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REPORT

Environmental Impact Report for the Kennecott Flambeau Project

Scope I.D.: 87K10

Volume I - Report Narrative

Kennecott Minerals Company
Ladysmith, Wisconsin

April 1989

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Kennecott

87K10-61

Kathy Curtner, Acting Director
Wisconsin Department of Natural Resources
Bureau of Environmental Analysis and Review
P. O. Box 7921
Madison, WI 53707

Dear Ms. Curtner:

RE: Kennecott Flambeau Project
Environmental Impact Report

Kennecott Minerals Company (Kennecott) is pleased to provide the Wisconsin Department of Natural Resources (WDNR) with 40 complete copies of the report and appendices titled *Environmental Impact Report for the Kennecott Flambeau Project* prepared by Foth & Van Dyke.

As per a previous understanding developed with Mr. Robert Ramharter of your staff, it is our understanding that the WDNR will be responsible for the distribution of the final EIR to appropriate state and federal agencies. Kennecott will distribute the document to appropriate local officials.

This Environmental Impact Report has been prepared and is submitted to support the Mining Permit Application for the Kennecott Flambeau Project which has been simultaneously submitted to Mr. Gordon Reinke, Bureau of Solid Waste Management, WDNR.

Kennecott requests that the Wisconsin Department of Natural Resources initiate the following action on the documents being filed:

1. Prepare and finalize a draft and final Environmental Impact Statement (EIS) for the proposed Project described in the EIR and Mining Permit Application.

2. Coordinate with federal agencies to assure that the Department's EIS will be responsive to the needs of federal agencies that have permitting jurisdiction over the proposed Project.

3. Review and approve all permit applications, license applications, and similar documents regarding the proposed Project that are filed with and require approval of the Department.

If you or your staff have any questions regarding the final EIR please contact me at your convenience.

Sincerely,

KENNECOTT

Lawrence E. Mercando

Lawrence E. Mercando
Director, Process Development

Enclosure

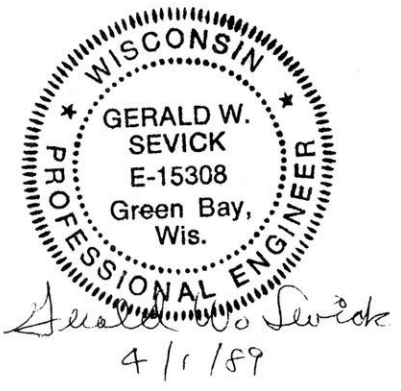
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VOLUME 1
ENVIRONMENTAL IMPACT REPORT
FOR THE
KENNECOTT FLAMBEAU PROJECT



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APRIL 1989

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PROJECT SUMMARY

Kennecott Minerals Company (Kennecott) has a long history of metal exploration in Wisconsin, beginning in the early 1950s. The relatively small Flambeau copper deposit, located approximately one mile southwest of Ladysmith in Rusk County, was discovered in 1968. In 1974, after delineation drilling of the deposit and environmental baseline studies had been completed, the company submitted an Environmental Impact Report (EIR). During the next two years Kennecott submitted an addendum report to the EIR and a detailed mine permit application to the Wisconsin Department of Natural Resources (WDNR). In 1976, an Environmental Impact Statement (EIS) prepared by the WDNR was approved. However, later that year Kennecott withdrew the mine permit application and postponed plans for developing the project until 1987.

Kennecott has revised its original mine development plans which were used as a basis for the 1976 EIS. The project has been scaled down to its current scope and a carefully engineered plan has been developed to achieve the proposed action with minimal impact to the local community natural environment. Evaluation of the proposed plan and alternatives to this plan were heavily influenced by lengthy public discussions. Public concerns, as well as positive input during the 1976 EIS process and negotiation of the 1988 Local Agreement with local municipalities provided Kennecott with invaluable local opinion. At the same time, Notice of Intent (NOI) to collect data and Scope of Study (SOS) documents were filed with the WDNR. After discussions with the WDNR, as well as input through a public hearing, Kennecott received the WDNR's concurrence and approval to proceed with a new and updated environment baseline data collection program. Submittal of the EIR, mining permit and reclamation plan have been made in accordance with Wisconsin Statutes.

The attached 1989 EIR, the Mining Permit Application with Reclamation Plan, and various support permits and documents are a result of extensive data collection, synthesis of this data through corporate deliberations, and consideration of public input over the past 20 years. The result is a comprehensive mine development plan, carefully thought out and conceived to co-exist within the surrounding environment without adverse long range impacts.

The steeply dipping Flambeau deposit is tabular in shape and has been delineated by over 100 diamond drill core holes. A like number of soil borings and groundwater monitor wells have determined the depth of burial of the deposit and hydrogeologic conditions. The top 225 feet of the deposit has been enriched in copper values through actions of an ancient fluctuating

groundwater table, and it is this portion of the deposit that will be mined. The lower portion of the deposit that contains lessor copper values has been evaluated and judged by Kennecott to be uneconomical based upon projected metal prices.

The proposed action as described in detail within the Mining Permit is substantially reduced in scope and size from the original 1976 proposal. It will take approximately one year to construct the various surface facilities to service the mine as well as to expose the deposit. Mining will occur, over a six year period, within a small, 32-acre open pit using conventional shovel and truck hauling methods. The open pit will be safely located approximately 140 east of the Flambeau River and 600 feet west of STH 27. Ore will be crushed to approximately 12 inches in size and shipped via rail for out-of-state processing at an existing mill. Average daily ore production rate will be 1300 tons for a yearly total of 320,000 tons of ore. Mining will normally occur five to six days per week, eight hours per day although construction activities will probably occur around the clock.

Total waste materials to be excavated over the construction and mine production life will be about 17,500,000 tons. These materials will be carefully segregated for temporary, short-termed surface storage based upon sulfur content. Extensive waste rock and overburden characterization testing indicate that certain waste rock containing over one percent sulfur are referred to as Type II material will be stored in a lined stockpile with leachate collection system. This material will be stored in a managed stockpile covering about 27 acres south of the pit. Contact water from this stockpile and from the open pit will be directed to a wastewater treatment plant. Waste rock and overburden containing less than one percent sulfur referred to as Type I material, can be safely stored on an unlined 40 acre stockpile located north of the open pit. Water from this stockpile will be directed by gravity to a series of settling ponds for clarification. The stockpile heights will range from 60 to 70 feet. A third stockpile for the topsoil will cover about seven acres and serve as a public observation post as well as a vegetated buffer between the pit and STH 27.

Various other ancillary buildings such as a maintenance shop, administration office, guard house, etc. will be positioned south of the pit between the ore crusher and wastewater treatment plant. The entire mine site will be enclosed within a security fence except for the railroad spur east of STH 27.

At the end of the mining operation, the waste rock and overburden will be sequentially returned to the open pit in the order that they were excavated together with settling pond and wastewater plant precipitates. In this fashion, the open pit will be returned to its approximate original contour. There will be sufficient waste rock and overburden to refill the open

pit since a rock swell factor increases the solid rock volume when broken and compacted during mining and backfilling respectively. In addition 160,000 cubic yards of material such as sand, gravel and concrete bought on-site during construction will also be backfilled into the open pit. All ancillary facilities will be removed during site reclamation unless requested to be left by local governments. The backfilling operation is anticipated to take approximately two years.

Several alternatives to the project were considered before selection of the preferred action described above. Primary considerations during the alternative evaluations were the placement of various project components as closely around the open pit as possible and out of the 1,000-foot set back from STH 27. However, these alternatives, including in-pit storage of waste rock, were found to be impractical since the east end of the pit intrudes within the setback as well as for various environmental and economic reasons.

A comprehensive environmental baseline data collection program was completed in 1987 and 1988 to cover a full 12-month period. During this intensive data collection period, information was gathered from the regional and local areas including archeological background, climate and ambient air quality monitoring, geology, waste rock characterization testing, surface and groundwater monitoring, river sediment studies, aquatic and terrestrial biology, ambient noise, land use and socio-economics. This baseline data is supplemented by much of the previous baseline data collected from 1968 to 1974 and by additional monitoring work conducted by Kennecott in part of the period between the two EIR documents.

Impacts of the preferred alternative were carefully evaluated and generally found to be insignificant due to the short term, and small scaled nature of the operation. In general, the decline in groundwater levels near the pit that were predicted by a 1983 modeling program using a considerably larger and deeper open pit is not expected to affect any private well water levels surrounding the project area more than that expected as a result of normal groundwater fluctuations. Regardless, private well owners south of the Flambeau River that surround Kennecott land are protected under the terms of a Local Agreement. In this agreement, Kennecott guarantees a water supply to any significantly affected residential well located in agreed-upon areas provided the affected well in question was impacted by the mining operation.

Bedrock groundwater conditions similar to those existing before mining will be returned after reclamation. As a precaution, lime for neutralization of contact water will be added as the waste rock is backfilled into the open pit.

Protection of surface water quality and quantity has also been an integral part of the project design. A complete water control system will be employed once mining commences to direct all non-contact water, i.e. water that does not come into contact with ore or Type II materials, to ponds for settling. Once suspended solids in the water settle, the water will be decanted either to a nearby wetland or to the Flambeau River. Contact water from within the open pit and Type II stockpile will be directed towards the wastewater treatment plant. Here the water will be neutralized and treated to meet desired effluent quality. There will be no long termed impacts to the quantity of either the surface or groundwater resources.

The socio-economic impact is very positive as the potential economic benefit to local governments and the state is predicted to be about $36 million over the life of the project. Local units of government (Rusk County, City of Ladysmith, and Town of Grant) will receive approximately $2,400,000 to $4,400,000 million as well as $720,000 in property taxes. The existing infrastructure of the community can readily accept a project of this size. Fifty to 60 jobs will be created in an area of Wisconsin where unemployment is running well above the state average. Kennecott has guaranteed that 75 percent of the jobs during mining operation will be given to residents in or within ten miles of the Rusk County border. The fiscal impact will be significant with an estimated total labor cost of over $14,000,000 including fringe benefits. Approximately $11,000,000 of the payroll not including benefits will significantly stimulate the local economy through increased sales and saving deposits. Infrastructure within the city of Ladysmith is more than adequate to handle a project the size of the Flambeau mine project.

Total suspended particulate from the project has been calculated to be a maximum of 53 tons per year for the entire project area. This is well below the 250-tons-per-year rate at which the Clean Air Act would require a Prevention of Significant Deterioration review and permit. Likewise, noise levels from the crusher and truck haulage operations were carefully studied and modeled. Results from those studies showed that four Kennecott-owned residences would be subjected to noise levels of between 6 to 15 dBA. However, noise levels would not exceed levels acceptable for residential areas outside of lands owned by Kennecott.

A temporary effect on the local area will be changes in land use. However, by careful site selection the entire operation has been confined to an area less than 180 acres including the spur line. Through careful siting of the plant facilities, disturbance to the wetlands has been minimized to 8.3 acres. A wetland located northwest of the open pit will be preserved during the operation by additions of water. The largest wetland in the vicinity of the open pit, located east of STH 27, is perched and therefore will not be impacted by the project. None

of the wetlands inventoried serve any unique functions nor are they uncommon in the region. Mitigation of wetlands during and after the operation will result in essentially no long term loss of this land type because of the mining operation.

A total of 66 acres of agricultural land will be temporarily taken out of production, however, none of this agricultural land falls within the Rusk County Farmland Preservation Plan. No currently habitated farms or residences will be affected by the project.

Another impact of the mining operation will be the removal of the open pittable portion of the deposit. However, extraction of this ore would result in a local mineral reserve becoming a long term useable resource to the nation. Copper can remain in use for over a century through continued use as in electric wiring or through recycling. Backfilling of the open pit will be conducted in such a fashion as not to preclude extraction of the deeper mineralization should future metal prices determine this resource to be economical.

Finally, the small area affected by the project is not known to support or to play an important role in the life cycle of any rare, threatened or endangered aquatic or terrestrial species listed by the State of Wisconsin or U.S. Fish and Wildlife Service.

Mitigation plans for this project area started many years ago with the planting of thousands of trees by Kennecott. Many of these trees, plus naturally occurring forests will be left in place during the operation to serve as visual screens and buffer areas between the mine and the public. Kennecott plans to move many natural and company planted trees out of the mine site to temporary on-site nurseries. Upon conclusion of mining and backfilling and grading of the mine site most of these trees will be planted over the reclaimed area. Additional trees, shrubs and ground cover seed will be planted to complete the reclamation job.

Monitoring of the reclaimed site is the final responsibility that Kennecott will fulfill in its obligation to operate and return the project area to close to its original condition.

Under terms of the Local Agreement long range monitoring will be conducted over a 30-year period. During this time, Kennecott will monitor surface and groundwater quality, assess and bolster the reclamation process as necessary and manage the site in a prudent and conscientious manner. While the mine is in operation a bond to a maximum amount of $6,041,000 will be posted as a guarantee to the state that sufficient funds are available to complete the reclamation plan.

HOW TO USE THIS ENVIRONMENTAL IMPACT REPORT

This Environmental Impact Report (EIR) concerning the proposed Flambeau mining project near Ladysmith, Wisconsin, is one of a number of documents which Kennecott Minerals Company (Kennecott) is submitting in order to fulfill the requirements of the mine permitting process in the state of Wisconsin. In addition to the EIR, Kennecott is submitting a Mining Permit Application pursuant to NR 132, which provides a detailed description of the proposed mining operation. Other permit applications and documents being submitted in connection with this mining proposal, in accordance with applicable portions of Wisconsin and Federal regulations, include the following:

- Air Pollution Control Permit
- Industrial Wastewater Treatment Plant Permit
- Wisconsin Pollution Discharge and Elimination System Permit
- Water Quality Certification
- Groundwater Withdrawal Approval
- Water Regulatory Permits under Wisc. Stat. ch. 30
- Water Regulation Permit under Section 404 of the Federal Clean Water Act
- Permit to Excavate and/or Fill on Highway Right-of-Way
- Railroad Spur Grade Crossing
- Private Entrance
- Request for Storage of Explosives
- Notice of Blasting

All of these documents are related to the project and each provides information concerning the proposed project as it pertains to that particular permit or approval. The documents cross-reference each other where necessary. For these reasons, the documents should be read together in order to comprehend the scope of the entire project. The EIR and the Mining Permit Application, in particular, should be considered as companion documents.

Overview of Environmental Impact Report

The EIR is divided into major sections as described in the following paragraphs:

Section 1.0, *Introduction,* accomplishes three tasks: 1) it summarizes the history of exploration of the Flambeau deposit; 2) it states the purpose of this EIR; 3) it describes the specific actions which are requested of the Wisconsin Department of Natural Resources.

Section 2.0, *Alternatives,* describes the process by which the reasonable alternatives to the project have been considered, and a preferred project configuration chosen.

Section 3.0, *Description of Environmental Setting,* discusses the background environmental setting of the proposed project. This section is divided into thirteen subsections, each of which describes the physical environment of the project in terms of a particular environmental discipline.

Section 4.0, *Environmental Impacts*, discusses both the environmental impacts of the proposed project and the impacts which would occur if other alternatives are selected.

Section 5.0, *Mitigation of Impacts*, describes Kennecott's plans for minimizing impacts to the environment both during and after mining operations.

Section 6.0, *References*, lists all references used in the compilation of this EIR in a standard bibliographic format. References generally available in the scientific literature are given as such. Reports written by consultants working on the EIR are generally referenced as appendices attached to the EIR. Unpublished materials not attached as appendices to the EIR have been placed into the Kennecott Flambeau Project file at the Wisconsin Department of Natural Resources, Madison, Wisconsin, where such materials are available for public viewing.

Section 7.0, *Appendices*, contains all appendices for the EIR. The appendices are in order by section. The appendix identification number has been assigned by giving it the second-level section number followed by a letter to designate the individual appendix. For instance, the first appendix to Section 3.5 (Geology) is Appendix 3.5-A; the second is Appendix 3.5-B, and so on.

A glossary of commonly-used terms, abbreviations, and acronyms is provided in this front matter of the report, before the Table of Contents.

Area Definitions

Throughout the EIR, there are references to the "project area," the "mine site," and the "study area." These terms have specific meanings, as follows:

- Project Area - This is defined as the area east of the Flambeau River, west of State Highway 27, north of the south line of Section 9, and south of Blackberry Lane. Also included is a 24 to 36-foot wide corridor east of State Highway 27 on which the railroad spur line is to be constructed. (Refer to Figure No. 2.4-1 in Section 2.4.2.1.)

- Mine Site - This is defined as an area within the project area which will be enclosed by a security fence and which encompasses the proposed open pit, stockpile sites, plant area, and other ancillary surface facilities.

- Study Area - This is a term which is uniquely defined by each specific environmental discipline within the EIR. It denotes the area within which the discipline was studied for this project. The study areas for different disciplines differ in size and emphasis.

Figures and Tables

Numbering of figures and tables is similar to that described above for appendices. Identification numbers have been assigned to figures and tables by giving them their second-level section number followed by another number to designate the individual figure or table. For example, the first figure in Section 3.5 (Geology) is Figure No. 3.5-1; the second is Figure No. 3.5-2, and so on. Numbering of tables is exactly the same as for figures. The first table in Section 3.5 is Table No. 3.5-1.

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Northern Lake Services 400 North Lake Avenue Crandon, WI 54520	72102640
Enviroscan 303 West Military Road Rothschild, WI 54474	737053130
McCoy and McCoy 85 East Hoel Avenue P. O. Box 907 Madisonville, KY 42431	No Wisconsin Certification Quality Control for Uranium Analysis Certified through U.S. EPA- Las Vegas

Glossary of Terms

The Kennecott Environmental Impact Report

Term	Definition
A-weighted	A frequency weighting network which corresponds to the A Scale on a standard sound level meter. The A Scale suppresses frequencies below 1,000 hertz (cycles per second).
Acoustical	Pertaining to hearing or sound.
Algae	A class of plants including microscopic, single-celled, and more complex, such as seaweed. Occurring in water or on land.
Amphibians	Cold-blooded vertebrate animals with gilled larvae but air-breathing adults.
Anaerobic	The absence of oxygen.
Anuran	Frogs and toads; an order of amphibians; "without tails".
Anomalous	Abnormal.
Aquifer	A formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield economical quantities of water to wells and springs.
Archaeological	The study of historic or prehistoric areas or peoples by analysis of their artifacts and other remains.
Artesian	A well or spring deriving its water from a confined aquifer in which the water level stands above the ground surface.
Artifact	An object made by man to be used for some purpose.

Assay	To analyze a material or mineralization for one or more specific components.
Avian	Pertaining to birds.
Bench Mark	A permanent natural or artificial object with a known elevation. Used by surveyors to determine other elevations.
Benthic	All bottom terrain, from a shoreline to the greatest depth of a water body.
Boomshocking	Use of an electric shocking device, mounted on a long pole, to collect live fish.
C-weighted Scale	A frequency network which corresponds to the C Scale on a standard sound level meter. The C Scale provides even responses through the entire audible spectrum.
Canopy Species	A species of tree forming the uppermost, spreading, branchy layer of a forest.
Carnivorous	Flesh-eating.
cfs	Cubic feet per second.
Chert	A compact siliceous rock formed of interlocking quartz or grains generally not discernable under a microscope.
Colluvial	Consisting of rock fragments and soil.
Composite Sample	A sample created by combining a number of individual samples.
Covariate	A variance according to a fixed mathematical relationship.

Creel Census	Fish sampling data compiled from a census of fishermen.
CTH	County Trunk Highway.
dBA	Decibels, A-weighted.
dBC	Decibels, C-weighted
Decibels	A logarithmic unit which expresses the ratio between two sound pressures. A ratio of 10 in root-mean-square pressure corresponds to a difference of 10 decibels.
Deposit	A term used to designate a natural occurence of a useful mineral or collection of minerals in sufficient extend and degree of concentration to invite mining.
Detritus	Material that is produced by the disintegration of rock and has been moved from its site of origin.
Demographics	Population statistics.
Diatom	A microscopic, single-celled plant which grows in marine or fresh water.
Direct Shear Test	A soil or rock test in which a normal, perpendicular stress is applied to the face of the sample and a shear force is applied parallel to the face of the sample.
Durable Manufacturing	The making of permanent or lasting goods.
EIR	Environmental Impact Report.
EIS	Environmental Impact Statement.
EMT	Emergency Medical Technician. A professional certified as an ambulance attendant.

Endangered Species	Species, listed by a federal or state agency, that are in danger of extinction throughout all or significant portions of their ranges.
Energy-averaged	A mean obtained by conversion of sound levels in decibels to correspond to sound pressures on a logarithmic scale.
Ericad	A family of plants.
Evapotranspiration	Loss of water from a land area through plant transpiration and soil evaporation.
Gamma-logged	A method of logging boreholes by detecting the natural radioactivity of the rock.
Geomechanical	Combining structural geology with the response of natural earth materials to applied deforming forces.
Genus, s.; Genera, pl.	The major subdivision of a class of plants or animals, including more than one species.
Gill Netting	A fish sampling method which uses nets to capture fish by their gills.
Gley	A blue-grey soil developed under moisture.
Gossan	A yellow to reddish deposit of hydrated iron oxides produced near the surface by the oxidation and leaching of sulfide minerals.
gpd	Gallons per day.
gpm	Gallons per minute.
Ground-truthing	Confirmation by field observation of information interpreted from aerial photography.

Groundwater Table	The subsurface boundary between the saturated and unsaturated zones.
Habitat	The environment which supplies the life needs of a plant or animal.
HDPE	High density polyethylene. A lining material commonly used to seal areas that contain leachates and prevents escape to the environment.
Herbivorous	Plant-eating.
Hydraulic Gradient	The rate of change of total groundwater head per unit of distance of flow in a given direction.
Hydric	Refers to a soil subject to relatively consistent saturation.
Hydrophytic	Pertaining to a plant that grows in water or in wet soil conditions.
ICP	Inductively Coupled Plasma. A spectrophotometer used in the analysis of metals using atomic emissions.
Intermittent	Alternately ceasing and starting again. A stream or lake where water flows only part of the time.
Jointing	Discontinuous fractures in rock along which no appreciable movement has occurred.
Lacustrine	Pertaining to lakes.
Leaching	To wash or drain by percolation. Also, to dissolve minerals out of rock, soil or other solid materials.
Lithology	The character of a rock formation.
Littoral	Occurring near the shoreline.
Macrophytes	Large vascular plants.

Macroinvertebrates	Macroscopic animals without backbones.
Mean	Average.
Median Household Income	The middle income point, where an equal number of incomes fall above it and below it.
Mesophyte	A plant that grows in well-balanced moisture conditions.
Metamorphism	The altering of rocks by pressure, heat, and introduction of new chemical substances.
ml	Milliliter. One thousandth of a liter; equivalent to a cubic centimeter.
MSL	Mean sea level.
Net Fiscal Balance	The difference between total government revenues and total government expenditures.
Nonassessed	Land which is not assessed for property tax purposes.
Nondedicated Revenues	Revenues that have not been assigned to specific uses.
Omnivorous	Plant- and flesh-eating.
One-hundred-year Flood	The flood elevation of a river, such that the level is encountered, on the average, only once every 100 years.
Ore body	A volume of rock containing extractable mineral commodities which can be mined and sold at a profit.
Ornithology	The study of birds.
Orthogonal	Intersecting or lying at right angles.

ORTEK	Oneida Environmental Technology Center; a Foth & Van Dyke affiliate providing laboratory services.
OSHA	Occupational Safety and Health Administration.
Outwash	Sand and gravel removed or washed out from a glacier by meltwater streams.
Overburden	Loose friable material, which, for this project includes soil, gravel, till, sandstone and saprolite materials which can be readily ripped by a bulldozer and which overlies the unrippable bedrock.
Own-source Revenues	Revenues coming from local sources, not from intergovermental transfers.
Palustrine	Pertaining to material deposited in a swamp environment.
Perched	Groundwater separated from an underlying body of groundwater by an unsaturated zone.
Periphyton	Aquatic biotic community living on a submerged, fixed substrate.
Permeability	The capacity of rock or soil to transmit water.
pH	The unit used to indicate the acidic-basic balance of a substance.
Phytoplankton	Floating plants, such as diatoms.
Piezometer (PZ)	A special type of groundwater observation well, finished so as to permit the measurement of the water level in a particular stratum or zone.
Pleistocene	A period starting about one million years ago, characterized by widespread glacial ice and the appearance of humans.

Precambrian	Pertaining to the earliest era, which the earth's crust was formed.
Prehistoric	Prior to recorded history.
psi	Pounds per square inch.
PVC	Polyvinyl chloride.
Pyrite	Iron disulfide, (FeS_2).
Quadrant	A quarter of a circle.
Raptors	A species of predator birds with claws and bills adapted for seizing their prey.
Rhombic	Shaped like an oblique-angled parallelogram.
Riffle	A shallow extending across a stream bed; a short rapid.
Riverine	Pertaining to a river.
Saprolite	A soft, earthy, clay-rich, thoroughly decomposed rock and is characterized by preservation of structures that are present in the unweathered rock.
SEM	Scanning electron microscope.
Slurry	A thin mixture of water or liquid and other substances, such as clay particles.
Sociocultural	Pertaining to the interaction of social and cultural elements.
Socioeconomic	Pertaining to the interaction of social and economic factors.
Sorption	Includes both absorption and adsorption; important to removing pollutant particles.
Sparging	Agitation of a liquid by means of compressed gas entering through a pipe.

Species	The basic category of biological classification of plants and animals; the major subdivision under the genus.
Sphagnum	A soft moss found mainly on the surface of bogs.
STH	State Trunk Highway.
Swale	A slight, marshy depression or drainageway in level land.
Taxanomy	The orderly classification of plants and animals according to their presumed natural relationships.
Threatened Species	Species, listed by a federal or state agency, which are likely to become endangered unless measures are taken to restore the population.
Till	A very poorly sorted mixture of gravel, sand, silt, and clay that was deposited by glacial ice without reworking by meltwater or gravity flow.
Titration	A chemical test to determine the quantity of a constituent in a solution.
Transducer	A device that transmits energy from one system to another.
Translocation	A transfer from one place to another.
Transect	A sampling area in the form of a long, continuous strip.
Triangulation	A surveying technique which uses triangles to establish the distance between points, or their positions.

Triaxial Compression Test	A cylindrical specimen of soil or rock encased in an impervious membrane, subjected to continuing pressure, and loaded externally to failure.
Tricone Bit	A drill bit consisting of three rollers that exert a crushing and chipping action on the rock or sediment.
TSP	Total Suspended Particulates. Entrained particules in the ambient air.
TSS	Total suspended solids in water or other liquid. Those particles that have not settled out of the water column.
ug/g	Microgram per gram; equivalent to parts per million.
ug/m^3	Microgram per cubic meter.
Uniaxial Compression Test	Application of normal stress in a single direction.
Understory	The plants of a forest undergrowth.
USDA	United States Department of Agriculture.
USDOT	U.S. Department of Transportation.
USEPA	U.S. Environmental Protection Agency.
USGS	U.S. Geological Survey.
USH	U.S. Highway.
VPD	Vehicles per day.
VPH	Vehicles per hour.
Vertical Hydraulic Gradient	The flow of a fluid in a vertical direction.
WASS	Wisconsin Agricultural Statistics Service.

Watershed	The contained area which drains by gravity into a given river.
Water Table	See Groundwater Table.
WDNR	Wisconsin Department of Natural Resources.
WDOA	Wisconsin Department of Administration.
Wetlands	(See Appendix 3.8-B.)
WITC	Wisconsin Indianhead Technical College.
Xerophyte	A plant with low water requirements.
Zooplankton	Animal forms of plankton which consume phytoplankton.

1.0 INTRODUCTION

Kennecott Minerals Company (Kennecott) has a long history of metals exploration in Wisconsin, beginning in the early 1950s. The relatively small Flambeau copper-gold deposit was discovered using airborne geophysical techniques in 1968. It is located approximately one mile southwest of Ladysmith and lies between the Flambeau River and State Highway 27.

The size and quality of mineralization at the Flambeau site was determined by over 100 core holes drilled from the surface. In 1974, Kennecott submitted a comprehensive Environmental Impact Report to the Wisconsin Department of Natural Resources (WDNR) in support of a proposed project to develop the deposit. An addendum was filed the following year. In 1976, Kennecott submitted a detailed mine permit application to the WDNR, also in support of the project. An Environmental Impact Statement addressing the project was prepared by the WDNR in 1976 and was approved. That same year, however, the mine permit application was withdrawn by Kennecott, and plans for developing the deposit were indefinitely postponed.

Kennecott has revised its original plans and now proposes to mine the upper portion of the Flambeau deposit. The revised mining plan is substantially reduced in scope and size from the original plan proposed in the 1970s. As described in the accompanying Mining Permit Application, the deposit will be mined from a small 32-acre open pit, and the ore will be shipped out-of-state for processing at an existing mill. At the completion of mining, the open pit will be backfilled and the mine site reclaimed to its approximate original state. Figure No. 1.0-1 illustrates the proposed site plot plan for the project.

In July 1987, Kennecott filed a document titled *Notification of Intent to Collect Data - Kennecott Flambeau Project* with the WDNR, in accordance with NR 132.05. The document was prepared to notify the WDNR of Kennecott's intent to collect data in support of a mining permit application for the Flambeau deposit.

An additional document was filed in October 1987, titled *Scope of Study for the Kennecott Flambeau Project,* in accordance with NR 132.05(7). This second document outlined the proposed scope of the environmental studies to be performed, and incorporated comments received from the WDNR and those generated by the general public during a September 9, 1987 Notice of Intent public hearing held in Ladysmith. Subsequent to the public hearing the WDNR approved a Scope of Study plan.

On August 1, 1988, Kennecott signed a Local Agreement with Rusk County, the Town of Grant, and the City of Ladysmith for

development of the Kennecott Flambeau Mine and was issued a *Conditional Land Use Permit.*

1.1 Purpose of the Environmental Impact Report

This Environmental Impact Report is submitted in fulfillment of the applicable regulatory requirements and in support of the accompanying Mining Permit Application and additional necessary permits.

1.2 Action Requested of the Wisconsin Department of Natural Resources

Kennecott requests that the Wisconsin Department of Natural Resources initiate the following action on the documents being filed:

1. Prepare and finalize an Environmental Impact Statement (EIS) for the proposed Project described in the EIR and Mining Permit Application.

2. Coordinate with federal agencies to assure that the Department's EIS will be responsive to the needs of federal agencies that have permitting jurisdiction over the proposed Project.

3. Review and approve all permit applications, license applications, and similar documents regarding the proposed Project that are filed with and require approval of the Department.

Figures for Section 1.0



NOTES:

1. SITE LOCATION: SECTIONS 9, 10, 15 & 16, T34N, R6W, RUSK COUNTY, WISCONSIN.
2. TOPOGRAPHIC BASE MAP PREPARED FROM AERIAL SURVEY BY SURDEX CORPORATION, CHESTERFIELD, MISSOURI. DATE OF PHOTOGRAPHY - APRIL 24, 1970. ROADS, TREES AND BUILDINGS WERE UPDATED AS PER AERIAL PHOTOGRAPH TAKEN BY MARKHURD CORPORATON, MINNEAPOLIS, MINNESOTA. DATE OF PHOTOGRAPHY - SEPTEMBER 14, 1987.
3. ELEVATIONS BASED ON MEAN SEA LEVEL DATUM. CONTOUR INTERVAL IS TWO FEET.
4. HORIZONTAL DATUM BASED ON PROJECT SITE GRID SYSTEM. SITE GRID COORDINATES CORRELATION TO STATE PLANE COORDINATES DERIVED AS FOLLOWS:

CONTROL MONUMENT F-1	SITE GRID COORDINATES	STATE PLANE COORDINATES
40000 N =		587,357.8087 N
40000 E =		1,713,516.1229 E

THE ANGULAR ROTATION FROM STATE PLANE BEARINGS TO SITE GRID BEARINGS IS 359°-13'-23" RIGHT WITH CONTROL POINT F-1 AS THE BASE POINT.

5. MINE FACILITIES DESIGN BY FORD, BACON & DAVIS, INCORPORATED, SALT LAKE CITY, UTAH AND PINCOCK, ALLEN & HOLT, INCORPORATED, LAKEWOOD, COLORADO.

LEGEND

- 1100 — EXISTING CONTOUR
- EXISTING PAVED ROADWAY
- EXISTING TRAIL/GRAVEL SURFACE
- TREES AND/OR BRUSH
- FENCE
- F-1 CONTROL MONUMENT

FOTH & VAN DYKE
GEOSCIENCES & ENVIRONMENTAL MANAGEMENT DIVISION
GREEN BAY, WISCONSIN

FLAMBEAU PROJECT
LADYSMITH, WISCONSIN

KENNECOTT MINERALS COMPANY
555 MINERAL SQUARE
SALT LAKE CITY, UTAH 8412

FIGURE NO. 1.0-1
SITE PLOT PLAN

MICROFILM | JOB
DRAWING NO. | REV.
DIVISION DRAWING NO.
SCALE | SEE BAR SCALE

REFERENCES	DWG. NO.	DESCRIPTION

REFERENCES	DWG. NO.	DESCRIPTION

NO.	DATE	REVISIONS	BY	CHK'D	ENG'R	PROJ. MGR.

NO.	DATE	REVISIONS	BY	CHK'D	ENG'R	PROJ. MGR.

PROJ. ENG'R / MGR. PROJECT ENGR. / ENGR'ING MGR.	BY	DATE

	BY	DATE
DESIGN		
DRAWN	MSO	3/89
CHK'D	TJW	3-89
DES. ENG'R		
DEPT. ENG'R		

2.0 ALTERNATIVES

2.1 Introduction

This section examines possible alternatives to the proposed project. From those possible alternatives, several alternatives are identified which will be examined further in Section 4.0.

Site selection for the project and its various operating elements is predicated on the location and orientation of the mineral deposit. Mining, by its very nature, places a major constraint on siting alternatives since the position of the deposit is fixed.

The proposed action of excavating and shipping 1.9 million tons of mineralization from Kennecott's Flambeau project has a long history. Various alternatives have been evaluated since the early 1970s. Over the past 18 years a wide variety of engineering procedures were developed and carefully considered from environmental and economic perspectives. During the last two years, during which the project has been scaled down to its current scope, a carefully selected engineering plan has been developed to achieve the proposed action. This engineering plan is described in the Mine Permit Application which accompanies this Environmental Impact Report. Both documents are submitted for the consideration and approval of the WDNR. The Mine Plan, submitted as part of the Mine Permit Application, details the preferred alternative as proposed by Kennecott.

Evaluation of the alternatives, and selection of the preferred alternative, were heavily influenced by lengthy public discussion. Public concerns, as well as positive input during the 1976 Environmental Impact Statement process and negotiation of the 1988 Local Agreement, provided the company with invaluable local opinions. Selection of the preferred alternative was, therefore, equally influenced by a combination of economic and environmental data as well as public opinion.

This section has been subdivided into seven subsections: No Action, Mining, Surface Facilities, Other Facilities, Land Use Alternatives, Reclamation and Final Land Use, and Alternatives for Impact Analysis.

A summary of reasonable alternatives remaining for further impact analysis is found at the conclusion of each subsection.

2.2 No Action

The no-action alternative is abandonment of the project by Kennecott. Kennecott does not have any employees in Wisconsin but would maintain its present temporary office in a company-owned house. Files and drawings would continue to be stored there as well as other project information and equipment.

Kennecott could sell the land and mineral rights, or consider these and other options such as leasing. If no action is taken, then all the piezometer drill holes, soil borings and monitoring wells would be permanently abandoned and the sites graded and revegetated. The drill sites would eventually revert to forest or be allowed to return to meadow and farmland. Permanently abandoning the drill holes would allow Kennecott to secure the release of its exploration bond.

Compared to the development of the preferred alternative, selection of the no-action alternative would have negative fiscal and economic implications for private businesses and for local, state, and federal governments. Projected tax revenues, local employment opportunities, and cash flow would be lost forever or indefinitely deferred.

2.3 Mining

Discussion of alternatives in the following subsections--mining methods, open pit design, and open pit operations--is structured to present the pros and cons of each proposed action. Each subsection concludes with the preferred alternative.

2.3.1 Mining Methods

Generally, several mining methods are available for extracting copper mineralization, of which underground, open pit, and a combination of open pit/underground methods are the most common.

Economic studies have been recently conducted on the possibility of mining the entire deposit to to a depth of approximately 600 feet beneath the surface using a combination of open pit and underground mining methods. Interpretation of these studies concluded that extraction of the lower portion, below 225 feet, would be uneconomical. In any case, Kennecott is, at this time, unable to obtain a permit to mine this deep ore under the provisions of the current Local Agreement. A discussion of mining the enriched ore above 225 feet by underground, open pit, and combination methods is found below in Sections 2.3.1.1., 2.3.1.2, and 2.3.1.3, respectively.

2.3.1.1 Underground Mining to 225 Feet

Theoretically, the deposit could be mined by sinking a shaft or decline near the center of the deposit and extracting ore to a depth of approximately 225 feet below the surface.

However, the economics of this approach are such that Kennecott would not proceed with the project if this approach was dictated. Thus, this option would ultimately be equivalent to the no action alternative.

2.3.1.2 Open Pit Mining of the Upper 225 Feet

Open pit mining studies were conducted for the enriched upper 225-foot portion of the deposit only.

Open pit mining is the only reasonable alternative to mine this deposit for several economic and environmental reasons. The chief reason is that the deposit ideally lends itself to open pit mining, which is the industry's best-proven method for efficient and safe extraction of shallow hardrock mineralization. The depth of ore burial is extremely shallow, ranging from 10 to 60 feet. This compares favorably to other deposits, located in the western United States, where several hundreds of feet of overburden have to be removed.

Furthermore, the deposit is unique within the Canadian Precambrian shield in that the upper 50 to 225 feet has been enriched and copper values significantly increased. This unusual economic aspect of the Flambeau deposit allows Kennecott to undertake the very costly measure of backfilling the open pit. Thus the resource can be mined via open pit for maximum ore extraction over a short period of time. This short time period, coupled with a carefully designed, steep-walled pit, minimizes environmental impacts. Backfilling of the pit during reclamation means that the project area can be closely returned to its original contour.

2.3.1.3 Combined Open Pit and Underground Mining To 225 Feet

Combinations of open pit and underground mining of the enriched ore left between the east bank of the river and various distances to the west edge of the pit were considered. These various distances, ranging from 140 to over 550 feet, were selected based on setbacks dictated by state and county zoning and engineering considerations.

Upon review, combined open pit and underground mining of the deposit was not considered as a reasonable alternative. In addition to safety and environmental considerations, the high capital and operating costs required for underground mining to recover the ore between the various pit limits and 133 feet from the normal river edge was prohibitive.

Engineering studies have determined that the pit limit can be safely located at a distance of 140 feet from the normal river edge. The proposed plans do not have provisions for mining any ore closer than 140 feet from the normal river edge.

2.3.1.4 Conclusions

There are no compelling short- or long-term environmental or economic reasons for considering underground or combinations of underground/open pit mining as reasonable alternatives.

2.3.2 Open Pit Design

Design of an open pit and ultimate perimeter is dependent upon many variables, some of which include geometry of the deposit, preferred production rate, equipment size, waste-to-ore ratio, economics, and pit-wall slope. Whereas economics is the controlling force in selection of the ultimate pit size, there are, nevertheless, several other considerations which directly or indirectly guide the engineer in the final selection of the preferred pit-wall slope. A variety of pit slopes were considered in the past. Two pit slope angles were evaluated in the final analysis: one involving an interramp angle of approximately 35° and another at 50°.

A 50° slope, which is considered to be a safe slope under existing conditions, was selected over a flatter slope for the following reasons:

- Reduced operating costs since the total quantity of waste rock removed is reduced.
- Since waste tonnage is reduced, there will be fewer truck trips over the pit life. This means less consumption of fuels, less fugitive dust, and lower ambient noise levels.
- Less surface area is disturbed during the course of open pit mining.
- Less land is required for storage of waste rock.
- Impacts to wetlands around the pit are reduced.
- Less precipitation caught within the pit area and, therefore, fewer gallons to be handled in the wastewater treatment plant.

A flatter, 35° sloped pit design was rejected since the tonnage of waste rock would dramatically increase. This translates directly into a less economically attractive project. In addition, more land surface would be impacted through an expanded pit perimeter and larger waste rock storage areas. Steeper slopes were rejected because of safety considerations.

2.3.3 Open Pit Operations

The following discussion considers various operational alternatives that could be employed during mining from an open pit. These alternatives are internal pit storage of waste rock, different production rates, conveyor versus truck haulage, and mine water inflow control.

2.3.3.1 Internal Pit Storage of Waste Rock

This novel open pit mining operation was evaluated to determine the viability for minimizing the handling and storage of waste materials.

Phase 1 would follow removal of all till, sandstone, and saprolite material over the proposed pit. The west one-half of the deposit would then be mined with the waste rock being deposited onto the top of the east end of the proposed pit. Phase 2 would involve backhauling of the Phase 1 waste rock to nearly its original position. Phase 2 would then require mining the east one-half of the deposit, using the west end as a storage area.

This alternative mining method would proceed as follows:

- Remove all the till, sandstone, and saprolite material during the pre-production period, and store on the land surface in a reduced-size Type I stockpile.
- Mine Phase 1, with Type I and Type II waste rock stacked on top of the Phase 2 ore within the ultimate pit limits. Overburden is hauled to the Type I stockpile area.
- On completion of Phase 1, deposit all Type I and II waste rock into Phase 1 excavation.
- Mine Phase 2 with all waste rock stacked on top of the backfilled Phase 1.
- On completion of Phase 2, level backfilled waste by depositing into the Phase 2 excavation.
- Backfill saprolite, sandstone and till from surface storage and reclaim surface.

Pros:

- Minimizes fugitive dust because hauling distances are shorter, less fuel is consumed, and land disturbance areas are less.
- Improved site aesthetics because there is only one waste rock stockpile and therefore surface disturbance is less. This assists in reducing reclamation time and cost at end of operation.

Cons:

- Increased safety concerns to workers due to increased height of waste pile and decreased operating room.
- No cash flow when switching from Phase 1 to Phase 2.

- More difficult to separately manage waste rock because of acreage restrictions placed by ultimate pit perimeter.
- Overall difficulty in controlling the backfilling sequence.
- More difficult to collect and control potential contact water from in-pit stockpiles.
- Height of waste piles could exceed 75-foot limit stated in Local Agreement. This would cause waste rock piles to take up acreage beyond the proposed pit perimeter in order to reduce height.
- Reduces mining efficiency and greatly hampers mining flexibility because of smaller operating pits and fewer ore faces exposed.

The internal pit storage alternative is not the preferred alternative. Environmental and economic benefits due to less surface area impacted as a result of the elimination of most of the surface storage areas are not sufficient to risk the operating inefficiencies and increased potential of impacting groundwater quality. In addition, backfilling and segregation of materials could not be engineered to optimize reclamation. Nevertheless, this alternative will be reviewed in greater detail in Section 4.0 - Environmental Impacts.

2.3.3.2 Different Mine Production Rates

In general, the size and geometry of the deposit, mining method, and number of working hours per day determine ore production rates within a narrow range. Flambeau's enriched ore allows Kennecott to direct-ship ore to out-of-state processing plants. The upper limits of ore production are influenced by the reserve capacity of existing mills under consideration. On the other hand, substantial reductions in ore production rates result in lower cash flow without a corresponding decrease in capital investment, and are not economically attractive.

Daily ore production fluctuations are common to the mining industry due to mine scheduling, maintenance, and weather conditions. Under the proposed mine plan it is expected that the Flambeau ore production could range from zero to 2,000 tons per day, averaging 1,300 tons per day over the life of the mine.

Expanded Average Production Rate

The size of the deposit and the resultant open pit configuration limit the size of the mining equipment and, thereby, restrict the hourly production rate. The daily and annual production rate can be increased by mining more than eight hours per day and/or five days per week as proposed. However, the Local Agreement does preclude significant increases in mining time

since blasting, crushing, and rail shipment are restricted to daylight hours.

A shortened mine life due to an expanded production rate could lessen the time for potential environmental impacts. However, socioeconomic impacts to the community would be intensified due to a shorter employment period for more workers.

Pros:

- Higher annual employment.
- Less time in operation, which means that land surface impacts would take place over a shorter term.
- Higher state revenues per year.
- Less total water to treat and discharge from wastewater treatment plant.

Cons:

- Increased emissions of fugitive particulates per day due to increased vehicular traffic.
- Increased noise impacts per day due to round-the-clock activities.
- Increased community impacts due to increased commuter traffic.
- Production rate influenced by off-site process plant capacity.

Temporary increases to the proposed mine plan daily production rate are likely because of expected occasional need to make up for days when the mining rate is lower than planned. However, it is unlikely that a significantly higher average daily production rate could be sustained over a long period of time due to constraints of pit size, equipment capabilities and handling limitation of receiving processing facilities.

Reduced Average Production Rate

Operating at a reduced average production rate is also possible. Major reasons for reducing average production rates would be a significant lower metal demand and copper prices. Temporary reduced daily production rates are likely over short periods of time due to equipment failure, transportation problems, fire, or other reasons.

Pros:

- Reduced fugitive dust emission rates and noise impacts per day.
- Slightly less impact on the community infrastructure since the work force is fewer in number.

Cons:

- More total wastewater to treat and discharge from wastewater treatment plant.
- Extended time-frame for the limited environmental and land surface impacts.
- Economically less attractive to Kennecott because of the reduced annual cash flow without a corresponding decrease in capital investment.
- Fewer jobs available for local residents.
- Less annual tax revenue to the state.

Conclusion

Mine scheduling, existing out-of-state mill capacities, and economic analyses discount a significant sustained expansion or reduction to the ore production rate.

2.3.3.3 Conveyor Versus Truck Haulage

There are several techniques by which ore and waste can be removed from an open pit. These are truck, train, and conveyor. Conveying, which would require the placement of a mobile crushing unit within the pit, was considered. Listed below are the advantages and disadvantages of using in-pit crusher and conveyor systems to transfer ore out of the pit. Waste rock would be hauled by truck in either case, since the quantity of multiple destination points renders conveying totally uneconomic.

Pros:

- In-pit crushing would reduce fugitive dust emissions and ambient noise levels at the site perimeters.
- Could reduce potential of contact water entering groundwater because ore haulage and surface crushing is eliminated or significantly reduced.

Cons:

- Restricts flexibility during mining.

- Limited room in pit for truck/crusher maneuverability.
- Conveyor system would require frequent moves, which are costly.
- The pit life is too short to economically justify the higher capital cost of this type of system.
- In-pit crushing would probably require a larger size pit with its attendant environmental impacts.

It was concluded that in-pit crushing and conveyor belt haulage of ore out of the pit is impractical. This system can be advantageous in an open pit where the benches are wide so that the conveyor can be located and moved infrequently. The Flambeau pit, because it is long, narrow and short-lived, is not suited for an in-pit crusher/conveyor.

2.3.3.4 Mine Water Inflow Control

Four water inflow control measures, perimeter dewatering wells, slurry wall, in-pit perimeter trench and an in-pit sump system, were evaluated and are discussed below.

Climatic and hydrogeologic conditions present in northern Wisconsin dictate that precipitation and some groundwater seepage will occur and be collected in the lower pit sump regardless of what water inflow measures are employed. This escaped seepage from the overburden and sandstone into the pit bottom will have to be treated before discharge.

Perimeter Dewatering Wells

Several hydrogeologic studies predict that a perimeter dewatering well system would be ineffective due to low soil permeabilities. This alternative was also rejected because of the extremely high construction and operating costs.

Perimeter Slurry Wall

This system is likely to be more effective than perimeter wells in minimizing water inflows. It has minimal operational costs, but was nevertheless rejected because of high installation costs. In addition, even though most of the groundwater seepage would be stopped, an in-pit sump would still be required to collect rainwater for wastewater treatment.

In-Pit Perimeter Trench

An in-pit perimeter trench water collection system was considered but rejected. Interpretation of soil borings and groundwater monitoring well data indicate that the Precambrian bedrock surface is irregular. Therefore, placing a perimeter

trench at grade in the top of the clay-altered Precambrian bedrock would not be technically feasible. There would be a potential for groundwater seepage at the base of the trench in areas where the trench rests on Cambrian sandstone or glacial sands and gravels.

In-Pit Sump System

It is recognized from current hydrogeologic data that groundwater seepage into the pit will not be uniform around the perimeter. Some areas, such as the outwash on the north side of the pit, will probably supply moderate amounts of groundwater throughout the life of the mine. It is also proposed that preproduction pit dewatering take place before excavation of the ore starts in the open pit. A series of trenches parallel to the deposit, dug to a depth which is above the bedrock but not greater than the limit of the excavating equipment, should assist in reducing the amount of groundwater seepage when the project proceeds into mining.

Pros:

- Highly flexible since sumps with wing trenches located parallel to the pit perimeter can be constructed on the upper bench where needed.
- Less costly to construct and maintain since excavation and installation is simple and only relatively small amounts of material must be removed.
- Sumps and trenches can be positioned correctly to intercept any areas of significant seepage.
- Provides several sources of water for mine operations; e.g., water truck.

Cons:

- The operational cost to pump, transfer, and treat collected water will be higher than a single perimeter trench system.

The in-pit sump collection system with trenches was considered to be the most efficient, flexible and practical method to intersect groundwater inflow.

2.3.4 Preferred Mining Alternative

The preferred mining alternative is governed by applicable environmental, economic, safety, engineering, and other factors. A small open pit having a surface area of approximately 32 acres, length of 2,600 feet, and average width of 550 feet was determined to be the optimum pit design. An average depth of 225 feet will ensure maximum recovery of the enriched portion of the deposit. Open pit mining will be conducted using standard

shovel and truck mining methods, consisting of drilling, blasting, ripping, loading, and hauling of the ore and waste.

The production schedule is based on rail shipping of about 320,000 dry short tons per year of crushed ore. Mining will normally take place five days per week (250 days per year) requiring an average daily mining rate for ore of 1,300 tons. Supply of this quantity of ore on a continuous basis will require waste mining at a rate of 3,900 tons per day. Peak total material, ore plus waste, is projected to be about 7,200 tons per day for the operation. An important factor influencing the desired ore removal rate is the ability of processing plants located out-of-state to receive this volume of material.

In-pit water inflows will be intercepted by a series of strategically located sumps with short trenches as needed. Water will be pumped either to settling ponds or a water treatment plant depending upon whether the water came in contact with sulfide mineralization or not. Materials trucked out of the pit will exit on the northeast side.

Mining operations for any bench will begin in the northern portion of the pit and proceed towards the deposit. Proceeding from the footwall direction or south side was dismissed since the footwall boundary of the deposit is more difficult to determine. Also, approaching from this side would mean coming in under the deposit which dips steeply towards the northwest. It is, therefore, more difficult to prevent loss of ore, which could occur if ore drops on top of the footwall waste during removal of the waste rock. Approaching the deposit from the hanging wall (or north) side, therefore, takes advantage of the geometry of the deposit; the ore/waste contact on this side is clearly recognizable. The decision to access the deposit on the northeast end of the open pit was a major determinant in site selection of surface and ancillary facilities.

2.3.4.1 Other Alternatives for Further Impact Analysis

Section 4.0, Environmental Impacts, will further assess the preferred mining alternative as well as the following alternatives:

- No action.
- Internal pit storage of waste rock.

2.4 Surface Facilities

2.4.1 Introduction

This section addresses alternative locations for the surface facilities of the project. These surface facilities include four major items: 1) the open pit, 2) Type I material, 3) Type

II waste rock, and 4) physical plant facilities such as the wastewater treatment plant.

Site selection for the surface facilities, stockpiles, and plant facilities is predicated on the location and orientation of the deposit. Capital and operating cost considerations, wetlands, and various other environmental concerns were used individually or in combination in order to arrive at the preferred site layout described in the mine plan.

Ideally, it is preferable to site all surface facilities close to the haulage road exit from the pit due to logistic and mine operation cost considerations. At the Flambeau site, this would be on the north side of the mine. Unfortunately, land surface restrictions, setbacks, and natural barriers such as the Flambeau River do not allow for location of all surface facilities on one side of the pit.

The site selection discussion is divided into three main sections. Section 2.4.2 discusses general siting considerations in and around Section 9. Section 2.4.3 considers the surface facilities individually for optimum siting of the Type I and II material and topsoil. Section 2.4.4 considers plant siting alternatives. Finally, the preferred surface facilities layout and alternatives are identified in Section 2.4.5 for impact assessment analyses.

2.4.2 Surface Facility Site Selection

2.4.2.1 Site Selection Outside of Section 9

The preferred site is Section 9. However, alternative sites within parts of Section 9 and immediately adjacent to Section 9 were also considered before a final selection was made. These are as follows: 1) alternative sites located west of the Flambeau River in Section 9, 2) north of Blackberry Lane in Section 9, 3) south of Section 9 within Section 16, and 4) east of Section 9 within Section 10. These sites are discussed below and can be located using Figure No. 2.4-1.

West

The Flambeau River establishes a natural boundary on the west side of the deposit. A large and very costly bridge would have to be erected in order to access company-owned lands on the west bank. Costs, aesthetic considerations, and infringement on the river bank quickly caused this option to be rejected as being impractical.

North

Blackberry Lane, located north of the deposit, partially separates land owned by Kennecott from privately owned land. Site selection north of Blackberry Lane was rejected because of

proximity to the community of Ladysmith, underlying soil conditions, close proximity to the Flambeau River, an active gravel pit operation, and land held in private ownership.

South

The area south of the proposed project area in Section 16 and extending to Meadowbrook Creek was also considered but rejected early in the site selection process. Haulage distances around the east end of the pit and south into Section 16 are long. Available land for waste rock storage is limited, being restricted to a narrow, elongated strip located between the STH 27 setback on the east and the river to the west. Therefore, haulage distance to the south end of the site and return is well over two miles. Environmentally, the site is unattractive, as it is located in a mature forest parallel to the Flambeau River.

East

An alternative site for all surface facilities lies in Section 10 east of STH 27 and west of the railroad track. Doughty Road and Jansen Road lie to the north and south respectively. Preliminary screening of alternative surface facility layouts concluded that this option was undesirable due to increased aesthetic intrusions due to bridge construction and truck operations; increased land area affected for extended haul road; increased air emissions and noise from additional truck traffic; and the need to collect and return contact water to the mine site or discharge to wetlands in Section 10. Although this alternative would eliminate the need for variances from setback criteria from STH 27, for surface facilities, the environmental disadvantages are significant enough to determine that locating the Type I stockpile in Section 10 is not a reasonable alternative.

A possible layout of the Section 10 layout is shown in Figure No. 2.4-2. Storage of Type I material and topsoil would be in Section 10 north and south of the spur track. Type II waste rock was moved north of the open pit and down hydraulic gradient in the area formerly occupied by the Type I material. The plant was rearranged south of the pit close to the spur track, the position of which does not change when considering Section 9 or 10 siting. In this fashion, the project surface facilities could be arranged to comply with setback requirements.

It is preferable, both economically and environmentally with respect to land disturbance, to cluster the surface facilities as close to the pit as possible and beside the haul road as it exits the pit.

2.4.2.2 Site Selection Within Section 9

The two possibilities were a single site north of the pit or a single site south of the pit. Within Section 9, the possibility of a single contiguous site for all of the facilities was examined. The location of the deposit and resultant ultimate open pit effectively bisects the acreage available in Section 9. Because of this and other constraints such as wetlands, proximity to the river, and highly permeable soils in the northwest corner of Section 9, it is impossible to locate all surface facilities entirely on one side of the pit.

It was therefore concluded that land on both sides of the pit will be required. It was decided to locate noise-generating increments of the plant, such as the crusher and rail-car loading, south of the pit and as far away from the community of Ladysmith as possible. Also, Type II waste rock is better situated south of the pit, so that the pit would act as an emergency sump in case of any escaped water seepage or runoff. Type I material and soil stockpiles can be conveniently located north of the pit and close to the haul road exit from the mine.

The challenge is how to subdivide the siting of these facilities in a practical, economic and environmentally sound manner north and south of the open pit. These issues will be discussed in the following sections.

2.4.3 Waste Storage Areas Within Section 9

There are three types of waste materials that require separate surface storage: 1) Type I material that contains less than one percent sulfur, 2) Type II waste rock containing greater than one percent sulfur, and 3) topsoil. Type I material does not require a lined site as indicated by exhaustive leach volume testing conducted by Kennecott's environmental consultant as described in Section 3.5.6 of this report. For this reason, environmental siting requirements are not nearly as stringent as those required for Type II waste rock.

A height limitation of 75 feet for storage of waste rock was imposed on the project during negotiations for the Local Agreement. The acreage required for both Type I and Type II material is, therefore, a function of the amounts of waste materials identified within the pit, pit wall slope (ore-to-waste ratio), angle of repose of the truck-dumped materials, and height of the waste pile. These areas were determined to be 40 acres and 27 acres in size for Type I and II stockpiles, respectively.

Selection of sites involved consideration of economics, distance from the community, zoning restrictions, proximity to wetlands, underlying soil conditions, and groundwater flow direction. A part of the site selection process also involved studying in-pit waste disposal as described in Section 2.3.3.1. After rejection

of in-pit storage, the alternative study focused on sites located north and south of the proposed pit.

2.4.3.1 Type II Stockpile, Section 9

North of the Pit

Pros:

- Improved project economics through shorter haulage distance and less fuel consumption.
- Existing tree screens along west side of STH 27.

Cons:

- In the unlikely event of leakage from the storage area, there would be an increased potential of seepage entering the groundwater and into the Flambeau River because of greater permeability of underlying soils.
- Hydraulically downgradient of the open pit; thus, the benefit of utilizing the pit as an emergency sump is negated.
- Necessity of a variance to construct close to STH 27.

South of Pit

Pros:

- Hydraulically upgradient of the proposed open pit, so that the open pit could act as an emergency groundwater collection sump.
- Reasonably short haulage distance.
- Ability to combine the ore and Type II material handling facilities and to locate these facilities (crusher, ore loadout and Type II waste rock stockpile) onto a common lined area.
- Not visible from the Flambeau River.
- Removed from the community of Ladysmith.

Cons:

- Visible from STH 27.
- Requires a variance to construct waste rock stockpile close to the highway.

2.4.3.2 Type I Waste, Section 9

South of Pit

Pros:

- Removed from the community of Ladysmith and several Town of Grant residences.
- Hydraulically upgradient of the proposed Flambeau open pit.
- Open pit could act as an emergency groundwater collection sump.
- Reasonably short haulage distance.
- Not visible from the Flambeau River.

Cons:

- Visible from STH 27.
- Requires a variance to construct waste storage area close to the highway.

North of Pit

Pros:

- Because Type I material does not require a lined storage site, it can be placed downgradient of the pit.
- Improved project economics through shorter haulage distance.
- Existing tree screens along STH 27.

Cons:

- Closer to the community of Ladysmith and several residences in the Town of Grant.
- Requires a variance to construct site close to STH 27.

The Type I stockpile was placed onto a meadow east of the abandoned gravel pit instead of in the gravel pit for several reasons. First, leach volume testing and local soil attenuation studies, Section 3.5.6, concluded that it is preferable to locate Type I material onto silty soils such as those underlying the meadow. Any metal ions escaping the Type I stockpile would be quickly attenuated by such soils. These soils are absent in the gravel pit. Second, it has long been Kennecott's policy to preserve the Flambeau River environment and aesthetics and, for this reason, Type I and Type II stockpiles were moved as far

away from the river as practically possible. Third, filling the gravel pit with Type I material would add to the operating cost given the longer haul distances, site topography, and reclamation plan.

2.4.3.3 Topsoil, Section 9

Three sites were considered for storage of topsoil, including the floor of an abandoned gravel pit, between the open pit and the abandoned gravel pit, and between the open pit and STH 27. It was decided to place the topsoil stripped during the pre-production on the east side of the pit, and to place this material so as to form a visitor's observation point. A second site was selected between the open pit and gravel pit to take advantage of a short haul distance. Site 3, in the gravel pit, was rejected since the haulage distance is the longest, and because it could complicate removal of gravel should any be required during and after the operation. Storage of the topsoil is further discussed in Section 4.0.

2.4.4 Physical Plant Facilities

Project costs during construction of the site and operation of the wastewater treatment plant could be reduced by having Type II waste rock, crusher and ore loadout facilities sharing a common lined area. It was also decided to locate the plant as far south of Ladysmith as possible so as to minimize noise and dust impacts to the community.

Some consideration was given to locating the crusher and crushed ore stacking conveyor in a separate location south of the Type II waste rock stockpile and within Section 16. However, the need to control contact water from this location would require construction of another costly high-density-polyethylene (HDPE)-lined system and pumping facilities. This consideration was, therefore, not viewed as a reasonable alternative.

2.4.5 Preferred Alternative for Surface Facilities

Surface plant facilities required to support the mining operation need to be located in close proximity to the open pit to minimize the length of haul roads and associated air emissions and provide effective supervision. Hauling and handling ore is relatively simple and straightforward for this project. Trucks loaded with ore and Type II waste rock will exit the mine on the northeast and proceed in a southerly direction to the crusher and storage site. These facilities will share a common lined pad together with the rail loadout facilities. Contact water collected by this system would be diverted to the wastewater treatment plant located on the east end of the plant facility area.

The crusher and loadout sites are ideally sited for easy access by a railroad spur line to a major transportation system. The spur line can be constructed across Section 10 along a carefully selected and aligned corridor to minimize environmental impacts.

Trucks loaded with Type I material and topsoil will exit the pit and be stored north or east of the pit, respectively. A second temporary soil stockpile site could be available between the open pit and gravel pit. Therefore, all surface facilities will be contained within Section 9 bounded by the Flambeau River, Blackberry Lane, STH 27 and the south line of Section 9. Although the storage piles will be visible from STH 27, the impact is minimized by the fact that the piles will reach their maximum height for a very short time and will be totally removed during the reclamation phase of the project.

2.4.5.1 Other Alternatives for Further Impact Analyses

Alternatives which have been identified for further impact analyses are:

- siting in Section 10
- other potential topsoil stockpile locations
- in-pit storage of waste rock.

Topsoil could be relocated in two alternative sites away from STH 27 and these will be discussed and assessed in Section 4.0.

2.5 Other Facilities

2.5.1 Introduction

Other facilities include the transportation system required to take the crushed ore to the main line railroad, wastewater discharge points, settling ponds, and sludge disposal areas. Siting of these facilities is governed in part by selection of the surface facilities sites. Thus, the alternatives for siting other facilities are limited as these facilities should be located close to sites that have been selected for the major surface elements of the proposed mining operation.

2.5.2 Transportation of Ore

There are two major transportation systems for delivery of ore to out-of-state process plants. Truck haulage was rejected because of the long distances involved and the low unit value per ton of material. Such a method is not considered viable for interstate hauling but is an alternative for taking crushed ore to the mainline railroad system. Therefore, rail haulage is the only reasonable alternative for delivery of ore out-of-state.

Four alternatives were considered for transporting crushed ore from the plant to the existing mainline railroad. Three of these considered various railroad spur line alignments and the fourth, truck haulage. In choosing spur line alignments, factors such as length of line, utilization of natural contours to minimize cut and fill, and avoidance of wetlands were considered before final selection. Trucking, on the other hand, would require the construction of a very costly bridge over STH 27 and haul road along the preferred spur line corridor. In this manner public roads would receive minimum impact by truck haulage of the ore.

Also, the truck loadout facilities at the mainline track would need to be lined and captured contact water would need to be transported back to the wastewater treatment plant at some considerable expense. Truck haulage of ore from the plant to the mainline track is further discussed in Section 4.0.

2.5.2.1 Railroad Spur Alignments

Three alternative railroad spur alignments were considered. The first alignment ran parallel and north of Jansen Road. The second alternative crossed STH 27 at the same location as alternative one, then proceeded north to join the preferred alternative as shown on Figure No. 1.0-1. However, these two alternatives were rejected as being too close to the intersection of Jansen Road and the plant access road to STH 27.

Therefore, the third and preferred alternative is to exit the mine site area north and parallel to intermittent Stream C's crossing of STH 27. This alternative was designed to minimize impacts on wetlands in Section 10.

2.5.2.2 Conclusions With Respect To Other Facilities

Trucking crushed ore to the mainline track was rejected because of economic and environmental considerations stated in Section 2.5.2. Spur line alignments, parallel to Jansen Road, were rejected due to interferences at the Jansen Road intersection and wetland disturbance.

2.5.3 Treated Wastewater Discharge Points

Two treated wastewater discharge points were considered, one which discharged into intermittent Stream C and the other into the Flambeau River. WDNR effluent limitations provide equal water protection to either alternative. Based on economic criteria only, intermittent Stream C would be the preferred alternative. However, discharge into intermittent Stream C was rejected because of uncertainties due to potential increased stream bed erosion and increased flooding risk.

The Flambeau River was selected as the preferred alternative since there is essentially no risk of additional siltation due to rip-rapping at the outfall points and due to discharge water being clarified either through treatment or settling.

2.5.4 Settling Ponds

Two alternative sites were considered for locating a series of settling ponds to serve the Type I stockpile and storm runoff north of the open pit. One site, on the base of the abandoned gravel pit with a discharge to the Flambeau River, was considered. The other alternative, located west of the Type I stockpile, would retain the water in settling ponds and also discharge it to the Flambeau River. It was decided to site the settling ponds west of the Type I stockpile and to discharge water west to the Flambeau River. On the way to the river, controllable discharge points would be installed for use in maintaining water levels in Wetland Area 1 if required. Therefore, the Wetland Area 1 and forest screen along the east bank of the river north of the pit would be preserved during the life of the mine.

2.5.4.1 Gravel Pit Location

Pros:

- Existing graded site.
- Aesthetically well-positioned and out of public view.
- Can accept water via gravity from Type I stockpile.

Cons:

- Restricts availability of gravel for backfill during reclamation of the open pit if any further material is required.
- More difficult to discharge to Wetland No. 1 if needed.

2.5.4.2 West of Type I Stockpile

Pros:

- Requires little site preparation.
- Well screened and out of public view.
- Can accept water via gravity from Type I stockpile.
- Better positioned for providing controlled discharge points in order to maintain water levels in Wetland Area 1.

Cons:

- None.

2.5.4.3 Settling Ponds Conclusions

The alternative site south of the abandoned gravel pit and west of the Type I stockpile is the preferred site. A direct discharge to the river is preferred since monitoring of the discharged water is easier to control.

2.5.5 Sludge Disposal

Two methods of sludge disposal from the wastewater treatment plant were considered based upon the percent solids contained within the disposed sludge. One method considered a sludge having 50 percent solids by weight while the second and preferred method would produce a sludge containing 25 percent solids.

2.5.5.1 50 Percent Solids

One method of sludge disposal utilized a vacuum filter in the wastewater treatment building to produce a sludge containing 50 percent solids. This sludge, however, presented a material handling problem, due to its sticky and colloidal nature, and required a specially designed dump truck for transport. Disposal on the stockpile would be by "tailgating" from the dump truck which could result in less uniform layering on the pile.

2.5.5.2 25 Percent Solids

Under this alternative, the underflow sludge from the wastewater treatment clarifier, containing various metal hydroxides, gypsum and inert sediments, will report to an 8,000-gallon holding tank inside the wastewater treatment building. A pump will transfer the sludge to a 4,000-gallon tank truck for hauling and disposal on the Type II waste rock pile. The truck will periodically spread the sludge mixture, containing approximately 25 percent solids, uniformly in a thin layer on freshly graded waste rock. Water contained in the sludge mixture will aid in compacting the Type II waste rock. Any excess water will percolate through the pile or run off to the perimeter collection ditch for recycling to the wastewater treatment plant.

2.5.5.3 Sludge Disposal Conclusions

Production of a 25 percent solids sludge mixture is the preferred alternative because of ease in handling and deposition.

2.5.6 Preferred Alternative for Other Facilities

The preferred alternative for Other Facilities is to deliver crushed ore to the main line railroad via a spur line. This spur line would be carefully aligned through Section 10 in order to minimize wetland impacts. The spur line would cross STH 27 immediately south of and parallel to intermittent Stream C.

Wastewater discharge from the treatment plant located in the southeast corner of Section 9 would be to the Flambeau River. A rip-rapped outfall structure would direct the water flow into the river for discharge.

Settling ponds would be sited south of the abandoned gravel pit in an area that optimized gravity flow from Type I stockpile. Runoff water would be discharged to the Flambeau River or used to supplement water needs in Wetland No. 1.

Sludge generated by the wastewater treatment plant will be trucked to the Type II waste rock stockpile. Composition of the slurry will be 25 percent solids by weight, which is a consistency that facilitates loading, unloading and spreading of the sludge onto the stockpile.

2.5.6.1 Other Alternatives for Impact Assessment

Other alternatives to be further discussed under Section 4.0 include the following:

- Truck versus rail haulage of crushed ore to the mainline railroad.
- Spur line parallel to and north of Jansen Road.
- Settling ponds.

2.6 Land Use Alternative

This section reviews potential land use alternatives to the mine project. There are two basic land use alternatives to be considered: 1) mining followed by site reclamation, or 2) no action followed by some other land use. If mining is not an alternative, then the project area would either remain in its present land use or be allowed to develop for other purposes.

Current land use is as follows. All the land in the project area is owned by Kennecott. The area in Section 9, which is required for the mining project, is adjacent to nine homes owned and rented out by Kennecott, and one home owned by Kennecott which is currently unoccupied. The area required for mining includes approximately ten acres which are leased out by Kennecott for farming; the remaining area is either old meadows or forest. The nine homes which are owned and rented out by Kennecott will not be affected by the project. The unoccupied

Kennecott-owned home is in poor condition and will be removed. The only areas to be directly affected by the mine are the areas which are leased out by Kennecott for farming, open spaces which were once meadows, and the forest.

The area in Section 10 between STH 27 and the Wisconsin Central Railroad main line is primarily a wetland area. The railroad spur, which is the only facility which will be located in this area, has been designed to minimize the impact on these wetlands and, therefore, minimal change in land use is anticipated.

If the project area is used for mining, then all areas could be returned to their pre-mining use after the project is completed, unless agreement is reached to allow local governments to establish an industrial park in the area.

Based on the fact there will be a minor effect on the present use of the land required for mining, Kennecott believes that mining for minerals is substantially better and more beneficial than its present use. Mining of the deposit should be considered as a temporary use of this land, because this activity will cease after about eight years. Reclamation, as proposed by Kennecott and its consultants, will ensure that the land can either revert to its pre-mining use or be considered for other land uses.

2.7 Reclamation and Final Land Use Alternatives

Two alternatives are possible for mine site reclamation. These involved allowing the pit to fill with water to form a lake, and backfilling. The flooding of the pit would result in the creation of a small lake. The pit lake would not only increase the aesthetic value of the reclaimed project site but could also add to the land value since water bodies are in high demand when developing land. This alternative was considered in detail in the 1970s.

Landscaping of the pit prior to flooding could involve sloping and scalloping to provide a safe and visually pleasing shoreline. In addition, tree plantings could be made to assist in slope stabilization together with establishment of ground cover. Once completed, this lake would provide long-term recreational benefits to the site.

Creation of the lake was rejected because of concerns raised by the public, the public's presumed preference to have the site returned to its approximate original contour, and NR 132-suggested reclamation preference of backfilling when possible.

The preferred action is to sequentially backfill the pit with waste rock and overburden stored on the surface. A more complete site reclamation description is available in the Mining Permit Application submitted concurrently with this document. The Type II material would be placed at the bottom of the pit

and covered by Type I material. Both materials would be compacted by normal operation of equipment working in the pit during hauling, dumping or grading. Saprolite would be placed on top of the Type I material to provide a less permeable layer. Sandstone and overburden placement would complete the backfilling operation. Soil would be spread over the site and ground cover established. The restored site will be regraded to approximately match the original surface topography.

After backfilling the open pit and revegetating the area where the open pit and waste rock storage piles were located, alternative uses of the surface facilities will be re-evaluated. If no desirable alternative uses of the surface facilities are found at that time, the buildings, equipment and other facilities will be removed and the land returned close to its pre-mining use and condition.

The evaluation of the potential use of the land will consider the following:

- The stated interest of the Local Governments (Rusk County, Town of Grant and City of Ladysmith) to purchase or lease the land, equipment, and facilities for use as an industrial park.

- Potential for future mining of the mineralized material below the enriched ore.

- Impact of completion of the mining operation.

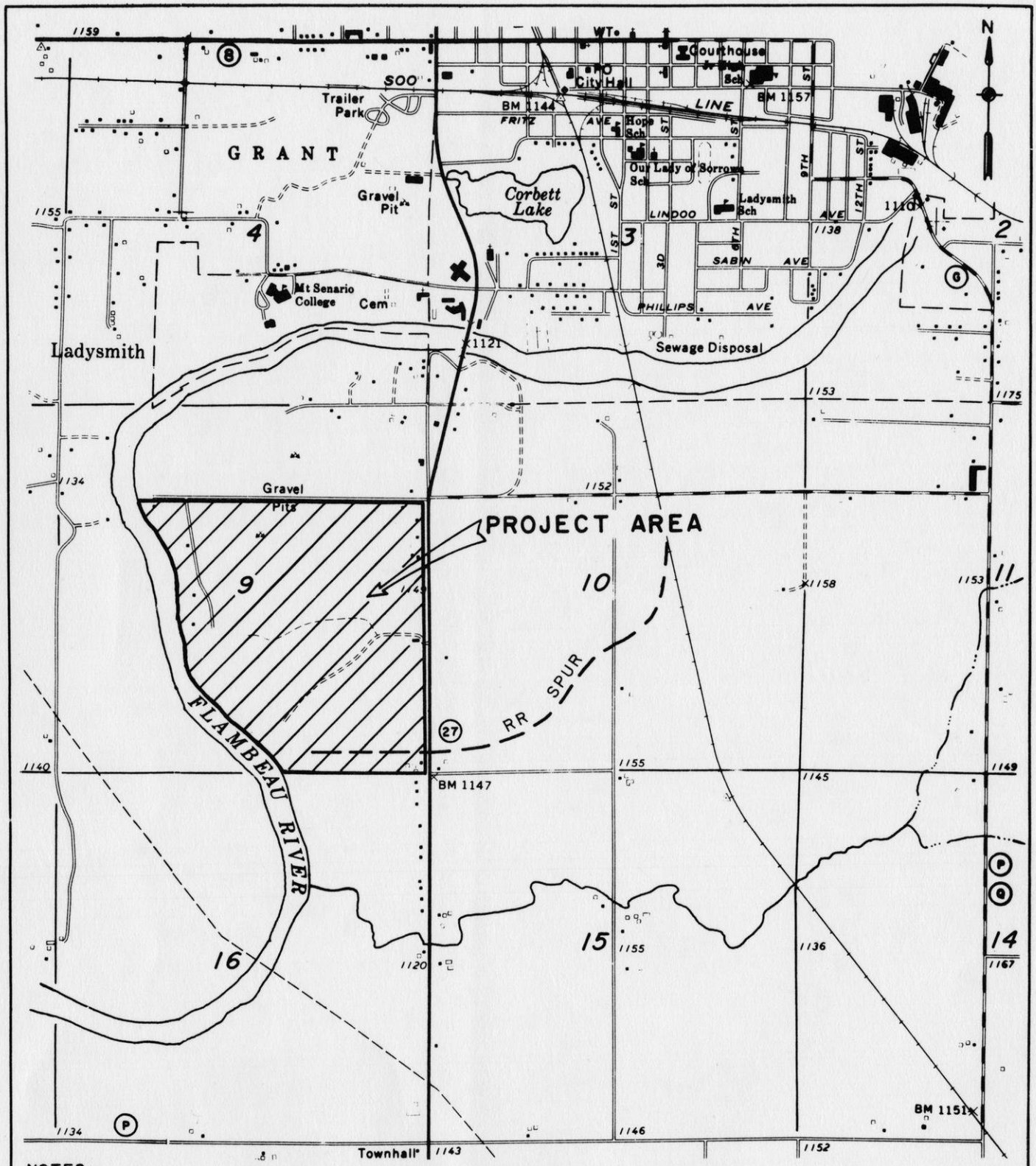
A Local Agreement between Rusk County, the Town of Grant, the City of Ladysmith and Kennecott Exploration (Australia) Ltd. (now Kennecott Minerals Company) for development of the Kennecott Flambeau Mine was approved and signed by all parties August 1, 1988. The Local Agreement includes several provisions related to the reclamation and final use of the land, equipment, and other facilities which may be exercised by the local governments.

2.8 Alternatives for Environmental Impact Analysis

The following are alternatives to the preferred alternative that are examined in more detail in Section 4.0.

- No action.
- In-pit storage of waste rock.
- Section 10 for partial surface plant siting.
- Topsoil siting.
- Truck versus rail haulage to the mainline track.
- Settling ponds siting.

Figures for Section 2.0



NOTES:

PROJECT AREA INCLUDES A 36 FOOT WIDE CORRIDOR ALONG RAILROAD SPURLINE EAST OF STH 27.

BASE MAP PREPARED FROM U.S.G.S MAPS 7.5 MINUTE SERIES, LADYSMITH AND THORNAPPLE WI. QUADRANGLES

FOTH & VAN DYKE
GEOSCIENCES & ENVIRONMENTAL MANAGEMENT DIVISION
GREEN BAY, WISCONSIN

KENNECOTT MINERALS COMPANY
FLAMBEAU PROJECT
LADYSMITH, WISCONSIN

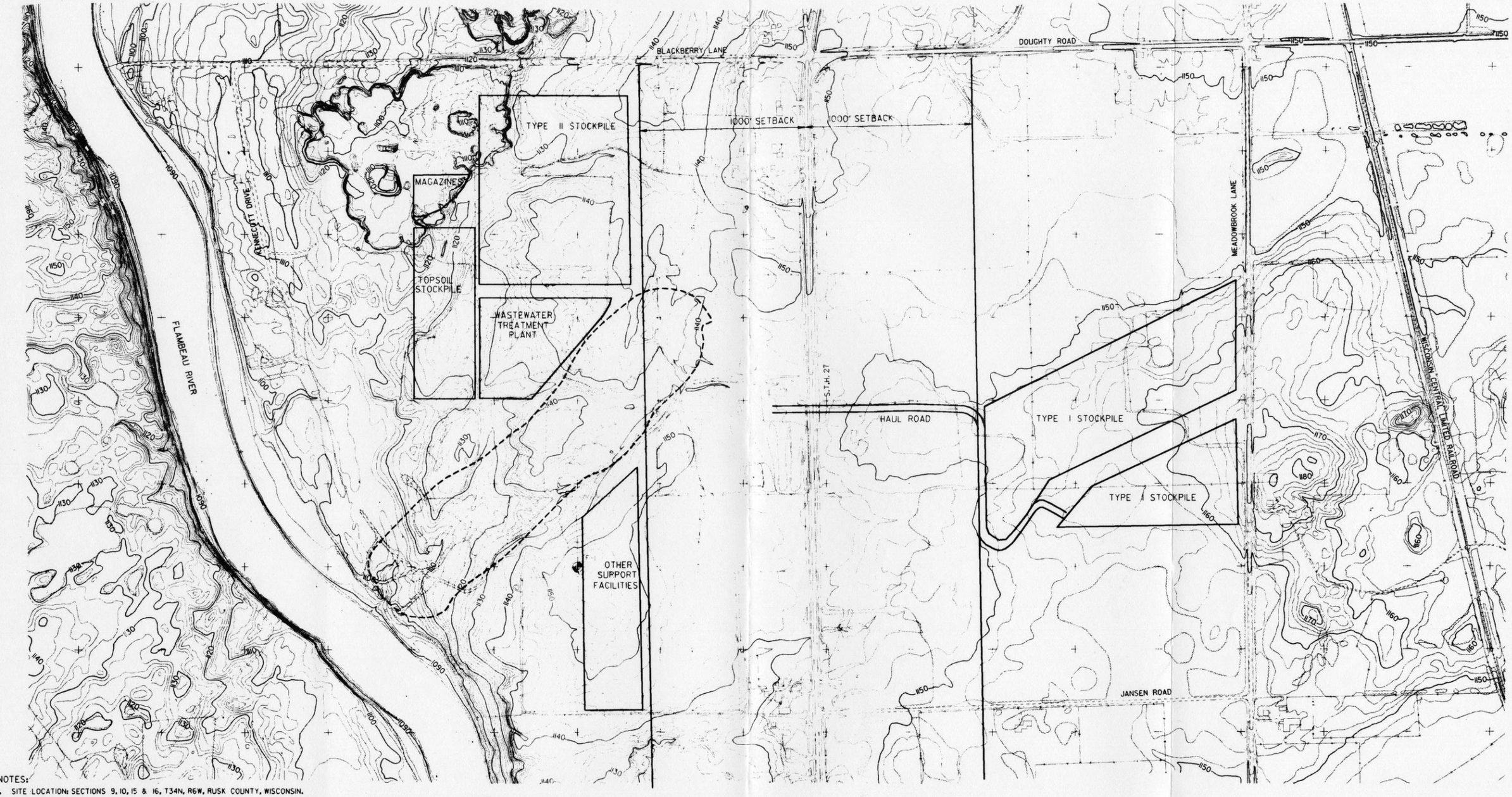
NOTES	APPROVAL		DATE
	DESIGNED BY		
	DRAWN BY	SJL	2/89
	CHECKED BY	TJW	3/89
	APPROVED BY		
	CAD No.	SCALE 1"=2000'	

FIGURE NO. 2.4-1
PROJECT AREA LOCATION

Job No	Dwg No	REV

37000 E | 38000 E | 39000 E | 40000 E | 41000 E | 42000 E | 43000 E | 44000 E | 45000 E

43000 N | 42000 N | 41000 N | 40000 N | 39000 N



NOTES:

1. SITE LOCATION: SECTIONS 9, 10, 15 & 16, T34N, R6W, RUSK COUNTY, WISCONSIN.
2. TOPOGRAPHIC BASE MAP PREPARED FROM AERIAL SURVEY BY SURDEX CORPORATION, CHESTERFIELD, MISSOURI. DATE OF PHOTOGRAPHY - APRIL 24, 1970. ROADS, TREES AND BUILDINGS WERE UPDATED AS PER AERIAL PHOTOGRAPH TAKEN BY MARKHURD CORPORATON, MINNEAPOLIS, MINNESOTA. DATE OF PHOTOGRAPHY - SEPTEMBER 14, 1987.
3. ELEVATIONS BASED ON MEAN SEA LEVEL DATUM. CONTOUR INTERVAL IS TWO FEET.
4. HORIZONTAL DATUM BASED ON PROJECT SITE GRID SYSTEM. SITE GRID COORDINATES CORRELATION TO STATE PLANE COORDINATES DERIVED AS FOLLOWS:

SITE GRID COORDINATES CONTROL MONUMENT F-1	STATE PLANE COORDINATES
40000 N =	587,357.8087 N
40000 E =	1,713,516.1229 E

THE ANGULAR ROTATION FROM STATE PLANE BEARINGS TO SITE GRID BEARINGS IS 359°-13'-23" RIGHT WITH CONTROL POINT F-1 AS THE BASE POINT.

LEGEND

- 1100 — EXISTING CONTOUR
- EXISTING PAVED ROADWAY
- EXISTING TRAIL/GRAVEL SURFACE
- TREES AND/OR BRUSH
- FENCE
- F-1 CONTROL MONUMENT
- PIT PERIMETER

N

0 300' 600'
SCALE

FOTH & VAN DYKE
GEOSCIENCES & ENVIRONMENTAL MANAGEMENT DIVISION
GREEN BAY, WISCONSIN

FLAMBEAU PROJECT
LADYSMITH, WISCONSIN

KENNECOTT MINERALS COMPANY
136 MINERAL SQUARE
SALT LAKE CITY, UTAH
8402

FIGURE NO. 2.4-2
SCHEMATIC SITE PLOT PLAN
SECTION 10 ALTERNATIVE

MICROFILM | JOB
DRAWING NO. | REV.
DIVISION DRAWING NO.
SCALE SEE BAR SCALE

REFERENCES	DWG. NO.	DESCRIPTION

REFERENCES	DWG. NO.	DESCRIPTION

NO.	DATE	REVISIONS	BY	CHK'D	ENG'R	SUP. MGR.

NO.	DATE	REVISIONS	BY	CHK'D	ENG'R	SUP. MGR.

	BY	DATE
PROJ. ENG'R		
MGR. PROJECTS ENG'R		
ENG'R MGR.		

	BY	DATE
DESIGN		
DRAWN	MJO	3/89
CHK'D	TSW	3-89
RES. ENG'R		
SECT. ENG'R		

3.0 DESCRIPTION OF ENVIRONMENTAL SETTING

3.1 Location

The project area will be all of that part of Section 9, Township 34 North, Range 6 West, Rusk County, Wisconsin lying east of the Flambeau River and south of Blackberry Lane; and the area required for a one-mile (approximately) long railroad spur line located in the southwest quarter of Section 10, Township 34 North, Range 6 West, Rusk County, Wisconsin, lying west of the main line of the Wisconsin Central Ltd.

The proposed project area may be reached from the north by traveling south on State Highway 27 (STH 27) from its junction with U.S. Highway 8 (USH 8), a distance of 1.6 miles.

Ladysmith, the county seat of Rusk County, is located in northwestern Wisconsin, approximately 130 miles east and north of Minneapolis-St. Paul; 240 miles north and west of the Wisconsin state capitol at Madison; and approximately 400 miles north of Chicago. It is at the junction of major north-south (STH 27) and east-west (USH 8) highways and a major Wisconsin Central, Ltd. railroad junction.

3.2 Regional and Local Setting

Rusk County is an area of 579,840 acres, with a population of 15,456, according to 1988 estimates by the Wisconsin Department of Administration (WDOA). The county is predominantly rural in nature, with approximately 91 percent of land in the county classified as forest land or agricultural land.

The area was almost completely logged of its original white pine, hemlock, and hardwoods by the beginning of the 20th century. Its major industries deal primarily with wood, but most of the wood used is from sources outside of Rusk County. Dairying is the largest agricultural source of income; relatively few small grains and seed crops are grown.

Within 40 miles of Ladysmith there are numerous lakes, rivers, creeks, and streams, although few lakes are present in the near vicinity of Ladysmith. The city is situated between three major river flowages, Lake Flambeau, three miles northeast, Lake Chippewa, 35 miles north, and Lake Holcombe, 17 miles to the south.

Fishing, hunting, and other outdoor activities are popular forms of recreation within the county. The recreation, resort, and tourist trade is served by facilities in Ladysmith and, to a lesser extent, in other areas within the county.

The county is sparsely settled. Population declined during the period from 1950 through 1970, but has gained slightly during the 1980s. Unemployment within the county is high relative to the rest of the state, and there have been recent losses in jobs in the area.

3.3 Historical and Archeological Background

Several historical and archeological studies have been undertaken in the project area. A historical survey was conducted in 1976 by the State Historical Society. That survey examined whether any existing structures in the study area could have special historic or other cultural significance (Smith, 1976). The study concluded that none of the buildings on-site had any historic or otherwise special cultural significance. Mr. Smith's letter is included in this report as Appendix 3.3-A.

During the 1970s, two separate archeological surveys were also conducted. Reports of these surveys were titled *Report of the Archeological Site Survey Conducted at the Bear Creek Mining Flambeau Project Site, Rusk County, Wisconsin* (McHugh and Gregg, 1973) and *Archaeological Survey of the Flambeau Mining Corporation's Proposed Copper Mining Project, Rusk County, Wisconsin* (Tiffany, 1976).

In 1988, a third archaeological survey using accepted techniques was conducted by Dr. Margie Staab in order to be certain that all of the potentially affected property had been reviewed by a professional archaeologist, and to survey the area to the north of the proposed pit that had not been covered in the first two investigations. Dr. Staab's report is given in Appendix 3.3-B. All three surveys concluded that there is no evidence of prehistoric occupation of any portion of the project area.

Each of the reports discuss a local collection of miscellaneous artifacts discovered by local farmers, known as the Drum collection, which is located outside of the project area. The reported location of the source for this collection is about one-half mile east-northeast of the project area, between Meadowbrook Road and the Wisconsin Central Limited Railroad. This area is located to the north of the proposed railroad spur right-of-way.

