of the MWDF is located between the MWDF and Hemlock Creek. The general ground water flow in this area is toward Hemlock Creek.

Q. You testified that the seepage from the ponds will occur at relatively low rates. What precisely will the amount of seepage be?

A. EXHIBIT 337 shows the seepage rate from the tailings ponds during different periods. Mr. Moe has discussed in more detail the specific tailings ponds seepage values. During the operation period, the annual tailings ponds seepage rate will be 0.68 in/yr. This seepage will be essentially eliminated after the reclamation caps are in place. For my modeling purposes, I assumed a ten percent failure in the reclamation caps. This would result in a seepage rate of 0.066 inches per year during the post-operation period. This translates to 1.33 gallons per minute for total seepage from all the tailings ponds.

Q. You have mentioned that any concentrations would be diluted and reduced as they moved away from the ponds. What causes the dilution?

A. Let me here refer you to EXHIBIT 348. Chemical constituents contained in the seepage would migrate along with the ground water once the seepage reached the ground water. However, the concentrations of these constituents would be reduced and they would spread as they migrated with the flow due to dispersion and dilution processes. Dispersion occurs as the result of chemical spreading of the concentrations and physical spreading relating to the winding path ground water must follow to move around the sand and other particles in saturated soils. The migration of chemical constituents in ground water flow, affected by dispersion, creates a concentration plume emanating from the source of the constituents. Existing ground water quality and natural recharge would continuously dilute the concentration of chemical constituents as they traveled with ground water.

Q. Before proceeding with the details of your analysis and findings, Dr. Djafari, would you summarize briefly for us your conclusions as to the effects of seepage from the MWDF?

A. Our analysis indicates that, even assuming the cap failure and seepage rates discussed above, sulfate concentrations at the compliance boundary would be below State limits, and the concentrations would be less than the U.S. EPA recommended secondary drinking water standards. The concentration of sulfate at the compliance boundary would be less than 100 parts per million (ppm). It would take several hundred years before equilibrium was established. The increase in sulfate concentration in Hemlock Creek would be less than 2 ppm. I wish to repeat and emphasize that when the mine is closed and the MWDF is sealed and reclaimed, these concentrations, if they occurred at all, would be stabilized at steady-state values. That is to say, the concentration of these chemicals at the compliance boundaries would not increase over time when steady-state condition has been reached.

Q. Why do you concentrate on sulfates?

A. Although there are other chemical constituents present in the tailings, sulfate has one of the highest concentrations. Sulfate also is one of the most mobile species present. Other materials are attenuated and their movement is retarded by the soil in the area. Therefore, I selected sulfate as a tracer. If we know that the sulfate concentrations at the compliance boundary are within the acceptable limits, we can be assured that these other less mobile species are also well below their respective limits.

Q. Dr. Djafari, how did you arrive at these conclusions?

A. Once again, we relied on the models that I discussed earlier in my testimony. These models relied on ground water flow computations and on specified dispersion parameters and enabled us to calculate the chemical constituent concentrations at the compliance boundary over time. We used both horizontal and vertical dispersion simulations.

Q. What do you mean by a "horizontal" and "vertical" dispersion simulation?

A. The chemical concentrations in ground water will vary with location relative to the tailings pond source areas. Concentrations may be at a particular level at Point X but lower at Point Y and higher at Point Z as a result of the direction of ground water flow, geologic conditions, and other factors. This is what we mean by "horizontal dispersion." The horizontal model predicts the lateral movement of the chemical constituents in the ground water. On the other hand, as chemical constituents move laterally, some of them will move downward through partially saturated materials and will reach the ground water. This phenomena will cause varying concentrations both in different horizontal as well as vertical portions of the saturated materials. This is what we mean by "vertical dispersion." Thus, when we look at any one location on the compliance boundary, it is important for us to consider the varying concentrations that will occur at different depths immediately below that point. It is important to bear in mind that the horizontal dispersion figures that I will discuss represent the average of the vertical dispersion figures for various levels beneath each location.

Q. You mentioned that various parameters were introduced to the model. What were those parameters, and how were they selected?

A. One important factor was to determine the projected concentrations of the various parameters as they would occur in the seepage as it left the tailings ponds. Let me here refer you to EXHIBIT 349, which presents the projected tailings ponds concentrations of the five parameters I will be discussing today.

Q. What other factors did you rely on as input to your modeling efforts?

A. In addition to ground water flow parameters and concentration of tailings, we have used the dispersion coefficient, which is the measure of degree of spreading of the chemical because of variations in soil and rock conditions and ground water flow rates.

Q. How were these data obtained?

A. I have already mentioned how we obtained ground water flow parameters such as permeability and recharge. Based on the characteristics of the geologic units, we selected the dispersion coefficient value from the literature. As I will discuss later, we performed parametric studies to analyze the effect of variations of this parameter on our conclusion. I should mention that variation in the dispersion coefficient has no effect on how much constituent will reach Hemlock Creek. However, different dispersion coefficient values will have different results in distribution of constituents at the compliance boundary.

Q. What were the results of your horizontal dispersion simulations?

A. Let me here refer you to EXHIBIT 350, which illustrates the computed long-term concentration locations for dispersion from the MWDF. These concentrations represent the concentration of sulfate. Maximum computed sulfate concentrations averaged over the full depth of the aquifer at the compliance boundary would be 40 ppm in the northeastern portion of the compliance boundary near Hemlock Creek. The maximum concentration at any single depth would be 100 ppm.

Q. What about the other parameters you have referred to, iron and manganese?

A. As I testified earlier, the levels of iron and manganese present in ground water in this area already exceed maximum levels under state and federal standards. The manganese concentration at the monitoring wells has reached 10 ppm which is greater than the U.S. EPA secondary drinking water standard. The seepage from the tailings ponds, although containing levels of iron and manganese, would not make this currently existing situation worse. Furthermore, their concentration in tailings would decrease substantially as presented in EXHIBIT 349. Therefore, by the time these chemicals reached the ground water, their source concentration would decrease.

Q. What was the nature of your vertical dispersion modeling?

A. The vertical, or cross-sectional, ground water model was set up for a cross-section through the Mine Waste Disposal Facility area, oriented in the primary direction of ground water flow. EXHIBIT 351 illustrates this cross section. The cross section depicts the location of two tailings ponds, Hemlock Creek, and the approximate location of the compliance boundary. As you can see on EXHIBIT 352, a grid was developed and the various geologic materials were represented by different zones. Aquifer recharge was incorporated in the model, and recharge in the tailings pond area was specified according to the seepage rate schedule that I discussed earlier. The resulting ground water elevations and flow directions are shown in EXHIBIT 353.

This flow system was used to compute concentrations through time resulting from tailings pond seepage. Chemical concentrations were introduced to the top of the model, beneath the tailings ponds.

Q. What were the results of this vertical modeling?

A. Let me here introduce EXHIBIT 354, which shows the steady-state computed concentration for sulfates. The vertical model determined sulfate concentrations at the compliance boundary and at every other point within the vertical model. That would include concentrations at Hemlock Creek and at the edge of the tailings pond. The model also determined concentrations at various points after the MWDF had been capped. The model predicts that when steady-state was reached, sulfate concentrations at the compliance boundary would not exceed 100 parts per million. When steady-state was reached, the concentrations of sulfate and other chemicals in the tailings would not increase because balance would be reached between the amount of seepage from the tailings and the dilution from the ground water system. It would take several thousand years to reach steady-state conditions. The model tells us that sulfate concentrations at the compliance boundary would not be greater than 100 parts per million, and that concentrations thereafter would never increase beyond that level. Perhaps I should add that time periods here are immaterial. I am confident that the model is correctly predicting steady-state conditions, and in as much as those conditions are well within the compliance requirements, it is immaterial whether they would be reached in a hundred years or a thousand years.

Q. Before proceeding to pose several concluding questions to you, Dr. Djafari, may I ask you to expand on your discussion of ranges of confidence and sensitivity analyses with respect to the drawdown cone created by mine dewatering?

A. Because of the effect of certain parameters on results, numerous additional analyses were performed to determine how sensitive the results were to variations in these critical parameters. The sensitivity results provide a range of confidence for the predictions.

Q. What is your range of confidence with respect to your predictions?

A. I have looked at the sensitivity of my predictions with respect to four major parameters. These parameters are permeability, recharge, dispersion coefficients, and lake seepage rates.

Q. Would you explain the sensitivity of predictions to variations in these parameters?

A. With respect to permeability, we have seen that the results are not particularly sensitive to variations in permeability. Therefore, I am confident that the various ranges we have tested (25 to 44 feet per day) represent the best estimate of the site aquifer permeability. Similarly, the sensitivity of the model is very low to the recharge value. We have done numerous sensitivity analyses with regard to recharge value and they support our high degree of confidence in the model results. The average recharge value at the site is from 6 to 11 inches per year. My own opinion is that the recharge is most likely around 8.5 inches per year or less.

Q. How about the sensitivity of your model for the other two parameters?

A. The model has shown moderate sensitivity to dispersion coefficient. This sensitivity is only for distribution of chemical concentrations in a vertical direction. This means that, if we use a different dispersion coefficient we might see a different concentration profile in a vertical direction. We have evaluated the various ranges of the dispersion coefficients and I am confident that the computed concentration of chemical constituents of interest are predicted correctly with the necessary confidence level. I should also mention that the variation of dispersion coefficient will not affect the prediction of average concentrations at Hemlock Creek.

Q. How about lake seepage?

A. We have performed numerous sensitivity analyses for lake seepage values. The proposed Contingency Plan reflects the DNR's worst-case conditions for seepage. Even our own analysis of the reasonable worst-case indicates that lake seepage will be substantially less than projected for the DNR's worst-case. Therefore, I am confident that Exxon's Contingency Plan, which is based on the DNR's worst-case conditions, will be more than enough to mitigate for the range of reasonably possible impacts.

Q. Does your sensitivity analysis pertain to the effects of seepage from the tailings ponds as well as to the effects of the drawdown cone created by mine dewatering?

A. Yes sir. The sensitivity analysis covers both systems. Additionally, we studied the probable effect of a complete tailings pond cap system failure--as opposed to the ten-percent failure I earlier discussed--and predicted the consequences of such a complete failure on ground water quality.

Q. And what was the conclusion?

A. The conclusion was that, even if the cap system completely failed, the EPA drinking water standards would not be exceeded for a few decades, leaving decades in which to correct the failure.

Q. Dr. Djafari, I would now like to conclude by posing to you a series of questions based on standards promulgated by state and local laws. For each of these questions, I will ask you to state your expert opinion to a reasonable degree of engineering certainty. I will then ask you to explain the basis for your opinion. Let us first begin with a series of questions pertaining to the water quality issues we have just discussed. Will the location, design, construction, and operation of the Mine Waste Disposal Facility cause significant damaging effects on ground water?

A. No sir. Even assuming an indefinite, uncorrected ten-percent failure in the cap system, the average increase at the compliance boundary for sulfate, which is a conservative indicator for all constituents relevant to seepage, would be less than 100 parts per million, which is much lower than the EPA standard of 250 parts per million. Similarly, increase in the concentration at Hemlock Creek would be less than two parts per million. As the water from Hemlock Creek entered Swamp Creek it would be further diluted. By the time it reached Rice Lake, the change in the sulfate concentration would be negligible. Therefore, in my opinion, there will be no detrimental or damaging impact on these water bodies as a result of the construction and operation of the Mine Waste Disposal Facility.

Q. And on what do you base this opinion?

A. This opinion is based on my analysis of site conditions, on analysis of the result of various mathematical and computer models which I have presented, and on my professional experience of more than twenty years.

Q. Dr. Djafari, in your opinion, will the location, design, construction, and operation of the Mine Waste Disposal Facility meet applicable water quality standards?

A. Yes sir.

Q. And on what do you base this opinion?

A. The same basis as I gave in answer to your previous question.

Q. Dr. Djafari, will the surface water quality standards be violated as a result of seepage from the Mine Waste Disposal Facility?

A. No sir.

Q. And on what do you base this opinion?

A. The same basis as given earlier, plus my analysis of water quality in Hemlock and Swamp creeks and other creeks and lakes adjacent to the site.