Most of the artifacts from the Drum collection were reported by Mr. A. Drum to have come from the areas he farmed around the now-filled ancient lake in the W 1/2, SW 1/4, NE 1/4 of Section 10, T34N,R6W. The overwhelming majority of artifacts in this collection are projectile points which indirectly suggest that a substantial amount of prehistoric hunting activity occurred around the shores of this small lake. Projectile point typology indicates the presence of Late Archaic (2,000 BC - 1,000 BC), Early Woodland (1,000 BC - 500 BC), Middle Woodland (500 BC - AD 500), and Late Woodland (AD 500 - AD 1,400) activity around this small prehistoric lake. Several of the small points in the collection are made of locally-available quartzite, but the others are made of chert, and are foreign to the project study area.

Previous physical surveys of selected parts of the surrounding region, located several small collections of miscellaneous artifacts. The archaeological surveys of the project area determined that prehistoric cultural activities have left no traces in the form of artifacts on the project area. Dr. Staab specifically states that "...no evidence of any prehistoric or significant historic occupation was discovered within the Project Area..." (Staab, 1988).

3.4 Climatology, Meteorology, and Air Quality

3.4.1 Field and Laboratory Methods

3.4.1.1 Station Locations

Monitoring stations consisting of high-volume air samplers for total suspended particulates (TSP) and particulates equal to or less than ten microns in diameter (PM10) were placed at two sites in the vicinity of the mine site. A meteorological station, consisting of wind speed and direction sensors and a precipitation gauge, collected data concurrently with the particulate samplers.

The sampling sites being used are in close proximity to those that were used by Kennecott during an air monitoring program conducted in the late 1970s. A description of the TSP sampling sites is as follows:

North Sampling Site:

Property Owner:	Rusk County Community Hospital
Location:	Southwest corner of the intersection of Highway 27 and College Avenue West.
General Description:	Samplers are located on the roof of the hospital. The face plate of each sampler is 45.2 feet from the ground. Two roads are located approximately 400 feet from the samplers. One runs on the north side of the hospital complex, the other runs along the east side. The Flambeau River flows 200 feet to the south. There are woods and adjacent hospital buildings to the west.

South Sampling Site:

Property Owner:	Kennecott
Location:	Northeast corner of the intersection of Jansen Road and State Highway 27 (STH 27).
General Description:	The face plate of each sampler is seven feet from the ground. The area is predominantly low and clear with a tree stand approximately 100 feet away along the east shoulder of STH 27. There is an old silo approximately 100 feet to the

	northeast. These are far enough away to prevent interference. STH 27 is 150 feet to the west and Jansen Road 100 feet to the south.

Meteorological Site:

Property Owner:	Kennecott
Location:	The location of the meteorological station is on STH 27 approximately one mile south of the south particulate sampling site. The station is situated on a 35-foot tall tower at the northwest corner of Highway 27 and County Road P.
General Description:	The meteorological tower is sited in the southeast corner of a large hay field. There are two roads nearby, County Road P to the south and STH 27 to the east. Both are more than 100 yards away. Scrub trees and an old silo were removed, so there are no obstructions within 100 yards of the meteorological station.

The locations of the TSP/PM10 sampling stations and the corresponding mining operation are shown on Figure No. 3.4-1.

3.4.1.2 Monitoring Schedule

The high-volume samplers were operated every second day from May through July 1988 (24 hours on, commencing at midnight, and 24 hours off). The sampling schedule was extended to every third day during the August through October sampling period. Filters were removed one day after the operating day to avoid nonrepresentative particulate loading.

The meteorological instruments operated continuously 24 hours per day throughout the monitoring period. Meteorological data were collected on a hourly basis.

3.4.1.3 Instrumentation

3.4.1.3.1 Total Suspended Particulates

Each of the two air sampling sites was equipped with a TSP Hi-Volume sampler consisting of the following:

- Sierra-Anderson Hi-Volume air sampler (motor and enclosure).
- Pressure transducer flow recorder.
- Combined flow controller/digital timer-programmer.

- Glass fiber filter media.
- Wooden support platform.

The Hi-Volume air sampler is equipped with a flow controller so that a desired flow can be achieved. The flow was adjusted to approximately 50 cubic feet per minute (CFM) so as to be within the required range of 40 to 60 CFM.

3.4.1.3.2 PM10 Particulates

Each of the two sampling sites was equipped with a PM10 Hi-Volume sampler consisting of the following:

- Sierra-Anderson Hi-Volume air sampler (motor and enclosure).
- PM10 size selective sampling inlet.
- Pressure transducer flow recorder.
- Combined flow controller/digital timer-programmer.
- Glass fiber filter media.
- Wooden support platform.

The Hi-Volume sampler, which is equipped with a flow controller, was adjusted to the desired flow of 40 CFM.

3.4.1.3.3 Meteorological Sensors

Meteorological sensors consisted of wind sensors and a precipitation gauge. The wind sensors were located approximately 35 feet off the ground where they would be free of air turbulence caused by ground-level obstructions such as buildings and trees. The wind sensors continuously recorded hourly wind speed and direction on an analog strip chart recorder and data logger. The following wind sensors were employed:

	Model	Accuracy	Range	Threshold
Wind direction	Natural Power 01503	±3% Degrees	0-360 Degrees	2.0 MPH
Wind speed	Natural Power 01503	±1.2 MPH	0-125 MPH	1.3 MPH

Signals from the wind instruments were recorded on a Climatronics recorder mounted in a weatherproof enclosure at the base of the tower. A precipitation gauge having the following characteristics was implemented:

- Natural Power Model No. A70-R
- Type - tipping bucket
- Sensitivity - 1 tip per 0.01"
- Resolution - 0.01"
- Accuracy - 1% at 3"/hr.

Precipitation amounts were recorded on an externally-mounted digital strip chart recorder and data logger.

3.4.1.4 Analytical Procedures

Prior to the start of the TSP and PM10 sampling program, sampling and analysis equipment was calibrated. Laboratory calibration activities included checking of the analytical balance, relative humidity indicator, elapsed time meter, on-off timer, and flowrate transfer standard. The calibration procedures followed those outlined in Section 2.2.2, U.S. Environmental Protection Agency (USEPA) document 600/4-77-027a, *Reference Method for the Determination of Suspended Particulates in the Atmosphere (High Volume Method) (EPA, 1983).*

Each high volume sampler also required calibration. The samplers have within them a flowrate measurement device (orifice) capable of indicating total sampled volumetric flow. A pressure recorder is interfaced with the orifice to provide a continuous record of daily flow.

Calibration of the high volume samplers required calibration of these flow indicators so that they provide accurate flowrate data. The samplers were calibrated for the average temperature and pressure conditions at the sampling sites.

High volume sampler flowrate devices were calibrated at:

- Prestart-up, 3-22-88
- After maintenance, 7-23-88 and 10-8-88
- Prior to shutdown, 2-18-89

TSP and PM10 ambient concentrations were determined following procedures outlined in USEPA document 600/4-77-027a, Section 2.2. Details of the sampling and determination of particulate levels are outlined in the *Ambient Air Monitoring Quality Assurance Plan* (F&VD, 1988). This plan, dated May 1988, was approved by the WDNR. The WDNR also conducted calibration audits before and after the sampling period and verified and validated the equipment used in the program.

3.4.1.4.1 Chemical Analysis of Particulate

As a means of characterizing the metallic components of TSP caught by the filter media, chemical analysis was undertaken. The analysis involved the testing of composite samples from each of the monitoring stations. Composites included filter material from each two-month period. A total of three composites were obtained from each site during the TSP monitoring study.

The chemical analysis was performed by a State of Wisconsin Certified Laboratory (NR 149). Methods employed for the determination of metal components in the TSP included atomic

absorption (flame, HGA graphite furnace, and cold vapor) and inductively-coupled plasma. Specific methods for the determination of each metal are listed in Table No. 3.4-1.

Samples were prepared by cutting individual filters into 1/4-inch square pieces. A two-gram sample was then digested in a 20-ml solution of HNO_3 employing microwaves as an energy source. After digestion, the sample was diluted to 100 ml with deionized water and analyzed.

Blanks were analyzed along with the TSP samples to screen any possible false readings resulting from the filter media or analytic methods. The blank filters were subjected to the pre-treatment, digestion, and dilution and then analyzed on the instrument that the associated samples were analyzed by. Table No. 3.4-2 lists the results of the analysis of metals. This data is analyzed and discussed in Section 3.4.3.2.

3.4.1.4.2 Particle Size Distribution

As part of the particle characterization study, filters with particulate loadings equal to or in excess of 75 micrograms per cubic meter (ug/m^3) were subjected to microscopic analysis. The analysis included sectioning the filter and examining the detached piece (subsample) microscopically to determine the size distribution and particle shape.

The particulate was categorized in diameter ranges of 0 to <5, 5 to <10, 10 to <20, 20 to <30 and greater than 30 microns. In addition, particles were categorized by shape. Designations included platy, rhombic, pollen, and rounded.

The filter subsamples were cut from the central portion of each filter. Two one-centimeter-diameter sections were collected from each subsample with a core bore and mounted on an aluminum stub. The mounted samples were coated with carbon and examined with a scanning electron microscope (SEM).

Random photographs were taken from each of the two SEM mounts, totalling ten per mount. Each photograph was taken at a magnification of 1130X as determined by measuring a calibrated grid. Three representative photographs, which contain a minimum of grain overlap, were selected for particle counting, determination of diameter, and shape categorization. Each of those photographs was examined three times and particles counted to calculate a mean value on a size basis.

3.4.2 Climatology-Meteorology

Data on precipitation, wind speed, wind direction and daily high and low temperatures were collected for the months May through October 1988.

TABLE NO. 3.4-1

Metals and Methods of Analysis for
TSP Composite Samples

Component	USEPA SW-846 Method No.	Method	Detection Limit (ug/g)
Antimony	7041	G	0.25
Arsenic	7060	G	0.15
Barium	7080	F	4.00
Beryllium	6010	ICP	0.05
Cadmium	7131	G	0.015
Chromium	7191	G	0.15
Cobalt	7200	F	2.0
Copper	7210	F	0.50
Lead	7421	G	0.1
Manganese	7460	F	0.55
Mercury	7471	CV	0.1
Molybdenum	6010	ICP	1.5
Nickel	7520	F	1.5
Selenium	7740	G	0.15
Thallium	7841	G	0.10
Tin	6010	ICP	3.4
Zinc	7950	F	0.55

G - Graphite Furnace
F - Flame
CV - Cold Vapor
ICP - Inductively Coupled Plasma

TABLE NO. 3.4-2

Gross Chemical Results of Particulate Samples

Element	Concentration in ug/g							
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Average[1]	Blank
Antimony	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25	0.25	<0.25
Arsenic	0.40	0.25	0.30	0.40	0.35	0.30	0.33	<0.15
Barium	7.1	4.5	4.2	11.	4.4	4.7	6.0	4.3
Beryllium	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.05	<0.05
Cadmium	0.31	0.26	0.25	0.26	0.19	0.88	0.36	0.10
Chromium	0.80	0.75	0.55	1.0	0.85	0.68	0.77	0.55
Cobalt	<2.	<2.	<2.	<2.	<2.	<2.	2.	<2.
Copper	48.	69.	37.	52.	100.	48.	59.	1.1
Lead	6.2	2.7	2.7	4.4	2.8	3.1	3.7	0.35
Manganese	9.3	7.7	5.3	15.	9.1	6.7	8.8	<0.55
Mercury	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	<0.1
Molybdenum	3.6	1.8	<1.5	1.9	<1.5	<1.5	2.0	<1.5
Nickel	<1.5	<1.5	<1.5	1.5	<1.5	<1.5	1.5	1.5
Phosphorus	330.	320.	210.	310.	340.	200.	285.	97.
Selenium	0.35	0.30	0.25	0.40	0.40	0.20	0.32	<0.15
Thallium	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.10	<0.10
Tin	5.4	<3.4	<3.4	<3.4	<3.4	11.	5.0	6.8
Zinc	19.	10.	15.	16.	11.	13.	14.	4.4

1. Wherever a non-detect was reported for any test result, the detection limit was used to calculate the average value.

Three monitoring stations were included in the study to compile the necessary data: the primary site, operated by Kennecott, located south of the project area; the Ladysmith Ranger Station; and the National Weather Service Station at Eau Claire County Airport.

3.4.2.1 Precipitation

Precipitation data was accumulated at both the Kennecott meteorological station (MET) and the Ladysmith Ranger Station. Figure No. 3.4-2 illustrates data from the MET Station for total rainfall (in inches) for each of the monitoring months. Because the summer of 1988 was unusually dry and might not be representative of local conditions during the life of the mine, data collected at the Ladysmith Ranger Station for the years 1982 through 1986 is also included in this document to provide precipitation information that is more representative of typical conditions. Figure No. 3.4-3 is a graphical representation of the additional data.

3.4.2.2 Wind Velocity and Direction

Wind velocity and direction data were acquired from all three meteorological stations. Five years of meteorological data are required to enable an accurate assessment of the impact of the proposed mining operation on the surrounding area. Only the NWS Station at Eau Claire had sufficient data to accommodate this assessment. Because Eau Claire and Ladysmith are separated by 60 miles, a comparison of measurements taken at Eau Claire with those at the Ladysmith Ranger Station and Kennecott MET Station was undertaken. Figure Nos. 3.4-4 and 3.4-5 illustrate those comparisons. Examination of the figures suggests that the NWS data is representative of the conditions at Ladysmith and can be used with a high degree of confidence.

Figure No. 3.4-6 depicts the wind velocity and direction at the Eau Claire NWS Station for the years 1982 through 1987 in the form of a wind rose. The wind rose indicates that the primary wind direction is from the south and west.

3.4.2.3 Temperature

High and low ambient surface temperatures were recorded at both the NWS and Ladysmith Ranger Stations during the sampling period. The high and low temperature data collected are depicted in Figure No. 3.4-7.

3.4.3 Background Air Quality

Air monitoring was conducted for the months May through October 1988 at two sites in the vicinity of the project area as described above. Following is a discussion of the results.

3.4.3.1 Ambient Air Particulate Concentration

Ambient particulate concentrations were determined in order to provide data for establishing background levels. These levels are to be used to establish a baseline. Because of the importance of establishing the "true" background level, careful scrutiny was given to discount days on which unnatural phenomena created excessively high TSP levels.

At present, the WDNR Bureau of Air Management considers a particulate level of greater than 150 ug/m^3 an "excursion." TSP and PM10 levels at the two monitoring stations varied considerably from one day to the next. However, on only one occasion, was an excursion seen to occur. On May 19, 1988, an excursion was noted at the hospital monitor. This excursion can be attributed to demolition activity at the STH 27 bridge adjacent to the monitoring station. It should be noted that a new PM10 standard is expected to replace the existing TSP standard.

Unique or unnatural phenomena observed during the monitoring study and which contributed to elevated TSP concentrations included: demolition of a concrete bridge adjacent to the hospital property; reconstruction of the roadbed on STH 27; and new construction on a nursing home building across from the hospital. These events occurred during one of the driest summers on record, and were specific to the summer of 1988, the period during which the ambient air monitoring took place. Because these were unique and nonrecurring events, the elevated particulate levels which could be attributed to these sources were discounted as they were not truly representative of "normal" background levels. This conclusion is further supported by the ambient air monitoring data collected at the site in the late 1970s and early 1980s.

Figure Nos. 3.4-8 and 3.4-9 depict the results of the TSP sampling study for the Jansen Road and hospital sites, respectively. Additional TSP and PM10 data analysis is presented in the *Ambient Air Monitoring Report Phase II* (March 1989). It should be noted that monitoring data showed that background PM10 values were within acceptable levels.

In an attempt to screen out nonrepresentative TSP values, potential generators of TSP were questioned on days that high levels were observed. Construction activity, batch processing of cement, and gravel mining were found to be evident during the days for which elevated TSP was observed. In addition, wind direction was found to influence the level of TSP found at the monitoring stations. In-depth details of the analysis are presented in the *Ambient Air Monitoring Report Phase I* (November 1988).

Because background or ambient levels in the vicinity of the mine site should be consistent, a further analysis compared the TSP levels at both sites. Solutions were sought for the discrepancies for days when high readings were recorded at one monitoring station but not the other. Figure No. 3.4-10 illustrates the TSP comparison.

Analysis of the data sampled at the two monitoring stations indicated that neither site consistently showed higher TSP values than the other on the same day. Peaks at one of the monitoring stations without a corresponding peak at the other was concluded to be the result of isolated activity at or near the site. Based on discounting these random peaks as time-specific, nonrepresentative ambient data, the background level was determined to be 60 ug/m^3. The 60 ug/m^3 value represents the high second high value for particulate with 120 ug/m^3 as the high.

3.4.3.2 Particle Characterization

Particulate characterization included determination of the chemical composition and particle size distribution. Samples from days on which TSP values exceeded 75 ug/m^3 were used to establish a distribution based on particle diameter. A 75 ug/m^3 setpoint was established by the WDNR. Composite samples of particulate for each two-month period were analyzed for designated metal constituents. Table No. 3.4-3 lists the sample dates designated for the respective analyses. Table Nos. 3.4-4 and 3.4-5 give results of the characterization study.

Particulate was categorized by shapes, which included: platy, rhombic, pollen, and rounded grain. Platy grains are considered to be clay minerals but may not include other phyllosilicates such as chlorite or micas. The rhombic grains include cleavage fragments of hexagonal carbonates and are probably calcite and dolomite. Rounded grains with diameters in the zero to five micron range were found to have a high degree of sphericity and are typically formed as a result of condensation. Rounded grains with diameters larger than five microns are less well rounded and less spherical than are their smaller counterparts.

Examination of the data from the microscopic analysis of entrained particulate captured at the two monitoring sites concluded that:

- More than 50 percent, and with the exception of one sample, more than 70 percent, of the grains counted had rounded shapes.

- In general, the samples taken at the Jansen Road station contained more rhombic-shaped particles than the hospital site. The larger percentage of rhombic shapes is suggestive of road construction activity conducted along STH 27, adjacent to the Jansen Road monitor.

TABLE NO. 3.4-3

Sample Dates Used in Particulate Analysis for Hospital Site

Sample	Date
0001	5-19-88
0027	6-14-88
0049	7-6-88

Sample Dates Used in Particulate Analysis for Jansen Road Site

Sample	Date
0008	5-25-88
0014	5-31-88
0050	7-6-88

TABLE NO. 3.4-4

Particle Size Distribution by Percent

	Particle Size					
Sample No.	0-<5	5-<10	10-<20	20-<30	>30	Total
Hospital						
0001	96.6	3.0	0.4	0	0	100.0
0027	93.5	4.9	1.4	0.2	0	100.0
0049	97.8	2.0	0.2	0	0	100.0
Jansen Road						
0008	91.6	6.9	1.5	0	0	100.0
0014	95.0	4.0	1.0	0	0	100.0
0050	91.2	6.0	2.5	0.3	0	100.0

TABLE NO. 3.4-5

Particle Shape Characterization by Percent

Sample No.	Platy	Rhombic	Pollen	Rounded	Total
Hospital					
0001	8.0	4.6	0.1	87.3	100.0
0027	17.8	7.9	0	74.3	100.0
0049	5.9	2.0	0.2	91.9	100.0
Jansen Road					
0008	37.8	10.0	0.2	52.0	100.0
0014	8.5	17.6	0.3	73.6	100.0
0050	15.6	4.0	0.3	80.1	100.0

- More than 90 percent of the grains counted in all of the samples are in the 0 to 5 micron range. A significantly smaller percentage was found to be within the 10 to 20 and 20 to 30 micron ranges and virtually none were counted which exceeded 30 microns in diameter.

In comparison to the Jansen Road monitoring station, the hospital site contains a slightly larger percentage of rounded particles. This could be due, in part, to a hospital incinerator located near the monitor.

Jansen Road samples contained a slightly higher percentage of platy and rhombic shaped particles in comparison to the hospital site. This is indicative of road construction activity near the monitoring station.

Chemical analysis of composite particulate samples from the two monitoring stations indicated that the major constituents within each sample were copper, lead, manganese, phosphorous, and zinc. The component with the highest net concentration was phosphorous at 188 ug/g. Table No. 3.4-2 lists the chemical components and their respective net concentrations within each of the six samples.

Ambient concentrations of each component within the TSP were arrived at by calculating the product of the TSP level of 60 ug/m^3, which has been established as the background level, and the arithmetic averaging for each component of the six samples. The results of these multiplications are also included in Table No. 3.4-6.

TABLE NO. 3.4-6

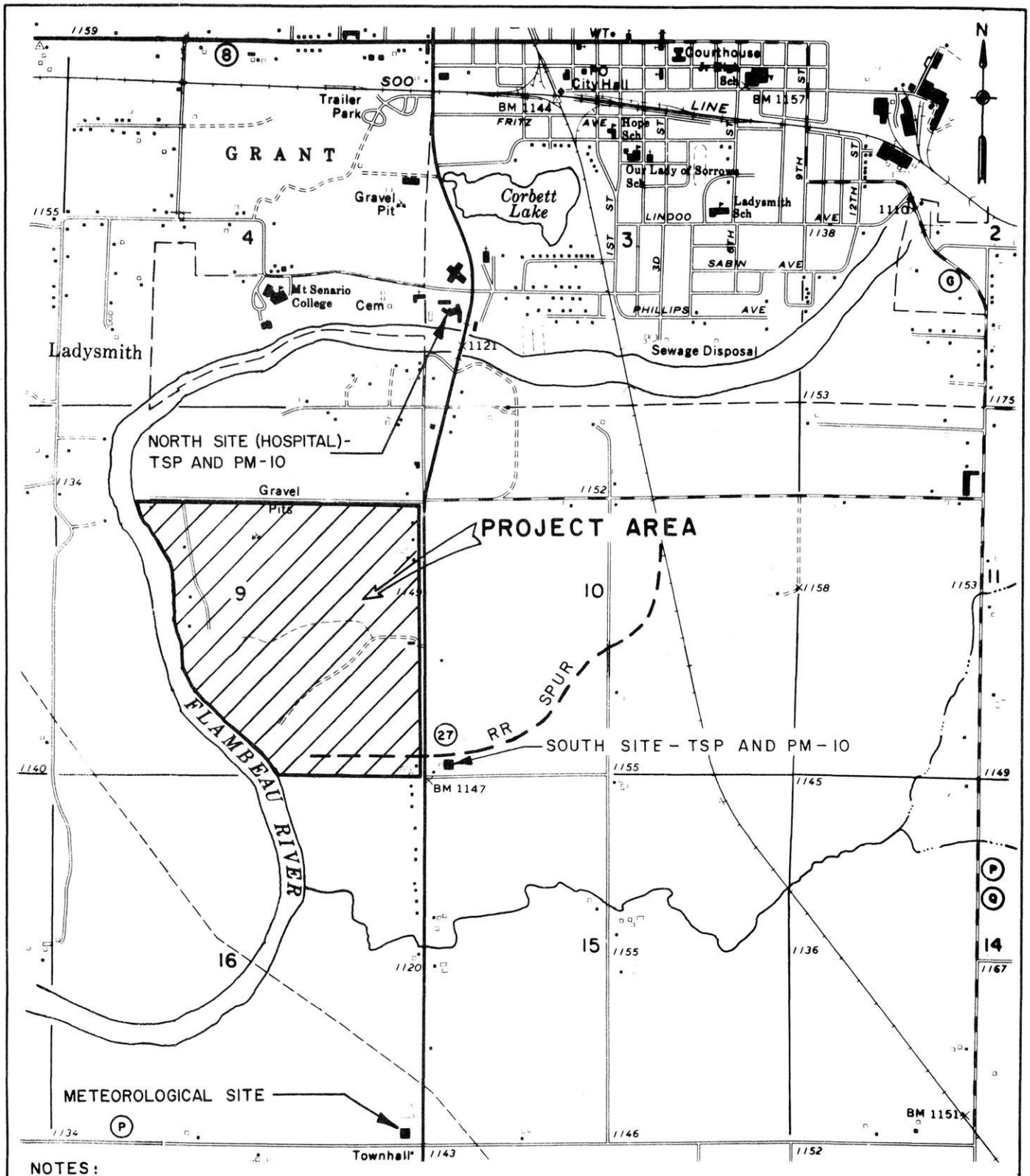
Net Chemical Results of Composite Particulate Samples

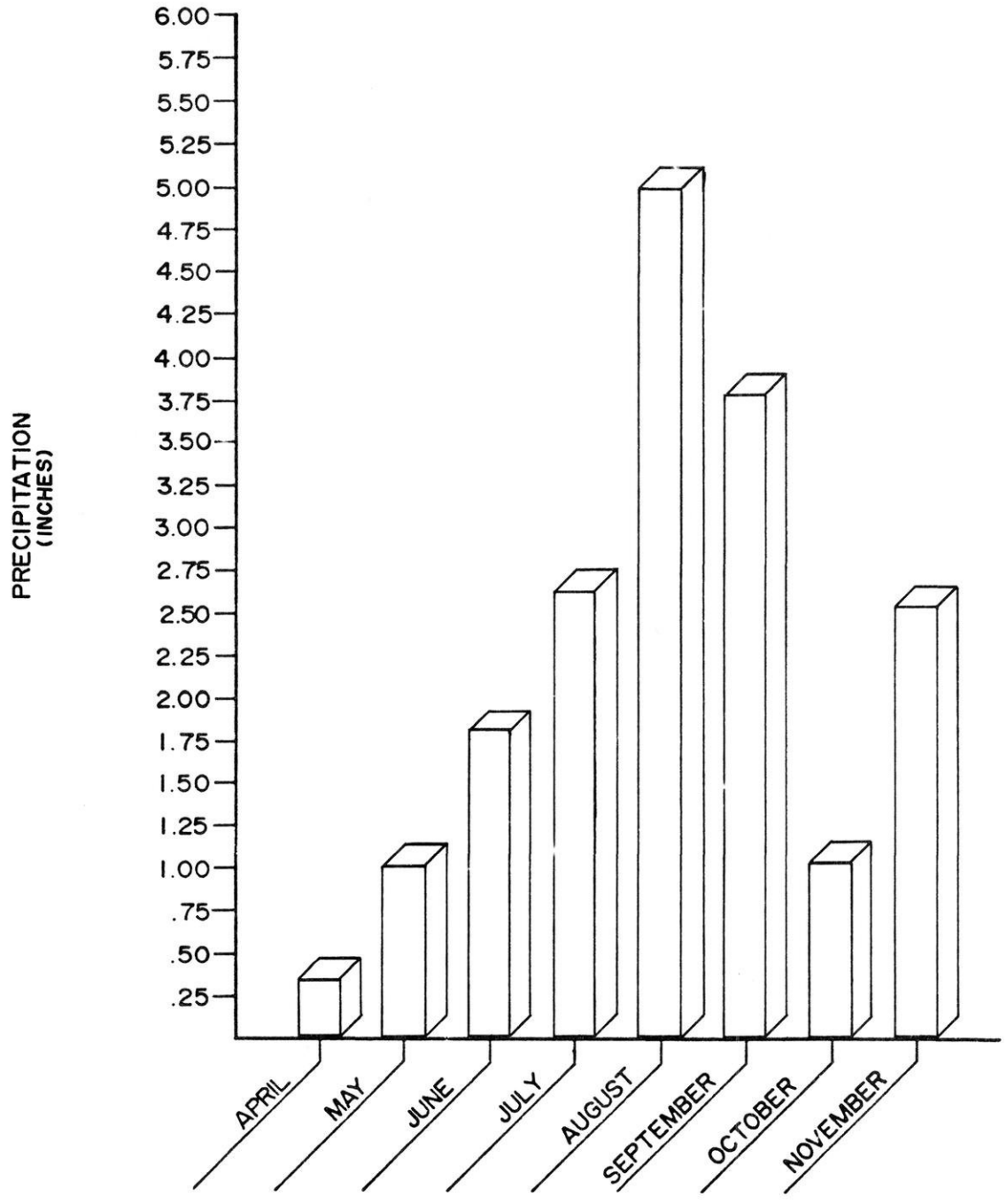
Element	Net[1] (ug/g)	TSP_{amb}[2] (ug/m^3) x10^6
Antimony	0.00	0
Arsenic	0.18	11
Barium	1.7	100
Beryllium	0.00	0
Cadmium	0.26	16
Chromium	0.22	13
Cobalt	0.	0
Copper	57.9	3470
Lead	3.4	200
Manganese	8.3	500
Mercury	0.0	0
Molybdenum	0.5	30
Nickel	0.00	0
Phosphorus	188.	11,300
Selenium	0.17	10
Thallium	0.00	0
Tin	0.0	0
Zinc	9.6	580

[1]Net is equal to the difference between the "average" and "blank" values shown on Table No. 3.4-2.

[2]TSP (ambient) equals "net" concentration times the established background particulate level of 60 ug/m^3.

Figures for Section 3.4


N
Courthouse
City Hall
Trailer Park
SOO LINE
BM 1144
BM 1157
FRITZ AVE
Hope Lutheran Sch
Our Lady of Sorrows Sch
Ladysmith Sch
GRANT
Gravel Pit
Corbett Lake
LINDOO AVE
SABIN AVE
PHILLIPS AVE
Mt Senario College
Cem
Ladysmith
Sewage Disposal
NORTH SITE (HOSPITAL)- TSP AND PM-10
Gravel Pits
PROJECT AREA
RR SPUR
SOUTH SITE - TSP AND PM-10
BM 1147
FLAMBEAU RIVER
METEOROLOGICAL SITE
Townhall
BM 1151
1ST ST
3D ST
4TH ST
9TH ST
12TH ST
1ST AVE
2ND AVE
3RD AVE
4TH AVE
5TH AVE
6TH AVE
7TH AVE
8TH AVE
9TH AVE
10TH AVE
11TH AVE
12TH AVE
1ST ST
2ND ST
3RD ST
4TH ST
5TH ST
6TH ST
7TH ST
8TH ST
9TH ST
10TH ST
11



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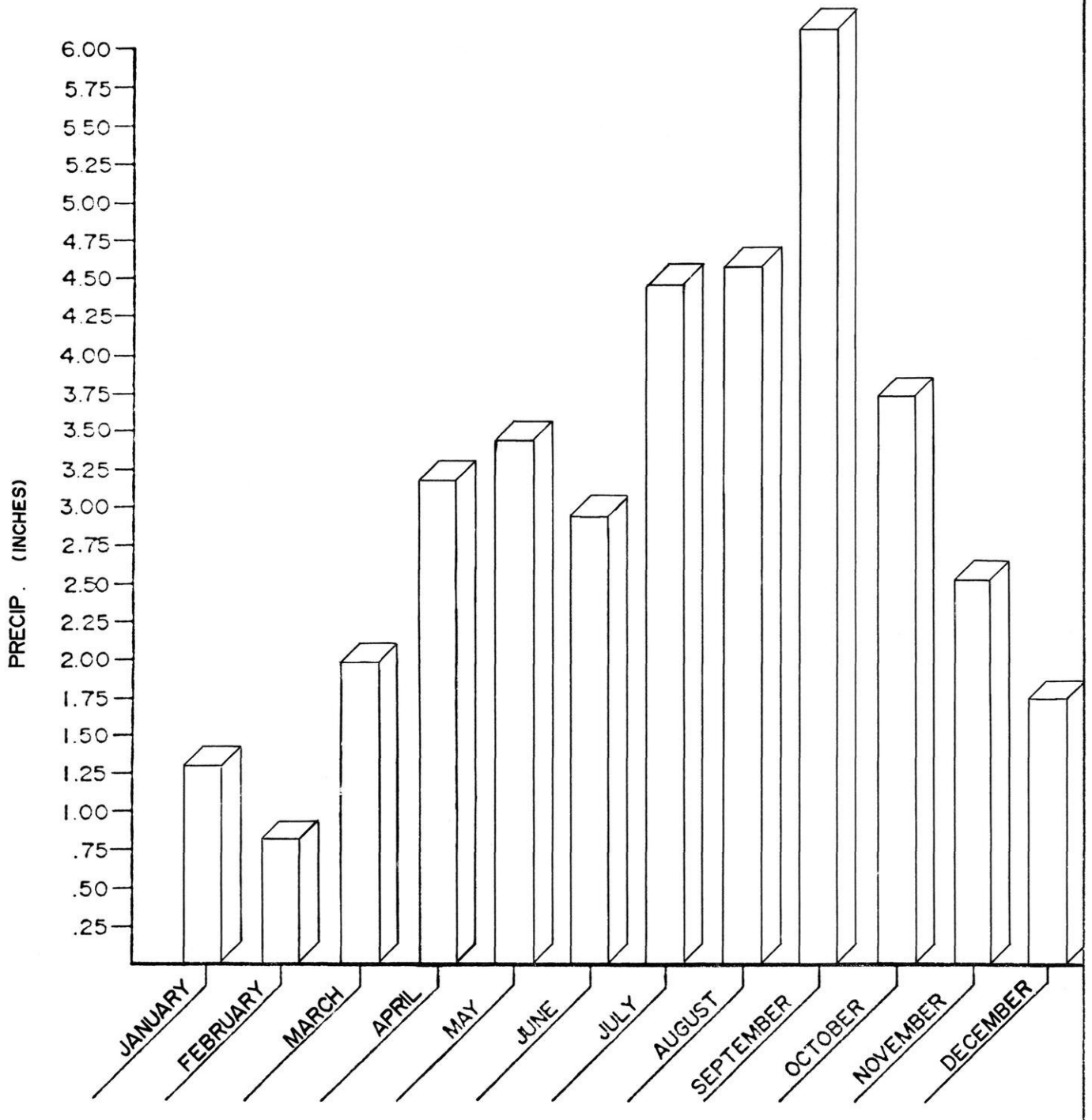
KENNECOTT MINERALS COMPANY

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FIGURE NO. 3.4-2
PRECIPITATION AT KENNECOTT MET STATION (1988)

NOTES	APPROVAL		DATE
	DESIGNED BY		
	DRAWN BY	SDL	2/89
	CHECKED BY	RLP	3/89
	APPROVED BY		
	CAD No.	SCALE	

Job No	Dwg No	REV



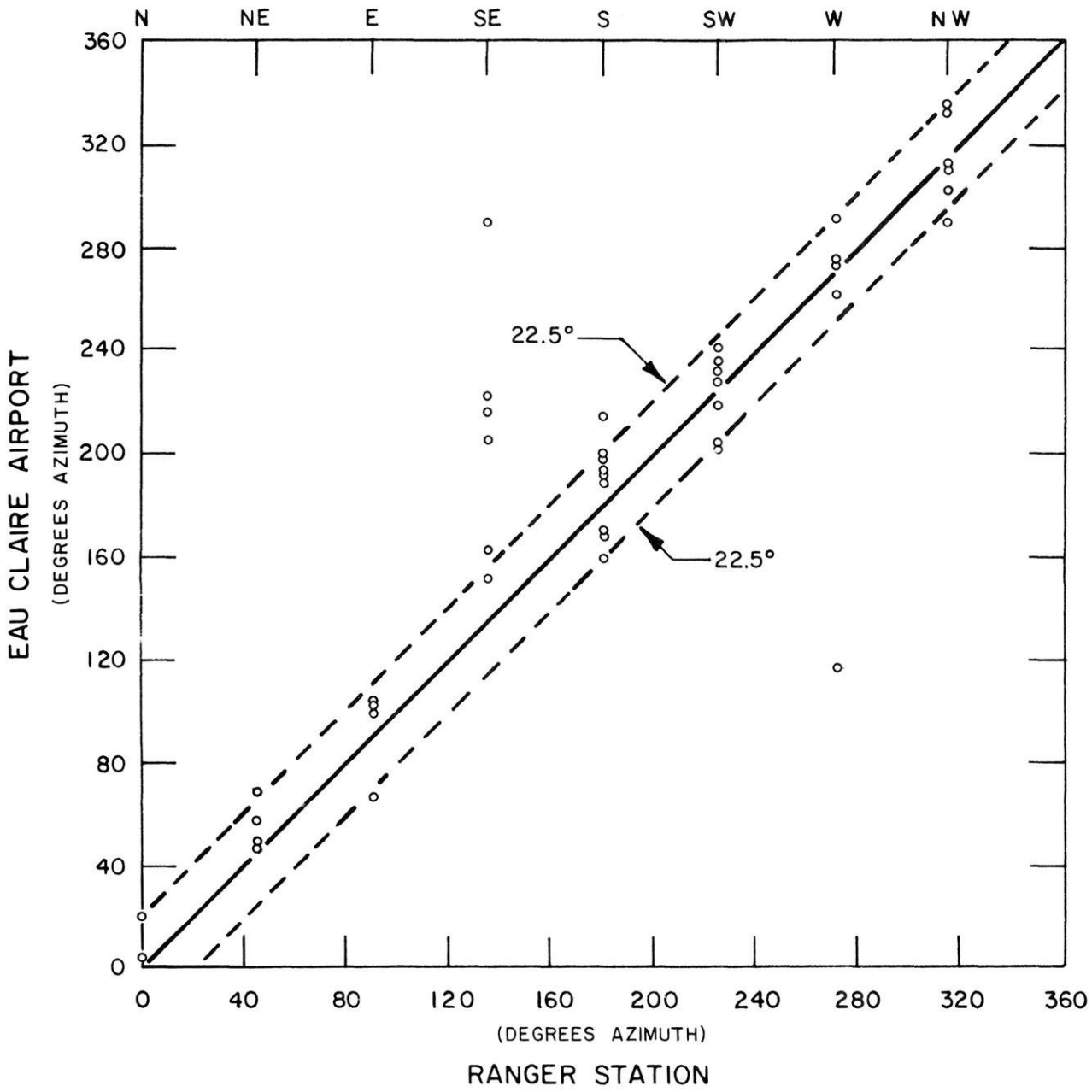
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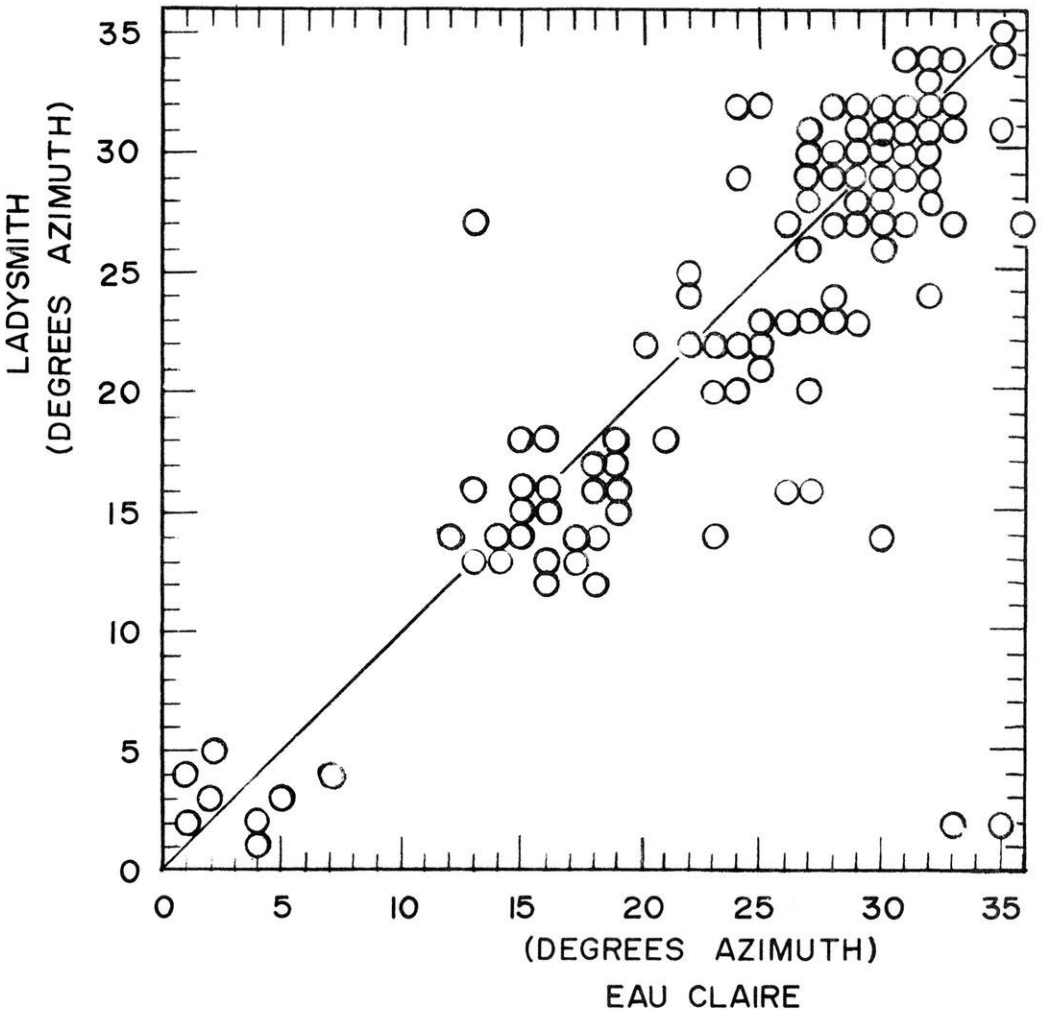
FIGURE NO. 3.4-3
PRECIPITATION AT LADYSMITH RANGER STATION (1982 – 1986)

NOTES	APPROVAL		DATE
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	CHECKED BY	RLP	3/89
	APPROVED BY		
	CAD No.	SCALE	

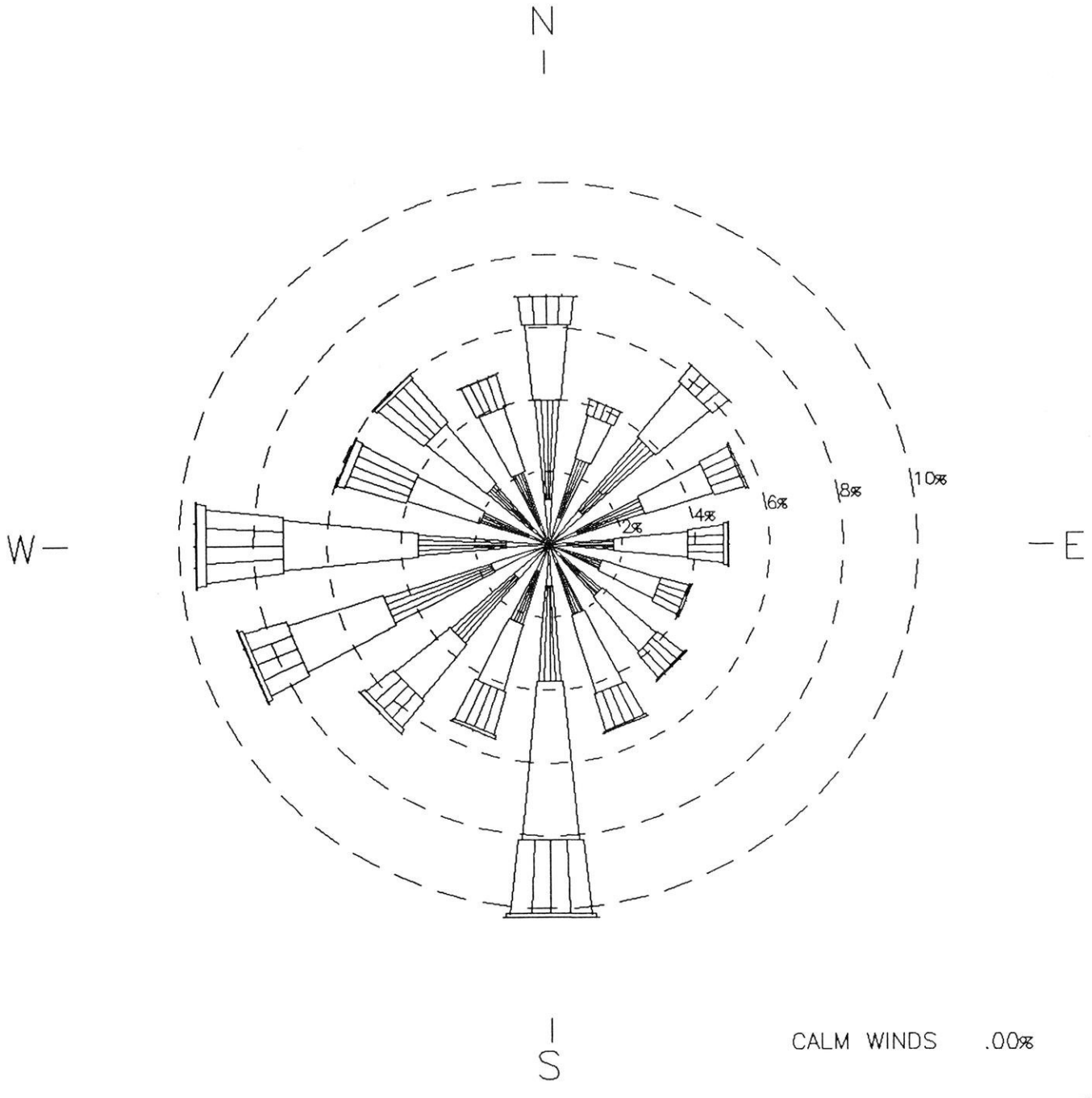
Job No	Dwg No	REV



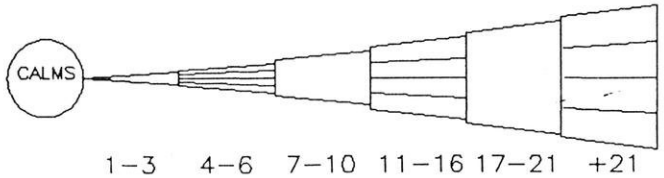
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NOTES	APPROVAL	DATE	FIGURE NO. 3.4-4 CORRELATION OF RANGER STATION AND EAU CLAIRE WIND DIRECTION
	DESIGNED BY		
	DRAWN BY SJL	2/89	
	CHECKED BY RLP	3/89	
	APPROVED BY		
	CAD No. SCALE		Job No / Dwg No / REV



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NOTES	APPROVAL	DATE	FIGURE NO. 3.4-5 CORRELATION OF KENNECOTT MET AND EAU CLAIRE WIND DIRECTION
	DESIGNED BY		
	DRAWN BY S.D.L.	1/89	
	CHECKED BY R.L.P.	3/89	
	APPROVED BY		
	CAD No. / SCALE		Job No / Dwg No / REV



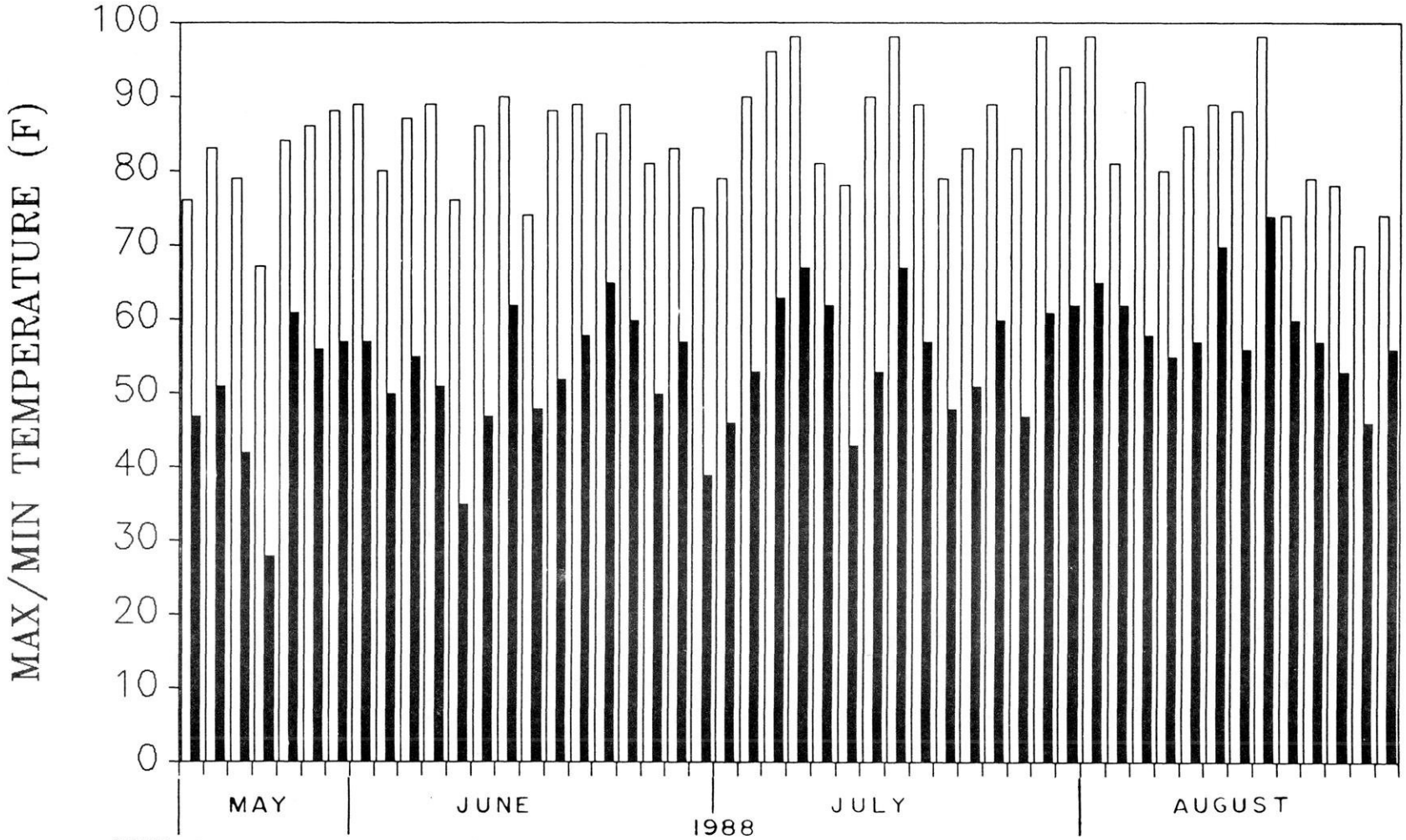
CALM WINDS .00%



WIND SPEED CLASS
(KNOTS)

WINDROSE
EAU CLAIRE, WI
1982-86

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NOTES	APPROVAL	DATE	FIGURE 3.4-6 FREQUENCY OF WIND SPEED AND DIRECTION
	DESIGNED BY		
	DRAWN BY SJL	3/89	
	CHECKED BY RLP	3/89	
	APPROVED BY		
	CAD No. SCALE		Job No / Dwg No / REV



NOTE: TEMPERATURES TAKEN APPROXIMATELY EVERY OTHER DAY BEGINNING MAY 19, 1988 AND ENDING AUGUST 25, 1988

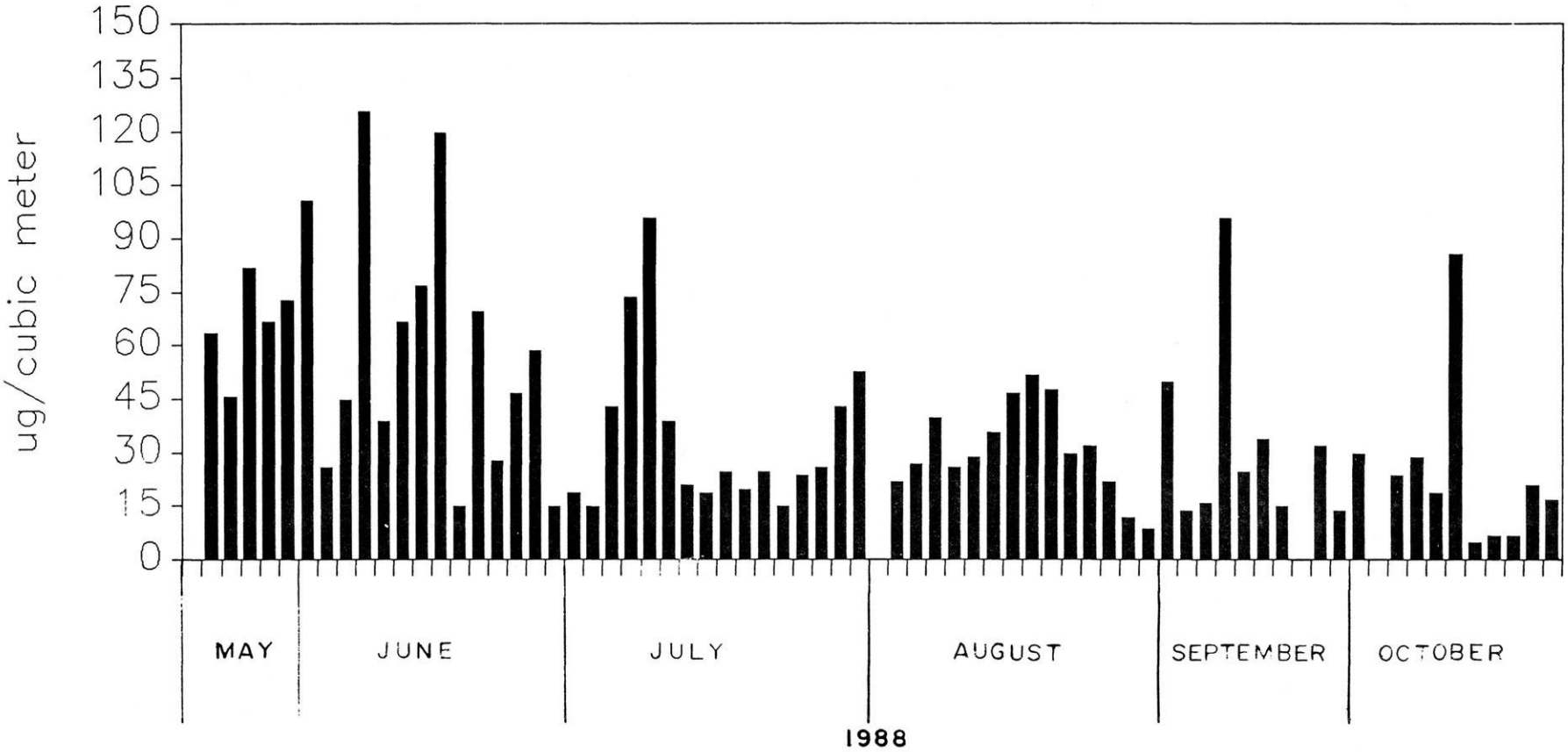
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FIGURE NO. 3.4-7
DAILY MAX/MIN. TEMPERATURES
AT LADYSMITH RANGER STATION

No	REVISIONS	NOTES	APPROVAL	DATE
			DESIGNED BY	
			DRAWN BY RDM	2/89
			CHECKED BY RLP	3/89
			APPROVED BY	
			CAD No.	SCALE

Job No	Dwg No	REV



NOTE: SAMPLES TAKEN APPROXIMATELY EVERY OTHER DAY BEGINING MAY 19TH, 1988 AND ENDING OCTOBER 30TH, 1988

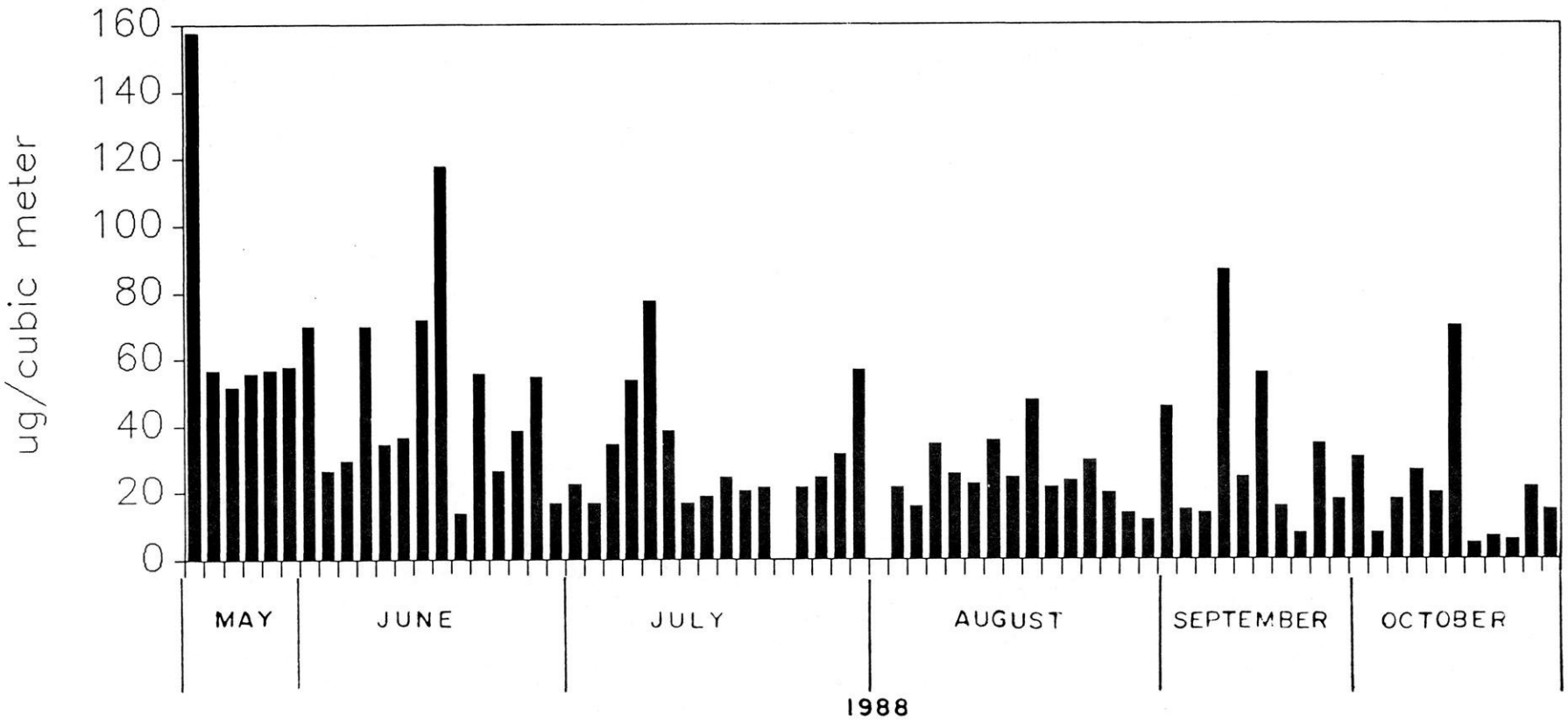
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FIGURE NO. 3.4-8
TOTAL SUSPENDED PARTICULATES
JANSEN ROAD SITE

No	REVISIONS	NOTES	APPROVAL	DATE
			DESIGNED BY	
			DRAWN BY RDM	2/89
			CHECKED BY RLP	3/89
			APPROVED BY	
			CAD No.	SCALE NONE

Job No	Dwg No	REV



NOTE: SAMPLES TAKEN APPROXIMATELY EVERY OTHER DAY BEGINING MAY 19TH, 1988 AND ENDING OCTOBER 30TH, 1988

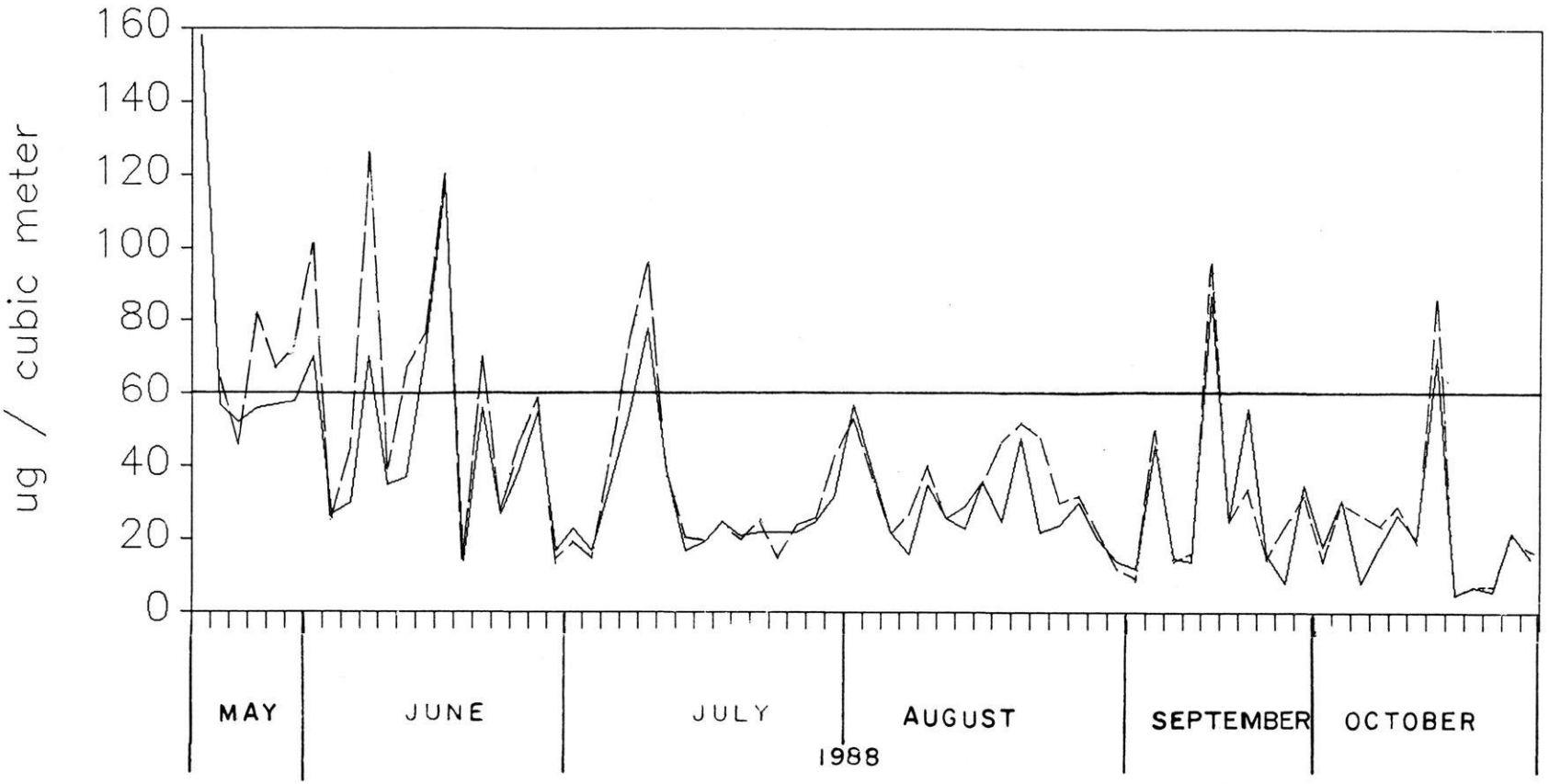
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FLAMBEAU PROJECT
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FIGURE NO. 3.4-9
TOTAL SUSPENDED PARTICULATES
HOSPITAL SITE

No	REVISIONS	NOTES	APPROVAL	DATE
			DESIGNED BY	
			DRAWN BY RDM	2/89
			CHECKED BY RLP	3/89
			APPROVED BY	
			CAD No.	SCALE NONE

Job No	Dwg No	REV



LEGEND

——— HOSPITAL TSP

— — — — JANSEN ROAD TSP

NOTE: SAMPLES TAKEN APPROXIMATELY EVERY OTHER DAY BEGINING MAY 19TH, 1988 AND ENDING OCTOBER 30TH, 1988

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FIGURE NO. 3.4-10
TOTAL SUSPENDED PARTICULATES

No	REVISIONS	NOTES	APPROVAL		DATE
			DESIGNED BY		
			DRAWN BY	RDM	2/89
			CHECKED BY	RLP	3/89
			APPROVED BY		
			CAD No.	SCALE NONE	

Job No	Dwg No	REV

3.5 Geology

The geologic information presented in this report is the result of several field investigations and laboratory testing programs conducted since 1968. Part of the geologic information was collected prior to the approval of the 1976 EIS. The rest of the geologic information was collected in 1987 through 1989 prior to this submittal.

3.5.1 Field and Laboratory Methods

Sections 3.5.1.2 through 3.5.1.6 describe the diamond core, hydrogeologic, waste characterization borings, and geotechnical drilling programs conducted on or around the project area from 1968 to 1988. Table No. 3.5-1 summarizes the project drilling.

3.5.1.1 Site Grid System

In 1969, five on-site triangulation control points were established by a professional engineer using standard surveying techniques. The control points were established for surveying drill hole locations and are based on a U.S. Cadastral Survey benchmark located adjacent to State Highway 27 near Meadowbrook Creek.

A north-south mine coordinate grid system was established based on control point F1, which was designated 40,000 North and 40,000 East as shown on Figure No. 3.5-1. A baseline oriented in a N45°E direction, parallel to the strike of the ore body, was also established. The baseline was designated 20,000 North for computer evaluation of mineral reserves and mine design studies. Points every 200 feet along the baseline from the Flambeau River to Highway 27 were surveyed and section lines were established at these points perpendicular to the baseline. These points were used to locate drill holes. The following equations can be used to convert the coordinates from the mine grid to the oblique (baseline) grid.

$$\text{Oblique N} = (\text{Mine N} - \text{Mine E})\ (0.707107) + 19{,}421.40$$
$$\text{Oblique E} = (\text{Mine E} + \text{Mine N})\ (0.707107) - 15{,}617.16$$

3.5.1.2 Initial Investigations

Discovery of the Flambeau Deposit occurred on November 6, 1968, when the first diamond drill hole intersected copper sulfide mineralization. From 1968 to 1974, a total of 135 diamond drill holes were completed to provide core samples for assaying and this data used to delineate the deposit. Table No. 3.5-1 lists all diamond drill holes, borings, and wells drilled on and around the project area from 1968 to 1988.

During the period 1968 to 1971, diamond drill holes numbered DDH 22-1 through DDH 22-117 were drilled. In 1974, 18 additional

TABLE NO. 3.5-1

List of Core, Borehole and Well Drilling

Drilling Program	Identification of Holes
1968 - 1975	
Delineation Core Drilling	(135) 22-1 to 22-135
Soil Test Holes	(65) ST-9-1 to ST-9-13 ST-9-17 to ST-9-29 ST-9-30 to ST-9-56 and ST-9-68 ST-9-57 to ST-9-67
Water Wells	(29) OW-1 to OW-20 OTW-29 and OTW-34 OW-39 to OW-45
1987 - 1988	
Infill Core Drilling	(26) 22-136 to 22-162
Baseline Groundwater Monitoring	MW-1000, MW-1000P, MW-1001, MW-1001G, MW-1001P, MW-1002, MW-1002G, MW-1003, MW-1003P, MW-1004, MW-1004S, MW-1004P, MW-1005, MW-1005G, MW-1005P
Wetlands	PZ-1006, PZ-1006G, PZ-1006S, PZ-1A, PZ-1B
Geotechnical - Soils	PZ-S1, PZ-S2, B-S2A, PZ-S3, PZ-S4, B-S4A, B-S5, B-S5A
Rock	PZ-R1 (22-137A) (22-137), B-R4 (22-140), B-R6 (22-141) PZ-R2 (22-138), PZ-R5 (22-136), PZ-R7 (22-142) PZ-R3 (22-139)

TABLE NO. 3.5-1 (Cont.)

Drilling Program	Identification of Holes		
Waste Characterization	B-WC-1	B-WC-2	B-WC-3
	B-WC-1A	B-WC-2A	B-WC-3A
	B-WC-1B		
Permeability Test Wells	TW-K1	TW-K4	TW-K6R
	TW-K2	TW-K5	TW-K7
	TW-K3	TW-K5R	TW-K17B
	TW-K3R	TW-K6	PZ-K8
Groundwater Modeling	PZ-1007S	PZ-1009G	PZ-K2PP
	PZ-1008	PZ-SP6	PZ-K4P
	PZ-1008G	PZ-SP8	PZ-K4PP
	PZ-1009	PZ-K2P	
Type II Waste Rock Storage Area	B-SP1	B-SP4	B-SP7
	B-SP2	B-SP5	PZ-SP8
	B-SP3	PZ-SP6	
Railroad Spur	B-RS1	B-RS5	B-RS9
	B-RS2	B-RS6	B-RS10
	B-RS3	B-RS7	B-RS11
	B-RS4	B-RS8	B-RS12

holes (DDH 22-118 through DDH 22-135) were drilled on the west half of the deposit. All drilling was conducted by Longyear Company using standard wire-line rock coring techniques. HQ, NQ, and BQ cores were obtained.

Mud rotary drilling methods with a tricone bit were used in the overburden. These methods were also sometimes used in the Cambrian sandstone and the top of the extremely clay-altered Precambrian rock. Cuttings were examined to identify the Precambrian surface.

The locations of the diamond drill holes are shown on Figure No. 3.5-1. Logs of drill holes used to construct geologic sections H-H' through J-J' (Figure Nos. 3.5-14 through 3.5-16 located in Section 3.5.3.4.2) are included in Appendix 3.5-A.

Thirteen soil test holes (borings ST-9-1 through ST-9-13) were drilled in and south of the proposed pit area in 1972. In 1973, 13 additional soil test holes (borings ST-9-17 through ST-9-29) were drilled. The drilling was conducted by STS Consultants Limited, using auger or mud rotary drilling methods and standard split-barrel sampling techniques. Piezometers constructed of PVC pipe were installed in several of these borings.

In 1975, 28 additional soil test holes (ST-9-30 through ST-9-56 and ST-9-68) were drilled south of the proposed open pit and 11 borings (ST-9-57 through ST-9-67) were drilled within the proposed pit. Borings that penetrated to the Precambrian bedrock surface were used in this report. Geologic logs and soil test data of these borings are included in Appendix 3.5-B and locations are shown on Figure No. 3.5-2.

The purpose of the soil boring program was to provide hydrogeologic and geotechnical information, including *in-situ* and recompacted soil permeabilities, densities, grain size analyses, and Atterberg Limits.

From 1987 to 1989, those STS borings which had been completed as piezometers were used for groundwater elevation measurements. The locations of the STS borings that were used for the 1987-1989 investigations are shown on Figure No. 3.5-2. The geologic logs and laboratory analytical data from the 1972, 1973, and 1975 investigations were also used in the geologic and hydrogeologic site characterization provided in this report.

In 1970 and 1971, 20 water wells (OW-1 through OW-20) were drilled by Longyear Company north and south of the proposed mine site. Also drilled in 1971 were two large diameter pump-test wells (OTW-29 and OTW-34). In 1972, seven additional wells (OW-39 through OW-45) were drilled. The wells were drilled using mud rotary drilling methods in the overburden and coring methods in the Precambrian bedrock. Cuttings were examined to determine approximate thicknesses of overburden strata. Logs of

these wells are included as Appendix 3.5-C. Several of these wells were used in the 1987-1989 investigation for groundwater elevations. Wells that were used during 1987-1989 are shown on Figure No. 3.5-2, and are designated as "OW" wells.

3.5.1.3 1987-1988 Coring Program

The 1987-1988 coring program was conducted to increase the confidence of the supergene enriched reserve estimate on the east one-half of the deposit, to verify the presence, grade, and continuity of gossan mineralization, and to provide samples for rock mechanics testing.

A total of eight inclined holes (DDH 22-136 through DDH 22-142 and 22-137A) were drilled for rock mechanics investigations. In addition, seven inclined and thirteen vertical holes (DDH 22-143 through DDH 22-162) were drilled on generally 100-foot horizontal spacings. Total footage amounted to 4,542 feet. HQ core (2.4-inch diameter) was drilled using split tubes to improve core recovery.

Core was logged to a scale of one inch equals ten feet. Core recoveries averaged 84.5 percent. This relatively low recovery figure includes poor core recoveries in the intensely weathered and clay-altered bedrock. Core recoveries in the sulfide mineralization were greater than 95 percent. Twenty-four holes were surveyed using a down-hole camera. Readings were taken at appropriate intervals and were interpreted to indicate a slight trend of borehole alignment to the east.

Core from sulfide-rich areas was analyzed for base and precious metals, and sulfur, on intervals ranging from a fraction of a foot to ten feet. Core outside of the mineralized horizon was sampled by taking a representative six-inch piece of unsplit core from each two feet over ten-foot intervals and analyzed for sulfur. Core collected within the mineralized horizon was generally split in half, with one-half sent for analysis, and the other half stored. Samples of mineralization and waste rock were also collected for density measurements.

All diamond drill holes were backfilled with a neat cement grout upon completion of drilling. Drill sites were straw-mulched and seeded using a grass mixture recommended by the Wisconsin Department of Natural Resources (WDNR) district office. The WDNR conducted several site inspections during the 1987-1988 drilling program to inspect the effectiveness of site reclamation.

3.5.1.4 Hydrogeologic Drilling Programs

Hydrogeologic drilling investigations completed during 1987-1988 included baseline groundwater monitoring, wetland investigations, rock permeability, and well installation for groundwater evaluation. Another investigation tested the

permeability of the soil strata in the river pillar, which is the area between the Flambeau River and the west end of the proposed open pit.

Additional geologic and hydrogeologic information was obtained from the soil and rock geotechnical testing program for the pit design, and from the waste rock characterization borings. Boring programs were also used to supply geologic data for the Type II waste rock storage area and the railroad spur corridor. A list of borings and wells completed for each program is presented on Table No. 3.5-1. Geologic logs, well construction diagrams, and well development forms are presented in Appendices 3.5-D through 3.5-K of this report. This data was used to prepare geologic Cross Sections A-A' through G-G' as shown on Figure Nos. 3.5-3 through 3.5-9.

In addition to the geologic information obtained from drilling programs, geophysical data was obtained for selected wells and piezometers. In January 1989, 16 wells were gamma-logged by Foth & Van Dyke using a Johnson-Keck Model GR-81 gamma-logger. The gamma logs found in Appendices 3.5-A through 3.5-K were used primarily to help determine geologic contacts in the OW-wells. Geologic logs, well construction diagrams, and well development forms for the hydrogeologic program are also found in these appendices.

3.5.1.4.1 Baseline Groundwater Monitoring

Fifteen groundwater monitoring wells, MW-1000 through MW-1005P, were installed during the period of September 16, 1987, to October 5, 1987, as shown in Figure No. 3.5-2.

Nine monitoring wells (four piezometers and five water table wells, Table No. 3.5-1) were drilled and installed by Wisconsin Test Drilling, Inc., Schofield, Wisconsin, using a CME-55 truck-mounted drill rig. Hollow-stem augers (4.25-inch inner diameter) or mud rotary methods using a tricone bit (6-inch diameter) were used to complete the borings. Each boring was sampled at five-foot intervals using standard split-barrel sampling methods.

Six monitoring wells (five piezometers and one water table well) were drilled and installed by Luisier Drilling, Inc., Lena, Wisconsin, using a Schramm T66-HB air/rotary drill rig. The borings were completed using mud rotary methods with a tricone bit (6.5-inch diameter) from the ground surface to the top of the Precambrian surface. A split-barrel sampler (three-inch outer diameter) was pushed or driven with an air hammer to obtain samples. In each boring completed for the purpose of installing a piezometer, about 30 feet of altered bedrock schist was cored, using a 4.875-inch diameter carbide bit to obtain 3.25-inch diameter core.

3.5.1.4.2 Wetlands

Three piezometers, PZ-1006, PZ-1006G, and PZ-1006S, were installed on September 23 and 24, 1987. As shown on Figure No. 3.5-2, this well nest is located about 100 feet west of State Highway 27. The well nest was installed to investigate hydrologic conditions between the proposed open pit and wetlands located on the east side of the highway. The boring for PZ-1006S was sampled at five-foot intervals using standard split-barrel sampling methods. Piezometers PZ-1006 and PZ-1006G were installed in adjacent, unsampled borings.

Two piezometers, PZ-1A and PZ-1B, were installed on October 30, 1987, in the wetland adjacent to the Flambeau River and northwest of the proposed pit. These piezometers were installed by Wisconsin Test Drilling, Inc., using either a track-mounted CME-45 or a truck-mounted CME-55 drill rig, and hollow-stem augers (4.25-inch inner diameter) or mud rotary drilling methods. The boring for piezometer PZ-1A was continuously sampled using standard split-barrel sampling procedures (ASTM D-1586); piezometer PZ-1B was installed in an unsampled boring located about five feet south.

3.5.1.4.3 Permeability Test Wells

Six test wells, TW-K1 through TW-K6, were installed by Luisier Drilling, Inc., between March 6 and 9, 1988 (Table No. 3.5-1). All of these wells are located on the pit perimeter and were installed to investigate the general permeability of the Precambrian bedrock along the proposed pit perimeter.

The wells were drilled with an air-rotary drill rig. A nine-inch-diameter tricone bit and bentonite drilling fluid were used in the segment of the hole drilled through Quaternary sediments and Cambrian sandstone. A six-inch-diameter down-hole air hammer was used for the segment of the hole drilled into the Precambrian bedrock. Rock cuttings were collected at ten-foot intervals. The nine-inch borings were drilled into the Precambrian bedrock for a distance of two to 15 feet. The drilling fluid was then replaced with a thick bentonite slurry. Steel casing with a six-inch inner diameter was placed through the slurry and driven with an air hammer into bedrock for a distance of 0.5 to 17 feet, depending on the hardness of the rock. The wells were then completed using the down-hole air hammer and air, or air and water as drilling mediums.

Three of the wells, TW-K3, TW-K5, and TW-K6, caved shortly after completion and before adequate permeability testing could be done. The three wells were redrilled on March 24 to 27, 1988. Four-inch-diameter PVC was set in these three wells. These wells were developed by surging and bailing with a cable tool rock bailer (13 feet long by 4.5-inch diameter) and/or surged and bailed with compressed air using the drill rig.

In addition to the rock test wells, three shallow wells, TW-K7, PZ-K8, TW-K17B, were installed during the period of September 19 to 21, 1988, to determine the thickness, extent, and permeability of overburden sediments in the area of the river pillar.

Each boring was sampled at five-foot intervals using a three-inch outer diameter, split-barrel sampler and mud rotary and/or air drilling methods. The sampler was pushed or driven with an air hammer. The depth to the Precambrian surface ranged from 14 to 45 feet at the three locations along the river pillar.

Two four-inch-diameter PVC wells, TW-K7 and TW-K17B, were installed in the Pleistocene gravel and one two-inch-diameter PVC well, PZ-K8, was installed in the uppermost part of the clay-altered Precambrian bedrock. The four-inch-diameter wells were developed by surging with air and jetting with a jetting tool. The two-inch-diameter well was developed by surging and bailing with a PVC hand bailer.

Pump tests were conducted on wells TW-K2, TW-K3R, TW-K4, TW-5R, and TW-K17B. Methods and results are discussed in Section 3.6.1.2.5.

3.5.1.4.4 Groundwater Evaluation

Five water table piezometers and six deeper piezometers (Table No. 3.5-1) were installed at seven locations to obtain water elevations for groundwater evaluation. The piezometers PZ-1007S, PZ-1008, PZ-1008G, PZ-1009, and PZ-1009G were installed by Wisconsin Test Drilling, Inc., on November 8 to 15, 1988, using mud rotary and auger drilling methods. The borings were sampled at five-foot intervals using standard split-barrel sampling methods and standard procedures as described in Section 3.5.1.8.2.

Piezometers PZ-SP6 and PZ-SP8 were installed on November 15, 1988, by Twin City Testing Corporation, St. Paul, Minnesota. These piezometers were installed in borings completed for the geotechnical investigation of the proposed Type II waste rock storage area. The drilling was done using mud rotary drilling methods and standard procedures as outlined in Section 3.5.1.8.2.

The piezometers PZ-K2P and PZ-K2PP, PZ-K4P and PZ-K4PP were installed in existing six-inch-diameter test wells TW-K2 and TW-K4, respectively. The piezometers were constructed by Luisier Drilling, Inc. The deep piezometers, PZ-K2PP and PZ-K4PP, were installed on November 14, 1988. A five-foot screen and seven-foot sand pack were placed at the bottom of TW-K2 and TW-K4. Bentonite grout was then placed up to the level of the bottom of the shallower piezometers PZ-K2P and PZ-K4P. The shallower piezometers were installed on November 15, 1988. A few feet of

sand was placed above the grout seal of the deeper piezometers. The shallower piezometers were then constructed with five-foot screens using standard well construction procedures.

3.5.1.5 Waste Characterization Boring Program

From December 2 through December 6, 1987, Luisier Drilling, Inc., completed three borings, B-WC-1, B-WC-2, and B-WC-3, to obtain soil samples for waste characterization studies. The three borings were sampled continuously using a three-inch diameter, split-barrel sampler, and coring methods (3.25-inch-diameter core). Depth to hard rock was less than anticipated, so borings B-WC-1A and B-WC-1B, B-WC-2A, and B-WC-3A were drilled adjacent to B-WC-1, B-WC-2, and B-WC-3, respectively, in order to obtain a sufficient volume of sample for testing.

3.5.1.6 Geotechnical Drilling Programs

The geotechnical drilling programs conducted during 1987 and 1988 included geotechnical testing of soil and rock samples for material characterization and strength testing for open pit design. Soil borings and laboratory testing of soils were also completed for the Type II waste rock storage area and railroad spur.

3.5.1.6.1 Geotechnical Logging Testing for Open Pit Design - Soils

Eight borings, as listed on Table No. 3.5-1, were completed at five locations along the projected ultimate pit perimeter. These borings were completed to provide soil information, and also to obtain samples for material characterization investigations and rock mechanics strength testing for pit slope design. The locations are shown on Figure No. 3.5-2. A soil test rig was used to obtain blow counts using standard split-barrel sampling methods. Due to the presence of boulders and extremely dense soils, it was necessary to use a large rotary rig and air hammer to drive the split barrel and obtain undisturbed soil samples. Borings PZ-S1, PZ-S2, PZ-S4, and B-S5 were drilled to obtain soil samples; borings B-S2A, B-S4A, and B-S5A were drilled adjacent to PZ-S2, PZ-S4, and B-S5, respectively, to obtain blow counts.

Boring PZ-S3 was drilled by Wisconsin Test Drilling, Inc., using mud rotary drilling methods and a CME-45 track-mounted drill rig on October 28 to 29, 1987. A piezometer was installed in the boring at a depth of 32 feet and screened in sandstone. The boring was sampled at five-foot intervals using standard split-barrel sampling procedures (ASTM D-1586). Additional samples were obtained using thin-wall tubes and plastic liners in a split-barrel sampler with a three-inch diameter.

Borings B-S2A, B-S4A, and B-S5A were completed on November 30 through December 1, 1987, using standard split-barrel sampling procedures and hollow-stem augers or mud rotary methods. Blow counts, soil samples, and water levels were obtained from these borings. No attempt was made to drill and obtain blow counts at location PZ-S1 due to the known occurrence of large boulders.

Luisier Drilling, Inc., completed four geotechnical borings, PZ-S1, PZ-S2, PZ-S4, and B-S5, from November 30 through December 9, 1987. Soil and rock samples for material properties and strength testing were obtained from these borings. Piezometers were installed in three of the borings to obtain water level measurements and permeability information from the top of the Precambrian bedrock.

The geotechnical borings were sampled at five-foot intervals using a three-inch outer diameter, split-barrel sampler and mud rotary and/or air drilling methods. Attempts were made to obtain additional, undisturbed samples of the till, sandstone, and clay-altered bedrock using (Shelby) thin-wall tubes, or plastic liners in the three-inch-diameter split-barrel sampler. A few samples were obtained using these sampling methods. However, the dense and variable nature of the soil and bedrock resulted in collapse or crumpling of most of the thin-wall tubes and plastic liners.

An alternative sampling method using two-foot lengths of galvanized pipe with 0.25-inch-thick walls was used to obtain undisturbed samples. The pipe was driven using an air hammer. Samples of till and clay-altered bedrock were obtained using the galvanized pipe. An attempt to sample the sandstone was also made. The pipe could be driven into the sandstone, but was not strong enough to be withdrawn without ripping. Samples of clay-altered bedrock were also obtained by coring, using a 4.875-inch carbide bit to obtain a 3.25-inch-diameter sample.

Undisturbed samples of till, clay-altered bedrock, and sandstone were also obtained using the three-inch-diameter split-barrel sampler. Split-barrel samples were retained in plastic bags. Undisturbed split-barrel samples were wrapped in plastic wrap and foil to preserve the moisture; tube samples were sealed with paraffin wax and/or plastic wrap and tape.

3.5.1.6.2 Geotechnical Logging and Testing for Open Pit Design - Rock

Geotechnical rock logging for open pit slope design included the measurement of the frequency and orientation of fractures in oriented and unoriented rock core, packer testing of selected intervals of rock, and installation of piezometers in selected angled core holes. Piezometer numbers and the corresponding angled core holes are listed on Table No. 3.5-1.

From October 1987 to January 1988, eight inclined, oriented core holes were drilled at angles ranging from 55° to 60° from the horizontal. The vertical depths of the holes ranged from 198 to 340 feet. The core holes were drilled employing triple-tube core barrels to provide subsurface structural, lithologic, and geomechanical information as well as core samples for strength testing. The core holes were located to thoroughly characterize the river pillar geotechniques and to provide maximum information for pit slope design. (Figure Nos. 3.5-14, 3.5-15, and 3.5-16 located in Section 3.5.3.4.2, show the locations of these geotechnical rock core holes.)

Core orienting was done employing the Call clay imprint technique (Call, 1988). Measurements included fracture attitude, spacing, and type. Geotechnical field measurements were conducted in eight oriented core holes and 19 exploration holes drilled in 1988. Measurements were taken to evaluate material strength, fracture spacing, fracture dip, broken zone intervals, rock-quality designation (RQD), and point load tests.

Packer tests were conducted in the oriented core holes to estimate bedrock permeability. The packer tests were done during and after drilling by Longyear Company under the direction of Kennecott personnel. Packer tests were conducted on intervals of the core hole from which core with the greatest amount of fracturing was obtained. The most fractured and presumably most permeable intervals were tested. The driller was instructed to clean the holes of excess mud and cuttings prior to inserting the packers. Single and double packers were used to isolate intervals of the borehole ranging from five to 27 feet. The target interval was five feet. Where caved intervals of the borehole were encountered, the interval was increased until a seal could be obtained.

The packers were inflated with helium to pressures ranging from 320 to 530 pounds per square inch (psi). Three tests were then conducted at each depth interval. Water pressure was applied to the test interval and a flow meter reading was recorded at the beginning and end of each test. The water pressure was set at approximately one-half the design pressure for the first and third tests; and at the design pressure for the second test. Water pressures ranged from 60 to 340 psi. Results of the packer tests are summarized in Section 3.6.

Upon completion of drilling and packer testing, five of the borings (R1, R2, R3, R5, and R7) were converted to piezometers. The piezometers consist of 1.25-inch-diameter PVC pipe and screen installed in the 3.875-inch-diameter drill holes. Each piezometer was constructed with 20 feet of screen and a sand pack of variable length located in the most permeable section of the borehole. Permeable sections were identified by the presence of fractures in the core and by results of the packer tests. A bentonite grout seal was installed in each piezometer above the sand pack to the ground surface. Prior to

construction, the borings were flushed with clear water. Development consisted of cleaning out the well with air and of bailing and surging with a hand bailer.

3.5.1.6.3 Type II Waste Rock Storage Area

Eight borings were drilled during the period from November 7 to 11, 1988, in the proposed Type II waste rock storage area as shown in Table No. 3.5-1. The borings were completed by Twin City Testing Corporation using mud rotary and/or auger drilling methods. Six borings (B-SP3 through B-SP8) were completed to a depth of 36 feet; two borings (B-SP1 and B-SP2) were completed at the Precambrian bedrock surface. Two of the borings, B-SP6 and B-SP8, were completed as piezometers PZ-SP6 and PZ-SP8. Standard field methods as described in Section 3.5.1.8.2 were used.

Additional geologic information for the proposed Type II waste rock storage area was obtained from borings ST-9-12, ST-9-13, ST-9-33, and ST-9-42. These borings were drilled in 1972 and 1975 by STS Consultants Limited, and were terminated at the Precambrian bedrock surface.

3.5.1.6.4 Railroad Spur Corridor

Twelve borings, B-RS1 through B-RS12 as listed on Table No. 3.5-1 and shown on Figure No. 3.5-2, were completed by Twin City Testing Corporation in the proposed railroad spur corridor. The drilling was done during the period from November 14 to 17, 1988. The borings were completed to a depth of 21 feet using hollow-stem augers. The borings were sampled at 2.5-foot intervals using standard split-barrel sampling methods and standard field procedures as described in Section 3.5.1.8.2.

3.5.1.7 Soil and Rock Testing

Soil and rock samples were tested as part of several programs. Consolidated, undrained triaxial compression and direct shear tests were performed on samples of silty sand till, sandstone, and clay-altered bedrock. The testing was done as part of the geotechnical testing program for pit design. The testing was done in 1988 by STS Consultants Ltd., using the triaxial compression test procedures outlined in the Corps of Engineers Testing Manual EM110-21906, Appendix X, and the direct shear test procedures (ASTM D-3080) outlined by the American Society for Testing and Materials, (ASTM, 1988). Results of these analyses are included in Appendix 3.5-L.

Additional soils testing performed for the geotechnical and other testing programs included grain-size analysis, determination of Atterberg Limits, and determination of moisture/density relations. These analyses were done by Foth & Van Dyke's Soil Testing Laboratory using standard procedures ASTM D-422, ASTM D-4318, and ASTM D-1557-Method "A",

respectively. Densities of soil and rock samples were determined using ASTM D-2937, and moisture contents were determined using ASTM D-2216 (ASTM, 1988).

The permeability of granular soils was determined using the constant head method as outlined by the standard method ASTM D-2434. The permeability of fine-grained soil samples (thin-wall and rigid-wall) was determined using EPA Method 9100 (EPA, 1986). These analyses were also done by Foth & Van Dyke. Results are included in the appropriate appendices for each testing program.

Comprehensive laboratory testing was performed on rock samples as another portion of the slope design program. This program was designed to determine strength, density, and elastic properties. Rock testing was conducted at the University of Utah and the University of Arizona in late 1987 and early 1988. Rock samples were selected to provide a representative areal distribution for all major rock types in the study area. Soil testing was conducted by Foth & Van Dyke and STS Consultants, Ltd. in early 1988. Additional soil test data are also available from the 1975-1976 and 1972 laboratory work by Soil Testing Services of Wisconsin. Most of this data is included in a report written by Call as a part of the evaluation of pit slope design (Call, 1988).

Rock testing of 2.1 to 2.4-inch-diameter core included 26 uniaxial compression tests with ten elastic property determinations, 18 triaxial tests, 16 Brazilian disk tension tests, seven direct shear tests on foliation and joint planes, and 63 density determinations. In addition, routine point load tests (diametral and irregular lump) were conducted at approximately five-foot core intervals during the field logging program. A total of 686 point load tests were completed.

Average uniaxial compressive strengths ranged from 5,534 psi (metadacite) to 47,831 psi (metachert). Young's modulus values ranged from 1.2×10^6 psi to 11.0×10^6 psi and Poisson's ratios ranged from 0.15 to 0.31. Triaxial compression tests revealed mean intact rock cohesions from 120 to 1065 psi with mean angles of internal friction of 24° to 64°. Average Brazilian tension strengths ranged from 112 psi (biotite schist) to 697 psi (footwall chlorite schist). Direct shear tests along foliation planes revealed a mean cohesion of 7.78 psi with a mean angle of internal friction of 18.3°. The joint direct shear strength was determined to have a 0.81 psi cohesion and angle of internal friction of 32.4°. Mean rock density values ranged from 130 lbs/ft^3 (metadacite) to 302 lbs/ft^3 (massive sulfide). Median (IS 50) point-load test results ranged from 65 psi (biotite schist) to 1,301 psi (semi-massive sulfide). The geologic terms in parenthesis are further described in Section 3.5.3.4.2.

Flambeau River Pillar

A river pillar slope stability analysis was conducted as part of the Flambeau slope design program. Geotechnical and geologic findings revealed that rock conditions within the river pillar are suitable for safe and stable slope conditions. No adverse structures or rock strengths have been identified to preclude overall wall stability. The river pillar stability analysis included site-specific strength estimates of intact rock and joint shear strengths previously described. It was determined, using rotational shear analysis, that only six percent intact rock is required along the potential failure path to assure river pillar stability. This condition is easily exceeded because the rotational shear surface cuts across the joint and foliation orientation.

A structurally controlled failure analysis was also conducted for the river pillar. Conservative assumptions for failure analysis were employed. The assumption of a wedge, bounded by continuous foliation and cross-joint structures, resulted in a safety factor of 1.75 under dry conditions and 1.15 when saturated. Fracture shear strengths as described above were employed in this analysis, together with the fracture orientation data derived from core holes drilled in the river pillar. Cross-jointing is not expected to be continuous; fracture spacing from the oriented-core drilling program was found to be 2.1 feet for the prominent Flambeau foliation and 9.0 feet for cross-jointing.

3.5.1.8 Quality Assurance/Quality Control Procedures

The general procedures that were followed to provide valid field and laboratory data are summarized below. Specific variations to the general procedures are included as part of the description of individual drilling programs. The individual drilling programs were described above in Section 3.5.1.2 through 3.5.1.6.

3.5.1.8.1 Core Drilling, Assaying, and Data Analysis

Core Drilling

In the 1968-1971, 1974, and 1987-1988 diamond core drilling programs, rotary tricone drilling was used to penetrate the overburden and most of the Cambrian sandstone. Core drilling commenced upon the observation of Precambrian or Cambrian lithologies in the rotary cuttings. In a few instances, ore mineralization was lost in the cuttings prior to switching to core drilling. A Kennecott geologist or consultant was on-site at all times to monitor the drilling and to determine hole locations, orientations, depths, and type of drilling (rotary or core) to be employed.

Core was removed from the core barrel and placed in appropriate core boxes located on-site. The top and bottom footage of each drill run was labeled, and each core box identified as to project, hole number, box number, and footage. The core boxes were then transferred to a nearby facility for core logging and storage.

Upon completion of each hole drilled during the 1960s and 1970s, down-hole deviations in the inclination of the hole were generally determined at 200-foot intervals using then standard down-hole acid bottle surveying methods. Most holes drilled during the 1987-1988 program were surveyed at appropriate intervals using a Sperry-Sun single-shot camera to obtain down-hole deviations for both the inclination and azimuth of the hole. Down-hole deviations for the azimuth were obtained for six inclined holes prior to the 1987-1988 program and little to no deviation was observed in the vertical holes.

Upon completion of the down-hole surveys, the holes were marked on the surface, and the collar elevations and mine coordinates were determined and recorded using standard surveying techniques.

Core Logging and Splitting

All core was logged by a Kennecott geologist or consulting geologist at a nearby core storage facility using standard logging procedures. Core recovery measurements were made and recorded. Lithologies, alteration, mineralization, and structures (including angle of core to bedding) were noted. Geotechnical data, including fracture frequency and orientation, were obtained from core drilled during 1987-1988.

Intervals for assaying were designated for all mineralized core. Drill runs and lithologic/mineralization contacts were used to pick assay intervals. An attempt was made to use five-foot assay intervals in similar lithologies; however, in some instances, shorter intervals were used to provide more detail in ore zones. Ten-foot assay intervals were occasionally used in areas of little to no sulfide mineralization.

After each hole was logged and the assay intervals designated, the core was prepared for assaying using the following procedure.

1. Core for each assay interval was split in half using a hydraulic core splitter or rock saw.

2. One core half was returned to the core box and is presently stored, unless used for metallurgical or waste rock characterization testing.

3. The other core half was crushed to minus 0.25-inch, and the crushed sample was split in half using a 0.5-inch riffle splitter. Each half was placed in a separate bag, labeled with the same sample number based on preprinted sample tags. The sample number and assay interval were entered onto an assay log for each hole. One half was sent to a commercial laboratory for assaying. The other half is in storage, unless it was used in metallurgical or waste rock characterization testing. During the 1987-1988 program, the core half for assaying was not crushed on-site but was sent directly to a laboratory for preparation and analysis.

Assaying

All prepared samples for assaying were sent to independent commercial laboratories for analysis as follows:

DDHs 22-1 through 22-58 (1968-1970)	Union Assay Office, Inc. Salt Lake City, UT
DDHs 22-59 through 22-117 (1970-1971)	Lerch Brothers, Inc. Hibbing, MN
DDHs 22-118 through 22-135 (1974)	Union Assay Office, Inc. Salt Lake City, UT
DDHs 22-136 through 22-162 (1987-1988)	Bondar-Clegg, Inc. Lakewood, CO

All three laboratories are well established and recognized in the industry for providing accurate and precise assays.

In general, 0.25-inch samples received by the laboratory were crushed to minus 10-mesh. A split taken from the minus 10-mesh material was then ground to a minus 100-mesh pulp for assaying.

Samples were routinely assayed for copper, gold, silver, zinc, and sulfur. Samples were occasionally assayed for copper oxide and lead.

Gold and silver were assayed using standard fire assay methods. Copper, zinc, and sulfur were analyzed using standard wet chemical gravimetric, titration and/or atomic absorption techniques.

All unused minus 10-mesh coarse rejects and pulps were returned to Kennecott, and are currently stored in a facility located near the project area.

Assay Quality Control

No check assaying was conducted on a systematic basis. A small number of samples (19) from previous years were reassayed by

Hawley and Hawley in Tucson, Arizona, in 1970. This small number of check assays did not indicate any significant problems with work done by Union Assay Office and Lerch Brothers. Both laboratories have been used by Kennecott for large mining or development projects, where extensive internal quality control procedures were used.

Minus 10-mesh coarse rejects (39) for assay intervals from most ore zones encountered during the 1987-1988 drilling were reassayed by Rocky Mountain Geochemical Corporation (RMGC) in Salt Lake City in 1988, and the pulps generated by RMGC were reassayed by CMS in Salt Lake City.

Check assays, in general, confirmed initial assays. Check assays on the pulp of the same sample show good reproducibility, and were within acceptable levels established for the industry. Check assays on separate coarse rejects of the same sample showed some variation which could be improved by grinding a larger portion of the sample to minus 100-mesh before assaying.

Data Analysis

All drill hole data, including collar elevations and coordinates, down-hole surveys, sample intervals, assay results, and geologic codes were computerized for ore reserve calculations. The computer printouts with these data were checked against original survey notes, assay certificates, and drill hole logs in 1988.

3.5.1.8.2 Surficial Geology, Geotechnical, and Hydrogeologic Drilling Programs

1987-1988 Drilling Programs

A Foth & Van Dyke geologist/hydrogeologist or geological engineer supervised the drilling and sampling of all boreholes and the installation of all monitoring wells and piezometers. Appropriate ASTM Standards and guidelines set by the WDNR were followed for all field investigations.

Some borehole and well locations were located in the field by pacing off distances and were later surveyed by the civil engineering company of Morgan and Parmley, Ltd., Ladysmith, Wisconsin. Other locations were initially surveyed by Morgan and Parmley and, after completion of drilling and well installation, measuring-point elevations and locations were surveyed. The mine site coordinate system with 40,000 N and 40,000 E designated at ground control monument F1 was used to locate all core hole, well, and boring locations and all hole locations were also tied into the state plane coordinate system.

Soil samples were collected according to ASTM Standard D-1586, *Penetration Test and Split-Barrel Sampling of Soils* (ASTM, 1988).

An exception to the standard procedure was made when extremely dense soils were encountered. In these cases, additional blow counts were used to obtain an amount of soil sample sufficient to conduct laboratory analyses. Split-barrel samples were collected at five-foot intervals, unless otherwise specified for a particular drilling program, or if additional samples were necessary to adequately describe changes in stratigraphy.

Each boring was logged in the field by Foth & Van Dyke's geologists/hydrogeologists or geological engineers. The soil and rock samples were described and classified using the Unified Soil Classification System (USCS) according to ASTM Standard D-2488, *Description and Identification of Soils*(ASTM, 1988). Munsell Color notation was used to describe the color of soil and rock samples (Munsell Color, 1975). Color photographs were taken of split-barrel samples and rock core and are on file at Foth & Van Dyke's Green Bay office.

After completion of sampling and geologic logging, each boring was backfilled with bentonite or cement grout according to WDNR regulations. The grout was tremied in from the bottom of the boring to within about one foot below the ground surface. The upper foot of the boring was backfilled with soil cuttings.

Soil samples were transported from the site to the testing laboratory according to ASTM Standard D-4220, *Preserving and Transporting Soil Samples* (ASTM, 1988).

Soil samples were analyzed for grain-size distribution according to ASTM Standard D-422 and Atterberg Limits were determined according to ASTM D-4318 (ASTM, 1988) by Foth & Van Dyke's Soil Testing Laboratory. The geologists' field logs, drillers' logs, and laboratory soil test data were used to prepare the geologic logs presented in Appendices 3.5-D through 3.5-K and used to construct the geologic cross sections shown in Figure Nos. 3.5-3 through 3.5-9.

Initial Investigations

Geologic data collected for the 1974 EIR were reviewed and evaluated by Foth & Van Dyke's geologists in terms of field methods employed, documentation of field activities, qualifications of personnel involved in the acquisition of data, and laboratory procedures. The data was checked for general correspondence with data collected in the 1987-1988 investigations. In most cases, the old data corresponded closely with the 1987 to 1988 findings. Any revisions or reinterpretations of the old data were noted on the original

data sheets included as Appendix 3.5-B or are discussed in the text. After the data was evaluated and determined to be reliable, it was used in conjunction with the new data.

3.5.2 Regional Geology

The Flambeau deposit is located in the Chippewa River drainage basin within rocks of Precambrian age. In central and southwestern Rusk County, the Precambrian rocks are unconformably overlain by sandstone of Cambrian age. The Cambrian sandstone thickens to the west and south to a maximum thickness of about 800 feet at the southwest edge of the Chippewa River basin at the Wisconsin/Minnesota state border (Young and Hindall, 1972). Glacial and fluvial deposits of Quaternary age overlie the Precambrian and Cambrian bedrock and cover most of the county. The geologic time scale for the region is shown on Table No. 3.5-2.

3.5.2.1 Regional Geomorphology and Topography

Most of the landforms in central and eastern Rusk County are of glacial or fluvial origin. The landforms in northwestern Rusk County are predominantly low dissected bedrock hills. This is an area of Precambrian quartzite and includes the Blue Hills which extend west into Barron County (Figure No. 3.5-11, Section 3.5.2.3.2). The bedrock hills are covered by glacial deposits known as the Chippewa Moraine.

The Chippewa Moraine is a broad end moraine that trends approximately north-south in western Rusk County. The moraine was formed by the Chippewa Sublobe of the Lake Superior Lobe of the Laurentide Ice Sheet in Late Wisconsinan time. Ice advanced out of the Lake Superior Basin and flowed predominantly from the northeast toward the southwest over Rusk County. The elevation of the moraine ranges from about 1,700 feet at the northern end of the county, where it overlies the Precambrian rock, to about 1,100 feet at the southern end, where it overlies Cambrian sandstone.

East of the Chippewa Moraine is a broad area of collapsed glacial-fluvial sediment and other ice-contact sediments. These sediments are located primarily adjacent and roughly parallel to the Chippewa and Flambeau Rivers. The surface of the collapsed glacial-fluvial sediment is at an elevation of about 1,250 feet at the northern edge of the county and slopes to an elevation of 1,150 feet at the southern end. Eastern Rusk County is covered by low-relief ground moraine on the upland areas and uncollapsed glacial-fluvial sediment in most of the stream and river valleys (Hadley and Pelham, 1976). The most prominent landform features in eastern Rusk County are low drumlins that trend northeast/southwest. Eskers occur in the shallow drainageways which parallel the drumlins.

TABLE NO. 3.5-2

Regional Geologic Time Scale

ERA	Period	Epoch	Age	Approximate Number of Million Years Ago
Cenozoic	Quaternary	Recent Pleistocene	Wisconsinan	0.007-0.075
		Disconformity		
Paleozoic	Cambrian			505-600
		Angular Unconformity		
Precambrian		Late Middle Early		600-1600 1600-2500 >2500

3.5.2.2 Regional Surficial Geology

The Quaternary glacial and glacial-fluvial deposits generally range from 50 to 100 feet thick over most of the county. The thickest deposits occur in the Chippewa Moraine and in the river valleys (Young and Hindall, 1972).

Most of these glacial and glacial-fluvial deposits were deposited by ice and melt-water of the Chippewa Sublobe. The oldest deposits of the Chippewa Sublobe belong to the Marathon Formation and may be Illinoian and Early Wisconsinan in age. The Marathon Formation is overlain by deposits of the Lincoln Formation which are greater than 40,800 years old (Mickelson *et al.*, 1983). The uppermost stratigraphic unit is the Copper Falls Formation which is less than 25,000 years old (Johnson, 1986).

The following descriptions of the glacial stratigraphic units is summarized from Mickelson *et al*(1984). The units are described using the United States Department of Agriculture (USDA) classification system. Average ratio of percentages by weight of sand:silt:clay are given for the matrix material of the tills. Clay is the grain-size fraction less than 0.002 mm in diameter. Silt is the grain-size fraction 0.002 to 0.05 mm in diameter. Sand is the grain size fraction 0.05 to 2 mm in diameter.

The Marathon Formation has two till members. The lower Wausau Member contains brown, noncalcareous, loam till. Percent sand:silt:clay ratios are 43:34:23, respectively. The till was deposited by the southeastward-flowing ice of the Chippewa Sublobe. Overlying the Wausau Member is the siltier, calcareous Edgar Member. The Edgar Member is brown loam till. Percent sand:silt:clay ratios are 33:43:24, respectively. The till was deposited by the southward flowing ice of the Chippewa Sublobe. The Wausau Formation is a surface unit in Wood, Marathon, and Clark Counties. The formation thickens to the north and extends beneath the Lincoln Formation; its northward extent beneath the Copper Falls Formation (further north) is not known.

The till of the Lincoln Formation is darker red brown than the underlying Marathon Formation and overlying Copper Falls Formation. The Lincoln Formation includes two till members. The lower Bakerville Member is red brown, sandy loam till. Percent sand:silt:clay ratios are 62:25:13, respectively. The till was deposited by the southward-flowing Chippewa Sublobe. The upper Merrill Member is dark red brown, sandy loam till. Percent sand:silt:clay ratios are 62:28:10, respectively. The till was deposited by the south-southeastward-flowing St. Croix Sublobe. The Lincoln Formation is the surface unit in much of Marathon, Clark, Langlade, Lincoln, and Marathon County. The formation thickness to the north and extends beneath the Copper Falls Formation; however, its northward extent beneath the

Copper Falls Formation is not known. The Copper Falls Formation is the surface glacial stratigraphic unit over Rusk County and most of northwestern Wisconsin.

The Copper Falls Formation consists of roughly one-half fluvial sediment and one-half till. The fluvial sediment was deposited from melt-water in front of the ice sheet, on top of stagnant ice, or under the ice as eskers. The till consists of 35 to 80 percent sand, 15 to 50 percent silt, and 2 to 15 percent clay with some pebbles, cobbles, and boulders. The till of the main Superior Lobe in Douglas County averages about 70 percent sand, 25 percent silt, and 5 percent clay; the till of the Chippewa Sublobe in Bayfield, Ashland, and Iron Counties averages about 60 percent sand, 35 percent silt, and 5 percent clay. At the type section of the Copper Falls Formation in Ashland County, the till varies from silt loam to loam and sandy loam. The percentage of sand generally increases to the south and the tills are redder to the north. The till is slightly calcareous. Most of the Copper Falls Formation was deposited in Late Wisconsinan time but may include some Early Wisconsinan material.

Detailed studies have been conducted in Barron County and four till members have been defined (Johnson, 1986). The southern limit of the Copper Falls Formation is the St. Croix and Chippewa Moraines. Two till members of the Copper Falls Formation deposited by ice of the Chippewa Sublobe have been described in Barron County. The lower Pokegama Creek Member is yellow red to strong brown sandy loam till that was deposited between 25,000 and 15,000 years ago. Percent sand:silt:clay ratios are 69:20:11, respectively. The Mikana Member is red brown sandy loam till that was deposited about 15,000 years ago. Percent sand:silt:clay ratios are 71:24:08, respectively.

3.5.2.3 Regional Bedrock Geology

3.5.2.3.1 Cambrian

Cambrian-age sandstone of the Mt. Simon Formation occurs in southwestern Rusk County and throughout west-central Wisconsin. The contact between the Cambrian sandstone and the underlying Precambrian rock is an angular unconformity. During the Late Precambrian, and possibly the early Cambrian, weathering produced a saprolite at the top of the Precambrian rock (Cummings and Scrivner, 1980). Weathered material from the saprolite was incorporated into the basal unit of the upper Cambrian Mt. Simon Formation. The Precambrian/Cambrian contact is exposed at several localities in west-central Wisconsin, including south of Ladysmith.

The Mt. Simon Formation was deposited during the late Cambrian (Dresbachian). The formation ranges from a few feet thick in

central Rusk County to about 100 feet thick at Chippewa Falls. It reaches a maximum thickness of about 800 feet in southern Wisconsin (Asthana, 1969).

The Mt. Simon Formation contains three units. The lowermost is a conglomeratic or pebbly sandstone. The middle unit is a coarse to medium-grained sandstone. The uppermost unit is a coarse to very fine-grained sandstone.

Fossil fragments and trace fossils in the sandstone indicate marine deposition. The Mt. Simon Formation has been interpreted as sediment deposited during marine transgression onto the Precambrian Shield.

3.5.2.3.2 Precambrian

The Southern Province of the Canadian Precambrian Shield is a large block of ancient rock that stretches from southwestern Ontario south into upper Minnesota, Wisconsin, and Michigan. In northern and central Wisconsin, the Province consists of three ages of rock which are, in order of decreasing age, Early, Middle, and Late Precambrian (Sims, 1976). The distribution of rock types of these three ages is shown on Figure No. 3.5-10.

Early Precambrian rocks are those dated older than 2,500 million years. These rocks consist of highly altered sediments and granite. They occur throughout central Wisconsin and as narrow belts north of Rusk County. Middle Precambrian rocks have been age-dated between 1,600 and 2,500 million years. They consist of interbedded and altered volcanic, sedimentary, and granitic rocks (Sims, 1976). The Flambeau deposit occurs within a Middle Precambrian-age volcanic belt that is approximately 30 miles wide by 180 miles long as shown on Figure No. 3.5-10.

Late Precambrian rocks range in age from 600 to 1,600 million years. These rocks contain thick lava flows, flat-lying weakly altered sandstone, and shale. Late Precambrian rocks are located north of Rusk County and are best exposed in the Apostle Islands State Park, Bayfield, Wisconsin.

Early and Middle Precambrian rocks occur as steeply dipping belts that trend east-northeast. These rock belts were folded and faulted about 1,800 million years ago.

The distribution of Precambrian and Cambrian rocks in Rusk County are shown on Figure No. 3.5-11. The Precambrian-age rocks consist of east-northeast trending, steeply dipping schistose belts of volcanic and sedimentary rock. The volcanics and sediments have been regionally altered and are referred to as "greenstones". The term greenstone is frequently used for rocks rich in the mineral chlorite that have been so extensively altered that accurate rock names are sometimes difficult to apply. Surrounding the greenstone belts are large intrusive bodies of various rock compositions. Unconformably overlying

the middle Precambrian rocks are outcrops of gently dipping Barron quartzite found throughout much of northwestern Rusk County.

3.5.3 Geology of the Project Area

The Flambeau deposit occurs within a complex suite of Middle Precambrian-age volcanic rocks that dip about 70° to the northwest and trend northeast-southwest across the project area. In the northwestern and central part of the project area, Cambrian sandstone overlies the Precambrian rocks. Silty sand till or glacial-fluvial sediments overlie the bedrock. A generally thin layer of windblown silt and fine sand is the surface sediment over most of the area.

3.5.3.1 Geomorphology and Topography of the Project Area

Four geomorphic surfaces are present in the project area. These surfaces (A, B, C, and D), the proposed pit, and the Type I and Type II waste rock storage areas are delineated on Figure No. 3.5-12.

It is proposed that the Type II stockpile be located in an upland area (Area A), the surface of which is generally at an elevation of about 1,150 feet. This surface continues to the east and includes the area of the proposed railroad spur. The upland area is primarily a glacial depositional feature. As shown on Cross Sections A-A′ and F-F′ (Figure Nos. 3.5-3 and 3.5-8), the upland area is underlain by a thick layer of silty sand till.

The Type I stockpile and most of the proposed pit is located on a dissected terrace surface (Area B), the elevation of which is generally about 1,140 feet. The dissected terrace surface is probably an erosional feature cut into the silty sand till, with some deposition of glacial-fluvial sediment at the surface. The surface may have been formed by glacial melt-water which eroded a broad channel into the till surface. Later, glacial-fluvial sediment was deposited as melt-water flow subsided. As shown on Cross Sections B-B′, C-C′, and E-E′ (Figure Nos. 3.5-4, 3.5-5, and 3.5-7), a variable thickness of glacial-fluvial sediment occurs over the silty sand till in some parts of the dissected terrace surface.

Northwest and west of the proposed Type I stockpile is an area of pitted glacial-fluvial sediment. This is Area C as shown on Figure No. 3.5-12. The pitted surface is generally at an elevation of 1,120 to 1,130 feet and as shown on Cross Section B-B′ (Figure No. 3.5-4), the surface is underlain by coarse-grained glacial-fluvial sediment. The glacial-fluvial sediment is irregularly bedded and stratified, very poorly sorted, and typically contains cobbles and some large boulders. The coarse texture and poor sorting probably indicate the sediment was

deposited by melt-water near the margin of the ice sheet. After recession of the ice margin, the Flambeau River cut into the glacial-fluvial sediment.

In the area of the southwest end of the proposed pit, the Precambrian surface is at a higher elevation, and the Flambeau River flows on bedrock as shown on Cross Section E-E', Figure No. 3.5-7.

Area D as shown on Figure No. 3.5-12 is a low, relatively flat area at a general elevation of 1,100 to 1,110 feet. The area is located east of and adjacent to the Flambeau River and includes a small elongate wetland. The area is underlain by poorly sorted glacial-fluvial sediment with probably some Recent, fine-grained, alluvial sediment at the surface. The surface was probably formed by the meandering Flambeau River in Recent time.

3.5.3.2 Soils in the Project Area

The soils in the vicinity of the proposed mine were mapped by Soil Conservation Service personnel in 1964 to 1966. The mapping was updated by Soil Conservation Service personnel in June and August 1988 at the request of Foth & Van Dyke to verify soil boundaries. These activities have resulted in the production of the map shown in Figure No. 2 in Appendix 3.8-C, the Wetlands Inventory and Assessment. The soil mapping was conducted using Soil Conservation Service guidelines and soil classification. Brief descriptions of the soil units encountered during the mapping and verification are presented in Table No. 3.5-3.

Soils of the Rosholt-Bevent-Chetek and Magnor-Auburndale Associations, and Seelyville Muck, were identified and mapped in the site area. Approximately two-thirds of the mapped soils are part of the Rosholt-Bevent-Chetek Association. These soils are well-drained to excessively well-drained and have formed in loamy deposits which overlie sand and gravel outwash plains. Slopes of these soils range from gently sloping to moderately steep. Soils of this association are most common in the northwestern part of the site.

The Rosholt Sandy Loam is the most common soil series mapped on the site. The surface layer of this soil consists of dark brown sandy loam, six inches thick, overlying eight inches of yellowish brown and dark brown sandy loam. The subsoil is dark brown sandy loam in the upper eight inches and yellowish red, gravelly loamy sand in the lower seven inches. The substratum is pale brown stratified sand and gravel. The Rosholt Series ranges in slope from two to 12 percent on the site.

The Magnor-Auburndale soils are silt loams which have formed in loess overlying loamy glacial till. These upland soils are nearly level to gently sloping and are somewhat poorly to poorly

TABLE NO. 3.5-3

Brief Descriptions of the Soil Mapping Units
in the Vicinity of the Proposed Mine

Soil No.	Soil Type	Description	Slope
33	Chetek Sandy Loam	Somewhat excessively drained, sloping loamy soils developed in sand and gravel stream terraces	2-20%
38	Rosholt Sandy Loam	Well-drained, nearly level to moderately sloping loamy soils developed in stratified sand and gravel stream terraces	2-12%
43	Antigo Silt Loam	Well-drained, gently rolling silty soils developed in sand and gravel stream terraces	2-6%
44	Terrace excarpment	Well-drained, steeply sloping sandy to loamy soils developed in sand and gravel stream terraces	>30%
48	Brill Silt Loam	Moderately well-drained, gently sloping silty soils developed in sand and gravel stream terraces	2-6%
77	Auburndale Silt Loam	Poorly drained, nearly level silty soils developed in loamy glacial till on uplands	0-2%
156	Magnor Silt Loam	Somewhat poorly drained, nearly level to gently sloping silty soils developed in glacial till on uplands	0-6%
157	Freeon Silt Loam	Moderately well-drained, moderately steep sloping silty soils developed in ground moraine	6-12%

Table No. 3.5-3 (Cont.)

Soil No.	Soil Type	Description	Slope
324	Poskin Varient Silt Loam	Somewhat poorly drained, nearly level silty soils developed in sand and gravel outwash plains	0-2%
326	Cable Silt Loam	Very poorly drained, nearly level silty soils developed in loess deposits which overlie glacial till	0-2%
334	Plover Sandy Loam	Somewhat poorly drained, nearly level loamy soils developed in stratified lacustrine deposits which overlie sand and gravel stream terraces	0-2%
339	Bevent Loamy Fine Sand	Well-drained, gently rolling sandy soils which developed in stratified loamy and sandy deposits, stream terraces, and glacial lake basins	2-6%
400	Seelyville Muck	Very poorly drained, nearly level organic soils developed in depressions under marsh and swamp vegetation	0-2%

drained. The imperfect internal drainage of the soils has resulted in the development of the mottles commonly observed in the subsurface horizons.

The Seelyville Muck commonly adjoins the soils of the Magnor-Auburndale Association. This very poorly drained muck has formed in topographic depressions under marsh vegetation. These soils contain high concentrations of sapric material in their surface horizons.

3.5.3.3 Surficial Geology of the Project Area

The surficial deposits in the project area include a thin layer of windblown silt and fine silty sand, siltysand till, glacial-fluvial sand and gravel, and glacial-fluvial gravel and sand. The combined thickness of the surficial deposits varies from about ten feet (MW-1000) at the river pillar at the southwest end of the proposed pit, to 65 feet (B-SP1) at the northwest corner of the proposed Type II waste rock storage area. Northwest of the project area, glacial-fluvial sand and gravel adjacent to the Flambeau River is more than 90 feet thick.

3.5.3.3.1 Surface Silt and Sand

The sediment at the ground surface varies from brown or red-brown silt to silty fine sand. The sediment is typically less than five feet thick, but has a variable distribution over the project area. It probably was deposited by aeolian processes and may include some fine-grained, well-sorted fluvial sediment.

3.5.3.3.2 Till

The most widespread surficial deposit is silty-sand till. The till is thickest in the upland area. It averages about 40 feet thick in the area of the Type II stockpile as shown on Cross Section F-F', Figure No. 3.5-8. In the area of the pit, the till is thinner and is overlain or interbedded with glacial-fluvial sediment as shown on Cross Section E-E', Figure No. 3.5-7.

Approximately 10 to 20 feet of till is present in the proposed area of the pit; the till is generally thinner over the ore body and is slightly thicker to either side. At the southwest end of the proposed pit, at the location of MW-1000 shown on Figure No. 3.5-2 and Cross Section D-D', Figure No. 3.5-6, only about five feet of till occurs above the rock surface. To the southeast of MW-1000, the till thickens to about 45 feet at the location of MW-1001. To the northwest of MW-1000, the till is absent at the river pillar.

The till is typically red-brown (5Y 4/4) or dark red brown (5Y 3/4), well-graded, silty, fine sand, with fine and coarse gravel. The percentage of gravel ranges from one to 26 percent; the percentage of sand ranges from 48 to 78 percent; and the

percentage of silt and clay varies from 21 to 43 percent. The average percent gravel:sand:P200 (silt and clay) ratios are 10:66:28, respectively (13 samples analyzed). The pebble-size fraction consists mostly of igneous and metamorphic rock types. The till is slightly calcareous as determined by waste characterization studies. Laboratory analytical data are summarized on Table No. 3.5-4.

The till is predominantly silty sand, but ranges from clayey sand to sandy-silt. The finer-grained till occurs below the silty-sand till in the area southeast of the proposed pit, and the area of the Type II storage pile. The range of grain size distributions probably indicates that more than one stratigraphic till member is present in the project area. Most of the till, however, is likely to belong to the Copper Falls Formation. The lower, more clayey till, may correlate with the Lincoln or Marathon Formations (Johnson, 1986).

3.5.3.3.3 Glacial-Fluvial Sediment

The glacial-fluvial sediment is thickest in the area to the west of the proposed Type I stockpile. It has a variable thickness on the dissected terrace surface in the area of the Type I stockpile and pit. The sediment ranges from a few feet thick in the area of the pit to a maximum of about 42 feet at TW-K17B as shown on Cross Section D-D', Figure No. 3.5-6.

The glacial-fluvial sediment varies from well-graded, silty sand with gravel, to poorly graded gravel. The glacial-fluvial sediment is typically thin-bedded, and is extremely variable in texture, both horizontally and vertically. Although generalized, Cross Section D-D' shown on Figure No. 3.5-6 illustrates the textural variability of the glacial-fluvial sediment. Grain-size analysis data are summarized on Table Nos. 3.5-5 and 3.5-6.

The gravelly, glacial-fluvial sediment contains 53 to 83 percent gravel, 12 to 35 percent sand, and four to 12 percent silt and clay. Average percentages of gravel:sand:P200 (silt and clay) were 70:24:6, respectively (five samples analyzed). The sandy glacial-fluvial sediment contains 10 to 30 percent gravel, 54 to 87 percent sand, and three to 18 percent silt and clay. The average gravel:sand:P200 (silt and clay) percentages are 22:70:9, respectively (eight samples analyzed).

3.5.3.4 Bedrock Geology of the Project Area

Cambrian-age sandstone of the Mt. Simon Formation occurs in the project area. The sandstone is underlain by metamorphosed volcanic rocks of Precambrian age.

TABLE NO. 3.5-4

Summary of Soil Test Data
Silty Sand Till (SM)

Boring No.	Sample No.	Depth (ft)	USCS Class	LL	PI	% g-s-P200*	Permeability (cm/sec)	Max. Dry Density (PCF)	Opt. Moisture (%)	Date of Test
ST-9-25	3	15-16	SM	-	-	05-72--23-	-	-	-	1973
ST-9-26	6	30-31.5	SM	-	-	07-64--29-	-	-	-	1973
ST-9-26	7	35-36.5	SM	-	-	15-64--21-	-	-	-	1973
ST-9-27B	1	10-11.5	SM	-	-	12-63--25-	-	-	-	1973
ST-9-28B	2	10-11.2	SM	-	-	05-78--17-	-	-	-	1973
ST-9-29	2	10-10.5	SM	-	-	13-59--28-	-	-	-	1973
PZ-S3	7	21-22	SM	-	-	26-52--22-	-	-	-	1973
B-S5	3	15-16	SM	17.2	4.2	-	-	-	-	1987
B-S5	3-7	15-25	SM	-	-	-	-	137.7	6.5	1987
B-S5	4	18-20	SM	-	-	11-58--31-	-	-	-	1987
B-S5	7	25-27	SM	-	-	10-60-24-06	-	-	-	1987
PZ-1008S	6	30-31.5	SM	-	-	08-62-20-10	-	-	-	1988
PZ-1009G	5	25-26.5	SM	-	-	17-55-19-09	$K_L=2.1x10^{-7}$	-	-	1988
PZ-1009G	9	45-46.5	SM	-	-	01-70-22-07	-	-	-	1988
B-SP1	11	49.5-51	SM/SC	20.4	8.1	06-56-22-16	-	-	-	1988
B-SP1	13	59.5-61	SC	34.0	16.4	06-48-27-19	-	-	-	1988
			Min.	17.2	4.2	01-48--21-				
			Max.	34.0	16.4	26-78--43-				
			Ave.	23.9	9.6	10-62--28-				
			n =	3		14				

*P200 = Clay (<0.005 mm fraction) plus silt (<0.075 to 0.005 mm fraction).

TABLE NO. 3.5-5

Summary of Soil Test Data
Glacial-Fluvial Gravel and Sand

Boring No.	Sample No.	Depth (ft)	USCS Class	% g-s-P200*	Date of Test
ST-9-19A	1	21-22.2	GW	72-22-06	1973
ST-9-23A	2	25-26.5	GP	83-12-05	1973
PZ-S1	2	10-11.5	GP	66-30-04	1987
PZ-S3	3	10-12	GP-GM	53-35-12	1987
PZ-S4	4	11-12	GP	76-20-04	1987
			Min.	53-12-04	
			Max.	83-35-12	
			Ave.	70-24-06	
			n =	5	

*P200 = Clay (<0.005 mm fraction) plus silt (<0.075 to 0.005 mm fraction).

TABLE NO. 3.5-6

Summary of Soil Test Data
Glacial-Fluvial Sand and Gravel

Boring No.	Sample No.	Depth (ft)	USCS Class	% g-s-P200*	Date of Test
ST-9-17A	4	35-36.5	SW	15-77-08	1973
ST-9-17A	5	40-41.5	SW	30-60-10	1973
ST-9-18	3	15-16.5	SW-SM	30-55-15	1973
ST-9-20	5	25-26.2	SW-SM	41-54-05	1973
ST-9-22A	1	15-16.5	SW	14-87-03	1973
ST-9-23A	2A	25-26.5	SW	15-74-11	1973
PZ-1008S	10	50-51.5	SP	18-78-04	1988
B-SP4	8	34.5-36	SM	10-72-18	1988
			Min.	10-54-03	
			Max.	30-87-18	
			Ave.	22-70-09	
			n =	8	

*P200 = Clay (<0.005 mm fraction) plus silt (<0.075 to 0.005 mm fraction).

3.5.3.4.1 Cambrian Sandstone

Fine and medium-grained sandstone of the Mt. Simon Formation is the uppermost bedrock unit in the project area. Sandstone was not encountered in borings at the southwest end of the pit as shown on Cross Sections D-D′ and E-E′, Figure Nos. 3.5-6 and 3.5-7, respectively. In the area of the northwest one-third of the pit, 20 to 30 feet of sandstone is present. The thickness of sandstone increases to the northwest, as shown on Cross Sections A-A′ and E-E′, Figure Nos. 3.5-3 and 3.5-7, respectively.

The sandstone is about five to 15 feet thick in the northern part of the Type II waste rock stockpile area but does not occur under the southern part.

The sandstone has variable color, grain-size distribution, and degree of cementation. Mineralogically, the sandstone is predominantly quartz. Near the base of the unit, clays such as kaolinite and sericite have been eroded from saprolitic Precambrian rock and incorporated into the sandstone as small aggregates of grains, dispersed matrix material, or thin laminations. The sandstone is typically pale brown (10YR 6/3) or pale yellow (2.5Y 7/4). It varies to light green-gray (5GY 7/1) or light olive gray (5Y 6/2) where it contains silty matrix material eroded from the Precambrian, or yellow red (5YR 5/6) at the contact with the overlying till.

The sandstone is typically poorly cemented, but varies from loose to well-cemented. The sandstone typically contains coarse quartz grains and silty material at the base of the sequence and grades upward to loose, fine and medium-grained sandstone at the top of the sequence. As indicated by blow counts, the sandstone is very dense.

Using the USCS system, the sandstone is classified as poorly graded sand (SP) or poorly graded sand with silt (SP-SM) as found on Table No. 3.5-7. The sandstone is composed of zero to eight percent gravel-size fragments, 87 to 99 percent sand, and one to ten percent silt and clay from 15 samples analyzed. The average gravel:sand:P200 (silt and clay) ratios are 1:95:4, respectively.

3.5.3.4.2 Precambrian

Rocks containing the Flambeau deposit were originally a complex suite of interfingering volcanic flows, ash, and ejecta material which were deposited in an oceanic volcanic basin. The deposit was later overturned during a period of mountain building that included intense folding, faulting, and alteration of the rock. After overturning, the volcanic rocks were eroded, clay-altered, and the top of the deposit was supergene-enriched. The topography at the top of the buried Precambrian bedrock is shown on Figure No. 3.5-13.

TABLE NO. 3.5-7

Summary of Soil Test Data
Sandstone (SP, SP-SM)

Boring No.	Sample No.	Depth (ft)	USCS Class	LL	PI	% g-s-P200*	Permeability cm/sec at % compaction)	Max. Dry Density (PCF)	Opt. Moisture (%)	Date of Test
ST-9-19	6B	28-28.5	SP-SM	-	-	0-93-07	-	-	-	1973
ST-9-22	8	40-41	SP-SM	-	-	0-90-10	-	-	-	1973
ST-9-22	9	45-46.5	SP-SM	-	-	0-96-04	-	-	-	1973
ST-9-24	5	25-26	SP	-	-	0-96-04	-	-	-	1973
ST-9-24	6	30-30.2	SP	-	-	0-99-01	-	-	-	1973
PZ-S1	4	17-18	SP	-	-	0-97-03	-	-	-	1987
PZ-S1	6	20-21	SP	-	-	1-98-01	-	-	-	1987
PZ-S3	9	27.5-28	SP	-	-	-	$K_L=8.8x10^{-5}$	-	-	1988
PZ-S4	14	34-35.5	SP	-	-	8-90-02	-	-	-	1987
PZ-S4	15	35.5-37	SP	-	-	2-96-02	$3.6x10^{-3}$(90%)	-	-	1987
PZ-S4	18	41-43	SP	-	-	0-98-02	-	-	-	1987
PZ-S5	8	29.8-31.5	SP	-	-	1-96-03	$3.5x10^{-3}$(91.5%)	-	-	1987
B-WC-2A	12	25-26	SP	-	-	1-98-01	-	-	-	1987
B-WC-3	8	31-34	SP	-	-	0-96-04	$2.8x10^{-3}$(90%)	-	-	1988
PZ-1007S	11	55-56.5	SP-SM	-	-	4-87-09	-	-	-	1988
Composite**	-	-	SP	-	-	-	-	113.9	10.9	1988
					Min.	0-87-01				
					Max.	8-99-10				
					Ave.	1-95-04				
					n =	14				

*P200 = Clay (<0.005 mm fraction) plus silt (<0.075 to 0.005 mm fraction).
**Sample composited from PZ-S1, S3, S4, S5 and B-WC2A, WC3.

For a detailed description of the Flambeau deposit, the reader is referred to May (1977).

Volcanic Rock and Alteration

Volcanic rock hosting the ore deposit is generally made up of thick sequences of flow rock, ejecta debris, ash, and volcanic sediments. Rock layers immediately beneath the deposit are usually thinner and more complexly interfingered.

Two types of alteration, regional metamorphic and supergene, have significantly changed the composition, fabric and texture of the Precambrian rock. Regional alteration of the volcanic rock probably occurred during folding and mountain building processes. Metamorphic mineral assemblages of chlorite, biotite, and andalusite are common within these rocks, and indicate that when the rocks were uplifted, they were subjected to intense pressure at low and medium temperature.

Supergene alteration is a process in which fluctuating acidic groundwater reacts with the rock to form a different suite of minerals. This process, which may represent ancient weathering, has intensely altered the bedrock to depths of 50 to 400 feet below the surface. The upper ten to twenty feet of volcanic rock has been intensely altered by the supergene process to form saprolite. The saprolite grades into altered volcanic rock. Dark-colored minerals such as chlorite, which are rich in iron and magnesium, have had iron and magnesium leached, resulting in a bleached appearance. Chlorite and other such minerals have been highly altered to clay and micaceous-type minerals.

The combined effects of regional metamorphism and subsequent superimposed intense supergene alteration have obliterated much of the original rock texture and structure. Rock identification is impossible in the saprolite and difficult in the deeper, less decomposed and altered rock. Relict textural evidence and extrapolation of rock types encountered at depth were used to classify and interpret much of the rock in the supergene-altered portion of the Flambeau deposit. Waste rock fractures within the zone of supergene alteration generally contain an abundance of clay and platy silicate minerals.

Rocks that occur within the proposed pit have been subdivided into hanging wall, mineralized horizon, and footwall. Hanging wall volcanic rocks lie above or "hang over" the northwest-dipping deposit and, therefore, occur along the north wall of the pit. The mineralized horizon contains variable amounts of iron pyrite mineralization with lesser amounts of associated copper and gold. Lying beneath the mineralized horizon or at the "foot" of the horizon are the footwall volcanic rocks. These rocks occur along the south side of the proposed pit wall.

The Precambrian rocks on the project site strike approximately N45°E and dip about 70°NW. The bedrock geology is shown on geologic Cross Sections H-H', I-I', and J-J' as shown on Figure Nos. 3.5-14 through 3.5-16. These geologic sections are constructed along mine sections 401, 410, and 422, respectively. Geologic logs of core holes used to construct the cross sections are presented in Appendix 3.5-A. The locations of the sections are shown on Figure No. 3.5-1.

The rock classification used for the Flambeau deposit is based on characteristic metamorphic mineral assemblages. Whole-rock chemical analysis and thin sections studies have aided in interpretation of parent rock types.

Hanging Wall Rocks

Hanging wall rocks consist of four series of volcanic-derived material. Closest to the mineralized horizon is a series of rocks termed andalusite-biotite schist which are Units 2a, 2b, and 2c as shown on Figure Nos. 3.5-14 through 3.5-16. The combined thickness of these units ranges from 140 to 280 feet. Originally, the rock was probably volcanic ash, sediments, and pebble-size ejecta. Intense pressure and temperature created during regional alteration have flattened the pebble ejecta into thin lensoids and have altered the rock to a schist which contain crystals that are aligned parallel to the schist strike direction (N45°W).

Figure No. 3.5-15 shows a metadacite flow rock (Unit 5) which ranges in thickness from 120 feet to 380 feet. This rock is distinguished from other volcanic rock in that it has poorly developed schistosity. The rock is more massive in texture and contains crystals that are more randomly oriented than the schists.

Thin beds of volcanic-derived sediments (Unit 4a and Unit 4b) occur scattered throughout the major rock units in the hanging wall, but do not occur adjacent to the mineralized horizon. These beds generally have well-developed schistosity and contain distinctive chlorite and garnet minerals.

Quartz-augen schist (Unit 3a) occurs in the hanging wall rock but at a greater distance from the mineralized zone than the other rock units. The quartz augen were formed from fragments ejected from a volcanic pipe in a super-heated cloud of ash and steam. The thickness of this rock unit is unknown but has been cored over distances of 260 feet.

Mineralized Horizon

The Flambeau deposit occurs within a distinctive volcanic-sedimentary package of rock termed the mineralized horizon. The horizon trends the length of the proposed pit and ranges in thickness from 20 to 200 feet. Dominant rock types within the

mineralized horizon are a quartz-rich sediment and volcanic ash (Unit 1a), massive sulfide (Unit 1c), semi-massive sulfide (hatched) and chert (Unit 1b). Only the quartz-rich sediment (Unit 1a) has well-developed schistosity.

The hanging wall contact of the mineralized horizon is usually sharp, whereas the footwall contact is interbedded with volcanic layers. The mineralized horizon forms a bedrock ridge which has resisted erosion due to a higher quartz content than the surrounding volcanic rock. This ridge is illustrated on Figure No. 3.5-14.

The Flambeau deposit is generally tabular in shape and occurs along the hanging wall of the mineralized horizon. Figure No. 3.5-17 shows in plan view the distribution of the massive and semi-massive sulfide mineralization that makes up the deposit. Significant sulfide mineralization has not been intersected by core holes drilled west of the Flambeau River or east of State Highway 27.

The top 50 to 180 feet of the deposit has been altered by supergene weathering processes which have produced a higher grade of copper in the upper part of the horizon. Below the supergene-enriched copper zone are primary sulfides that contain lower grade copper mineralization. The mined ore will be recovered primarily from the enriched part of the deposit.

Asbestiform mineralization will not pose a problem since bedrock formations that could include small amounts of these minerals have been intensely clay-altered. This alteration has destroyed most of these asbestiform minerals. The above bedrock formations nearly all fall outside of the proposed pit limits. No asbestiform minerals occur within the massive sulfide enriched portion of the deposit.

Footwall Rocks

The footwall rocks (Unit 2c, Unit 4a, and Unit 4c) that lie close to the mineralized zone are thin-layered. These footwall rocks contain more chlorite and carbonate minerals such as dolomite and calcite and are possibly flow rocks or sediments. Andalusite-biotite schist (Unit 2a) envelopes the west one-third of the deposit. Quartz-augen schists (Unit 3a) of unknown thickness occur further out into the footwall.

Saprolite

The upper ten to twenty feet of volcanic rock has been intensely altered by the supergene process to form saprolite. The saprolite is generally thicker and more clayey where it is developed from the more mafic rock types such as the metadacite. Using the USCS, the saprolite generally is silt (ML), but ranges from silty gravel (GM) to fat clay (CH) as shown on Table No. 3.5-8. The average percentages of gravel:sand:P200 (silt

TABLE NO. 3.5-8

Summary of Soil Test Data
Saprolite (ML)

Boring No.	Sample No.	Depth (ft)	USCS Class	LL	PI	% g-s-P200**	Permeability cm/sec at % compaction)	Max. Dry Density (PCF)	Opt. Moisture (%)	Date of Test
ST-9-1	9,10, 11	52-59	ML	28.4	NP	-	$1.1x10^{-6}$(95%)	111.4	16.0	1972
ST-9-2	14-18	65-77	ML	-	-	-	$5.0x10^{-6}$(96%)	134.6	8.0	1972
ST-9-3	14-16, 18	65-75	ML	-	-	-	$6.4x10^{-6}$(88%)	125.0	11.5	1972
ST-9-4	7,9, 10,11	32-43	ML	25.1	4.3	-	$1.1x10^{-6}$(95%)	121.2	10.5	1972
ST-9-5	7-9, 12,13	31-41	ML	34.1	9.4	-	$6.1x10^{-5}$(94%)	110.0	16.8	1972
ST-9-7	12,15 18,19	45-53	CH*	56.0	25.6	-	$2.5x10^{-8}$(98%)	97.8	23.1	1972
PZ-S1	8	25-27	ML	33.2	6.4	08-17-75	$K_V=3.3x10^{-8}$***	-	-	1988
PZ-S1	7-10	23-31	ML	-	-	-	-	119.5	11.7	1988
B-S2	4	15.5-17.5	GM*	-	NP	60-23-17-1	-	-	-	1987
PZ-S2	5	17-18.5	ML	-	-	-	$K_V=3.3x10^{-7}$	-	-	1988
PZ-S2	6	20-21.5	SM*	-	-	22-55-23	-	-	-	1987
PZ-S3	14-16	36-39	ML	34.3	8.5	01-26-73	-	-	-	1987
PZ-S3	20	49.5-50.5	ML	35.9	4.2	00-07-93	-	-	-	1987
PZ-S4	22	50-51.5	SM*	-	-	32-41-27	-	-	-	1987
PZ-S4	23	51.5-53	ML/CL-ML	24.7	3.8	06-42-52	-	-	-	1987
B-S5	11	45-46	ML	28.7	2.9	00-22-78	-	-	-	1987
B-S5	12	47-51.5	ML	30.6	3.2	-	-	115.5	11.9	1987
B-S5	15	55-57	ML	-	-	-	$K_V=2.2x10^{-7}$	-	-	1988
B-S5	18	62-67	ML	26.2	2.7	04-36-60	-	-	-	1987
			Min.	24.7	2.7	00-07-52				
			Max.	35.9	9.4	08-42-93				
			Ave.	30	5	03-25-72				
			n =	10		6				

*Data not used in averages or ranges.
**P200 = Clay (<0.005 mm fraction) plus silt (<0.75 to 0.005 mm fraction).
***Thin-wall or flex-wall permeability.

and clay) in the silty saprolite are 3:25:72, respectively (ten samples analyzed).

Structure

Schistosity is the dominant rock fabric and imparts a distinctive platy texture to the rock enclosing the deposit. Several faults have been intersected by core drilling; these offset the deposit from one to 30 feet. Rock fragments, interpreted to be fault breccia, have been observed in the more brittle massive sulfide rock. However, faults within the volcanic rock are generally thin and filled with clay and micaceous minerals. The orientations of the faults are uncertain, but an east-southeast direction is inferred. Schistosity planes are interpreted to be continuous along strike particularly at or near the footwall contact. Cross-cutting fractures are expected to be discontinous.

3.5.4 Seismology/Earthquakes

No earthquakes have been recorded in the Ladysmith area in historic times (Mudrey, 1984). The closest earthquake epicenters have been located in southeastern Wisconsin and the Upper Peninsula of Michigan (Docekal, 1970).

3.5.5 Summary of Geological Information

Investigations conducted since 1968 have provided detailed information for geologic, hydrogeologic, and geotechnical site characterization.

The Quaternary sediments consist predominantly of silty sand till and generally poorly sorted, glacial-fluvial sediment. These sediments are probably mostly Late Wisconsinan in age and belong to the Copper Falls Formation. However, finer-grained till was encountered in a few boreholes and probably occurs as patchy remnants in depressions in the bedrock surface.

The Quaternary sediments are underlain by Cambrian-age sandstone of the Mt. Simon Formation. The sandstone is composed of fine to coarse-grained quartz sand with variable amounts of fines and cementation. The lower part of the sandstone contains saprolitic material eroded from the underlying Precambrian rocks.

The underlying Precambrian rock is a metamorphosed suite of interfingering volcanic flows, ash, and ejecta material that was deposited in an oceanic volcanic basin. The rocks have undergone regional metamorphism and intense supergene alteration. These processes have resulted in extensive alteration of the rock to clay minerals. The upper part of the rock has been intensively altered to saprolite. The thickness of the saprolite and degree of alteration of the underlying rock is variable, depending largely on original rock composition.

Because the original rock compositions were complexly interfingered, the subsequent alteration also has a complex pattern of alteration. The more mafic hanging wall rocks, such as the metadacite, have been most extensively altered. Throughout the rock, secondary clay minerals, quartz, and earthy iron oxides characteristically fill in foliation planes and cross-cutting fractures.

The upper one to 30 feet of the deposit has been intensely weathered to produce an iron-oxide-rich gossan. The deposit has been enriched in copper below the gossan to a maximum depth of 225 feet. Chalcocite and bornite in a matrix of pyrite and chert (quartz) make up the deposit.

3.5.6 Waste Characterization

3.5.6.1 Introduction

The mining operation will include the removal and temporary stockpiling of topsoil, overburden, and waste rock. These materials will be stored in designated stockpiles during the operation of the mine and then returned to the open pit as backfill during site reclamation.

The objectives of the waste characterization study included the establishment of baseline concentrations and distributions of selected components within the topsoil, overburden, and waste rock. In addition, these materials were characterized with regard to their leachability in order to determine the method necessary to temporarily store these materials during the proposed short-term operation of the mine. Finally, the chemical behavior of the materials was used to determine the best environmental approach to backfilling and reclamation.

The characteristics of the topsoil are such that this material can be safety stored in an unlined site. It will be stored separately from all of the other waste materials so that it can be used as the final cover on the reclaimed site. Using this native topsoil as the final cover will enhance the site reclamation by accelerating the revegetation.

The overburden consists of glacial till, sandstone, and saprolite. Each of these materials was characterized separately since each has significantly different physical and chemical properties and mineralogy. It has been concluded that the till and sandstone can be stored in an unlined site known as the Type I stockpile. Stormwater runoff from this site will be collected in a series of settling ponds for clarification before discharge to surface waters of the state. The overburden will be returned to the open pit in the approximate stratigraphic position that they currently occupy in order to promote the reestablishment of the natural groundwater flow patterns.

Saprolite is a gritty material rich in silt and clay, which has been formed in the upper part of the Precambrian bedrock. Characterization of this material revealed that one-half of it could also be stored in the unlined Type I site. Approximately one-half of the total saprolite has an acid production potential and/or chemical leachability such that it will have to be stockpiled in a lined storage site. This lined site, known as the Type II stockpile, will contain a system for the collection and treatment of the water which comes in contact with this waste material.

Waste rock is defined as the Precambrian bedrock. It will be necessary to separate the waste rock in the field for placement in lined and unlined stockpiles based on observation and/or sulfur analysis. Approximately 30 percent of the waste rock can be stored in an unlined site, with the remaining 70 percent being stored in a lined site.

Saprolite and waste rock that will be stored in an unlined stockpile is referred to as Type I material. Saprolite and waste rock that will be stored in a lined stockpile is referred to as Type II material. Type I material contains less than one percent total sulfur. Type II material contains greater than one percent total sulfur. Experimental data shows that the actual level for dividing the saprolite and waste rock into Type I and Type II materials is close to two percent total sulfur based on leachability tests. The one percent level was chosen to provide an additional margin of safety.

The Type II material, which contains greater than one percent total sulfur, will be backfilled into the mine pit prior to the Type I waste rock. As the Type II material is returned to the pit, lime will be added to the material in order to retard the lowering of the pH and potential release of chemicals from the waste as it reacts with the inflowing groundwater. The accumulating rock will be sloped in order to enhance internal drainage. Sumps will collect the contact water and pumps will deliver to the wastewater treatment facility for as long as is required for safe operations in the pit.

Following the return of the Type I waste rock to the open pit, the Type I saprolite will then be added to the pit. The saprolite will be placed within the pit at approximately the same stratigraphic position it now occupies. This reworked saprolite will have a relatively low permeability and will retard the exchange of groundwater within the lower waste rock with that within the overlying sediments.

3.5.6.2 Materials and Sample Preparations

Samples of topsoil, overburden (till, sandstone, and saprolite), and waste rock were collected for testing and evaluation. Each of these materials was collected and handled in different manners.

Collected samples were transported to Foth & Van Dyke facilities using chain-of-custody procedures as outlined below. From the point of collection the name of the person who collected the samples, the date, time, and place of collection was recorded. The date, time, and name of persons assuming custody of the samples on behalf of Foth & Van Dyke was also recorded. Also, the name of the person who relinquished custody of the samples to Foth & Van Dyke was recorded with the date and time the transfer occurred. In addition to the above, WDNR personnel observed both the selection of the core materials and verified that the selected cores matched the Kennecott core logs, and observed waste rock sample treatment and compositing at Foth & Van Dyke's offices.

Two sets of topsoil samples were collected. The locations of both sets, KWC and KWR, are shown in Figure No. 3.5-18. The KWC series were collected from six backhoe pits dug within the perimeter of the open pit. These samples were double-bagged and refrigerated during collection.

These soils (KWC) were composited in the laboratory by cone and quartering for use in the chemical leaching studies. Part of the sample collection in the field and preparation in the laboratory was observed by WDNR personnel. Detailed soil pit descriptions are included in Appendix 3.5-M. The samples were composited such that there were three final samples representing the eastern, central, and western soils in the open pit area. Sample compositing data are included in Table No. 1 of Appendix 3.5-N.

The KWR soils were collected with a hand auger at the ten sites shown in the above-mentioned figure. The sites are located beneath the Type I stockpile area. The samples were collected from the upper ten to twenty inches of soil at each site. The samples were double-bagged and refrigerated during collection, shipment, and storage in the laboratory until they were composited to form one sample. Sample compositing data are included in Table No. 1 of Appendix 3.5-N. Subsamples of the composited soil were used in the soil sorption study.

The till, sandstone, and saprolite samples were obtained from soil borings conducted as part of the geotechnical and exploration coring program previously described. The location of the sampling sites are shown in Figure No. 3.5-19 and the logs and sample descriptions are presented in Appendices 3.5-F and 3.5-G. The samples were bagged and refrigerated upon collection and during transportation to, and storage in, the laboratory.

The till and sandstone samples were composited to form three major composites representing material in the east, central, and west portions of the open pit. A single composite was formed from Type I and II of the saprolite samples. Sample compositing

data are included in Table No. 1 of Appendix 3.5-N. Subsamples of the composites were used in the chemical leaching and soil sorption studies. Subsamples of till and saprolite were also used to generate artificial stormwater runoff for the polymer testing portion of the wastewater treatment program. Sample compositing was observed by WDNR personnel.

Five waste rock composites were prepared based upon the percent sulfur assay values, which had been previously determined by Kennecott. The five samples, WR-1 through 5, represent the range of sulfide mineralization, from least to most, that will be expected in the waste rock. The range of sulfide mineralization is shown in Table No. 3.5-10 (Section 3.5.6.3.1). An additional composite, WW-1, was prepared from semi-massive sulfides. Each composite contains samples from a wide spatial distribution within the open pit and represents the major waste rock lithologies expected to be excavated in the pit.

The waste rock samples were selected from cores which had been stored in a secure facility in the vicinity of Ladysmith since they were collected in the late 1960s and early 1970s. WDNR personnel observed the selection of the core materials and verified that the selected core samples matched the Kennecott core logs. The locations of the samples used in the composites are shown in Figure No. 3.5-20.

The core samples were transported to the laboratory where they were broken into chips with a mean median diameter of one to two inches. Each chip was brushed in order to remove any attached fine material. This was done to distinguish and separate the chips from the fines. The major orthogonal axes of each chip were measured to the nearest millimeter. The mean axial lengths for each sample were calculated from the chip data. Volumes and surface areas were calculated using a density correction factor. The measurements, calculations, and data are included in Table Nos. 2 and 3 of Appendix 3.5-N.

A representative subsample of each waste rock sample was ground in a ball mill grinder in order to produce rock powder of less than 400 mesh mean diameter. The samples were ground in order of increasing total sulfur content and calculations were made of the carryover of iron and sulfur from sample to sample. The data and calculations included in Table No. 4 and the preceding five pages in Appendix 3.5-N show that the carryover is not considered to be a significant problem.

The samples were carefully composited in a fashion to assure comparability between coarse and ground rock composites. The sample treatment and compositing were also observed by WDNR personnel. Sample compositing data are included in Table No. 5 of Appendix 3.5-N. The waste rock composites were used for the acid production/neutralization potential, chemical leaching, and EP toxicity tests; and bench test studies.

Based on an evaluation of cross sections of waste rock distribution, it is estimated that approximately 98 percent of the waste rock materials that will be stored in the unlined Type I storage site are typified by sample WR-1. These materials contain less than 0.2 percent; total sulfur. Since it is possible that some degradation of the primary sulfide minerals may have occurred in the core samples stored for 15 to 20 years, an additional composite core sample was made from very low sulfur-bearing rock, which was collected in 1987. This "fresh" composite, WR-1A, was tested for its acid production potential and was found to be similar in behavior to the "old" low sulfur composite, WR-1. Sample compositing data from WR-1A are also included in Table No. 5 of Appendix 3.5-N. It was determined that aging of samples WR-2 through WR-5, would not affect the reliability of the results of the waste characterization study.

Other material, such as wastewater treatment plant precipitate and settling pond solids, are characterized in Section 3.5.6.3.7.

3.5.6.3 Laboratory Analyses

3.5.6.3.1 Bulk Chemical Analyses

Bulk chemical analyses were performed on all of the waste materials. The parameters analyzed, as listed in Appendix 3.5-O, include the major and minor elements approved by WDNR. As seen in the appendix, there was some variation in parameters analyzed depending upon the type of material. The results of the analyses are included in Appendix 3.5-O.

A summary table listing the major element concentrations of the topsoil, till, sandstone, and saprolite is presented in Table No. 3.5-9. As seen therein, the major component of these materials is silicon, followed by lesser amounts of aluminum and iron. Minor concentrations of titanium were found in all of the samples. Also, minor amounts of tin were found in the till, sandstone, and saprolite samples. Calcium and magnesium are minor constituents in the topsoil, till, and saprolite.

The compositions of the topsoil and till are quite similar with the exception that the till contains more tin and copper than the topsoil. This general similarity was expected since the soils have formed within the glacial till.

The west topsoil and till composites have more iron than the other topsoil and till composites. The west till composite also contains more copper and titanium than the central and east composites. The west sandstone composite has elevated copper values, and the east sandstone composite has elevated manganese values as compared to the other sandstone composites.

TABLE NO. 3.5-9

Major Element Concentrations from the Bulk Chemical Analyses of the Topsoil, Till, Sandstone, and Saprolite Samples

Parameters	Units	Topsoil			Till			Sandstone			Saprolite
		West	Central	East	West	Central	East	West	Central	East	
Al	ug/g	30,600	28,000	32,600	52,600	38,900	41,200	6,140	7,530	5,440	34,800
Si	ug/g	259,000	260,000	295,000	344,000	336,000	318,000	437,000	395,000	376,000	347,000
Ca	ug/g	1,200	1,100	800	2,600	1,800	1,700	110	140	560	2,100
K	ug/g	260	180	110	310	240	170	69	16	27	130
Mg	ug/g	840	620	780	2,000	3,000	1,400	190	46	77	1,000
Na	ug/g	22	19	16	9	6	14	6	7	6	6
Cr	ug/g	9.5	6.0	7.5	9.1	9.6	11	2.3	1.7	1.6	9.2
Cu	ug/g	4.0	2.7	2.8	83	13	15	34	3	13	160
Fe	ug/g	10,000	4,400	6,000	10,000	5,700	7,000	680	430	1,100	12,000
Mn	ug/g	610	280	470	460	160	190	10	67	200	310
Pb	ug/g	9.0	5.0	10	2.3	3.5	2.3	0.4	0.6	1.3	29
Sn	ug/g	<200	<233	<200	1,600	620	1,900	710	960	570	560
Ti	ug/g	3,100	3,190	3,110	4,100	1,800	2,400	630	430	180	1,300
Zn	ug/g	18	19	17	21	18	22	3	3	10	110
MOISTURE	%	23	23	14	8.3	9.7	8.4	13	13	13	13
C	ug/g	-	-	-	590	630	510	1,700	200	190	280
S	%	0.21	0.21	0.20	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10

The major element concentrations found in the waste rock samples are summarized in Table No. 3.5-10. Similar to the topsoil and overburden samples, the waste rock composites are made up primarily of silicon with lesser amounts of aluminum and iron. Also, titanium is a minor constituent in these samples. Its occurrence is further discussed below.

Several progressive compositional changes can be observed in the data. The sulfur and copper concentrations increase from sample WR-1 to WR-5, while the opposite trend is noted for calcium and manganese. There is also some noteworthy variability in the elemental compositions. High tin and zinc concentrations were found in sample WR-1. The high lead and zinc content of WR-3 is probably due to small amounts of galena (PbS) and sphalerite (ZnS). The small amounts of cobalt and nickel also found in WR-3 are common minor constituents of sphalerite and pyrite (FeS).

The results of the bulk chemical analyses of the waste materials are to be used as a basis of comparison of the leachability of the different wastes. They are also used to establish the baseline concentration of the measured parameter within the waste materials and of the topsoil and till beneath the Type I stockpile.

The measured parameters of the topsoil, till and saprolite are within the normal ranges of these parameters determined through other soil studies in the United States (Kabata-Pendias and Pendias, 1984). The metal concentrations measured within the sandstone are less than or equal to those measured in other sandstones (Krauskopf, 1972). The range of metal and sulfur values measured within the waste rock samples generally falls within a broad range of values normally expected in areas of disseminated sulfide mineralization associated with massive sulfide deposits (BCMC, 1974).

3.5.6.3.2 Acid Production and Neutralization Studies

The acid production studies were conducted on samples of powdered waste rock in order to determine method of waste rock storage when waste rock is temporarily stockpiled during the mining operation. The neutralization studies were conducted to determine whether neutralization of the waste rock would be required during backfilling.

The estimation of acid production potential using powdered rock suspension provides a worst case approximation for the Flambeau waste rocks. The reasons for this are:

1. Powdered rock will be the material size for only two to three percent of the stockpiled waste and will represent a maximum of ten percent of the backfilled waste.

TABLE NO. 3.5-10

Major Element Concentrations from the Bulk Chemical Analyses of the Waste Rock Samples

Parameters	Units	WR - 1	WR - 2	WR - 3	WR - 4	WR - 5
Al	ug/g	109,000	122,000	124,000	108,000	109,000
Si	ug/g	357,000	330,000	336,000	349,000	269,000
Ca	ug/g	5,200	1,500	2,300	1,800	252
K	ug/g	700	590	360	870	118
Mg	ug/g	9,400	6,400	7,100	8,900	345
Na	ug/g	45	62	43	38	22
Co	ug/g	18	28	60	35	23
Cr	ug/g	24	29	25	17	2.3
Cu	ug/g	540	2,700	3,900	5,000	6,400
Fe	ug/g	33,000	38,000	42,000	45,000	38,000
Pb	ug/g	9	16	60	24	7
Mn	ug/g	310	160	130	180	19
Ni	ug/g	7.1	14	31	11	6.1
Sn	ug/g	2,600	<300	680	<300	460
Ti	ug/g	2,600	3,000	2,900	2,600	2,000
Zn	ug/g	1,200	98	7,900	830	41
S	%	<0.10	0.49	0.70	2.0	4.8

2. Chemical reactivity is related to exposed surface area. The surface area of the powder is about one million times greater per unit mass than that of the anticipated waste rock grain sizes. The powdered material will, therefore, be considerably more reactive than the actual waste.

3. The exposure of the sulfide grains was greatly enhanced by crushing these rocks. The sulfide minerals in most of the Flambeau rocks are concentrated within layers within the rocks rather than randomly distributed throughout the rocks. Therefore, the larger the size of the rock fragments the fewer sulfide grains, on average, that will be exposed for chemical reactions.

4. The powdered grain sizes are optimal for attack by micro-organisms such as *Thiobacillus ferrooxidans*. This aerobic bacteria produces sulfuric acid as a result of its oxidation of very fine-grained sulfide minerals, especially pyrite.

The initial acid production potential tests followed the methods of B.C. Research (1982). This included calculating the theoretical potential acid production which, in kilograms per tonne, is equivalent to the percent sulfur of the sample multiplied by 30.62 (factor from B.C. Research, 1982). After suspending waste rock powder in deionized (DI) water for 30 minutes, the "natural" pH could be determined. If the "natural" pH was greater than 3.50, the suspension was titrated with sulfuric acid to a pH of 3.50. The volume of acid used in the titration times 4.9 (for suspensions with liquid to solid ratios of 10 to 1) equals potential acid consumption, in kilograms per tonne, of the sample. If the potential acid production of a sample exceeded the potential consumption of acid, then theoretically it might release acid upon exposure to the surficial environment. Data from two duplicated acid consumption tests are included in Table No. 1 of Appendix 3.5-P.

In addition to the rapid titration employed in the above consumption tests, stepwise titration was performed on other sets of powdered waste rock samples. During these titrations, the suspension pH was recorded after each standard volume of acid was added to the suspension. The acid required to titrate the suspension to a pH of 3.50 was then determined graphically. The data from this test is included in Table No. 2 of Appendix 3.5-P. All of the "natural" pHs and quantities of acid consumption were different for each of these three tests.

Based upon the above experiments, it was concluded that the lowest sulfur-bearing waste rock samples, WR-1 through 2, would not be acid producers and that the higher sulfur-bearing samples, WR-3 through 5, may be acid producers. A sample of semi-massive sulfide ore, designated WW-1, was tested with the

waste rock samples as a check on the method. Sample WW-1, with a sulfur content of 34 percent, is a strong acid producer, as expected.

In order to determine if samples WR-3 through 5 would be acid producers, additional samples were suspended in a nutrient medium and inoculated with cultures of *Thiobacillus ferrooxidans*. This microbial confirmation test demonstrated that WR-3 and 4 would definitely not be acid producers and that WR-5 might. Data and procedures for this test are included in Table No. 3 of Appendix 3.5-P.

During the course of this study, it became apparent that two variables were causing the variables in the "natural" pH measurements and the determined acid production potentials. They were the time-dependent pH buffering capacity of the powdered waste rock, and the length of time that had lapsed between the time the rocks had been ground and when the tests had been conducted.

The time-dependent buffering capacity of the waste rock samples was evaluated by starting with the acid consumption test. Instead of terminating the experiment when the titration endpoint had been reached, the samples were allowed to rest for certain time periods as shown in Table No. 4 of Appendix 3.5-P. At the end of the time interval, the pH was measured and since this pH had always risen above 3.50, more acid was added to return the suspension pH to 3.50. These re-equilibrations were conducted for a total lapsed time of 130 to 140 hours. The results of the test, included in Appendix 3.5-P, indicate that although the buffering capacity of these wastes is low, it is persistent.

Numerous "natural" pH measurements were determined during this study. The data were tabulated and organized with respect to the time between addition of water to the sample, and the time that had elapsed between the grinding of the samples and determinations of sample pH. Certain trends in the data became apparent. The tabulated data, included in Table No. 5 of Appendix 3.5-P, shows that for a time lapse or "age", there was a slight increase in pH with increasing time of suspension in the low sulfur samples WR-1 through 3. There was a slight decrease in pH with increasing suspension time in the high sulfur samples WR-4 and 5 and WW-1. For a given time of suspension, the pH initially decreased with increasing "age" and then increased.

Calculated acid consumption values determined for different ages of waste rock powder are presented in Table No. 3.5-11. The data indicate that for each material tested the acid consumption decreased and then increased with increasing age of the powders. The highest acid consumption values were recorded in samples 180 to 300 days after they were ground.

TABLE NO. 3.5-11

Theoretical Potential Acid Production (kg/tonne),
Natural pH and Calculated Acid Consumption for the
Waste Rock Composites Aged for Various Times Before Testing

Sample	Percent Sulfur	Potential Acid Production	16 DAY		30 DAY		180 DAY		300 DAY	
			Natural pH	Acid Consumption	Natural pH	Acid Consumption	Natural pH	Acid Consumption	Natural pH	Acid Consumption
WR-1	<0.10	<3.06	6.88	2.55	6.48	1.08	6.95	13.92	7.93	13.72
WR-1A	<0.17	<5.21	8.06	2.45	--	--	--	--	7.64	3.82
WR-2	0.49	15.0	5.32	1.18	4.90	0.83	5.40	3.58	5.68	2.35
WR-3	0.70	21.4	5.15	1.67	4.75	1.23	5.15	2.70	5.45	4.95
WR-4	2.0	61.2	4.82	1.37	4.42	1.03	4.96	4.26	4.96	3.28
WR-5	4.8	147.0	4.30	0.39	4.30	0.48	4.40	1.37	4.28	1.03
WW-1	34	1,040.0	3.72	0.15	3.90	0.27	--	--	3.55	0.25

All of the powdered waste rock samples and WW-1 were progressively titrated with dilute calcium hydroxide solutions from their natural pHs to a pH greater than 9.0. Based upon the data included in Appendix 3.5-P, the quantity of calcium hydroxide, or lime, that would have to be added to the wastes to increase the suspension pH to 6.0 and 7.0 was calculated. An illustration of a typical base and acid titration of a waste rock suspension (WR-3) is shown in Figure 3.5-21. The calculated quantities of dry powdered lime were added to 20 grams of rock powder to which 200 mL of DI water were added. After stirring for one hour, the suspension pH was recorded and the samples were centrifuged and analyzed for sulfate, copper, iron, and manganese.

The results, included in Table No. 6 of Appendix 3.5-P, are summarized in Table No. 3.5-12 for samples WR-4, WR-5, and WW-1. The results indicate that no reduction in sulfate occurred with lime treatment and that only slight reductions in manganese occurred as a result of the lime addition. Other factors operate to mitigate these concentrations as discussed in Section 3.5.6.3.3.2. Significant reductions to copper and iron concentrations were recorded for different concentrations of added lime. The most significant reduction of copper in the suspensions occurred between the pH 6 and pH 7 treatments. The most significant reduction of iron occurred as a result of liming the suspension to pH 6.

The measured pHs of the "pH 6" suspensions ranged from 5.4 to 5.7 and those of the "pH 7" suspensions from 6.4 to 6.9. The fact that the actual pH values were lower than the calculated pH values is considered to be a function of incomplete dissolution of the calcium hydroxide, which is a sparingly soluble material.

3.5.6.3.3 Leaching Studies

Two different column leaching tests were performed on the materials that will be stored in stockpiles during the operation of the mine. One test, referred to as the wet/dry leaching test, simulated the reactions of the material stored above grade to alternating wet and dry cycles caused by rainwater infiltration. The other test, referred to as the saturated leaching test, simulated the reaction between those materials that will be returned to the pit which will ultimately be in continuous contact with groundwater. The column leaching tests were performed under the following conditions:

1. All materials were leached with a synthetic solution made up with DI water approximately the pH of rainwater (i.e., pH of 5.3). The columns were saturated for one day and allowed to drain for four days. This cycle was repeated 16 times. Leachate samples were collected during the first day of drainage during cycles 1, 2, 4, 8, and 16. Parameters for which there are no holding times, or for which there are very short holding times, were analyzed immediately.

TABLE NO. 3.5-12

A Comparison Between Selected Parameters of Three High Sulfur Wastes
Leached with DI Water and with Lime Added to Increase the Suspension pH

Parameter	Units	Untreated			pH 6			pH 7		
		WR-4	WR-5	WW-1	WR-4	WR-5	WW-1	WR-4	WR-5	WW-1
SO4	mg/l	180	180	180	200	190	730	190	380	750
Cu	ug/l	24,000	59,000	180,000	7,100	28,000	190,000	1,200	4,800	1,400
Fe	ug/l	450	11,000	130,000	120	530	1,500	400	570	1,200
Mn	ug/l	420	510	570	370	470	360	330	390	300
Ca(OH)2 ADDED	g/Kg	--	--	--	0.31	0.67	4.25	0.63	1.07	5.07
	(#/tonne)	--	--	--	0.68	1.48	9.36	1.39	2.36	11.20

These included pH, specific conductivity, temperature,mercury, and sulfate. A subsample from each column was preserved for metals analysis. Samples collected during cycles 4 and 8 were analyzed for key parameters. These key parameters were determined from the cycle 1, 2, and 16 sets of analyses. The selection of the key parameters was approved by the WDNR staff. The list of all parameters analyzed in the wet/dry leaching tests is presented in Table No. 3.5-13, and the complete chemical analyses are included in Appendix 3.5-Q. Those materials subjected to wet/dry leaching include the three topsoil, till and sandstone composites, the saprolite composite, and the powdered and chip-sized (one- to two-inch diameter) subsample of the five waste rock composites.

2. Some wet/dry leaching was performed on semi-massive ore composite WW-1. Most of the leachate derived from this material was used in the bench testing portion of the wastewater treatment facility design.

3. Those materials which will be in continuous contact with groundwater by being returned to the pit were further leached within their respective columns. These columns were further leached by a process of saturation with synthetic groundwater, cycled every two to three days, and maintained under anoxic conditions by sparging the columns with argon gas. The composition of the synthetic groundwater was based on the first seven consecutive months of analyses of groundwater samples collected from upgradient well nest MW-1005. The method of determination of the composition of the synthetic groundwater is included in Appendix 3.5-Q.

   Based upon the results of the analyses of the wet/dry leaching samples, a reduced list of parameters for the saturated leaching samples was approved by WDNR staff. Following the completion of the analyses of the cycle one and two leachate samples, additional reductions in the parameter list for the cycle 4 and 8 samples were approved by the WDNR staff. The complete list of saturated leaching parameters is presented in Table No. 3.5-14, and the complete chemical analyses are included in Appendix 3.5-Q. Following sample collection, removed leachate was immediately replaced by new synthetic groundwater.

4. Several sizes and types of columns were used in the leaching experiments depending upon the volume and nature of the material to be leached.

   The waste rock composite powders that have high liquid to solid ratios in these tests were leached in 250-mL polycarbonate centrifuge bottles. By centrifuging the samples each time a sample was to be collected (i.e. leachate drained), the retention of the powders could be maximized. However, this produced relatively small leachate

TABLE NO. 3.5-13

Parameters Analyzed During the Sampling Cycles for the Wet/Dry Leaching of the Waste Materials

Parameter	Topsoil					Till				
	Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16	Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16
Aluminum		X	X	X	X	X	X	X	X	X
Arsenic	X	X			X	X	X			X
Barium	X	X			X	X	X			X
Beryllium	X	X			X	X	X			X
Cadmium	X	X			X	X	X			X
Chromium	X	X	X	X	X	X	X	X	X	X
Cobalt	X	X			X	X	X			X
Copper	X	X			X	X	X	X	X	X
Iron	X	X	X	X	X	X	X	X	X	X
Lead	X	X			X	X	X			X
Manganese	X	X	X	X	X	X	X	X	X	X
Mercury	X	X	X	X	X	X	X	X	X	X
Molybdenum	X	X			X	X	X			X
Nickel	X	X			X	X	X			X
Selenium	X	X			X	X	X			X
Silver	X	X			X	X	X			X
Sodium	X	X			X	X	X			X
Thallium	X	X			X	X	X			X
Tin	X	X			X	X	X			X
Titanium	X	X	X	X	X	X	X	X	X	X
Uranium	X	X			X	X	X			X
Fluoride	X	X	X	X	X	X	X	X	X	X
Sulfate	X	X	X	X	X	X	X			X
TDS	X	X	X	X	X	X	X	X	X	X
Spec. Cond.	X	X	X	X	X		X	X		
pH	X	X	X	X	X	X	X	X	X	X
Temp.	X	X	X	X	X	X	X	X	X	X

TABLE NO. 3.5-13 (Cont.)

Parameter	Sandstone					Saprolite				
	Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16	Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16
Aluminum	X	X	X	X	X	X	X	X	X	X
Arsenic	X	X	X	X	X	X	X			X
Barium	X	X			X	X	X			X
Beryllium	X	X			X	X	X			X
Cadmium	X	X			X	X	X			X
Chromium	X	X	X	X	X	X	X	X	X	X
Cobalt	X	X			X	X	X			X
Copper	X	X	X	X	X	X	X	X	X	X
Iron	X	X	X	X	X	X	X	X	X	X
Lead	X	X	X	X	X	X	X	X	X	X
Manganese	X	X	X	X	X	X	X	X	X	X
Mercury	X	X	X	X	X	X	X	X	X	X
Molybdenum	X	X			X	X	X			X
Nickel	X	X			X	X	X			X
Selenium	X	X	X	X	X	X	X			X
Silver	X	X			X	X	X			X
Sodium	X	X	X	X	X	X	X			X
Thallium	X	X			X	X	X			X
Tin	X	X			X	X	X			X
Titanium	X	X	X	X	X	X	X	X	X	X
Uranium	X					X	X			
Zinc	X	X	X	X	X	X	X	X	X	X
Fluoride	X					X				
Sulfate	X	X	X	X	X	X	X	X	X	X
TDS	X	X				X	X			
Spec. Cond.	X	X	X	X	X	X	X	X	X	X
pH	X	X	X	X	X	X	X	X	X	X
Temp.	X	X	X	X	X	X	X	X	X	X

TABLE NO. 3.5-13 (Cont.)

Parameter	Rock Chips					Rock Powder				
	Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16	Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16
Aluminum	X	X	X	X	X	X	X	X	X	X
Arsenic	X	X			X	X	X			X
Barium	X	X			X	X	X			X
Beryllium	X	X			X	X	X			X
Cadmium	X	X			X	X	X			X
Chromium	X	X			X	X	X			X
Cobalt	X	X	X	X	X	X	X			X
Copper	X	X	X	X	X	X	X	X	X	X
Iron	X	X	X	X	X	X	X	X	X	X
Lead	X	X	X		X	X	X	X	X	X
Manganese	X	X	X	X	X	X	X	X	X	X
Mercury	X	X	X	X	X	X	X	X	X	X
Molybdenum	X	X			X	X	X			X
Nickel	X	X	X	X	X	X	X			X
Selenium	X	X			X	X	X			X
Silver	X	X			X	X	X			X
Sodium	X	X	X	X	X	X	X			X
Thallium	X	X			X	X	X			X
Tin	X	X			X	X	X			X
Titanium	X	X			X	X	X			X
Uranium	X	X			X	X	X			X
Zinc	X	X	X	X	X	X	X	X	X	X
Fluoride	X					X				
Sulfate	X	X	X	X	X	X	X	X	X	X
TDS	X	X				X				
Spec. Cond.	X	X	X	X	X	X	X	X	X	X
pH	X	X	X	X	X	X	X	X	X	X
Temp	X	X	X	X	X	X	X	X	X	X

TABLE NO. 3.5-14

Parameters Analyzed During the Sampling Cycles for the Saturated Leaching of the Waste Materials

Parameter	Till					Sandstone				
	Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16	Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16
Aluminum	X	X	X	X	X	X	X	X	X	X
Chromium	X	X			X	X	X	W	W	X
Copper	X	X	X	X	X	X	X	X	X	X
Iron	X	X	C	C	X	X	X	X	X	X
Lead	X	X			X	X	X			X
Manganese	X	X			X	X	X			X
Mercury	X	X	X	X	X	X	X	X	X	X
Sodium	X	X			X	X	X			X
Titanium	X	X	C	C	X	X	X	X	X	X
Zinc	X	X			X	X	X			X
Fluoride	X	X	X	X	X	X	X	X	X	X
Sulfate	X	X	X	X	X	X	X	X	X	X
Chloride	X	X	X	X	X	X	X	X	X	X
TDS	X	X	X	X	X	X	X	X	X	X
Alkalinity	X	X	X	X	X	X	X	X	X	X
Spec. Cond.	X	X	X	X	X	X	X	X	X	X
pH	X	X	X	X	X	X	X	X	X	X
Temp.	X	X	X	X	X	X	X	X	X	X

TABLE NO. 3.5-14 (Cont.)

Parameter	Saprolite				
	Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16
Aluminum	X	X	X	X	X
Copper	X	X	X	X	X
Iron	X	X	X	X	X
Lead	X	X	X	X	X
Manganese	X	X	X	X	X
Mercury	X	X			X
Sodium	X	X			X
Titanium	X	X	X	X	X
Zinc	X	X			X
Fluoride	X	X	X	X	X
Sulfate	X	X	X	X	X
Chloride	X	X	X	X	X
TDS	X	X	X	X	
Alkalinity	X	X	X	X	X
Spec. Cond.	X	X	X	X	X
pH	X	X	X	X	X
Temp.	X	X	X	X	X

Parameter	Rock Chips					Rock Powder				
	Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16	Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16
Aluminum	X	X	X	X	X	X	X	X	X	X
Copper	X	X	X	X	X	X	X	2-5	2-5	X
Iron	X	X	4,5	4,5	X	X	X	X	X	X
Lead	X	X			X	X	X	2,3	2,3	X
Manganese	X	X	2-5	2-5	X	X	X	5	5	X
Mercury	X	X	X	X	X	X	X	X	X	X
Zinc	X	X	2,4,5	2,4,5	X	X	X	X	X	X
Fluoride	X	X			X					
Sulfate	X	X	X	X	X	X	X	X	X	X
Chloride	X	X	X	X	X					
TDS	X	X	X	X	X					
Alkalinity	X	X	X	X	X					
Spec. Cond.	X	X	X	X	X	X	X	X	X	X
pH	X	X	X	X	X	X	X	X	X	X
Temp.	X	X	X	X	X	X	X	X	X	X

1. Where an "X" appears all of the composite samples (e.g., till) and all of the waste rock samples for that cycle and parameter were analyzed.
2. A "W", "C", or "E" means only the west, central, or east composite sample was analyzed.
3. In the waste rock analyses, a "2-5" means samples WR-2 through 5 were analyzed. A "2, 3" means samples WR-2 and 3 were analyzed.

sample volumes. These samples required disturbance to perform the test. They were the only samples that were disturbed during a given leaching experiment.

The waste rock chip composites and the saprolite composite were leached in 7-1/2-gallon cylindrical high-density polyethylene tanks. Since the saprolite composite contained both less than and greater than one percent sulfur bearing materials, these tests provided worst case analysis of the saprolite to be stored in the unlined area. The samples were supported above the base of the tanks by a circular plate made from sheet acrylic, in which drain holes had been drilled, and mounted on legs made of cast acrylic rod. In order to limit the loss of any fine grained material which might result from the leaching process, the top of the acrylic plate was covered with a mat of heavy metal-free borosilicate glass wool. During the saturated leaching, the argon gas was bubbled through the tank from beneath the support plate.

The till and topsoil composites were similarly leached but in five-gallon tanks. A drawing of a typical tank is shown in Figure No. 3.5-22.

Due to the difficulties experienced in obtaining sandstone samples, these materials were leached in columns made from two-inch-diameter by 24-inch-long sections of cast acrylic tubing. The set-up within the column was similar to that in the tanks with the exception of the differences in column materials and dimensions. These columns drained poorly and when the saturated leaching experiment was begun, these samples were quantitatively transferred to 3.8-liter polyethylene tanks. In spite of the difficulty in testing, the results are considered to be representative of field conditions.

Prior to initiating the leaching tests, all of the columns were leached with 1N nitric acid and thoroughly rinsed with DI water. This leaching was conducted to remove possible trace metal contaminants from the surfaces of the tanks and support materials. The charging of the columns with the waste materials and synthetic rainwater was observed by WDNR personnel. Sample weights, liquid volumes, and calculated liquid to solid ratios are included in Appendix 3.5-Q.