Q. Dr. Djafari, in your opinion, will the location, design, construction, and operation of the Mine Waste Disposal Facility allow any subsurface discharge into navigable waters that could cause violation of any state toxic discharge standards?

A. No sir.

Q. Finally, Dr. Djafari, will the location, design, and operation of the Mine Waste Disposal Facility prevent the discharge or disposal of any substance into surface or ground water in violation of state law which would adversely affect water quality?

A. Yes sir.

Q. And on what do you base this opinion?

A. The basis of my opinion is as stated before to which I would add my familiarity with the site operation plans.

Q. Dr. Djafari, let me now move to several questions that involve your opinions respecting the potential effects of the cone of depression created by mine dewatering. First, will the operation of the Crandon Project cause an unreasonable detriment to public or private water supplies?

A. No sir. My analysis includes my study of the unmitigated impacts on the surface waters contiguous to the mine site and my knowledge of Exxon's Contingency Plan. I don't purport to render a legal opinion regarding the effects of the cone of depression upon surface water bodies, but if the surface impacts are no greater than the expected case, it is my opinion that, with the possible exception of Skunk Lake, there would be no unreasonable detrimental impact on public waters as the result of the mine and the associated cone of depression even without contingency measures being taken.

In all events, under any reasonable expected or worst-case analyses of the impact on surface waters resulting from the cone of depression, it is quite clear to me, and it is my opinion, that Exxon's Contingency Plan can be implemented and when implemented will prevent any of the surface waters from suffering any unreasonable or even significant impact as a result of mining activity. As I testified, this includes the DNR's worst-case scenario. Moreover, as Carlton Schroeder has discussed, Exxon has committed to private well owners that it will replace or deepen any water wells as necessary to ensure that private water supplies are not harmed. Therefore, I conclude that with Exxon's proposed contingency actions there will be no unreasonable detrimental impacts to public or private water supplies.

Q. And on what do you base this opinion?

A. My opinion is based on the very extensive analysis of the cone of depression that I have undertaken and the effects of the cone of depression upon water levels and flows of the surface waters in or adjacent to the mining site; it is based upon my analysis of the expected case, my analysis of the DNR's worst-case, and further on my knowledge of the Exxon Contingency Plan which in my opinion can be implemented and is entirely reasonable.

Q. Dr. Djafari, can you summarize your opinion of the effect of the Crandon project on public and private waters?

A. As I have indicated, there will be a drop in the level of ground water. This will have some impact on surface waters and may impact private wells in the area. I do not believe that the impact on surface waters will be particularly significant, but in all events it can be mitigated and will be mitigated by the Exxon Contingency Plan. With respect to the private wells in the area, the Exxon Contingency Plan also provides for mitigation. So in general with the Exxon Contingency Plan I believe that the Crandon Project and the associated cone of depression will have insignificant effects on the public waters of the state of Wisconsin and the use of those waters, and insignificant effects on private water supplies.

Q. Dr. Djafari, does that conclude your testimony?

A. Yes sir.

Q. Thank you, Dr. Djafari.

0816R

SIROUS HAJI-DJAFARI

Professional Qualifications

Dr. Djafari has extensive experience in the areas of agricultural and civil engineering. His background includes academic and practical experience in surface and subsurface hydrology, hydraulic transients, ground water contaminant transport, irrigation, soil mechanics, construction management, and computer programming and modeling.

Since joining IT in 1976, Dr. Djafari has worked on numerous environmental science and engineering projects including site selection and evaluation, data analysis, impact assessments, remedial investigation and feasibility studies, project management, and design. He has participated as an expert witness in federal and local courts on the subject of ground water contamination assessment and assessments of cost-effective remedial alternatives. He has managed engineering projects ranging from a few thousand dollars up to several millions of dollars.

Education

Ph.D., Civil Engineering, Michigan State University, East Lansing, Michigan; 1975
M.S., Agricultural Engineering, Michigan State University, East Lansing, Michigan; 1972
B.S., Agricultural Engineering, University of Teheran, Iran; 1962

Experience and Background

1976 - Present: <u>General Manager of Engineering, IT Corporation, Pittsburgh, Pennsylvania</u>. Responsible for the overall management of engineering in the Northeast including remedial investigations and feasibility studies, site assessments design and field management, Resource Conservation and Recovery Act (RCRA) Part B applications, site closure plans, environmental audits, underground storage tank assessment, waste characterization studies, and computer modeling for hazardous and nonhazardous waste projects. Experience includes:

- Project manager for the environmental impact assessment of proposed waste disposal facilities.
- Expert witness in federal and local courts on the subject of ground water movement and contaminant transport.
- Project manager for the evaluation of several hazardous and nonhazardous waste disposal and storage sites. The principal objectives in these studies were to determine the sites' geologic and hydrogeologic integrities and assess site feasibility by considering waste characteristics, site criteria, and requirements of regulatory agencies.

- Principal contributor for preparation of ground water hydrology portions of a manual oriented toward identification and prediction of ground water inflow through underground coal mines.

- Principal investigator for identification of sources of seepage into a coal mine shaft in Illinois and design of remedial schemes utilizing horizontal drains to alleviate adverse conditions.

- Principal investigator for conducting a background radiological monitoring program for a proposed nuclear power plant site.

- Principal contributor for an alternative evaluation of waste disposal from in situ mining operations in Wyoming and Colorado including costs, radon emanation reduction, and construction feasibility.

- Project leader for the development of toxic waste management in West Virginia. The principal objectives of the investigation were to determine the rate of transport of toxic materials to significant aquifers, dispersion within the aquifers, and impacts of these toxic materials on local and regional water regimes.

- Principal investigator for predicting ground water inflow into deep coal mines in the eastern and western United States.

- Lead engineer responsible for evaluating environmental impact of uranium tailings pond on the ground water regime in Wyoming, including laboratory measurements of dispersion coefficient and permeability and computer modeling to predict the distribution of radionuclides and heavy metals during the facility life.

- Author of several computer models capable of predicting flow and mass transport in surface and subsurface flow regime.

- Project leader for the development of computer models to be utilized for small operator assistance program management. As part of this project, available surface water and ground water computer models were compiled and analyzed for their applicability to the project including their capability, validity of their mathematical equations, method of numerical development, and ease of usage.

- Manager or director of several projects for assessment of the extent of organic and inorganic contamination and development of the cost-effective remedial alternatives for control and containment of the contaminants.

1970 - 1976 Graduate Research Assistant, Michigan State University, East Lansing, Michigan. Contributed to a project dealing with drainage evaluation, meteorological instrumentation, hydrogeological assessment, and modeling. In addition, developed and verified several computer programs for the prediction of soil temperature at various depths based on air temperature and for the simulation of flow and mass transport in confined and unconfined aquifers using the finite difference and finite element techniques.

1966 - 1970 Director, Aras Dam Project, Ministry of Power and Water, Teheran, Iran. Responsible for the Iranian government's portion of population relocation, quality control for surface water and ground water, and construction supervision and management.

1964 - 1966 Engineer-in-Charge, Aras Dam Project, Ministry of Power and Water, Teheran, Iran. Responsible for site selection and investigation for the Aras Dam in northeastern Iran. The Aras Dam was a joint Iranian/Russian project designed to impound surface waters for agricultural irrigation of 190,000 hectares and hydroelectric power generation. As Engineer-in-Charge, gained practical experience in geologic mapping, subsurface exploration, foundation evaluations, hydrogeology, site selection, report preparation, and dam construction.

Registrations/Certifications

Professional Engineer: Michigan, Pennsylvania, Texas

Professional Affiliations

American Association for the Advancement of Science
American Geophysical Union
American Meteorological Society
American Society for Testing and Materials (ASTM)
American Society of Agricultural Engineers
American Society of Civil Engineers (ASCE)
American Society of Photometry
Sigma Xi

Publications

Batu, V., and S. Haji-Djafari, 1986, "The Use of Mathematical Modeling for the Environmental Impact Assessment of Hazardous Waste sites," Proceedings, the Third International Symposium on Environmental Management for Developing Countries, August 6 to 12, Istanbul, Turkey.

Haji-Djafari, S., 1986, "The Role of Hydrologic Simulation in the Selection of a Cost-Effective Remedial Program," Proceedings, The Third International Symposium on Environmental Management for Developing Countries, August 6 to 12, Istanbul, Turkey.

Wright, J. C., Jr., S. Haji-Djafari, and S. G. Shallard, 1984, "Selection of Appropriate Bentonites for Site-Specific Slurry Trench Cutoff Walls," Paper presented at the International Symposium on Impermeable Barriers for Soil and Rock, June 25, 1984, Denver, Colorado.

Srivastava, V. K., and S. Haji-Djafari, 1983, "In Situ Detoxification of Hazardous Waste," Proceedings, National Conference on Management of Uncontrolled Hazardous Waste Sites, October 31 to November 2, 1983, Washington, D.C., pp. 231-236.

Haji-Djafari, S. and J. C. Wright, Jr., 1983, "Determining the Long-Term Effects of Interactions Between Waste Permeants and Porous Media," Hazardous and Industrial Solid Waste Testing: Second Symposium, ASTM STP 805, R. A. Conway and W. P. Gulledge, eds., American Society for Testing and Materials, pp. 246-264.

Chen, C. S., R. Khalleel, and S. Haji-Djafari, 1981, "Contaminant Transport with Adsorption Process in Saturated-Unsaturated Porous Media," Spring Meeting of American Geophysical Union, Baltimore, Maryland.

Wright, J. C., Jr. and S. Haji-Djafari, 1980, "Development of a Procedure for Prediction of Acid-Front Migration in Geomedia," Geological Society of America Abstracts with Programs, Vol. 12, No. 7, Atlanta, Georgia, pp. 552.

Haji-Djafari, S., D. K. Hunt, and P. E. Antommaria, 1980, "Optimization of Waste Disposal Site Selection Using Interactive Screening Processes," Third Annual Madison Conference of Applied Research and Practice on Municipal and Industrial Waste, September 10-12, 1980, Madison, Wisconsin.

Haji-Djafari, S. and D. C. Wiggert, May 1980, "Improved Accuracy of Finite Element Simulation of Ground Water Contaminant Transport Using a Higher Order Time Approximation," Spring Meeting of American Geophysical Union, Toronto, Ontario.

Haji-Djafari, S., P. E. Antommaria, and H. L. Crouse, 1979, "Attenuation of Radionuclides and Toxic Elements by In Situ Soils at a Uranium Tailings Pond in Central Wyoming," published in Proceedings of ASTM 1979 Symposium on the Permeability and Ground Water Contaminant Symposium.

Haji-Djafari, S. and D. C. Wiggert, June 1976, "Two-Dimensional Analysis of Tracer Movement and Transient Flow in Phreatic Aquifer," The Second International Symposium on Finite Element Method in Flow Problems, Italy.

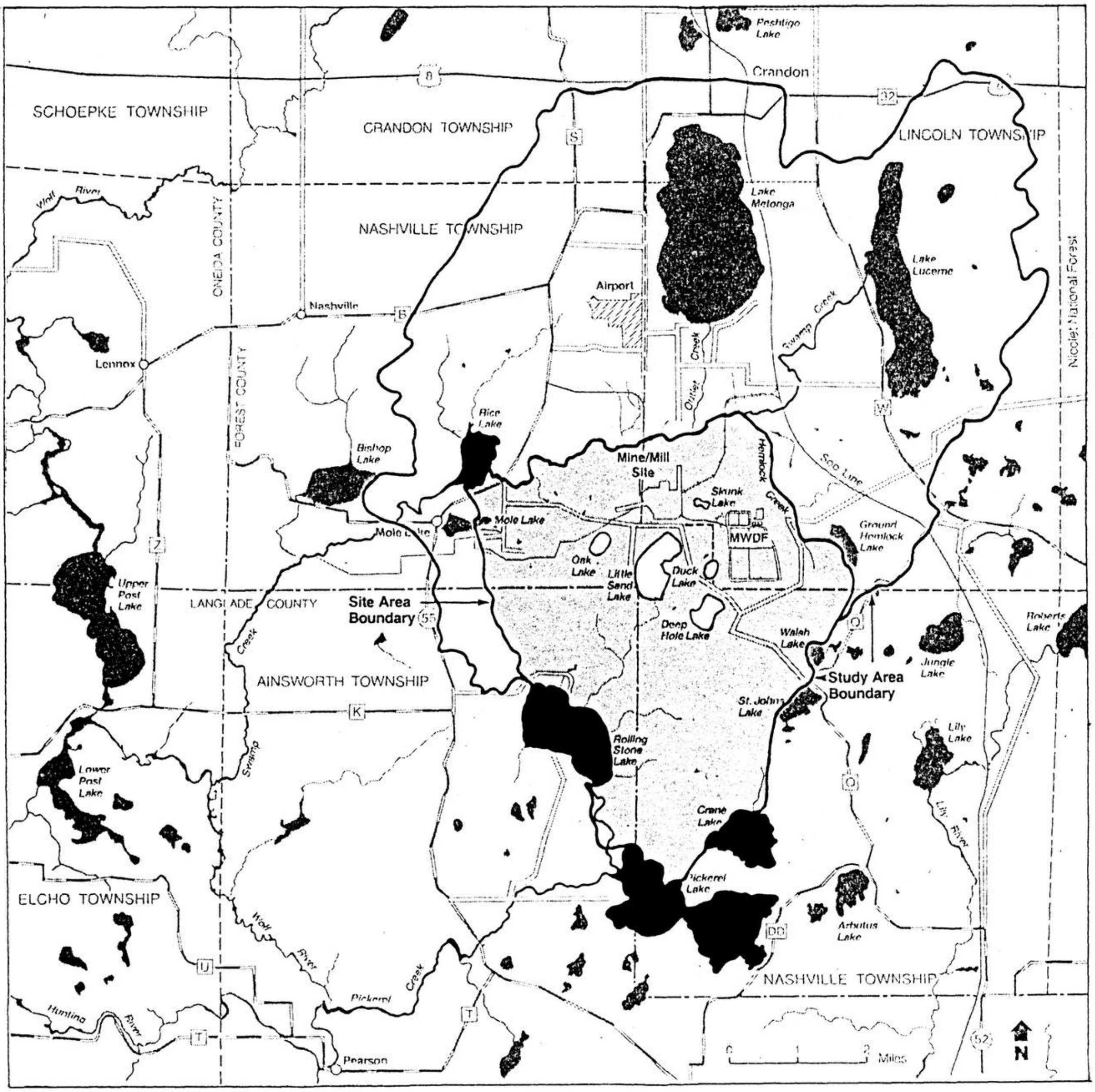
Haji-Djafari, S., 1976, "Two-Dimensional Finite Element Analysis of Transient Flow and Tracer Movement in Confined and Phreatic Aquifers," Ph.D. Thesis, Department of Civil Engineering, Michigan State University, East Lansing, Michigan.

Haji-Djafari, S. and D. C. Wiggert, September 1975, "Numerical Prediction of Tracer Concentration in Aquifers with Transient Ground water Flow by Finite Element Method," First Annual Meeting Midwestern Region of American Geophysical Union, Madison, Wisconsin.

Merva, G. E. and S. Haji-Djafari, 1972, "Conditions Conducive to Freeze-Cracking of Tile Drains," Report of Research, Department of Agricultural Engineering, Michigan State University, East Lansing, Michigan.

Haji-Djafari, S., 1972, "Soil Temperature Regime and Its Interaction with Submerged Tile," Unpublished M.S. Thesis, Agricultural Engineering, Michigan State University, East Lansing, Michigan.