5. Specific conductivity, temperature, and pH were always measured during each cycle, whether samples were collected or not.

3.5.6.3.3.1 Wet/Dry Leaching Study

The specific conductivity and pH measurements made for all of the wet/dry cycles of the topsoil and the till, sandstone, and saprolite composites are presented in Table No. 3.5-15. The pH

TABLE NO. 3.5-15

pH and Specific Conductivity Values for the Wet/Dry Leaching of the Topsoil Samples

Cycle	Date	Parameters	West	Central	Topsoil East
1	08/02/88	pH	6.35	6.70	6.67
		Spec. Con.	39	76	49
2	08/07/88	pH	5.70	5.75	5.75
		Spec. Con.	31	27	36
3	08/12/88	pH	5.38	5.62	5.58
		Spec. Con.	25	37	33
4	08/17/88	pH	5.46	5.67	5.57
		Spec. Con.	35	28	28
5	08/22/88	pH	5.73	5.94	5.77
		Spec. Con.	27	37	24
6	08/27/88	pH	5.53	5.84	5.60
		Spec. Con.	27	55	25
7	09/01/88	pH	5.60	5.96	5.68
		Spec. Con.	32	60	25
8	09/07/88	pH	5.68	6.02	5.68
		Spec. Con.	43	64	36
9	09/11/88	pH	5.60	5.90	5.62
		Spec. Con.	35	58	29
10	09/16/88	pH	5.82	6.39*	5.84
		Spec. Con.	42	306*	32
11	09/21/88	pH	5.85	6.12	5.89
		Spec. Con.	47	121	34
12	09/26/88	pH	5.84	6.17	5.91
		Spec. Con.	46	108	37
13	10/01/88	pH	6.11	6.28	6.21
		Spec. Con.	57	77	49
14	10/06/88	pH	5.90	6.25	6.07
		Spec. Con.	47	90	43

TABLE NO. 3.5-15 (Cont.)

Cycle	Date	Parameters	West	Central	Topsoil East
15	10/11/88	pH	6.00	6.26	6.04
		Spec. Con.	85	100	53
16	10/15/88	pH	5.83	6.09	5.93
		Spec. Con.	61	79	55

Units: pH - Standard units
Spec. Con. - umhos/cm
* = Slow-draining turbid sample

TABLE NO. 3.5-15 (Cont.)

pH and Specific Conductivity Values for the Wet-Dry
Leachings of the Till, Sandstone, and Saprolite Samples

Cycle	Date	Parameter	Till			Sandstone			Saprolite
			West	Central	East	West	Central	East	
1	03/17/88	pH	6.95	7.15	7.20	7.90	7.75	7.55	7.65
		Spec. Con.	16	10	39	75	273	321	52
2	03/22/88	pH	5.30	5.85	6.30	7.50	--	6.70	7.15
		Spec. Con.	20	22	29	214	852	271	26
3	03/27/88	pH	7.06	7.08	7.20	8.88	8.21	8.99	8.46
		Spec. Con.	21	23	24	156	245	176	38
4	04/01/88	pH	7.24	6.89	7.25	8.03	8.12	7.71	8.56
		Spec. Con.	39	32	66	--	180	73	98
5	04/06/88	pH	7.03	6.89	7.45	8.30	8.12	7.73	8.67
		Spec. Con.	17	17	30	273	146	94	33
6	04/11/88	pH	7.05	6.99	7.05	8.66	8.21	8.51	8.57
		Spec. Con.	13	13	22	--	105	235	30
7	04/16/88	pH	7.47	7.08	7.59	8.63	7.80	8.52	8.66
		Spec. Con.	11	12	22	--	89	--	29
8	04/21/88	pH	8.07	7.52	7.93	8.56	7.88	8.64	8.88
		Spec. Con.	31	15	19	--	79	--	29
9	04/26/88	pH	7.92	7.40	8.22	8.35	7.44	8.35	8.51
		Spec. Con.	14	13	20	--	82	--	26
10	05/01/88	pH	8.20	7.58	7.82	8.69	7.48	8.27	8.62
		Spec. Con.	32	20	23	--	75	--	32
11	05/06/88	pH	7.85	7.16	8.02	8.63	7.49	8.43	8.62
		Spec. Con.	14	13	24	--	64	--	35

TABLE NO. 3.5-15 (Cont.)

Cycle	Date	Parameter	Till			Sandstone			Saprolite
			West	Central	East	West	Central	East	
12	05/10/88	pH	8.38	8.50	7.95	8.79	7.59	8.53	8.85
		Spec. Con.	26	41	22	--	46	--	30
13	05/16/88	pH	8.18	8.18	8.22	8.07	7.30	8.30	8.80
		Spec. Con.	13	22	22	283	43	--	29
14	05/21/88	pH	8.45	8.47	8.22	8.06	7.40	8.35	8.80
		Spec. Con.	29	54	30	26	41	--	32
15	05/26/88	pH	8.34	8.07	7.95	8.00	7.30	8.20	8.76
		Spec. Con.	12	20	22	151	35	--	27
16	05/31/88	pH	8.04	8.04	7.63	7.90	7.30	8.16	8.76
		Spec. Con.	10	13	16	125	33	--	33

UNITS: pH - standard units
Spec. Con. - umhos/cm

values for the topsoil composites declined approximately one standard unit from Cycle 1 to Cycles 3 and 4. The values increased gradually through the remaining cycles, where they appear to have stabilized in the 5.7 to 6.2 range. The Cycle 16 values were about one-half standard unit below the Cycle 1 values.

The pH values measured in the till leachates declined by one and one-half units between Cycles 1 and 2. Thereafter the pH values rose, and by Cycle 16 were in the range of 7.8 to 8.3, approximately one standard unit above the initial readings. The sandstone leachate pH values declined about one-half to one unit between Cycles 1 and 2. However, they then increased more than two units between Cycles 2 and 3. Thereafter they decline, especially those of the central sandstone composite, to the Cycle 16 values which are in the range of 7.5 to 8.5 and essentially the same as the Cycle 1 values. The pH measurements in the saprolite composite indicate that a slight decline in pH occurs between Cycles 1 and 2. Following the second Cycle, they increase and appear to stabilize in the range of 8.5 to 9.0, which is about one standard unit greater than the Cycle 1 values.

Unlike the pH values, where trends were observable, the conductivity values fluctuated considerably. There were no particular trends in conductivity values evident.

Concentration of selected parameters measured in the leachate from the topsoil, till, sandstone, and saprolite composites are presented in Table No. 3.5-16. The quantities of these parameters leached from the composites were calculated by multiplying the concentrations by the volume of rainwater used to saturate the sample, divided by the amount of sample. These quantities are presented in Table No. 3.5-17. The quantities of metals leached, and the time when they were leached the most, varied considerably between types of composite materials.

The maximum quantities of aluminum, chromium, iron, and titanium leached from the topsoil occurred in Cycle 1. The quantities of these elements declined rapidly as the cycles proceeded. The quantities of copper leached varied with cycle number, but they were within a narrow range through the course of 16 cycles. Manganese leached increased as the cycles progressed. The maximum quantities of aluminum, chromium, iron, and titanium were found in the leachate from the central topsoil composite. The maximum manganese quantities were found in the west topsoil composite leachate.

The maximum quantities of aluminum, chromium, iron, manganese, and titanium were leached from the till composites during cycles 4 and 8. Copper quantities were greatest in the Cycle 1 leachate. The peak elemental quantities for most of the

TABLE NO. 3.5-16

Concentrations of Selected Parameters in Wet-Dry Topsoil, Till, Sandstone, and Saprolite Leachate

Topsoil Wet-Dry Leachate Concentrations

CYCLE 1

Parameter	Units	West	Central	East
Al	ug/L	3,380	36,800	18,600
Cr	ug/L	6	80	32
Cu	ug/L	10	23	14
Fe	ug/L	3,100	33,000	15,000
Mn	ug/L	110	860	260
Ti	ug/L	272	2,880	1,530

CYCLE 2

Parameter	Units	West	Central	East
Al	ug/L	498	653	7,770
Cr	ug/L	<2	2	13
Cu	ug/L	11	<10	7
Fe	ug/L	820	1,100	8,700
Mn	ug/L	60	54	210
Ti	ug/L	24	57	686

TABLE NO. 3.5-16 (Cont.)

CYCLE 4

Parameter	Units	West	Central	East
Al	ug/L	321	121	528
Cr	ug/L	2	3	3
Cu	ug/L	--	--	--
Fe	ug/L	460	150	640
Mn	ug/L	330	53	440
Ti	ug/L	81	66	98

CYCLE 8

Parameter	Units	West	Central	East
Al	ug/L	149	137	260
Cr	ug/L	<2	<2	<2
Cu	ug/L	--	--	--
Fe	ug/L	1,300	1,300	820
Mn	ug/L	1,200	1,300	1,500
Ti	ug/L	<4	<4	5

CYCLE 16

Parameter	Units	West	Central	East
Al	ug/L	117	30	80
Cr	ug/L	<2	<2	<2
Cu	ug/L	11	13	<10
Fe	ug/L	6,600	1,800	3,000
Mn	ug/L	1,900	1,900	3,100
Ti	ug/L	<4	<4	<4

TABLE NO. 3.5-16 (Cont.)

Till Wet-Dry Leachate Concentrations

CYCLE 1

Parameter	Units	West	Central	East
Al	ug/L	2,360	2,060	2,770
Cr	ug/L	<2	2	2
Cu	ug/L	1,000	530	110
Fe	ug/L	1,100	990	1,800
Mn	ug/L	110	23	110
Ti	ug/L	75	85	93

CYCLE 2

Parameter	Units	West	Central	East
Al	ug/L	3,640	9,250	8,010
Cr	ug/L	3	8	10
Cu	ug/L	46	25	38
Fe	ug/L	3,200	7,200	10,000
Mn	ug/L	92	92	130
Ti	ug/L	190	591	445

TABLE NO. 3.5-16 (Cont.)

CYCLE 4

Parameter	Units	West	Central	East
Al	ug/L	20,700	29,700	21,800
Cr	ug/L	18	43	31
Cu	ug/L	130	45	39
Fe	ug/L	13,000	19,000	35,000
Mn	ug/L	320	200	150
Ti	ug/L	1,100	1,910	1,300

CYCLE 8

Parameter	Units	West	Central	East
Al	ug/L	40,800	12,000	10,900
Cr	ug/L	38	<3	<3
Cu	ug/L	270	31	20
Fe	ug/L	28,000	7,000	7,400
Mn	ug/L	550	76	71
Ti	ug/L	2,200	775	667

CYCLE 16

Parameter	Units	West	Central	East
Al	ug/L	13,600	4,680	12,500
Cr	ug/L	19	7	12
Cu	ug/L	26	12	89
Fe	ug/L	5,500	3,400	7,700
Mn	ug/L	79	19	180
Ti	ug/L	903	242	606

TABLE NO. 3.5-16 (Cont.)

Sandstone Wet-Dry Leachate Concentrations

CYCLE 1

Parameter	Units	West	Central	East
Al	ug/L	13,400	10,200	3,050
Cr	ug/L	350	36	12
Cu	ug/L	3,800	110	54
Fe	ug/L	80,000	13,000	4,200
Pb	ug/L	75	23	5
Mn	ug/L	940	720	131
Ti	ug/L	649	245	58

CYCLE 2

Parameter	Units	West	Central	East
Al	ug/L	5,960	10,400	2,280
Cr	ug/L	120	66	13
Cu	ug/L	860	160	60
Fe	ug/L	22,000	26,000	3,500
Pb	ug/L	17	26	6
Mn	ug/L	180	340	48
Ti	ug/L	280	345	35

TABLE NO. 3.5-16 (Cont.)

CYCLE 4

Parameter	Units	West	Central	East
Al	ug/L	683	3,610	3,780
Cr	ug/L	7	28	13
Cu	ug/L	390	48	27
Fe	ug/L	890	8,770	2,200
Pb	ug/L	<30	8	2
Mn	ug/L	<150	220	40
Ti	ug/L	39	137	108

CYCLE 8

Parameter	Units	West	Central	East
Al	ug/L	127	786	100
Cr	ug/L	<6	<3	--
Cu	ug/L	22	24	--
Fe	ug/L	<110	310	--
Pb	ug/L	<2	<2	<2
Mn	ug/L	<22	13	--
Ti	ug/L	<4	15	<4

TABLE NO. 3.5-16 (Cont.)

CYCLE 16

Parameter	Units	West	Central	East
Al	ug/L	488	710	1,100
Cr	ug/L	2	<2	<40
Cu	ug/L	41	<10	<200
Fe	ug/L	330	120	<1,100
Pb	ug/L	<2	<2	<40
Mn	ug/L	<11	<11	<220
Ti	ug/L	<8	<8	<80

Saprolite Wet-Dry Leachate Concentrations

Parameter	Units	Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16
Al	ug/L	7,220	4,280	13,200	2,480	441
Cr	ug/L	4	5	16	<3	<2
Cu	ug/L	660	76	190	27	<10
Fe	ug/L	3,000	1,300	6,000	930	130
Pb	ug/L	68	11	18	9	<2
Mn	ug/L	570	38	100	19	<11
Ti	ug/L	181	91	320	52	<4
Zn	ug/L	240	59	99	19	<11

TABLE NO. 3.5-17

Calculated Quantities of Selected Parameters Leached from Wet-Dry Topsoil, Till, Sandstone, and Saprolite

Topsoil Wet-Dry Quantities Leached

Parameter	Units	Cycle 1			Cycle 2			Cycle 4		
		West	Central	East	West	Central	East	West	Central	East
Al	ug/g	1.53	11.02	6.18	0.23	0.20	2.58	0.15	0.036	0.18
Cr	ug/g	$2.7x10^{-3}$	0.024	0.011	$<9.1x10^{-4}$	$6.0x10^{-4}$	$4.3x10^{-3}$	$<9.1x10^{-4}$	$9.0x10^{-4}$	$9.9x10^{-4}$
Cu	ug/g	$4.5x10^{-3}$	$6.9x10^{-3}$	$4.6x10^{-3}$	$5.0x10^{-3}$	$<3.0x10^{-3}$	$5.6x10^{-3}$	--	--	--
Fe	ug/g	1.40	9.88	4.98	0.37	0.33	2.89	0.21	0.045	0.21
Mn	ug/g	0.050	0.26	0.086	0.027	0.016	0.070	0.15	0.016	0.15
Ti	ug/g	0.12	0.86	0.51	0.011	0.017	0.23	0.037	0.020	0.032

Parameter	Units	Cycle 8			Cycle 16		
		West	Central	East	West	Central	East
Al	ug/g	0.068	0.041	0.086	0.053	$9.0x10^{-3}$	0.027
Cr	ug/g	$<9.1x10^{-4}$	$<6.0x10^{-4}$	$<6.6x10^{-4}$	$<9.1x10^{-4}$	$<6.0x10^{-4}$	$<6.6x10^{-4}$
Cu	ug/g	----	----	----	$5.0x10^{-3}$	$3.9x10^{-3}$	$<3.3x10^{-3}$
Fe	ug/g	0.59	0.39	0.27	2.99	0.54	1.00
Mn	ug/g	0.54	0.39	0.50	0.86	0.57	1.03
Ti	ug/g	$<1.8x10^{-4}$	$<1.2x10^{-3}$	$1.7x10^{-3}$	$<1.8x10^{-3}$	$<1.2x10^{-3}$	$<1.3x10^{-3}$

Till Wet-Dry Quantities Leached

Parameter	Units	Cycle 1			Cycle 2			Cycle 4		
		West	Central	East	West	Central	East	West	Central	East
Al	ug/g	1.08	1.11	1.27	1.67	5.01	3.68	9.51	16.07	10.02
Cr	ug/g	$<9.2x10^{-4}$	$1.1x10^{-3}$	$9.2x10^{-4}$	$1.4x10^{-3}$	$4.3x10^{-3}$	$4.6x10^{-3}$	$8.3x10^{-3}$	0.023	0.014
Cu	ug/g	0.46	0.29	0.051	0.021	0.014	0.018	0.060	0.024	0.018
Fe	ug/g	0.51	0.54	0.83	1.47	3.90	4.60	5.97	10.28	16.09

TABLE NO. 3.5-17 (Cont.)

Topsoil Wet-Dry Quantities Leached

Parameter	Units	Cycle 1 West	Cycle 1 Central	Cycle 1 East	Cycle 2 West	Cycle 2 Central	Cycle 2 East	Cycle 4 West	Cycle 4 Central	Cycle 4 East
Mn	ug/g	0.050	0.012	0.051	0.042	0.050	0.060	0.15	0.11	0.069
Ti	ug/g	0.034	0.046	0.043	0.087	0.32	0.20	0.51	1.03	0.60

Parameter	Units	Cycle 8 West	Cycle 8 Central	Cycle 8 East	Cycle 16 West	Cycle 16 Central	Cycle 16 East
Al	ug/g	18.75	6.49	5.01	6.25	2.53	5.75
Cr	ug/g	0.018	$<1.6\times10^{-3}$	$<1.4\times10^{-3}$	8.7×10^{-3}	3.8×10^{-3}	5.5×10^{-3}
Cu	ug/g	0.12	0.017	9.2×10^{-3}	0.012	6.5×10^{-3}	0.041
Fe	ug/g	12.87	3.79	3.40	2.53	1.84	3.54
Mn	ug/g	0.25	0.041	0.033	0.036	0.043	0.083
Ti	ug/g	1.01	0.42	0.31	0.41	0.13	0.28

Sandstone Wet-Dry Quantities Leached

Parameter	Units	Cycle 1 West	Cycle 1 Central	Cycle 1 East	Cycle 2 West	Cycle 2 Central	Cycle 2 East	Cycle 4 West	Cycle 4 Central	Cycle 4 East
Al	ug/g	2.52	0.64	0.11	1.12	0.65	0.082	0.13	0.23	0.14
Cr	ug/g	0.066	2.3×10^{-3}	4.3×10^{-4}	0.023	4.1×10^{-3}	4.7×10^{-4}	1.3×10^{-3}	1.8×10^{-3}	4.7×10^{-4}
Cu	ug/g	0.71	6.9×10^{-3}	1.9×10^{-3}	0.16	0.01	2.2×10^{-3}	0.073	3.0×10^{-3}	9.7×10^{-4}
Fe	ug/g	15.05	0.82	0.15	4.14	1.63	0.13	0.17	0.55	0.079
Pb	ug/g	0.014	1.4×10^{-3}	1.8×10^{-4}	3.2×10^{-3}	1.6×10^{-3}	2.2×10^{-4}	<0.01	5.0×10^{-4}	7.2×10^{-5}
Mn	ug/g	0.18	0.045	4.7×10^{-3}	0.034	0.021	1.7×10^{-3}	<0.03	0.014	1.4×10^{-3}
Ti	ug/g	0.12	0.015	2.1×10^{-3}	0.053	0.022	1.3×10^{-3}	7.3×10^{-3}	8.6×10^{-3}	3.9×10^{-3}

TABLE NO. 3.5-17 (Cont.)

Sandstone Wet-Dry Quantities Leached

Parameter	Units	Cycle 1 West	Cycle 1 Central	Cycle 1 East	Cycle 2 West	Cycle 2 Central	Cycle 2 East	Cycle 4 West	Cycle 4 Central	Cycle 4 East
Al	ug/g	0.024	0.049	3.6×10^{-3}	0.092	0.045	0.040			
Cr	ug/g	$<1.1\times10^{-3}$	1.9×10^{-4}	----	3.8×10^{-4}	$<1.2\times10^{-4}$	$<1.4\times10^{-3}$			
Cu	ug/g	4.1×10^{-3}	1.5×10^{-3}	----	7.7×10^{-3}	$<6.3\times10^{-4}$	<0.01			
Fe	ug/g	<0.02	0.020	----	0.062	7.5×10^{-3}	<0.04			
Pb	ug/g	$<3.8\times10^{-4}$	$<1.2\times10^{-4}$	$<7.2\times10^{-5}$	$<3.8\times10^{-4}$	$<1.2\times10^{-4}$	$<1.4\times10^{-3}$			
Mn	ug/g	$<4.1\times10^{-3}$	8.2×10^{-4}	----	$<2.1\times10^{-3}$	$<6.9\times10^{-4}$	<0.01			
Ti	ug/g	$<7.5\times10^{-4}$	9.4×10^{-4}	$<1.4\times10^{-4}$	$<1.5\times10^{-3}$	$<5.0\times10^{-4}$	$<2.9\times10^{-3}$			

		Cycle 8			Cycle 16		
	West	Central	East	West	Central	East	

Saprolite Wet-Dry Quantities Leached

Parameters	Units	Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16
Al	ug/g	2.94	1.74	5.38	1.01	0.18
Cr	ug/g	1.6×10^{-3}	2.0×10^{-3}	6.5×10^{-3}	$<1.2\times10^{-3}$	$<8.1\times10^{-4}$
Cu	ug/g	0.27	0.031	0.077	0.011	$<4.1\times10^{-4}$
Fe	ug/g	1.22	0.53	2.44	0.38	<0.05
Pb	ug/g	0.027	4.5×10^{-3}	7.3×10^{-3}	3.7×10^{-3}	$<8.1\times10^{-4}$
Mn	ug/g	0.23	0.016	0.041	7.7×10^{-3}	$<4.5\times10^{-3}$
Ti	ug/g	0.074	0.037	0.13	0.021	$<1.6\times10^{-3}$
Zn	ug/g	0.10	0.24	0.040	7.7×10^{-3}	$<4.5\times10^{-3}$

selected metals from the central and eastern till leachates occurred in the Cycle 4 leachates. The peaks for the western till leachate tended to be found in the Cycle 8 leachate.

The west sandstone composite was clearly the most leachable of the sandstone composites. All of the selected parameters were measurably leached from all of the sandstone composites during the first two leaching cycles.

The saprolite composite released the most copper, lead, manganese, and zinc during Cycle 1. The maximum quantities of aluminum, chromium, iron, and titanium were leached during Cycle 4.

The sandstone composites are the most leachable material of the topsoil, till, sandstone, and saprolite group. The maximum values of iron and copper leached from these materials came from the sandstone. In terms of bulk chemistry, the sandstone samples have the lowest iron concentration and the second lowest copper concentration. Zinc and lead were common to all of these unconsolidated materials but are most abundant in saprolite, which leached the maximum quantity of each. Considering the other selected metals, the saprolite composite was the least leachable of the composites.

The pH measured in the waste rock chip leachate decreased from 5.4 for the lowest percent sulfur waste (WR-1) to approximately three for the highest percent sulfur waste during Cycle 1. In the later cycles, however, the pH of the WR-3 leachate is generally greater than that of WR-2. The pHs of all of the composites increased during the cycles. The Cycle 16 pHs are about two units greater than the Cycle 1 pHs. It is therefore expected that, when stockpiled, the leachate derived from the waste rock chips will become progressively more basic as time of storage increases, rather than more acidic. This relationshipis summarized in Table No. 3.5-18.

Cycle 1 pH measurements of the waste rock powder leachate also showed a general decrease from WR-1 (pH = 7.3) to WR-5 (pH = 4.4). However, the pH of the WR-3 leachate was always greater than that of WR-2, and with the exception of Cycle 1, the pH of WR-4 was always greater than that of WR-2. The pH of all of the powdered waste rock leachates increased about one unit during the 16 loading cycles. It is therefore expected that the leachate derived from stockpiled waste rock powder or chips, will become progressively more basic as storage time increases as shown on Table No. 3.5-18. The variability in relative pH between waste rock samples is a function of both the total sulfur content of the rocks and the specific sulfide minerals contained within the rocks.

Significant decreases in conductivity were observed in all of the leachates as the leaching progressed. The measured conductivities of the waste rock chip leachate were much greater

TABLE NO. 3.5-18

pH and Specific Conductivity for the Wet-Dry
Leaching of the Waste Rock Samples

Cycle	Date	Parameter	Rock Chips					Rock Powder				
			WR - 1	WR - 2	WR - 3	WR - 4	WR - 5	WR - 1	WR - 2	WR - 3	WR - 4	WR - 5
1	03/17/88	pH	5.40	4.45	4.20	3.60	2.95	7.30	5.65	5.75	5.15	4.35
		Spec. Con.	751	481	1,548	1,674	2,751	179	187	308	353	365
2	03/22/88	pH	5.80	4.10	4.25	3.55	3.15	7.40	5.45	6.15	5.75	4.70
		Spec. Con.	339	541	1,256	1,518	2,129	36	32	68	101	51
3	03/27/88	pH	6.48	4.31	4.62	3.74	3.27	7.99	6.48	7.18	6.68	5.26
		Spec. Con.	221	453	964	1,057	1,463	32	20	32	68	36
4	04/01/88	pH	6.95	4.44	4.67	3.60	3.17	7.97	6.42	7.31	6.67	5.37
		Spec. Con.	254	328	688	1,070	1,092	36	19	28	42	25
5	04/06/88	pH	6.62	4.44	4.95	3.94	3.61	8.38	6.50	7.38	6.82	5.50
		Spec. Con.	101	220	418	447	460	25	14	23	30	22
6	04/11/88	pH	6.90	4.70	5.15	4.07	3.72	7.73	6.02	7.24	6.70	5.18
		Spec. Con.	68	140	333	337	335	36	15	25	37	51
7	04/16/88	pH	7.08	5.25	5.27	4.10	3.77	8.26	6.26	7.46	6.77	5.16
		Spec. Con.	74	82	238	249	228	31	14	24	31	23
8	04/21/88	pH	7.20	5.40	5.45	4.33	3.93	7.96	6.17	7.40	6.78	5.19
		Spec. Con.	48	54	192	170	178	28	16	23	31	23
9	04/26/88	pH	7.18	5.70	5.61	4.38	3.73	8.04	6.30	7.35	6.83	5.22
		Spec. Con.	43	42	143	128	148	26	14	21	26	21
10	05/01/88	pH	7.27	5.39	5.78	4.31	3.91	7.96	6.08	7.30	6.61	5.00
		Spec. Con.	60	43	166	127	145	34	15	26	28	23
11	05/06/88	pH	7.10	5.50	5.70	4.58	3.85	7.69	5.84	7.25	6.59	4.94
		Spec. Con.	44	31	90	85	95	40	13	19	21	21
12	05/11/88	pH	7.85	6.00	5.90	4.71	4.13	7.78	6.07	7.02	6.72	5.16
		Spec. Con.	40	38	84	85	78	32	15	24	23	22
13	05/16/88	pH	7.34	5.93	5.85	4.69	4.18	8.12	6.30	7.27	6.78	5.23
		Spec. Con.	36	26	87	77	56	26	11	20	17	14
14	05/21/88	pH	7.61	6.06	6.00	4.66	4.13	7.85	6.16	7.24	6.64	5.12
		Spec. Con.	33	36	76	89	69	27	11	30	16	17
15	05/26/88	pH	7.40	6.05	5.90	4.95	4.12	7.99	6.11	7.37	6.93	5.18
		Spec. Con.	33	25	50	40	47	32	11	22	22	22
16	05/31/88	pH	7.46	5.94	5.87	5.15	4.10	8.00	6.11	7.11	6.73	5.13
		Spec. Con.	54	23	73	19	65	19	10	14	12	16

UNITS: pH - standard units
Spec. Con. - umhos/cm

than that of the waste rock powders. These apparent differences in conductivity and pH values are probably a result of the significant differences in liquid to solid ratios between the chip and powder columns. The liquid to solid ratio of the powder columns is 20 times greater than the ratio of the chip columns with respect to liquid. The pH and specific conductivity data for the waste rock leachates are presented in Table No. 3.5-18.

Concentrations of selected parameters in the wet/dry waste rock leachate are presented in Table No. 3.5-19. Calculated quantities of these parameters are presented in Table No. 3.5-20. The maximum leached quantities of all of the selected parameters occur in the Cycle 1 WR-1 chip leachate. These values, which are expected to be typical for Type I waste rock, are of low intensity. The quantities of these materials decrease sharply as the leaching proceeds through the cycles. In general, these trends are observed in the chip leachates from the WR-2 through 5 composites. The other composites differ from WR-1 in that the maximum quantity leached may occur during Cycle 2 and that the rate of decline of leaching is not as great. This is especially true for the waste rock composites with the higher sulfur contents. Lead was detected only in the rock chip-derived leachate from WR-3.

The results of the wet/dry waste rock chip leachings indicate that the greatest release of material will occur during the first few times the rocks are subjected to major precipitative events. The quantities of material decrease considerably after that time. The presence of lead in the WR-3 leachate is a function of the presence of galena in the WR-3 rock composite. No significant impact on the soils and water beneath the Type I stockpile is expected as a result of this release of lead. Not only is the quantity of lead leached very small, but the estimated amount of WR-3 in the Type I stockpile is less than one percent of the waste rock in that storage area.

The maximum quantities of the material leached from the powdered waste rock tend to occur during Cycles 4 and/or 8 for sample WR-1. As the sulfur content of the rocks increases, the cycle of maximum leaching shifts toward the earliest cycles. Most of the maximum for sample WR-5 occur during the first leaching cycle. Similar to the time-based quantities of material leached from the waste rock chips, the maximum quantities leached from the waste rock powder are expected to occur during the first few major precipitative events. In addition, the quantities leached will decrease thereafter with time.

The quantities of material leached from the rock powders are generally two to ten times greater than those leached from the rock chips. Since the bulk chemistry and mineralogy of the chip and powder form of each waste rock are identical, the difference in leachability can be assumed to be a function of the greater surface area per unit of mass of the powder. Since weathering

TABLE NO. 3.5-19

Concentrations of Selected Parameters in
Wet-Dry Waste Rock Leachate

WR-1 Wet-Dry Leachate Concentrations

Parameter	Units	Rock Chips					Rock Powder				
		CYCLE 1	CYCLE 2	CYCLE 4	CYCLE 8	CYCLE 16	CYCLE 1	CYCLE 2	CYCLE 4	CYCLE 8	CYCLE 16
Al	ug/L	1,740	89	181	41	52	166	646	10,200	14,000	2,110
Co	ug/L	390	100	<40	<40	<40	<40	<40	--	--	<40
Cu	ug/L	660	200	22	<10	<10	64	250	84	140	41
Fe	ug/L	1,800	95	65	<55	<55	280	2,600	14,000	14,000	2,100
Pb	ug/L	<2	<2	<2	--	<2	<2	2	20	20	8
Mn	ug/L	340	110	54	<11	<11	19	<11	23	<55	<11
Ni	ug/L	91	<30	--	--	<30	<30	<30	--	--	<30
Zn	ug/L	730	220	42	13	<11	27	130	270	380	120
SO4	mg/L	400	150	100	11	5	50	<25	<20	<50	<10

TABLE NO. 3.5-19 (Cont.)

WR-2 Wet-Dry Leachate Concentrations

Parameter	Units	Rock Chips					Rock Powder				
		CYCLE 1	CYCLE 2	CYCLE 4	CYCLE 8	CYCLE 16	CYCLE 1	CYCLE 2	CYCLE 4	CYCLE 8	CYCLE 16
Al	ug/L	1,400	2,360	693	31	31	136	122	3,280	9,400	280
Co	ug/L	148	230	99	<40	<40	<40	<40	--	--	<40
Cu	ug/L	29,000	34,000	9,100	670	150	1,100	92	120	270	97
Fe	ug/L	950	2,600	880	<55	<55	290	160	3,200	5,600	610
Pb	ug/L	<2	<2	<2	--	<2	<2	<2	12	12	9
Mn	ug/L	620	840	460	61	15	370	54	29	40	12
Ni	ug/L	85	110	<30	<30	<30	<30	<30	--	--	<30
Zn	ug/L	2,500	4,300	1,900	200	44	850	140	150	380	140
SO4	mg/L	240	270	150	20	7	70	<25	<50	<20	<10

TABLE NO. 3.5-19 (Cont.)

WR-3 Wet-Dry Leachate Concentrations

Parameter	Units	Rock Chips					Rock Powder				
		CYCLE 1	CYCLE 2	CYCLE 4	CYCLE 8	CYCLE 16	CYCLE 1	CYCLE 2	CYCLE 4	CYCLE 8	CYCLE 16
Al	ug/L	2,080	1,530	321	44	18	209	189	2,760	9,000	700
Co	ug/L	1,100	1,200	610	110	40	230	<40	--	--	<40
Cu	ug/L	240,000	180,000	56,000	7,300	1,700	3,300	82	150	500	110
Fe	ug/L	5,600	7,600	1,400	120	<55	210	220	2,600	5,600	520
Pb	ug/L	5	4	2	--	<2	2	<2	55	750	4
Mn	ug/L	2,200	2,100	1,000	300	83	512	84	19	<28	<11
Ni	ug/L	650	680	340	67	<30	130	<30	--	--	<30
Zn	ug/L	53,000	56,000	28,000	7,700	2,000	5,600	200	310	1,000	110
SO4	mg/L	930	790	380	74	26	150	<25	12	<20	<10

TABLE NO. 3.5-19 (Cont.)

WR-4 Wet-Dry Leachate Concentrations

Parameter	Units	Rock Chips					Rock Powder				
		CYCLE 1	CYCLE 2	CYCLE 4	CYCLE 8	CYCLE 16	CYCLE 1	CYCLE 2	CYCLE 4	CYCLE 8	CYCLE 16
Al	ug/L	12,800	16,400	8,430	473	46	181	81	1,830	1,000	570
Co	ug/L	1,100	1,200	720	80	<40	140	<40	--	--	<40
Cu	ug/L	280,000	210,000	100,000	10,000	610	21,000	380	160	290	81
Fe	ug/L	78,000	71,000	4,000	3,700	60	980	<55	820	1,300	240
Pb	ug/L	<2	2	<2	--	<2	<2	<2	37	<20	3
Mn	ug/L	1,600	1,900	1,400	180	<11	470	190	64	<110	19
Ni	ug/L	660	480	270	110	<30	51	<30	--	--	<30
Zn	ug/L	11,000	13,000	10,000	1,300	120	1,900	250	60	290	34
SO4	mg/L	1,100	940	670	60	22	180	<50	16	<20	<10

TABLE NO. 3.5-19 (Cont.)

WR-5 Wet-Dry Leachate Concentrations

Parameter	Units	Rock Chips					Rock Powder				
		CYCLE 1	CYCLE 2	CYCLE 4	CYCLE 8	CYCLE 16	CYCLE 1	CYCLE 2	CYCLE 4	CYCLE 8	CYCLE 16
Al	ug/L	30,500	22,900	8,550	353	41	1,260	83	361	546	100
Co	ug/L	1,700	1,400	580	55	<40	180	<40	--	--	<40
Cu	ug/L	620,000	470,000	200,000	24,000	5,200	65,000	7,500	3,600	3,800	1,800
Fe	ug/L	230,000	150,000	57,000	4,200	910	9,600	62	210	380	140
Pb	ug/L	<2	<2	<2	--	<2	2	<2	4	4	9
Mn	ug/L	6,100	4,500	1,800	210	77	540	57	15	<22	<11
Ni	ug/L	660	560	260	48	<30	79	<30	--	--	<30
Zn	ug/L	2,100	2,000	850	130	38	330	49	23	150	89
SO4	mg/L	2,100	1,500	700	60	22	170	<25	<10	<20	<10

TABLE NO. 3.5-20

Calculated Quantities of Selected Parameters
Leached from Wet-Dry Waste Rock

WR-1 Wet-Dry Leached Quantities

Parameter	Units	Rock Chips					Rock Powder				
		CYCLE 1	CYCLE 2	CYCLE 4	CYCLE 8	CYCLE 16	CYCLE 1	CYCLE 2	CYCLE 4	CYCLE 8	CYCLE 16
Al	ug/g	0.91	0.047	0.095	0.022	0.027	1.66	6.46	102.00	140.00	21.10
Co	ug/g	0.20	0.052	<0.02	<0.02	<0.02	<0.40	<0.40	<0.40	<0.40	<0.40
Cu	ug/g	0.35	0.10	0.012	<0.01	<0.01	0.64	2.50	0.84	1.40	0.41
Fe	ug/g	0.94	0.050	0.034	<0.03	<0.03	2.80	26.00	140.00	140.00	21.00
Pb	ug/g	<0.002	<0.002	<0.002	<0.002	<0.002	<0.02	0.02	0.20	0.20	0.08
Mn	ug/g	0.18	0.058	0.028	<0.01	<0.01	0.19	<0.11	0.23	<0.55	<0.11
Ni	ug/g	0.048	<0.02	--	--	<0.02	<0.30	<0.30	<0.30	<0.30	<0.30
Zn	ug/g	0.38	0.12	0.022	6.8x10(-3)	<0.01	0.27	1.30	2.70	3.80	1.20
SO4	mg/g	0.21	0.079	0.052	5.8x10(-3)	0.003	0.50	<0.25	<0.20	<0.50	<0.10

TABLE NO. 3.5-20 (Cont.)

WR-2 Wet-Dry Leached Quantities

Parameter	Units	Rock Chips					Rock Powder				
		CYCLE 1	CYCLE 2	CYCLE 4	CYCLE 8	CYCLE 16	CYCLE 1	CYCLE 2	CYCLE 4	CYCLE 8	CYCLE 16
Al	ug/g	0.74	1.24	0.37	0.016	0.016	1.36	1.22	32.80	94.00	2.80
Co	ug/g	0.078	0.12	0.052	<0.02	<0.02	<0.40	<0.40	--	--	<0.40
Cu	ug/g	15.29	17.92	4.80	0.35	0.079	11.00	0.92	1.20	2.70	0.97
Fe	ug/g	0.50	1.37	0.46	<0.03	<0.03	2.90	1.60	32.00	56.00	6.10
Pb	ug/g	<0.001	<0.001	<0.001	<0.001	<0.001	<0.02	<0.02	0.12	0.12	0.09
Mn	ug/g	0.33	0.44	0.24	0.032	7.9x10(-3)	3.70	0.54	0.29	0.40	0.12
Ni	ug/g	0.045	0.058	<0.02	<0.02	<0.02	<0.30	<0.30	--	--	<0.30
Zn	ug/g	1.32	2.27	1.00	0.11	0.021	8.50	1.40	1.50	3.80	1.40
SO4	ug/g	0.13	0.14	0.079	0.10	<4x10(-3)	0.70	<0.25	<0.50	<0.20	<0.10

TABLE NO. 3.5-20 (Cont.)

WR-3 Wet-Dry Leached Quantities

Parameter	Units	Rock Chips					Rock Powder				
		CYCLE 1	CYCLE 2	CYCLE 4	CYCLE 8	CYCLE 16	CYCLE 1	CYCLE 2	CYCLE 4	CYCLE 8	CYCLE 16
Al	ug/g	1.18	0.87	0.18	0.025	0.010	2.09	1.89	27.60	90.00	7.00
Co	ug/g	0.62	0.68	0.35	0.062	0.022	2.30	<0.40	--	--	<0.40
Cu	ug/g	135.80	101.80	31.68	4.13	0.96	33.00	0.82	1.50	5.00	1.10
Fe	ug/g	3.17	4.30	0.79	0.068	<0.03	2.10	2.20	26.00	56.00	5.20
Pb	ug/g	2.8x10(-3)	2.3x10(-3)	1.1x10(-3)	--	<0.002	0.02	<0.02	0.55	7.50	0.04
Mn	ug/g	1.24	1.19	0.57	0.17	0.047	5.12	0.84	0.19	<0.28	<0.11
Ni	ug/g	0.37	0.38	0.19	0.038	<0.02	1.30	<0.30	--	--	<0.30
Zn	ug/g	29.98	31.68	15.84	4.36	1.13	56.00	2.00	3.10	10.00	1.10
SO4	mg/g	0.53	0.45	0.21	0.042	0.015	1.50	<0.25	0.12	<0.20	<0.10

TABLE NO. 3.5-20 (Cont.)

WR-4 Wet-Dry Leached Quantities

Parameter	Units	Rock Chips					Rock Powder				
		CYCLE 1	CYCLE 2	CYCLE 4	CYCLE 8	CYCLE 16	CYCLE 1	CYCLE 2	CYCLE 4	CYCLE 8	CYCLE 16
Al	ug/g	6.26	8.02	4.12	0.23	0.022	1.81	0.81	18.30	10.00	5.70
Co	ug/g	0.54	0.59	0.35	0.039	<0.02	1.40	<0.40	--	--	<0.40
Cu	ug/g	137.00	102.70	48.92	4.89	0.30	210.00	3.80	1.60	2.90	0.81
Fe	ug/g	38.16	34.73	1.96	1.81	0.029	9.80	<0.55	8.20	13.00	2.40
Pb	ug/g	<0.001	0.001	<0.001	--	<0.001	<0.02	<0.02	0.37	<0.62	0.03
Mn	ug/g	0.78	0.93	0.68	0.088	<0.01	4.70	1.90	0.64	<1.1	0.19
Ni	ug/g	0.32	0.23	0.13	0.054	<0.01	0.51	<0.30	--	--	<0.30
Zn	ug/g	5.38	6.36	4.89	0.64	0.059	19.00	2.50	0.60	2.90	0.34
SO4	mg/g	0.54	0.46	0.33	0.029	0.011	1.80	<0.50	0.16	<0.20	<0.10

TABLE NO. 3.5-20 (Cont.)

WR-5 Wet-Dry Leached Quantities

Parameter	Units	Rock Chips					Rock Powder				
		CYCLE 1	CYCLE 2	CYCLE 4	CYCLE 8	CYCLE 16	CYCLE 1	CYCLE 2	CYCLE 4	CYCLE 8	CYCLE 16
Al	ug/g	11.58	8.70	3.25	0.13	0.016	12.60	0.83	3.61	5.46	1.00
Co	ug/g	0.65	0.53	0.22	0.021	<0.02	1.80	<0.40	--	--	<0.40
Cu	ug/g	235.50	178.50	75.96	9.12	1.97	650.00	75.00	36.00	38.00	18.00
Fe	ug/g	87.35	56.97	21.65	1.60	0.35	96.00	0.62	2.10	3.80	1.40
Pb	ug/g	<0.001	<0.001	<0.001	--	<0.001	0.02	<0.02	0.04	0.04	0.09
Mn	ug/g	2.32	1.71	0.68	0.080	0.029	5.40	0.57	0.15	<0.22	<0.11
Ni	ug/g	0.25	0.21	0.10	0.018	<0.01	0.79	<0.30	--	--	<0.30
Zn	ug/g	0.80	0.76	0.32	0.049	0.014	3.30	0.49	0.23	1.50	0.89
SO4	mg/g	0.80	0.57	0.27	0.023	8.4x10(-3)	1.70	<0.25	<0.10	<0.20	<0.10

1. All quantities represent material leached or desorbed.

and leaching are processes that involve surface physical and chemical reactions, those materials with the greater surface areas like the rock powders will react to a greater extent and produce leachates with greater metal concentrations than those with lesser surface areas.

Some of the leaching trends exhibited by the waste rock samples reflect variation in bulk chemistry between the samples. For instance, the sulfur and copper concentrations decrease from WR-5 to WR-1. The leached quantities of sulfur and copper for both the chips and powders are greatest for WR-5 materials, and lowest for WR-1 materials. The bulk iron concentration is greatest in WR-1 and decreases with increasing sulfur content to WR-5. The greatest quantity of iron is leached from the WR-5 chip columns, and the least from the WR-1 chip columns. This reversal is probably due to the dual release of iron and sulfur due to the hydrolysis of the pyrite grain. The WR-5 material has considerably more pyrite than the other samples, and would therefore be expected to release more of both sulfur and iron than the other samples. In fact, the release of sulfur due to the weathering of pyrite must be accompanied by a release of iron. This coupled release is the part of the main acid-generating reaction (Nordstrom, 1982).

The bulk chemical concentration of aluminum is essentially the same for all of the waste rock composites. It is interesting to note that the maximum quantity of aluminum leached from the waste rock chips is from sample WR-5, and the minimum is from sample WR-1. This trend is reversed from the rock powders.

A comparison of the leachability of the waste rock samples with that of the topsoil and overburden reveals several observations. Although all of the materials contain quantities of tin and titanium, both of these elements occur in compounds of extremely low solubility. In addition, these two elements are usually not chemically reactive. Tin was not detected in any of the leachates. Titanium was found in the topsoil and overburden leachates.

Cobalt, nickel, and sulfate are not found in the leachate from the topsoil and overburden materials. Chromium and titanium are not found in the leachate from the waste rock composites. The waste rock powders release more aluminum, copper, iron, zinc, and sulfate to their leachates than the topsoil and overburden samples do to theirs. In addition, the powder release more lead and manganese than the topsoil and overburden composites release.

The quantities of metals leached from those materials that will be stockpiled in unlined sites decreased after the first leachings to levels typical (Kabata-Pendias and Pendias, 1984) of that formed in soil solution with the exception of iron and aluminum in the topsoil and till. The ability of the soils

beneath these stockpiles to sorb and retain these metals is a consideration for determining the acceptability of using unlined sites for the temporary stockpiling of waste materials.

As seen in the next section, soil and till beneath the stockpiles have significant capacities to retain copper and iron from solutes equilibrated with these materials. It is shown in the *Preliminary Engineering Report for Wastewaster Treatment Facilities* that most of the iron is in colloidal rather than the dissolved state. In soils, iron and aluminum both tend to be in the colloidal state and to exhibit similar behavior at near neutral pHs. It is expected that the aluminum colloids released during the leaching of the topsoil and till will be retained as iron will be.

The released manganese is similar to that found in soil solutions elsewhere (op. cit.). Leached sulfate quantities are low enough such that it would be expected that dilution by the soil solution would prevent detectable concentrations of sulfate from appearing in the groundwater beneath the unlined sites.

3.5.6.3.3.2 Saturated Leaching Study

When the 16 wet/dry leaching cycles had been completed, synthetic groundwater was added to the columns and the argon gas was fed into the basal parts of the columns. Every five days of saturation completed a saturated cycle. Sixteen saturated cycles were completed. At the end of each cycle, pH, specific conductivity and temperature were measured. Also, leachate samples were collected at the end of Cycles 1, 2, 4, 8, and 16.

The pH and specific conductivity values measured at the end of all of the cycles for the saturated leaching of the till, sandstone and saprolite composites are presented in Table No. 3.5-21. The data show that there was very little change in pH between Cycle 16 wet/dry values and Cycle 1 saturated values. During the course of the saturated leaching test there was virtually no change in the pH of the leachate of these materials. Specific conductivity values, however, gradually increased such that the Cycle 16 conductivities were about one and one-half times those of the Cycle 1 conductivities.

Concentrations of selected parameters measured in the saturated leachates from the till, sandstone and saprolite composites are presented in Table No. 3.5-22. The calculated quantities of leachate matter are presented in Table No. 3.5-23.

Of considerable importance is the fact that most of the overburden composite samples sorbed, or retained, iron and manganese during most of the cycles. The till and sandstone samples also sorbed sulfate during most of the cycles. In addition, till also sorbed the bicarbonate alkalinity most of the time. The saprolite composite sorbed neither the sulfate nor the bicarbonate. The sandstone composites sorbed

TABLE NO. 3.5-21

pH and Specific Conductivity Values for the Saturated Leaching of the Till, Sandstone, and Saprolite Samples

Cycle	Date	Parameter	Till			Sandstone			Saprolite
			West	Central	East	West	Central	East	
1	08/06/88	pH	7.81	7.76	8.00	8.25	7.74	8.07	8.65
		Spec. Con.	275	279	325	355	354	347	383
2	08/11/88	pH	7.38	7.37	7.63	8.56	7.90	8.44	8.40
		Spec. Con.	285	313	356	416	415	414	410
3	08/16/88	pH	7.31	7.24	7.78	8.86	8.26	8.79	8.52
		Spec. Con.	308	325	379	423	425	425	425
4	08/21/88	pH	7.31	7.20	7.78	8.92	8.61	8.87	8.42
		Spec. Con.	302	317	399	426	428	428	434
5	08/26/88	pH	7.40	7.34	8.04	9.08	8.94	8.52	8.67
		Spec. Con.	337	351	424	435	435	439	445
6	08/31/88	pH	7.27	7.30	8.25	8.94	8.79	8.77	8.65
		Spec. Con.	330	351	440	435	432	435	457
7	09/06/88	pH	7.44	7.45	8.16	7.69	7.82	7.80	8.73
		Spec. Con.	320	355	406	461	458	455	574
8	09/10/88	pH	7.35	7.42	8.20	8.90	8.65	8.69	8.59
		Spec. Con.	327	346	453	444	441	441	474

TABLE NO. 3.5-21 (Cont.)

Cycle	Date	Parameter	Till			Sandstone			Saprolite
			West	Central	East	West	Central	East	
9	09/15/88	pH	7.23	7.32	8.04	9.18	9.00	8.93	8.65
		Spec. Con.	339	360	439	412	410	410	473
10	09/20/88	pH	7.20	7.31	7.98	9.16	8.89	8.94	8.65
		Spec. Con.	344	360	452	415	410	404	489
11	09/25/88	pH	7.36	7.36	8.06	9.14	8.92	8.94	8.73
		Spec. Con.	337	362	463	412	406	401	492
12	09/30/88	pH	7.44	7.50	8.08	9.11	8.86	8.92	8.70
		Spec. Con.	343	870	468	424	413	409	505
13	10/05/88	pH	7.29	7.57	8.11	9.17	8.95	8.95	8.66
		Spec. Con.	339	376	478	425	410	402	501
14	10/10/88	pH	7.47	7.70	8.13	9.13	9.00	8.78	8.68
		Spec. Con.	339	360	478	426	410	408	502
15	10/15/88	pH	7.40	7.93	8.04	9.03	8.87	8.84	8.70
		Spec. Con.	347	363	492	436	415	415	529
16	10/20/88	pH	7.60	8.05	8.07	9.15	8.87	8.93	8.69
		Spec. Con.	344	358	489	442	413	413	535

UNITS: pH - standard units
Spec. Con. - umhos/cm

TABLE NO. 3.5-22

Concentrations of Selected Parameters in Saturated Till, Sandstone, and Saprolite Leachate

Sandstone Saturated Leachate Concentrations

CYCLE 1

Parameter	Units	West	Central	East
Al	ug/L	4,540	617	1,370
Cr	ug/L	42	5	7
Cu	ug/L	210	<10	22
Fe	ug/L	5,300	400	2,533
Mn	ug/L	92	41	180
Ti	ug/L	344	5	63
SO4	mg/L	<5	10	17
Alk	mg/L	14	18	16

CYCLE 2

Parameter	Units	West	Central	East
Al	ug/L	7,290	1,220	3,833
Cr	ug/L	59	<3	<3
Cu	ug/L	290	13	48
Fe	ug/L	7,500	550	5,100
Mn	ug/L	92	39	460
Ti	ug/L	756	44	177
SO4	mg/L	9	15	9
Alk	mg/L	18	23	23

TABLE NO. 3.5-22 (Cont.)

CYCLE 4

Parameter	Units	West	Central	East
Al	ug/L	811	240	338
Cr	ug/L	4	--	--
Cu	ug/L	35	<10	<10
Fe	ug/L	720	130	550
Mn	ug/L	22	<11	43
Ti	ug/L	61	<4	13
SO4	mg/L	11	7	17
Alk	mg/L	28	37	29

CYCLE 8

Parameter	Units	West	Central	East
Al	ug/L	1,190	165	324
Cr	ug/L	6	--	--
Cu	ug/L	45	<10	<10
Fe	ug/L	1,200	200	600
Mn	ug/L	23	<11	46
Ti	ug/L	102	<4	<4
SO4	mg/L	13	13	13
Alk	mg/L	36	36	57

CYCLE 16

Parameter	Units	West	Central	East
Al	ug/L	430	420	510
Cr	ug/L	<3	<3	<3
Cu	ug/L	40	21	9
Fe	ug/L	530	300	1,100

TABLE NO. 3.5-22 (Cont.)

Parameter	Units	West	Central	East
Mn	ug/L	<11	23	89
Ti	ug/L	9	5	27
SO4	mg/L	11	10	11
Alk	mg/L	27	29	29

Till Saturated Leachate Concentrations

CYCLE 1

Parameter	Units	West	Central	East
Al	ug/L	963	5,040	845
Cr	ug/L	4	9	5
Cu	ug/L	27	27	<10
Fe	ug/L	710	3,300	650
Mn	ug/L	23	47	<11
Ti	ug/L	38	326	34
SO4	mg/L	10	<5	9
Alk	mg/L	32	37	50

CYCLE 2

Parameter	Units	West	Central	East
Al	ug/L	472	1,030	459
Cr	ug/L	<3	<3	<3
Cu	ug/L	17	13	10
Fe	ug/L	400	860	420
Mn	ug/L	22	19	<11
Ti	ug/L	16	51	6
SO4	mg/L	98	12	9
Alk	mg/L	18	37	50

TABLE NO. 3.5-22 (Cont.)

CYCLE 4

Parameter	Units	West	Central	East
Al	ug/L	379	299	203
Cr	ug/L	--	--	--
Cu	ug/L	20	<10	<10
Fe	ug/L	--	240	--
Mn	ug/L	--	--	--
Ti	ug/L	--	<4	--
SO4	mg/L	9	6	7
Alk	mg/L	18	28	57

CYCLE 8

Parameter	Units	West	Central	East
Al	ug/L	211	108	1,360
Cr	ug/L	--	--	--
Cu	ug/L	21	<10	13
Fe	ug/L	--	110	--
Mn	ug/L	--	--	--
Ti	ug/L	--	<4	--
SO4	mg/L	9	6	8
Alk	mg/L	21	33	90

CYCLE 16

Parameter	Units	West	Central	East
Al	ug/L	340	580	190
Cr	ug/L	<3	<3	<3
Cu	ug/L	50	22	17
Fe	ug/L	170	410	110
Mn	ug/L	35	<11	<11

TABLE NO. 3.5-22 (Cont.)

Parameter	Units	West	Central	East
Ti	ug/L	<4	32	4
SO4	mg/L	13	10	10
Alk	mg/L	36	29	87

TABLE NO. 3.5-22 (Cont.)

Saprolite Saturated Leachate Concentrations

Parameter	Units	CYCLE 1	CYCLE 2	CYCLE 4	CYCLE 8	CYCLE 16
Al	ug/L	321	756	68	83	93
Cu	ug/L	35	31	14	24	31
Fe	ug/L	180	300	<55	75	<55
Mn	ug/L	55	39	42	37	<11
Ti	ug/L	357	--	<4	<4	--
SO4	mg/L	30	36	39	42	42
Alk	mg/L	80	85	89	140	170

TABLE NO. 3.5-23

Calculated Quantities of Selected Parameters Leached From the Saturated Till, Sandstone, and Saprolite Samples

Saturated Till Quantities Leached

CYCLE 1

Parameter	Units	West	Central	East
Al	ug/g	0.44	2.73	0.39
Cr	ug/g	1.8x10(-3)	4.9x10(-3)	2.3x10(-3)
Cu	ug/g	0.012	0.015	<4.6x10(-3)
Fe	ug/g	+0.82	0.44	+0.85
Mn	ug/g	+0.11	+0.12	>+0.11
Ti	ug/g	0.018	0.18	<1.6x10(-3)
SO_4	mg/g	+1.4x10(-3)	>+3.3x10(-3)	+1.9x10(-3)
Alk	mg/g	5.1x10(-3)	9.0x10(-3)	0.013

CYCLE 2

Parameter	Units	West	Central	East
Al	ug/g	0.22	0.56	0.21
Cr	ug/g	<1.4x10(-3)	<1.6x10(-3)	<1.4x10(-3)
Cu	ug/g	7.8x10(-3)	7.0x10(-3)	4.6x10(-3)
Fe	ug/g	+1.15	+1.09	+1.19
Mn	ug/g	+0.13	+0.16	>+0.14
Ti	ug/g	7.4x10(-3)	0.028	2.8x10(-3)
SO_4	mg/g	0.038	+4.1x10(-4)	+3.1x10(-3)
Alk	mg/g	+2.7x10(-3)	7.0x10(-3)	0.011

TABLE NO. 3.5-23 (Cont.)

CYCLE 4

Parameter	Units	West	Central	East
Al	ug/g	0.17	0.16	0.093
Cr	ug/g	--	--	--
Cu	ug/g	9.2x10(-3)	<5.4x10(-3)	4.6x10(-3)
Fe	ug/g	--	+1.64	--
Mn	ug/g	--	--	--
Ti	ug/g	--	<2.2x10(-3)	--
SO_4	mg/g	+3.7x10(-3)	+4.6x10(-3)	+5.2x10(-3)
Alk	mg/g	+4.7x10(-3)	1.5x10(-4)	0.012

CYCLE 8

Parameter	Units	West	Central	East
Al	ug/g	0.097	0.058	0.62
Cr	ug/g	-- --	--	
Cu	ug/g	9.6x10(-3)	<5.4x10(-3)	6.0x10(-3)
Fe	ug/g	--	+1.92	--
Mn	ug/g	--	-- --	
Ti	ug/g	--	<2.2x10(-3)	--
SO_4	mg/g	+4.6x10(-3)	+5.4x10(-3)	+5.9x10(-3)
Alk	mg/g	+4.4x10(-3)	+4.6x10(-3)	0.026

TABLE NO. 3.5-23 (Cont.)

CYCLE 16

Parameter	Units	West	Central	East
Al	ug/g	0.16	0.31	0.087
Cr	ug/g	<1.4x10(-3)	<1.4x10(-3)	<1.4x10(-3)
Cu	ug/g	0.023	0.012	7.8x10(-3)
Fe	ug/g	+1.78	+1.97	+2.0
Mn	ug/g	+0.18	>+0.23	>+0.21
Ti	ug/g	<1.8x10(-3)	0.017	1.8x10(-3)
SO_4	mg/g	+3.6x10(-3)	+4.2x10(-3)	+6.4x10(-3)
Alk	mg/g	5.4x10(-3)	+2.3x10(-3)	0.023

1. Those quantities marked with a plus sign (+) denote quanities sorbed or retained by the samples.
2. All other quantities are leached or desorbed.

TABLE NO. 3.5-23 (Cont.)

Saturated Sandstone Quantities Leached

CYCLE 1

Parameter	Units	West	Central	East
Al	ug/g	2.85	0.19	0.33
Cr	ug/g	0.026	1.6x10(-3)	1.7x10(-3)
Cu	ug/g	0.13	<3.1x10(-3)	5.3x10(-3)
Fe	ug/g	1.75	+0.66	8.2x10(-3)
Mn	ug/g	+0.11	+0.72	+0.022
Ti	ug/g	0.22	1.6x10(-3)	0.015
SO_4	mg/g	>+5.1x10(-3)	+9.6x10(-4)	1.0x10(-3)
Alk	mg/g	+4.2x10(-3)	+9.4x10(-4)	+1.2x10(-3)

CYCLE 2

Parameter	Units	West	Central	East
Al	ug/g	4.57	0.38	0.92
Cr	ug/g	0.037	<9.4x10(-4)	<7.2x10(-4)
Cu	ug/g	0.18	4.1x10(-3)	0.011
Fe	ug/g	3.13	+0.62	0.62
Mn	ug/g	+0.11	+0.073	0.045
Ti	ug/g	0.47	0.014	0.042
SO_4	mg/g	+2.6x10(-3)	6.1x10(-4)	+9.4x10(-4)
Alk	mg/g	+1.7x10(-3)	6.3x10(-4)	5.2x10(-4)

TABLE NO. 3.5-23 (Cont.)

Parameter	Units	West	Central	East
		CYCLE 4		
Parameter	Units	West	Central	East
Al	ug/g	1.000	0.075	0.081
Cr	ug/g	2.5x10(-3)	--	--
Cu	ug/g	0.022	<3.1x10(-3)	<2.4x10(-3)
Fe	ug/g	+1.12	+0.79	+0.47
Mn	ug/g	+0.16	>+0.08	+0.055
Ti	ug/g	0.038	<1.2x10(-3)	3.1x10(-3)
SO_4	mg/g	+1.3x10(-3)	+1.9x10(-3)	9.8x10(-4)
Alk	mg/g	4.6x10(-3)	5.0x10(-3)	2.0x10(-3)
		CYCLE 8		
Parameter	Units	West	Central	East
Al	ug/g	0.75	0.052	0.078
Cr	ug/g	3.8x10(-3)	--	--
Cu	ug/g	0.028	<3.1x10(-3)	<2.4x10(-3)
Fe	ug/g	+0.82	+0.73	+0.46
Mn	ug/g	+0.16	>+0.08	+0.054
Ti	ug/g	0.064	<1.2x10(-3)	<9.6x10(-4)
SO_4	mg/g	+4.9x10(-5)	+1.5x10(-5)	2.1x10(-5)
Alk	mg/g	9.6x10(-3)	4.7x10(-3)	8.7x10(-3)

TABLE NO. 3.5-23 (Cont.)

CYCLE 16

Parameter	Units	West	Central	East
Al	ug/g	0.27	0.13	0.12
Cr	ug/g	<1.9x10(-3)	<9.4x10(-4)	<7.2x10(-4)
Cu	ug/g	0.025	6.6x10(-3)	2.2x10(-3)
Fe	ug/g	+1.24	+0.70	+0.34
Mn	ug/g	>+0.16	+0.078	+0.044
Ti	ug/g	5.6x10(-3)	1.5x10(-3)	6.5x10(-4)
SO_4	mg/g	+1.3x10(-4)	+9.6x10(-4)	+4.6x10(-4)
Alk	mg/g	3.9x10(-3)	2.5x10(-3)	2.0x10(-3)

1. Those quantities marked with a plus sign (+) denote quantities sorbed or retained by the samples.
2. All other quantities are leached or desorbed.

TABLE NO. 3.5-23 (Cont.)

Calculated Quantities of Selected Parameters Leached from the
Saturated Till, Sandstone, and Saprolite Samples
Saturated Saprolite Quantities Leached

PARAMETER	UNITS	CYCLE 1	CYCLE 2	CYCLE 4	CYCLE 8	CYCLE 16
Al	ug/g	0.13	0.31	0.028	0.034	0.038
Cu	ug/g	0.014	0.013	5.7x10(-3)	9.8x10(-3)	0.013
Fe	ug/g	+0.95	+1.03	>+1.25	+1.37	>+1.51
Mn	ug/g	+0.088	+0.10	+0.12	+0.13	>+0.17
Ti	ug/g	0.15	--	<1.6x10(-3)	<1.6x10(-3)	--
SO_4	mg/g	6.9x10(-3)	8.7x10(-3)	9.3x10(-3)	9.8x10(-3)	9.2x10(-3)
Alk	mg/g	0.024	0.025	0.025	0.045	0.056

1. Those quantities marked with a plus sign (+) denote quantities sorbed or retained by the samples.
2. All other quantities are leached or desorbed.

bicarbonate during some of the cycles. The importance of these sorptions or retentions is that the concentrations of iron and manganese released to groundwater in contact with the backfilled waste rock will be reduced to background levels as the groundwater saturates the backfilled pit. In addition, the retention of the anions, sulfate and bicarbonate, will enhance the long-term retention of iron, manganese and other metals by the formation of stable secondary minerals.

During the transition from the wet/dry leaching to the saturated leaching, the amounts of leachable aluminum, chromium and titanium in the till composite leachates decreased. As the saturated leaching progressed, the quantities leached of each of these metals decreased further. The quantity of leached copper remained essentially the same during the transition, and, although the amounts of copper leached varied during the saturated cycles, there was little overall change in the quantity leached during the saturated cycles.

The quantities of aluminum, chromium, copper, and titanium leached from the sandstone composites increased during the transition from the wet/dry to the saturated leaching. The leached quantities of these metals then decreased during the saturated leachings.

The quantities of copper, titanium and sulfate leached from the saprolite increased during the transition between the wet/dry and saturated leachings and the quantity of aluminum remained about the same. During the saturated leachings, the quantities of aluminum, copper, and titanium leached from the saprolite decreased. The leached amounts of sulfate, however, increased as the saturated leachings progressed.

The pH and specific conductivity values measured during each of the saturated waste rock leachings are presented in Table No. 3.5-24. The data show that during the transition between the wet/dry and saturated leachings of the waste rock chips the pH of the WR-3 through WR-5 leachate remained the same while the pH of the WR-1 and WR-2 leachate increased by approximately one-half a standard unit. During the course of the saturated leaching, the pH of the WR-1 through WR-3 remained unchanged and the pH of WR-4 and WR-5 decreased approximately one, and one-half, units, respectively.

During the transition between the two leaching tests, the leachate pH of all of the powered waste rock composites increased between one-half and one standard units. As the saturated leaching progressed, the leachate pH of WR-1 remained the same. The leachate pHs of the other waste rock samples increased between one and three units.

Concentration of selected parameters in saturated waste rock leachate are presented in Table No. 3.5-25 and calculated quantities of the parameters are also presented in Table

TABLE NO. 3.5-24

pH and Specific Conductivity Values for the Saturated Leaching of the Waste Rock Samples

Cycle	Date	Parameter	Rock Chips					Rock Powder				
			WR - 1	WR - 2	WR - 3	WR - 4	WR - 5	WR - 1	WR - 2	WR - 3	WR - 4	WR - 5
1	08/06/88	pH	8.00	6.71	5.95	5.41	3.80	8.67	7.00	7.65	7.48	5.58
		Spec. Con.	469	373	511	569	604	293	291	310	313	307
2	08/11/88	pH	7.65	6.41	5.80	4.63	3.58	7.78	7.27	7.75	7.31	7.15
		Spec. Con.	497	384	540	598	655	445	432	425	448	435
3	08/16/88	pH	8.00	6.65	5.83	4.50	3.70	8.25	8.00	8.10	8.20	8.30
		Spec. Con.	506	400	543	609	655	424	446	421	427	445
4	08/21/88	pH	7.85	6.46	5.65	4.28	3.56	8.07	7.98	8.25	8.15	8.40
		Spec. Con.	531	414	571	651	680	439	459	420	441	488
5	08/26/88	pH	8.08	6.70	6.07	4.38	3.70	8.80	8.50	8.58	8.69	8.93
		Spec. Con.	546	430	572	662	697	431	430	430	432	433
6	08/31/88	pH	7.83	6.50	5.94	4.38	3.63	8.82	8.43	8.15	8.42	8.85
		Spec. Con.	558	435	580	671	683	446	438	432	435	453
7	09/06/88	pH	7.99	6.82	5.56	4.38	3.43	8.22	7.87	7.90	8.10	8.47
		Spec. Con.	550	442	693	789	710	460	443	437	445	471
8	09/10/88	pH	7.80	6.34	5.84	4.28	3.36	8.60	8.30	8.35	8.40	8.63
		Spec. Con.	592	450	604	708	755	483	460	443	454	483
9	09/15/88	pH	8.07	6.55	5.88	4.29	3.41	8.82	8.48	8.50	8.66	8.98
		Spec. Con.	575	451	586	687	777	413	395	395	400	433
10	09/20/88	pH	7.95	6.44	5.89	4.30	3.38	8.62	8.31	8.40	8.51	8.60
		Spec. Con.	580	461	603	706	808	441	397	392	401	468

TABLE NO. 3.5-24 (Cont.)

Cycle	Date	Parameter	Rock Chips					Rock Powder				
			WR - 1	WR - 2	WR - 3	WR - 4	WR - 5	WR - 1	WR - 2	WR - 3	WR - 4	WR - 5
11	09/25/88	pH	8.03	6.51	5.96	4.36	3.40	8.70	8.38	8.47	8.54	8.52
		Spec. Con.	598	469	610	727	844	464	406	395	404	488
12	09/30/88	pH	7.94	6.42	6.04	4.51	3.54	8.56	8.37	8.48	8.52	8.53
		Spec. Con.	591	479	636	781	892	475	413	397	408	535
13	10/05/88	pH	8.14	6.75	6.08	4.48	3.47	8.68	8.40	8.58	8.54	8.54
		Spec. Con.	609	484	660	785	910	535	427	406	411	569
14	10/10/88	pH	8.20	6.75	6.12	4.44	3.42	8.89	8.48	8.60	8.50	8.82
		Spec. Con.	622	494	666	786	972	497	435	407	424	546
15	10/15/88	pH	8.11	6.36	5.97	4.31	3.28	8.73	8.40	8.46	8.44	8.62
		Spec. Con.	628	494	701	816	1,025	535	442	415	426	568
16	10/20/88	pH	8.11	6.36	6.04	4.35	3.29	8.65	8.55	8.63	8.62	8.93
		Spec. Con.	655	513	688	841	1,070	580	439	415	424	580

UNITS: pH - standard units
Spec. Con. - umhos/cm

TABLE NO. 3.5-25

Concentrations of Selected Parameters in Saturated Waste Rock Leachate

WR-1 Saturated Quantities Leached

Parameter	Units	Rock Chips					Rock Powder				
		Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16	Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16
Al	ug/L	73	35	73	74	130	742	904	85	46	80
Cu	ug/L	17	18	<10	24	38	22	<20	--	--	15
Fe	ug/L	81	<55	--	--	<55	1,200	1,200	840	160	<110
Mn	ug/L	32	34	--	--	34	34	<4	--	--	<22
Zn	ug/L	35	<11	--	--	<11	62	74	22	<22	<22
SO4	mg/L	48	55	60	75	92	15	20	14	16	140
Alk	mg/L	78	82	87	130	130	--	--	--	--	--

WR - 2 Saturated leachate Concentrations

Parameter	Units	Rock Chips					Rock Powder				
		Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16	Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16
Al	ug/L	48	31	40	31	92	392	476	192	87	110
Cu	ug/L	230	250	230	340	460	270	40	<20	<20	31
Fe	ug/L	<55	<55	--	--	<55	500	840	340	160	<110
Mn	ug/L	270	250	290	340	440	320	6	--	--	<22
Zn	ug/L	180	<11	190	210	220	750	60	26	<22	<22
SO_4	mg/L	49	65	70	76	110	50	24	38	21	<100
Alk	mg/L	<10	<10	<10	<10	<10	--	--	--	--	--

TABLE NO. 3.5-25 (Cont.)

Concentrations of Selected Parameters in Saturated Waste Rock Leachate

WR - 3 Saturated Leachate Concentrations

Parameter	Units	Rock Chips					Rock Powder				
		Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16	Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16
Al	ug/L	41	46	18	24	69	627	262	78	62	69
Cu	ug/L	7,200	6,800	7,200	6,900	5,000	41	60	<20	<20	34
Fe	ug/L	69	64	--	--	<55	750	680	140	150	<110
Mn	ug/L	650	690	780	900	1,100	28	16	--	--	<22
Zn	ug/L	12,000	12,000	--	--	11,000	110	136	32	30	26
SO_4	mg/L	120	190	150	190	210	39	50	15	17	<50
Alk	mg/L	<10	<10	<10	<10	<10	--	--	--	--	--

WR - 4 Saturated Leachate Concentrations

Parameter	Units	Rock Chips					Rock Powder				
		Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16	Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16
Al	ug/L	272	335	831	290	330	443	146	71	124	120
CU	ug/L	16,000	14,000	22,000	25,000	30,000	50	42	36	38	82
Fe	ug/L	1,200	1,100	490	500	<55	310	210	170	240	<110
Mn	ug/L	450	460	570	630	880	130	<4	--	--	< 22
Zn	ug/L	2,300	1,900	3,000	3,300	4,200	27	<11	30	<22	54
SO_4	mg/L	170	190	180	220	280	48	17	35	21	< 60
Alk	mg/L	<10	<10	<10	<10	<10	--	--	--	--	--

TABLE NO. 3.5-25

Concentrations of Selected Parameters in Saturated Waste Rock Leachate

WR - 5 Saturated Leachate Concentrations

Parameter	Units	Rock Chips					Rock Powder				
		Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16	Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16
Al	ug/L	1,000	954	751	820	2,000	489	--	106	38	59
Cu	ug/L	53,000	63,000	76,000	93,000	165,000	5,500	--	36	20	31
Fe	ug/L	3,100	14,000	11,000	310	440	100	--	<110	<110	<110
Mn	ug/L	1,100	1,100	1,400	1,700	3,000	110	--	<22	<22	<22
Zn	ug/L	370	400	450	530	830	120	--	<22	<22	<22
SO4	mg/L	190	200	210	220	400	66	21	23	24	43
Alk	mg/L	<10	<10	<10	<10	<10	--	--	--	--	--

No. 3.5-26. The calculations of the quantity of iron in the leachate samples of all of the waste rock composite (for all but a few cycles of the WR-5 rock chips column) revealed that iron is retained by the waste material, probably by the precipitation of one or more iron-bearing minerals. This is also the case for manganese but only when the pH of the leachate is greater than approximately 6.5. Bicarbonate was retained by all of the rock chips columns. Bicarbonate may also have been retained by the rock powder, but alkalinity was not quantitated in the rock powder leachate, so this was not determined.

A blank sample of synthetic groundwater was equilibrated and tested under the same conditions as all of the saturated waste samples. During the saturated leaching cycles, it was observed that a dark reddish-brown precipitate formed and collected within the centrifuge bottle containing the blank solution. The changes in the composition of the blank solution suggest that, in addition to the probable precipitation of the dark reddish-brown ferrihydrite (hydrous ferric oxide), calcium and magnesium carbonate also precipitate from solution.

When the saturated leaching tests were completed, the waste rock columns were carefully unpacked in order to check the chip surfaces for precipitates. Most of the chips within the WR-1 through WR-4 columns were covered with a thin dark reddish-brown precipitates which are probably ferrihydrite. The surfaces of the chips in the WR-5 column were covered with a light yellowish-brown precipitate, which is probably jarosite, a hydrous potassium ferric sulfate. The formation of jarosite is favored by low pH and high sulfate concentration, conditions which are met in the WR-5 chip column. Where individual pyrite grains are visible in the rock chips in all of the columns, they are partially or completely covered with ferrihydrite. When the columns were first charged, the pyrite grains were a bright brassy color.

Some of the rock chips in all of the waste rock columns contain the hydrous copper carbonate minerals azurite and malachite, which is the more common of the two. Some of the malachite grains in the WR-3 through WR-5 columns have epitaxial overgrowths of malachite on them. The copper concentrations in the leachate solutions in these columns are great enough to support the precipitation of this mineral (Kern and Weisbrod, 1967).

The precipitation of mineral phases within the waste rock columns suggests that the increased release of metals observed during the course of the saturated leaching tests will be initially limited by the solubility product of those minerals. Eventually the rate of diffusion of metals through these phases will govern the rate of metal release.

TABLE NO. 3.5-26

Calculated Quantities of Selected Parameters Leached from Saturated Waste Rock

WR-1 Saturated Quantities Leached

Parameter	Units	Rock Chips					Rock Powder				
		Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16	Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16
Al	ug/g	0.038	0.018	0.038	0.039	0.018	7.42	9.04	0.85	0.46	0.80
Cu	ug/g	8.9×10^{-3}	9.4×10^{-3}	$<0.5 \times 10^{-3}$	1.3×10^{-3}	0.020	0.22	<0.22	----	----	0.15
Fe	ug/g	+1.27	>+1.38	----	----	>+1.67	+13.0	+13.0	+16.6	+23.4	>+23.9
Mn	ug/g	+0.13	+0.13	----	----	+0.17	+ 2.4	+ 2.7	----	----	>+ 2.5
Zn	ug/g	0.018	$<5.8 \times 10^{-3}$	----	----	$<5.8 \times 10^{-3}$	0.62	0.74	0.22	<0.22	<0.22
SO_4	mg/g	0.018	0.022	0.024	0.031	0.039	0.020	0.070	0.010	0.030	1.27
Alk.	mg/g	0.030	0.031	0.033	0.055	0.054	----	----	----	----	----
WR-2 Saturated Quantities Leached											
Al	ug/g	0.025	0.016	0.021	0.016	0.049	3.92	4.76	1.92	0.87	1.10
Cu	ug/g	0.12	0.13	0.12	0.18	0.24	2.70	0.40	<0.20	<0.20	0.31
Fe	ug/g	>+1.29	>+1.39	----	----	>+1.71	+20	+17	+22	+23	>+24
Mn	ug/g	2.3×10^{-3}	+0.018	+0.007	$+7.5 \times 10^{-4}$	0.042	0.50	+2.6	----	----	>+2.5
Zn	ug/g	0.095	0.10	0.10	0.11	0.12	7.50	0.60	0.26	<0.22	<0.22
SO_4	mg/g	0.019	0.027	0.029	0.032	0.049	0.37	0.11	0.25	0.08	<0.87
Alk.	mg/g	>+0.01	>+0.01	>+0.01	>+0.01	<+0.01	----	----	----	----	----
WR-3 Saturated Quantities Leached											
Al	ug/g	0.023	0.026	0.067	0.14	0.049	6.27	2.62	0.78	0.62	0.69
Cu	ug/g	4.07	3.85	4.07	3.90	2.83	0.41	0.60	<0.20	<0.20	0.34
Fe	ug/g	+1.37	+1.49	----	----	>+1.49	+17.5	+18.2	+24.6	+23.5	>+23.9
Mn	ug/g	0.21	0.23	0.26	0.32	0.42	+ 2.4	+ 2.5	----	----	>+2.5
Zn	ug/g	6.79	6.79	----	----	6.22	1.10	1.36	0.32	0.30	0.26
SO_4	mg/g	0.060	0.10	0.076	0.10	0.11	0.26	0.37	0.02	0.04	<0.37
Alk.	mg/g	>+0.01	>+0.01	>+0.01	>+0.01	>+0.01	----	----	----	----	----

TABLE NO. 3.5-26 (Cont.)

WR-4 Saturated Quantities Leached

Parameter	Units	Rock Chips					Rock Powder				
		Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16	Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16
Al	ug/g	0.13	0.16	0.41	0.14	0.16	4.43	1.46	0.71	1.24	1.20
Cu	ug/g	7.83	6.85	10.76	12.23	14.68	0.50	0.42	0.36	0.38	0.82
Fe	ug/g	+0.63	+0.76	+1.13	+1.21	>+1.49	+21.9	+22.9	+23.3	+22.6	>+22.9
Mn	ug/g	0.088	0.085	0.13	0.15	0.27	+1.4	>+2.6	----	----	>+2.5
Zn	ug/g	1.13	0.93	1.47	1.61	2.05	0.27	<0.11	<0.30	<0.20	0.54
SO_4	mg/g	0.077	0.086	0.081	0.10	0.13	0.35	0.040	0.22	0.080	<0.47
Alk.	mg/g	>+0.01	>+0.01	>+0.01	>+0.01	>+0.01	----	----	----	----	----
WR-5 Saturated Quantities Leached											
Al	ug/g	0.38	0.36	0.28	0.31	0.76	4.89	----	1.06	0.38	0.59
Cu	ug/g	20.1	23.9	28.9	35.3	62.7	55.0	----	0.36	0.20	0.31
Fe	ug/g	0.23	4.3	3.10	+1.03	+1.04	+24.0	----	>+24	>+24	>+24
Mn	ug/g	0.32	0.31	0.41	0.52	1.01	+1.6	----	>+2.5	>+2.5	>+2.5
Zn	ug/g	0.14	0.15	0.17	0.20	0.32	1.20	----	<0.22	<0.22	<0.22
SO_4	mg/g	0.067	0.071	0.074	0.078	0.14	0.53	0.080	0.10	0.11	0.30
Alk.	mg/g	>+4.2x10^{-3}	>+4.7x10^{-3}	>+5.3x10-3	>+5.8x10^{-3}	>+6.2x10^{-3}	----	----	----	----	----

The quantities of metals leached from the rock chip columns tended to increase during the transition from wet/dry to saturated leaching. During the saturated cycles, the quantities leached continued to increase. Similar observations can be made in a general sense, with regard to the waste rock powder column tests. These saturated leaching studies demonstrated what could occur within the pit when the backfilled material comes in contact with groundwater. If no lime is added to the backfilled Type II material, then release of some metals will occur. The actual quantity of metals released will be a partial function of the solubility products of several secondary minerals. It has been shown previously that the addition of lime to the waste rock when it is returned to the pit will substantially decrease the concentration of iron and copper in the water in contact with the waste rock. Although the lime treatment had little effect on the manganese and sulfate concentration, the saturated leaching studies show that these substances will be retained by the waste rock without any treatment. Therefore, based on the test results no significant quantities of copper, iron, manganese, or sulfate will be released from the backfilled pit.

3.5.6.3.4 Soil Sorption

The objective of this study was to evaluate the capacity of the soils beneath the Type I waste storage site (KWR soils) and the underlying till to sorb, or retain, leachate released by the Type I materials. In addition, samples of sandstone and saprolite were also reacted with the leachate in order to determine how they, in addition to the till, might react to site-generated leachate within the stockpile.

Leachate formed from a till composite was generated following the method included in Appendix 3.5-R. The method of sample equilibration is also included in Appendix 3.5-R, along with the laboratory analyses of the final equilibrated solutions. A summary of the results of the equilibration of iron and copper is presented in Table No. 3.5-27.

The reactions between the soils and iron and copper differed for each type of material. When high concentrations of iron and copper were reacted with till samples, the till sorbed or retained some of the iron and copper from the equilibrating solutions. At lower concentrations the till desorbed or released iron and copper. It appears that the topsoil reacted in similar fashion, but the quantities sorbed were less and desorbed greater than those by the till.

The sandstone samples desorbed iron, copper, and chromium for all leachate compositions. The behavior of the sandstone was predictable based on the leaching studies. The saprolite material desorbed iron under all tested conditions. However, the saprolite sorbed copper at high copper concentration and desorbed it at lower concentrations of applied copper.

TABLE NO. 3.5-27

Calculated Gains (+) and/or Losses (-) of Iron and Copper by Equilibrated Topsoil and Overburden Samples

Equilibrating Solution (ug Fe/L)	Topsoil		Till		Sandstone		Saprolite	
	Final Solution (ug/L)	Soil Gain/Loss (ug/g)	Final Solution (ug/L)	Soil Gain/Loss (ug/g)	Final Solution (ug/L)	Soil Gain/Loss (ug/g)	Final Solution (ug/L)	Soil Gain/Loss (ug/g)
9,400	9,500	~	3,900	+48.3	18,000	-56.1	12,000	-19.2
4,700	8,600	-36.3	2,400	+19.7	11,000	-44.4	9,600	-37.1
2,350	3,800	-13.9	2,300	~	7,100	-34.1	9,100	-49.8
940	3,700	-27.3	1,700	-7.0	9,600	-63.7	6,700	-41.0
0	2,700	-27.0	1,400	-12.7	9,900	-72.6	9,100	-67.1
(ug Cu/L)								
50	31	+0.19	23	+0.24	430	-2.81	35	+0.11
25	20	+0.047	19	+0.051	250	-1.59	25	~
12.5	<10	+ ?	18	-0.050	190	-1.27	17	-0.033
5	<10	?	12	-0.064	250	-1.80	24	-0.14
0	<10	?	10	-0.091	250	-1.83	47	-0.35

Several of the project groundwater monitoring wells are screened in the till. One of these wells, MW-1005, had variable but unusually high (several thousand ug/l) concentrations of iron in the well water when compared to other parts of the state, but is typical for the local area. Several wells near the site, also screened in the till, have been reported to contain high concentrations of iron in the water (Hindall, 1979). The results of the sorption study indicate that the till will naturally support elevated concentrations of iron in groundwater (see final solution concentrations in Table No. 3.5-27). Apparently this behavior is duplicated in the field in at least some of the surrounding area. The result of the retention of iron and copper by the topsoil and till samples is that the water leaving the till and entering the groundwater is expected to contain concentrations of iron and copper equivalent to those found in the on-site monitoring wells.

3.5.6.3.5 Extraction Procedure Toxicity

Extraction procedure toxicity for eight metals have been determined for the powdered waste rock samples WR-1 through WR-5. The standard U.S. EPA procedure was used and the extracts were analyzed for arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver. The results of the analyses, included in Appendix 3.5-R, indicate that none of the waste rock would be classified as hazardous.

3.5.6.3.6 Radiochemistry

In 1978, Kennecott staff conducted a thorough study of ore and waste rock core samples in order to determine if any of them were radiation emitters. All Flambeau drill cores were examined for general radiation using a Model 111B scintillation counter. All resulting readings were within the normal background count range of 0.005 to 0.015 MR/HR.

Five composite samples made from 14 mill bench test samples were prepared in 1980. These composite samples were analyzed for Gross Alpha, Gross Beta, and Radium-226 by Eberline Laboratories (Albuquerque, NM). The results of these analyses, included in Appendix 3.5-R, indicate that the radioactivity in the ore from the Flambeau deposit is within normal background ranges for Precambrian bedrock.

The results of the bulk chemical analyses of the waste rock samples indicate that the uranium content of these materials is less than microgram per gram (see Appendix 3.5-O). At these uranium concentrations, it would be expected that only very low level or background radiation would be emitted. Also, the concentration of radium-226, a daughter product of uranium decay, would be expected to be very low.

3.5.6.3.7 Characterization of Wastewater Treatment Plant Lime Sludge and Settling Pond Polymer Solids

The wastewater treatment plant for the proposed project will treat contact water for acid neutralization and to remove metals. The treatment process will produce a treated effluent that will be discharged to the Flambeau River, and a lime sludge that will be placed on the Type II stockpile.

Runoff from the Type I stockpile will be directed to a series of settling ponds for sediment removal prior to discharge to the Flambeau River. At times it may be necessary to add polymer and possibly lime to the runoff to assist in removing colloids. These colloids may contain trace amounts of metals.

Bench test studies were completed to demonstrate the adequacy and efficiency of the wastewater treatment plant process design, and the efficiency of polymer addition to the Type I runoff. During the studies, samples of lime sludge from the wastewater treatment bench test and samples of settled colloids from the settling pond bench test were chemically characterized. These samples were analyzed for arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, zinc, and iron. The results of these analyses, along with those of the test supernatants and raw wastewaters, are included in Appendix B of the Kennecott Flambeau Project *Preliminary Engineering Report for the Wastewater Treatment Facilities* (March 1989).

One result of the bench test studies was that the solids content of both the wastewater treatment plant sludge and polymer solids was less than one percent. This occurrence is not uncommon in bench scale testing. While the solids content in the bench test study was less than what would be expected during full-scale operation, the bench test sludge analyses are considered to be reasonable approximations of the composition of the sludge and solids that will result from actual operations. In the wastewater treatment plant, thickeners have been included in the process to bring the solids content of sludge to 25 percent.

Table No. 3.5-28 compares the test results of the raw wastewater to those for the wastewater treatment plant lime sludge on a weight-per-weight basis. The derivation of the values is shown in the table included in Appendix 3.5-R. As expected, the quantities of metals in the sludge exceed those in the raw wastewater due to concentration in the treatment process.

Lime sludge at 25 percent solids will be trucked from the wastewater treatment plant and spread on the material within the Type II stockpile. The hydroxides, oxyhydroxides, and sulfates which make up the sludge are soluble under acidic conditions. Since the Type II stockpile is expected to be acidic, the applied sludge will probably dissolve. The concentrations of the metals released by the dissolution of the lime sludge will

TABLE NO. 3.5-28

Quantities of Metals Leached From the Semi-Massive Waste Rock Sample (WW-1) Compared with Those in the Wastewater Lime Sludge Produced From the Leachate

Parameter	Quantity of Metals Leachated (ug/g)	Quantity of Metals in Sludge (ug/g)
As	0.036	159
Cu	34.2	163,000
Hg	2.7×10^{-4}	1.5
Se	2.2×10^{-3}	<5
Ag	6.2×10^{-3}	37
Cd	0.034	165
Pb	0.10	37
Ni	0.030	130
Zn	8.74	45,000
Cr	5.1×10^{-3}	7.3

exceed the solubility products for several minerals that will be stable under the conditions that will be encountered within and on the stockpile. Since the sludge will be spread mainly on the central portion of the stockpile, the formation of insoluble and sparingly soluble oxyhydroxides and sulfates within the pile will be enhanced. These minerals will form as solubility products are exceeded due to the slow evaporation of water within the stockpile. A portion of the metals released from the dissolution of the lime sludge will be transported through the stockpile. These will be collected along the base of the stockpile and will be recycled back to the wastewater treatment facility.

When the Type II waste rock is backfilled into the pit, some of the secondary minerals that formed within the stockpile, especially the oxides and oxyhydroxides, will be stable. Others, such as the sparingly soluble sulfates, will slowly be transformed into stable oxides, oxyhydroxides and carbonates. The soluble hydrous sulfates, which will make up only a minor proportion of the secondary minerals, will dissolve. The dissolved minerals, along with the materials released as a result of the short-term leaching during backfilling of the waste rock, will slowly form new secondary minerals that will be in equilibrium with the groundwater within the crystalline bedrock. Therefore, materials in the sludge will form stable secondary minerals in both the stockpile and the backfilled open pit and will not be released to the groundwater.