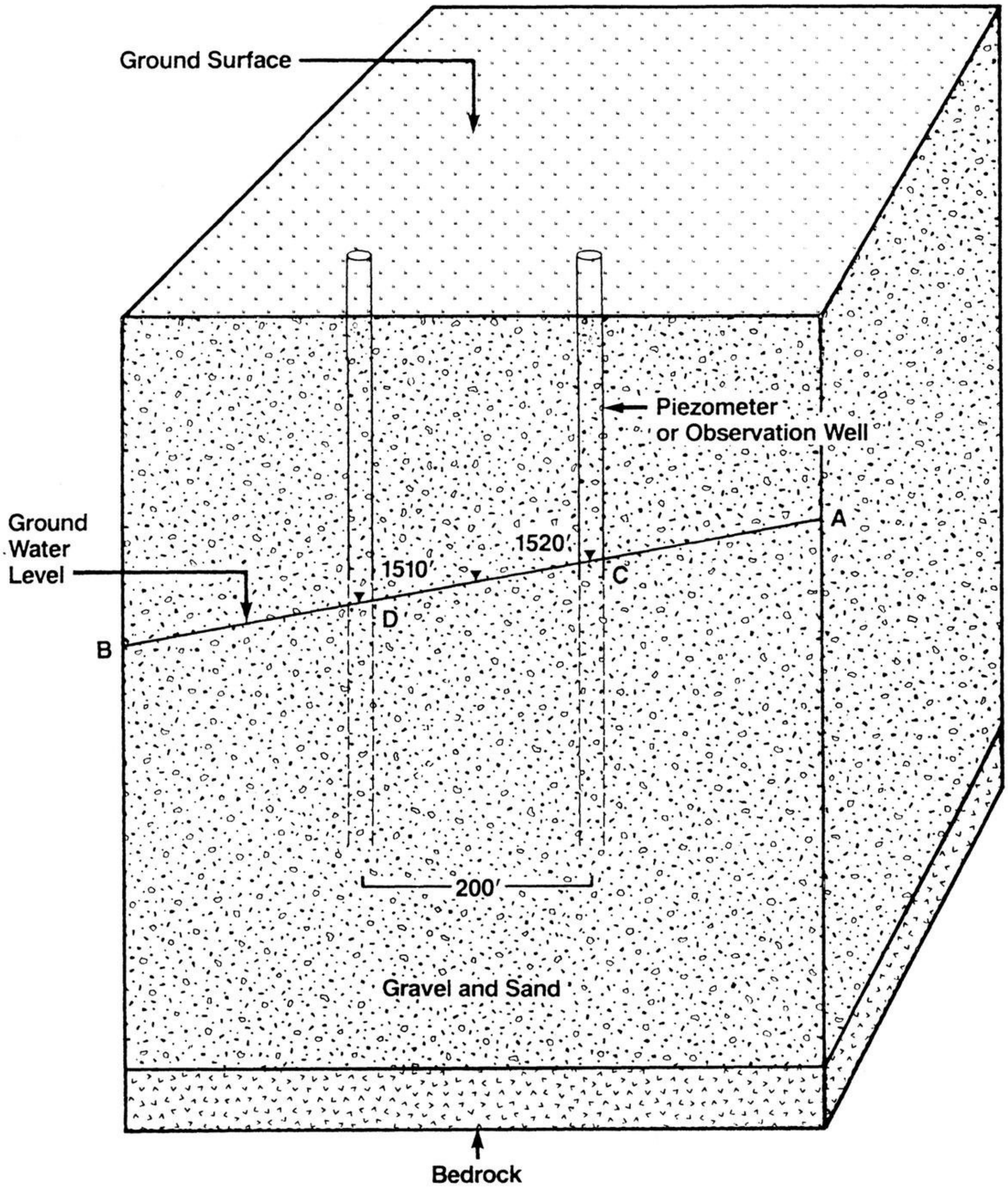
Site and Study Area
Boundaries



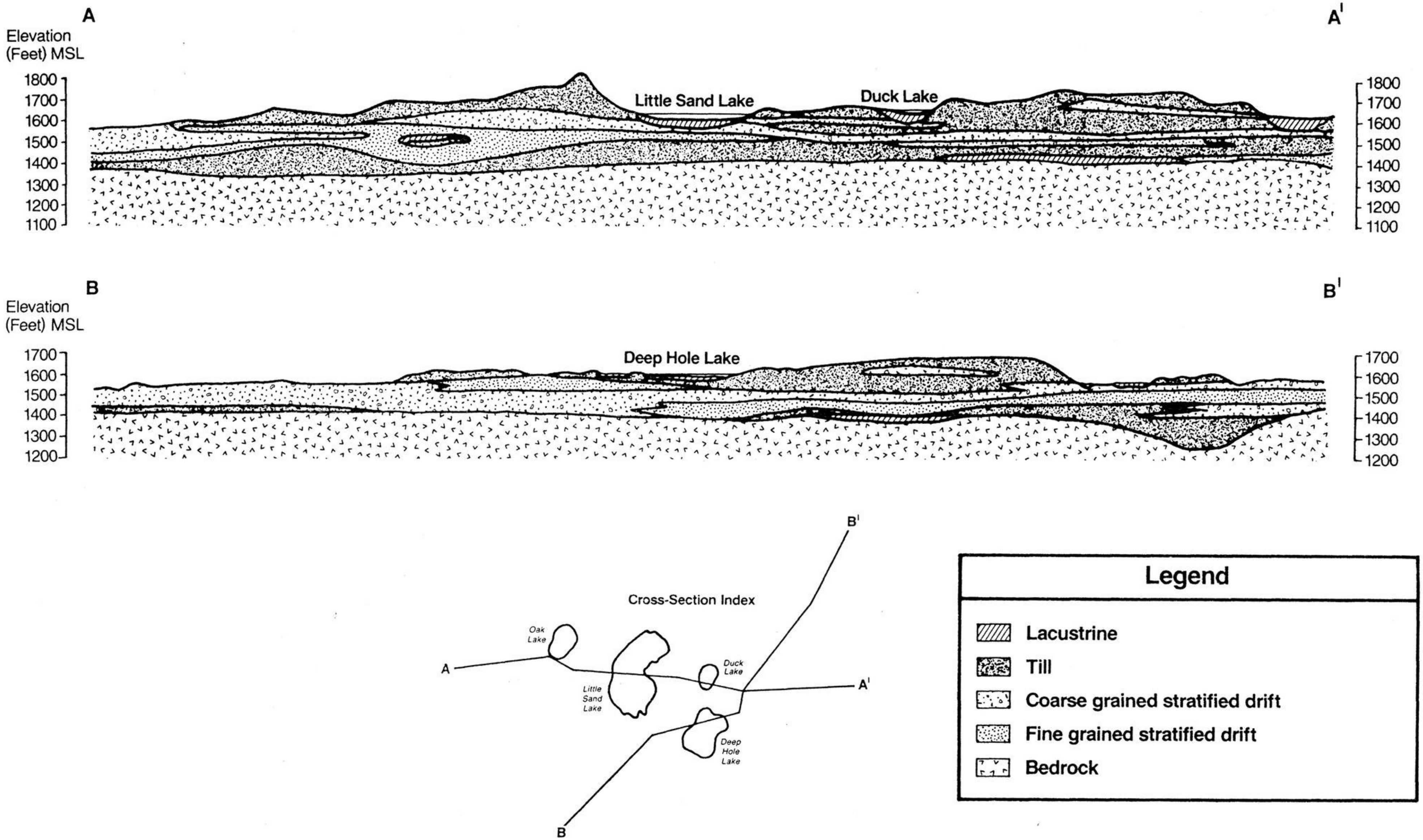
Legend

- Recharge areas
- Discharge areas

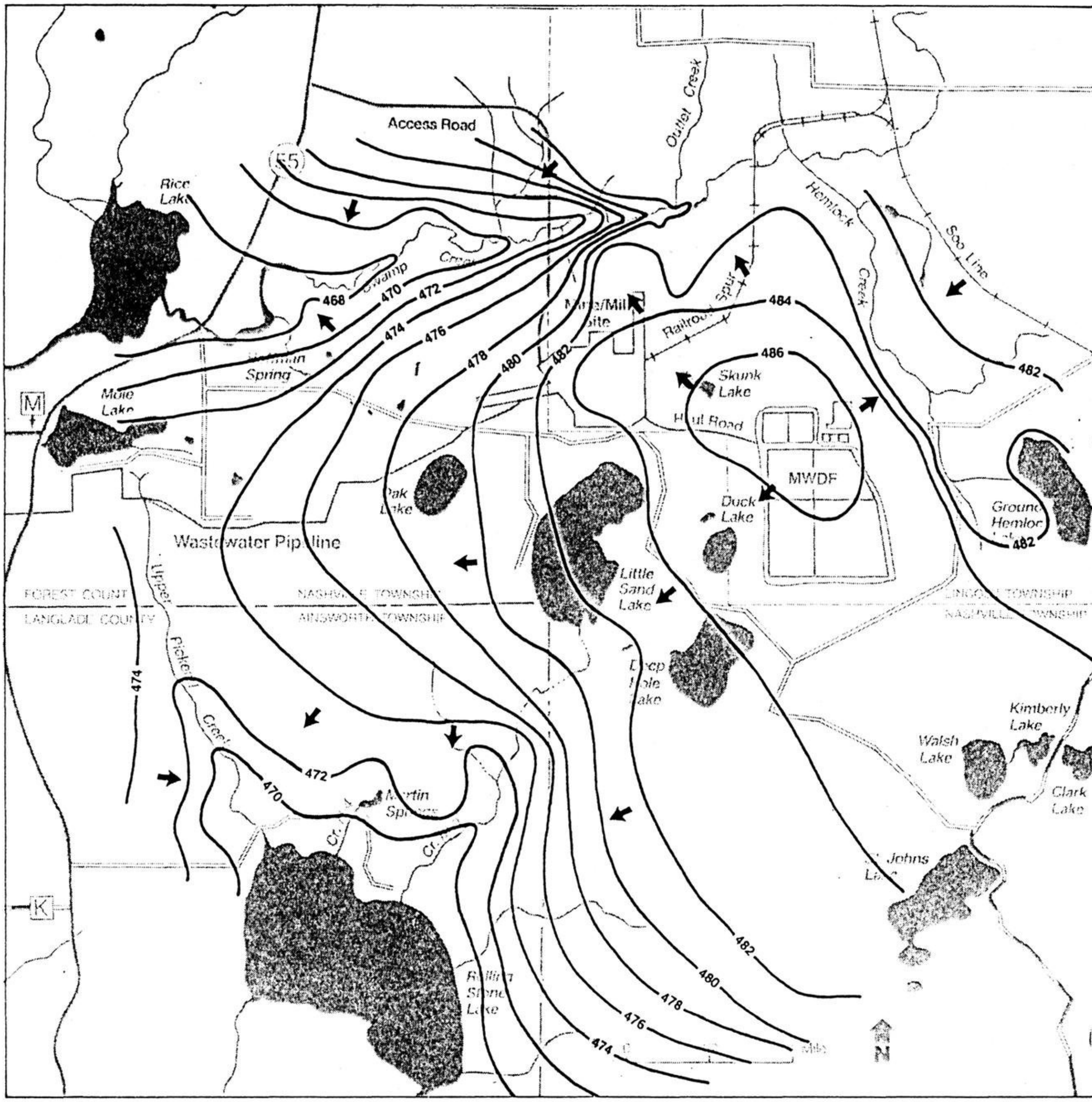
Hydrogeologic Profile
Schematic



Glacial Cross Section



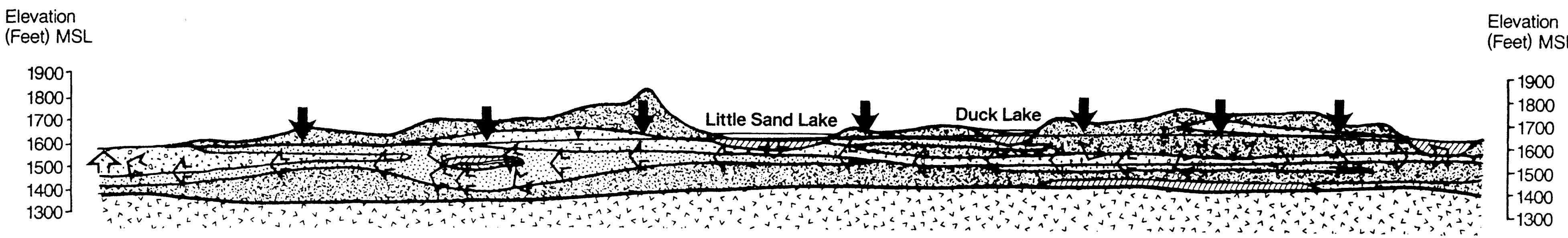
Potentiometric
Surface Contours



Legend

- Ground water contours in meters above sea level
- General ground water flow direction

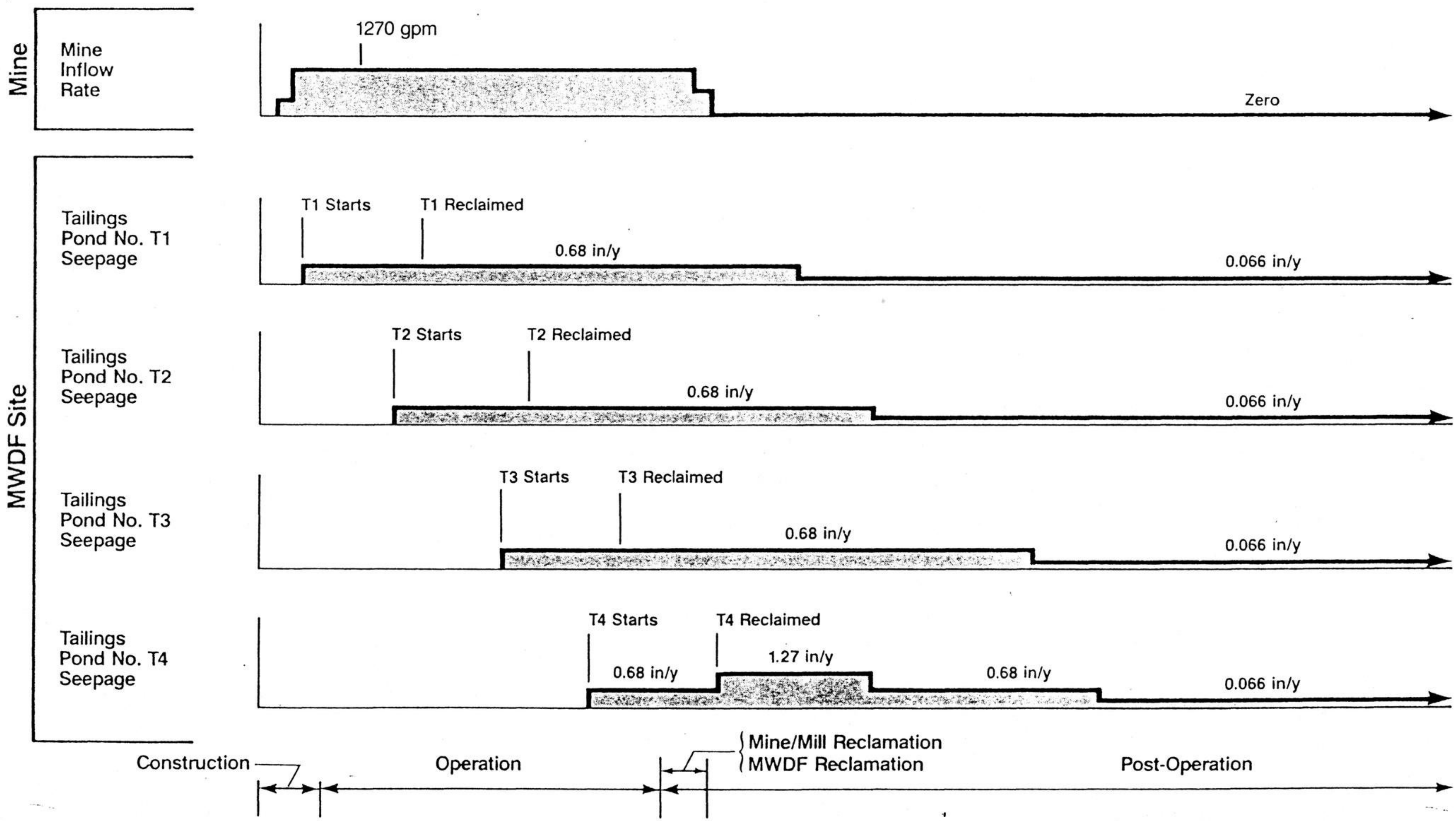
Ground Water Flow Cross Section



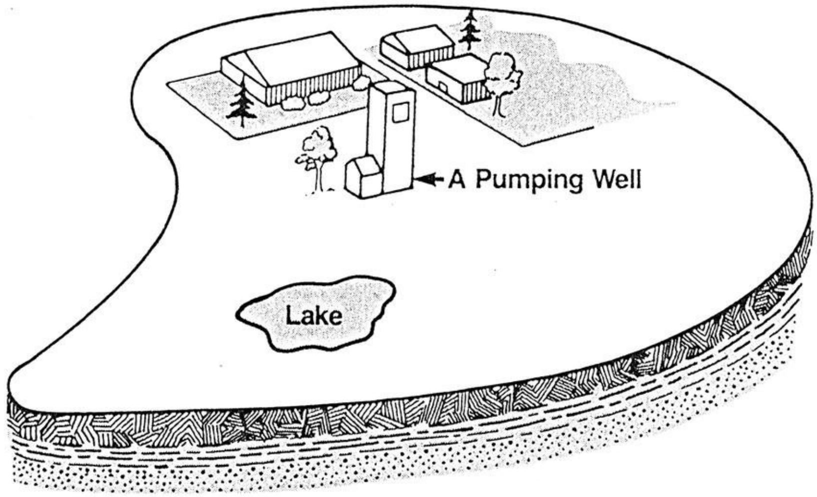
Legend

- Lacustrine
- Till
- Coarse grained stratified drift
- Fine grained stratified drift
- Bedrock
- Percolation through unsaturated zone
- Representation of ground water movement
- Potentiometric surface

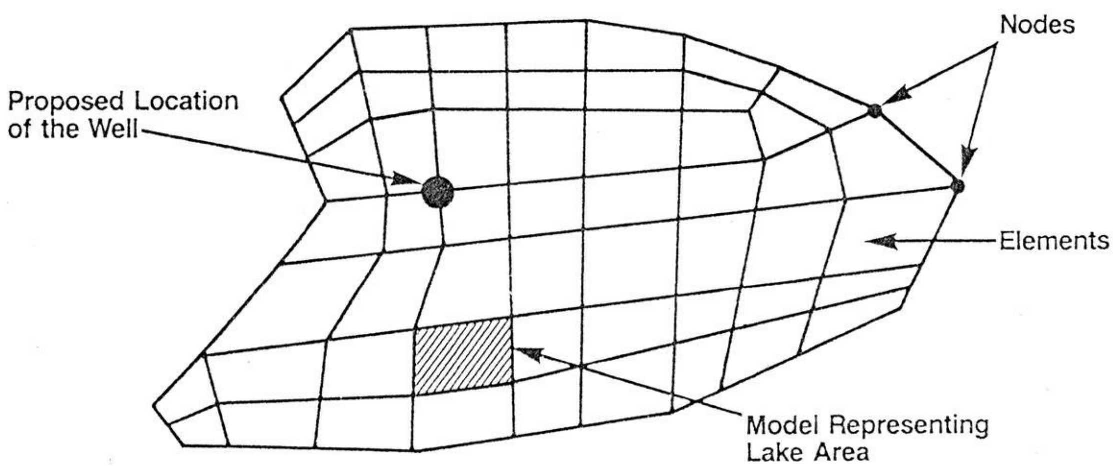
Hydrologic Schedule



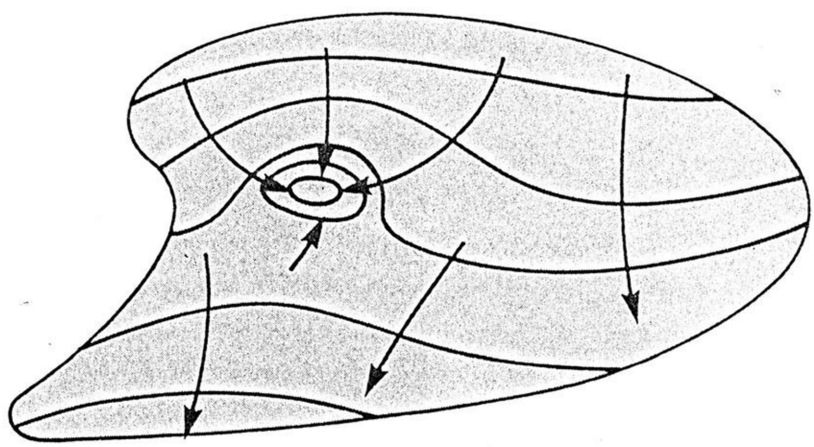
Modeling Approach



Hydrologic Environment



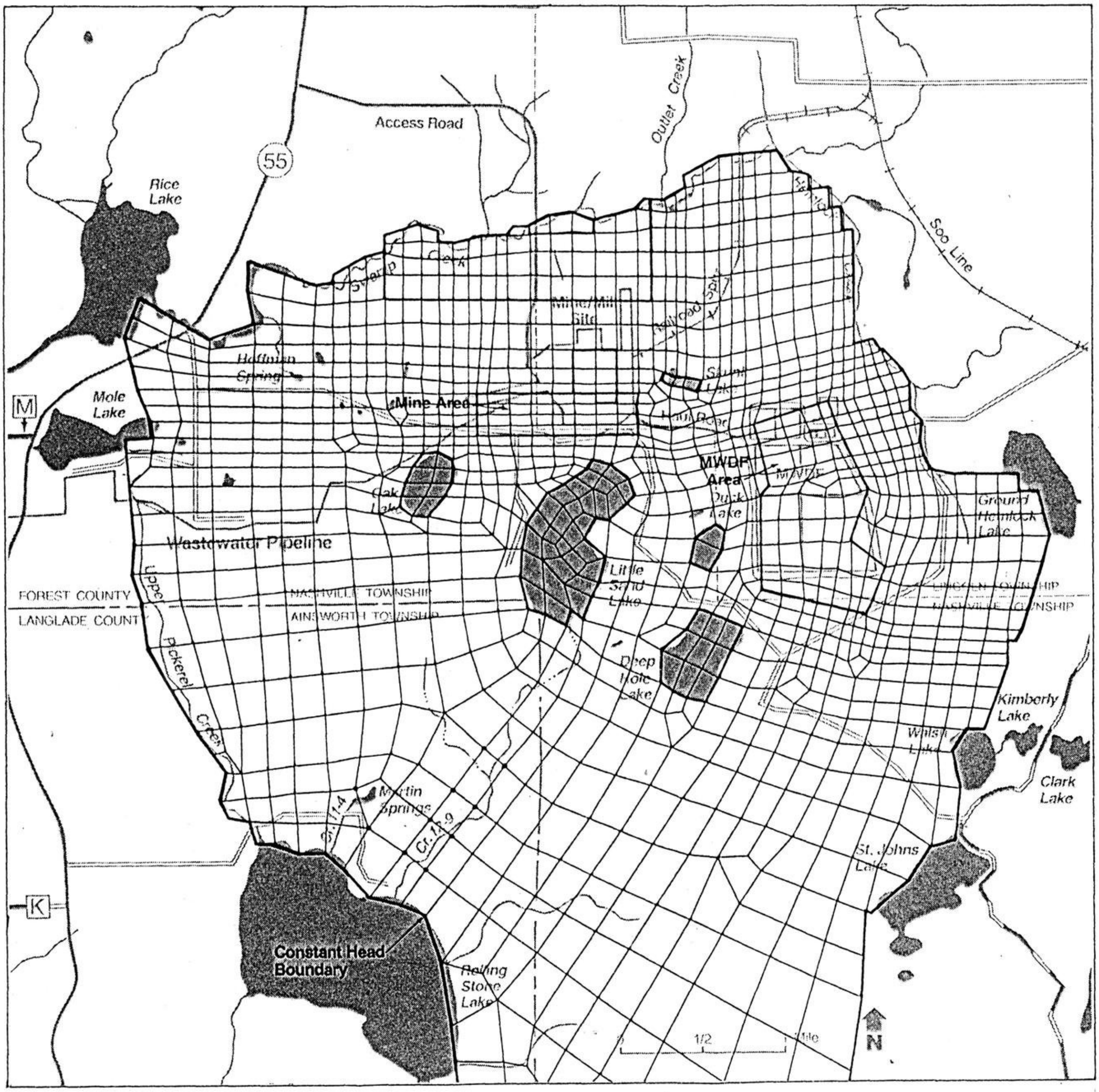
Model Grid



Computed Ground Water
Elevation Contours

Finite Element Grid System

Horizontal Model

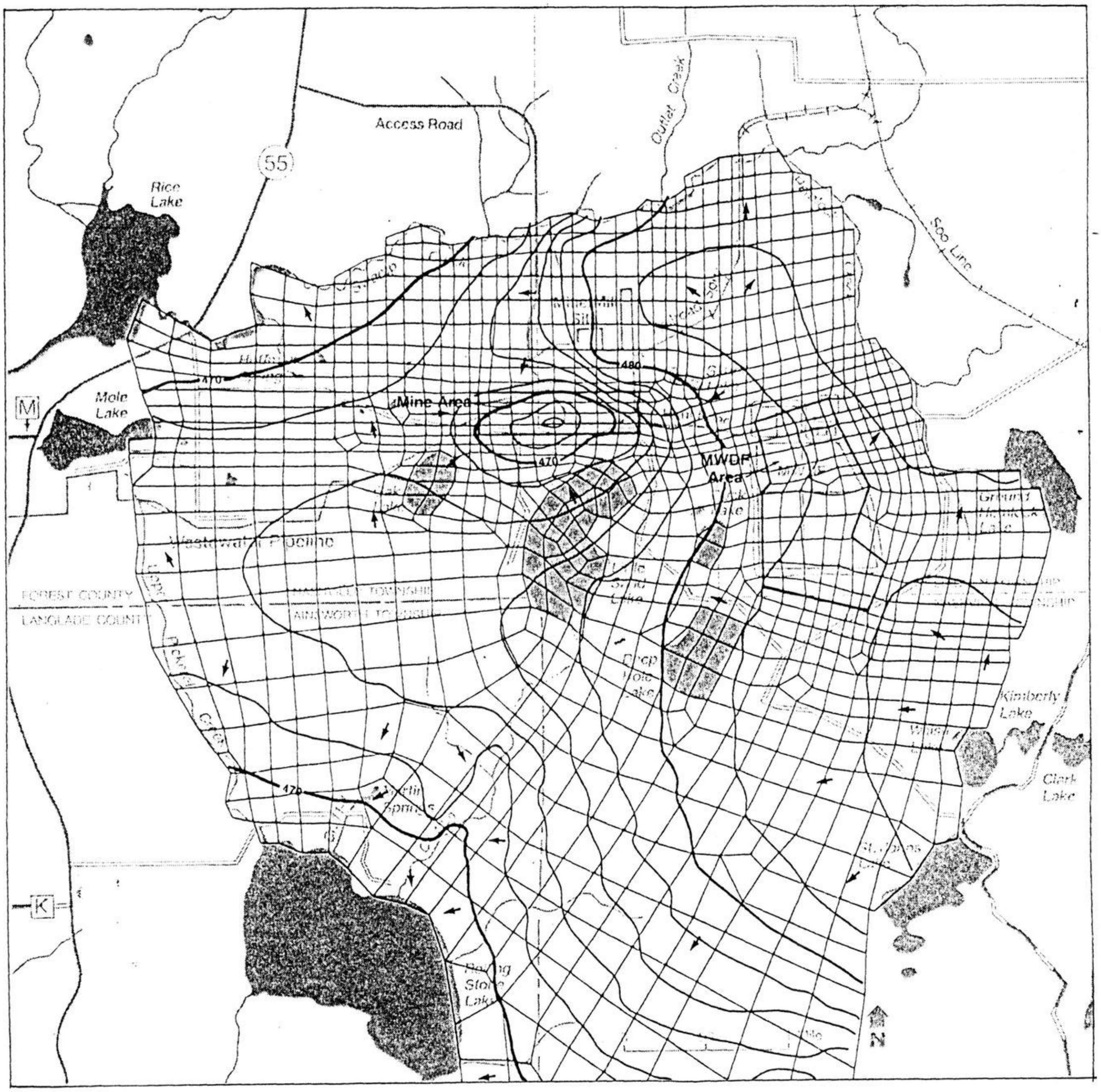


Horizontal Model Input Data

- Stratified Drift Permeability = 34.5 Feet Per Day
- Till/Drift Mixture Permeability = 20.5 Feet Per Day
- Recharge Rate = 8.5 Inches Per Year
- Thickness of Saturated Materials = Values Selected Based on Measured Thicknesses

Potentiometric Surface

Predicted Full Impact Conditions

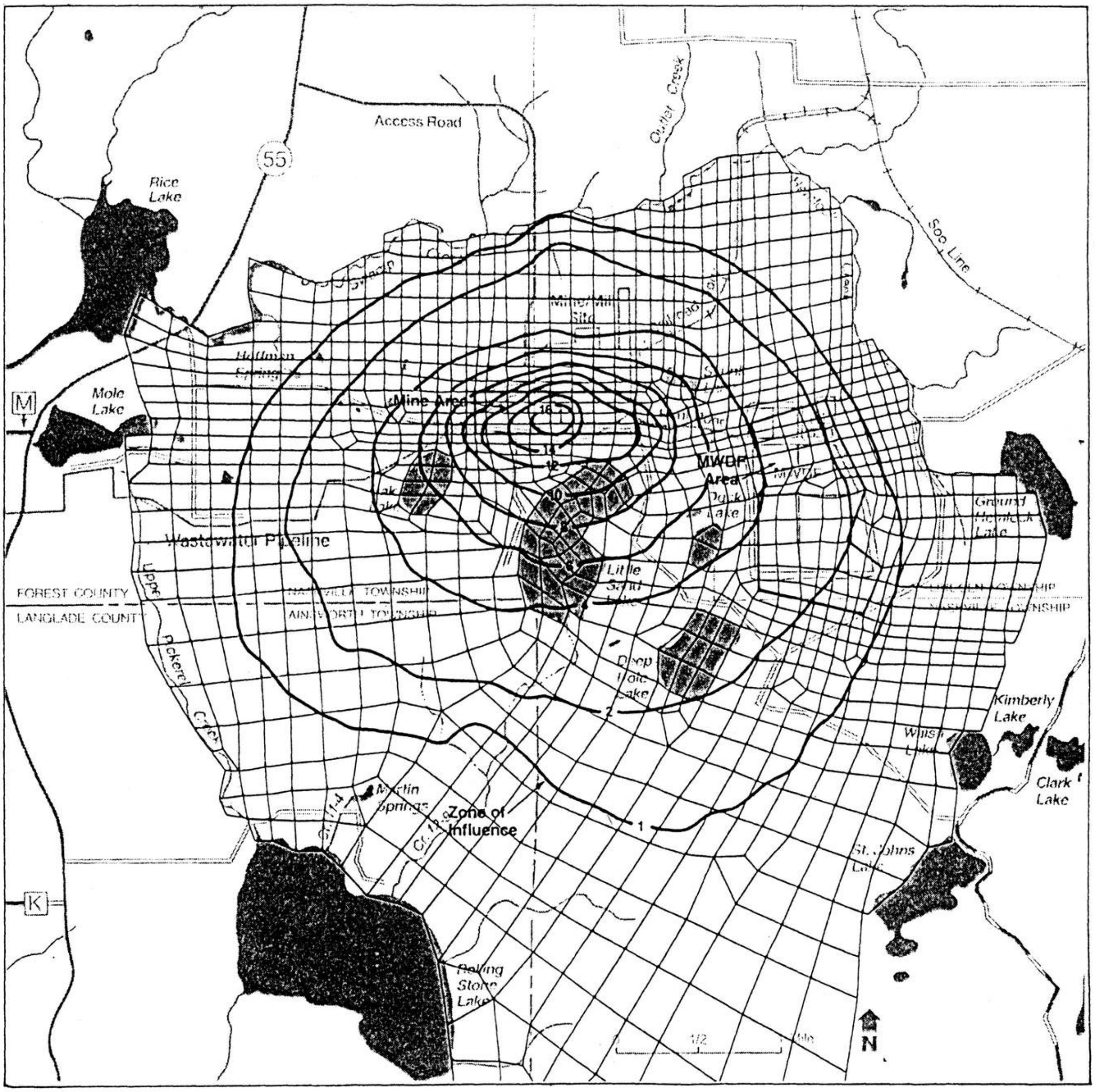


NOTE: Prediction based on 8.5 inches per year recharge

Legend
— Ground water contours in meters above sea level
← General ground water flow direction