Table No. 3.5-29 compares the results of the raw Type I runoff to those for the polymer solids on a weight-per-weight basis. The derivation of these values is also included in Appendix 3.5-R. Also as expected, the quantities of metals in the polymer solids exceeds those in the raw runoff.

Only a small amount of polymer solids is expected to be produced during the mining operation. They will be removed from the settling ponds along with accumulated sediments on an as-needed basis, and transported to the Type I stockpile where they will be spread on the till stored there. Past experience has shown that the polymers will physically break down to colloid-sized material when they are stored in an aerated environment. Since the solids will be stored on the stockpile till, and since the till contains numerous fine pores, the colloids will be trapped within these pores, thereby preventing their migration through the Type I stockpile. The application of the solids to the till will not measurably alter the bulk composition of the original till material. When the till is backfilled to the mine pit the colloids will be stable and will not release dissolved metals.

3.5.6.3.8 Quantitation and Distribution of Total Sulfur in the Waste Rock

The Flambeau deposit is a stratabound sulfide deposit (May 1977). In this type of deposit the zones of mineralization are

TABLE NO. 3.5-29

Quantities of Metals Leached (in Runoff) from the Till and Till/Saprolite Composites Compared with Those in the Polymer Sludge Produced from the Runoff

Parameter	Till Runoff - Series 1		Till Runoff-Series 2		Till/Saprolite Runoff	
	Runoff[1] (Raw)	Polymer[1] Sludge	Runoff[1] (Raw)	Polymer[1] Sludge	Runoff[1] (Raw)	Polymer[1] Sludge
As	5.9×10^{-3}	12	3.7×10^{-3}	16	5.6×10^{-3}	16
Cd	$<1.6 \times 10^{-3}$	<2.0	$<5.4 \times 10^{-3}$	<1.9	$<5.6 \times 10^{-3}$	<1.8
Cr	0.022	36	0.013	36	0.018	33
Cu	0.064	170	0.047	190	0.22	530
Pb	5.4×10^{-3}	19	3.2×10^{-3}	19	0.056	86
Hg	$<2.7 \times 10^{-4}$	<0.17	$<2.7 \times 10^{-4}$	<0.35	$<2.8 \times 10^{-4}$	<0.17
Ni	<0.016	22	<0.016	23	<0.017	21
Se	$<1.6 \times 10^{-3}$	0.62	$<1.6 \times 10^{-3}$	0.58	$<1.7 \times 10^{-3}$	0.54
Ag	$<2.1 \times 10^{-4}$	<10	<2.1 x 10	<10	6.1×10^{-4}	<10
Zn	0.036	58	0.024	72	0.083	170
Fe	0.011[2]	22[2]	7.0×10^{-3} [2]	23[2]	8.4×10^{-3} [2]	22[2]

1. ug/g unless otherwise noted.
2. mg/g

confined to specific strata or lithologic units. The Flambeau deposit was altered by a supergene process which enriched the copper content of the upper part of the mineralized zone and also depleted this altered part of much of the sulfur.

The quantity of pyritic sulfur in mining wastes is considered to be the determining factor in the acid production potential and leachability of these wastes (Nordstrom, 1982). In sulfide deposits, such as the Flambeau deposit, pyritic sulfur is essentially equivalent to total sulfur. A considerable data base has been compiled by Kennecott Mining Corporation. This data was collected as part of the rock assay program. Additional total sulfur analyses have been conducted on some previously unassayed core and a compilation of all of the total sulfur analyses is included in Appendix 3.5-S.

The release of sulfate and the subsequent production of acid normally occurs in exposed surficial (i.e. oxidizing) environments. It may occur via inorganic or biochemical reactions, or both. If the pH of the water is in the range of 2.0 to 3.5, the production of acid is greatly enhanced by microbial activity, especially by the bacteria *Thiobacillus thiooxidans* and *T. ferrooxidans* (Stevenson, 1986). It is, therefore, necessary to store wastes which have reaction pH near 3.5 in storage sites where the acid produced, plus consequent leached metals, can be collected and treated. The pH of WR-5 approached 3.5 during the wet/dry leaching study, while leachate from WR-1 tends to have near-neutral pH.

The total sulfur analyses of the waste rocks indicate that a wide range of sulfur concentrations exist within these rocks, ranging from less than 0.10 to more than 30 percent. There is, however, a strong bimodal distribution of sulfur within the waste rocks. Most of the rocks contain either less than 0.2 percent or more than 2 percent total sulfur.

Based upon the results of the acid production and leaching analyses of the waste rock, it was concluded that waste rock with a total sulfur content of less than one percent total sulfur could be stockpiled in the unlined Type I storage site. Waste rock containing more than one percent total sulfur will be stockpiled in the lined Type II storage site.

The combined distribution of stratabound sulfur and the supergene alteration zones were plotted on geologic cross sections in order to delineate the area of Type I and Type II waste rock. Three such sections are shown in Figure Nos. 3.5-23 through 3.5-25. Only a small amount, approximately two to three percent, of the waste rock contains sulfur concentrations in the range of one-half to two percent. The delineation of the division between Type I and Type II waste rock will be quite evident in the field. Based upon the plotted sulfur distributions, it is evident that nearly all (approximately 98

percent) of the Type I waste rock will be similar to the WR-1 waste rock composite. In addition, it is considered that most of the Type II waste rock will be similar to the WR-5 waste rock composite.

3.5.6.4 Conclusions

The results of the waste characterization studies have led to the development of five conclusions. They are as follows:

1. The temporary stockpiling of the topsoil, overburden, and waste rock can be accomplished using a combination of lined and unlined storage facilities.

2. These materials can be returned to the mine site as part of the reclamation activities. This can be accomplished in a manner such that the groundwater and surrounding environment will not be significantly impacted.

3. It has been determined that none of the waste rock material is hazardous in terms of the EP Toxicity Test for the eight target metals.

4. Neither the ore nor the waste rock are emitters of radiation. Neither the ore nor the waste rock contain more than trace concentrations of uranium.

5. The baseline concentration of metals and sulfate has been established for all of the materials, including those that occur beneath the unlined stockpiles.

The above-grade storage of waste materials will be in three sites. One will be an unlined site which will store the topsoil. Another will be designated the Type I storage site; it will contain the till, sandstone, saprolite, and waste rock which contain less than one percent total sulfur. The third site will be lined and will contain the saprolite and waste rock which contain more than one percent total sulfur.

Precipitation which contacts the Type II waste rock will be collected and treated in order to remove metals and sulfate from this water prior to its discharge to the Flambeau River.

The tests of the waste rock acid production and leachability were performed on materials of two different grain sizes. These sizes were chosen to represent truly "worst case" scenarios. The very reactive powdered waste rock will represent approximately two to three percent of the fresh waste rock when it is first added to the stockpiles. As weathering proceeds and trucks compress the rock, more fine-grained material will be formed (Whiting, 1985). It is estimated that not more than ten percent, by volume, of the waste will eventually be fine-grained.

Both weathering and leaching are surface phenomena. Smaller particles have a greater surface area per unit weight than larger particles. The greater the surface area of rock particles, the greater will be the leachability of the materials within the particles (Krauskopf, 1972). The sizes of the chips used in the previously described waste rock evaluation are considered to represent the smallest-sized particles that preserve the prominent lithologic layering observed in the samples. The average-sized rock fragment stockpiled in the storage site is expected to be about one cubic foot. The proportion of exposed sulfide grains will be considerably less for the larger fragments than for those used in the tests.

The wet/dry leaching experiments also overestimated the leachate generation since the leaching columns were constructed to promote free drainage. In typical waste rock stockpiles, the quantity and speed of drainage is considerably less (Whiting, 1985). It is conservatively estimated that the actual quantities of metals and sulfate leached from the stockpiled waste rock will be less than one-tenth of those measured in the laboratory.

It is expected that the concentration of metals that exfiltrate from the base of the unlined storage sites will be considerably reduced before the water bearing those metals reaches the groundwater. Most metals that form ionized cationic species, such as copper, iron, and manganese, are retained by soils through sorption or precipitation reactions (Ellis, *et al*, 1983). The previously discussed soil sorption study demonstrated that the topsoil and till that is located beneath the Type I storage site has the capacity to sorb, or retain, significant quantities of copper and iron. This was especially true when concentrations of these metals were greater than those found within the groundwater monitored at the site. It is not expected that sulfate concentrations would be reduced based upon these studies and upon reported studies conducted elsewhere (Mehlich, 1981).

Overburden materials will be placed in the Type I storage area before waste rock is added to the area. *In situ* sorption, or retention, of metals can be enhanced by stockpiling the till material first. The sandstone material should be added on top of the till so that the till can retain the metals released by this leachable sandstone. The sandstone at the Flambeau site is especially leachable, probably due to the occurrences of the widely distributed patches of black, amorphous, metal-bearing material within it (for data, refer to Appendix 3.5-R).

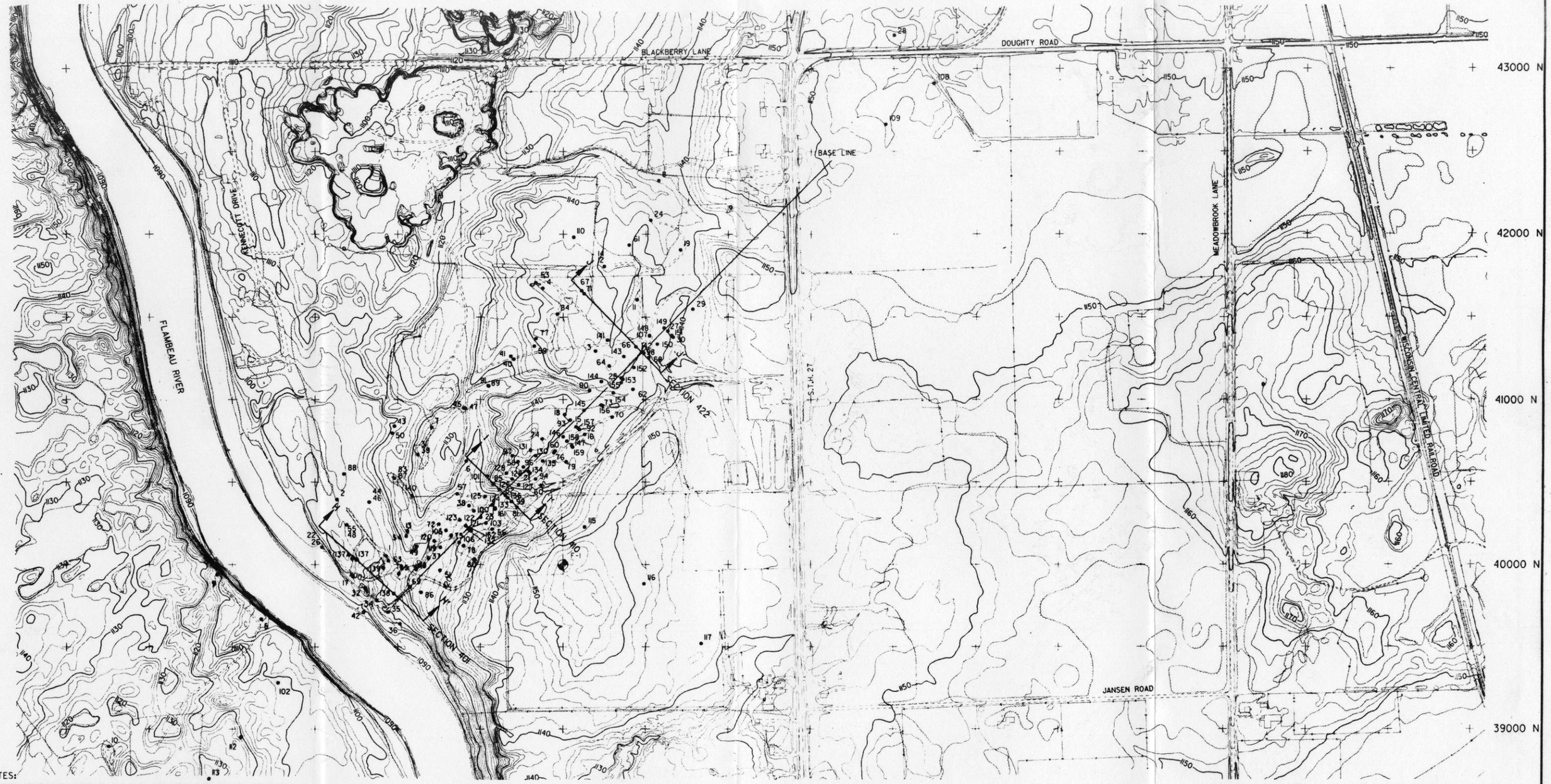
The backfilling of the open pit should begin with the emplacement of the Type II material in a manner such that contact water can be collected and treated during the backfilling. Lime should be added to the rock in order to maintain a pH of 6.5 to 7.0 in this contact water while the pit

is being filled. The Type I waste rock should be backfilled next, followed by the Type I saprolitic material. Even though the saprolite is chloritic (Appendix 3.5-R), it does have the ability to sorb iron and manganese (see Section 3.5.6.3.3.2). In addition, the saprolite will retard the transfer of water between the crystalline bedrock and the overlying till due to its low permeability. The permeability will become even lower as the saprolite is spread and consequently compressed.

The upper part of the pit should be filled with the sandstone, followed by the till, and lastly with the topsoil. Careful replacement of overburden has resulted in the creation of reclaimed sites with favorable soil environments, especially where lime and fertilizer have been added to the topsoil (Singh *et al*, 1982).

Figures for Section 3.5

37000 E | 38000 E | 39000 E | 40000 E | 41000 E | 42000 E | 43000 N | 42000 N | 41000 N | 40000 N | 39000 N



NOTES:

1. SITE LOCATION: SECTIONS 9, 10, 15 & 16, T34N, R6W, RUSK COUNTY, WISCONSIN.
2. TOPOGRAPHIC BASE MAP PREPARED FROM AERIAL SURVEY BY SURDEX CORPORATION, CHESTERFIELD, MISSOURI. DATE OF PHOTOGRAPHY - APRIL 24, 1970. ROADS, TREES AND BUILDINGS WERE UPDATED AS PER AERIAL PHOTOGRAPH TAKEN BY MARKHURD CORPORATON, MINNEAPOLIS, MINNESOTA. DATE OF PHOTOGRAPHY - SEPTEMBER 14, 1987.
3. ELEVATIONS BASED ON MEAN SEA LEVEL DATUM. CONTOUR INTERVAL IS TWO FEET.
4. HORIZONTAL DATUM BASED ON PROJECT SITE GRID SYSTEM. SITE GRID COORDINATES CORRELATION TO STATE PLANE COORDINATES DERIVED AS FOLLOWS:

SITE GRID COORDINATES CONTROL MONUMENT F-1	STATE PLANE COORDINATES
40000 N =	587,357.8087 N
40000 E =	1,713,516.1229 E

THE ANGULAR ROTATION FROM STATE PLANE BEARINGS TO SITE GRID BEARINGS IS 359°-13'-23" RIGHT WITH CONTROL POINT F-1 AS THE BASE POINT.

LEGEND

- 1100 — EXISTING CONTOUR
- EXISTING PAVED ROADWAY
- EXISTING TRAIL/GRAVEL SURFACE
- TREES AND/OR BRUSH
- FENCE
- F-1 CONTROL MONUMENT
- 110 DIAMOND DRILL HOLE LOCATION AND NUMBER

N

0 300' 600'
SCALE

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GEOSCIENCES & ENVIRONMENTAL MANAGEMENT DIVISION
GREEN BAY, WISCONSIN

FLAMBEAU PROJECT
LADYSMITH, WISCONSIN

KENNECOTT MINERALS COMPANY
155 MINERAL SQUARE
SALT LAKE CITY, UTAH
84112

FIGURE NO. 3.5-1
LOCATION MAP OF
DIAMOND DRILL HOLES
AND BEDROCK CROSS SECTIONS

MICROFILM | JOB
DRAWING NO. | REV.
DIVISION DRAWING NO.
SCALE | SEE BAR SCALE

REFERENCES DWG. NO.	DESCRIPTION

REFERENCES DWG. NO.	DESCRIPTION

NO.	DATE	REVISIONS	BY	CK'D	ENG'R	ENG'R MGR.

NO.	DATE	REVISIONS	BY	CK'D	ENG'R	ENG'R MGR.

	BY	DATE
PROJ. ENG'R		
MGR. PROCESS ENG'R		
ENG'R MGR.		

	BY	DATE
DESIGN		
DRAWN	MJD	3/89
CK'D	BJS	3/89
DES. ENG'R		
SECT ENG'R		

37000 E 38000 E 39000 E 40000 E 41000 E 42000 E 43000 E 44000 E 45000 E

43000 N 42000 N 41000 N 40000 N 39000 N

BLACKBERRY LANE DOUGHTY ROAD KENNECOTT DRIVE FLAMBEAU RIVER MEADOWBROOK LANE WISCONSIN CENTRAL LIMITED RAILROAD S.T.H. 27 JANSEN ROAD

A A' B B' C C' D D' E E' F F' G G'

PZ-1007S PZ-1006G PZ-1006 PZ-1006S PZ-1009G PZ-1009 PZ-1008G PZ-1008

OW-18 OW-16 OW-17 OW-45 OW-14 OW-15 OW-12 OW-10 OTW-34 OW-37 OW-36 OW-43 OW-9 PZ-1S PZ-1D OTW-29 OW-31 OW-42 OW-8 OW-41 OW-40 OW-39 OW-7 OW-6 OW-5 MW-1005P MW-1005 MW-1005S

MW-1002G MW-1002 MW-1003P MW-1003 MW-1004G MW-1004 MW-1004P MW-1000 MW-1000P MW-1001G MW-1001 MW-1001P

TW-K5 TW-K6 TW-K3 TW-K4 TW-K1 TW-K2 TW-K7 TW-K8

B-S5 B-R6 B-WC-3 ST-9-22 PZ-R7 PZ-K4P PZ-K4PP PZ-S4 B-SP1 B-WC-2 B-SP4 B-SP3 B-SP7 B-SP5 B-SP2 B-WC-1 B-SP6 B-R5 B-R4 B-R3 B-R2 B-R1 PZ-S1 PZ-S3 PZ-S2 PZ-K2S PZ-K2D PZ-K2SP PZ-SP8 B-RS11 B-RS10 B-RS9 B-RS8 B-RS7 B-RS6 B-RS5 B-RS4 B-RS3 B-RS2

ST-9-20 ST-9-3 ST-9-2 ST-9-1 ST-9-65 ST-9-66 ST-9-64 ST-9-63 ST-9-62 ST-9-61 ST-9-7 ST-9-60 ST-9-19 ST-9-59 ST-9-58 ST-9-57 ST-9-5 ST-9-24 ST-9-4 ST-9-8 ST-9-26 ST-9-27 ST-9-9 ST-9-10 ST-9-11 ST-9-12 ST-9-23A ST-9-23 ST-9-30 ST-9-13 ST-9-31 ST-9-32 ST-9-33 ST-9-34 ST-9-35 ST-9-36 ST-9-38 ST-9-39 ST-9-37 ST-9-42 ST-9-40 ST-9-41

NOTES:

1. SITE LOCATION: SECTIONS 9, 10, 15 & 16, T34N, R6W, RUSK COUNTY, WISCONSIN.
2. TOPOGRAPHIC BASE MAP PREPARED FROM AERIAL SURVEY BY SURDEX CORPORATION, CHESTERFIELD, MISSOURI. DATE OF PHOTOGRAPHY - APRIL 24, 1970. ROADS, TREES AND BUILDINGS WERE UPDATED AS PER AERIAL PHOTOGRAPH TAKEN BY MARKHURD CORPORATION, MINNEAPOLIS, MINNESOTA. DATE OF PHOTOGRAPHY - SEPTEMBER 14, 1987.
3. ELEVATIONS BASED ON MEAN SEA LEVEL DATUM. CONTOUR INTERVAL IS TWO FEET.
4. HORIZONTAL DATUM BASED ON PROJECT SITE GRID SYSTEM. SITE GRID COORDINATES CORRELATION TO STATE PLANE COORDINATES DERIVED AS FOLLOWS:

SITE GRID COORDINATES CONTROL MONUMENT F-1	STATE PLANE COORDINATES
40000 N =	587,357.8087 N
40000 E =	1,713,516.1229 E

THE ANGULAR ROTATION FROM STATE PLANE BEARINGS TO SITE GRID BEARINGS IS 359°-13'-23" RIGHT WITH CONTROL POINT F-1 AS THE BASE POINT.

LEGEND

- —1100— EXISTING CONTOUR
- EXISTING PAVED ROADWAY
- EXISTING TRAIL/GRAVEL SURFACE
- TREES AND/OR BRUSH
- FENCE
- F-1 CONTROL MONUMENT
- MW-1004 GROUNDWATER MONITORING WELL LOCATION AND NUMBER
- PZ-R5 / OW-39 PIEZOMETER LOCATION AND NUMBER
- SP SANDPOINT LOCATION AND NUMBER
- B-SP2 / ST-9-29 SOIL BORING LOCATION AND NUMBER
- TW-K6 / OWT-34 TEST WELL LOCATION AND NUMBER

N

0 300' 600' SCALE

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GREEN BAY, WISCONSIN

FLAMBEAU PROJECT
LADYSMITH, WISCONSIN

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1515 MINERAL SQUARE
SALT LAKE CITY, UTAH
84112

FIGURE NO. 3.5-2
LOCATION MAP OF GROUNDWATER MONITORING WELLS, PIEZOMETERS, TEST WELLS, BORINGS AND CROSS SECTIONS

MICROFILM | JOB
DRAWING NO. | REV.
DIVISION DRAWING NO.
SCALE SEE BAR SCALE

REFERENCES	DWG. NO.	DESCRIPTION

REFERENCES	DWG. NO.	DESCRIPTION

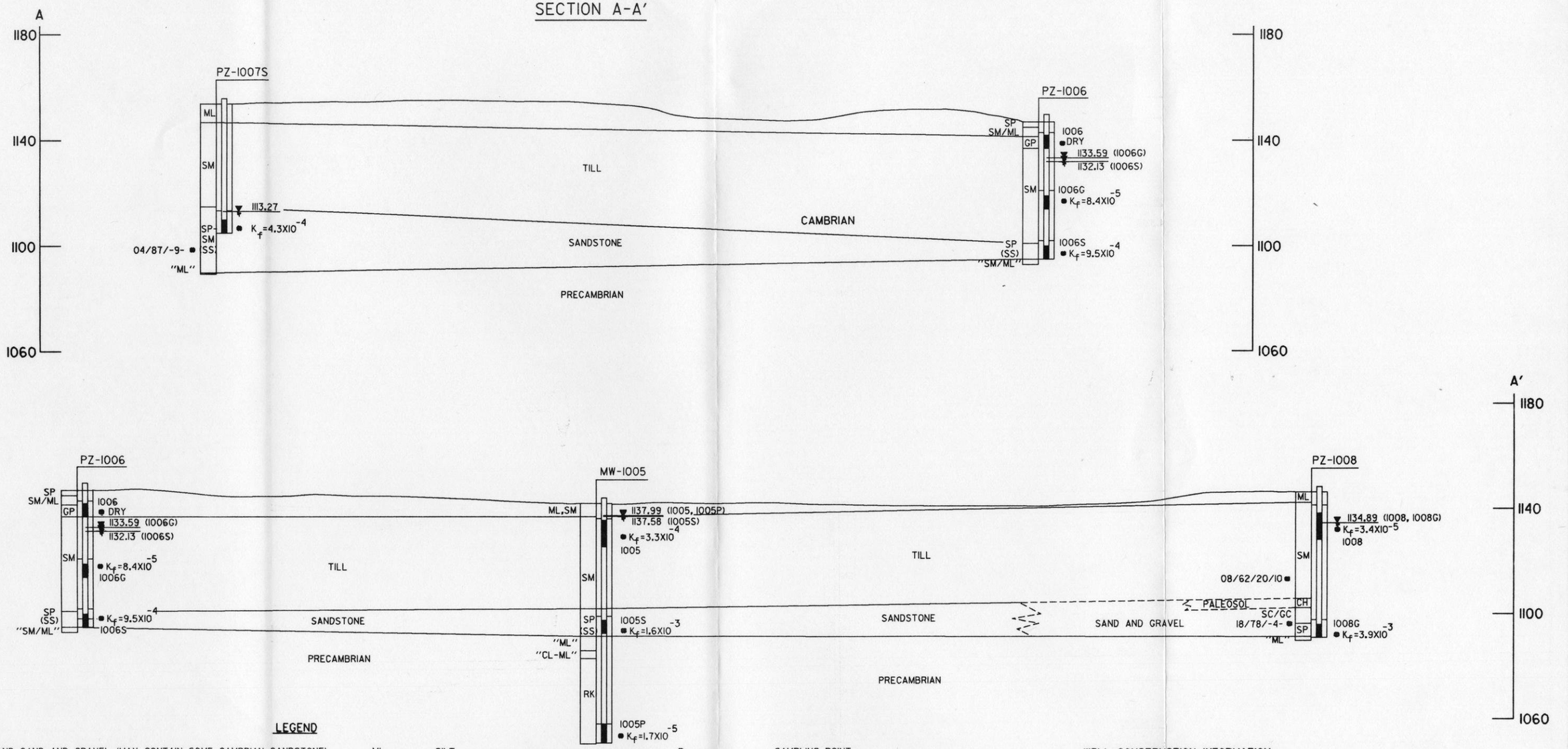
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NO.	DATE	REVISIONS	BY	CH'D	ENG'R	ENG'R MGR.

	BY	DATE
PROJ. ENG'R		
MGR. PROGRESS ENG'R		
ENG'R MGR.		

	BY	DATE
DESIGN		
DRAWN	MJO	3/89
CH'D	TSS	3/89
DES. ENG'R		
SECT. ENG'R		

SECTION A-A'



LEGEND

QUATERNARY

Qt	TILL, AND SAND AND GRAVEL (MAY CONTAIN SOME CAMBRIAN SANDSTONE)
SM	SILTY SAND
SW-SM	WELL GRADED SAND WITH SILT
SP	POORLY GRADED SAND
SP-SM	POORLY GRADED SAND WITH SILT
SW	WELL GRADED SAND
SP-SM, SW	POORLY GRADED SAND WITH SILT INTERBEDDED WITH WELL-GRADED SAND
SM,SP	SILTY SAND INTERBEDDED WITH POORLY GRADED SAND
SW,SM	WELL GRADED SAND INTERBEDDED WITH SILTY SAND
SM/ML	SILTY SAND/SILT
SC/SM	CLAYEY SAND/SILTY SAND
SC	CLAYEY SAND
SC-SM	SILTY-CLAYEY SAND
GW	WELL GRADED GRAVEL
GW-GM	WELL GRADED GRAVEL WITH SILT
GP	POORLY GRADED GRAVEL
GM	SILTY GRAVEL
SP,GP	POORLY GRADED SAND INTERBEDDED WITH POORLY GRADED GRAVEL
SM/GM	SILTY SAND/SILTY GRAVEL
SM,GW-GM	SILTY SAND INTERBEDDED WITH POORLY GRADED GRAVEL WITH SILT
GM/SM	SILTY GRAVEL/SILTY SAND

ML	SILT
CL-ML	SILTY CLAY
CL	LEAN CLAY
CL/ML	LEAN CLAY/SILT

CAMBRIAN

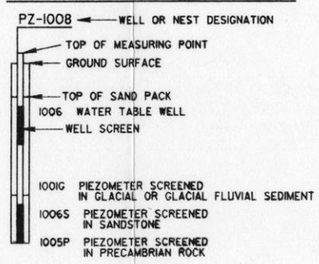
SS	SANDSTONE

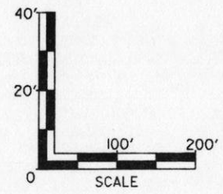
PRECAMBRIAN

RK	ROCK
Qtz	QUARTZ
(1a)	SERICITE-QUARTZ SCHIST
(2)	BIOTITE SCHIST
(3)	AUGEN SCHIST
(5)	METADACITE (VOLCANIC FLOW ROCK)
"ML"	ROCK THAT DISAGGREGATES TO SILT
"SM"	ROCK THAT DISAGGREGATES TO SILTY SAND
"GM"	ROCK THAT DISAGGREGATES TO SILTY GRAVEL
"CL/ML"	ROCK THAT DISAGGREGATES TO LEAN CLAY/SILT
"SM/ML"	ROCK THAT DISAGGREGATES TO SILTY SAND/SILT
"SM,ML"	ROCK THAT DISAGGREGATES TO INTERBEDS OF SILTY SAND AND SILT

- SAMPLING POINT
- LL/PL ATTERBERG LIMITS
- K_f=7.9X10^{-5} IN-FIELD PERMEABILITY VALUE (CM/SEC)
- K_L=4.0X10^{-9} LABORATORY PERMEABILITY VALUE (CM/SEC)
- 01/50/41/08 GRAVEL/SAND/SILT/CLAY PERCENTAGES
- 0/93/-7- GRAVEL/SAND/P200 PERCENTAGES
- 1113.27 AVERAGE WATER LEVEL (SEPT. 1987 TO NOV. 1988)
- CONTACTS-REASONABLY CERTAIN
- UNCERTAIN
- VERY UNCERTAIN

WELL CONSTRUCTION INFORMATION





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FLAMBEAU PROJECT
LADYSMITH, WISCONSIN

KENNECOTT MINERALS COMPANY
555 MINERAL SQUARE
SALT LAKE CITY, UTAH 8412

FIGURE NO. 3.5-3
GEOLOGIC CROSS SECTION
A-A'

REFERENCES	DWG. NO.	DESCRIPTION

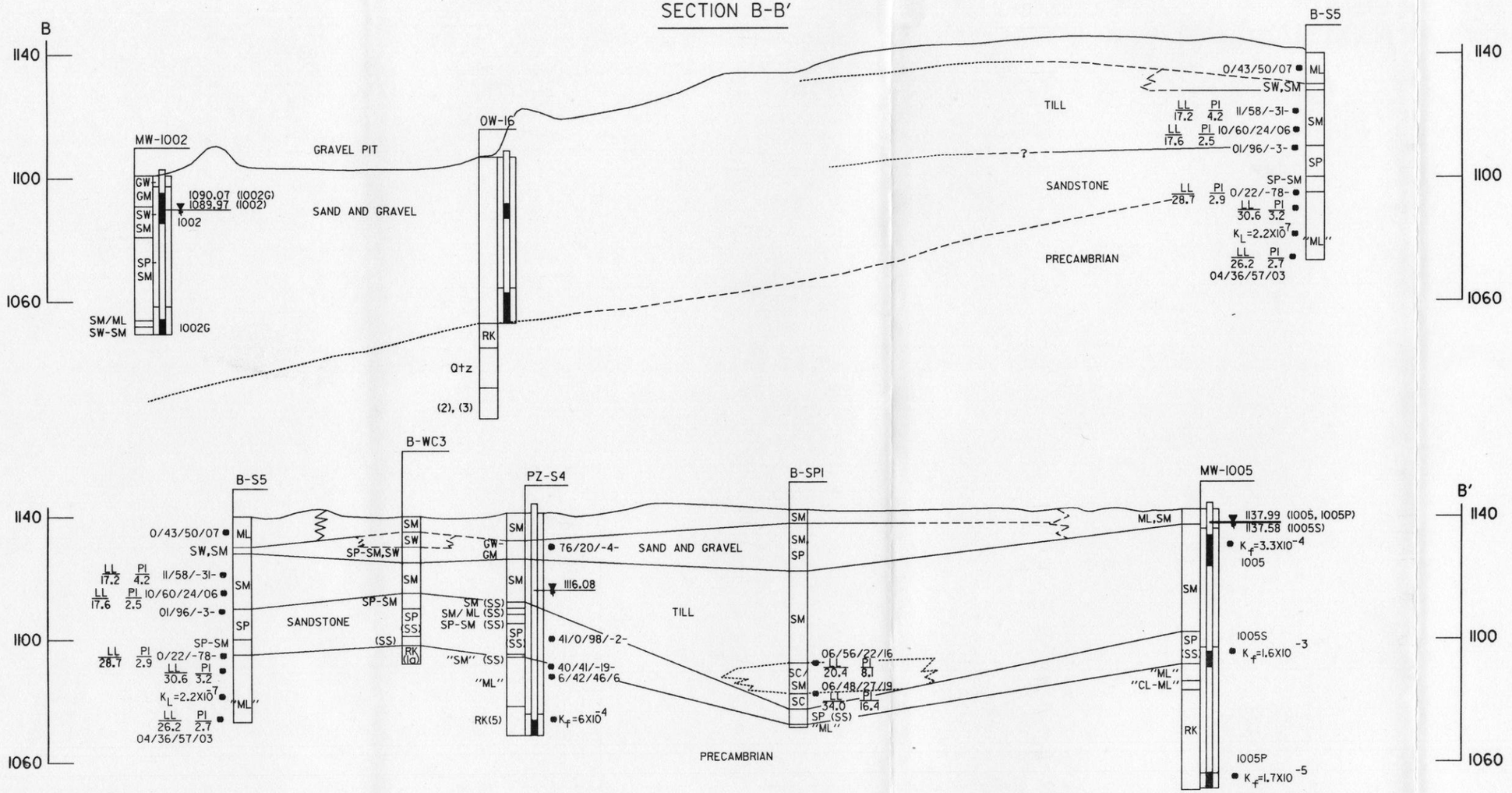
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	BY	DATE
PROJ. ENG'R		
MGR. PROCESS ENG'R		
ENG'R MGR.		

	BY	DATE
DESIGN		
DRAWN	MRS	2/89
CHK'D	TJS	3/89
DES. ENG'R		
SECT ENG'R		

MICROFILM	JOB
DRAWING NO.	REV.
DIVISION DRAWING NO.	
SCALE	SEE BAR SCALE

SECTION B-B'



LEGEND

QUATERNARY

Qt	TILL, AND SAND AND GRAVEL (MAY CONTAIN SOME CAMBRIAN SANDSTONE)
SM	SILTY SAND
SW-SM	WELL GRADED SAND WITH SILT
SP	POORLY GRADED SAND
SP-SM	POORLY GRADED SAND WITH SILT
SW	WELL GRADED SAND
SP-SM, SW	POORLY GRADED SAND WITH SILT INTERBEDDED WITH WELL-GRADED SAND
SM,SP	SILTY SAND INTERBEDDED WITH POORLY GRADED SAND
SW,SM	WELL GRADED SAND INTERBEDDED WITH SILTY SAND
SM/ML	SILTY SAND/SILT
SC/SM	CLAYEY SAND/SILTY SAND
SC	CLAYEY SAND
SC-SM	SILTY-CLAYEY SAND
GW	WELL GRADED GRAVEL
GW-GM	WELL GRADED GRAVEL WITH SILT
GP	POORLY GRADED GRAVEL
GM	SILTY GRAVEL
SP,GP	POORLY GRADED SAND INTERBEDDED WITH POORLY GRADED GRAVEL
SM/GM	SILTY SAND/SILTY GRAVEL
SM,GW-GM	SILTY SAND INTERBEDDED WITH POORLY GRADED GRAVEL WITH SILT
GM/SM	SILTY GRAVEL/SILTY SAND
ML	SILT
CL-ML	SILTY CLAY
CL	LEAN CLAY
CL/ML	LEAN CLAY/SILT

CAMBRIAN

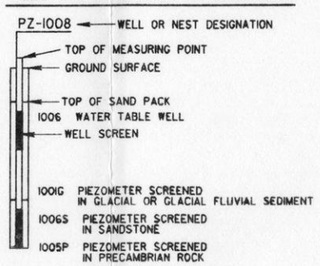
SS	SANDSTONE

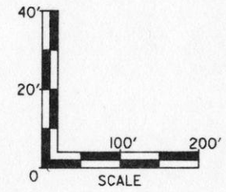
PRECAMBRIAN

RK	ROCK
Qtz	QUARTZ
(Iq)	SERICITE-QUARTZ SCHIST
(2)	BIOTITE SCHIST
(3)	AUGEN SCHIST
(5)	METADACITE (VOLCANIC FLOW ROCK)
"ML"	ROCK THAT DISAGGREGATES TO SILT
"SM"	ROCK THAT DISAGGREGATES TO SILTY SAND
"GM"	ROCK THAT DISAGGREGATES TO SILTY GRAVEL
"CL/ML"	ROCK THAT DISAGGREGATES TO LEAN CLAY/SILT
"SM/ML"	ROCK THAT DISAGGREGATES TO SILTY SAND/SILT
"SM,ML"	ROCK THAT DISAGGREGATES TO INTERBEDS OF SILTY SAND AND SILT

- SAMPLING POINT
- LL 26 PI 13 — ATTERBERG LIMITS
- K_f=7.9X10^-5 — IN-FIELD PERMEABILITY VALUE (CM/SEC)
- K_L=4.0X10^-9 — LABORATORY PERMEABILITY VALUE (CM/SEC)
- 01/50/41/08 — GRAVEL/SAND/SILT/CLAY PERCENTAGES
- 0/93/-7- — GRAVEL/SAND/P200 PERCENTAGES
- 1113.27 — AVERAGE WATER LEVEL (SEPT. 1987 TO NOV. 1988)
- CONTACTS-REASONABLY CERTAIN
- UNCERTAIN
- VERY UNCERTAIN

WELL CONSTRUCTION INFORMATION





FOTH & VAN DYKE
GEOSCIENCES & ENVIRONMENTAL MANAGEMENT DIVISION
GREEN BAY, WISCONSIN

FLAMBEAU PROJECT
LADYSMITH, WISCONSIN

KENNECOTT MINERALS COMPANY
555 MINERAL SQUARE
SALT LAKE CITY, UTAH 84112

FIGURE NO. 3.5-4
GEOLOGIC CROSS SECTION
B-B'

	BY	DATE
PROJ. ENG'R		
MGR. PROCESS ENG'R		
ENG'R MGR.		
DESIGN		
DRAWN	MRS	2/89
CHK'D	BSS	3/89
DES. ENG'R		
SECT ENG'R		

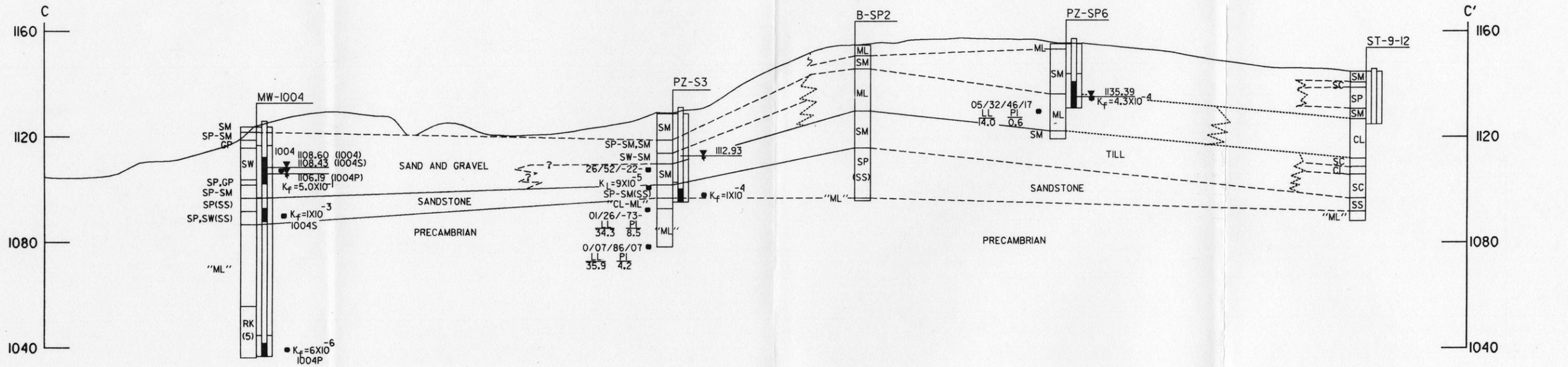
MICROFILM | JOB
DRAWING NO. | REV.
DIVISION DRAWING NO.
SCALE: SEE BAR SCALE

REFERENCES

DWG. NO.	DESCRIPTION

NO.	DATE	REVISIONS	BY	CHK'D	ENG'R	ENG'R MGR.

SECTION C-C'



LEGEND

QUATERNARY

Qt	TILL, AND SAND AND GRAVEL (MAY CONTAIN SOME CAMBRIAN SANDSTONE)
SM	SILTY SAND
SW-SM	WELL GRADED SAND WITH SILT
SP	POORLY GRADED SAND
SP-SM	POORLY GRADED SAND WITH SILT
SW	WELL GRADED SAND
SP-SM, SW	POORLY GRADED SAND WITH SILT INTERBEDDED WITH WELL-GRADED SAND
SM,SP	SILTY SAND INTERBEDDED WITH POORLY GRADED SAND
SW,SM	WELL GRADED SAND INTERBEDDED WITH SILTY SAND
SM/ML	SILTY SAND/SILT
SC/SM	CLAYEY SAND/SILTY SAND
SC	CLAYEY SAND
SC-SM	SILTY-CLAYEY SAND
GW	WELL GRADED GRAVEL
GW-GM	WELL GRADED GRAVEL WITH SILT
GP	POORLY GRADED GRAVEL
GM	SILTY GRAVEL
SP,GP	POORLY GRADED SAND INTERBEDDED WITH POORLY GRADED GRAVEL
SM/GM	SILTY SAND/SILTY GRAVEL
SM,GW-GM	SILTY SAND INTERBEDDED WITH POORLY GRADED GRAVEL WITH SILT
GM/SM	SILTY GRAVEL/SILTY SAND

ML	SILT
CL-ML	SILTY CLAY
CL	LEAN CLAY
CL/ML	LEAN CLAY/SILT

CAMBRIAN

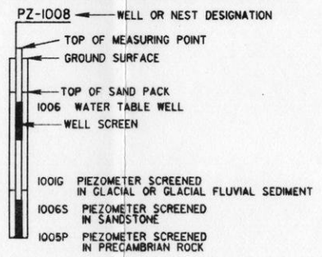
SS	SANDSTONE

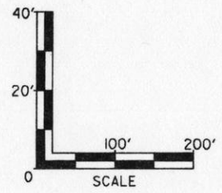
PRECAMBRIAN

RK	ROCK
Qtz	QUARTZ
(Ig)	SERICITE-QUARTZ SCHIST
(2)	BIOTITE SCHIST
(3)	AUGEN SCHIST
(5)	METADACITE (VOLCANIC FLOW ROCK)
"ML"	ROCK THAT DISAGGREGATES TO SILT
"SM"	ROCK THAT DISAGGREGATES TO SILTY SAND
"GM"	ROCK THAT DISAGGREGATES TO SILTY GRAVEL
"CL/ML"	ROCK THAT DISAGGREGATES TO LEAN CLAY/SILT
"SM/ML"	ROCK THAT DISAGGREGATES TO SILTY SAND/SILT
"SM,ML"	ROCK THAT DISAGGREGATES TO INTERBEDS OF SILTY SAND AND SILT

- LL / PI — SAMPLING POINT
- ATTERBERG LIMITS
- K_f=7.9X10^{-5} — IN-FIELD PERMEABILITY VALUE (CM/SEC)
- K_L=4.0X10^{-9} — LABORATORY PERMEABILITY VALUE (CM/SEC)
- 01/50/41/08 — GRAVEL/SAND/SILT/CLAY PERCENTAGES
- 0/93/-7- — GRAVEL/SAND/P200 PERCENTAGES
- ▼ 1113.27 — AVERAGE WATER LEVEL (SEPT. 1987 TO NOV. 1988)
- ——— CONTACTS-REASONABLY CERTAIN
- – – – – UNCERTAIN
- ····· VERY UNCERTAIN

WELL CONSTRUCTION INFORMATION





FOTH & VAN DYKE
GEOSCIENCES & ENVIRONMENTAL MANAGEMENT DIVISION
GREEN BAY, WISCONSIN

FLAMBEAU PROJECT
LADYSMITH, WISCONSIN

KENNECOTT MINERALS COMPANY
155 MINERAL SQUARE
SALT LAKE CITY, UTAH 8412

FIGURE NO. 3.5-5
GEOLOGIC CROSS SECTION
C-C'

MICROFILM | JOB
DRAWING NO. | REV.
DIVISION DRAWING NO.
SCALE: SEE BAR SCALE

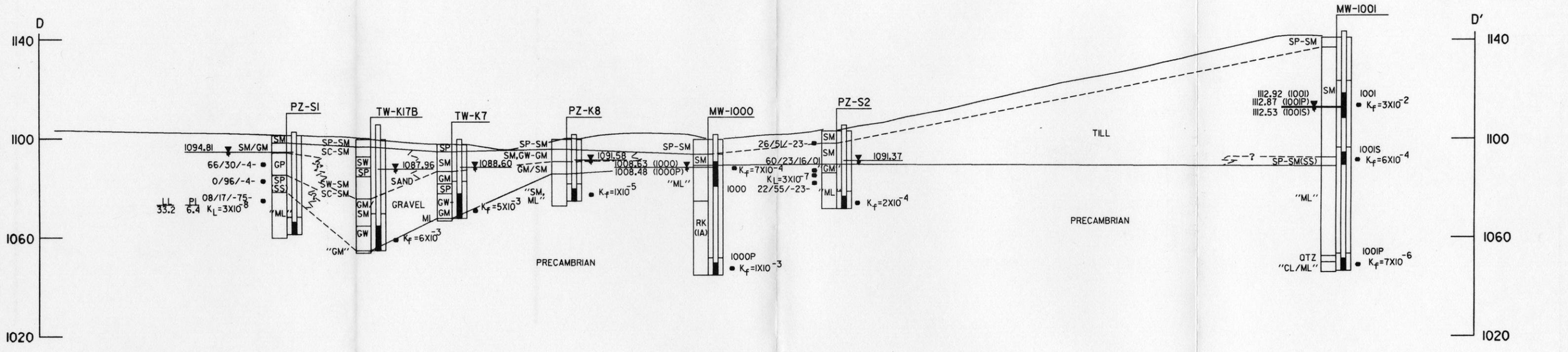
REFERENCES	DWG. NO.	DESCRIPTION

NO.	DATE	REVISIONS	BY	CHK'D	ENG'R	ENG'R MGR.

	BY	DATE
PROJ. ENG'R		
MGR. PROCESS ENG'R		
ENG'R MGR.		

	BY	DATE
DESIGN		
DRAWN	MBS	2/89
CHK'D	BSS	3/89
DES. ENG'R		
SECT ENG'R		

SECTION D-D'



LEGEND

QUATERNARY

Qt	TILL, AND SAND AND GRAVEL (MAY CONTAIN SOME CAMBRIAN SANDSTONE)
SM	SILTY SAND
SW-SM	WELL GRADED SAND WITH SILT
SP	POORLY GRADED SAND
SP-SM	POORLY GRADED SAND WITH SILT
SW	WELL GRADED SAND
SP-SM, SW	POORLY GRADED SAND WITH SILT INTERBEDDED WITH WELL-GRADED SAND
SM,SP	SILTY SAND INTERBEDDED WITH POORLY GRADED SAND
SW,SM	WELL GRADED SAND INTERBEDDED WITH SILTY SAND
SM/ML	SILTY SAND/SILT
SC/SM	CLAYEY SAND/SILTY SAND
SC	CLAYEY SAND
SC-SM	SILTY-CLAYEY SAND
GW	WELL GRADED GRAVEL
GW-GM	WELL GRADED GRAVEL WITH SILT
GP	POORLY GRADED GRAVEL
GM	SILTY GRAVEL
SP,GP	POORLY GRADED SAND INTERBEDDED WITH POORLY GRADED GRAVEL
SM/GM	SILTY SAND/SILTY GRAVEL
SM,GW-GM	SILTY SAND INTERBEDDED WITH POORLY GRADED GRAVEL WITH SILT
GM/SM	SILTY GRAVEL/SILTY SAND
ML	SILT
CL-ML	SILTY CLAY
CL	LEAN CLAY
CL/ML	LEAN CLAY/SILT

CAMBRIAN

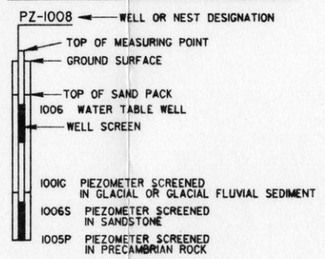
SS	SANDSTONE

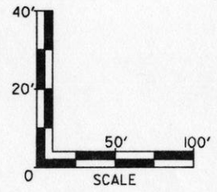
PRECAMBRIAN

RK	ROCK
Qtz	QUARTZ
(Ia)	SERICITE-QUARTZ SCHIST
(2)	BIOTITE SCHIST
(3)	AUGEN SCHIST
(5)	METADACITE (VOLCANIC FLOW ROCK)
"ML"	ROCK THAT DISAGGREGATES TO SILT
"SM"	ROCK THAT DISAGGREGATES TO SILTY SAND
"GM"	ROCK THAT DISAGGREGATES TO SILTY GRAVEL
"CL/ML"	ROCK THAT DISAGGREGATES TO LEAN CLAY/SILT
"SM/ML"	ROCK THAT DISAGGREGATES TO SILTY SAND/SILT
"SM,ML"	ROCK THAT DISAGGREGATES TO INTERBEDS OF SILTY SAND AND SILT

- LL 26 PI 13 — SAMPLING POINT
- K_f=7.9X10^-5 — ATTERBERG LIMITS
- K_L=4.0X10^-9 — IN-FIELD PERMEABILITY VALUE (CM/SEC)
- 01/50/41/08 — LABORATORY PERMEABILITY VALUE (CM/SEC)
- 0/93/-7- — GRAVEL/SAND/SILT/CLAY PERCENTAGES
- 1113.27 — GRAVEL/SAND/P200 PERCENTAGES
- AVERAGE WATER LEVEL (SEPT. 1987 TO NOV. 1988)
- CONTACTS-REASONABLY CERTAIN
- UNCERTAIN
- VERY UNCERTAIN

WELL CONSTRUCTION INFORMATION





FOTH & VAN DYKE
GEOSCIENCES & ENVIRONMENTAL MANAGEMENT DIVISION
GREEN BAY, WISCONSIN

FLAMBEAU PROJECT
LADYSMITH, WISCONSIN

KENNECOTT MINERALS COMPANY
55 MINERAL SQUARE
SALT LAKE CITY, UTAH 8412

FIGURE NO. 3.5-6
GEOLOGIC CROSS SECTION
D-D'

MICROFILM | JOB
DRAWING NO. | REV.
DIVISION DRAWING NO.
SCALE | SEE BAR SCALE

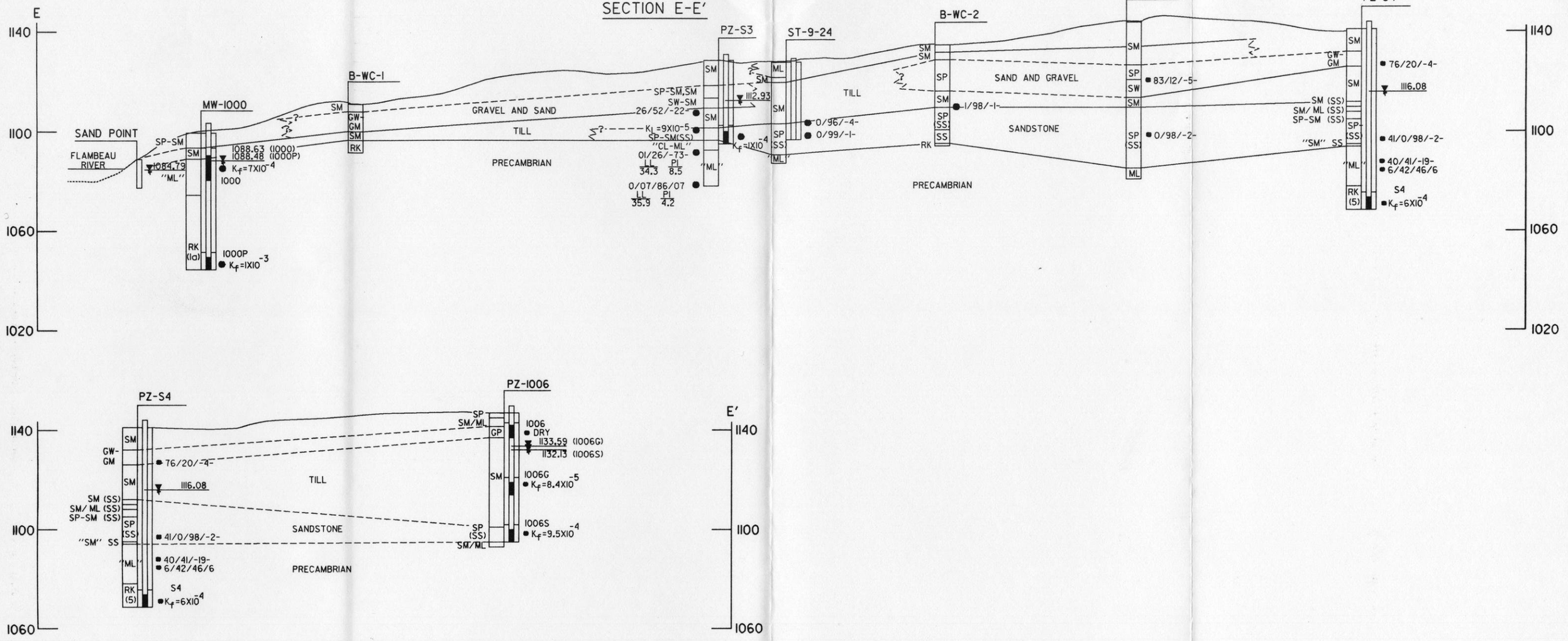
	BY	DATE
DESIGN		
DRAWN	MRS	2/89
CHK'D	BSS	3/89
DES. ENG'R		
SECT ENG'R		
PROJ. ENG'R		
MGR. PROCESS ENG'R		
ENG'R MGR.		

REFERENCES

DWG. NO.	DESCRIPTION

NO.	DATE	REVISIONS	BY	CHK'D	ENG'R	ENG'R MGR.

SECTION E-E'



LEGEND

QUATERNARY

Qt	TILL, AND SAND AND GRAVEL (MAY CONTAIN SOME CAMBRIAN SANDSTONE)
SM	SILTY SAND
SW-SM	WELL GRADED SAND WITH SILT
SP	POORLY GRADED SAND
SP-SM	POORLY GRADED SAND WITH SILT
SW	WELL GRADED SAND
SP-SM, SW	POORLY GRADED SAND WITH SILT INTERBEDDED WITH WELL-GRADED SAND
SM,SP	SILTY SAND INTERBEDDED WITH POORLY GRADED SAND
SW,SM	WELL GRADED SAND INTERBEDDED WITH SILTY SAND
SM/ML	SILTY SAND/SILT
SC/SM	CLAYEY SAND/SILTY SAND
SC	CLAYEY SAND
SC-SM	SILTY-CLAYEY SAND
GW	WELL GRADED GRAVEL
GW-GM	WELL GRADED GRAVEL WITH SILT
GP	POORLY GRADED GRAVEL
GM	SILTY GRAVEL
SP,GP	POORLY GRADED SAND INTERBEDDED WITH POORLY GRADED GRAVEL
SM/GM	SILTY SAND/SILTY GRAVEL
SM,GW-GM	SILTY SAND INTERBEDDED WITH POORLY GRADED GRAVEL WITH SILT
GM/SM	SILTY GRAVEL/SILTY SAND

ML	SILT
CL-ML	SILTY CLAY
CL	LEAN CLAY
CL/ML	LEAN CLAY/SILT

CAMBRIAN

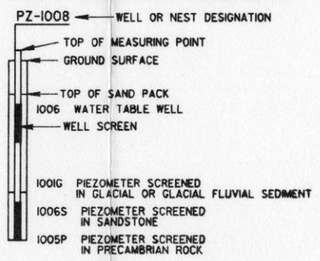
SS	SANDSTONE

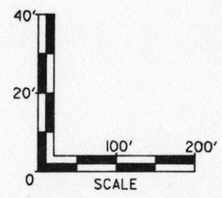
PRECAMBRIAN

RK	ROCK
Qtz	QUARTZ
(Ia)	SERICITE-QUARTZ SCHIST
(2)	BIOTITE SCHIST
(3)	AUGEN SCHIST
(5)	METADACITE (VOLCANIC FLOW ROCK)
"ML"	ROCK THAT DISAGGREGATES TO SILT
"SM"	ROCK THAT DISAGGREGATES TO SILTY SAND
"GM"	ROCK THAT DISAGGREGATES TO SILTY GRAVEL
"CL/ML"	ROCK THAT DISAGGREGATES TO LEAN CLAY/SILT
"SM/ML"	ROCK THAT DISAGGREGATES TO SILTY SAND/SILT
"SM,ML"	ROCK THAT DISAGGREGATES TO INTERBEDS OF SILTY SAND AND SILT

- ● LL PI / 26 13 — SAMPLING POINT
- K_f=7.9X10^{-5} — ATTERBERG LIMITS
- K_L=4.0X10^{-9} — IN-FIELD PERMEABILITY VALUE (CM/SEC)
- 01/50/41/08 — LABORATORY PERMEABILITY VALUE (CM/SEC)
- 0/93/-7- — GRAVEL/SAND/SILT/CLAY PERCENTAGES
- ▼ 1113.27 — GRAVEL/SAND/P200 PERCENTAGES
- ——— — AVERAGE WATER LEVEL (SEPT. 1987 TO NOV. 1988)
- – – – – — CONTACTS-REASONABLY CERTAIN
- ····· — UNCERTAIN
- VERY UNCERTAIN

WELL CONSTRUCTION INFORMATION





FOTH & VAN DYKE
GEOSCIENCES & ENVIRONMENTAL MANAGEMENT DIVISION
GREEN BAY, WISCONSIN

FLAMBEAU PROJECT
LADYSMITH, WISCONSIN

KENNECOTT MINERALS COMPANY
555 MINERAL SQUARE
SALT LAKE CITY, UTAH 84102

FIGURE NO. 3.5-7
GEOLOGIC CROSS SECTION
E-E'

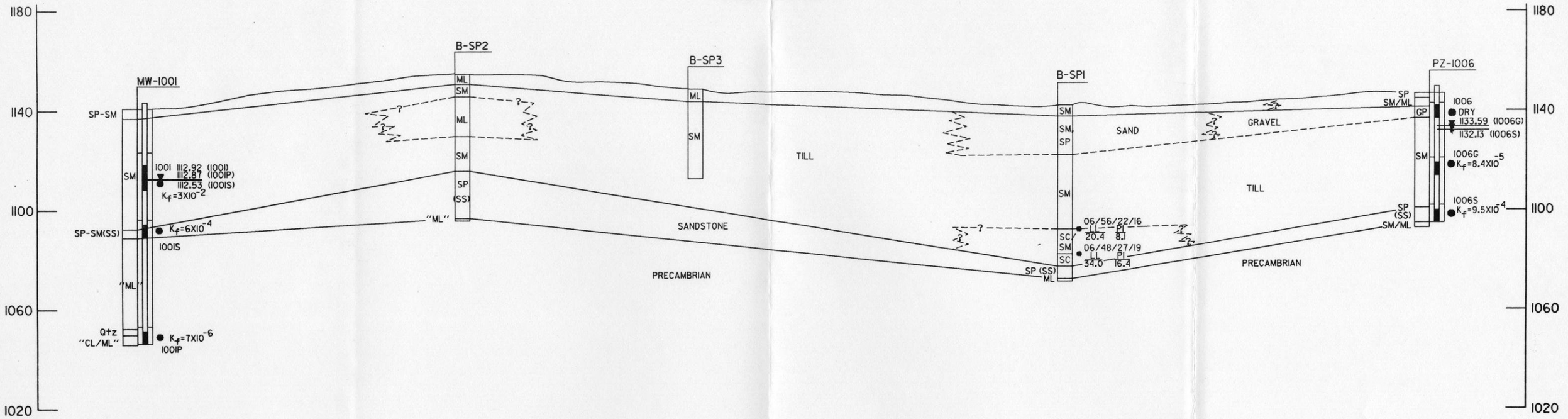
REFERENCES	DWG. NO.	DESCRIPTION

NO.	DATE	REVISIONS	BY	CHK'D	ENG'R	ENG'R MGR.

	BY	DATE
PROJ. ENG'R		
MGR. PROCESS ENGR.		
ENG'R MGR.		
DESIGN		
DRAWN	MRS	2/89
CHK'D	TSS	3/89
DES. ENG'R		
SECT ENG'R		

MICROFILM | JOB
DRAWING NO. | REV.
DIVISION DRAWING NO.
SCALE | SEE BAR SCALE

SECTION F-F'



LEGEND

QUATERNARY

Q+	TILL, AND SAND AND GRAVEL (MAY CONTAIN SOME CAMBRIAN SANDSTONE)
SM	SILTY SAND
SW-SM	WELL GRADED SAND WITH SILT
SP	POORLY GRADED SAND
SP-SM	POORLY GRADED SAND WITH SILT
SW	WELL GRADED SAND
SP-SM, SW	POORLY GRADED SAND WITH SILT INTERBEDDED WITH WELL-GRADED SAND
SM,SP	SILTY SAND INTERBEDDED WITH POORLY GRADED SAND
SW,SM	WELL GRADED SAND INTERBEDDED WITH SILTY SAND
SM/ML	SILTY SAND/SILT
SC/SM	CLAYEY SAND/SILTY SAND
SC	CLAYEY SAND
SC-SM	SILTY-CLAYEY SAND
GW	WELL GRADED GRAVEL
GW-GM	WELL GRADED GRAVEL WITH SILT
GP	POORLY GRADED GRAVEL
GM	SILTY GRAVEL
SP,GP	POORLY GRADED SAND INTERBEDDED WITH POORLY GRADED GRAVEL
SM/GM	SILTY SAND/SILTY GRAVEL
SM,GW-GM	SILTY SAND INTERBEDDED WITH POORLY GRADED GRAVEL WITH SILT
GM/SM	SILTY GRAVEL/SILTY SAND

ML	SILT
CL-ML	SILTY CLAY
CL	LEAN CLAY
CL/ML	LEAN CLAY/SILT

CAMBRIAN

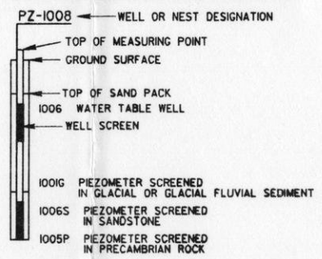
SS	SANDSTONE

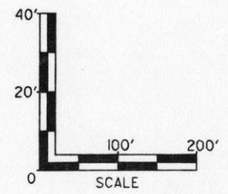
PRECAMBRIAN

RK	ROCK
Q+z	QUARTZ
(Ia)	SERICITE-QUARTZ SCHIST
(2)	BIOTITE SCHIST
(3)	AUGEN SCHIST
(5)	METADACITE (VOLCANIC FLOW ROCK)
"ML"	ROCK THAT DISAGGREGATES TO SILT
"SM"	ROCK THAT DISAGGREGATES TO SILTY SAND
"GM"	ROCK THAT DISAGGREGATES TO SILTY GRAVEL
"CL/ML"	ROCK THAT DISAGGREGATES TO LEAN CLAY/SILT
"SM/ML"	ROCK THAT DISAGGREGATES TO SILTY SAND/SILT
"SM,ML"	ROCK THAT DISAGGREGATES TO INTERBEDS OF SILTY SAND AND SILT

●	SAMPLING POINT
LL/PI 26/13	ATTERBERG LIMITS
K_f=7.9X10^{-5}	IN-FIELD PERMEABILITY VALUE (CM/SEC)
K_L=4.0X10^{-9}	LABORATORY PERMEABILITY VALUE (CM/SEC)
01/50/41/08	GRAVEL/SAND/SILT/CLAY PERCENTAGES
0/93/-7-	GRAVEL/SAND/P200 PERCENTAGES
▼ 1113.27	AVERAGE WATER LEVEL (SEPT. 1987 TO NOV. 1988)
———	CONTACTS-REASONABLY CERTAIN
- - - - -	UNCERTAIN
.....	VERY UNCERTAIN

WELL CONSTRUCTION INFORMATION





FOTH & VAN DYKE
GEOSCIENCES & ENVIRONMENTAL MANAGEMENT DIVISION
GREEN BAY, WISCONSIN

FLAMBEAU PROJECT
LADYSMITH, WISCONSIN

KENNECOTT MINERALS COMPANY
155 MINERAL SQUARE
SALT LAKE CITY, UTAH 8412

FIGURE NO. 3.5-8
GEOLOGIC CROSS SECTION
F-F'

	BY	DATE
DESIGN		
DRAWN	MBS	2/89
CHK'D	[illegible]	3/89
DES. ENG'R		
SECT ENG'R		
PROJ. ENG'R		
MGR. PROCESS ENG'R		
ENG'R MGR.		

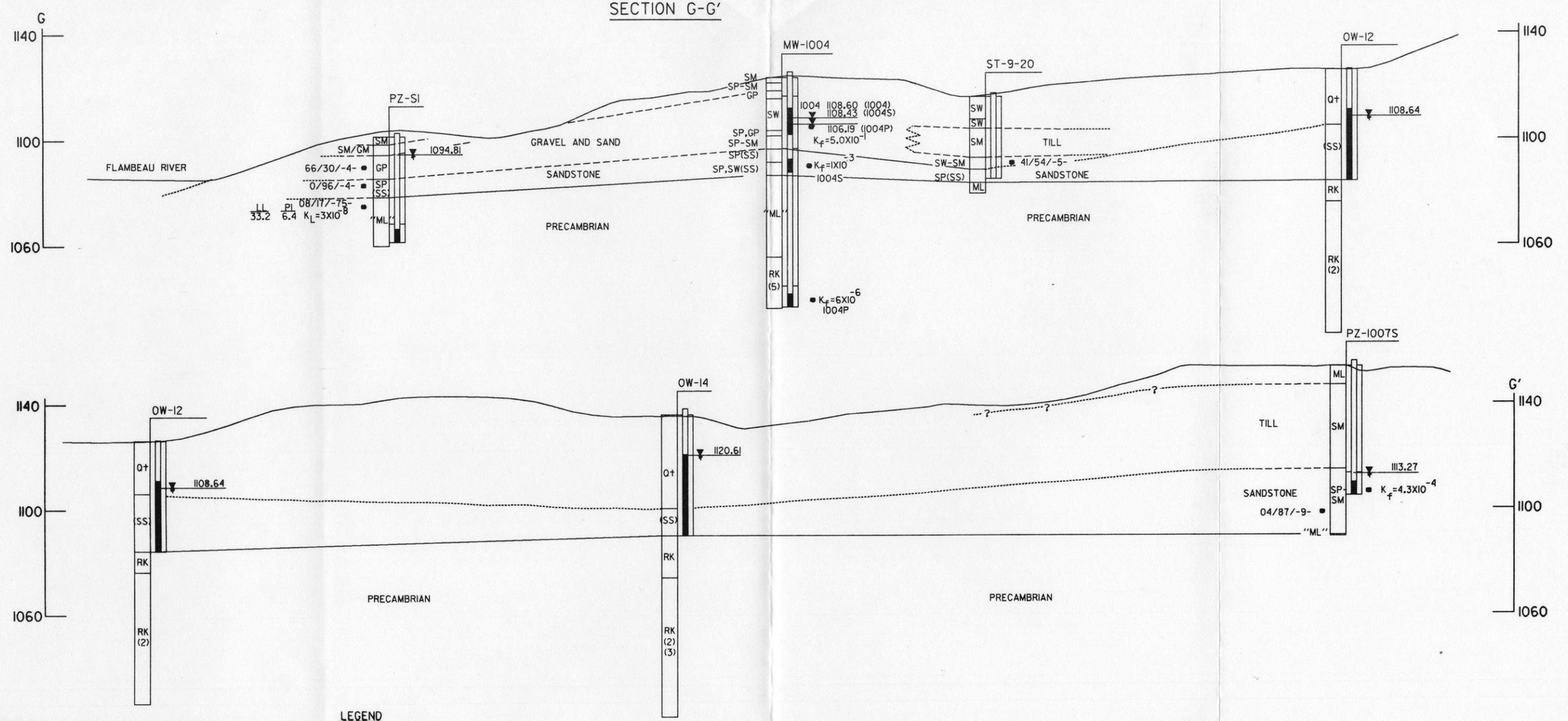
MICROFILM | JOB
DRAWING NO. | REV.
DIVISION DRAWING NO.
SCALE | SEE BAR SCALE

REFERENCES

DWG. NO.	DESCRIPTION

NO.	DATE	REVISIONS	BY	CHK'D	ENG'R	ENG'R MGR.

SECTION G-G'



LEGEND

QUATERNARY

Q+	TILL, AND SAND AND GRAVEL (MAY CONTAIN SOME CAMBRIAN SANDSTONE)
SM	SILTY SAND
SW-SM	WELL GRADED SAND WITH SILT
SP	POORLY GRADED SAND
SP-SM	POORLY GRADED SAND WITH SILT
SW	WELL GRADED SAND
SP-SM, SW	POORLY GRADED SAND WITH SILT INTERBEDDED WITH WELL-GRADED SAND
SM,SP	SILTY SAND INTERBEDDED WITH POORLY GRADED SAND
SW,SM	WELL GRADED SAND INTERBEDDED WITH SILTY SAND
SM/ML	SILTY SAND/SILT
SC/SM	CLAYEY SAND/SILTY SAND
SC	CLAYEY SAND
SC-SM	SILTY-CLAYEY SAND
GW	WELL GRADED GRAVEL
GW-GM	WELL GRADED GRAVEL WITH SILT
GP	POORLY GRADED GRAVEL
GM	SILTY GRAVEL
SP,GP	POORLY GRADED SAND INTERBEDDED WITH POORLY GRADED GRAVEL
SM/GM	SILTY SAND/SILTY GRAVEL
SM,GW-GM	SILTY SAND INTERBEDDED WITH POORLY GRADED GRAVEL WITH SILT
GM/SM	SILTY GRAVEL/SILTY SAND
ML	SILT
CL-ML	SILTY CLAY
CL	LEAN CLAY
CL/ML	LEAN CLAY/SILT

CAMBRIAN

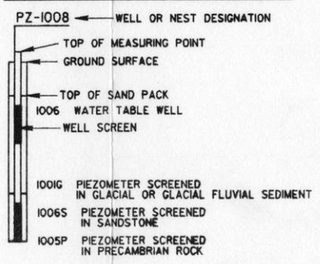
SS	SANDSTONE

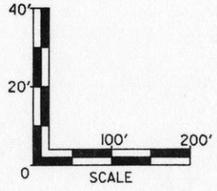
PRECAMBRIAN

RK	ROCK
Q+z	QUARTZ
(1a)	SERICITE-QUARTZ SCHIST
(2)	BIOTITE SCHIST
(3)	AUGEN SCHIST
(5)	METADACITE (VOLCANIC FLOW ROCK)
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"SM"	ROCK THAT DISAGGREGATES TO SILTY SAND
"GM"	ROCK THAT DISAGGREGATES TO SILTY GRAVEL
"CL/ML"	ROCK THAT DISAGGREGATES TO LEAN CLAY/SILT
"SM/ML"	ROCK THAT DISAGGREGATES TO SILTY SAND/SILT
"SM,ML"	ROCK THAT DISAGGREGATES TO INTERBEDS OF SILTY SAND AND SILT

- SAMPLING POINT
- LL 26 PI 13 — ATTERBERG LIMITS
- K_f=7.9X10^-5 — IN-FIELD PERMEABILITY VALUE (CM/SEC)
- K_L=4.0X10^-9 — LABORATORY PERMEABILITY VALUE (CM/SEC)
- 01/50/41/08 — GRAVEL/SAND/SILT/CLAY PERCENTAGES
- 0/93/-7- — GRAVEL/SAND/P200 PERCENTAGES
- ▼ 1113.27 — AVERAGE WATER LEVEL (SEPT. 1987 TO NOV. 1988)
- ——— CONTACTS-REASONABLY CERTAIN
- – – – – UNCERTAIN
- ····· VERY UNCERTAIN

WELL CONSTRUCTION INFORMATION





REFERENCES	DWG. NO.	DESCRIPTION

REFERENCES	DWG. NO.	DESCRIPTION

NO.	DATE	REVISIONS	BY	CHK'D	ENG'R	ENG'R MGR.

NO.	DATE	REVISIONS	BY	CHK'D	ENG'R	ENG'R MGR.

	BY	DATE
PROJ. ENG'R		
MGR. PROGRESS ENG'R		
ENG'R MGR.		

	BY	DATE
DESIGN		
DRAWN	MRS	2/89
CHK'D	[illegible]	3/89
DES. ENG'R		
SECT ENG'R		

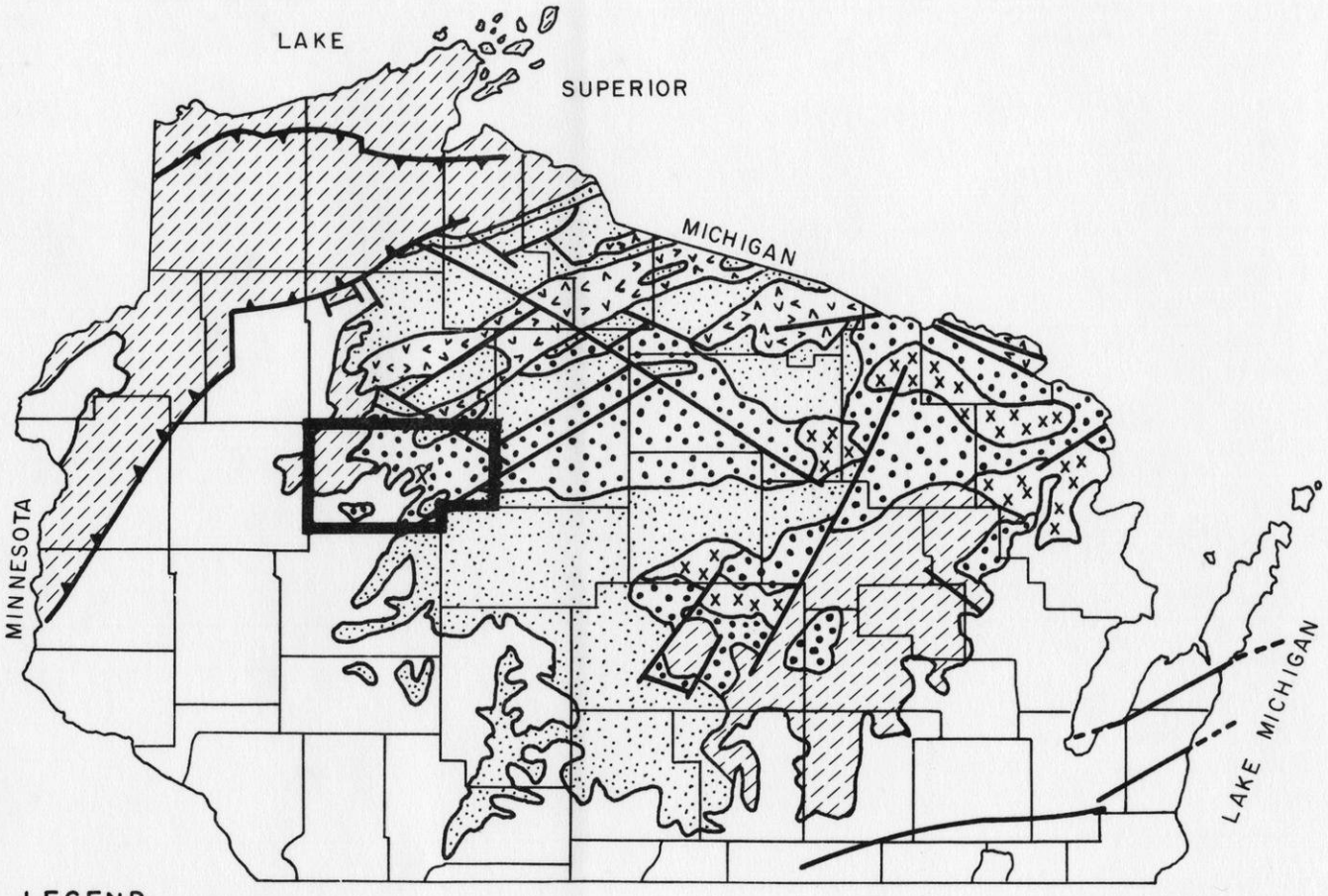
FOTH & VAN DYKE
GEOSCIENCES & ENVIRONMENTAL MANAGEMENT DIVISION
GREEN BAY, WISCONSIN

FLAMBEAU PROJECT
LADYSMITH, WISCONSIN

KENNECOTT MINERALS COMPANY
155 MINERAL SQUARE
SALT LAKE CITY, UTAH 84112

FIGURE NO. 3.5-9
GEOLOGIC CROSS SECTION
G-G'

MICROFILM	JOB
DRAWING NO.	REV.
DIVISION DRAWING NO.	
SCALE	SEE BAR SCALE



GEOLOGY MODIFIED FROM SIMS 1976

LEGEND

PALEOZOIC

SANDSTONE, SHALE, LIMESTONE AND DOLOMITE

PRECAMBRIAN

LATE

BASALTIC FLOWS, METASEDIMENTARY SHALE, SANDSTONE, AND INTRUSIVE IGNEOUS ROCKS

MIDDLE

GRANITIC ROCK

METASEDIMENTARY ROCK

METAVOLCANIC ROCK

EARLY

GNEISS, MIGMATITE

RIFT FAULTING

FAULT

FLAMBEAU DEPOSIT, RUSK COUNTY

N

0 40 80

SCALE MILES

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GREEN BAY, WISCONSIN

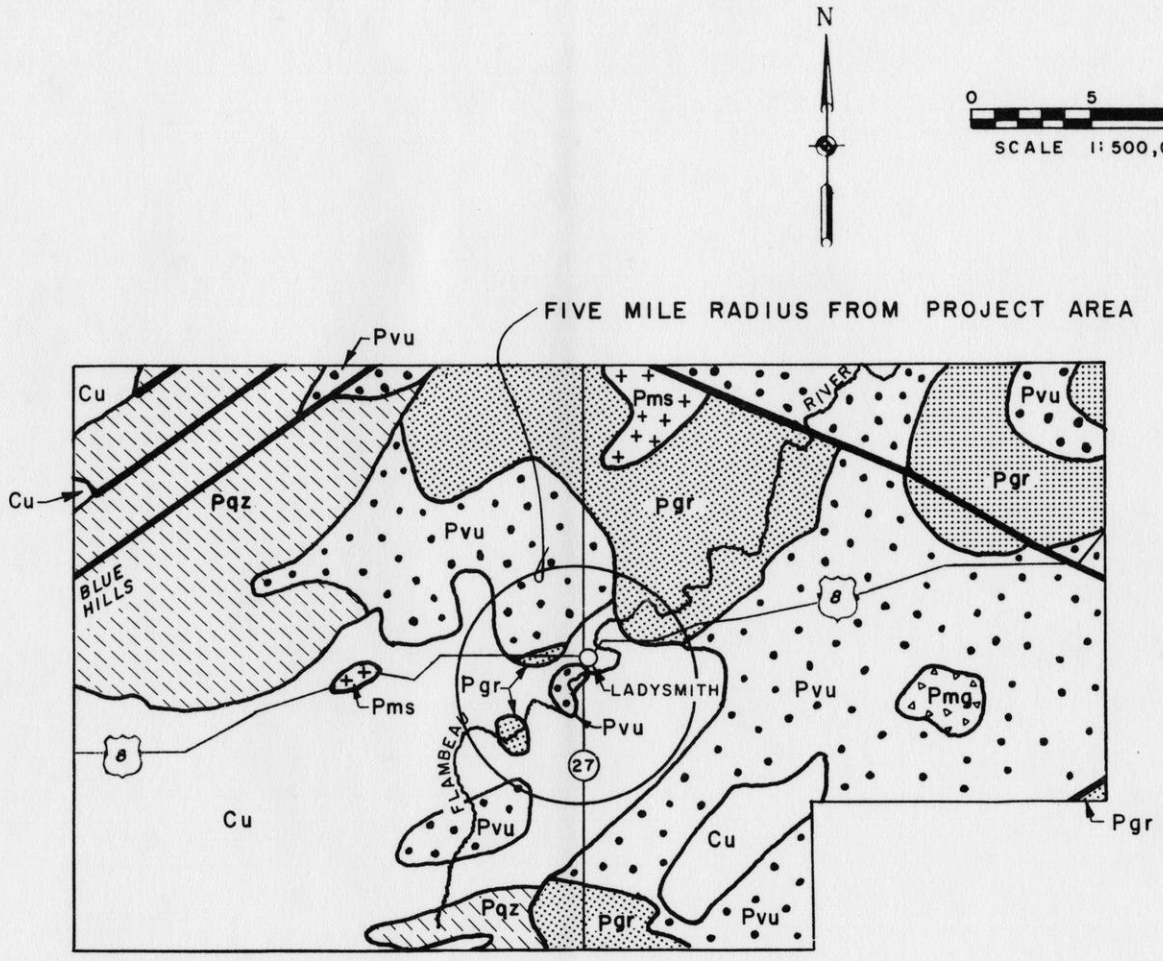
KENNECOTT MINERALS COMPANY
FLAMBEAU PROJECT
LADYSMITH, WISCONSIN

FIGURE NO. 3.5-10

GENERALIZED GEOLOGIC MAP OF PRECAMBRIAN ROCKS IN NORTHERN WISCONSIN

NOTES	APPROVAL		DATE
	DESIGNED BY		
	DRAWN BY	SJL	12/88
	CHECKED BY	BJS	12/88
	APPROVED BY		
	CAD No.	SCALE	

Job No	Dwg No	REV



LEGEND

CAMBRIAN

Cu — SANDSTONE

PRECAMBRIAN

Pqz — QUARTZITE

Pgr — INTERMEDIATE TO GRANITIC INTRUSIVE ROCKS

Pmg — METAMORPHOSED ULTRAMAFIC TO MAFIC INTRUSIVE ROCKS

Pms+ — METAVOLCANIC AND METASEDIMENTARY ROCKS

Pvu — MAFIC, INTERMEDIATE AND FELSIC METAVOLCANIC ROCKS WITH SUBORDINATE METASEDIMENTARY ROCKS; DOMINANTLY OF GREENSCHIST METAMORPHIC FACIES

FAULT

MAP SOURCE: BEDROCK GEOLOGY MAP OF WISCONSIN BY MUDREY, BROWN, AND GREENBERG, 1982, UNIVERSITY OF WISCONSIN-EXTENSION GEOLOGIC AND NATURAL HISTORY SURVEY

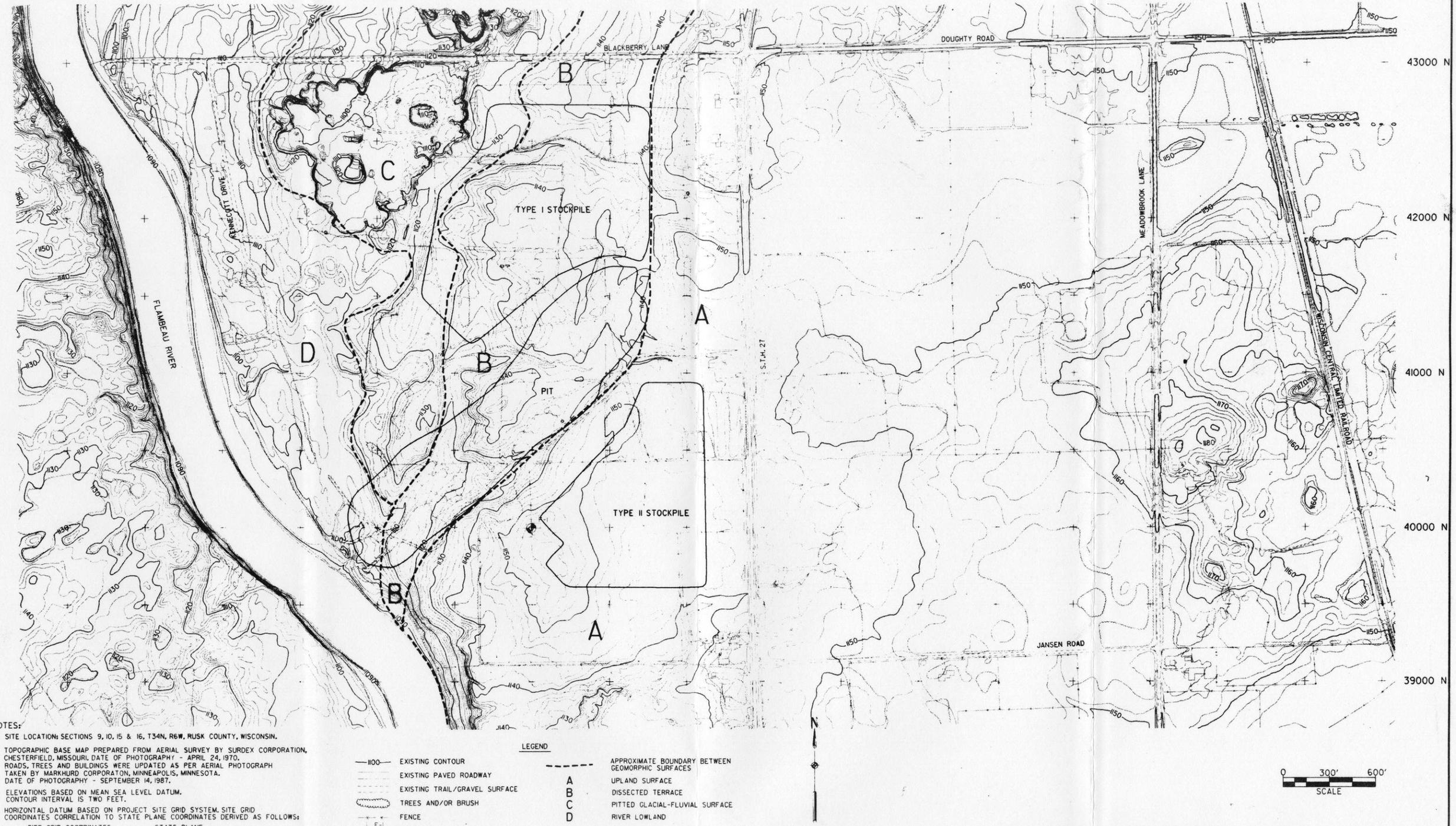
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GEOSCIENCES & ENVIRONMENTAL MANAGEMENT DIVISION
GREEN BAY, WISCONSIN

KENNECOTT MINERALS COMPANY
FLAMBEAU PROJECT
LADYSMITH, WISCONSIN

NOTES	APPROVAL		DATE
	DESIGNED BY		
	DRAWN BY	SJL	1/89
	CHECKED BY	BJS	3/89
	APPROVED BY		
	CAD No.	SCALE	

FIGURE NO. 3.5-11
BEDROCK GEOLOGY OF RUSK COUNTY, WISCONSIN

Job No	Dwg No	REV



NOTES:

1. SITE LOCATION: SECTIONS 9, 10, 15 & 16, T34N, R6W, RUSK COUNTY, WISCONSIN.
2. TOPOGRAPHIC BASE MAP PREPARED FROM AERIAL SURVEY BY SURDEX CORPORATION, CHESTERFIELD, MISSOURI. DATE OF PHOTOGRAPHY - APRIL 24, 1970. ROADS, TREES AND BUILDINGS WERE UPDATED AS PER AERIAL PHOTOGRAPH TAKEN BY MARKHURD CORPORATON, MINNEAPOLIS, MINNESOTA. DATE OF PHOTOGRAPHY - SEPTEMBER 14, 1987.
3. ELEVATIONS BASED ON MEAN SEA LEVEL DATUM. CONTOUR INTERVAL IS TWO FEET.
4. HORIZONTAL DATUM BASED ON PROJECT SITE GRID SYSTEM. SITE GRID COORDINATES CORRELATION TO STATE PLANE COORDINATES DERIVED AS FOLLOWS:

SITE GRID COORDINATES CONTROL MONUMENT F-1	STATE PLANE COORDINATES
40000 N =	587, 357. 8087 N
40000 E =	1, 713, 516. 1229 E

THE ANGULAR ROTATION FROM STATE PLANE BEARINGS TO SITE GRID BEARINGS IS 359°-13'-23" RIGHT WITH CONTROL POINT F-1 AS THE BASE POINT.