Potentiometric Drawdown

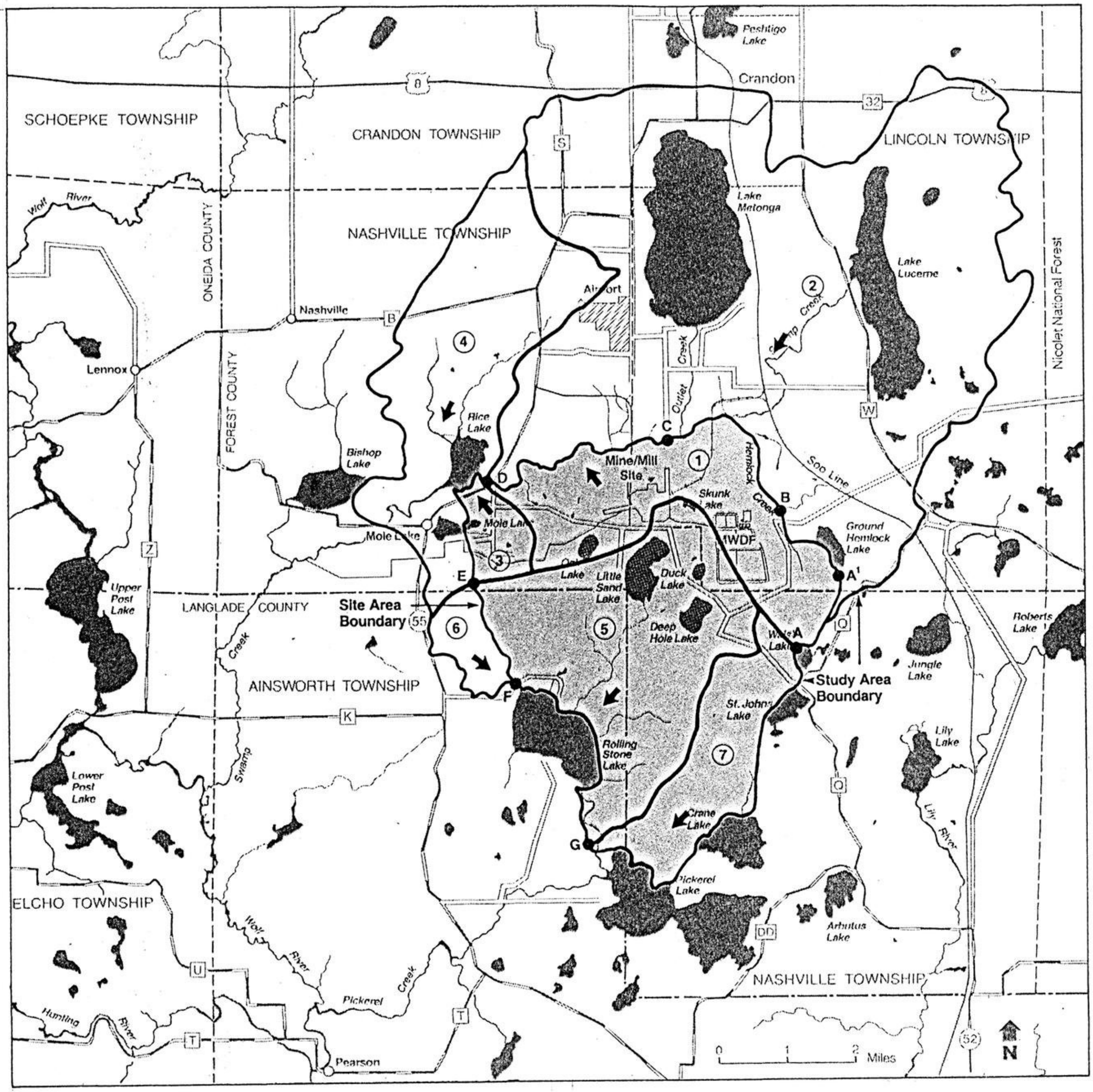
Predicted Full Impact Conditions



NOTE: Prediction based on
8.5 inches per year recharge

Legend
— Ground water decline contours in meters

Drainage Basins



Legend

- ② Basin number
- General direction of ground water discharge
- Basin boundary
- A–B Site area boundary segment

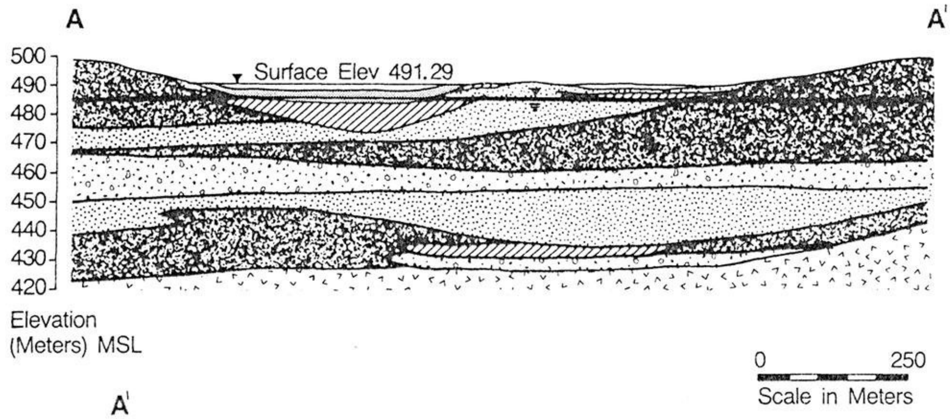
Stream Flow Rates

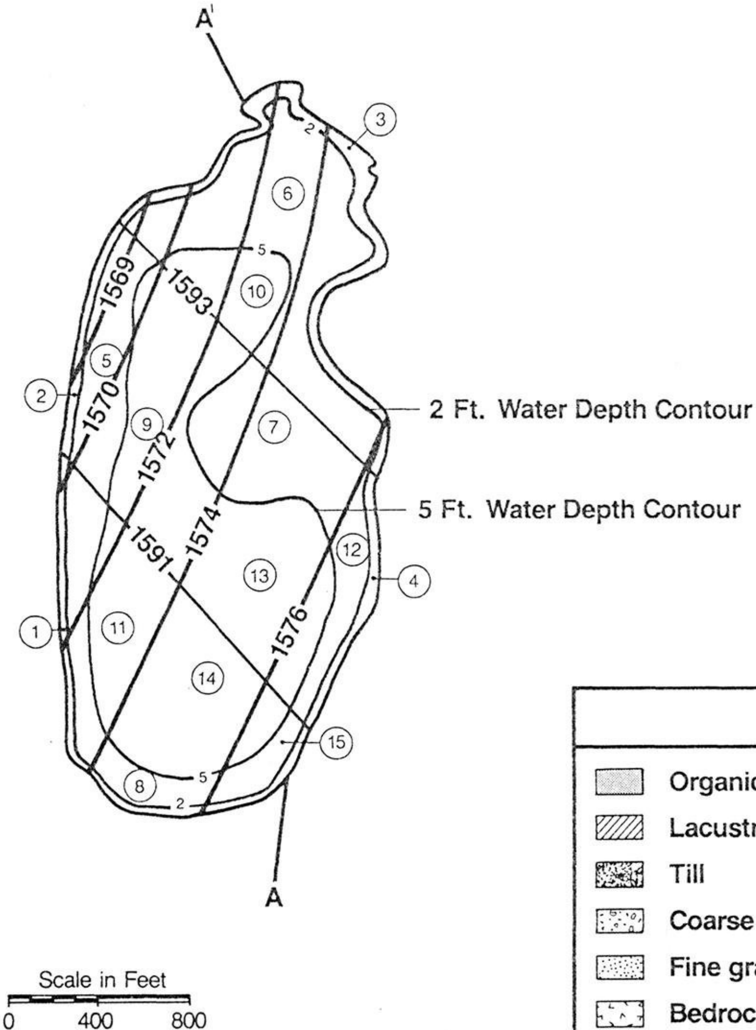
Full Impact Conditions

		Calculated Average Annual Total Flow Rate (cfs)			Average Annual Base Flow Rate (cfs)		
Segment Description	Segment	Pre-Construction	At Full Impact	Percent Reduction	Pre-Construction	At Full Impact	Percent Reduction
Hemlock and Swamp Creeks	ABCD	46.2	44.71	3.2	19.0	17.51	7.8
Rolling Stone Lake and Pickerel Creek	EFG	14.1	13.81	2.1	7.0	6.71	4.1

Duck Lake Area

Cross Section and Plan View

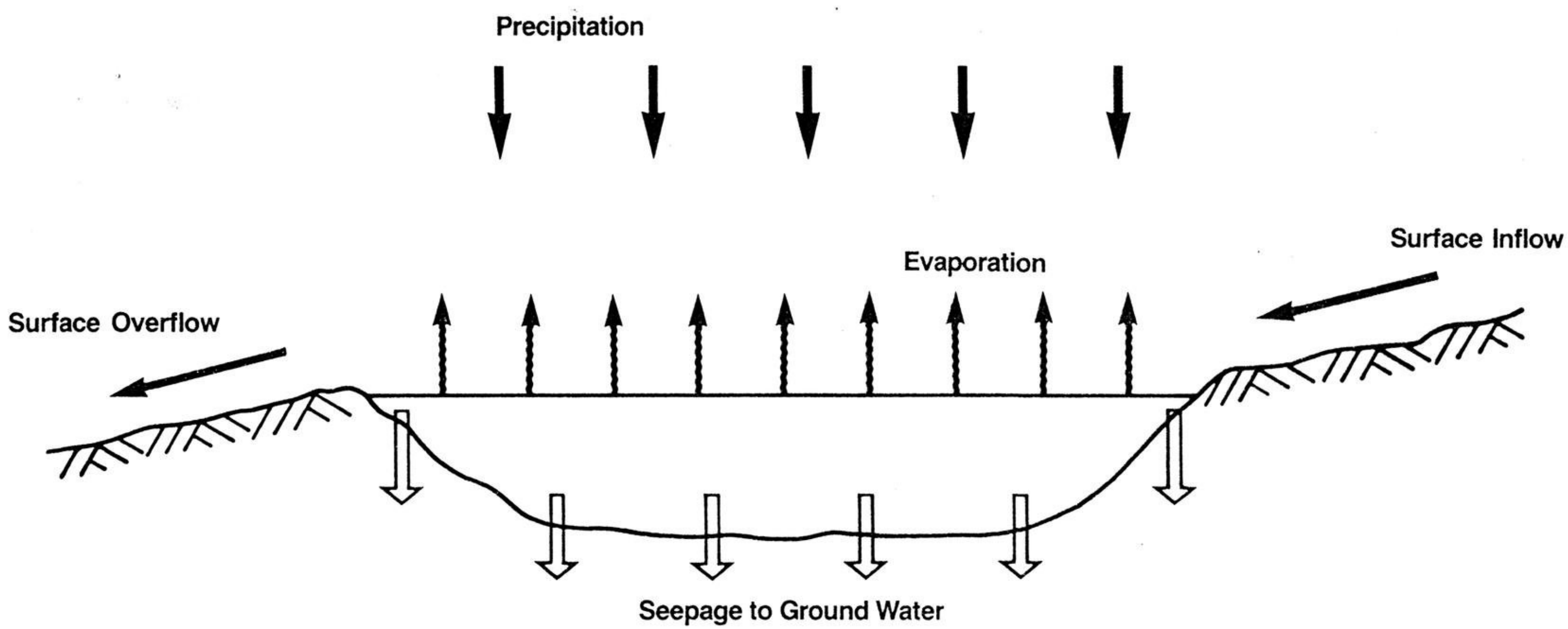




Legend

- Organic silt
- Lacustrine
- Till
- Coarse grained stratified drift
- Fine grained stratified drift
- Bedrock
- Lake water level
- Ground water potentiometric surface
- -1593- Preconstruction potentiometric surface in feet above MSL
- -1576- Predicted potentiometric surface (Full impact conditions) in feet above MSL
- (10) Zone number

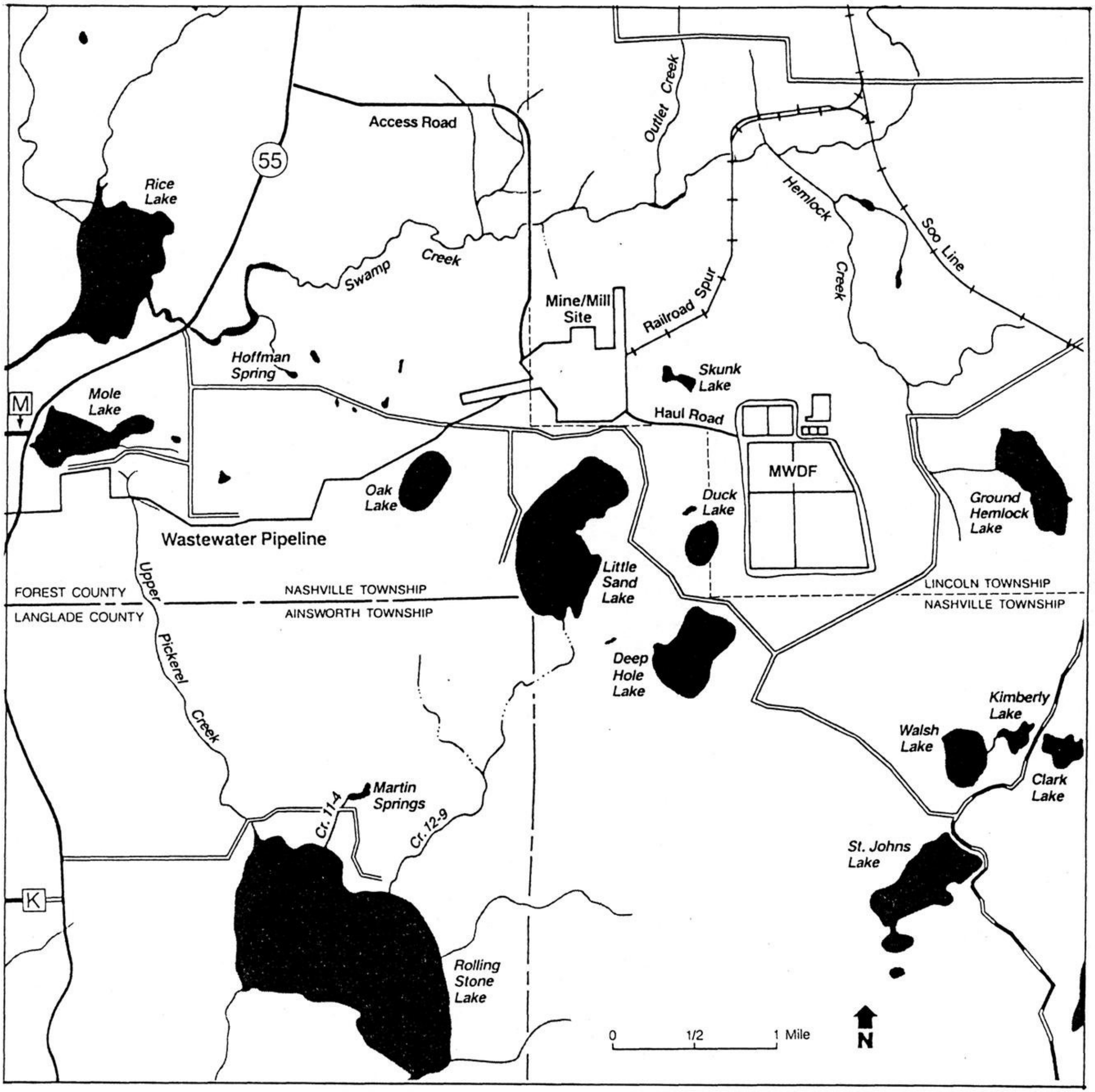
Lake Water Balance Components



Gains	Losses
• Surface Inflow	• Surface Outflow
• Precipitation	• Evaporation
	• Seepage

Change in lake level equals gains minus losses

Project Area Map

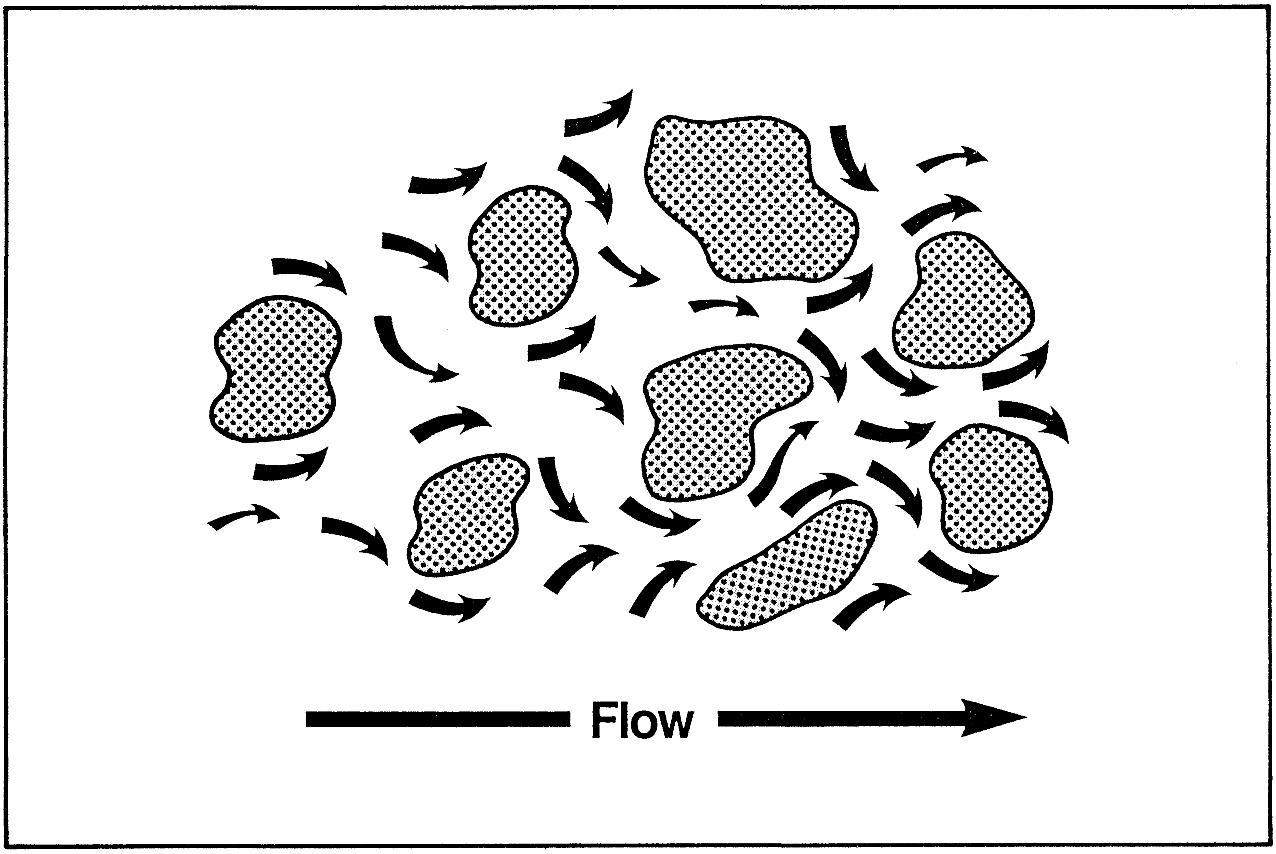


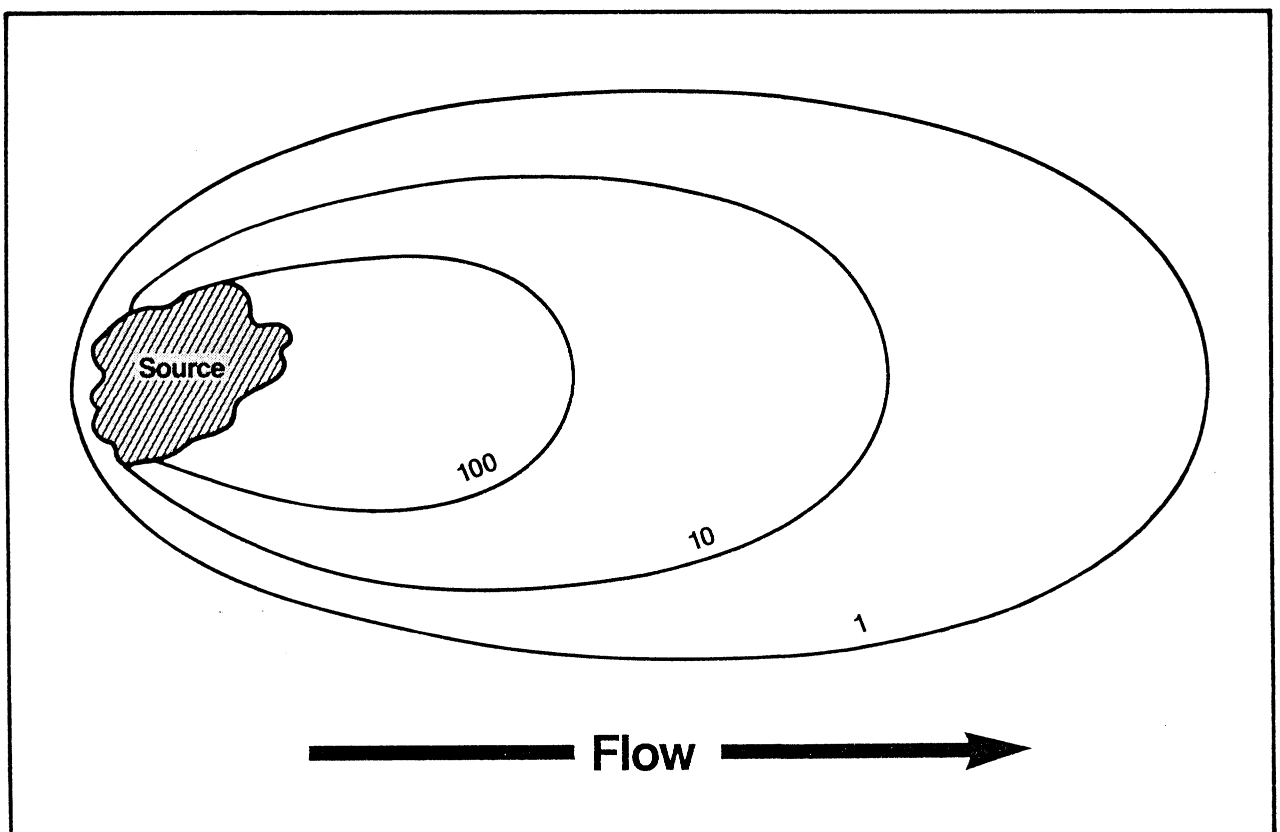
Baseline Water Quality

Parameter	Average Ground Water Concentration[1]	Average Surface Water Concentration[2]	Drinking Water Standards
Total Dissolved Solids	1.66	153	500
Arsenic	<0.001	<0.001	0.05
Sulfate	<9	<4	250
Iron	1.74	0.11	0.3
Manganese	0.42	0.028	0.05

[1] Concentration in Parts Per Million
[2] Represents Hemlock Creek Water Quality