LEGEND

- —1100— EXISTING CONTOUR
- EXISTING PAVED ROADWAY
- EXISTING TRAIL/GRAVEL SURFACE
- TREES AND/OR BRUSH
- FENCE
- F-1 CONTROL MONUMENT
- APPROXIMATE BOUNDARY BETWEEN GEOMORPHIC SURFACES
- A UPLAND SURFACE
- B DISSECTED TERRACE
- C PITTED GLACIAL-FLUVIAL SURFACE
- D RIVER LOWLAND

REFERENCES

DWG. NO.	DESCRIPTION

REFERENCES

DWG. NO.	DESCRIPTION

NO.	DATE	REVISIONS	BY	CHK'D	ENG'R	ENG'R MGR.

NO.	DATE	REVISIONS	BY	CHK'D	ENG'R	ENG'R MGR.

	BY	DATE
PROJ. ENG'R		
MGR. PROCESS ENG'R		
ENG'R MGR.		

	BY	DATE
DESIGN		
DRAWN	MJO	3/89
CHK'D	BTS	3/89
DES. ENG'R		
SECT. ENG'R		

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GEOSCIENCES & ENVIRONMENTAL MANAGEMENT DIVISION
GREEN BAY, WISCONSIN

KENNECOTT MINERALS COMPANY
155 MINERAL SQUARE
SALT LAKE CITY, UTAH 8412

FLAMBEAU PROJECT
LADYSMITH, WISCONSIN

FIGURE NO. 3.5-12
GEOMORPHIC SURFACES

MICROFILM | JOB
DRAWING NO. | REV.
DIVISION DRAWING NO.
SCALE | SEE BAR SCALE

38,000E

39,000E

40,000E

41,000E

42,000N

41,000N

40,000N

FLAMBEAU RIVER

Open Pit Perimeter

MW-1002

MW-1003

MW-1004

MW-1000

MW-1001

MW-1005

PZ-1006, 1006G 1006S

STN 27

F-4

F-1

S1

S5

WC2

WCR

N

0 100' 200' 300' 400'

SCALE

LEGEND

- 29 SOIL BORING LOCATION AND NUMBER
- MW-1001 GROUNDWATER MONITORING WELL LOCATION AND NUMBER
- 39 PIEZOMETER LOCATION AND NUMBER
- 16 TEST PIT LOCATION AND NUMBER
- 94 DIAMOND DRILL HOLE LOCATION AND NUMBER
- OPEN PIT PERIMETER
- MASSIVE SULPHIDE MINERALIZATION

FOTH & VAN DYKE

GEOSCIENCES & ENVIRONMENTAL MANAGEMENT DIVISION

GREEN BAY, WISCONSIN

FLAMBEAU PROJECT

LADYSMITH, WISCONSIN

KENNECOTT MINERALS COMPANY

1915 MINERAL SQUARE

SALT LAKE CITY, UTAH

84112

FIGURE NO. 3.5-13

STRUCTURE CONTOUR MAP

TOP OF PRECAMBRIAN

	BY	DATE
DESIGN		
DRAWN	RMH	MAR. 89
CHK'D	BJS	MAR. 89
DES. ENG'R		
SECT ENG'R		
PROJ. ENG'R		
MGR. PROCESS ENG'R		
ENG'R MGR.		

MICROFILM | JOB

DRAWING NO. | REV.

DIVISION DRAWING NO.

SCALE: SEE BAR SCALE

REFERENCES

DWG. NO.	DESCRIPTION

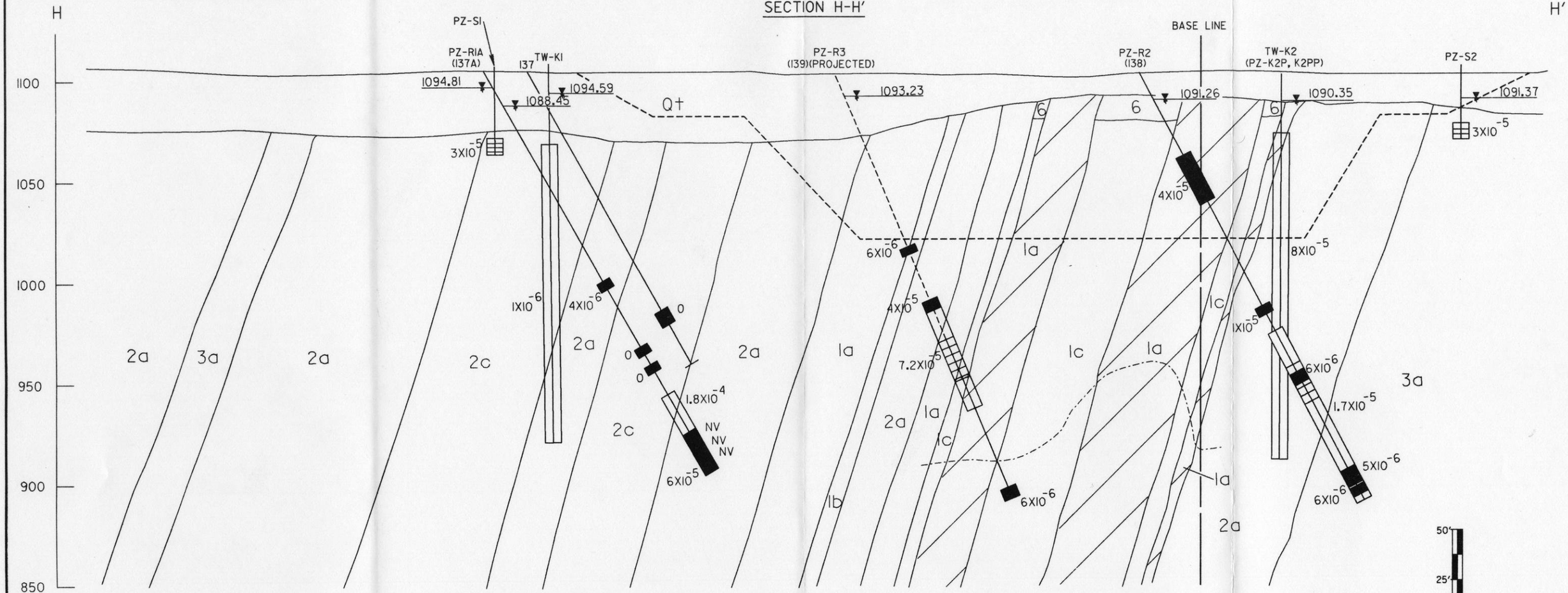
REFERENCES

DWG. NO.	DESCRIPTION

NO.	DATE	REVISIONS	BY	CHK'D	ENG'R	ENG'R MGR.

NO.	DATE	REVISIONS	BY	CHK'D	ENG'R	ENG'R MGR.

SECTION H-H'



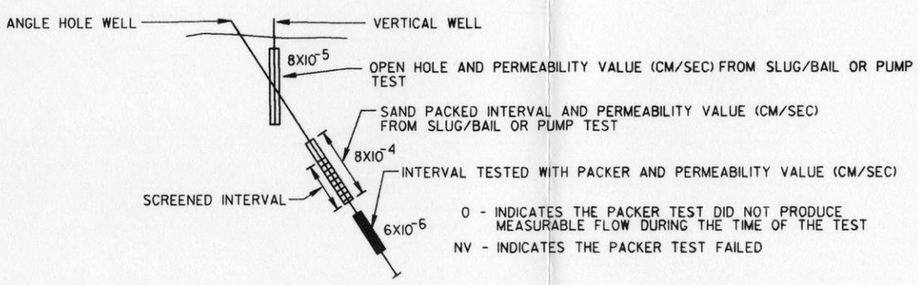
LEGEND

PLEISTOCENE
- Qt GLACIAL TILL

CAMBRIAN
- €s CAMBRIAN SANDSTONE

-ANGULAR UNCOMFORMITY-

MIDDLE PRECAMBRIAN
- 4 CHLORITE SCHIST
  - 4a QUARTZ-CHLORITE SCHIST
  - 4b SPESSARTITE-CHLORITE SCHIST
  - 4c CHLORITE SCHIST
- 1 MINERALIZED HORIZON
  - 1a SERICITE-QUARTZ SCHIST
  - 1b METACHERT
  - 1c MASSIVE SULFIDE (>50 WT.%)
  - SEMI-MASSIVE SULFIDE (20-50 WT.%)
- 2 BIOTITE SCHIST
  - 2a ANDALUSITE-BIOTITE SCHIST
  - 2b ANDALUSITE-BIOTITE-SERICITE SCHIST
  - 2c BIOTITE SCHIST
- 3 AUGEN SCHIST
  - 3a QUARTZ-AUGEN SCHIST
- 5 METADACITE (VOLCANIC FLOW ROCK)
- 6 GOSSAN
- BASE OF SUPERGENE ENRICHMENT
- PROPOSED OPEN PIT PERIMETER



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FLAMBEAU PROJECT
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165 MINERAL SQUARE
SALT LAKE CITY, UTAH 84112

FIGURE NO. 3.5-14
GEOLOGIC CROSS-SECTION H-H'
SECTION 40'

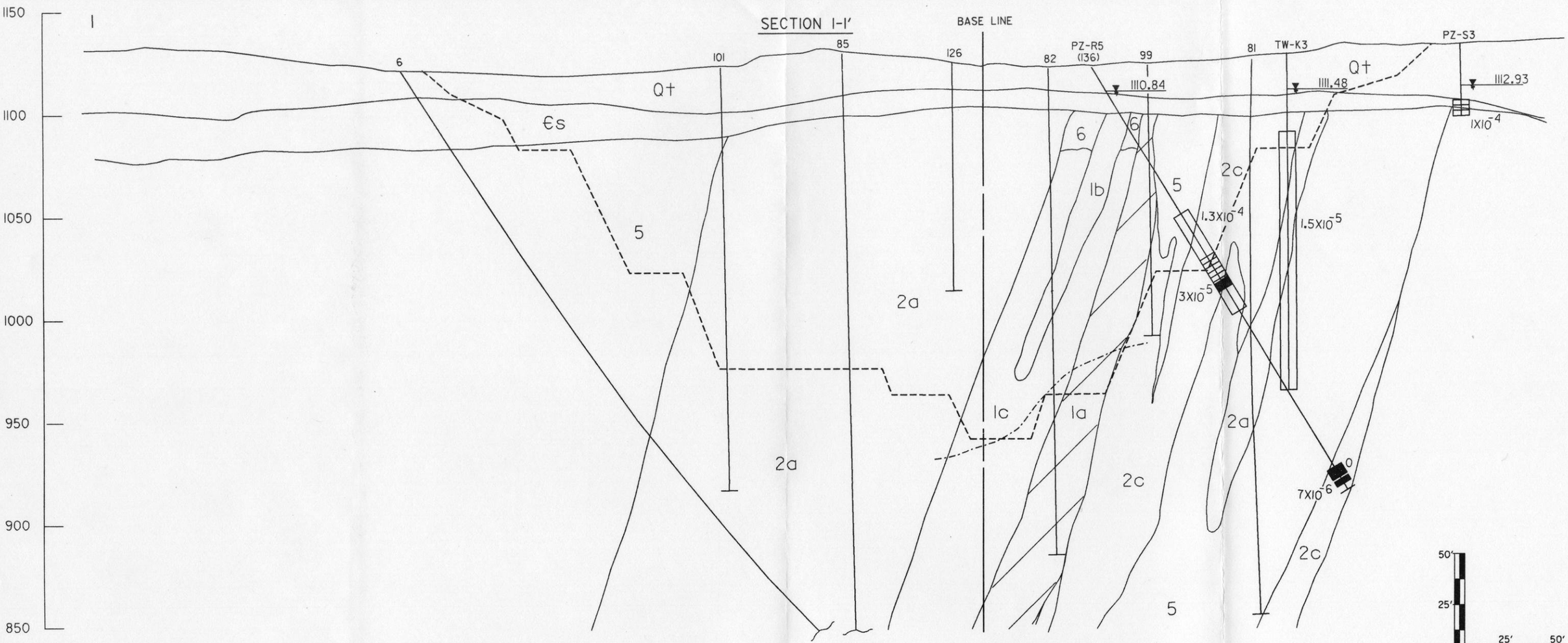
	DRAWN	CHK'D	DES. ENG'R	SECT ENG'R
BY	SAG	BJS		
DATE	2/89	3/89		

MICROFILM | JOB
DRAWING NO. | REV.
DIVISION DRAWING NO.
SCALE: SEE BAR SCALE

REFERENCES

DWG. NO.	DESCRIPTION

NO.	DATE	REVISIONS	BY	CHK'D	ENG'R	ENG'R MGR.



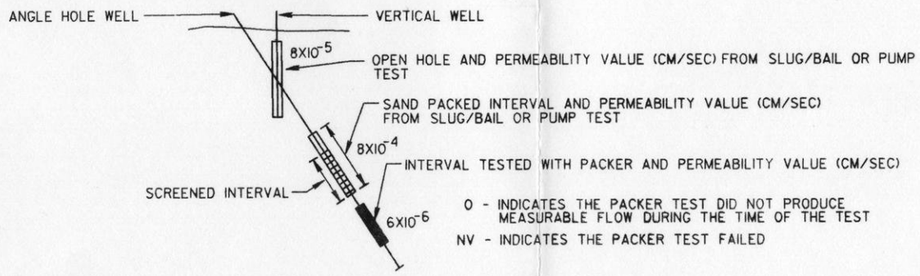
LEGEND

PLEISTOCENE
- Qt GLACIAL TILL

CAMBRIAN
- Es CAMBRIAN SANDSTONE

-ANGULAR UNCONFORMITY-

MIDDLE PRECAMBRIAN
- 4 CHLORITE SCHIST
  - 4a QUARTZ-CHLORITE SCHIST
  - 4b SPESSARTITE-CHLORITE SCHIST
  - 4c CHLORITE SCHIST
- 1 MINERALIZED HORIZON
  - 1a SERICITE-QUARTZ SCHIST
  - 1b METACHERT
  - 1c MASSIVE SULFIDE (>50 WT.%)
  - SEMI-MASSIVE SULFIDE (20-50 WT.%)
- 2 BIOTITE SCHIST
  - 2a ANDALUSITE-BIOTITE SCHIST
  - 2b ANDALUSITE-BIOTITE-SERICITE SCHIST
  - 2c BIOTITE SCHIST
- 3 AUGEN SCHIST
  - 3a QUARTZ-AUGEN SCHIST
- 5 METADACITE (VOLCANIC FLOW ROCK)
- 6 GOSSAN
- BASE OF SUPERGENE ENRICHMENT
- PROPOSED OPEN PIT PERIMETER



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155 MINERAL SQUARE
SALT LAKE CITY, UTAH 84112

FIGURE NO. 3.5-15
GEOLOGIC CROSS-SECTION I-I'
SECTION 410

	BY	DATE
PROJ. ENG'R		
MGR. PROCESS ENG'R		
ENG'R MGR.		
DESIGN		
DRAWN	SAG	2/89
CHK'D	BJS	3/89
DES. ENG'R		
SECT ENG'R		

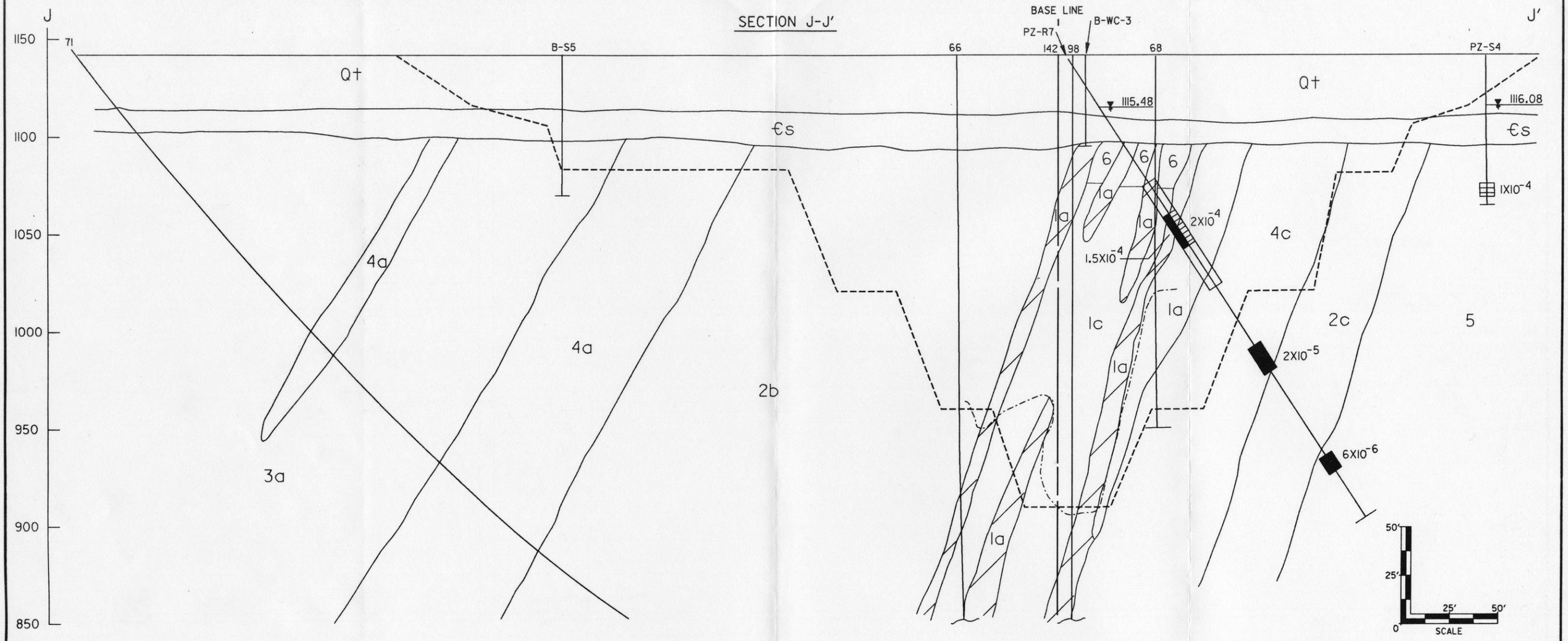
MICROFILM | JOB
DRAWING NO. | REV.
DIVISION DRAWING NO.
SCALE | SEE BAR SCALE

REFERENCES

DWG. NO.	DESCRIPTION

NO.	DATE	REVISIONS	BY	CHK'D	ENG'R	ENG'R MGR.

SECTION J-J'



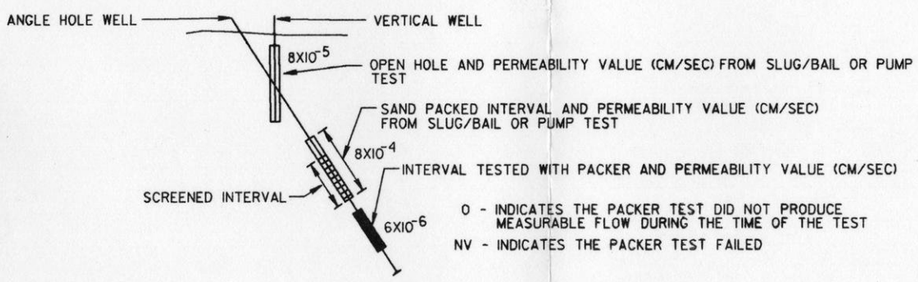
LEGEND

PLEISTOCENE
- Qt GLACIAL TILL

CAMBRIAN
- Cs CAMBRIAN SANDSTONE

-ANGULAR UNCONFORMITY-

MIDDLE PRECAMBRIAN
- 4 CHLORITE SCHIST
  - 4a QUARTZ-CHLORITE SCHIST
  - 4b SPESSARTITE-CHLORITE SCHIST
  - 4c CHLORITE SCHIST
- 1 MINERALIZED HORIZON
  - 1a SERICITE-QUARTZ SCHIST
  - 1b METACHERT
  - 1c MASSIVE SULFIDE (>50 WT.%)
  - SEMI-MASSIVE SULFIDE (20-50 WT.%)
- 2 BIOTITE SCHIST
  - 2a ANDALUSITE-BIOTITE SCHIST
  - 2b ANDALUSITE-BIOTITE-SERICITE SCHIST
  - 2c BIOTITE SCHIST
- 3 AUGEN SCHIST
  - 3a QUARTZ-AUGEN SCHIST
- 5 METADACITE (VOLCANIC FLOW ROCK)
- 6 GOSSAN
- BASE OF SUPERGENE ENRICHMENT
- PROPOSED OPEN PIT PERIMETER



0 - INDICATES THE PACKER TEST DID NOT PRODUCE MEASURABLE FLOW DURING THE TIME OF THE TEST

NV - INDICATES THE PACKER TEST FAILED

REFERENCES	DWG. NO.	DESCRIPTION

REFERENCES	DWG. NO.	DESCRIPTION

NO.	DATE	REVISIONS	BY	CHK'D	ENG'R	ENG'R MGR.

NO.	DATE	REVISIONS	BY	CHK'D	ENG'R	ENG'R MGR.

	BY	DATE
PROJ. ENG'R		
MGR. PROCESS ENG'R		
ENG'R MGR.		

	BY	DATE
DESIGN		
DRAWN	SAG	2/89
CHK'D	BJS	2/89
DES. ENG'R		
SECT ENG'R		

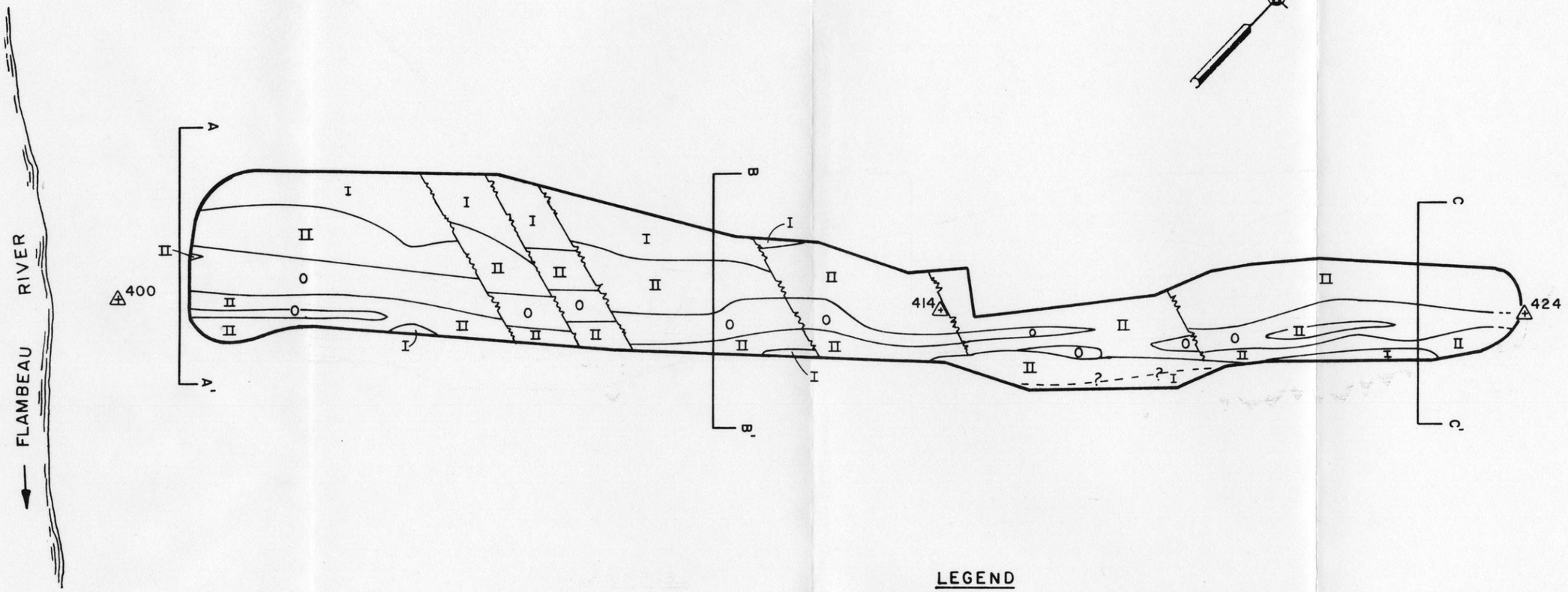
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SALT LAKE CITY, UTAH
84112

FIGURE NO. 3.5-16
GEOLOGIC CROSS-SECTION J-J'
SECTION 422

MICROFILM	JOB
DRAWING NO.	REV.
DIVISION DRAWING NO.	
SCALE	SEE BAR SCALE



LEGEND

- I — TYPE I WASTE ROCK (CONTAINS LESS THAN 1% SULFUR)
- II — TYPE II WASTE ROCK (CONTAINS MORE THAN 1% SULFUR)
- O — MASSIVE SULFIDE MINERALIZATION
- INFERRED FAULT
- PROPOSED PIT PERIMETER, 1000 FOOT BENCH LEVEL
- 400 BASELINE STATION

0 200' 400'
SCALE

REFERENCES

DWG. NO.	DESCRIPTION

REFERENCES

DWG. NO.	DESCRIPTION

NO.	DATE	REVISIONS	BY	CHK'D	ENG'R	ENG'R MGR.

NO.	DATE	REVISIONS	BY	CHK'D	ENG'R	ENG'R MGR.

	BY	DATE
PROJ. ENG'R		
MGR. PROCESS ENG'R.		
ENG'R MGR.		

	BY	DATE
DESIGN		
DRAWN	S.J.L.	1/89
CHK'D	BJS	3/89
DES. ENG'R		
SECT. ENG'R		

FOTH & VAN DYKE
GEOSCIENCES & ENVIRONMENTAL MANAGEMENT DIVISION
GREEN BAY, WISCONSIN

FLAMBEAU PROJECT
LADYSMITH, WISCONSIN

KENNECOTT MINERALS COMPANY
1515 MINERAL SQUARE
SALT LAKE CITY, UTAH
84112

FIGURE NO. 3.5-17
DISTRIBUTION OF SULFIDES
AT THE 1000 BENCH LEVEL
AND CROSS SECTION
LOCATION

MICROFILM	JOB
DRAWING NO.	REV.
DIVISION DRAWING NO.	
SCALE	



NOTES:

1. SITE LOCATION: SECTIONS 9, 10, 15 & 16, T34N, R6W, RUSK COUNTY, WISCONSIN.
2. TOPOGRAPHIC BASE MAP PREPARED FROM AERIAL SURVEY BY SURDEX CORPORATION, CHESTERFIELD, MISSOURI. DATE OF PHOTOGRAPHY - APRIL 24, 1970. ROADS, TREES AND BUILDINGS WERE UPDATED AS PER AERIAL PHOTOGRAPH TAKEN BY MARKHURD CORPORATON, MINNEAPOLIS, MINNESOTA. DATE OF PHOTOGRAPHY - SEPTEMBER 14, 1987.
3. ELEVATIONS BASED ON MEAN SEA LEVEL DATUM. CONTOUR INTERVAL IS TWO FEET.
4. HORIZONTAL DATUM BASED ON PROJECT SITE GRID SYSTEM. SITE GRID COORDINATES CORRELATION TO STATE PLANE COORDINATES DERIVED AS FOLLOWS:

SITE GRID COORDINATES CONTROL MONUMENT F-1	STATE PLANE COORDINATES
40000 N =	587,357.8087 N
40000 E =	1,713,516.1229 E

THE ANGULAR ROTATION FROM STATE PLANE BEARINGS TO SITE GRID BEARINGS IS 359-13'-23" RIGHT WITH CONTROL POINT F-1 AS THE BASE POINT.

REFERENCES	DWG. NO.	DESCRIPTION

REFERENCES	DWG. NO.	DESCRIPTION

NO.	DATE	REVISIONS	BY	CHK'D	ENG'R	ENGR MGR.

NO.	DATE	REVISIONS	BY	CHK'D	ENG'R	ENGR MGR.

	BY	DATE
PROJ. ENG'R		
MGR. PROCESS ENG'R		
ENGR. MGR.		

	BY	DATE
DESGN		
DRAWN	MJC	3/89
CHK'D	JGT	3/89
RES. ENG'R		
SECT. ENG'R		

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GEOSCIENCES & ENVIRONMENTAL MANAGEMENT DIVISION
GREEN BAY, WISCONSIN

FLAMBEAU PROJECT
LADYSMITH, WISCONSIN

KENNECOTT MINERALS COMPANY
555 MINERAL SQUARE
SALT LAKE CITY, UTAH 8412

FIGURE NO. 3.5-18
SOIL SAMPLE LOCATIONS

MICROFILM JOB
DRAWING NO REV.
DIVISION DRAWING NO.
SCALE SEE BAR SCALE



NOTES:

1. SITE LOCATION: SECTIONS 9, 10, 15 & 16, T34N, R6W, RUSK COUNTY, WISCONSIN.
2. TOPOGRAPHIC BASE MAP PREPARED FROM AERIAL SURVEY BY SURDEX CORPORATION, CHESTERFIELD, MISSOURI. DATE OF PHOTOGRAPHY - APRIL 24, 1970. ROADS, TREES AND BUILDINGS WERE UPDATED AS PER AERIAL PHOTOGRAPH TAKEN BY MARKHURD CORPORATON, MINNEAPOLIS, MINNESOTA. DATE OF PHOTOGRAPHY - SEPTEMBER 14, 1987.
3. ELEVATIONS BASED ON MEAN SEA LEVEL DATUM. CONTOUR INTERVAL IS TWO FEET.
4. HORIZONTAL DATUM BASED ON PROJECT SITE GRID SYSTEM. SITE GRID COORDINATES CORRELATION TO STATE PLANE COORDINATES DERIVED AS FOLLOWS:

SITE GRID COORDINATES CONTROL MONUMENT F-1	STATE PLANE COORDINATES
40000 N =	587,357.8087 N
40000 E =	1,713,516.1229 E

THE ANGULAR ROTATION FROM STATE PLANE BEARINGS TO SITE GRID BEARINGS IS 359°-13'-23" RIGHT WITH CONTROL POINT F-1 AS THE BASE POINT.

LEGEND

- 1100 — EXISTING CONTOUR
- EXISTING PAVED ROADWAY
- EXISTING TRAIL/GRAVEL SURFACE
- TREES AND/OR BRUSH
- FENCE
- F-1 CONTROL MONUMENT
- B-WC-2 WASTE CHARACTERIZATION BORING LOCATION AND NUMBER
- PZ-S3 GEOTECHNICAL WELL LOCATION AND NUMBER
- PROPOSED PIT PERIMETER

N

0 300' 600'
SCALE

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KENNECOTT MINERALS COMPANY
155 MINERAL SQUARE
SALT LAKE CITY, UTAH
8412

FIGURE NO. 3.5-19
TILL, SANDSTONE AND SAPROLITE SAMPLE LOCATIONS

MICROFILM | JOB
DRAWING NO. | REV.
DIVISION DRAWING NO.
SCALE SEE BAR SCALE

REFERENCES	DWG. NO.	DESCRIPTION

REFERENCES	DWG. NO.	DESCRIPTION

NO.	DATE	REVISIONS	BY	CHK'D	ENG'R	ENGR MGR.

NO.	DATE	REVISIONS	BY	CHK'D	ENG'R	ENGR MGR.

	BY	DATE
PROJ. ENG'R		
MGR. PROCESS ENG'R		
ENG'R MGR.		

	BY	DATE
DESIGN		
DRAWN	MJO	3/89
CHK'D	JHT	3/89
DES. ENG'R		
SECT. ENG'R		



NOTES:

1. SITE LOCATION: SECTIONS 9, 10, 15 & 16, T34N, R6W, RUSK COUNTY, WISCONSIN.
2. TOPOGRAPHIC BASE MAP PREPARED FROM AERIAL SURVEY BY SURDEX CORPORATION, CHESTERFIELD, MISSOURI. DATE OF PHOTOGRAPHY - APRIL 24, 1970. ROADS, TREES AND BUILDINGS WERE UPDATED AS PER AERIAL PHOTOGRAPH TAKEN BY MARKHURD CORPORATON, MINNEAPOLIS, MINNESOTA. DATE OF PHOTOGRAPHY - SEPTEMBER 14, 1987.
3. ELEVATIONS BASED ON MEAN SEA LEVEL DATUM. CONTOUR INTERVAL IS TWO FEET.
4. HORIZONTAL DATUM BASED ON PROJECT SITE GRID SYSTEM. SITE GRID COORDINATES CORRELATION TO STATE PLANE COORDINATES DERIVED AS FOLLOWS:

SITE GRID COORDINATES CONTROL MONUMENT F-1	STATE PLANE COORDINATES
40000 N =	587,357.8087 N
40000 E =	1,713,516.1229 E

THE ANGULAR ROTATION FROM STATE PLANE BEARINGS TO SITE GRID BEARINGS IS 359°-13'-23" RIGHT WITH CONTROL POINT F-1 AS THE BASE POINT.

LEGEND

- —1100— EXISTING CONTOUR
- EXISTING PAVED ROADWAY
- EXISTING TRAIL/GRAVEL SURFACE
- TREES AND/OR BRUSH
- FENCE
- F-1 CONTROL MONUMENT
- 70 DIAMOND DRILL HOLE LOCATION AND NUMBER
- PROPOSED PIT PERIMETER

0 300' 600'
SCALE

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FIGURE NO. 3.5-20
WASTE ROCK SAMPLE LOCATIONS

MICROFILM JOB
DRAWING NO. REV.
DIVISION DRAWING NO.
SCALE SEE BAR SCALE

REFERENCES	DWG. NO.	DESCRIPTION

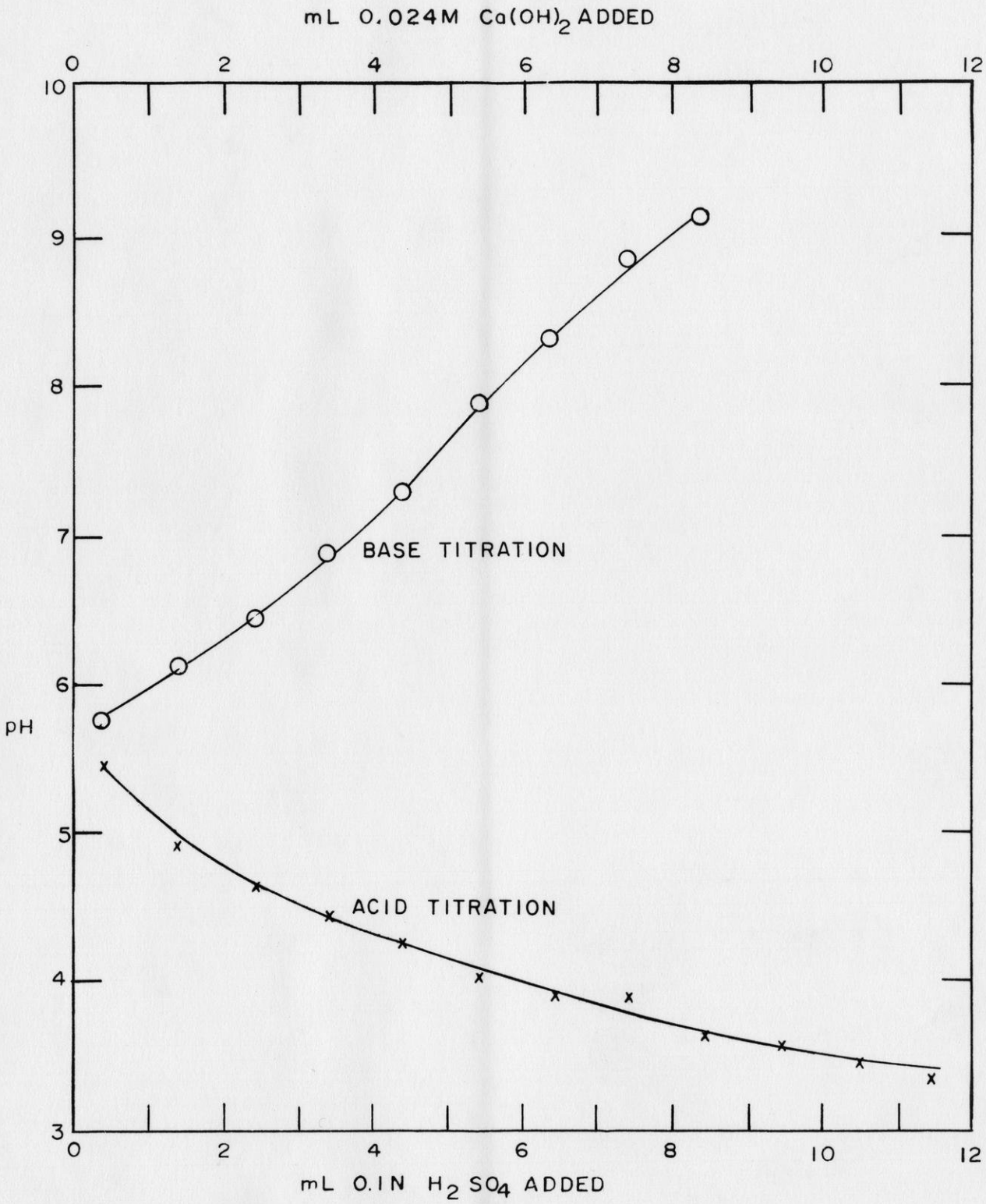
REFERENCES	DWG. NO.	DESCRIPTION

NO.	DATE	REVISIONS	BY	CHK'D	ENG'R	ENG'R MGR.

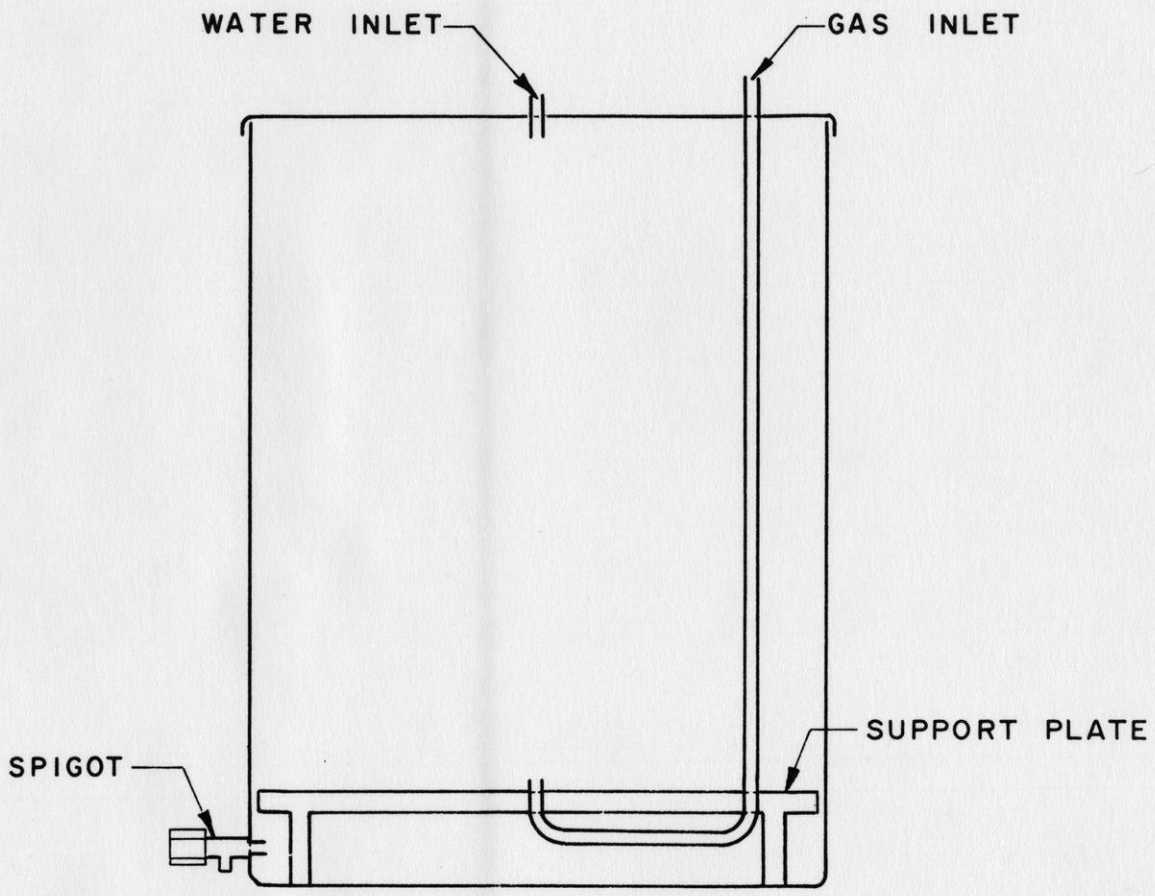
NO.	DATE	REVISIONS	BY	CHK'D	ENG'R	ENG'R MGR.

	BY	DATE
PROJ. ENG'R		
MGR. PROCESS ENG'R		
ENG'R MGR.		

	BY	DATE
DESIGN		
DRAWN	MJC	3/89
CHK'D	JVT	3/89
DES. ENG'R		
DEPT. ENG'R		



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NOTES	APPROVAL	DATE	FIGURE NO. 3.5-21 ACID AND BASE TITRATION OF WR-3 SUSPENSION
	DESIGNED BY		
	DRAWN BY R.D.M.	2/89	
	CHECKED BY J.E.T.	3/89	
	APPROVED BY		
	CAD No. SCALE NONE		Job No / Dwg No / REV



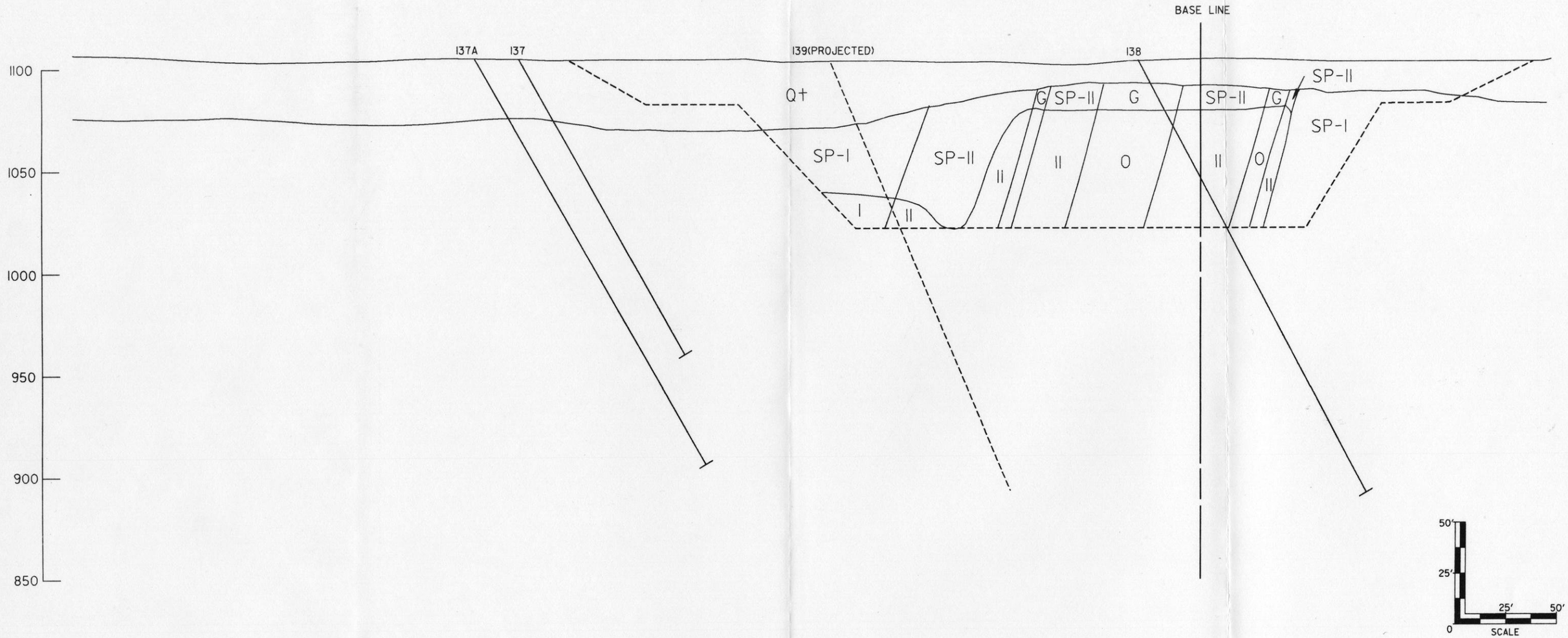
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KENNECOTT MINERALS COMPANY
FLAMBEAU PROJECT
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NOTES	APPROVAL		DATE
	DESIGNED BY		
	DRAWN BY	SJL	1/89
	CHECKED BY	JET	3/89
	APPROVED BY		
	CAD No.	SCALE NO SCALE	

FIGURE NO. 3.5-22
DETAIL OF LEACHING EXPERIMENT TANK

Job No	Dwg No	REV



LEGEND

- Q† QUATERNARY PLEISTOCENE UNCONSOLIDATED MATERIAL
- Cs PALEOZOIC CAMBRIAN SANDSTONE

PRECAMBRIAN

- G GOSSAN
- Sp SAPROLITE
- O MASSIVE, SEMI-MASSIVE SULFIDE ORE
- I TYPE I WASTE ROCK, CONTAINING < 1% SULFUR
- II TYPE II WASTE ROCK, CONTAINING > 1% SULFUR
- ---- PROPOSED PIT PERIMETER

REFERENCES	DWG. NO.	DESCRIPTION

REFERENCES	DWG. NO.	DESCRIPTION

NO.	DATE	REVISIONS	BY	CHK'D	ENG'R	ENG'R MGR.

NO.	DATE	REVISIONS	BY	CHK'D	ENG'R	ENG'R MGR.

	BY	DATE
PROJ. ENG'R		
MGR. PROCESS ENG'R		
ENG'R MGR.		

	BY	DATE
DESIGN		
DRAWN	SAG	2/85
CHK'D	JET	3/85
DES. ENG'R		
SECT ENG'R		

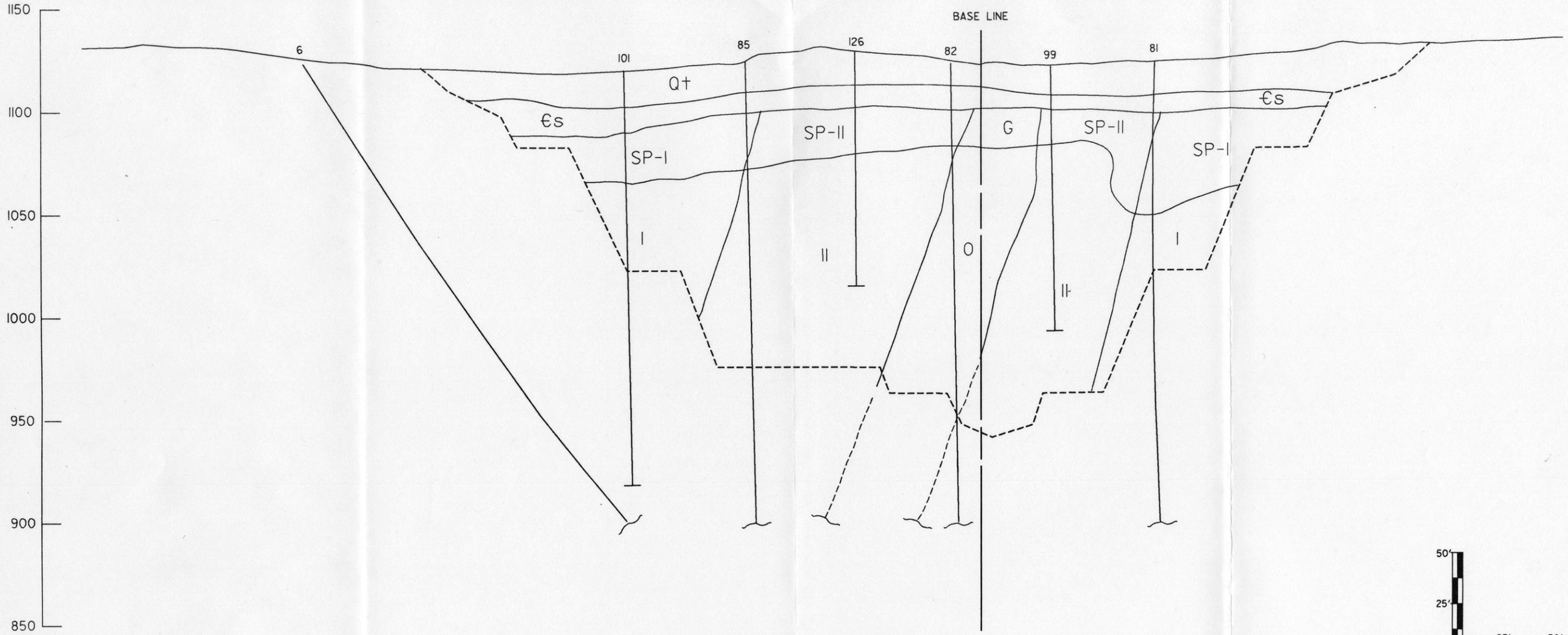
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FIGURE NO. 3.5-23
GEOLOGIC CROSS-SECTION
SECTION 40'
WASTE ROCK AND
MATERIAL WASTE DELINEATIONS

MICROFILM	JOE
DRAWING NO.	REV.
DIVISION DRAWING NO.	
SCALE	SEE BAR SCALE



LEGEND

- Q+ QUATERNARY PLEISTOCENE UNCONSOLIDATED MATERIAL
- €s PALEOZOIC CAMBRIAN SANDSTONE

PRECAMBRIAN

- G GOSSAN
- Sp SAPROLITE
- O MASSIVE, SEMI-MASSIVE SULFIDE ORE
- I TYPE I WASTE ROCK, CONTAINING < 1% SULFUR
- II TYPE II WASTE ROCK, CONTAINING > 1% SULFUR
- ---- PROPOSED PIT PERIMETER

REFERENCES

DWG. NO.	DESCRIPTION

REFERENCES

DWG. NO.	DESCRIPTION

NO.	DATE	REVISIONS	BY	CHK'D	ENG'R	ENG'R MGR.

NO.	DATE	REVISIONS	BY	CHK'D	ENG'R	ENG'R MGR.

	BY	DATE
PROJ. ENG'R		
MGR. PROCESS ENG'R		
ENG'R MGR.		

	BY	DATE
DESIGN		
DRAWN	JAG	2/89
CHK'D	JWF	3/89
DES. ENG'R		
SECT ENG'R		

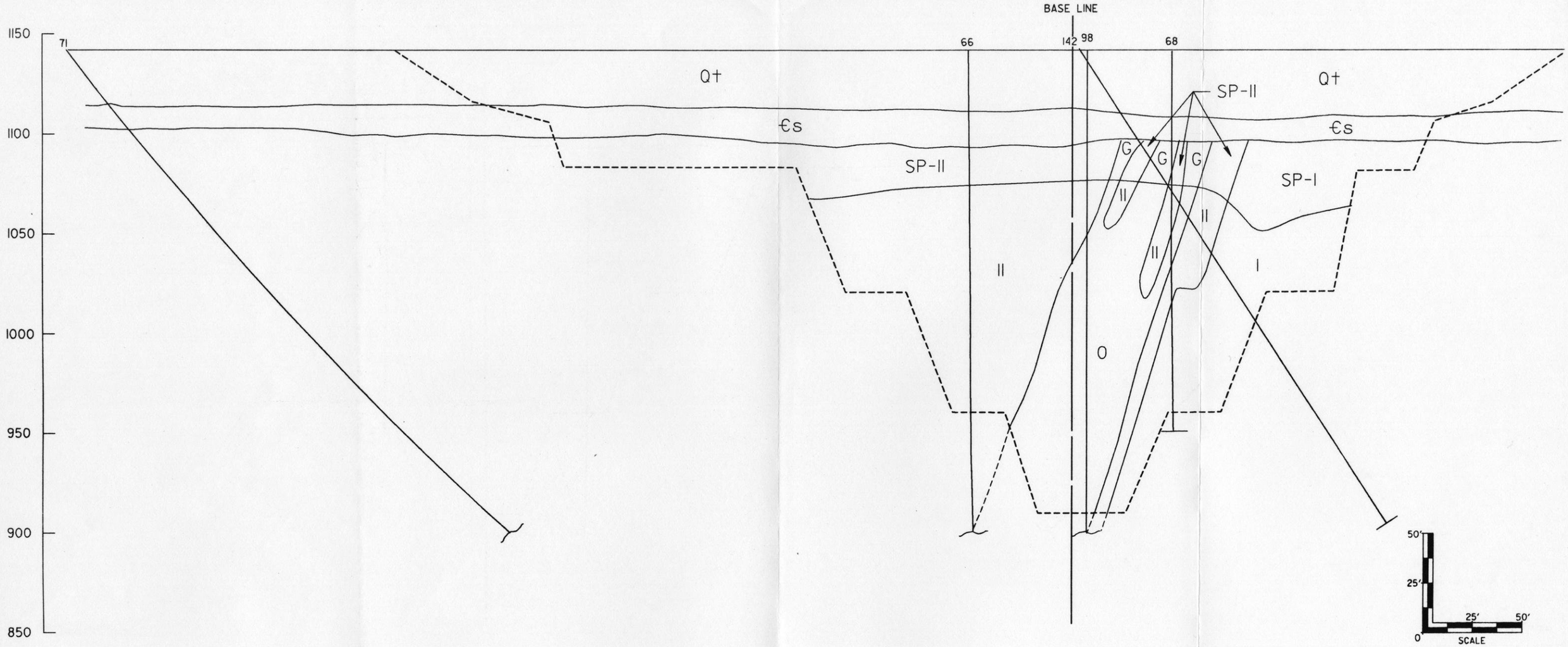
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FIGURE NO. 3.5-24
GEOLOGIC CROSS-SECTION
SECTION 410
WASTE ROCK AND
MATERIAL WASTE DELINEATIONS

MICROFILM	JOB
DRAWING NO.	REV.
DIVISION DRAWING NO.	
SCALE	SEE BAR SCALE



LEGEND

- Q† QUATERNARY PLEISTOCENE UNCONSOLIDATED MATERIAL
- €s PALEOZOIC CAMBRIAN SANDSTONE

PRECAMBRIAN

- G GOSSAN
- SP SAPROLITE
- O MASSIVE, SEMI-MASSIVE SULFIDE ORE
- I TYPE I WASTE ROCK, CONTAINING < 1% SULFUR
- II TYPE II WASTE ROCK, CONTAINING > 1% SULFUR
- ---- PROPOSED PIT PERIMETER

REFERENCES	DWG. NO.	DESCRIPTION

REFERENCES	DWG. NO.	DESCRIPTION

NO.	DATE	REVISIONS	BY	CHK'D	ENG'R	ENG'R MGR.

NO.	DATE	REVISIONS	BY	CHK'D	ENG'R	ENG'R MGR.

	BY	DATE
PROJ. ENG'R		
MGR. PROCESS ENG'R		
ENG'R MGR.		

	BY	DATE
DESIGN		
DRAWN	SAG	2/89
CHK'D	JMT	3/89
DES. ENG'R		
SECT ENG'R		

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84112

FIGURE NO. 3.5-25
GEOLOGIC CROSS-SECTION
SECTION 422
WASTE ROCK AND
MATERIAL WASTE DELINEATIONS

MICROFILM | JOB
DRAWING NO. | REV.
DIVISION DRAWING NO.
SCALE SEE BAR SCALE

3.6 Groundwater

Existing hydrogeologic and groundwater quality conditions in the vicinity of the proposed mine are discussed in this section. A discussion of these conditions is presented in the following four sub-sections:

3.6.1 Field and Laboratory Methods - discusses the procedures followed during data acquisition from the project site's 92 monitoring wells.

3.6.2 Regional Hydrogeology - discusses hydrogeologic conditions within a five-mile radius of the project area as set forth in NR182.08(2)(c)4.

3.6.3 Project Site Hydrogeology - discusses hydrogeologic conditions within the project area (generally, south of Blackberry Lane, east of the Flambeau River, north of Meadowbrook Creek, and west of Meadowbrook Road.

3.6.4 Groundwater Quality - discusses groundwater quality within the project area.

3.6.1 Field and Laboratory Methods

Extensive hydrogeologic information was collected as part of the 1976 EIS and Mining Permit Application preparations. These data, derived from the installation and testing of 42 monitoring wells, were used in part to determine the groundwater flow and chemistry characteristics within the glacial fluvial and till deposits (i.e., glacial overburden) and the sandstone of the project area. The 1976 effort did not characterize groundwater flow within the Precambrian bedrock because of its low permeability and small impact on the overall hydrologic regime. King (1983) presented, as a Ph.D. dissertation, a hydrogeologic and groundwater modeling study of the project site. This effort summarized site hydrogeology and estimated the hydrologic impacts of the proposed project assuming the 1976 mining plan.

To expand upon and verify this previous work, hydrogeological field and laboratory investigations, involving the installation and testing of 50 additional monitoring wells, were conducted from 1987 to 1989 to further define:

1. The nature and orientation of the groundwater flow in the glacial overburden, sandstone, and Precambrian units.

2. Background groundwater quality from samples collected from monitoring wells at the project site and from private water supply wells near the project site.

Data acquisition methods are first presented for the previous hydrogeologic investigations, including the King dissertation,

and then for the 1987-89 hydrogeologic investigation.

3.6.1.1 Previous Initial Hydrogeologic Investigations

The hydrogeological investigations conducted during the 1970s and early 1980s included the installation of water wells and piezometers for water level measurements and single well aquifer response tests (KEN-35, 1987), and the performance of pump tests (KEN-36, 1987). Methods followed for each of the above investigations are presented below.

3.6.1.1.1 Water Wells and Piezometers

In 1970 and 1971, 20 water wells, OW-1 through OW-20, were drilled north and south of the 1976 proposed open pit. Also drilled in 1971 were two large-diameter (ten inches) pump test wells, OTW-29 and OTW-34. In 1972, seven additional wells, OW-39 through OW-45, were drilled in the vicinity of the proposed open pit. Also, in 1972, one groundwater well (ST-9-2) was installed in the northeast portion of the proposed open pit. In 1973, 12 additional groundwater wells were installed in the vicinity of the 1976 proposed open pit. These wells were labeled ST-9-17A, ST-9-19A to ST-9-23A, ST-9-23, ST-9-24, ST-9-26, and ST-9-27A to ST-9-29A. The drilling and soil sampling methods used for the above water well and piezometer borings are described in Section 3.5.1.2 of this report. Well locations are shown on Figure No. 3.5-2. Well construction information and geologic logs of these wells are included as Appendix 3.5-C.

The water wells (OW and OTW designation) were installed using air rotary techniques and were constructed of black steel casing with torch-cut slots. Some wells were slotted over more than one depth interval. Therefore, water quality data collected from the wells in the 1970s are not used for this report. However, water level measurements from wells that were slotted over only one depth interval provide useful data. Logs of the boring cuttings provide useful geologic information, such as the depth to the top of the Precambrian surface.

Piezometers (ST designation) were drilled with hollow-stem augers and constructed with 1.25-inch PVC screen and casing surrounded by pea gravel backfill.

From the date of installation through December 1980, depth to groundwater measurements were taken periodically on all of the OW and OTW waterwells, and on selected ST piezometers (KEN-35, 1977). Hydrographs of water level elevations in many of these wells for this period of record are contained in Appendix 3.6-A.

3.6.1.1.2 Pump Test and Single-Well Aquifer Response Tests

In 1971 and 1972 several of the water wells (OW-5, 6, 8, 9, 18, 29, 34, 39, 40, 41, 42, and 43) were pumped. Transmissivity values were calculated (KEN-36, 1976) from drawdown and recovery water levels in the pumping and nearby wells. Permeability was calculated by dividing the transmissivity by the estimated unit saturated thickness. These data are summarized on Table No. 3.6-1.

Subsequent to each ST piezometer installation, falling head or constant head permeability tests were performed. Results of these tests are provided in Table No. 3.6-2. It should be noted that the screens of these piezometers were wrapped with filter fabric, which is likely to lead to an underestimate of permeability. Therefore these data were used only for comparative purposes in the evaluations performed in this report.

3.6.1.2 1987 to 1989 Hydrogeological Investigations

From 1987 to 1989 several hydrogeologic investigations were completed including: baseline groundwater monitoring well and piezometer installation; groundwater level measurements; 12-month baseline groundwater monitoring program; single-well aquifer response tests; and multi-well pump tests. Subsections discussing the methods used in these investigations are presented below.

3.6.1.2.1 Well and Piezometer Installation

During the period of September 1987 to November 1988, 50 additional groundwater wells and piezometers were installed at the project site. Wells were installed for several different purposes.

In September and October 1987, 15 baseline groundwater monitoring wells, MW-1000 through MW-1005P, as listed on Table No. 3.5-1, were installed to provide groundwater samples for establishing baseline water quality. The wells comprise six nests; locations are indicated on Figure No. 3.5-2. Groundwater samples were also taken, though at a lesser frequency, from well nest PZ-1006. The nests consist of a water table well, a piezometer in the Pleistocene sediments or Cambrian sandstone, and/or a piezometer installed in the upper 50 feet of the Precambrian rock. The drilling of the wells is described in Section 3.5.1.4.1 of this report. Well construction data are summarized on Table No. 3.6-3 and well construction diagrams and well development forms are included in Appendix 3.5-D.

The wells were constructed of two-inch-diameter PVC casing and well screens. Schedule 40 PVC was used for shallow wells in

TABLE NO. 3.6-1

Summary of Data From 1971 Pump Tests

Well No.	Pump Rate (gpm)	Maximum Duration (minutes)	Maximum Drawdown (ft)	Calculated Average Transmissivity (gdf)	Calculated Permeability (cm/sec)	Geologic* Material	Observation Wells Used
OW-5	0.5	42	>16	12	1.1×10^{-5}	Till (and SS)	29, 49
OW-6	2.3	54	--	32	3.0×10^{-5}	Till (and SS)	?
OW-8	7.7	?	8 to 14	2,000	3.8×10^{-3}	SS, S&G	41, 42
OW-9	22 to 52	220	2 to 15	10,000	1.3×10^{-2}	S&G	43
OW-10	0.7 to 1.1	?	8 to 8.5	47	6.3×10^{-5}	Till, and/or S&G	?
OW-16	5.1 to 6.3	?	16.3 to 16.6	2,000	1.3×10^{-3}	S&G	?
OW-18	43 to 52.3	210	9.3	50,000	2.8×10^{-2}	S&G	?
OTW-29	18.2	479	16	2,000	4.7×10^{-3}	S&G	30, 31, 32, 33
OTW-34	2.6 to 6.2	107	14 to 21	400	4.7×10^{-4}	Till, and/or S&G	35, 36, 37, 38
OW-39	1.5	75	8.8	70	2.2×10^{-4}	Till	40
OW-40	2.2	60	4.2	290	2.0×10^{-3}	Till	39, 41
OW-41	13.4	120	12.2	850	2.5×10^{-3}	S&G	8
OW-42	8.9	1,500	17.0	2,000	4.7×10^{-3}	S&G	8, 9, 29, 31, 33
OW-43	39.9	240	0.9	24,000	2.3×10^{-2}	S&G	9

*Approximated from well log, gamma log, and/or adjacent sampled borings.

TABLE NO. 3.6-2

Summary of Field Permeability
Conducted by STS (1973)

Test No.	Permeability cm/sec	Description of Zone Tested
ST9-17A	1.38×10^{-3}	Fine coarse sand trace to some gravel-trace silt (SW)
ST9-18	1.96×10^{-8}	Fine coarse sand some fine coarse gravel-trace silt (SW-SM)
ST9-19	2.00×10^{-3}	Sandstone
ST9-19A	3.75×10^{-3}	Fine coarse sand-some fine coarse gravel-trace silt (SW)
ST9-20A	1.56×10^{-6}	1.5′ of fine coarse sand with gravel 5.5′ sandstone
ST9-21	4.64×10^{-4}	Sandstone
ST9-22	2.83×10^{-8}	Sandstone
ST9-22A	9.37×10^{-4}	Fine coarse sand-trace to some gravel-trace silt (SW)
ST9-23	1.00×10^{-3}	Sandstone
ST9-23A	2.35×10^{-3}	Fine coarse sand-some fine medium gravel-trace silt (SW)
ST9-24	1.13×10^{-3}	Sandstone
ST9-25	7.27×10^{-4}	Silty fine coarse sand-trace to some gravel (SM)
ST9-26	5.1×10^{-6}	Silty fine coarse sand-trace to some gravel-trace clay (SM)
ST9-27B	1.70×10^{-5}	Silty fine coarse sand-trace to some gravel-trace clay (SM)
ST9-28B	4.0×10^{-4}	Fine coarse sand-trace to some silt-trace gravel (SM)
ST9-29	4.09×10^{-5}	Silty fine coarse sand-trace to some gravel (SM)

TABLE NO. 3.6-3

Summary of Well Construction Data - Baseline Monitoring Wells

Well No.	MW-1000	MW-1000P	MW-1001	MW-1001G	MW-1001P	MW-1002	MW-1002G	MW-1003
Installation date	10/87	10/87	9/87	9/87	10/87	9/87	9/87	9/87
Elevation of measuring point MSL (ft)	1101.92	1101.75	1143.32	1143.47	1143.26	1103.84	1104.04	1145.58
Ground elevation MSL (ft)	1099.59	1099.38	1141.01	1141.15	1140.78	1101.63	1101.71	1143.41
Casing diameter (inches)	2	2	2	2	2	2	2	2
Type of casing	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC
Casing length (from ground surface) (ft)	9	50	22.5	46.5	89.5	5.5	46.5	30.2
Screen diameter (inches)	2	2	2	2	2	2	2	2
Screen length (ft)	10	5	10	5	5	10	5	10
Type of screen	PVC	PVC	PVC	PVC	PVC	PVC	PVC	PVC
Screen slot size (inches)	0.006	0.010	0.010	0.010	0.006	0.010	0.010	0.010
Screened interval (depth in feet)	9-19	50-55	22.5-32.5	46.5-51.5	89.5-94.5	5.5-15.5	46.5-51.5	30.2-40.2
Screened interval (elevation MSL in feet)	1091-1081	1049-1044	1118-1108	1095-1090	1051-1046	1096-1086	1055-1050	1113-1103
Sand pack interval (depth in feet)	6-19	48-55	17.5-33	44.5-53.5	87.5-95	4-16	44.5-52	25.2-40.8
Sand pack interval (elevation MSL in feet)	1094-1081	1051-1046	1124-1108	1097-1088	1053-1046	1098-1086	1057-1050	1118-1103
Type of seal	Bentonite Pellets	Bentonite Pellets & Grout	Bentonite Pellets & Grout	Bentonite Pellets & Grout	Bentonite Pellets & Grout	Bentonite Pellets & Grout	Bentonite Pellets & Grout	Bentonite Pellets & Grout
Depth of borehole (ft)	19	55	33	53.5	95	16	52	40.8
Strata of Completion	Precambrian Rock, & Till	Precambrian Rock	Till	Till, & Sandstone	Precambrian Rock	Sand & Gravel	Sand & Gravel	Sandstone

TABLE NO. 3.6-3 (Cont.)

Well No.	MW-1003P	MW-1004	MW-1004S	MW-1004P	MW-1005	MW-1005S	MW-1005P
Installation date	10/87	9/87	9/87	9/87	9/87	9/87	10/87
Elevation of measuring point MSL (ft)	1145.60	1126.20	1125.77	1126.25	1144.11	1144.02	1144.13
Ground elevation MSL (ft)	1143.16	1123.80	1123.55	1123.91	1141.95	1141.89	1141.67
Casing diameter (inches)	2	2	2	2	2	2	2
Type of casing	PVC	PVC	PVC	PVC	PVC	PVC	PVC
Casing length (from ground surface) (ft)	81.5	11.5	30.8	82	8	42.3	86
Screen diameter (inches)	2	2	2	2	2	2	2
Screen length (ft)	5	10	5	5	10	5	5
Type of screen	PVC	PVC	PVC	PVC	PVC	PVC	PVC
Screen slot size (inches)	0.006	0.010	0.010	0.006	0.010	0.010	0.006
Screened interval (depth in feet)	81.5-86.5	11.5-21.5	30.8-35.8	82-87	8-18	45.3-50.3	86-91
Screened interval (elevation MSL in feet)	1062-1057	1112-1102	1093-1088	1042-1037	1134-1124	1097-1092	1056-1051
Sand pack interval (depth in feet)	79.5-86.5	7-21.5	28.8-38.4	79-87	6-18.5	42.3-51.5	84-91
Sand pack interval (elevation MSL in feet)	1064-1057	1117-1102	1095-1085	1045-1036	1136-1123	1100-1090	1058-1051
Type of seal	Bentonite Pellets & Grout	Bentonite Pellets & Grout	Bentonite Pellets & Grout	Bentonite Pellets & Grout	Bentonite Pellets & Grout	Bentonite Grout	Bentonite Pellets & Grout
Depth of borehole (ft)	86.5	21.5	38.4	87.5	18.5	51.5	91.5
Strata of Completion	Precambrian Rock	Sand & Gravel	Sandstone	Precambrian Rock	Till	Sandstone	Precambrian Rock

unconsolidated sediment; Schedule 80 PVC was used in the wells constructed in bedrock. In each nest, ten-foot- and five-foot-long screens were used for the water table wells and the deeper piezometers, respectively. Screens were factory-slotted with 0.010- or 0.006-inch slots. Joints were flush-threaded.

Filter packs consisting of #30-sieve, silica-based sand were placed around the screens. The filter packs extend approximately five feet above the top of the screens of the water table wells and approximately two feet above the top of the piezometer screens. A bentonite pellet seal at least two feet thick was placed above the filter pack. Bentonite grout was emplaced using a tremie pipe from the top of the bentonite pellets to the ground surface to seal the annular space. The grout was allowed to settle for at least 24 hours and was then topped off to a few feet below the ground surface. Four- or six-inch diameter protective steel casings with locking caps were installed. A sloping concrete apron was placed around the protective steel casing.

The wells were developed by surging and bailing until the water removed was clear of drilling fluid and excess fine sediment. Wells that could be bailed dry were allowed to recover and then surged and bailed. The procedure was repeated until the water cleared.

In addition to the baseline monitoring wells, a total of 35 other piezometers and test wells were installed from 1987 to 1988. The piezometers and test wells were installed for several hydrogeologic programs.

Five, two-inch diameter piezometers were installed to investigate the hydrogeologic conditions in the vicinity of the wetland areas located in the project area. Piezometers PZ-1A and PZ-1B were installed between Wetland Areas 1 and 2, immediately northwest of the proposed open pit. Piezometers PZ-1006, 1006G, and 1006S are located between the proposed open pit and Wetland Area 10a, across HWY 27 to the east. The locations for these piezometers are indicated on Figure 3.5-2. Well construction data for these piezometers are summarized on Table No. 3.6-4. The methods used for drilling and sampling of the borings for these piezometers are described in Section 3.5.1.4.2. Piezometers were installed and developed following the procedure described above. Piezometer construction and well development forms are included in Appendix 3.5-E.

Eleven, two-inch-diameter piezometers were installed to provide additional hydrogeological data for the calculation of permeabilities and the measurement of hydraulic gradients. These piezometers were labeled PZ-1007S, 1008 1008G, 1009, 1009G, SP6, SP8, K2P, K2PP, K4P, and K4PP. Piezometer locations are indicated on Figure 3.5-2. Piezometer construction data are summarized on Table No. 3.6-5. The methods used for drilling and sampling of the borings for these piezometers are described

TABLE NO. 3.6-4

Summary of Well Construction Data - Wetland Piezometers

Well No.	PZ-1006	PZ-1006S	PZ-1006G	PZ-1B	PZ-1A
Installation date	9/87	9/87	9/87	10/87	10/87
Elevation of measuring point MSL (ft)	1149.77	1149.79	1149.71	1106.29	1106.20
Ground elevation MSL (ft)	1147.50	1147.59	1147.39	1103.50	1103.50
Casing diameter (inches)	2	2	2	2	2
Type of casing	PVC	PVC	PVC	PVC	PVC
Casing length (from ground surface) (ft)	5	47	28	0.9	4.3
Screen diameter (inches)	2	2	2	2	2
Screen length (ft)	5	5	5	2	2
Type of screen	PVC	PVC	PVC	PVC	PVC
Screen slot size (inches)	0.010	0.010	0.010	0.010	0.010
Screened interval (depth in feet)	5-10	47-52	28-33	0.9-2.9	4.3-6.3
Screened interval (elevation MSL in feet)	1143-1138	1101-1096	1119-1114	1103-1101	1099-1097
Sand pack interval (depth in feet)	4-10	45-53.8	26-33	0.9-2.9	3.8-6.3
Sand pack interval (elevation MSL in feet)	1144-1138	1103-1094	1121-1114	1103-1101	1100-1097
Type of seal	Bentonite Pellets	Bentonite Pellets & Grout	Bentonite Pellets & Grout	Bentonite Pellets	Bentonite Pellets & Powder
Depth of borehole (ft)	10	53.8	33	2.9	6.3
Strata of Completion	Till	Sandstone	Till	Sand & Gravel	Sand & Gravel

TABLE NO. 3.6-5

Summary of Well Construction Data - Permeability/Gradient Wells

Well No.	PZ-1007S	PZ-1008	PZ-1008G	PZ-1009	PZ-1009G	PZ-K2P	PZ-K2PP
Installation date	11/88	11/88	11/88	11/88	11/88	11/88	11/88
Elevation of measuring point MSL (ft)	1155.09	1147.19	1147.01	1154.03	1154.14	1105.05	1105.13
Ground elevation MSL (ft)	1153.15	1145.43	1145.28	1152.59	1152.44	1102.3	1102.3
Casing diameter (inches)	2	2	2	2	2	2	2
Type of casing	PVC	PVC	PVC	PVC	PVC	PVC	PVC
Casing length (from ground surface) (ft)	43	7	49.2	8.4	45.3	110	187
Screen diameter (inches)	2	2	2	2	2	2	2
Screen length (ft)	5	10	5	10	5	5	5
Type of screen	PVC	PVC	PVC	PVC	PVC	PVC	PVC
Screen slot size (inches)	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Screened interval (depth in feet)	43-48	7-17	49.2-54.2	8.4-18.4	45.3-50.3	110-115	187-192
Screened interval (elevation MSL in feet)	1110-1105	1138-1128	1096-1091	1144-1134	1107-1102	992-987	915-910
Sand pack interval (depth in feet)	40.4-49	5-18	48.3-55.4	5.4-18.4	43.4-50.3	106-121	184-193
Sand pack interval (elevation MSL in feet)	1113-1104	1140-1127	1097-1090	1147-1134	1109-1102	996-981	918-909
Type of seal	Bentonite Pellets & Grout	Bentonite Pellets & Grout	Bentonite Pellets & Grout	Bentonite Pellets & Grout	Bentonite Pellets & Grout	Bentonite Grout	Bentonite Grout
Depth of borehole (ft)	64.6	31	56.5	25	50.3	193	193
Strata of Completion	Sandstone	Till	Sand & Gravel	Till	Till	Precambrian Rock	Precambrian Rock

TABLE NO. 3.6-5 (Cont.)

Well No.	PZ-K4P	PZ-K4PP	PZ-SP6	PZ-SP8
Installation date	11/88	11/88	11/88	11/88
Elevation of measuring point MSL (ft)	1143.04	1143.12	1156.13	1144.39
Ground elevation MSL (ft)	1140.1	1140.1	1154.8	1142.8
Casing diameter (inches)	2	2	2	2
Type of casing	PVC	PVC	PVC	PVC
Casing length (from ground surface) (ft)	85	151	14.3	10
Screen diameter (inches)	2	2	2	2
Screen length (ft)	5	5	10	10
Type of screen	PVC	PVC	PVC	PVC
Screen slot size (inches)	0.010	0.010	0.010	0.010
Screened interval (depth in feet)	85-90	151-156	14.3-24.3	10-20
Screened interval (elevation MSL in feet)	1055-1050	989-984	1140-1130	1133-1123
Sand pack interval (depth in feet)	81-93	148-161	11.3-24.3	7-20
Sand pack interval (elevation MSL in feet)	1059-1047	992-979	1144-1130	1136-1123
Type of seal	Bentonite Grout	Bentonite Grout	Bentonite Pellets & Grout	Bentonite Pellets & Cement
Depth of borehole (ft)	183	183	24.3	20
Strata of Completion	Precambrian Rock	Precambrian Rock	Till & Silt	Till w/ Sand Seams

in Section 3.5.1.4.4. Well construction and well development forms are included in Appendix 3.5-H.

Nine piezometers, five deep and four shallow, were installed in bedrock for the geotechnical testing program. The deep piezometers, labeled PZ-R1, R2, R3, R5, and R7, extend to depths ranging from 120 to 220 feet. The shallow borings extend into the Precambrian rock to depths varying from 16 to 25 feet. Three of these (PZ-S1, PZ-S2, and PZ-S4) were completed as piezometers in the shallow Precambrian rock and one (PZ-S3) was completed in the sandstone. The methods used for drilling and sampling of the borings for these piezometers are described in Section 3.5.1.6.2 and Section 3.5.1.6.3. Wells were installed and developed using the procedure described above with exceptions as noted in Sections 3.5.1.6.2 and 3.5.1.6.3. Piezometer locations are shown on Figure No. 3.5-2 and construction data are summarized on Table No. 3.6-6. Well construction and well development forms are included in Appendix 3.5-I.

Six, six-inch-diameter, open-hole wells, TW-K1 through TW-K6, were installed to investigate the general permeability of the Precambrian rock along the proposed pit perimeter. These six wells were cased down into the Precambrian rock to prevent cave-in of the glacial overburden and sandstone units and to hydraulically isolate the rock from the overburden. However, in three of the wells (TW-K3, TW-K5, and TW-K6) the rock itself caved shortly after drilling. These wells were replaced by test wells TW-3R, TW-5R, and TW-K6R, in which were placed four-inch-diameter PVC pipe and slotted screens.

In addition, two test wells, TW-K17B and TW-K7, were constructed of four-inch diameter PVC and slotted screens. These wells were screened in glacial fluvial sediment located between the west end of the proposed pit and the Flambeau River, and were designed to confirm unit permeability. Also, a two-inch diameter, shallow piezometer (PZ-K8) was installed for permeability testing of the Precambrian rock in the area between the proposed pit and the Flambeau River. The location of the test wells is shown on Figure No. 3.5-2. Well construction data is summarized on Table No. 3.6-7. The methods used for drilling, sampling, installing, and developing the wells is described in Section 3.5.1.4.3. Well construction diagrams and well development forms are included in Appendix 3.5-G.

A sandpoint was installed adjacent to the Flambeau River at the southwest end of the pit. This well, installed in permeable sand two feet from the river's edge, was used to determine the surface elevation of the river during monitoring events when groundwater measurements were made. The location of the sandpoint is indicated in Figure No. 3.5-2.

TABLE NO. 3.6-6

Summary of Well Construction Data - Geotechnical Piezometers

Well No.	PZ-S1	PZ-S2	PZ-S3	PZ-S4
Installation date	12/87	12/87	10/87	12/87
Elevation of measuring point MSL (ft)	1103.07	1105.79	1131.43	1144.03
Ground elevation MSL (ft)	1101.61	1103.40	1128.98	1141.19
Casing diameter (inches)	2	2	2	2
Type of casing	PVC	PVC	PVC	PVC
Casing length (from ground surface) (ft)	35	26.5	28.5	67.5
Screen diameter (inches)	2	2	2	2
Screen length (ft)	5	5	5	5
Type of screen	PVC	PVC	PVC	PVC
Screen slot size (inches)	0.006	0.006	0.010	0.006
Screened interval (depth in feet)	35-40	26.5-31.5	28.5-33.5	67.5-72.5
Screened interval (elevation MSL in feet)	1067-1062	1077-1072	1100-1095	1074-1069
Sand pack interval (depth in feet)	33-41.5	24.5-31.5	26-34	65.5-72.5
Sand pack interval (elevation MSL in feet)	1067-1060	1079-1072	1103-1095	1076-1069
Type of seal	Bentonite Pellets & Grout	Bentonite Pellets & Grout	Bentonite Pellets & Grout	Bentonite Pellets & Grout
Depth of borehole (ft)	41.5	31.5	53	72.5
Strata of Completion	Precambrian Rock	Precambrian Rock	Sandstone	Precambrian Rock

TABLE NO. 3.6-6 (Cont.)

Well No.	PZ-R1	PZ-R2	PZ-R3	PZ-R5	PZ-R7
Installation date	1/88	1/88	1/88	1/88	1/88
Elevation of measuring point MSL (ft)	1103.85	1105.5	1104.04	1124.87	1142.46
Ground elevation MSL (ft)	1101.13	1102.56	1100.79	1121.89	1139.44
Casing diameter (inches)	1.25	1.25	1.25	1.25	1.25
Type of casing	PVC	PVC	PVC	PVC	PVC
Casing length (from ground surface) (ft)	200	165	122	100	80
Screen diameter (inches)	1.25	1.25	1.25	1.25	1.25
Screen length (ft)	20	20	20	20	20
Type of screen	PVC	PVC	PVC	PVC	PVC
Screen slot size (inches)	0.020	0.020	0.020	0.020	0.020
Screened interval (depth in feet)	173-190	143-160	123-140	87-104	87-104
Screened interval (elevation MSL in feet)	928-911	959-941	978-961	1035-1018	1052-1035
Sand pack interval (depth in feet)	160-199	126-221	106-156	74-121	69-126
Sand pack interval (elevation MSL in feet)	941-902	977-882	995-945	1048-1001	1070-1013
Type of seal	Bentonite Grout	Bentonite Grout	Bentonite Grout	Bentonite Grout	Bentonite Grout
Angled length of borehole (ft)	230	255	230	250	290
Strata of Completion	Precambrian Rock	Precambrian Rock	Precambrian Rock	Precambrian Rock	Precambrian Rock

TABLE NO. 3.6-7

Summary of Well Construction Data - Test Wells

Well No.	TW-K1	TW-K2	TW-K3	TW-K3R	TW-K4	TW-K5	TW-K5R
Installation date	3/88	3/88	3/88	3/88	3/88	3/88	3/88
Elevation of measuring point MSL (ft)	1105.34	1105.22	1127.60	1126.80	1143.29	1145.43	1144.81
Ground elevation MSL (ft)	1102.48	1102.26	1124.62	1124.62	1140.10	1143.16	1143.16
Casing diameter (inches)	6	6	6	4	6	6	4
Type of casing	Steel	Steel	Steel	PVC	Steel	Steel	PVC
Casing length (from ground surface) (ft)	36	30.5	38	52	52	57	57
Screen diameter (inches)	6	6	6	4	6	6	4
Screen length (ft)	157	163	125	108	141	136	108
Type of screen	Open hole	Open hole	Open hole	PVC	Open hole	Open hole	PVC
Screen slot size (inches)	-	-	-	0.040	-	-	0.040
Screened interval (depth in feet)	36-193	30.5-193	38-163	52-160	52-193	57-193	57-165
Screened interval (elevation MSL in feet)	1066-909	1072-909	1087-962	1073-965	1088-932	1086-950	1086-978
Sand pack interval (depth in feet)	-	-	-	38-160	-	-	47-165
Sand pack interval (elevation MSL in feet)	-	-	-	1087-965	-	-	1096-979
Type of seal	Bentonite Grout	Bentonite Grout	Bentonite Grout	Bentonite Grout	Bentonite Grout	Bentonite Grout	Bentonite Grout
Depth of borehole (ft)	193	193	163	163	163	193	193
Strata of Completion	Precambrian Rock	Precambrian Rock	Precambrian Rock	Precambrian Rock	Precambrian Rock	Precambrian Rock	Precambrian Rock

TABLE NO. 3.6-7 (Cont.)

Well No.	TW-K6	TW-K6R	TW-K7	PZ-K8	TW-K17B
Installation date	3/88	3/88	9/88	9/88	9/88
Elevation of measuring point MSL (ft)	-	1120.16	1100.33	1102.12	1102.92
Ground elevation MSL (ft)	-	1118.24	1098.18	1099.70	1099.99
Casing diameter (inches)	6	4	4	2	4
Type of casing	Steel	PVC	PVC	PVC	PVC
Casing length (from ground surface) (ft)	60	65	20	18	35
Screen diameter (inches)	6	4	4	2	4
Screen length (ft)	123	118	10	5	10
Type of screen	Open hole	PVC	PVC	PVC	PVC
Screen slot size (inches)	-	0.040	0.040	0.010	0.040
Screened interval (depth in feet)	60-183	65-183	20-30	20-25	35-45
Screened interval (elevation MSL in feet)	-	1053-935	1078-1068	1080-1075	1065-1055
Sand pack interval (depth in feet)	-	40-183	15-32	18-25	30-46
Sand pack interval (elevation MSL in feet)	-	1078-935	1083-1066	1082-1075	1070-1054
Type of seal	Bentonite Grout	Bentonite Grout	Bentonite Pellets & Grout	Bentonite Pellets & Grout	Bentonite Pellets & Grout
Depth of borehole (ft)	183	186	32	25	46
Strata of Completion	Precambrian Rock	Precambrian Rock	Sand & Gravel	Precambrian Rock	Sand & Gravel

3.6.1.2.2 Groundwater Level Measurements

Groundwater levels were measured monthly from September 1987 through September 1988, and in November 1988 and January 1989. Water level measurements are included on the field sampling log sheets presented in Appendix 3.6-B. Static water level elevations for the entire study are tabulated on Table No. 3.6-8.

The depth to groundwater was measured using a Well Wizard M6000 water level indicator. The tape on the water level indicator is marked at 0.05-foot intervals and depths can be estimated to 0.01 feet. Water elevations were then determined by subtracting the depth to water from the elevation of the measuring point (top of casing).

Each well was surveyed to establish vertical (ground surface and top of casing) and horizontal (coordinates) control. Vertical control was established to 0.01 feet. Horizontal control was established to 0.1 feet. The survey work was done by Morgan and Parmley, Ltd., Ladysmith, Wisconsin. The surveyors are registered land surveyors in the State of Wisconsin.

3.6.1.2.3 Groundwater Sample Collection and Field Testing

The 15 baseline groundwater monitoring wells were sampled monthly for 12 consecutive months (October 1987 to September 1988) to determine baseline water quality at the project site. In addition to the 15 baseline wells, several other monitoring wells and four private wells were sampled during the investigation. These include samples from piezometers PZ-1006G and PZ-1006S, samples from the piezometers that were put in five of the angle holes drilled deep into the Precambrian, and samples from four private wells. In addition, samples tested for a limited set of indicator parameters were collected at 45 more private wells as part of the Kennecott well guarantee program. All the on-site groundwater sampling locations are indicated on Figure No. 3.6-1. The private well locations are indicated on Figure No. 3.6-2.

WDNR personnel were notified prior to each round of sampling so that they were able to observe procedures and/or split samples. WDNR personnel were present during the October 1987, November 1987, January 1988, and May 1988 sampling rounds.

Sampling procedures were observed and accepted by WDNR personnel and were consistent with those published in the WDNR PUBL-WR-153, *Groundwater Sampling Procedures Guidelines,* February 1987; and PUBL-WR-168, *Groundwater Sampling Procedures Field Manual,* September 1987.

Prior to sample collection, each well was purged by removing four times the volume of water in the monitoring well or until

TABLE NO. 3.6-8

Static Water Level Elevations (FT-MSL) in Monitoring Wells and Piezometers

Well No.	9/23/87	10/15/87	10/21/87	11/3/87	12/1/87	1/6/88	2/2/88	2/29/88	4/6/88	5/3/88	6/1/88	7/5/88	8/9/88	9/6/88	11/28/88	1/4/89
MW-1000	NI	1087.26	1087.42	1088.10	1088.47	1089.62	1089.90	1089.06	1091.06	1089.56	1088.51	1087.37	1088.00	1087.96	1088.51	1088.32
MW-1000P	NI	1087.20	1087.67	1087.66	1088.15	1089.43	1089.01	1088.93	1090.68	1088.73	1088.11	1087.74	1088.01	1088.71	1088.69	1088.83
MW-1001	NI	1114.59	1114.46	1114.51	1114.15	1113.48	1113.22	1112.97	1112.83	1112.75	1112.62	1112.37	1112.00	1110.94	1109.94	1109.70
MW-1001G	NI	1113.75	1113.62	1113.79	1113.43	1112.85	1112.56	1112.32	1112.37	1112.34	1112.14	1111.89	1111.72	1111.61	1111.01	1110.82
MW-1001P	NI	1114.19	1114.06	1114.11	1113.84	1113.18	1112.85	1112.70	1112.74	1112.60	1112.41	1112.24	1112.04	1111.91	1111.36	1111.11
MW-1002	NI	1089.64	1089.91	1089.86	1089.79	1090.05	1090.31	1090.13	1090.72	1090.39	1090.03	1089.39	1089.89	1089.44		1089.74
MW-1002G	NI	1089.68	1089.95	1089.89	1089.94	1090.22	1090.49	1090.28	1090.87	1090.66	1090.07	1089.53	1089.97	1089.53	1089.94	1089.92
MW-1003	NI	1111.00	1110.95	1110.87	1110.70	1110.54	1110.33	1110.02	1110.37	1110.73	1110.65	1110.31	1110.01	1109.91	1109.50	1109.50
MW-1003P	NI	1110.98	1110.91	1110.90	1111.22	1110.55	1110.36	1110.18	1110.35	1110.75	1110.63	1110.31	1110.02	1109.88	1109.50	1109.40
MW-1004	NI	1108.57	1108.79	1108.66	1108.88	1108.71	1108.43	1108.30	1109.69	1109.63	1109.02	1108.26	1107.93	1107.70	1107.86	1107.60
MW-1004S	NI	1108.41	1108.63	1108.49	1108.71	1108.55	1108.29	1108.08	1109.56	1109.46	1108.85	1108.05	1107.79	1107.49	1107.67	1107.40
MW-1004P	NI	1106.12	1106.30	1106.41	1106.59	1106.44	1106.17	1105.87	1107.20	1107.25	1106.65	1105.79	1105.43	1105.17	1105.28	1105.23
MW-1005	NI	1137.67	1138.26	1138.89	1139.36	1138.32	1137.30	1136.98	1139.10	1139.42	1138.65	1137.27	1137.07	1136.71	1136.88	1136.10
MW-1005S	NI	1137.56	1137.80	1138.17	1138.58	1138.01	1137.21	1136.82	1138.34	1138.76	1138.29	1137.26	1136.84	1136.51	1136.02	1135.61
MW-1005P	NI	1138.17	1138.31	1138.47	1138.87	1138.42	1137.60	1137.32	1138.53	1139.05	1138.69	1137.80	1137.33	1136.97	1136.38	1135.96
PZ-1006	NI	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
PZ-1006G	NI	1134.33	1134.21	1134.26	1134.06	1133.82	1133.40	1133.02	1133.82	1133.96	1133.97	1133.50	1133.07	1132.83	1131.94	1131.66
PZ-1006S	NI	1132.94	1132.82	1132.87	1132.62	1132.36	1132.01	1131.60	1132.13	1132.35	1132.43	1132.04	1131.57	1131.46	1130.56	1130.32
7	1115.15	1113.76	NM	1112.54	1111.51	1109.93	1109.32	1108.96	1105.97	1110.12	1111.09	1110.83	1109.95	1109.13	1107.79	1107.57
10	1094.06	1093.27	NM	1093.48	1093.69	1094.34	1094.52	1093.91	1094.81	1094.05	1093.45	1092.96	1093.08	1093.01	1093.54	1093.67
12	1109.04	1108.78	NM	1108.80	1108.70	1108.65	1108.50	1108.35	1109.14	1109.37	1109.08	1108.61	1108.24	1108.04	1107.72	1107.65
14	1118.90	1119.35	NM	1118.01	1116.76	1119.05	1118.38	1117.04	1124.84	1125.55	1124.36	1122.87	1121.83	1121.41	1120.19	1119.45
31	1097.69	1095.31	NM	1095.86	1096.38	1096.63	1096.24	1095.83	1097.82	1096.91	1095.92	1094.91	1094.71	1094.49	1095.06	1095.18
36	1096.75	1096.55	NM	1096.51	1096.41	1096.16	1096.05	1095.76	1096.57	1095.90	1095.54	1094.87	1095.64	1095.74	1096.09	1097.52
37	1093.71	Dry	NM	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
39	1099.81	1099.56	NM	1099.44	1099.24	1099.19	1099.22	1099.08	1099.26	1099.83	1099.66	1099.03	1098.70	1098.50	1097.99	1097.95
40	1095.02	1094.79	NM	1095.10	1095.45	1095.75	1095.65	1095.31	1096.85	1096.02	1095.26	1094.45	1094.45	1094.35	1094.57	1094.58
41	1095.04	1094.89	NM	1095.47	1096.05	1096.22	1095.89	1095.49	1097.50	1096.91	1095.84	1094.65	1094.40	1094.12	1094.56	1094.80
42	1094.03	1093.77	NM	1094.31	1094.94	1094.87	1094.38	1093.86	1096.10	1095.15	1093.93	1092.99	1092.88	1092.67	1093.08	1093.36
43	1087.90	1086.67	NM	1086.92	1087.06	1088.23	1088.32	1087.77	1088.65	1087.44	1086.85	1086.31	1086.76	1086.85	1087.23	1087.49
45	1091.99	1091.60	NM	1091.94	1092.29	1092.14	1092.14	1091.83	1093.63	1093.59	1092.53	1091.59	1092.05	1091.14	1091.57	1091.29
ST-2	Dry	1113.24	NM	1113.05	1112.77	1112.52	1112.33	1111.93	1114.87	1113.28	1112.33	1112.13	1111.99	1111.79	1111.20	1111.05
ST-17A	1087.45	1086.83	NM	1087.21	1087.46	1088.61	1088.88	1088.03	1089.57	1087.59	1087.03	1086.50	1087.19	1087.18	1088.05	1087.75
ST-19A	1109.32	1108.68	NM	1108.74	1108.97	1108.77	1108.51	1108.27	1109.77	1109.68	1109.07	1108.25	1107.98	1107.71	1107.98	1107.17
ST-20A	1108.98	1108.87	NM	1108.91	1107.94	1108.93	1108.62	1108.37	1109.49	1109.60	1109.14	1108.45	1108.09	1107.87	1107.82	1107.65
ST-22A	Dry	Dry	NM	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
ST-23	1117.85	1117.32	NM	1117.03	1116.66	1116.25	1116.03	1115.71	1115.45	1115.60	1115.66	1115.49	1115.30	1115.15	1114.51	1114.31
ST-23A	Dry	Dry	NM	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
ST-24	1114.54	1114.27	NM	1114.10	1113.77	1113.48	1113.29	1113.02	1113.18	1113.45	1113.37	1112.97	1112.01	NM	NM	NM

TABLE NO. 3.6-8 (Cont.)

Well No.	9/23/87	10/15/87	10/21/87	11/3/87	12/1/87	1/6/88	2/2/88	2/29/88	4/6/88	5/3/88	6/1/88	7/5/88	8/9/88	9/6/88	11/28/88	1/4/89
ST-26	1110.60	1110.28	NM	1110.09	1109.73	1109.61	1109.23	1109.00	1108.92	1109.12	1109.07	1108.76	1108.53	1108.38	1108.00	1107.67
ST-27A	Dry	Dry	NM	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
ST-28A	1095.87	Dry	NM	1096.27	1097.34	1097.16	1096.77	1096.49	1099.75	1098.95	1097.82	1096.25	1096.08	1095.52	1099.12	1097.62
ST-29A	Dry	Dry	NM	Dry	Dry	Dry	Dry	Dry	1094.99	1094.27	1092.71	Dry	Dry	Dry	Dry	Dry
Sand Poin	NI	NI	NI	1082.49	1085.64	Frozen	Frozen	1086.64	1086.84	1084.15	1083.61	1083.35	1084.88	1084.71	1085.57	1088.99
PZ-S1	NI	NI	NI	NI	NI	1096.28	1095.67	1095.23	1097.47	1096.85	1094.24	1093.17	1093.01	1092.85	1093.29	1093.49
PZ-S2	NI	NI	NI	NI	NI	1091.63	1091.89	1091.49	1092.76	1092.25	1091.56	1090.58	1090.48	1090.51	1090.58	1090.65
PZ-S3	NI	NI	NI	1113.86	1113.55	1113.32	1113.05	1112.78	1112.98	1113.26	1113.15	1112.79	1112.45	1112.25	1111.66	1111.51
PZ-S4	NI	NI	NI	NI	NI	1116.80	1116.53	1116.25	1116.00	1116.10	1116.21	1116.07	1115.86	1115.75	1115.19	1115.00
PZ-1B S	NI	NI	NI	1102.44	1102.65	1102.20	1101.68	1100.73	1103.13	1102.54	1101.42	Dry	1102.30	1101.17	1102.85	1102.15
PZ-1A N	NI	NI	NI	1100.88	1101.70	1100.82	1100.32	1099.71	1102.83	1101.64	1100.01	1098.91	1098.72	1098.21	1099.61	1099.14
PZ-R1	NI	NI	NI	NI	NI	NI	1089.23	1088.85	1090.40	1088.34	1087.72	1087.09	1087.49	1088.92	1088.04	1087.79
PZ-R2	NI	NI	NI	NI	NI	NI	1091.94	1091.77	1092.81	1091.41	1090.87	1090.29	1090.35	NM	1090.67	1090.91
PZ-R3	NI	NI	NI	NI	NI	NI	1094.88	1093.29	1094.90	1093.77	1093.02	1092.24	1092.38	1092.32	1092.31	1092.74
PZ-R5	NI	NI	NI	NI	NI	NI	1113.06	1110.60	1110.94	1111.34	1111.13	1110.58	1110.22	1110.09	1109.59	1109.39
PZ-R7	NI	NI	NI	NI	NI	NI	1118.13	1115.39	1115.21	1115.40	1115.42	1115.28	1115.07	1114.99	1114.43	1114.26
TW-K1	NI	NI	NI	NI	NI	NI	NI	NI	1096.64	1095.89	1094.94	1093.84	1093.63	1093.42	1093.76	1094.09
TW-K2	NI	NI	NI	NI	NI	NI	NI	NI	1092.27	1090.51	1089.99	1089.37	1089.96	1089.98	Replaced	Replaced
TW-K3	NI	NI	NI	NI	NI	NI	NI	NI	1111.45	1111.65	1111.52	1111.85	1111.58	1111.40	1110.88	1110.73
TW-K4	NI	NI	NI	NI	NI	NI	NI	NI	1116.17	1116.28	1116.39	1116.22	1116.02	1115.94	Replaced	Replaced
TW-K5	NI	NI	NI	NI	NI	NI	NI	NI	1112.66	1112.33	1112.40	1112.70	1112.50	1112.44	1111.93	1111.86
TW-K6R	NI	NI	NI	NI	NI	NI	NI	NI	1108.12	1108.08	1107.59	1107.79	1107.49	1107.26	1107.46	1107.26
TW-K7	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	1088.60	1088.38
TW-K8	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	1091.58	1091.62
TW-17B	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	1087.96	1087.72
PZ-1007S	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	1113.27	1113.20
PZ-1008	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	1134.89	1134.59
PZ-1008G	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	1134.89	1134.49
PZ-1009	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	1139.51	1139.41
PZ-1009G	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	1139.50	1139.34
PZ-SP6	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	1135.39	1135.06
PZ-SP8	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	1134.31	1134.31
PZ-K2P	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	1088.39	1089.34
PZ-K2PP	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	1077.51	1089.53
PZ-K4P	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	1115.30	1115.20
PZ-K4PP	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	1115.35	1115.35

NI = Not Installed
NM = Not Measured

the well was dewatered, whichever came first. The wells were purged with a dedicated PVC bailer. In the piezometers, water was drawn from above the screen in the uppermost part of the water column so that fresh water from the screen moved upward. Detailed field logs of purging procedures were maintained and are contained in Appendix 3.6-B.

Subsequent to purging, samples were removed with the same dedicated PVC bailer used for purging. Upon collection, the specific conductivity and pH of each sample were measured using a Lakewood LCD meter. The meter was calibrated in the field daily.

Aliquots of samples to be analyzed for metals were filtered in the field using a 2.5-liter Geo-Tech filter tank with 40 psi pressure capacity. New nitro-cellulose (0.45 micron) mesh filters were used to filter each sample.

De-ionized water from Foth & Van Dyke's soils laboratory was used to rinse all sampling apparatus between each well sample. If required by sample protocol, samples were preserved in the field using acid ampules. The quality control and quality assurance procedures outlined in WDNR PUBL-WR-168 were followed.

3.6.1.2.4 Single-Well Aquifer Response Tests

Single-well aquifer response test were conducted during 1987 and 1988 in order to update the 1970s permeability data within the three principal geologic units. Bail-down tests were conducted on wells and piezometers completed in the glacial overburden, the Cambrian sandstone, and the Precambrian rock. Packer tests were also conducted in boreholes within the Precambrian rock.

Bail-Down Tests

Bail-down tests were conducted on all monitoring wells and piezometers installed from 1987 to 1988. Bail-down tests were also conducted on test wells, TW-K1, TW-K2, TW-K3, TW-K4, and TW-K6R. The following test procedure was used.

Bail-down tests on fast-recovering wells were begun by putting a pressure transducer, with LCD readout in feet, into a well at a depth below the static water level. Bail-down tests on slow-recovering wells were begun by measuring the depth to groundwater with a water level indicator. The resulting initial starting water level (usually greater than 10.0 feet) or initial depth to water was recorded. In fast-recovering wells, a six-foot-long bailer was lowered into the well and then removed in order to lower the water level in the well. In slow recovering wells, the groundwater level was decreased via bailing. In either case, the minimum water level reading was recorded. At the instant this minimum was reached (allowing a few seconds to allow for water level stabilization), a stop watch was started and increasing water level measurements with time were recorded.

Also noted for the purposes of data evaluation were the well casing diameter, the sand pack radius, the sand pack length, the unit saturated thickness, and the depth of penetration of the well into the saturated unit.

The analytical methodology used to evaluate these data is based upon the work of Hvorslev (1951) and Bouwer and Rice (1976). Permeability data obtained from these aquifer response tests for the Quaternary sediments and the Cambrian sandstone are summarized in Table No. 3.6-9. Data for the Precambrian rock tests are summarized on Table No. 3.6-10. Each table lists the well number, the depth and elevation of the interval tested, the geologic unit tested, and the type of test. The Precambrian rock units listed in Table No. 3.5-10 are the major rock types as described in Section 3.5.3.4.2. Also listed is the location of the well relative to the deposit and hanging wall and footwall rock. The data and calculations supporting the data in these tables are contained in Appendix 3.6-C.

Packer Tests

Packer tests were conducted on the angled boreholes drilled for the geotechnical testing program. The intervals tested were those that appeared, on the basis of field core examination, to be the most fractured. The drilling and test methods used for this program are described in Section 3.5.1.6.2. Packer test permeabilities, test intervals, and corresponding rock units are summarized in Table No. 3.6-9. Supporting data and calculations are contained in Appendix 3.6-C.

3.6.1.2.5 Pump Tests

Short-term pump tests were conducted on test wells TW-K2 and TW-K4 on March 8 to 10, 1989. Additional pump tests were conducted on test wells TW-K3R and TW-K5R on March 24 to 27, 1989. Test well TW-K17B was pumped on September 22, 1988. The wells were pumped at rates ranging from one to 18 gallons per minute using an electric submersible pump. Pump test duration ranged from one to four hours. Drawdown and recovery data were obtained from the pumping wells, and the nearby monitoring wells and piezometers that served as observation wells. Calculated permeability values and drawdowns for the pumping wells and observation wells are listed in Table No. 3.6-11. Supporting data and calculations are contained in Appendix 3.6-C.

3.6.1.2.6 River Level/Groundwater Level Interaction

In order to evaluate the effect of dam-controlled fluctuations of the Flambeau River level on groundwater levels, simultaneous water level measurements were made on the sandpoint adjacent to the river and in several monitoring wells and piezometers near the river in September and October 1988. Twice-daily fluctuations of the Flambeau River range from 0.5 to 2.0 feet.

TABLE NO. 3.6-9

Summary of Permeability
Data for Quaternary Sediments and Cambrian Sandstone

Well Designation	Unit	Bail Tests	Pump Tests		Test Interval Elevation (ft)	Test Interval Depth (ft)
			Drawdown	Recovery		
PZ-1A	Glacial Fluvial	1.0×10^{-4}			1097-1100	3.8-6.3
PZ-1B	Glacial Fluvial	1.0×10^{-5}			1101-1103	0.9-2.9
TW-K7	Glacial Fluvial		4.8×10^{-3}		1068-1085	13-30
TW-K17B	Glacial Fluvial		6.5×10^{-3}		1054-1070	30-46
MW-1002	Glacial Fluvial	4.3×10^{-3}			1084-1094	6-16
MW-1002G	Glacial Fluvial	7.1×10^{-3}			1049-1054	46-51
MW-1004	Glacial Fluvial	1.7×10^{-1}			1093-1103	11-21
MW-1005	Till	4.3×10^{-4}			1124-1134	8-18
PZ-1006	Till	Dry			1137-1142	5-10
PZ-1006G	Till	8.4×10^{-5}			1114-1119	28-33
MW-1001	Till	5.5×10^{-3}			1108-1118	22-32
MW-1000	Till & Precambrian Rock	2.5×10^{-3}	3.6×10^{-4}	4.9×10^{-4}	1079-1099	9-19
MW-1001G	Till, Sandstone	5.7×10^{-4}			1089-1094	46-51
PZ-1008	Till	3.4×10^{-5}			1127-1140	5-18
PZ-1008G	Till, Sand Seam	3.9×10^{-3}			1090-1097	48.3-55.4
PZ-1009	Till	1.4×10^{-5}			1134-1147	5.4-18.4
PZ-1009G	Till	3.4×10^{-5}			1102-1109	43.4-50.3
PZ-SP6	Till	3.3×10^{-4}			1130-1144	11.3-24.3
PZ-SP8	Till	4.7×10^{-5}			1123-1136	7-20
MW-1003	Sandstone	1.8×10^{-3}			1102-1112	30-40
MW-1004S	Sandstone	1.3×10^{-3}			1079-1084	30-35
MW-1005S	Sandstone	1.6×10^{-3}			1093-1098	45-50
PZ-1006S	Sandstone/Glacial Fluvial	9.5×10^{-4}			1095-1100	47-52
PZ-1007S	Sandstone	4.3×10^{-4}			1104-1113	40.4-49
PZ-S3	Sandstone	1.0×10^{-4}			1096-1101	28-33

TABLE NO. 3-6-10

Summary of Permeability Test Data for Precambrian Rock

Well Designation	Well/Boring Location**	Precambrian Unit***	Bail Tests	Pump Tests Drawdown	Pump Tests Recovery	Packer Tests	Vertical Test Interval Elevation (ft)	Vertical Test Interval Depth (ft)
MW-1000P	O	1a (SMS)	9.0×10^{-7}	8.0×10^{-4}	4.6×10^{-4}		1051-1046	48- 55
MW-1001P	-	-	7.4×10^{-6}				1046-1053	87.5 - 95
MW-1003P	H	3a	9.8×10^{-7}				1057-1064	79.5 - 86.5
MW-1004P	H	5	6.0×10^{-6}				1036-1045	79- 87
MW-1005P	-	-	1.7×10^{-5}				1051-1058	84- 91
PZ-S1	H	2c	3.2×10^{-5}				1060-1067	33- 41.5
PZ-S2	F	3a	2.8×10^{-5}	1.2×10^{-4}	3.8×10^{-5}		1072-1079	24.5 - 31.5
PZ-S4	F	5	1.2×10^{-4}	5.6×10^{-4}			1069-1076	65.5 - 72.5
TW-K1	H	2c, 2a	1.6×10^{-6}*				909-1066	36-189
TW-K2	O,F	1c, 1b, 2a	9.9×10^{-5}	6.1×10^{-5}	8.0×10^{-5}		909-1072	30-193
PZ-K2P	F	2a	5.2×10^{-6}				996-981	106-121
PZ-K2PP	F	2a	2.8×10^{-7}				918-909	184-193
TW-K3	F	2c, 2a	1.8×10^{-5}*				962-1087	38-163
TW-K3R	F	2c, 2a		2.0×10^{-6}	3.5×10^{-6}		965-1087	38-160
TW-K4	F	5, 2c	1.5×10^{-5}*	1.5×10^{-5}	4.8×10^{-5}		932-1088	52-193
PZ-K4P	F	5, 2c	1.6×10^{-4}				1059-1047	81-93
PZ-K4PP	F	5, 2c	6.2×10^{-5}				992-979	148-161
TW-K5	H	2b	1.7×10^{-6}*				950-1086	57-193
TW-K5R	H	2b		4.2×10^{-6}	5.2×10^{-6}		978-1096	47-165
TW-K6	H	5	7.9×10^{-8}*				934-1057	60-183
TW-K6R	H	5			1.3×10^{-6}		934-1069	48-183
PZ-K8	H	2a	1.2×10^{-5}				1082-1075	18-25

Table No. 3.6-10 (Cont.)

Well Designation	Well/Boring Location**	Precambrian Unit***	Bail Tests	Pump Tests Drawdown	Pump Tests Recovery	Packer Tests	Vertical Test Interval Elevation (ft)	Vertical Test Interval Depth (ft)
PZ-R1A	H	2a				4.0×10^{-6}	995- 999	103-107
	H	2a				6.2×10^{-5}	903- 909	193-199
	H	2a, 2c	1.8×10^{-4}				903- 952	160-199
	H	2c				0	983- 977	118-124
	H	2c				0	964- 960	134-141
	H	2c				0	956- 951	145-150
PZ-R2	O	1a				4.4×10^{-5}	1039-1062	40- 63
	F	2a				9.9×10^{-6}	984- 989	113-118
	F	2a				6.1×10^{-6}	950- 954	148-152
	F	3a				5.3×10^{-6}	899- 909	193-203
	F	3a				6.0×10^{-6}	898- 902	200-204
	F	2a, 3a	1.7×10^{-5}	7.7×10^{-5}	8.5×10^{-5}		881- 976	126-221
PZ-R3	O	1a, 1b				6.2×10^{-6}	1014-1018	81- 85
	O	2a				4.4×10^{-5}	990- 994	105-109
	O	1c				5.7×10^{-6}	895- 904	193-204
	O	1a, 2a, 1c	7.2×10^{-5}				943- 993	106-156
B-R4	H	2a				1.3×10^{-5}	911- 915	202-206
PZ-R5	F	2a, 5				3.0×10^{-5}	1010-1014	107-111
	F	2c				6.6×10^{-6}	913- 919	202-208
	F	2c				0	916- 921	201-206
	F	2c, 5	1.3×10^{-4}	1.3×10^{-4}	1.1×10^{-4}		991-1047	74-130
B-R6	H	2b				1.1×10^{-6}	933- 940	199-206
	O	1a				4.4×10^{-6}	820- 825	314-319
PZ-R7	O	1a				1.5×10^{-4}	1045-1057	82- 94
	F	4c				2.1×10^{-5}	976- 990	149-163
	F	5				5.7×10^{-6}	926- 932	207-213
	O	1a, 1c	2.0×10^{-4}				1020-1073	66-119

*Data for calculation obtained during well construction or during development.
**Well Test/Location

O -Ore horizon
H -Hanging wall
F -Footwall

***Precambrian Rock Unit

1a-Sericite-Quartz Schist
SMS-Semimassive sulfides
1b-Metachert
1c-Massive Sulfide
2a-Biotite-Sericite-Quartz-Chlorite Schist (Local Andalusite)
2b-Biotite-Chlorite-Quartz-Sericite Schist (Local Andalusite)
2c-Biotite-Quartz-Chlorite Schist
3a-Quartz-Augen Schist
4c-Amphibole-Chlorite Schist
5 -Metadacite

TABLE NO. 3.6-11

Summary of Pump Test Data

Pumping Well	Date and Pump Test No.	Rate (gpm)	Duration (min.)	Well	Total Drawdown (ft.)	Permeability (cm/sec) Drawdown	Recovery
TW-K2	(1) 3-10-88	13.3	195	TW-K2	17.02	6.1×10^{-5}	8.0×10^{-5}
				MW-1000	0.82	3.6×10^{-4}	4.9×10^{-4}
				MW-1000P	0.60	8.0×10^{-4}	4.6×10^{-4}
				PZ-S2	2.22	1.2×10^{-4}	3.8×10^{-5}
				PZ-R2	5.55	7.7×10^{-5}	4.5×10^{-5}
				ST-9-40	1.05	1.0×10^{-3}	1.6×10^{-3}
TW-K3R	(1) 3-24-88	2.0	224	TW-K3R	150.00	7.7×10^{-6}	2.0×10^{-5}
				PZ-R5	1.08	1.3×10^{-4}	1.1×10^{-4}
	(2) 3-25-88	1 to 2	287	TW-K3R	56.4	4.0×10^{-6}	-
				PZ-R5	0.93	1.2×10^{-4}	1.2×10^{-4}
TW-K4	(1) 3-8-88	5	172	TW-K4	75.23	1.7×10^{-5}	4.1×10^{-5}
				PZ-S4	1.04	6.0×10^{-4}	5.6×10^{-4}
	(2) 3-9-88	5.3	110	TW-K4	43.75	1.4×10^{-5}	5.6×10^{-5}
				PZ-S4	0.85	6.0×10^{-4}	5.6×10^{-4}
TW-K5R	(1) 3-27-88	1.2	207	TW-K5R	71.55	4.2×10^{-6}	5.2×10^{-6}
				PZ-R7	0	-	-
TW-K17B	(1) 9-22-88	18.0	64	TW-K17B	6.64	5.9×10^{-3}	7.1×10^{-3}
				TW-K7	3.04	5.4×10^{-3}	4.3×10^{-3}

The pressure wave created by this stage change caused groundwater elevation changes in the following wells, all located within 400 feet of the river.

MW-1000	TW-K1	ST-9-17A	PZ-R1
MW-1000P	TW-K2	ST-9-26	PZ-R2
MW-1001G	TW-K7		PZ-R3
	TW-K17B		PZ-S1
			PZ-S2
			PZ-K8

Measurements in these wells were made using electric water level indicators and ISCO Model 1870 Flow/Level meters with pen and graph-paper recorders. The field data are included in Appendix 3.6-D.

A method of determining transmissivity from cyclic water-level fluctuations is described by Ferris (1963). However, to calculate transmissivity, the storage coefficient must be known. Therefore, permeability values in the glacial overburden and Precambrian units were determined only within an order of magnitude using this method. If a water table condition storage coefficient of 0.1 is assumed for the overburden (Driscoll, 1986), permeability values range from 1×10^{-2} to 1×10^{-3} cm/sec. If a confined condition storage coefficient of 0.001 is assumed in the bedrock (Driscoll, 1986), permeability values range from 1×10^{-4} to 1×10^{-5} cm/sec. Calculations supporting these ranges are contained in Appendix 3.6-D.

3.6.2 Regional Hydrogeology

According to NR182.08(2)(c), the term "regional" is defined as "that area which may affect or be affected by a proposed site. In most cases this will be the proposed site, and the area within a radius up to five miles from the site." Figure No. 3.6-3 illustrates the five-mile radial area surrounding the open pit location. NR182.08(2)(c)4 states that the regional hydrogeology discussion should include "depth to groundwater, flow directions, recharge and discharge areas, groundwater divides, aquifers, and the identification of the aquifers used by all public and private wells within at least 1200 feet of each proposed site." Each of these topics, plus regional groundwater quality, is discussed below.

3.6.2.1 Depth to Groundwater

Depths to groundwater in the regional area are relatively shallow, usually less than twenty feet. There are three main reasons for this. First, the regional topography is relatively flat, with less than 100 feet of total relief between the recharge zone and the discharge zone in any typical shallow groundwater flow system. Second, average precipitation results in groundwater recharge of approximately five inches per year (see Appendix 3.6-C). This recharge rate is sufficient to

maintain a mounded water table condition. Third, the till comprises the uppermost stratigraphic unit over a majority of the region (see Section 3.6.1.4). The permeability of this till is sufficiently low to enhance the mounding effect of the precipitation recharge.

3.6.2.2 Flow Directions

The region is characterized by a temperate zone climate so that there is sufficient groundwater recharge to maintain stream base flows year round. Therefore, groundwater movement in the region normally flows from recharge (i.e., upland areas) to discharge zones (i.e., adjacent flowing streams). However, in certain localized areas, groundwater flows toward man-made discharge zones, such as the cones of depression created by active water supply wells.

3.6.2.3 Recharge and Discharge Areas

As shown in Figure No. 3.6-3, the regional area is dominated by three principal groundwater flow systems. The major portion of the five-mile radial area, and the flow system within which the site occurs, is drained by the Flambeau River including Meadowbrook Creek flow system. The northwestern sector of the five-mile radial area is a flow system drained by the two branches of the Twin Creek flow system. The southeast sector is a flow system drained by the Deer Tail Creek flow system.

A groundwater discharge zone is defined as an area within which the net vertical component of groundwater movement is upward (Freeze and Cherry, 1979). Within the groundwater flow systems of the region, the discharge zone width is restricted to a narrow band, probably no more than a hundred yards wide in most cases, centered on the streams themselves. All of the remaining portions of the groundwater flow systems may be delineated as recharge areas.

The thickness of each flow system, as well as the presence of deeper intermediate flow systems, is a function of the distribution of permeabilities with depth and the degree of regional topographic relief. Generally, stacked flow systems are more likely to occur as both the thickness of permeable formations and the degree of topographic relief increase.

In the region of this study, both of these factors are relatively minimal. The only permeabilities of significance occur in the sandstone and glacial-fluvial sediments above the bedrock, and the saturated thickness of these layers seldom exceeds fifty feet in the region (Young and Hindall, 1972). As already discussed, the topographic relief is limited. Therefore the region is generally characterized by shallow (single layer) groundwater flow systems.

A baseflow separation analysis was performed on the Flambeau River watershed for Hydrologic Year 1988 (see Appendix 3.6-D). This analysis showed that 7.25 inches left the watershed via surface water flow in the Flambeau River, as measured at the gaging station below the Thornapple Dam. Of this 7.25 inches, the baseflow analysis showed that 5.10 inches moved into the river via the shallow groundwater flow system. The remaining 2.15 inches entered the river as direct overland runoff.

The 5.10 inches of groundwater runoff, distributed over the entire 1,860-square-mile Flambeau watershed, amounts to 2.20×10^{10} ft^3 of water. A comparison can be made between this volume and the total amount of groundwater in storage in all the Flambeau flow systems. The systems average saturated thickness is approximately 50 feet, and the average effective porosity is 20 percent, a representative median for glacial materials (Driscoll, 1986). Multiplying the area times the thickness times the effective porosity yields a water volume of 5.18×10^{11} ft^3. Therefore, at the rate the flow systems supplied water for baseflow in Hydrologic Year 1988, the combined Flambeau groundwater flow systems in the Flambeau River watershed yielded 4.2 percent of their water as groundwater discharge. At this rate, the average time for the flow systems to flush themselves is approximately 23.5 years. This must be assumed to be a maximum flushing time since 1988 was a drought year. In an average year, the flushing would be faster. In any case, even 23.5 years is a relatively short period of time in hydrogeologic terms, implying that the size of the typical Flambeau River flow system is relatively small and localized.

The baseflow analysis also noted that there are 834 miles of stream channel located in the Flambeau watershed. Therefore, in Hydrologic Year 1988, the total amount of groundwater runoff, 2.20×10^{10} ft^3, was equivalent to approximately 2.64×10^7 ft^3 of water per mile of stream channel. Since this groundwater runoff was derived from 5.10 inches of watershed water then it can be calculated that the amount of flow system drained by the average mile of channel is 2.23 square miles. Since the stream channel is typically centered within the flow system boundaries, it then follows that the average distance from the discharge point, the stream, to the average upland recharge point is half of this distance or 1.12 miles. The stream distribution on Figure No. 3.6-2 confirms that this recharge estimate is representative of the five mile radial region around the site. It is also consistent with the previously stated conclusion that the region's groundwater flow systems are relatively small and localized.

3.6.2.4 Groundwater Divides

Figure No. 3.6-2, as discussed above, shows the typical distribution of the groundwater flow systems in the regional area. The divides separating the flow systems are located beneath the topographically high ground separating the flowing

stream discharge areas. The groundwater divides are in approximately the same position as the overlying surface water watershed divides.

3.6.2.5 Groundwater Aquifers

The definition of the term aquifer is clear enough in its meaning, but often leaves considerable room for interpretation in its application. The classic definition of an aquifer is that it is a permeable water-bearing geologic unit that has the capacity to transmit significant quantities of water under ordinary hydraulic gradients (Freeze and Cherry, 1979). The room for interpretation lies in the term "significant quantities". Typically, the interpretation is made in the context of an existing or potential water use. If the use is a household well, a thin formation of modest permeability may serve as an aquifer. If the use is a high capacity well for public supply or industrial purposes, the same formation may not qualify as an aquifer.

Water quality may also be factored into the definition of the term by considering whether or not the quality of the water in a formation is suited to the application in question. If it is not, then the formation cannot be termed an aquifer since it is not possible to obtain significant quantities of usable water from the formation. This version of the definition of "aquifer" is used in this report.

Four fundamental geologic units are present in the five-mile radial region. These are the Precambrian bedrock, the Cambrian sandstone, the till, and the glacial-fluvial sediment.

The bulk of the Precambrian bedrock does not yield quantities of water sufficient enough to serve even as a single household supply. Isolated fractured or weathered zones within this rock may occasionally be able to produce water, but normally the Precambrian unit as a whole is not characterized as an aquifer.

The Cambrian sandstone, where it is present and of sufficient thickness, is normally permeable enough to serve as an aquifer for single-well private supplies.

The till, like the Precambrian bedrock, has relatively low permeability. Occasional thin sand or gravel lenses render it marginally usable as a single household well aquifer.

The glacial-fluvial sediment is moderately to highly permeable and in most areas is even more useful as an aquifer for public and industrial uses than is the sandstone.

3.6.2.6 Regional Groundwater Quality

According to Young and Hindall (1972), groundwater in the Ladysmith area typically has total dissolved solids

concentrations in excess of 300 mg/L. They point out that sodium, potassium, chloride, and sulfate concentrations are higher than in most of the rest of the Chippewa River Basin (of which the Flambeau River Basin is a part).

Hindall (1979), as part of a study for the U. S. Geological Survey, further reports on iron and manganese problems in the Ladysmith area groundwater. The six private wells and one public well tested by Hindall, were all located within five miles of the project site. Iron concentrations ranged from 0.01 mg/L to 14 mg/L, and averaged 4.2 mg/L. Manganese concentrations ranged from <0.01 mg/L to 0.65 mg/L, and averaged 0.34 mg/L. Both these average concentrations exceed the U. S. Public Health Service's Secondary Drinking Water Standards (these are aesthetic standards based on taste and odor thresholds) for iron, 0.3 mg/L, and manganese, 0.05 mg/L. Hindall speculates that the source of these concentrations is natural, from the aquifer materials.

Residents of the area readily and effectively deal with these aesthetic problems through the use of water softening, a simple and inexpensive technique that removes objectionable metal ions.

3.6.2.7 Aquifer Use

An evaluation of water supply well logs in the area obtained from the Wisconsin Department of Natural Resources and from the Wisconsin Geological and Natural History Survey (see Appendix 3.6-F) indicates that the majority (95%) of private wells in the area obtain their water either from the glacial-fluvial aquifers or from thin lenses of permeable material in the till. A few wells were drilled as deep as the sandstone and the Precambrian bedrock. Of the logs for approximately 200 private wells that occur within a two to three mile radius of the mine, five (2.5%) indicated that the well was completed in sandstone and six (3%) in the Precambrian.

3.6.3 Project Site Hydrogeology

The Kennecott project site is adjacent to the Flambeau River, a major groundwater discharge feature. Part of the site, in fact, is within the groundwater discharge area.

The geology of the site area is, in many respects, the geology of the Flambeau River watershed in microcosm. Most of the same types of geologic units found in the watershed (e.g., till, glacial-fluvial sediments, sandstone, Precambrian bedrock) are found on the site.

The period of record during which the bulk of the current investigation was conducted, from October of 1987 through September of 1988, was a relatively dry period. Precipitation in the watershed for the period was only 25.8 inches, 5.4 inches below the 31.2 inches long-term average (NOAA, 1988).

Therefore, groundwater levels over much of the project site underwent a net decline during the study. In spite of this, however, there was a spring recharge event during March and April of 1988 that allowed observations of the water table in a rising mode followed subsequently by a falling mode during the dry period between May and August 1988.

The following discussion is divided into the topics of groundwater occurrence, groundwater recharge/discharge regime, and groundwater use.

3.6.3.1 Groundwater Occurrence

Site area groundwater occurs within several units. Surficial glacial deposits include till and glacial-fluvial materials. The bedrock includes Cambrian-age sandstone and Precambrian-age metavolcanics and metasediments.

3.6.3.1.1 Surficial Deposits

The major units present on site are shown in plan view on Figure 3.5-15, and in cross section on Figure Nos. 3.5-4 and 3.5-5.

Glacial Fluvial Sediment

Adjacent to the river is a zone of glacial-fluvial sediment. It is present at the surface primarily to the northwest of the open pit, thickening in a northwest direction as the bedrock surface elevation declines in that direction. It also is present in thin layers beneath some of the tills. The glacial fluvial sediment consists of interbedded sands and gravels, cobbles, and boulders. The permeability of the material is somewhat variable due to the interbedding of well sorted and poorly sorted units. This is shown on Table No. 3.6-9, where the in-field testing of the piezometers installed into these various units ranged from 1.0×10^{-5} cm/sec to 1.7×10^{-1} cm/sec. The formation median and logarithmic mean permeability values are 4.8×10^{-3} and 2.7×10^{-3} cm/sec, respectively. Thus, despite the permeability variations, much of this material would be useful as an aquifer for modest amounts of groundwater withdrawal, but not generally for high capacity purposes.

The specific yield (effective porosity) of the glacial fluvial sediment is likely to be similar to "typical" sand and gravel mixes, between 15 and 25 percent (Driscoll, 1986). Pump testing has shown the aquifer to be under water table conditions. Therefore, a reasonable estimate of the storativity of the material is 20 percent.

Till

The till lies to the east of the glacial-fluvial material, over the deposit, and to the southeast of the orebody. To the south of the topsoil it lies very close to the river. It ranges in

thickness from zero at the outwash boundary to 70 feet immediately east of the proposed open pit. Two principal till areas are present as discussed above in Section 3.5.3.3. Adjacent to the glacial-fluvial material is an older terraced zone developed during the initial glacial meltback period. Topographically it is somewhat lower than the other till area, which is an upland till plain found on the eastern side of the project site. Both the till units are significantly less permeable than the glacial-fluvial material. As shown on Table No. 3.6-9, permeabilities in the units show some variability, ranging from 1.4 x 10^{-5} cm/sec to 5.5 x 10^{-3} cm/sec. The formation median and logarithmic mean permeability values are 3.6 x 10^{-4} and 2.7 x 10^{-4} cm/sec, respectively.

The most representative permeabilities for the till materials are those toward the lower end of the range. Permeability results on the higher end of the range were obtained from wells whose screens, in order to be functional, often were preferentially installed into intercepted sand and gravel layers within the till.

The specific yield (effective porosity) of the till can be determined from the density and moisture content testing of soil and rock samples discussed in Appendix 3.5-I. The average dry density of three undisturbed till samples was 126.7 lbs/ft^3. Dividing by 62.4 lbs/ft^3, the density of water, yields an average specific gravity of 2.03. The mineralogy of the till is mostly quartz, and quartz-containing rock fragments. The specific gravity of quartz is 2.65. Therefore, the total porosity of the till may be obtained by dividing 2.03 by 2.65, multiplying the quotient by 100, and subtracting the product from 100, yielding the result of 23.4 percent. The specific yield of till is probably less than half the total porosity (Driscoll, 1986). A reasonable estimate of specific yield for this till, therefore, is ten percent.

The suitability of the till as an aquifer is marginal, at best. The occasional thin sand lenses may provide sufficient water for a private residence. More often, wells must be drilled through the till into the underlying glacial-fluvial sediment or sandstone.

3.6.3.1.2 Bedrock

Sandstone

Underlying the till and overlying the Precambrian in most of the project site area is the Cambrian sandstone, a material that varies from friable to well cemented. Its thickness ranges from zero nearer the river to 34 feet in the central part of the project site area. As shown on Table No. 3.6-9, the permeabilities in this unit range from 1.0 x 10^{-4} cm/sec to 1.8 x 10^{-3} cm/sec. The formation median and logarithmic mean

permeability values are 1.1×10^{-3} and 7.3×10^{-4} cm/sec, respectively.

As was the case with the till, the specific yield (effective porosity) of the sandstone can be determined from the density and moisture content testing of rock and soil samples discussed in Appendix 3.5-I. The average dry density of the two sandstone samples tested was 111.8 lbs/ft^3, equivalent to a specific gravity of 1.79. Also like the till, the mineralogy of the sandstone is quartz, with a specific gravity of 2.65. Therefore, dividing 1.79 by 2.65, multiplying the quotient by 100, and subtracting the product from 100 yields a total porosity of 32.6 percent. In a friable, well sorted sandstone such as this, the specific yield is probably not much less than the total porosity (Driscoll, 1986). Therefore, a reasonable estimate of specific yield for this sandstone is 30 percent.

Because of limited thickness, sandstone yields in the project site area are marginal, probably only suitable in most cases for a private household supply.

Precambrian

The Precambrian bedrock in the site area is a series of overturned schists dipping steeply to the northwest. In the upper ten to fifty feet of the bedrock the schists are highly clay-altered, and appear in the field as a rather soft, almost claylike material. Deeper zones are harder, exhibiting significant jointing. It is in these joint fractures that the Precambrian permeability occurs. Overall, the permeabilities in the Precambrian unit are the lowest of any of the materials found on site. As shown on Table No. 3.6-10, permeability values are in the range of 7.9×10^{-8} cm/sec to 6.2×10^{-4} cm/sec. The formation median and logarithmic mean permeability values are 1.3×10^{-5} and 1.6×10^{-5} cm/sec, respectively.

The higher permeabilities in the Precambrian of the site area are found within zones close to the deposit itself. Thin, near-surface metacherts, generally laterally continuous for no more than 400 feet, were observed underlying the hanging wall edges of the massive sulfide unit. The contact between the metachert and the massive sulfide has greater permeability than the bulk of the Precambrian, an effect noticed during the permeability tests conducted in the vicinity of the TW-K2/MW-1000 area. The pump tests indicated that the contact has a permeability of about 1×10^{-4} cm/sec.

During the drilling program, geomechanical data, including Rock Quality Designation (RQD), fracture frequency, length of longest piece, rock hardness and broken-zone measurements were taken on core. In their report on the testing, Call (1988) state, "The ore zone appears to be bounded on the hanging wall side by a 20- to 35-foot-thick interval of strongly fractured rock and on the

footwall side by a somewhat thicker 40- to 70-foot-thick strongly fractured zone."

Fractured and weathered igneous rocks typically have porosities in the range of zero to 10 percent (Driscoll, 1986). Therefore, a reasonable specific yield (effective porosity) for the Precambrian rocks is five percent.

The Precambrian rocks cannot be classified as aquifer material. The normal yields are generally too low to support even a domestic single family home supply.

3.6.3.2 Groundwater Recharge/Discharge Regime

The groundwater flow regime at the site is straightforward. The majority of groundwater at the site moves within a shallow groundwater flow system. Figure Nos. 3.6-4 and 3.6-5 are water table maps drawn for the extremes in water table conditions that were observed during the period of record. Figure No. 3.6-4 represents the high water table, a condition which occurred in April 1988. Figure No. 3.6-5 represents the low water table, a condition which occurred in September 1988. Figure No. 3.6-6 shows the equipotential surface which is typical of the head distribution in the sandstone unit, and Figure No. 3.6-7 shows the equipotential surface in the shallow bedrock. Figure Nos. 3.6-8 and 3.6-9 are hydrogeological cross-sections which show the distribution of vertical heads with depth. The lines of section for these two figures are shown on the high water table map, Figure No. 3.6-4. Figure Nos. 3.6-10 through 3.6-19 are hydrographs of the water level elevations measured during the current study in selected monitoring wells and piezometer nests. Hydrographs for selected old wells measured in the 1970s are included in Appendix 3.6-A.

3.6.3.2.1 Surficial Deposits

Horizontal Gradients

The water table occurs within the till, the glacial fluvial sediments, and the sandstone. With one exception, shallow groundwater flow in the immediate vicinity of the mine site is to the west, toward the Flambeau River. Near the very northern edge of the project site area, along Blackberry Lane, the water table contour lines bend around to the east, paralleling the eastward bend in the river. In this area, flow is to the northwest and north.

The exception is a mounding condition that occurs adjacent to the southeast side of proposed open pit near piezometers PZ-S6 and PZ-S8. This is caused by the presence of a local topographic high underlain by the low-permeability till. On the eastern side of this mound, shallow groundwater flows for a short distance in an easterly and downward direction before turning back to the west.

Wetland/Groundwater Relationship

Wetland Areas 1 and 2, to the northwest of the proposed pit location, are supported by groundwater but are not classic groundwater discharge areas. The wetlands are located at the western edge of the till, at the foot of a sharp drop in slope. The land surface drops too quickly for the water table surface to conform and, as a result, a seep discharge occurs along the eastern edge of the wetlands. This phenomenon is shown in cross section on Figure No. 3.6-9. However, as the groundwater continues to flow to the west under the wetlands, the water table continues to drop off. At well nest PZ-1A and PZ-1B in the center of the wetlands, there is a very strong downward hydraulic gradient, averaging nearly -0.5 during the period of record (Figure No. 3.6-17). Such a high gradient demonstrates that the glacial-fluvial sediments underlying the wetlands are of low permeability. This in turn shows that only a minimal amount of water, (i.e., the seepage on the eastern side of the wetlands), is sufficient to maintain wetland conditions, even though the great majority of the wetlands occur over a strong groundwater recharge zone.

Evidence exists that Wetland Area 5c, to the southeast of the pit, is hydraulically isolated above the water table. Adjacent well nest 1005 shows that water table elevations typically occur more than four feet below the water level in the wetland. At the same nest are found strong downward hydraulic gradients averaging approximately -0.02, indicating the presence of low permeability materials beneath the wetland.

The hydrogeology of the other wetlands to the west of STH 27 (less than five acres, total; see Figure No. 3.6-20) was not evaluated because they will unavoidably be taken by the project.

Wetland Areas 3c, 10a, and the other wetlands to the east of STH 27 (Wetland Areas 6, 7, 8, and 9), are hydraulically isolated above the water table. A study of soils and hydrologic conditions in Section 10 (the area across Highway 27 to the east of the site) was performed by Kennecott in 1971. The report, contained in Appendix 3.6-G, has logs of backhoe pits excavated into the wetlands in the locations indicated on Figure No. 3.6-20. The presence of a granular unsaturated zone beneath a low-permeability peat layer was common in most of the pits. The depths to the underlying water table encountered in the excavations ranged from four to more than twenty feet. In no case was there evidence that the surficial wetland water level was directly connected to the underlying water table.

These observations are consistent with several other pieces of more recently collected data. Shown on Figure No. 3.6-20 are the locations of the borings drilled along the proposed railroad right-of-way. The depths to water encountered in these borings, as described in the logs in Appendix 3.5-20 are shown on Figure No. 3.6-20, also demonstrate that water table elevation is

significantly lower than the wetland water surface. Finally, the depths to water in wells PZ-1006G and PZ-1009, shown on Figure No. 3.6-20, also confirm that the water table is much lower than the wetland water level.

Vertical Gradients

The vertical gradients that were measured throughout the till during the current investigation were downward, or in one case (MW-1003), neutral. This is characteristic of groundwater recharge conditions. Even where the till does occur close to the river, at locations MW-1000 and MW-1001 for example, the permeabilities are still low enough to cause enough mounding of the groundwater so that recharge conditions were maintained most of the time during the period of record.

By contrast, levels recorded in the piezometer nest installed in the glacial fluvial sediments, MW-1002, show that gradients in this unit can be upward even at a location which is not immediately adjacent to the river.

In the Precambrian, upward gradients were observed in most locations, indicating preferential flow in the overlying glacial fluvial or sandstone units. A major exception to this occurs at nest 1004 where strong downward gradients exist in the shallow Precambrian. However, this is a location where the bedrock surface begins to drop off sharply toward the river, evidently causing a localized recharge condition.

Depth to Groundwater

Figure No. 3.6-21 is an isopach map of the depth to groundwater in the project site area. The shallowest depths occur in Wetland Areas 1 and 2 and beneath the upland till plain to the southeast and east of the proposed open pit. The greatest depths to water occur beneath the dissected till terrace where the water table drops off as groundwater flows to the west, but where the land surface remains high.

Flow and Discharge Rates

Based on the logrithmic mean permeability of 2.1×10^{-3} cm/sec, a measured hydraulic gradient of 0.02 ft/ft, and an effective porosity of 20 percent, the calculated flow velocity within the glacial fluvial material is 0.60 ft/day. The same numbers may be used to estimate the discharge through that portion of the glacial fluvial sediment which is presently generally downgradient of where the open pit will be. The Figure No. 3.5-4 and Figure No. 3.5-9 cross sections show that, along the river, the saturated glacial fluvial sediment thickness increases in a northerly direction from near zero to more than 60 feet. The width of the open pit on a line normal to groundwater flow is 800 feet. Using an average saturated thickness of 30 feet for this section of the unit the resultant

cross-sectional area would be 24,000 square feet. This dimension, combined with the logarithmic mean permeability and gradient stated above, yields an average discharge through the glacial-fluvial sediments of 21,400 gallons/day (14.9 gallons/minute).

Based on the logarithmic mean permeability of 2.7×10^{-4} cm/sec, a measured hydraulic gradient of 0.025 ft/ft, and an effective porosity of ten percent, the average flow velocity within the till is 0.19 ft/day. The same numbers may be used to estimate the existing discharge through that portion of the till which will be displaced by the open pit. Figure No. 3.5-4 shows that along the centerline of the open pit the average saturated thickness of the unit is 15 feet. At this point the width of section of till normal to flow that would intercept the open pit would be approximately 800 feet. Using these two dimensions plus the logrithmic mean permeability and gradient stated above, the average lateral discharge through the till would be 1,700 gallons/day (1.2 gallons/minute).

3.6.3.2.2 Bedrock

Sandstone

Where present, the Cambrian sandstone is the predominant bedrock flow unit. Piezometer nest data show (e.g., MW-1001 and MW-1005, Figure Nos. 3.6-11 and 3.6-15 respectively) that water typically flows into the sandstone from both the underlying Precambrian and the overlying till. This occurs because, in the till areas, the sandstone is the most permeable, continuous material present.

As Figure No. 3.6-6 shows, the general movement of groundwater through the sandstone is to the west toward the river and parallel to the general trend of the water table. No vertical gradients were measured within the sandstone unit, as the unit is too thin for such measurements to be meaningful.

Based on an a logarithmic mean permeability of 7.3×10^{-4} cm/sec, a measured hydraulic gradient of 0.025, and an effective porosity of 30 percent, the calculated flow velocity within the Cambrian sandstone is 0.17 ft/day. The same numbers may be used to estimate the discharge through that portion of the sandstone that will be displaced by the open pit. Figure No. 3.5-4 shows that along the centerline of the open pit the average thickness of the unit is 15 feet. At this point the width of section of sandstone normal to flow that would intercept the open pit would be approximately 800 feet. Using these two dimensions plus the average permeability and gradient stated above, the average discharge through the sandstone would be 4,600 gallons/day (3.2 gallons/minute).

Precambrian

Compared to the sandstone, little water moves through the Precambrian bedrock areas. Figure No. 3.6-7 shows that the flow in this unit, such as it is, is also westward toward the river. It is possible that some localized flow to the southwest occurs along the trend of the deposit, through the contact between the discontinuous metachert and the massive sulfide. However, if this occurs, it seems not to have affected the gradients measured in the remainder of the Precambrian unit.

Vertical gradients within the Precambrian were measured at two locations. Away from the river, at nested wells PZ-K4P and PZ-K4PP, the gradient is neutral, consistent with recharge zone conditions. Near the river, at well nest PZ-K2P and PZ-K2PP, the gradient is upward, typical of the discharge zone conditions that would be expected.

Based on the logarithmic mean permeability of 1.6×10^{-5} cm/sec, a measured hydraulic gradient of 0.025 ft/ft, and an effective porosity of five percent, the calculated flow velocity within the Precambrian is 0.022 feet/day. The same numbers are used to estimate the existing discharge through that portion of the Precambrian bedrock that will ultimately be displaced by the open pit. Using a depth of 175 feet, a width normal to flow of 600 feet, the permeability average stated above, and the gradient stated above, the average lateral movement through the Precambrian would be 890 gallons/day (0.62 gallons/minute).

3.6.3.2.3 Groundwater Discharge Summary

The total present-day flow through the area to be occupied by the open pit may be obtained by summing the flows through the till, sandstone, and Precambrian. The total is 6,690 gallons/day (4.6 gallons/minute), of which 18 percent is through the till, 69 percent is through the sandstone, and 13 percent is through the Precambrian. This groundwater ultimately discharges into the Flambeau River, which flows by the site at an average discharge of approximately 1,800 ft^3/sec (1.16×10^9 gallons/day or 808,000 gallons/minute), which is more than 170,000 times greater than the calculated current average groundwater discharge into the river.

3.6.3.3 Groundwater Use

Groundwater is presently being used near the project site area by Kennecott-owned residences along Kennecott Road northwest of the proposed open pit; along Blackberry Lane north of the proposed pit; and along HWY 27 east of the proposed open pit. The wells at these residences tap the glacial-fluvial material, sand and gravel layers within the till, and the Cambrian sandstone. No other groundwater use occurs within the project site area.

3.6.4 Groundwater Quality

This section consists of two parts. The first is a presentation of the data, and the second is a discussion of the data.

3.6.4.1 Baseline Monitoring Program Results

Per the requirements of NR 182.075(1)(d), and as described in the Kennecott Scope of Study document (Foth & Van Dyke, 1987), a baseline groundwater monitoring program was conducted. Samples were collected at the locations and at the frequency described above in Section 3.6.1.2.3.

Appendix No. 3.6-H is a tabulation of the groundwater quality data. The data are presented on three sets of tables in the appendix. On the first set, the data are presented as a series of parameter-oriented tables, with one table for each parameter. On the second set, the data are presented on a series of well-oriented tables, with one table for each well plus blanks. On the third set, the data are presented on a series of sampling event-oriented tables, with one table for each sampling event. In order to protect the confidentiality of the private well owners, the individual private well data sets are not included in the appendix. The data are, however, summarized on Table No. 3.6-12 (see below).

Appendix No. 3.6-H also contains a discussion of the comparison of the split sampling program conducted with the Wisconsin Department of Natural Resources. Overall, the correlation between the Kennecott samples and the WDNR splits was very good, indicating that the data set is accurate and representative of site conditions.

Table No. 3.6-12 is a summary of the data presented in the appendix and also of the private well data. The data are organized first by parameter. For each parameter, the maximum, minimum, median, and mean values, the numbers of samples tested, the numbers of detections made above the detection limit, and the percentage of detections made above the detection limit, were presented for groundwater collected in the overburden wells, the shallow Precambrian wells, the deep Precambrian wells, and the private wells (which are nearly all overburden wells).

Non-detection data points (e.g., values such as <0.05 mg/l) were accounted for in the construction of Table No. 3.6-12 by converting to values equal to one half the detection limit (e.g., 0.05 mg/l converts to a value of 0.025 mg/l). This explains the instances on the table where high, low, mean, and median values appear for parameters which had no detects. For example, thallium was tested for 40 times in the overburden groundwater and was never detected at the 0.005 mg/l detection level. Therefore, all the <0.005 mg/l non-detect values are recorded as 0.0025 mg/l, which then becomes the high, low, mean, and median value for thallium in Table No. 3.6-12.

TABLE NO. 3.6-12

Groundwater Quality Summary

Alkalinity	Overburden	Shallow PC	Deep PC	Pvt. Wells
Maximum	260	340	260	370
Minimum	14	81	150	17
Median	60	170	180	170
Mean	74	172	186	159
# of Tests	126	60	5	97
# of Detects	126	60	5	97
% of Detects	100.0%	100.0%	100.0%	100.0%

Aluminum	Overburden	Shallow PC	Deep PC	Pvt. Wells
Maximum	0.337	0.158	NA	NA
Minimum	0.034	0.034	NA	NA
Median	0.078	0.086	NA	NA
Mean	0.086	0.084	NA	NA
# of Tests	40	20	NA	NA
# of Detects	40	20	NA	NA
% of Detects	100.0%	100.0%	NA	NA

Arsenic	Overburden	Shallow PC	Deep PC	Pvt. Wells
Maximum	0.021	0.003	0.022	0.0015
Minimum	0.003	0.003	0.003	0.0015
Median	0.021	0.003	0.010	0.0015
Mean	0.003	0.003	0.010	0.0015
# of Tests	126	60	5	8
# of Detects	1	0	4	0
% of Detects	0.8%	0.0%	80.0%	0.0%

Barium	Overburden	Shallow PC	Deep PC	Pvt. Wells
Maximum	0.50	0.50	0.25	0.04
Minimum	0.25	0.25	0.25	0.04
Median	0.25	0.25	0.25	0.04
Mean	0.27	0.27	0.25	0.04
# of Tests	126.00	60.00	5.00	8
# of Detects	0	0	0	0
% of Detects	0.0%	0.0%	0.0%	0.0%

TABLE NO. 3.6-12 (Cont.)

Beryllium	Overburden	Shallow PC	Deep PC	Pvt. Wells
Maximum	0.0010	0.0005	NA	NA
Minimum	0.0005	0.0005	NA	NA
Median	0.0005	0.0005	NA	NA
Mean	0.0005	0.0005	NA	NA
# of Tests	40.00	20.00	NA	NA
# of Detects	1	0	NA	NA
% of Detects	2.5%	0.0%	NA	NA

Cadmium	Overburden	Shallow PC	Deep PC	Pvt. Wells
Maximum	0.0170	0.0240	0.0045	0.0002
Minimum	0.0002	0.0002	0.0035	0.0002
Median	0.0010	0.0012	0.0039	0.0002
Mean	0.0016	0.0025	0.0040	0.0002
# of Tests	126	60	5	8
# of Detects	96	37	5	0
% of Detects	76.2%	61.7%	100.0%	0.0%

Calcium	Overburden	Shallow PC	Deep PC	Pvt. Wells
Maximum	95	56	52	47
Minimum	8	17	31	15
Median	13	36	35	35
Mean	25	35	38	32
# of Tests	126	60	5	8
# of Detects	126	60	5	8
% of Detects	100.0%	100.0%	100.0%	100.0%

Chloride	Overburden	Shallow PC	Deep PC	Pvt. Wells
Maximum	230.0	6.0	9.0	81.0
Minimum	0.5	0.5	2.0	1.2
Median	3.0	1.0	3.0	8.0
Mean	24.1	1.8	5.0	16.7
# of Tests	126	60	5	97
# of Detects	83	27	5	83
% of Detects	65.9%	45.0%	100.0%	85.6%

TABLE NO. 3.6-12 (Cont.)

Chromium	Overburden	Shallow PC	Deep PC	Pvt. Wells
Maximum	0.0025	0.0025	0.0025	0.008
Minimum	0.0025	0.0025	0.0025	0.001
Median	0.0025	0.0025	0.0025	0.002
Mean	0.0025	0.0025	0.0025	0.003
# of Tests	126	60	5	8
# of Detects	0	0	0	4
% of Detects	0.0%	0.0%	0.0%	50.0%

Cobalt	Overburden	Shallow PC	Deep PC	Pvt. Wells
Maximum	0.025	0.025	NA	NA
Minimum	0.025	0.025	NA	NA
Median	0.025	0.025	NA	NA
Mean	0.025	0.025	NA	NA
# of Tests	40	20	NA	NA
# of Detects	0	0	NA	NA
% of Detects	0.0%	0.0%	NA	NA

COD	Overburden	Shallow PC	Deep PC	Pvt. Wells
Maximum	90.0	85.0	5.0	130.0
Minimum	2.5	2.5	2.5	2.5
Median	10.0	10.0	2.5	6.0
Mean	13.2	16.1	3.0	10.1
# of Tests	126	60	5	97
# of Detects	84	44	1	52
% of Detects	66.7%	73.3%	20.0%	53.6%

Copper	Overburden	Shallow PC	Deep PC	Pvt. Wells
Maximum	0.046	0.085	0.031	0.068
Minimum	0.003	0.003	0.010	0.005
Median	0.005	0.005	0.011	0.021
Mean	0.009	0.013	0.015	0.026
# of Tests	126	60	5	8
# of Detects	48	22	5	7
% of Detects	38.1%	36.7%	100.0%	87.5%

TABLE NO. 3.6-12 (Cont.)

Fluoride	Overburden	Shallow PC	Deep PC	Pvt. Wells
Maximum	2.50	0.60	0.30	0.2
Minimum	0.05	0.05	0.20	0.1
Median	0.20	0.20	0.30	0.1
Mean	0.35	0.26	0.26	0.1
# of Tests	126	60	5	4
# of Detects	68	51	5	3
% of Detects	54.0%	85.0%	100.0%	75.0%

Hardness	Overburden	Shallow PC	Deep PC	Pvt. Wells
Maximum	400	240	1,137	390
Minimum	2	63	143	1
Median	68	150	150	170
Mean	111	145	369	168
# of Tests	126	60	5	97
# of Detects	126	60	5	96
% of Detects	100.0%	100.0%	100.0%	99.0%

Iron	Overburden	Shallow PC	Deep PC	Pvt. Wells
Maximum	21.00	0.95	0.05	830.00
Minimum	0.05	0.05	0.05	0.03
Median	0.05	0.14	0.05	3.30
Mean	1.43	0.22	0.05	18.82
# of Tests	126	60	5	97
# of Detects	53	35	0	91
% of Detects	42.1%	58.3%	0.0%	93.8%

Lead	Overburden	Shallow PC	Deep PC	Pvt. Wells
Maximum	0.0025	0.0025	0.0025	0.004
Minimum	0.0025	0.0025	0.0025	0.001
Median	0.0025	0.0025	0.0025	0.003
Mean	0.0025	0.0025	0.0025	0.003
# of Tests	126	60	5	8
# of Detects	0	0	0	6
% of Detects	0.0%	0.0%	0.0%	75.0%

TABLE NO. 3.6-12 (Cont.)

Magnesium	Overburden	Shallow PC	Deep PC	Pvt. Wells
Maximum	41.0	24.0	19.0	15.0
Minimum	2.4	5.4	11.0	3.4
Median	5.7	14.0	13.0	10.5
Mean	9.7	13.9	13.8	9.9
# of Tests	126	60	5	8
# of Detects	126	60	5	8
% of Detects	100.0%	100.0%	100.0%	100.0%

Manganese	Overburden	Shallow PC	Deep PC	Pvt. Wells
Maximum	1.40	0.75	0.29	0.6300
Minimum	0.03	0.03	0.03	0.0055
Median	0.09	0.36	0.23	0.2550
Mean	0.25	0.35	0.19	0.2171
# of Tests	126	60	5	8
# of Detects	74	58	4	5
% of Detects	58.7%	96.7%	80.0%	62.5%

Mercury	Overburden	Shallow PC	Deep PC	Pvt. Wells
Maximum	0.00240	0.00025	0.00025	0.00025
Minimum	0.00025	0.00025	0.00025	0.00025
Median	0.00025	0.00025	0.00025	0.00025
Mean	0.00027	0.00025	0.00025	0.00025
# of Tests	126	60	5	8
# of Detects	2	0	0	0
% of Detects	1.6%	0.0%	0.0%	0.0%

Molybdenum	Overburden	Shallow PC	Deep PC	Pvt. Wells
Maximum	0.08	0.06	N/A	N/A
Minimum	0.01	0.01	N/A	N/A
Median	0.01	0.01	N/A	N/A
Mean	0.02	0.03	N/A	N/A
# of Tests	40	20	N/A	N/A
# of Detects	13	8	N/A	N/A
% of Detects	32.5%	40.0%	N/A	N/A

TABLE NO. 3.6-12 (Cont.)

Nickel	Overburden	Shallow PC	Deep PC	Pvt. Wells
Maximum	0.067	0.028	N/A	N/A
Minimum	0.004	0.004	N/A	N/A
Median	0.015	0.015	N/A	N/A
Mean	0.018	0.012	N/A	N/A
# of Tests	94	45	N/A	N/A
# of Detects	29	9	N/A	N/A
% of Detects	30.9%	20.0%	N/A	N/A

NO3+NO2-N	Overburden	Shallow PC	Deep PC	Pvt. Wells
Maximum	2.90	0.42	0.15	3.5
Minimum	0.03	0.03	0.07	0.1
Median	0.30	0.35	0.10	2.0
Mean	0.56	0.08	0.10	1.9
# of Tests	126	60	5	4
# of Detects	105	21	5	4
% of Detects	83.3%	35.0%	100.0%	100.0%

pH	Overburden	Shallow PC	Deep PC	Pvt. Wells
Maximum	7.07	7.38	7.04	6.93
Minimum	5.25	5.78	6.56	4.78
Median	6.21	6.52	6.93	6.16
Mean	6.24	6.58	6.86	6.12
# of Tests	126	60	5	97
# of Detects	126	60	5	97
% of Detects	100.0%	100.0%	100.0%	100.0%

Selenium	Overburden	Shallow PC	Deep PC	Pvt. Wells
Maximum	0.0025	0.0025	0.0025	0.0015
Minimum	0.0025	0.0025	0.0025	0.0015
Median	0.0025	0.0025	0.0025	0.0015
Mean	0.0025	0.0025	0.0025	0.0015
# of Tests	126	60	5	8
# of Detects	0	0	0	0
% of Detects	0.0%	0.0%	0.0%	0.0%

TABLE NO. 3.6-12 (Cont.)

Silver	Overburden	Shallow PC	Deep PC	Pvt. Wells
Maximum	0.0073	0.0070	0.0002	0.0002
Minimum	0.0002	0.0002	0.0002	0.0002
Median	0.0002	0.0002	0.0002	0.0002
Mean	0.0009	0.0009	0.0002	0.0002
# of Tests	126	60	5	8
# of Detects	10	5	0	0
% of Detects	7.9%	8.3%	0.0%	0.0%

Sodium	Overburden	Shallow PC	Deep PC	Pvt. Wells
Maximum	30.0	33.0	14.0	6.6
Minimum	1.2	1.4	9.6	3.0
Median	6.1	14.0	11.0	4.9
Mean	7.7	14.1	11.3	4.8
# of Tests	126	60	5	8
# of Detects	126	60	5	8
% of Detects	100.0%	100.0%	100.0%	100.0%

Spec. Cond.	Overburden	Shallow PC	Deep PC	Pvt. Wells
Maximum	954	876	439	716
Minimum	84	128	298	30
Median	159	315	339	260
Mean	245	324	344	284
# of Tests	126	60	5	97
# of Detects	126	60	5	97
% of Detects	100.0%	100.0%	100.0%	100.0%

Sulfate	Overburden	Shallow PC	Deep PC	Pvt. Wells
Maximum	46.0	48.0	10.0	25.0
Minimum	2.5	2.5	2.5	5.3
Median	11.0	8.0	5.0	6.0
Mean	11.3	9.9	5.8	10.6
# of Tests	126	60	5	4
# of Detects	96	45	3	4
% of Detects	76.2%	75.0%	60.0%	100.0%

TABLE NO. 3.6-12 (Cont.)

TDS	Overburden	Shallow PC	Deep PC	Pvt. Wells
Maximum	1,400	350	280	NA
Minimum	14	67	180	NA
Median	130	200	200	NA
Mean	247	213	210	NA
# of Tests	126	60	5	NA
# of Detects	126	60	5	NA
% of Detects	100.0%	100.0%	100.0%	NA

Thallium	Overburden	Shallow PC	Deep PC	Pvt. Wells
Maximum	0.0025	0.0025	NA	NA
Minimum	0.0025	0.0025	NA	NA
Median	0.0025	0.0025	NA	NA
Mean	0.0025	0.0025	NA	NA
# of Tests	40	20	NA	NA
# of Detects	0	0	NA	NA
% of Detects	0.0%	0.0%	NA	NA

Tin	Overburden	Shallow PC	Deep PC	Pvt. Wells
Maximum	0.136	0.285	NA	NA
Minimum	0.034	0.034	NA	NA
Median	0.034	0.034	NA	NA
Mean	0.042	0.068	NA	NA
# of Tests	40	20	NA	NA
# of Detects	4	7	NA	NA
% of Detects	10.0%	35.0%	NA	NA

Titanium	Overburden	Shallow PC	Deep PC	Pvt. Wells
Maximum	0.028	0.004	NA	NA
Minimum	0.002	0.002	NA	NA
Median	0.002	0.002	NA	NA
Mean	0.004	0.002	NA	NA
# of Tests	40	20	NA	NA
# of Detects	8	1	NA	NA
% of Detects	20.0%	5.0%	NA	NA

TABLE NO. 3.6-12 (Cont.)

Uranium	Overburden	Shallow PC	Deep PC	Pvt. Wells
Maximum	0.017	0.011	0.007	NA
Minimum	0.001	0.001	0.004	NA
Median	0.002	0.003	0.006	NA
Mean	0.002	0.003	0.006	NA
# of Tests	126	60	5	NA
# of Detects	81	45	5	NA
% of Detects	64.3%	75.0%	100.0%	NA

Zinc	Overburden	Shallow PC	Deep PC	Pvt. Wells
Maximum	0.320	1.800	0.070	0.1200
Minimum	0.005	0.005	0.025	0.0055
Median	0.025	0.025	0.025	0.0205
Mean	0.036	0.080	0.039	0.0464
# of Tests	126	60	5	8
# of Detects	31	12	2	6
% of Detects	24.6%	20.0%	40.0%	75.0%

Figure Nos. 3.6-22 through 3.6-29 graphically depict the data on Table No. 3.6-12. For the parameters for which enough detections were available to graph, Figure No. 3.6-22 displays the high, low, median, and mean values for the overburden groundwater quality. Figure Nos. 3.6-23, 3.6-24, and 3.6-25 display the same data for the shallow Precambrian (as sampled monthly in the nested C wells), the deep Precambrian (as sampled in once the R wells) and the private well groundwater (mostly overburden, sampled twice), respectively. Parameters not presented on these figures for lack of enough detections were arsenic, barium, beryllium, chromium, cobalt, lead, mercury, selenium, thallium, tin, and titanium. They were either not detected at all or not detected with sufficient frequency to calculate the pertinent statistics.

3.6.4.2 Discussion of the Data

The groundwater quality of the site area is variable. The data show no significant differences in groundwater upgradient and downgradient of the deposit. The differences, rather, are between the groundwater that occurs in the overburden (till, glacial-fluvial material, and sandstone) and the groundwater that occurs in the Precambrian. In the overburden materials the median data show that the groundwater is relatively soft and low in total dissolved solids (TDS). By contrast, the water in the Precambrian is approximately twice as hard, contains more than 50 percent more TDS, and has higher levels of metals.

The following sections discuss these differences on a parameter-by-parameter basis. Because the mean concentrations usually tend to be skewed upward by a few high values, the discussions below center on median concentrations.

3.6.4.2.1 Primary Drinking Water Standard Compounds

The baseline sampling program included extensive testing for the United State Public Health Service (USPHS) Primary Drinking Water Standard (PDWS) metals compounds arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver, and the non-metal PDWS compounds fluoride and nitrate. Of the PDWS metals, only cadmium was consistently found, albeit at median concentrations well below the PDWS of 0.0100 mg/L (median concentrations of 0.0010 mg/L, 0.0012 mg/L, and 0.0039 mg/L in the overburden, shallow Precambrian, and deep Precambrian, respectively).

Fluoride concentrations were below the 2.2 mg/L standard. The medians were 0.20 mg/L, 0.20 mg/L, and 0.30 mg/L, respectively, in the overburden, shallow Precambrian, and deep Precambrian groundwater.

The nitrate-nitrogen standard of 10 mg/L was not approached in any of groundwaters. The medians were 0.30 mg/L, 0.35 mg/L, and

0.10 mg/L, respectively, in the overburden, shallow Precambrian, and deep Precambrian groundwater.

3.6.4.2.2 Secondary Drinking Water Standard Compounds

The baseline program also included extensive testing for the USPHS Secondary Drinking Water Standard (SDWS) compounds iron, manganese, copper, zinc, chloride, sulfate, and TDS.

Compared to the SDWS of 0.3 mg/L, iron is present in lower concentrations (median=0.14 mg/L) in the shallow Precambrian groundwater, was not detected in the deep Precambrian, and was present in lower concentrations (median=0.05 mg/L) in the overburden. In the private wells, however, it was higher (median=3.3 mg/L). For manganese, all concentration medians were high compared to the SDWS (0.05 mg/L). The median concentrations in the shallow and deep Precambrian, in the overburden, and in the private wells (0.36 mg/L, 0.23 mg/L, 0.09 mg/L, and 0.26 mg/L, respectively) all exceed the SDWS.

Copper and zinc were detected, but at levels below SDWS levels of 1 mg/L and 5 mg/L, respectively. Copper was detected in approximately one-third of the monitoring well samples tested and in nearly 90 percent of the private well samples tested. Median values were lower than the standard in both the overburden and the shallow Precambrian (0.05 mg/L), in the deep Precambrian (0.11 mg/L) and in the private wells (0.21 mg/L). Zinc was detected less frequently than copper--just over 20 percent of the time. Zinc median values are 0.025 mg/L for all three types of on-site groundwater and 0.020 mg/L for private well groundwater.

Median chloride concentrations were below the standard of 250 mg/L. The medians were 3.0 mg/L, 1.0 mg/L, 3.0 mg/L, and 8.0 mg/L, respectively, in the overburden, shallow Precambrian, deep Precambrian, and private well groundwater. At one well, MW-1005, a reading as high as 230 mg/L was recorded. During the study this well consistently exhibited elevated chloride values, evidently affected by the proximity of the well to State Highway 27 where calcium chloride salt is used for de-icing (calcium readings were also relatively high at this well).

Sulfate concentrations were below the SDWS of 250 mg/L. The medians were 11 mg/L, 8 mg/L, 5 mg/L, and 6 mg/L, respectively, in the overburden, shallow Precambrian, deep Precambrian, and private well groundwater.

TDS concentrations were below the SDWS of 500 mg/L. The medians were 130 mg/L, 200 mg/L, and 200 mg/L, respectively, in the overburden, shallow Precambrian, and deep Precambrian groundwater.

3.6.4.2.3 Other Parameters

Several indicator parameters were monitored during the baseline program. These included the general indicators total alkalinity, field pH, total hardness, field specific conductivity, chemical oxygen demand (COD), and field temperature, and the metals calcium and magnesium.

The overburden groundwaters had a lower pH (median=6.21) and alkalinity (median=60 mg/L) than did the shallow Precambrian groundwater (pH median=6.52, alkalinity median=170 mg/L) or the deep Precambrian groundwater (pH median=6.93, alkalinity median=180 mg/L). For the private wells, the results were mixed. Relative to the other samples, the pH was low (median=6.16), but the alkalinity was high (median=170 mg/L).

The total hardness and field specific conductivity parameters generally parallel TDS. The values in the Precambrian bedrock groundwaters are approximately double those in the overburden groundwaters.

COD is relatively low at the site. It is somewhat higher in both the overburden and shallow Precambrian groundwaters (medians are 10.0 mg/L in both) than in the deep Precambrian groundwaters (median = 2.5 mg/L). In the private wells the median was 6.0 mg/L.

Field temperatures were more variable in water samples taken from shallow wells than from deep wells, fluctuating seasonally with the ambient air temperature.

Calcium and magnesium values were higher in the Precambrian groundwaters than in the overburden groundwater. The medians for calcium were 36 mg/L and 35 mg/L and for magnesium were 14 mg/L and 13 mg/L, in the shallow and deep Precambrian groundwaters, respectively, while in the overburden they were 13 mg/L and 5.7 mg/L, respectively. In the private wells the medians for calcium and magnesium were 35 mg/L and 10.5 mg/L, respectively.

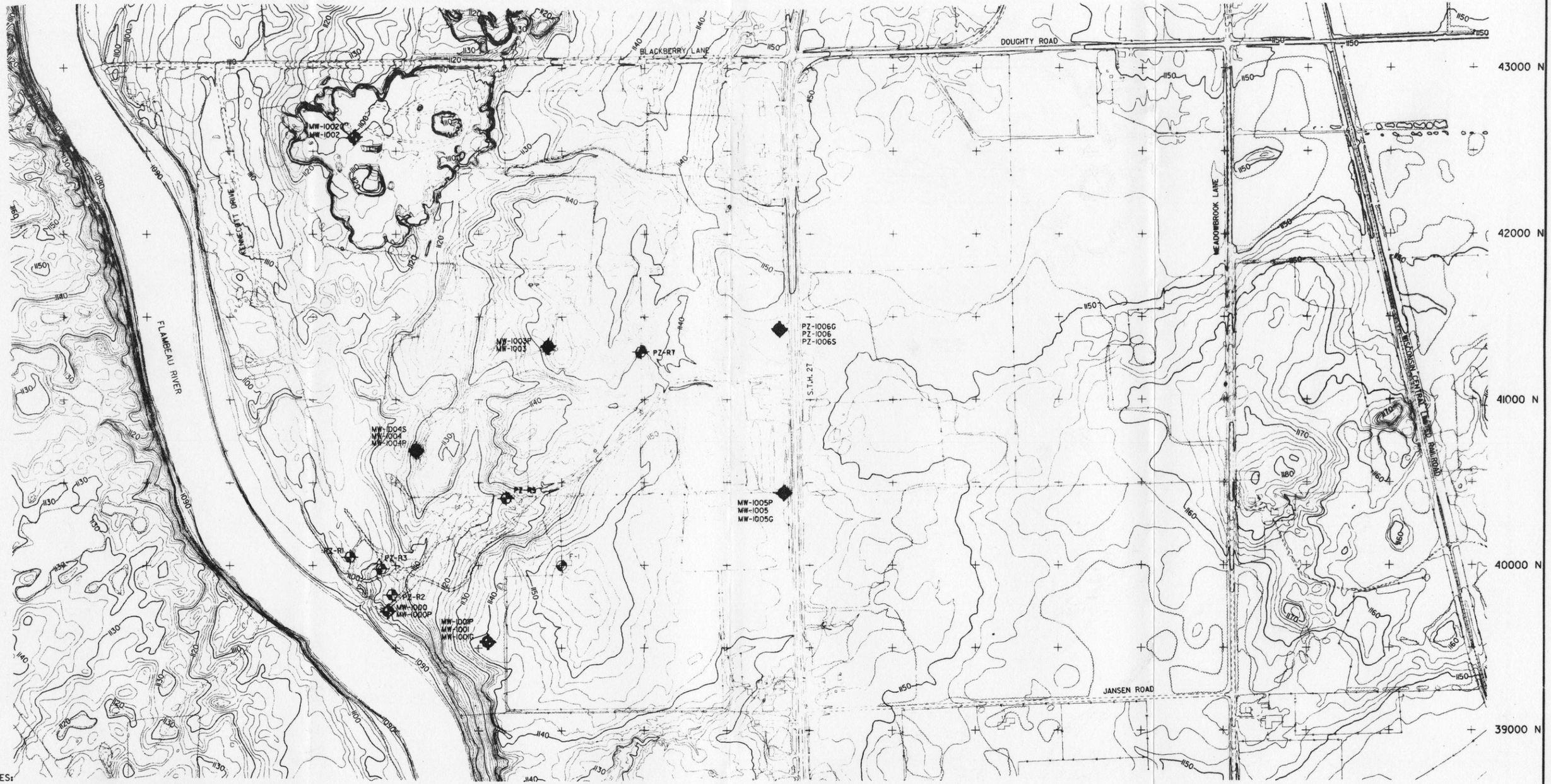
A number of metals not included in the drinking water standards or indicator parameter lists were analyzed. These included aluminum, beryllium, cobalt, molybdenum, nickel, thallium, tin, titanium, and uranium. Nickel and uranium were analyzed throughout the investigation. The other metals were run for the first four sampling periods and then dropped for lack of detects at significant concentrations.

Cobalt, selenium, and thallium were not detected in any of the samples tested. Beryllium was detected only once, in an overburden groundwater sample. Molybdenum, nickel, tin and titanium were all detected 10 to 30 percent of the time, generally at levels less than 0.05 mg/L. Uranium was detected in approximately two thirds of the samples tested, with median and mean values in the range of 0.002 to 0.003 mg/L. (The mean

value for uranium in groundwaters of the United States is 0.005 mg/L (USEPA, 1975), so the range at the site is low relative to average levels.) Aluminum was detected in all samples tested, at median values of approximately 0.08 mg/L.

No drinking water standards have been set for any of these additional metals. All the measured concentrations, including those for uranium, are quite low and should present no health problems.

Figures for Section 3.6



NOTES:

1. SITE LOCATION: SECTIONS 9, 10, 15 & 16, T34N, R6W, RUSK COUNTY, WISCONSIN.
2. TOPOGRAPHIC BASE MAP PREPARED FROM AERIAL SURVEY BY SURDEX CORPORATION, CHESTERFIELD, MISSOURI. DATE OF PHOTOGRAPHY - APRIL 24, 1970. ROADS, TREES AND BUILDINGS WERE UPDATED AS PER AERIAL PHOTOGRAPH TAKEN BY MARKHURD CORPORATON, MINNEAPOLIS, MINNESOTA. DATE OF PHOTOGRAPHY - SEPTEMBER 14, 1987.
3. ELEVATIONS BASED ON MEAN SEA LEVEL DATUM. CONTOUR INTERVAL IS TWO FEET.
4. HORIZONTAL DATUM BASED ON PROJECT SITE GRID SYSTEM. SITE GRID COORDINATES CORRELATION TO STATE PLANE COORDINATES DERIVED AS FOLLOWS:

SITE GRID COORDINATES CONTROL MONUMENT F-1	STATE PLANE COORDINATES
40000 N =	587,357.8087 N
40000 E =	1,713,516.1229 E

THE ANGULAR ROTATION FROM STATE PLANE BEARINGS TO SITE GRID BEARINGS IS 359°-13'-23" RIGHT WITH CONTROL POINT F-1 AS THE BASE POINT.

LEGEND

- 1100 — EXISTING CONTOUR
- EXISTING PAVED ROADWAY
- EXISTING TRAIL/GRAVEL SURFACE
- TREES AND/OR BRUSH
- FENCE
- F-1 CONTROL MONUMENT
- MW-1005 MONITORING WELL
- PZ-R3 PIEZOMETER

0 300' 600'
SCALE

FOTH & VAN DYKE
GEOSCIENCES & ENVIRONMENTAL MANAGEMENT DIVISION
GREEN BAY, WISCONSIN

FLAMBEAU PROJECT
LADYSMITH, WISCONSIN

KENNECOTT MINERALS COMPANY
555 MINERAL SQUARE
SALT LAKE CITY, UTAH 84112

FIGURE NO. 3.6-1
GROUNDWATER QUALITY SAMPLING LOCATIONS

MICROFILM | JOB
DRAWING NO. | REV.
DIVISION DRAWING NO.
SCALE | SEE BAR SCALE

REFERENCES	DWG. NO.	DESCRIPTION

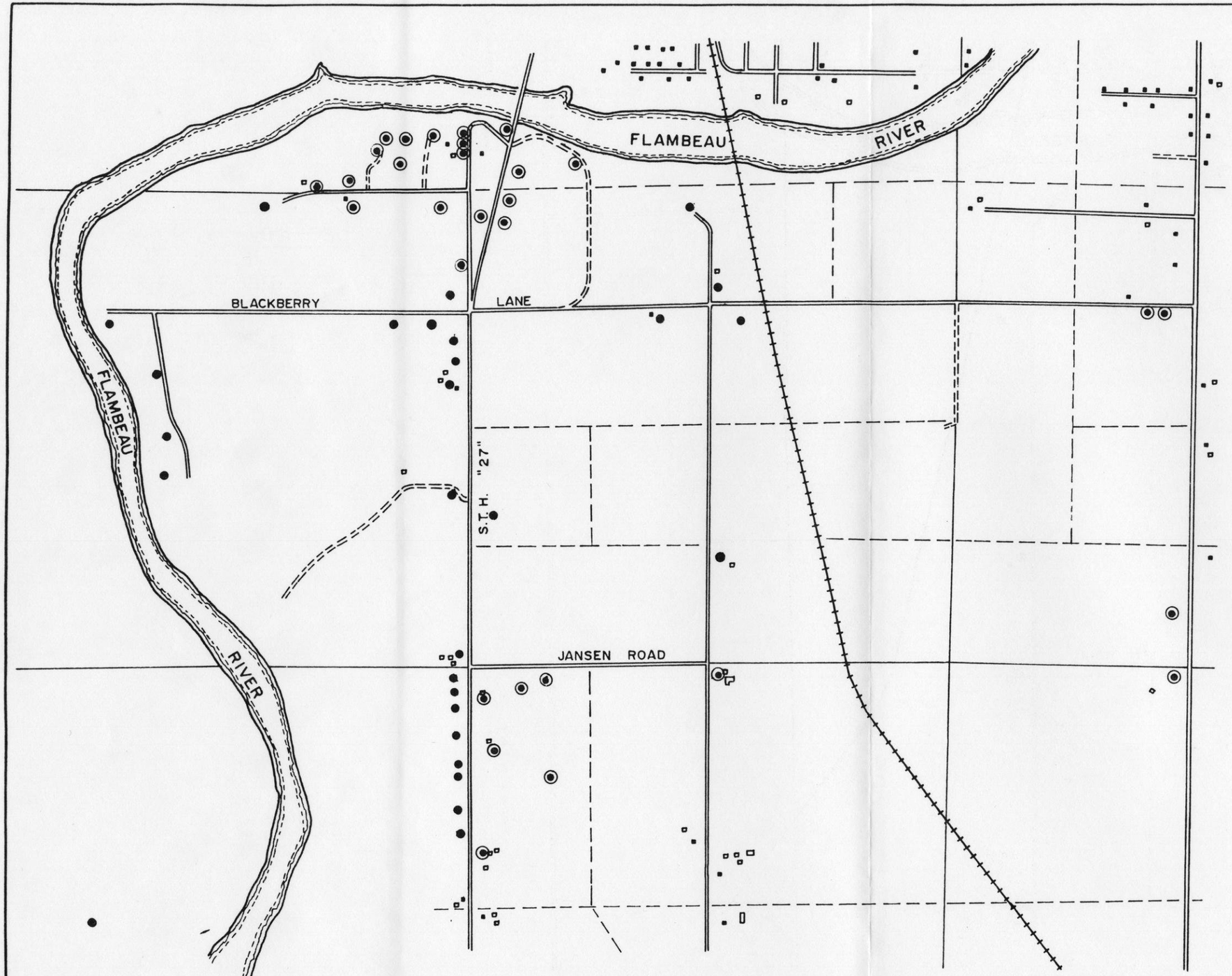
REFERENCES	DWG. NO.	DESCRIPTION

NO.	DATE	REVISIONS	BY	CHK'D	ENG'R	ENG'R MGR.

NO.	DATE	REVISIONS	BY	CHK'D	ENG'R	ENG'R MGR.

	BY	DATE
PROJ. ENG'R		
MGR. PROCESS ENG'R		
ENG'R MGR.		

	BY	DATE
DESIGN		
DRAWN	MJO	3/89
CHK'D	BNP	3/89
DES. ENG'R		
SECT ENG'R		



LEGEND

- ● KENNECOTT OWNED PROPERTY WITH ACTIVE WELL AND PROPERTY NUMBER
- ◉ PRIVATELY OWNED PROPERTY WITH ACTIVE WELL

REPRODUCED FROM USGS LADYSMITH AND THORNAPPLE 7.5 MINUTE SERIES TOPOGRAPHIC MAPS

REFERENCES

DWG. NO.	DESCRIPTION

REFERENCES

DWG. NO.	DESCRIPTION

NO.	DATE	REVISIONS	BY	CH'D	ENG'R	ENG'R MGR.