Dispersion Phenomena



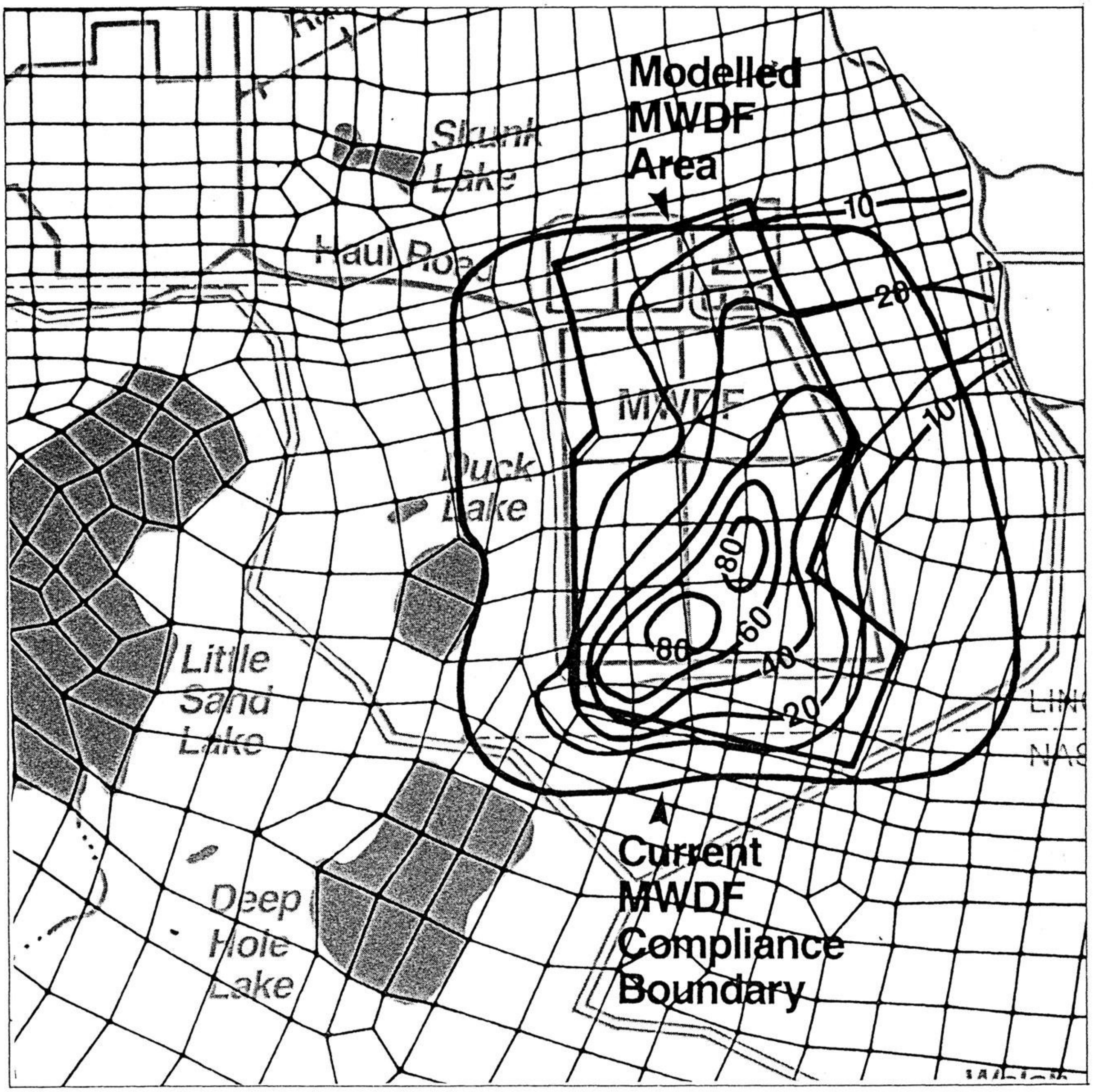


Tailings Seepage
Projected Chemistry

Concentrations in Parts Per Million		
Parameter	**Concentration Years 5-79**	**Concentration Years 80+**
Total Dissolved Solids	3,000	3,000
Arsenic	0.5	0.03
Sulfate	2,000	2,000
Iron	30	0.02
Manganese	20	0.02

Predicted Sulfate Concentrations

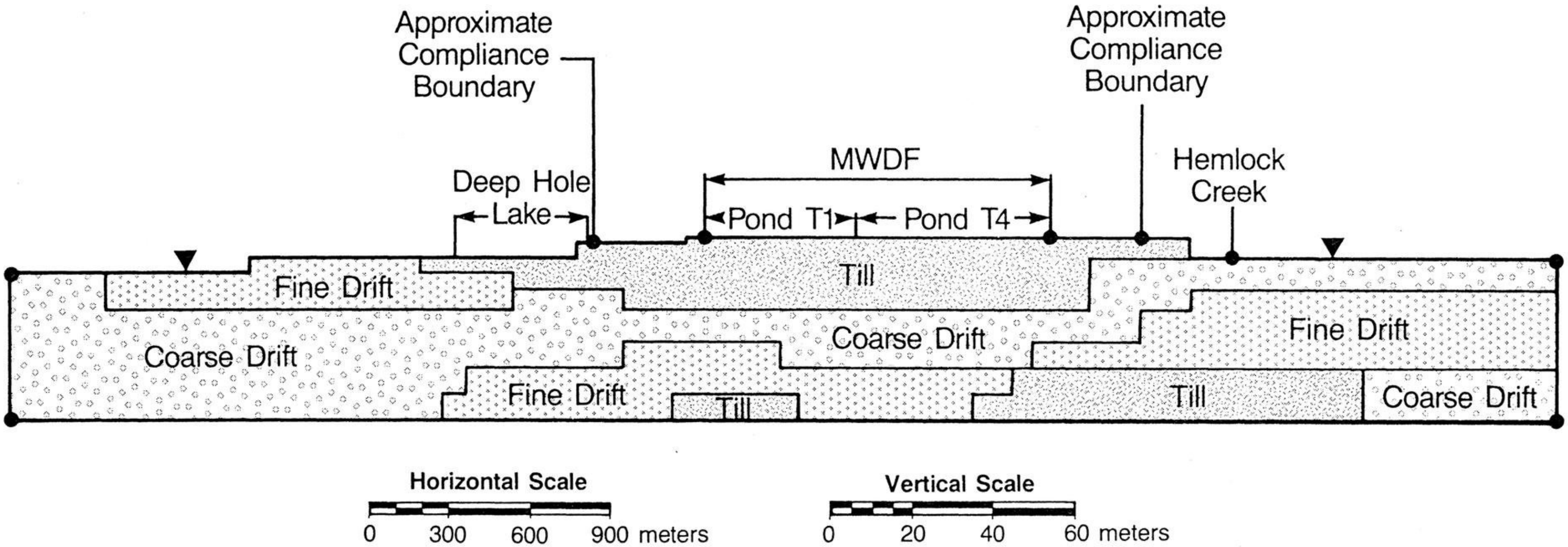
Full Impact Conditions



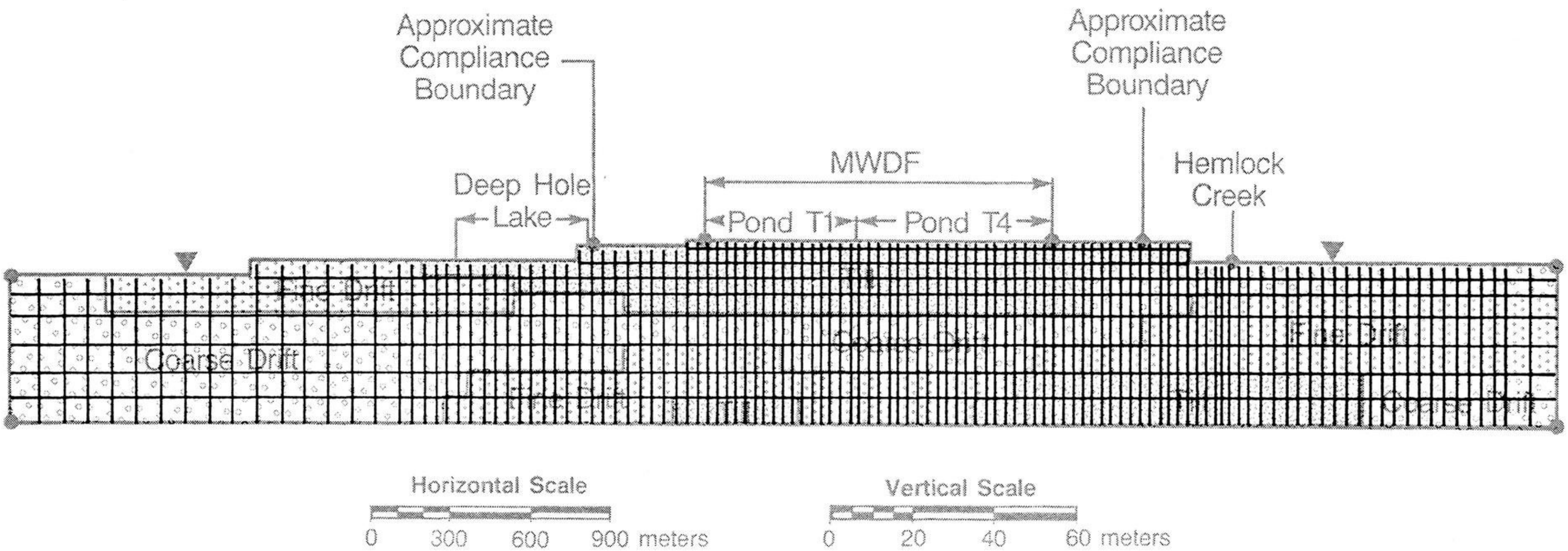
Legend

Sulfate concentration contours part per million (ppm)

Vertical Model Geologic Section

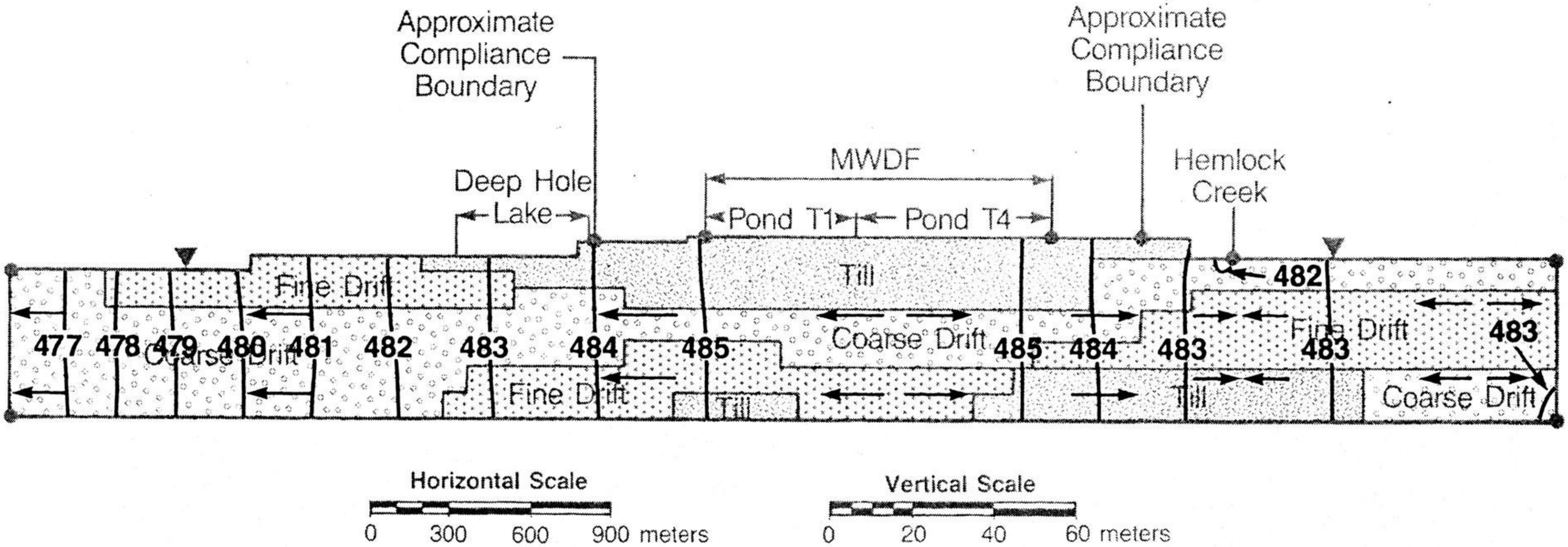


Vertical Model Grid System



Calibrated Potentiometric Surface

Vertical Model



Legend

- **Equal potentiometric lines in meters above sea level**
- Ground water flow direction

Predicted Steady State

Sulfate Concentrations