NO.	DATE	REVISIONS	BY	CH'D	ENG'R	ENG'R MGR.

	BY	DATE
PROJ. ENG'R		
MGR. PROCESS ENG'R		
ENG'R MGR.		

	BY	DATE
DESIGN		
DRAWN	RDM	3/89
CH'D	BNP	3/89
DES. ENG'R		
SECT ENG'R		

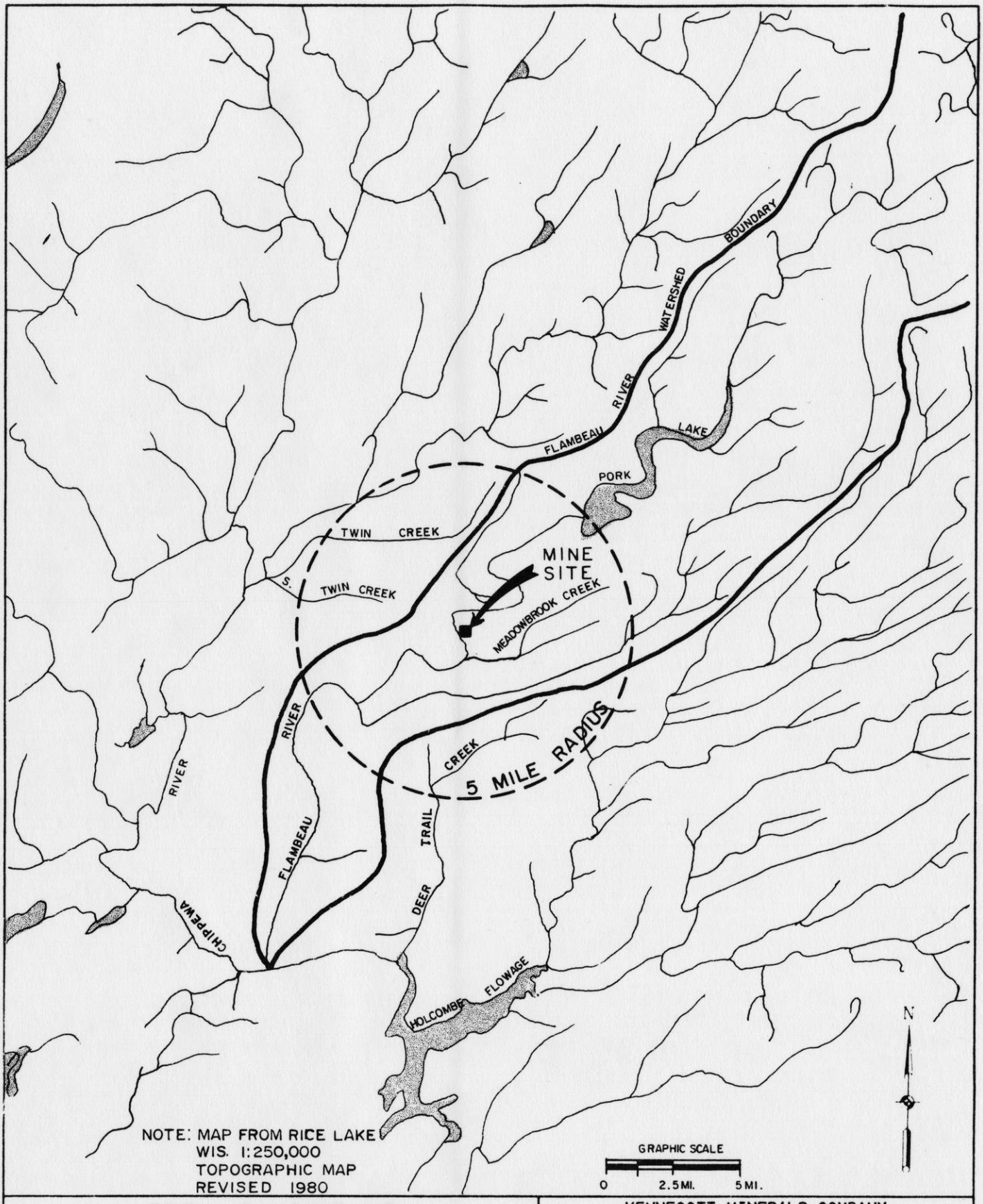
FOTH & VAN DYKE
GEOSCIENCES & ENVIRONMENTAL MANAGEMENT DIVISION
GREEN BAY, WISCONSIN

KENNECOTT MINERALS COMPANY
1515 MINERAL SQUARE
SALT LAKE CITY, UTAH 84112

FLAMBEAU PROJECT
LADYSMITH, WISCONSIN

FIGURE NO. 3.6-2
PRIVATE WATER SUPPLY
WELL LOCATION MAP

MICROFILM	JOB
DRAWING NO.	REV.
DIVISION DRAWING NO.	
SCALE	NTS



NOTE: MAP FROM RICE LAKE
WIS. 1:250,000
TOPOGRAPHIC MAP
REVISED 1980

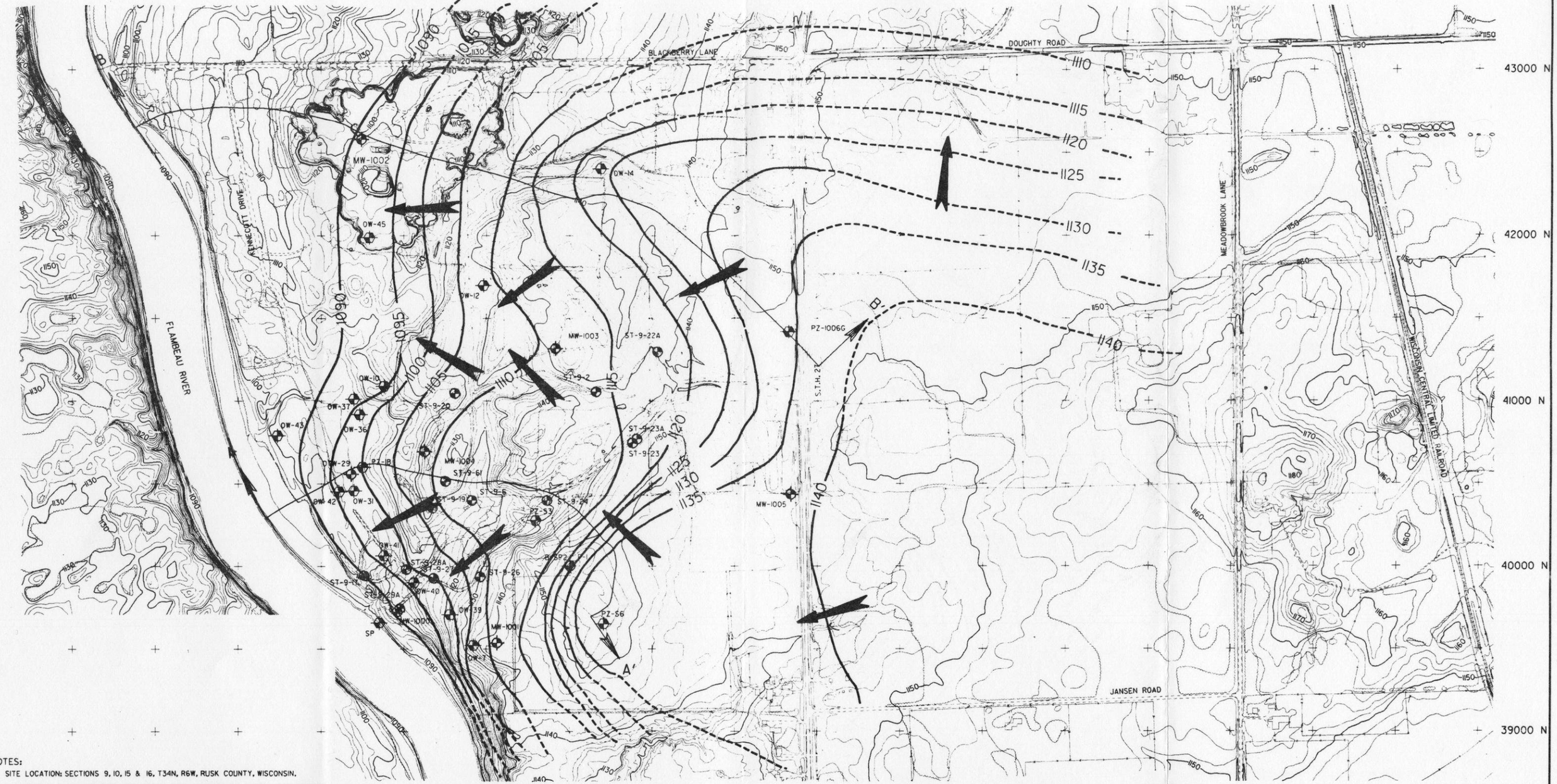
FOTH & VAN DYKE
GEOSCIENCES & ENVIRONMENTAL MANAGEMENT DIVISION
GREEN BAY, WISCONSIN

NOTES	APPROVAL	DATE
	DESIGNED BY	
	DRAWN BY R.M.H.	3/89
	CHECKED BY B.N.P.	3/89
	APPROVED BY	
	CAD No. SCALE	

KENNECOTT MINERALS COMPANY
FLAMBEAU PROJECT
LADYSMITH, WISCONSIN

FIGURE NO. 3.6-3
REGIONAL GROUNDWATER
FLOW SYSTEM DISTRIBUTION

Job No	Dwg No	REV



NOTES:

1. SITE LOCATION: SECTIONS 9, 10, 15 & 16, T34N, R6W, RUSK COUNTY, WISCONSIN.
2. TOPOGRAPHIC BASE MAP PREPARED FROM AERIAL SURVEY BY SURDEX CORPORATION, CHESTERFIELD, MISSOURI. DATE OF PHOTOGRAPHY - APRIL 24, 1970. ROADS, TREES AND BUILDINGS WERE UPDATED AS PER AERIAL PHOTOGRAPH TAKEN BY MARKHURD CORPORATON, MINNEAPOLIS, MINNESOTA. DATE OF PHOTOGRAPHY - SEPTEMBER 14, 1987.
3. ELEVATIONS BASED ON MEAN SEA LEVEL DATUM. CONTOUR INTERVAL IS TWO FEET.
4. HORIZONTAL DATUM BASED ON PROJECT SITE GRID SYSTEM. SITE GRID COORDINATES CORRELATION TO STATE PLANE COORDINATES DERIVED AS FOLLOWS:

SITE GRID COORDINATES CONTROL MONUMENT F-1	STATE PLANE COORDINATES
40000 N =	587,357.8087 N
40000 E =	1,713,516.1229 E

THE ANGULAR ROTATION FROM STATE PLANE BEARINGS TO SITE GRID BEARINGS IS 359°-13'-23" RIGHT WITH CONTROL POINT F-1 AS THE BASE POINT.

5. SEE FIGURE NO.'S 3.6-8 AND 3.6-9 FOR HYDRO GEOLOGIC CROSS SECTIONS.

LEGEND

- —1100— EXISTING CONTOUR
- EXISTING PAVED ROADWAY
- EXISTING TRAIL/GRAVEL SURFACE
- TREES AND/OR BRUSH
- FENCE
- F-1 CONTROL MONUMENT
- MW-1005 MONITORING WELL
- PZ-54 / OW-43 PIEZOMETER
- ST-9-2 SOIL BORING
- —1120— HIGH GROUNDWATER CONTOUR
- INFERRED GROUNDWATER CONTOUR
- GROUNDWATER FLOW DIRECTION

WELL	GROUNDWATER ELEVATION
MW-1000	1091.06
MW-1001	1112.83
MW-1002	1090.72
MW-1003	1110.37
MW-1004	1109.69
MW-1005	1139.10
ST-9-2	1114.87
ST-9-19A	1109.77
ST-9-22A	DRY

WELL	GROUNDWATER ELEVATION
ST-9-23	1115.45
ST-9-26	1108.92
ST-9-27A	DRY
ST-9-28A	1099.75
ST-9-29A	1094.99
OW-7	1105.97
OW-10	1094.81
OW-12	1109.14
OW-14	1124.84

WELL	GROUNDWATER ELEVATION
OW-36	1096.57
OW-37	DRY
OW-39	1099.26
OW-40	1096.85
OW-41	1097.50
OW-42	1096.10
OW-43	1088.65
OW-45	1093.63
SAND POINT (SP)	1086.84

0 300' 600'
SCALE

FOTH & VAN DYKE
GEOSCIENCES & ENVIRONMENTAL MANAGEMENT DIVISION
GREEN BAY, WISCONSIN

FLAMBEAU PROJECT
LADYSMITH, WISCONSIN

KENNECOTT MINERALS COMPANY
155 MINERAL SQUARE
SALT LAKE CITY, UTAH 84112

FIGURE NO. 3.6-4
HIGH WATER TABLE
CONTOUR MAP
APRIL 6, 1988

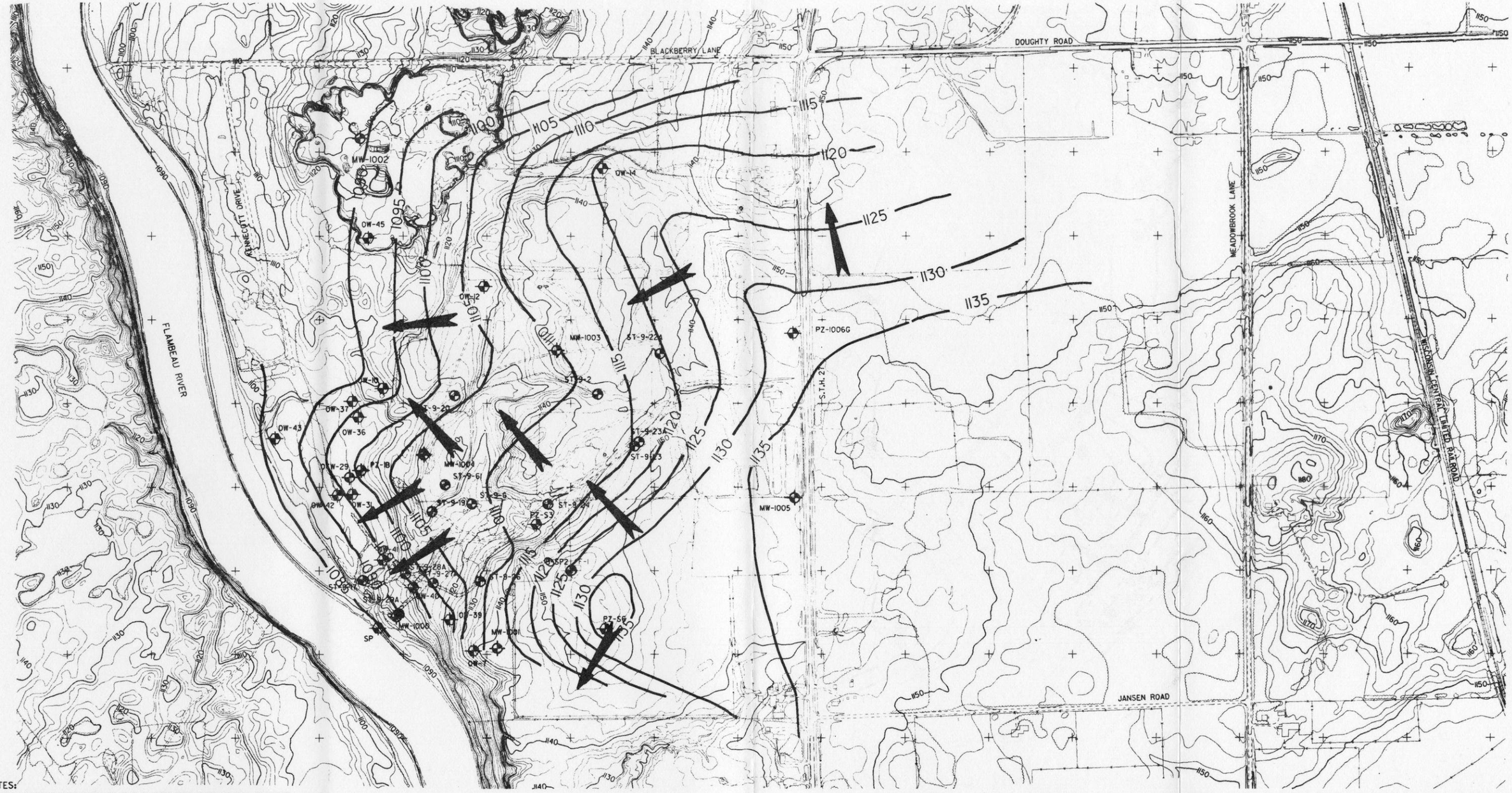
	BY	DATE
DESIGN		
DRAWN	M.J.O.	3/89
CHK'D	B.N.P.	3/89
DES. ENG'R		
SECT ENG'R		
PROJ. ENG'R		
MGR. PROCESS ENG'R		
ENG'R MGR.		

MICROFILM | JOB
DRAWING NO. | REV.
DIVISION DRAWING NO.
SCALE | SEE BAR SCALE

REFERENCES

DWG. NO.	DESCRIPTION

NO.	DATE	REVISIONS	BY	CHK'D	ENG'R	ENG'R MGR.



NOTES:

1. SITE LOCATION: SECTIONS 9, 10, 15 & 16, T34N, R6W, RUSK COUNTY, WISCONSIN.
2. TOPOGRAPHIC BASE MAP PREPARED FROM AERIAL SURVEY BY SURDEX CORPORATION, CHESTERFIELD, MISSOURI. DATE OF PHOTOGRAPHY - APRIL 24, 1970. ROADS, TREES AND BUILDINGS WERE UPDATED AS PER AERIAL PHOTOGRAPH TAKEN BY MARKHURD CORPORATON, MINNEAPOLIS, MINNESOTA. DATE OF PHOTOGRAPHY - SEPTEMBER 14, 1987.
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SITE GRID COORDINATES CONTROL MONUMENT F-1	STATE PLANE COORDINATES
40000 N =	587,357.8087 N
40000 E =	1,713,516.1229 E

THE ANGULAR ROTATION FROM STATE PLANE BEARINGS TO SITE GRID BEARINGS IS 359°-13'-23" RIGHT WITH CONTROL POINT F-1 AS THE BASE POINT.

LEGEND

- —1100— EXISTING CONTOUR
- EXISTING PAVED ROADWAY
- EXISTING TRAIL/GRAVEL SURFACE
- TREES AND/OR BRUSH
- FENCE
- F-1 CONTROL MONUMENT
- MW-1005 MONITORING WELL
- PZ-S4 PIEZOMETER
- ST-9-2 SOIL BORING
- —1120— LOW GROUNDWATER CONTOUR
- GROUNDWATER FLOW DIRECTION

N

WELL	GROUNDWATER ELEVATION
MW-1000	1087.96
MW-1001	1110.94
MW-1002	1089.44
MW-1003	1109.91
MW-1004	1107.70
MW-1005	1136.71
ST-9-2	1111.75
ST-9-19A	1107.71
ST-9-22A	DRY

WELL	GROUNDWATER ELEVATION
ST-9-23	1115.15
ST-9-26	1108.38
ST-9-27A	DRY
ST-9-28A	1095.52
ST-9-29A	DRY
OW-7	1109.13
OW-10	1093.01
OW-12	1108.04
OW-14	1121.41

WELL	GROUNDWATER ELEVATION
OW-36	1095.74
OW-37	DRY
OW-39	1098.50
OW-40	1094.35
OW-41	1094.12
OW-42	1092.67
OW-43	1086.85
OW-45	1091.14
SANDPOINT (SP)	1084.71

0 300' 600'
SCALE

FOTH & VAN DYKE
GEOSCIENCES & ENVIRONMENTAL MANAGEMENT DIVISION
GREEN BAY, WISCONSIN

FLAMBEAU PROJECT
LADYSMITH, WISCONSIN

KENNECOTT MINERALS COMPANY
155 MINERAL SQUARE
SALT LAKE CITY, UTAH
84112

FIGURE NO. 3.6-5
LOW WATER TABLE
CONTOUR MAP
SEPTEMBER 6, 1988

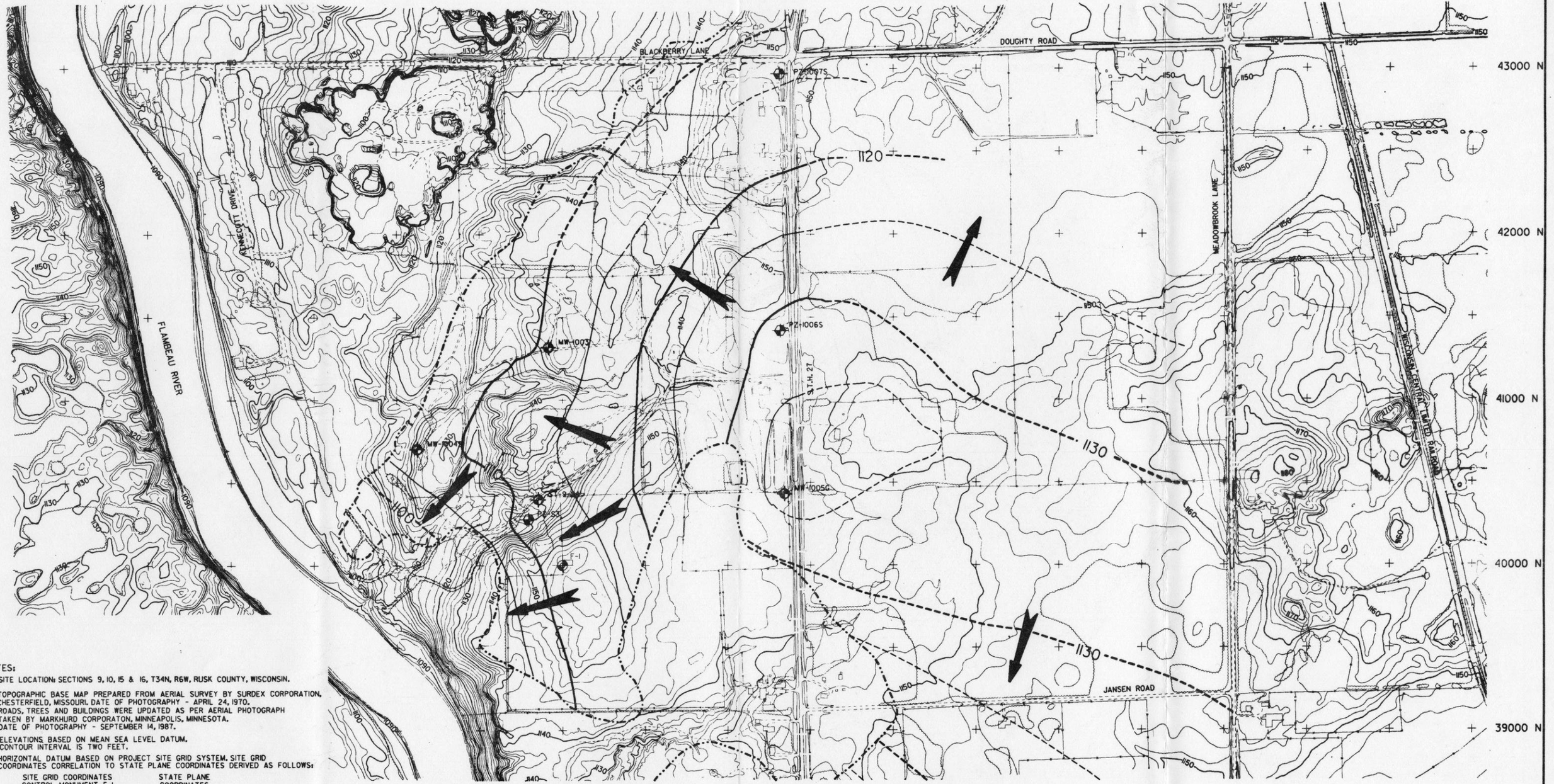
MICROFILM | JOB
DRAWING NO. | REV.
DIVISION DRAWING NO.
SCALE | SEE BAR SCALE

	BY	DATE
PROJ. ENG'R		
MGR. PROCESS ENG'R		
ENG'R MGR.		
DESIGN		
DRAWN	M.J.O.	3/89
CHK'D	B.N.P.	3/89
DES. ENG'R		
SECT ENG'R		

REFERENCES

DWG. NO.	DESCRIPTION

NO.	DATE	REVISIONS	BY	CHK'D	ENG'R	ENG'R MGR.



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THE ANGULAR ROTATION FROM STATE PLANE BEARINGS TO SITE GRID BEARINGS IS 359°-13'-23" RIGHT WITH CONTROL POINT F-1 AS THE BASE POINT.

5. AVERAGE POTENTIOMETRIC SURFACE DEVELOPED BY KRIGING AVERAGE GROUNDWATER ELEVATIONS (DECEMBER TO NOVEMBER 1988) FOR THE FOLLOWING WELLS:

WELL	AVERAGE GROUNDWATER ELEVATION
MW-1003	1110.28
MW-1004S	1108.41
MW-1005	1137.51
MW-1006S	1131.92
MW-1007S	1114.72
ST-9-24	1112.94
PZ-S3	1112.84

LEGEND

- —1100— EXISTING CONTOUR
- EXISTING PAVED ROADWAY
- EXISTING TRAIL/GRAVEL SURFACE
- TREES AND/OR BRUSH
- FENCE
- F-1 CONTROL MONUMENT
- MW-1005 MONITORING WELL
- PZ-S4 PIEZOMETER
- —1090— POTENTIOMETRIC SURFACE CONTOUR
- INFERRED POTENTIOMETRIC SURFACE CONTOUR
- LIMIT OF SANDSTONE
- GROUNDWATER FLOW DIRECTION

FOTH & VAN DYKE
GEOSCIENCES & ENVIRONMENTAL MANAGEMENT DIVISION
GREEN BAY, WISCONSIN

FLAMBEAU PROJECT
LADYSMITH, WISCONSIN

KENNECOTT MINERALS COMPANY
165 MINERAL SQUARE
SALT LAKE CITY, UTAH 84112

FIGURE NO. 3.6-6
AVERAGE POTENTIOMETRIC SURFACE
CAMBRIAN SANDSTONE

	BY	DATE
PROJ ENG'R		
MGR. PROCESS ENG'R		
ENG'R MGR.		

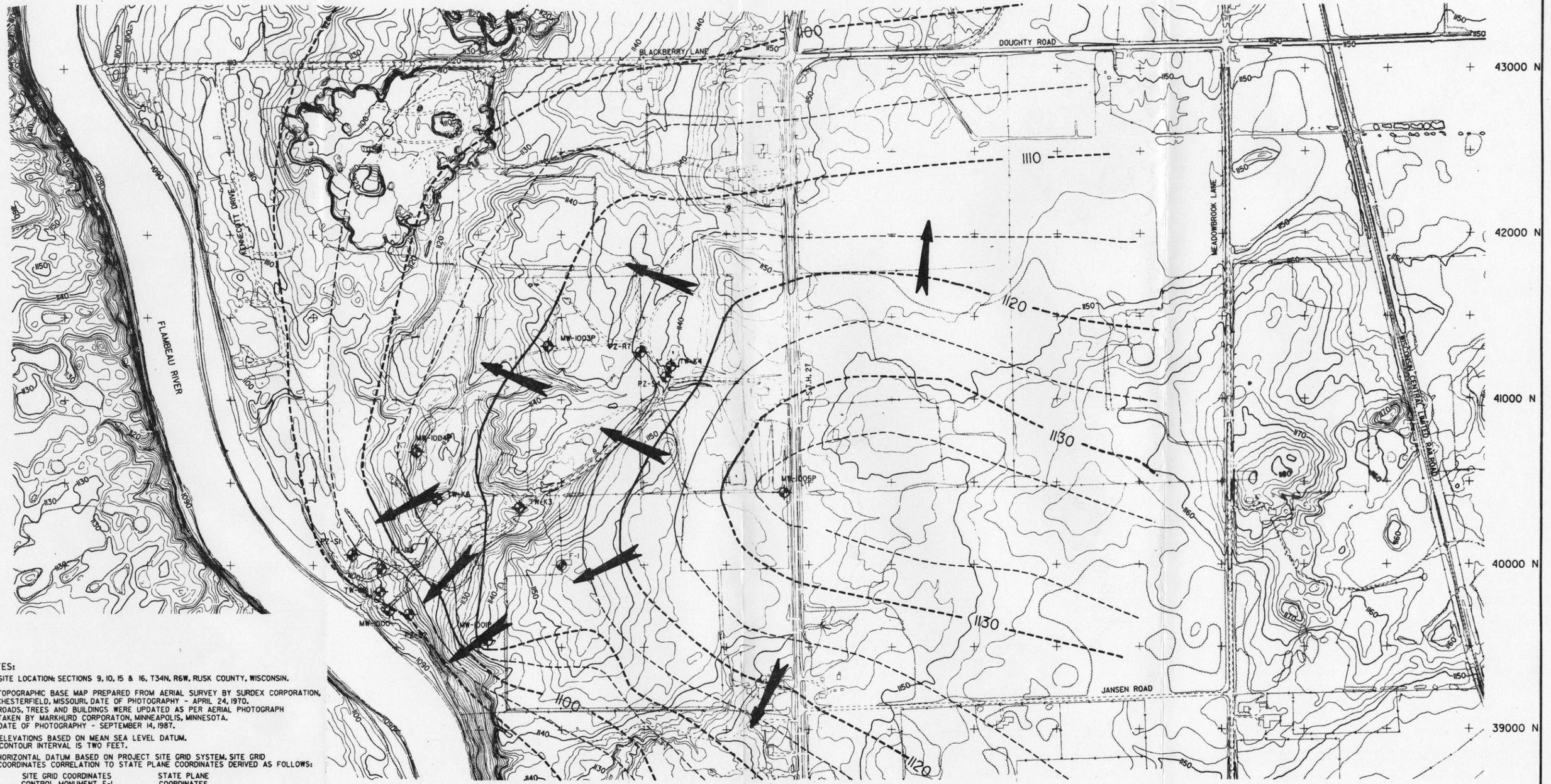
	BY	DATE
DESIGN		
DRAWN	MJD	3/89
CH'K'D	BNP	3/89
DES. ENG'R		
SECT ENG'R		

MICROFILM | JOB
DRAWING NO. | REV.
DIVISION DRAWING NO.
SCALE | SEE BAR SCALE

REFERENCES

DWG. NO.	DESCRIPTION

NO.	DATE	REVISIONS	BY	CH'K'D	ENG'R	ENG'R MGR.



NOTES:

1. SITE LOCATION: SECTIONS 9, 10, 15 & 16, T34N, R6W, RUSK COUNTY, WISCONSIN.
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3. ELEVATIONS BASED ON MEAN SEA LEVEL DATUM. CONTOUR INTERVAL IS TWO FEET.
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SITE GRID COORDINATES CONTROL MONUMENT F-1	STATE PLANE COORDINATES
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40000 E =	1,713,516.1229 E

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5. AVERAGE POTENTIOMETRIC SURFACE DEVELOPED BY KRIGING AVERAGE GROUNDWATER ELEVATIONS (DECEMBER TO NOVEMBER 1988) FOR THE FOLLOWING WELLS:

WELL	AVERAGE GROUNDWATER ELEVATION	WELL	AVERAGE GROUNDWATER ELEVATION
MW-1000	1088.91	PZ-S4	1116.17
MW-1001P	1112.53	PZ-R3	1093.30
MW-1003P	1110.34	PZ-R7	1115.41
MW-1004P	1106.17	TW-K3	1111.67
MW-1005P	1137.91	TW-K4	1116.34
PZ-S1	1094.95	TW-K6	1107.88
PZ-S2	1091.41	TW-K8	1092.09

LEGEND

- —1100— EXISTING CONTOUR
- EXISTING PAVED ROADWAY
- EXISTING TRAIL/GRAVEL SURFACE
- TREES AND/OR BRUSH
- FENCE
- F-1 CONTROL MONUMENT
- MW-1005 / TW-K4 MONITORING WELL
- PZ-S4 PIEZOMETER
- —1090— POTENTIOMETRIC SURFACE CONTOUR
- INFERRED POTENTIOMETRIC SURFACE CONTOUR
- GROUNDWATER FLOW DIRECTION

N

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GEOSCIENCES & ENVIRONMENTAL MANAGEMENT DIVISION
GREEN BAY, WISCONSIN

FLAMBEAU PROJECT
LADYSMITH, WISCONSIN

KENNECOTT MINERALS COMPANY
555 MINERAL SQUARE
SALT LAKE CITY, UTAH 8412

FIGURE NO. 3.6-7
AVERAGE POTENTIOMETRIC SURFACE
TOP OF PRECAMBRIAN ROCK

	BY	DATE
PROJ. ENG'R		
MGR. PROCESS ENGR.		
ENG'R MGR.		

	BY	DATE
DESIGN		
DRAWN	M.J.O.	3/89
CHK'D	B.N.P.	3/89
DES. ENG'R		
SECT ENG'R		

MICROFILM	JOB
DRAWING NO.	REV.
DIVISION DRAWING NO.	
SCALE	SEE BAR SCALE

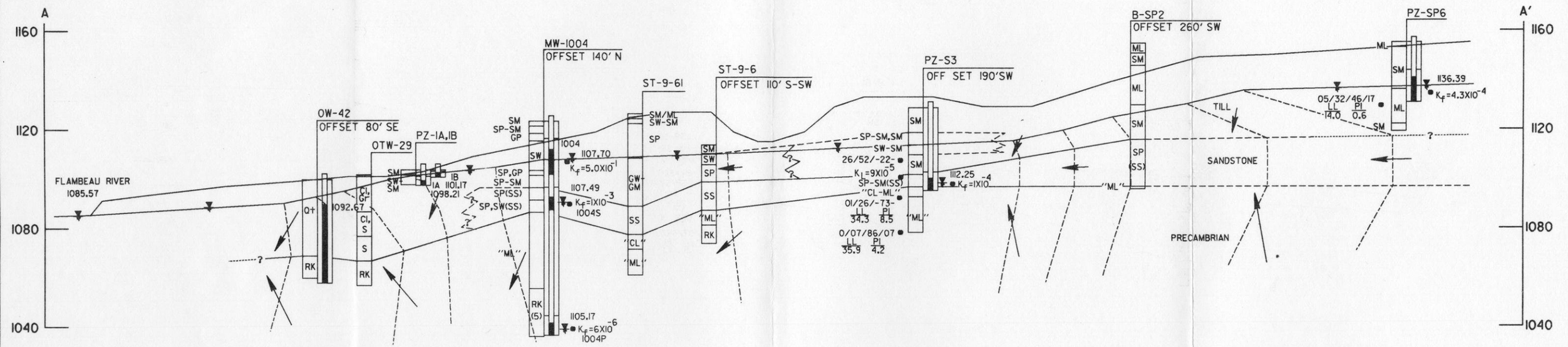
REFERENCES

DWG. NO.	DESCRIPTION

NO.	DATE	REVISIONS	BY	CHK'D	ENG'R	ENG'R MGR.

SECTION A-A'

(LINE OF SECTION SHOWN ON FIGURE NO. 3.6-4)



LEGEND

QUATERNARY

Q+	TILL, AND SAND AND GRAVEL (MAY CONTAIN SOME CAMBRIAN SANDSTONE)
SM	SILTY SAND
SW-SM	WELL GRADED SAND WITH SILT
SP	POORLY GRADED SAND
SP-SM	POORLY GRADED SAND WITH SILT
SW	WELL GRADED SAND
SP-SM, SW	POORLY GRADED SAND WITH SILT INTERBEDDED WITH WELL-GRADED SAND
SM,SP	SILTY SAND INTERBEDDED WITH POORLY GRADED SAND
SW,SM	WELL GRADED SAND INTERBEDDED WITH SILTY SAND
SM/ML	SILTY SAND/SILT
SC/SM	CLAYEY SAND/SILTY SAND
SC	CLAYEY SAND
SC-SM	SILTY-CLAYEY SAND
GW	WELL GRADED GRAVEL
GW-GM	WELL GRADED GRAVEL WITH SILT
GP	POORLY GRADED GRAVEL
GM	SILTY GRAVEL
SP,GP	POORLY GRADED SAND INTERBEDDED WITH POORLY GRADED GRAVEL
SM/GM	SILTY SAND/SILTY GRAVEL
SM,GW-GM	SILTY SAND INTERBEDDED WITH POORLY GRADED GRAVEL WITH SILT
GM/SM	SILTY GRAVEL/SILTY SAND
ML	SILT
Cl,S	CLAY AND SAND
Cl,Gr	CLAY AND GRAVEL
S	SAND

CAMBRIAN

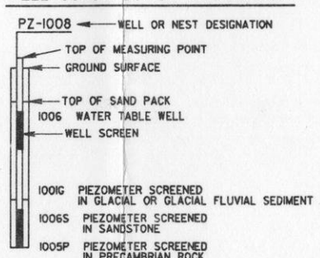
SS	SANDSTONE

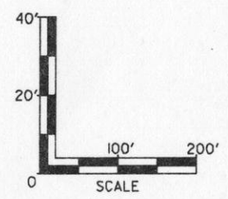
PRECAMBRIAN

RK	ROCK
Q+z	QUARTZ
(Ia)	SERICITE-QUARTZ SCHIST
(2)	BIOTITE SCHIST
(3)	AUGEN SCHIST
(5)	METADACITE (VOLCANIC FLOW ROCK)
"ML"	ROCK THAT DISAGGREGATES TO SILT
"SM"	ROCK THAT DISAGGREGATES TO SILTY SAND
"GM"	ROCK THAT DISAGGREGATES TO SILTY GRAVEL
"CL/ML"	ROCK THAT DISAGGREGATES TO LEAN CLAY/SILT
"SM/ML"	ROCK THAT DISAGGREGATES TO SILTY SAND/SILT
"SM,ML"	ROCK THAT DISAGGREGATES TO INTERBEDS OF SILTY SAND AND SILT

- LL / PI — ATTERBERG LIMITS
- K_F=7.9X10^{-5} — IN-FIELD PERMEABILITY VALUE (CM/SEC)
- K_L=4.0X10^{-9} — LABORATORY PERMEABILITY VALUE (CM/SEC)
- 01/50/41/08 — GRAVEL/SAND/SILT/CLAY PERCENTAGES
- 0/93/-7- — GRAVEL/SAND/P200 PERCENTAGES
- 1113.27 — LOW WATER LEVEL SEPTEMBER 6, 1988
- CONTACTS-REASONABLY CERTAIN; UNCERTAIN; VERY UNCERTAIN
- ESTIMATED GROUNDWATER CONTOUR
- GROUNDWATER FLOW DIRECTION

WELL CONSTRUCTION INFORMATION





FOTH & VAN DYKE
GEOSCIENCES & ENVIRONMENTAL MANAGEMENT DIVISION
GREEN BAY, WISCONSIN

FLAMBEAU PROJECT
LADYSMITH, WISCONSIN

KENNECOTT MINERALS COMPANY
155 MINERAL SQUARE
SALT LAKE CITY, UTAH 8412

FIGURE NO. 3.6-8
HYDRO GEOLOGIC CROSS SECTION
A-A'

	BY	DATE
PROJ. ENG'R		
MGR. PROCESS ENG'R		
ENG'R MGR.		
DESIGN		
DRAWN	M.J.O.	3/89
CHK'D	B.N.P.	3/89
DES. ENG'R		
SECT ENG'R		

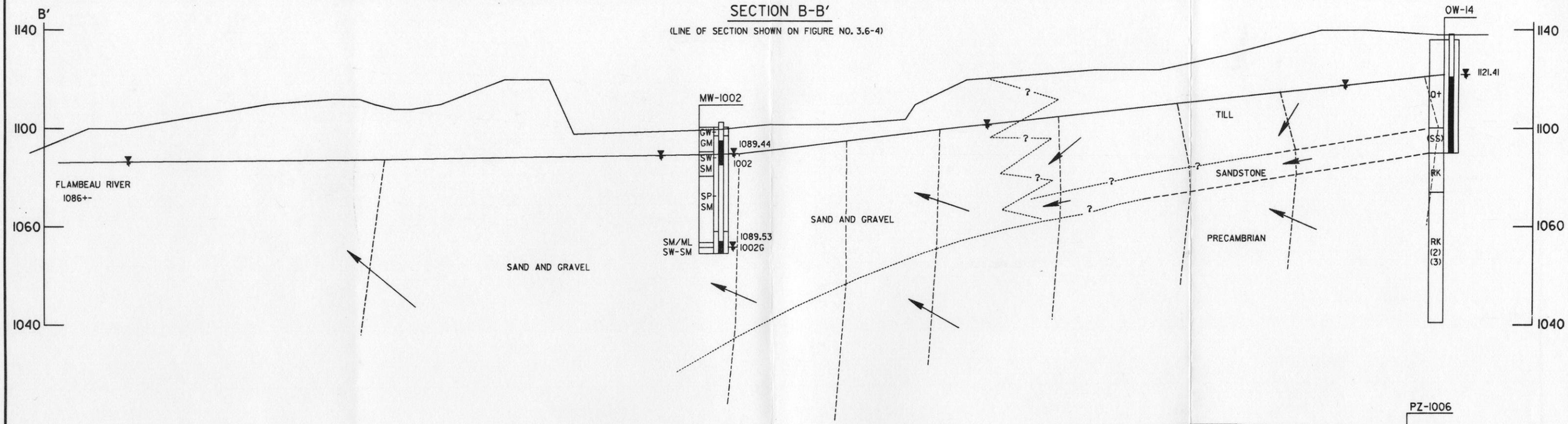
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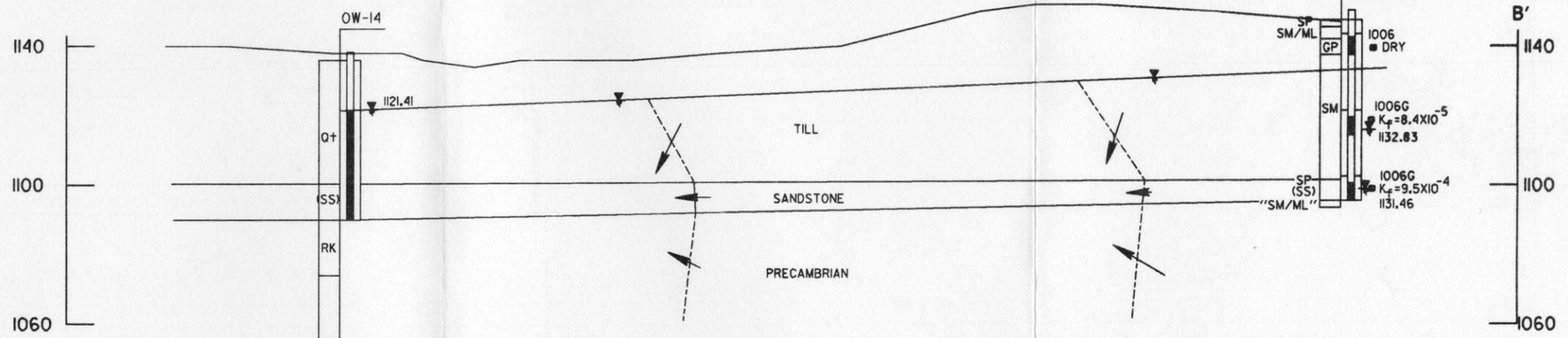
NO.	DATE	REVISIONS	BY	CHK'D	ENG'R	ENG'R MGR.

MICROFILM | JOB
DRAWING NO. | REV.
DIVISION DRAWING NO.
SCALE: SEE BAR SCALE

SECTION B-B'

(LINE OF SECTION SHOWN ON FIGURE NO. 3.6-4)





LEGEND

QUATERNARY

Qt	TILL, AND SAND AND GRAVEL (MAY CONTAIN SOME CAMBRIAN SANDSTONE)
SM	SILTY SAND
SW-SM	WELL GRADED SAND WITH SILT
SP	POORLY GRADED SAND
SP-SM	POORLY GRADED SAND WITH SILT
SW	WELL GRADED SAND
SP-SM, SW	POORLY GRADED SAND WITH SILT INTERBEDDED WITH WELL-GRADED SAND
SM,SP	SILTY SAND INTERBEDDED WITH POORLY GRADED SAND
SW,SM	WELL GRADED SAND INTERBEDDED WITH SILTY SAND
SM/ML	SILTY SAND/SILT
SC/SM	CLAYEY SAND/SILTY SAND
SC	CLAYEY SAND
SC-SM	SILTY-CLAYEY SAND
GW	WELL GRADED GRAVEL
GW-GM	WELL GRADED GRAVEL WITH SILT
GP	POORLY GRADED GRAVEL
GM	SILTY GRAVEL
SP,GP	POORLY GRADED SAND INTERBEDDED WITH POORLY GRADED GRAVEL
SM/GM	SILTY SAND/SILTY GRAVEL
SM,GW-GM	SILTY SAND INTERBEDDED WITH POORLY GRADED GRAVEL WITH SILT
GM/SM	SILTY GRAVEL/SILTY SAND

ML	SILT
Cl,S	CLAY AND SAND
Cl,Gr	CLAY AND GRAVEL
S	SAND

CAMBRIAN

SS	SANDSTONE

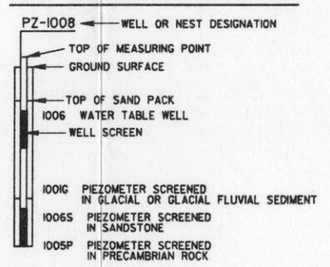
PRECAMBRIAN

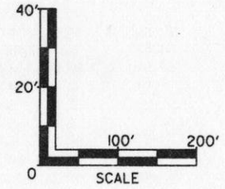
RK	ROCK
Qtz	QUARTZ
(Ia)	SERICITE-QUARTZ SCHIST
(2)	BIOTITE SCHIST
(3)	AUGEN SCHIST
(5)	METADACITE (VOLCANIC FLOW ROCK)
"ML"	ROCK THAT DISAGGREGATES TO SILT
"SM"	ROCK THAT DISAGGREGATES TO SILTY SAND
"GM"	ROCK THAT DISAGGREGATES TO SILTY GRAVEL
"CL/ML"	ROCK THAT DISAGGREGATES TO LEAN CLAY/SILT
"SM/ML"	ROCK THAT DISAGGREGATES TO SILTY SAND/SILT
"SM,ML"	ROCK THAT DISAGGREGATES TO INTERBEDS OF SILTY SAND AND SILT

LL 26 PI 13
K_f=7.9X10^{-5}
K_L=4.0X10^{-9}
01/50/41/08
0/93/-7-
113.27

SAMPLING POINT
ATTERBERG LIMITS
IN-FIELD PERMEABILITY VALUE (CM/SEC)
LABORATORY PERMEABILITY VALUE (CM/SEC)
GRAVEL/SAND/SILT/CLAY PERCENTAGES
GRAVEL/SAND/P200 PERCENTAGES
LOW WATER LEVEL SEPTEMBER 6, 1988
CONTACTS-REASONABLY CERTAIN
UNCERTAIN
VERY UNCERTAIN
ESTIMATED GROUNDWATER CONTOUR
GROUNDWATER FLOW DIRECTION

WELL CONSTRUCTION INFORMATION





FOTH & VAN DYKE
GEOSCIENCES & ENVIRONMENTAL MANAGEMENT DIVISION
GREEN BAY, WISCONSIN

FLAMBEAU PROJECT
LADYSMITH, WISCONSIN

KENNECOTT MINERALS COMPANY
555 MINERAL SQUARE
SALT LAKE CITY, UTAH 84112

FIGURE NO. 3.6-9
HYDRO GEOLOGIC CROSS SECTION
B-B'

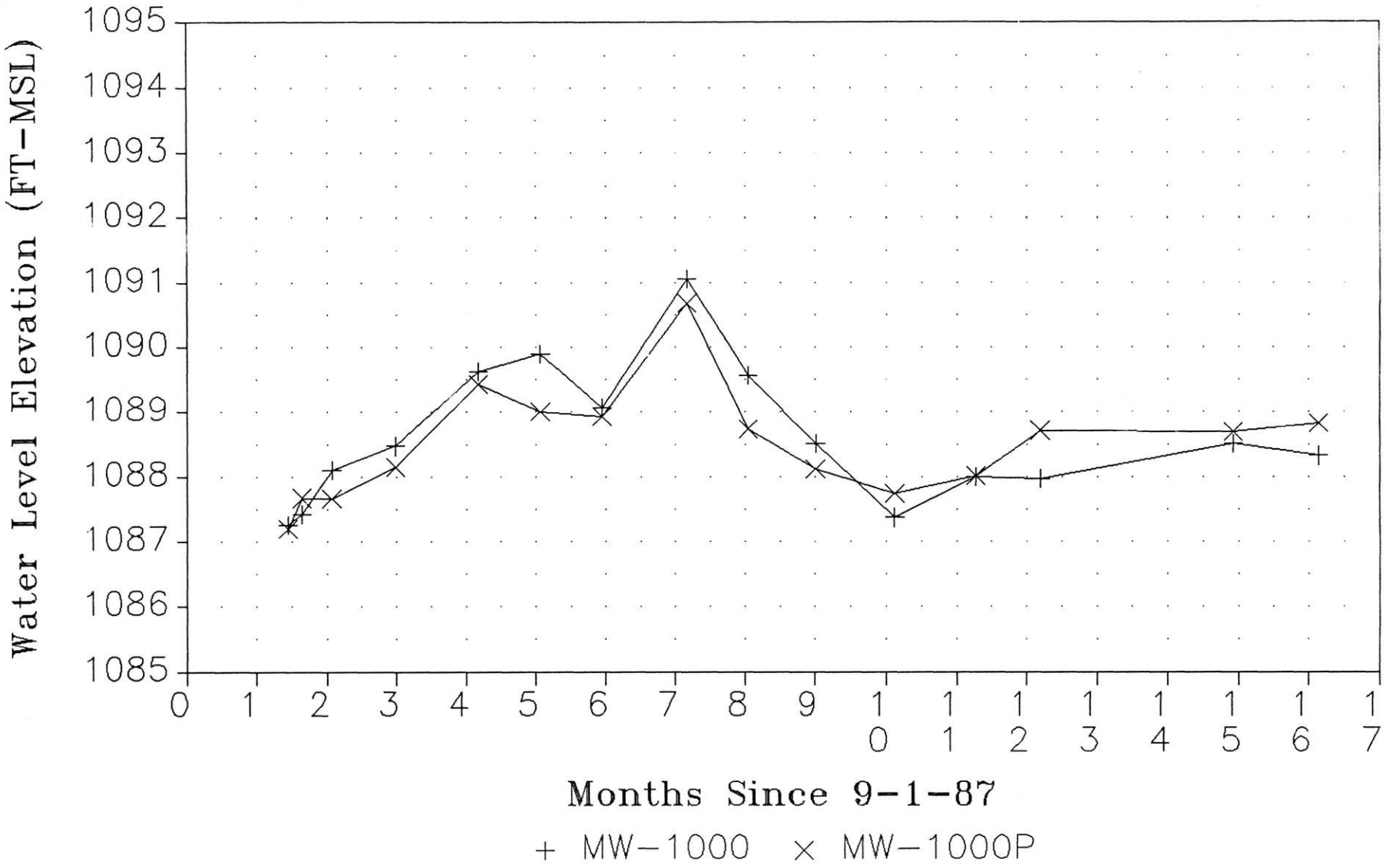
	BY	DATE
PROJ. ENG'R		
MGR. PROCESS ENG'R		
ENG'R MGR.		
DESIGN		
DRAWN	M.J.O.	3/89
CHK'D	B.N.P.	3/89
DES. ENG'R		
SECT ENG'R		

MICROFILM | JOB
DRAWING NO. | REV.
DIVISION DRAWING NO.
SCALE

REFERENCES

DWG. NO.	DESCRIPTION

NO.	DATE	REVISIONS	BY	CHK'D	ENG'R	ENG'R MGR.



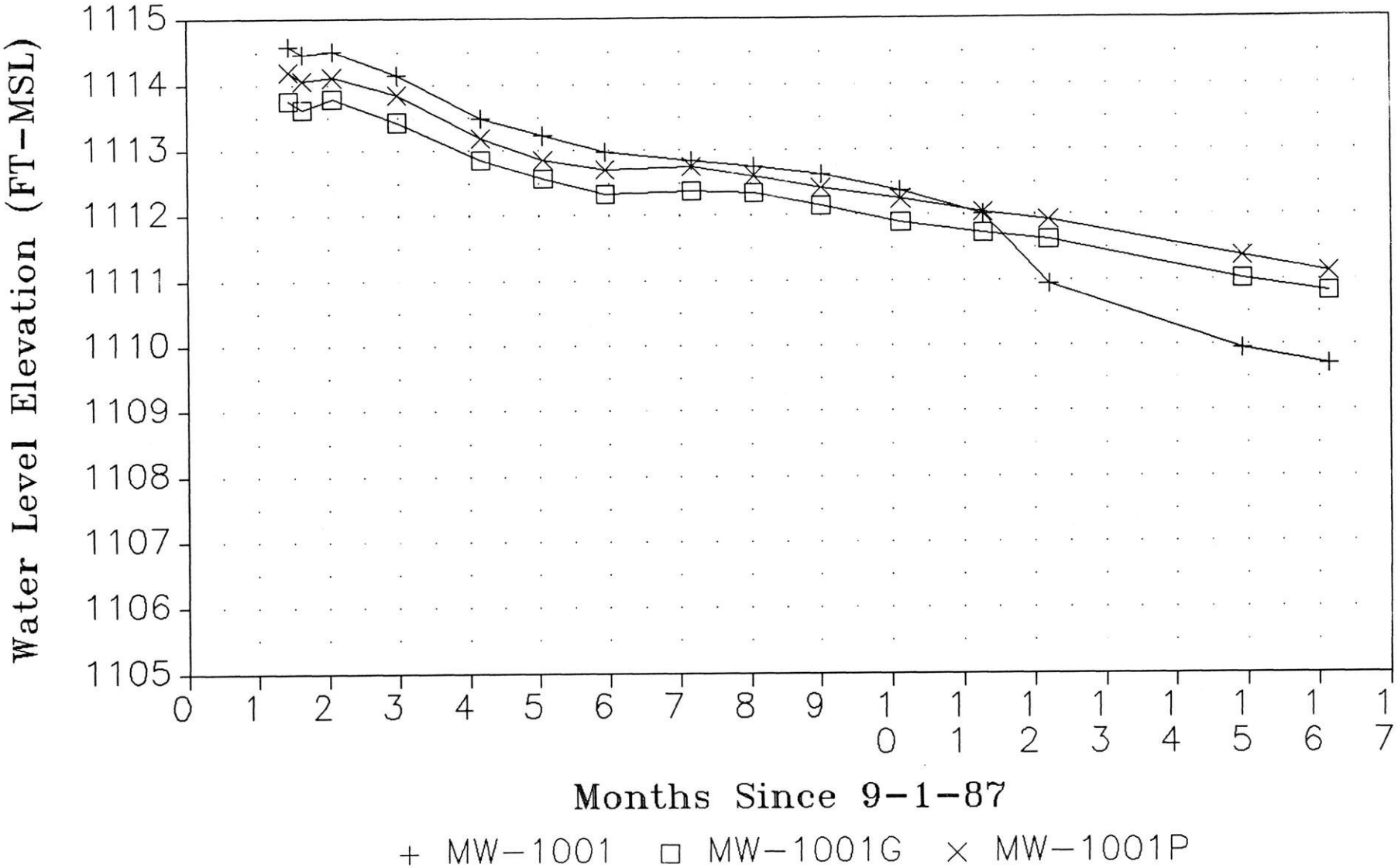
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FIGURE NO 3.6-10
HYDROGRAPH
WELL NEST 1000

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			DRAWN BY	
			CHECKED BY	
			APPROVED BY	
			CAD No.	SCALE

Job No	Dwg No	REV



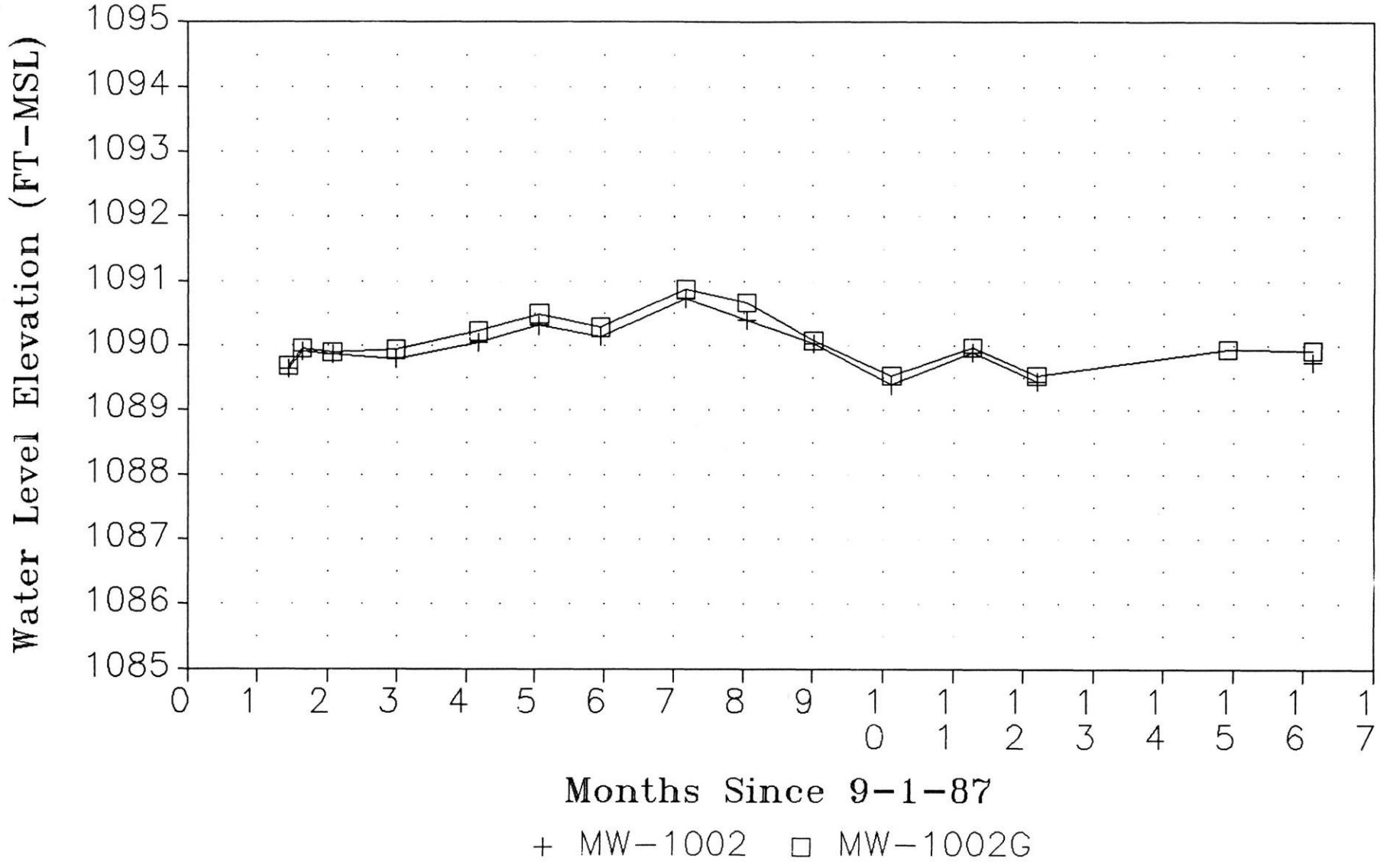
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FIGURE NO 3.6-11
HYDROGRAPH
PIEZOMETER NEST 1001

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			DRAWN BY RDM	3/89
			CHECKED BY BNP	3/89
			APPROVED BY	
			CAD No. / SCALE	

Job No	Dwg No	REV



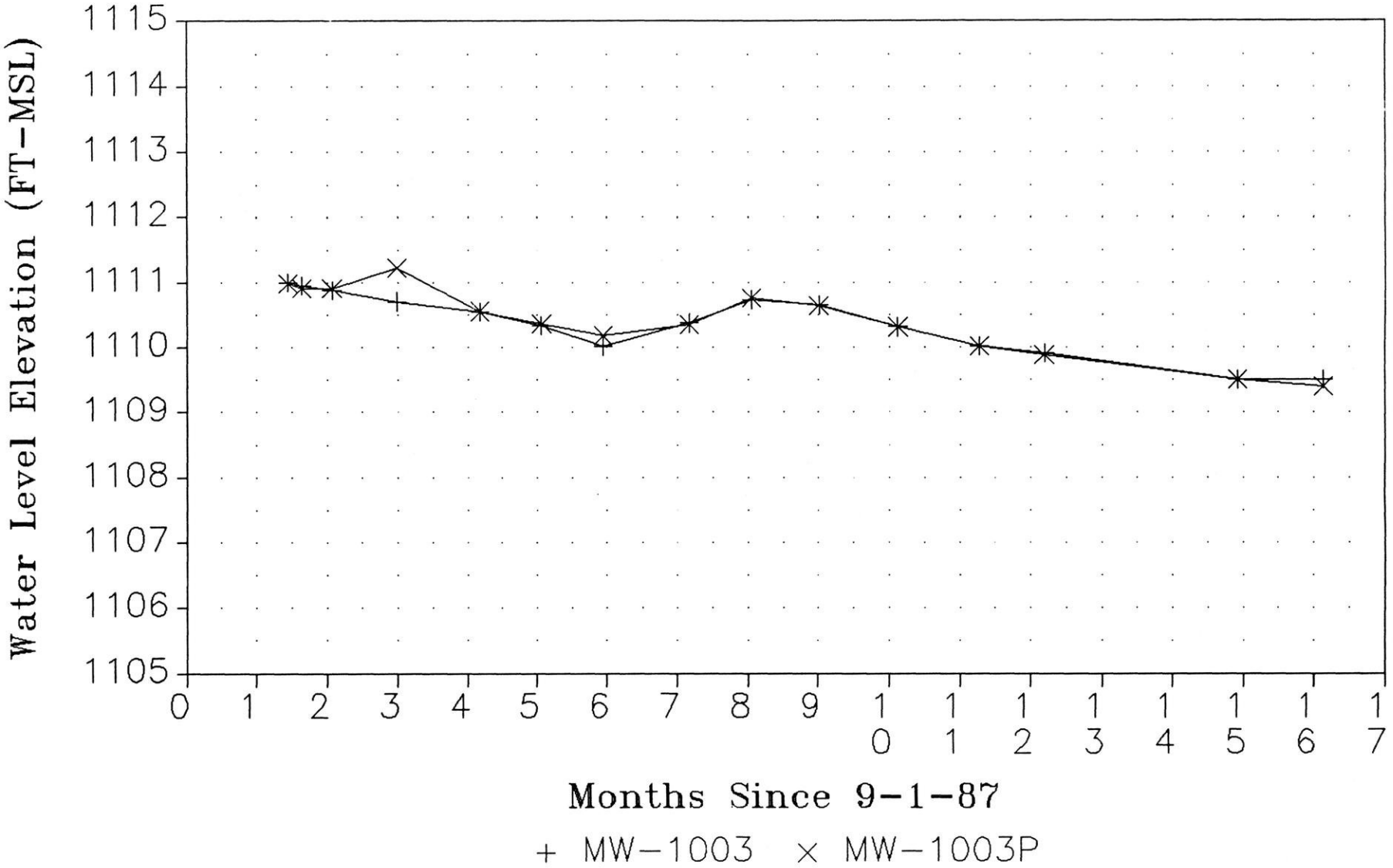
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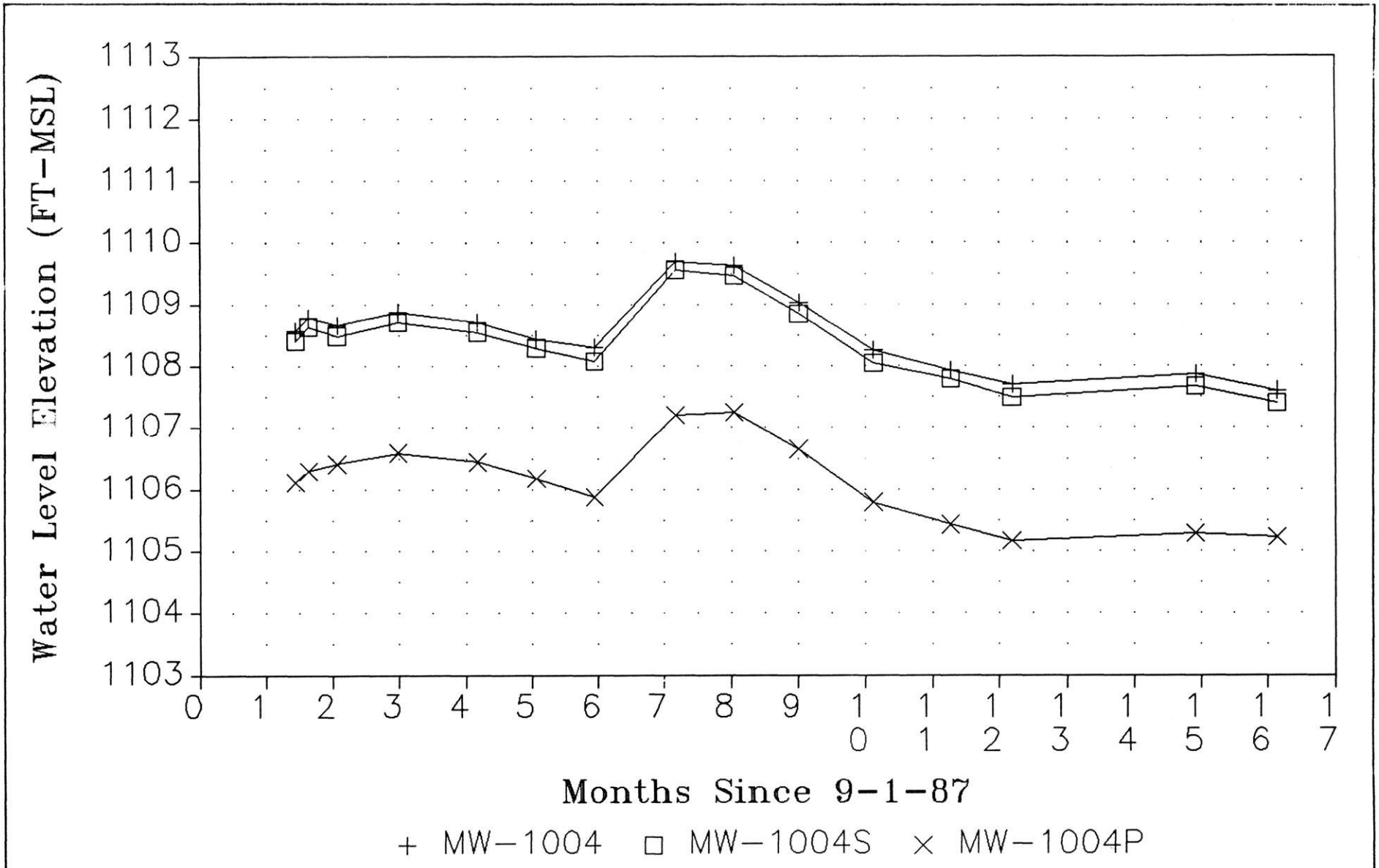
FIGURE NO 3.6-12
HYDROGRAPH
WELL NEST 1002

No	REVISIONS	NOTES	APPROVAL	DATE
			DESIGNED BY	
			DRAWN BY RDM	3/89
			CHECKED BY BNP	3/89
			APPROVED BY	
			CAD No. SCALE	

Job No	Dwg No	REV



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No	REVISIONS	NOTES	APPROVAL / DATE	FIGURE NO 3.6-13 HYDROGRAPH WELL NEST 1003
			DESIGNED BY	
			DRAWN BY RDM	3/89
			CHECKED BY BNP	3/89
			APPROVED BY	
			CAD No. / SCALE	Job No / Dwg No / REV



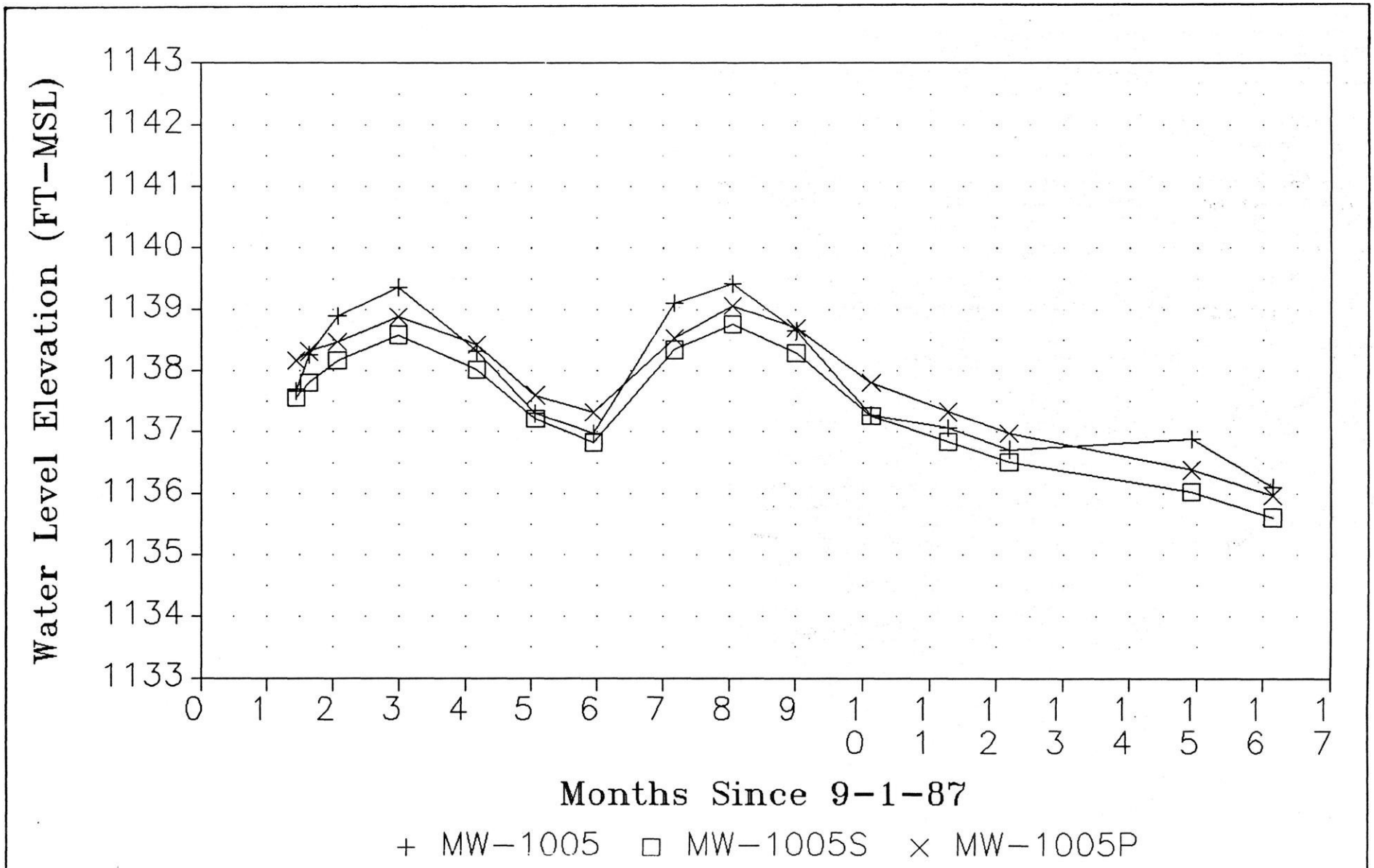
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GEOSCIENCES & ENVIRONMENTAL MANAGEMENT DIVISION
GREEN BAY, WISCONSIN

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FLAMBEAU PROJECT
LADYSMITH, WISCONSIN

FIGURE NO 3.6-14
HYDROGRAPH
WELL NEST 1004

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			DRAWN BY RDM	3/89
			CHECKED BY BNP	3/89
			APPROVED BY	
			CAD No. SCALE	

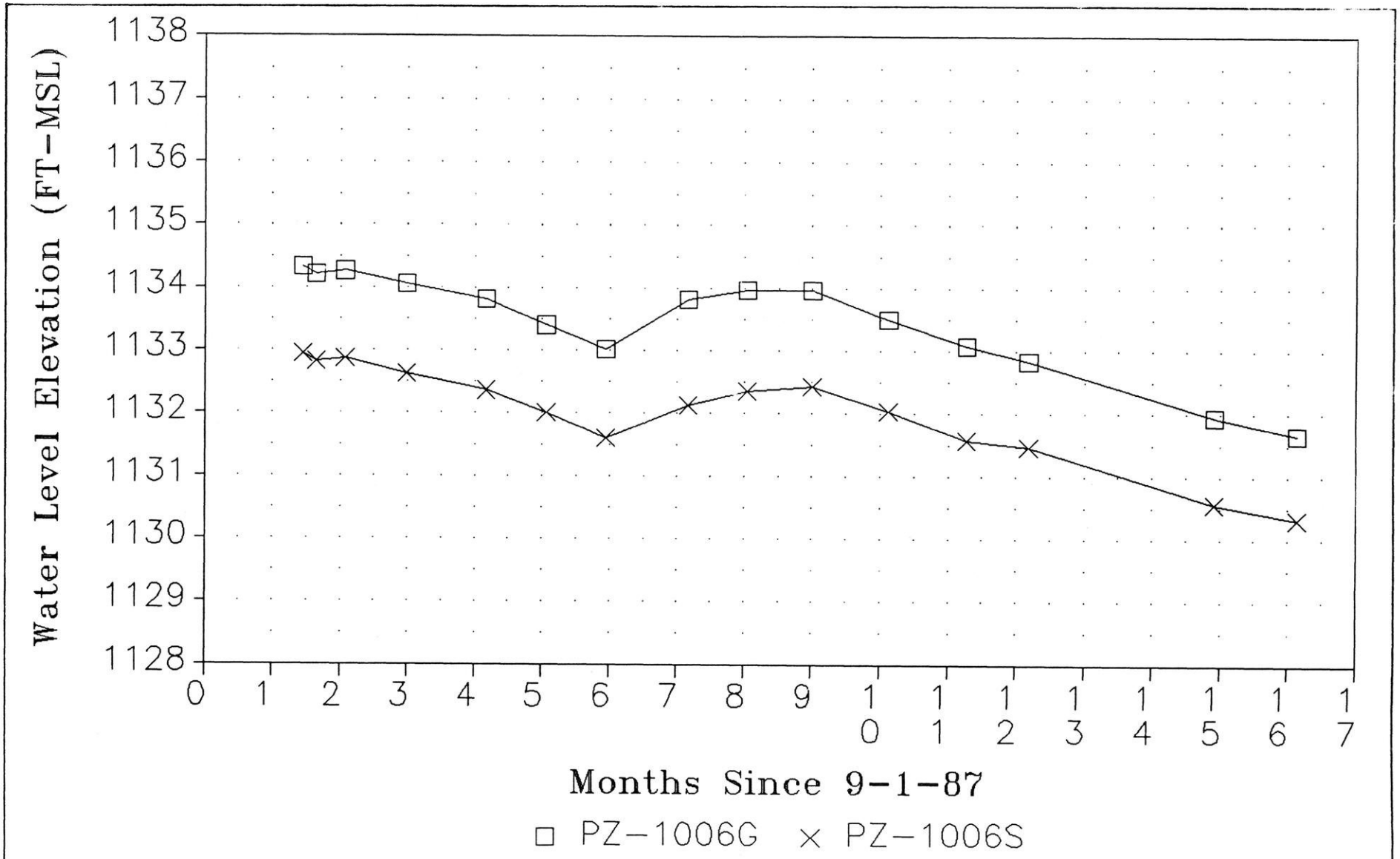
Job No | Dwg No | REV



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	FIGURE NO 3.6-15 HYDROGRAPH WELL NEST 1005

No	REVISIONS	NOTES	APPROVAL	DATE
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			DRAWN BY RDM	3/89
			CHECKED BY BNP	3/89
			APPROVED BY	
			CAD No. SCALE	

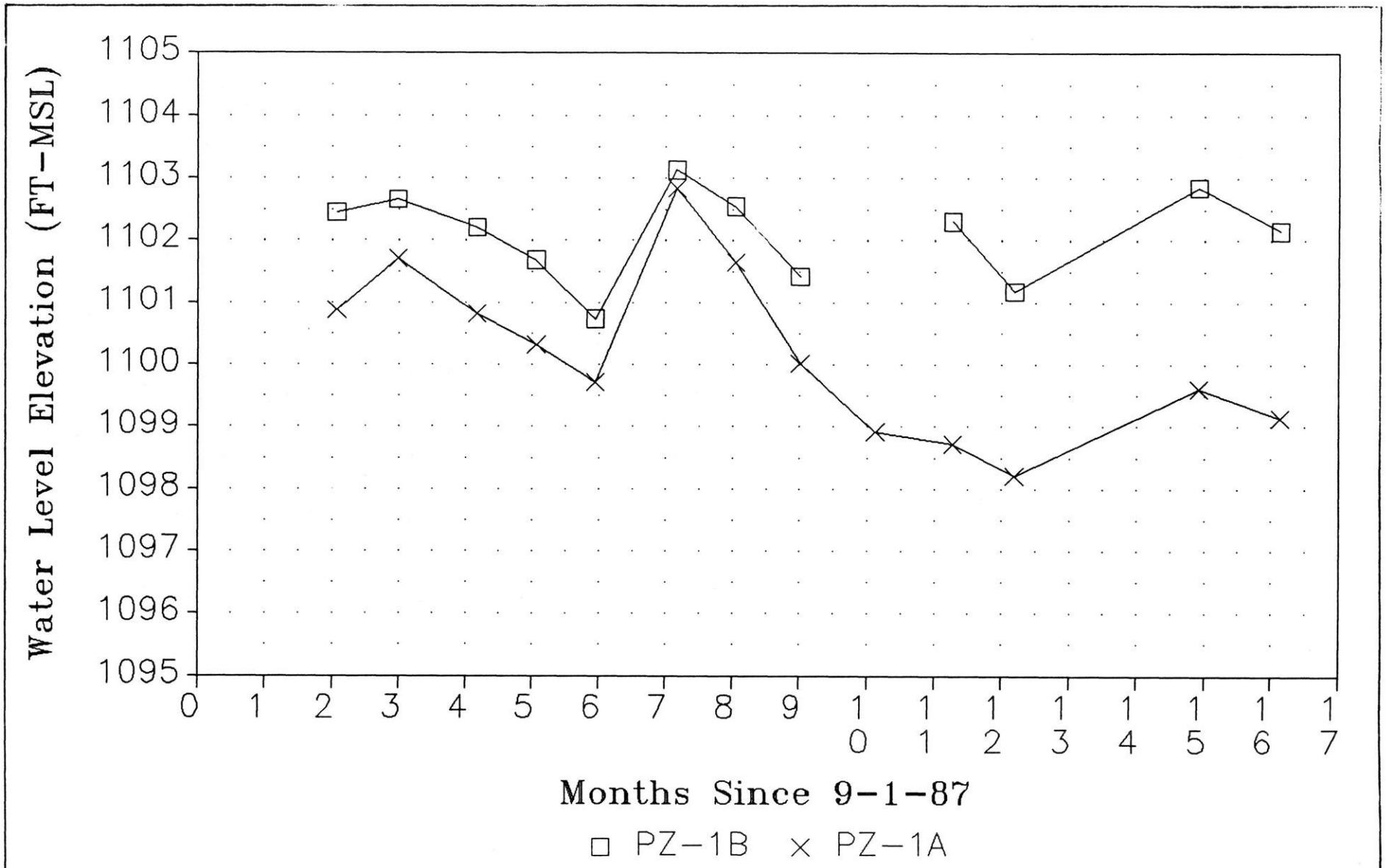
Job No	Dwg No	REV



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	FIGURE NO. 3.6-16 HYDROGRAPH PIEZOMETER NEST 1006

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			DRAWN BY RDM	3/89
			CHECKED BY BNP	3/89
			APPROVED BY	
			CAD No.	SCALE

Job No	Dwg No	REV



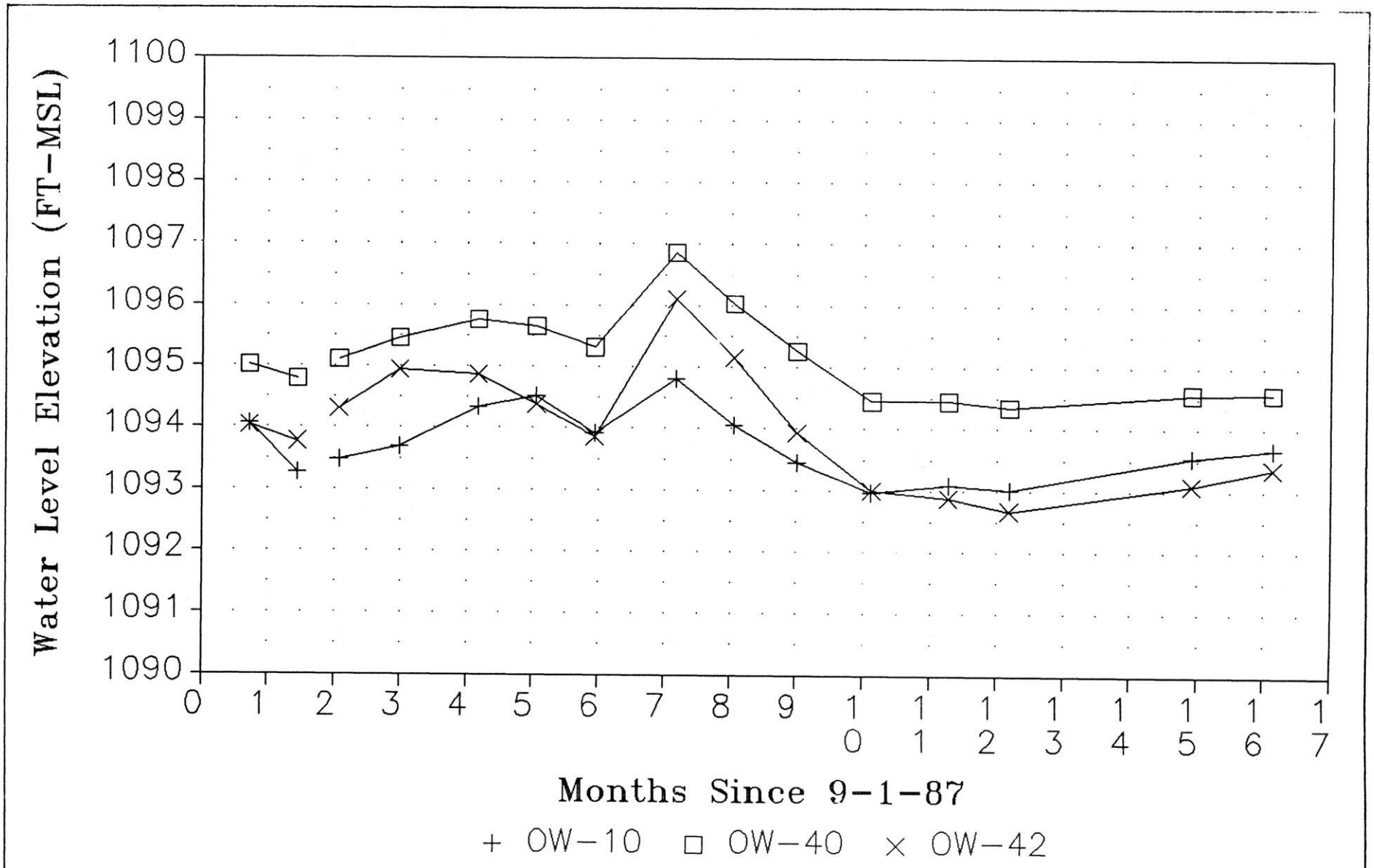
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GREEN BAY, WISCONSIN

KENNECOTT MINERALS COMPANY
FLAMBEAU PROJECT
LADYSMITH, WISCONSIN

FIGURE NO 3.6-17
HYDROGRAPH
PIEZOMETER NEST PZ-1

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			DESIGNED BY	
			DRAWN BY RDM	3/89
			CHECKED BY BNP	3/89
			APPROVED BY	
			CAD No.	SCALE

Job No | Dwg No | REV



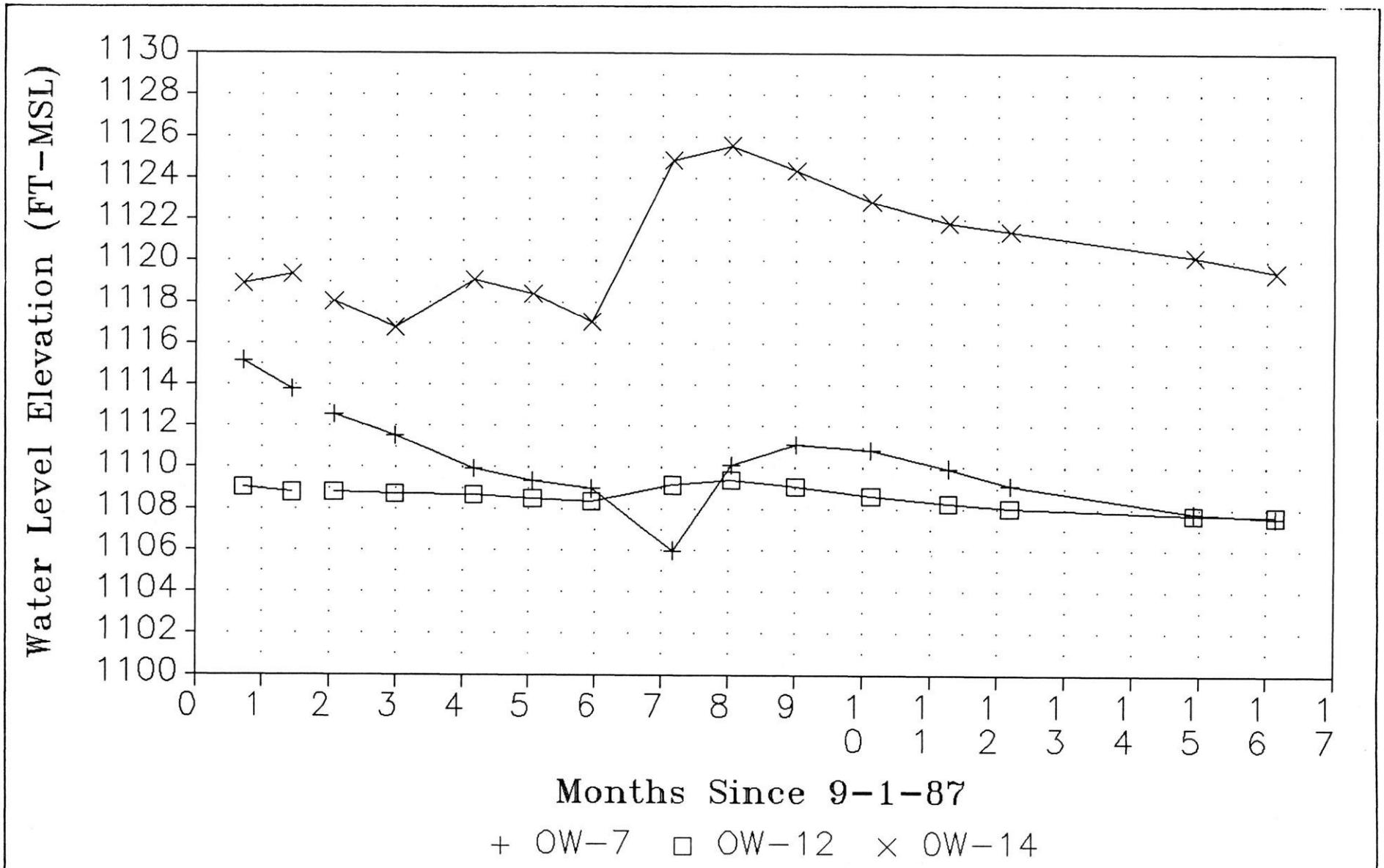
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			CHECKED BY BNP	3/89
			APPROVED BY	
			CAD No.	SCALE

FIGURE NO 3.6-18
HYDROGRAPH
OW 10, 40, AND 42

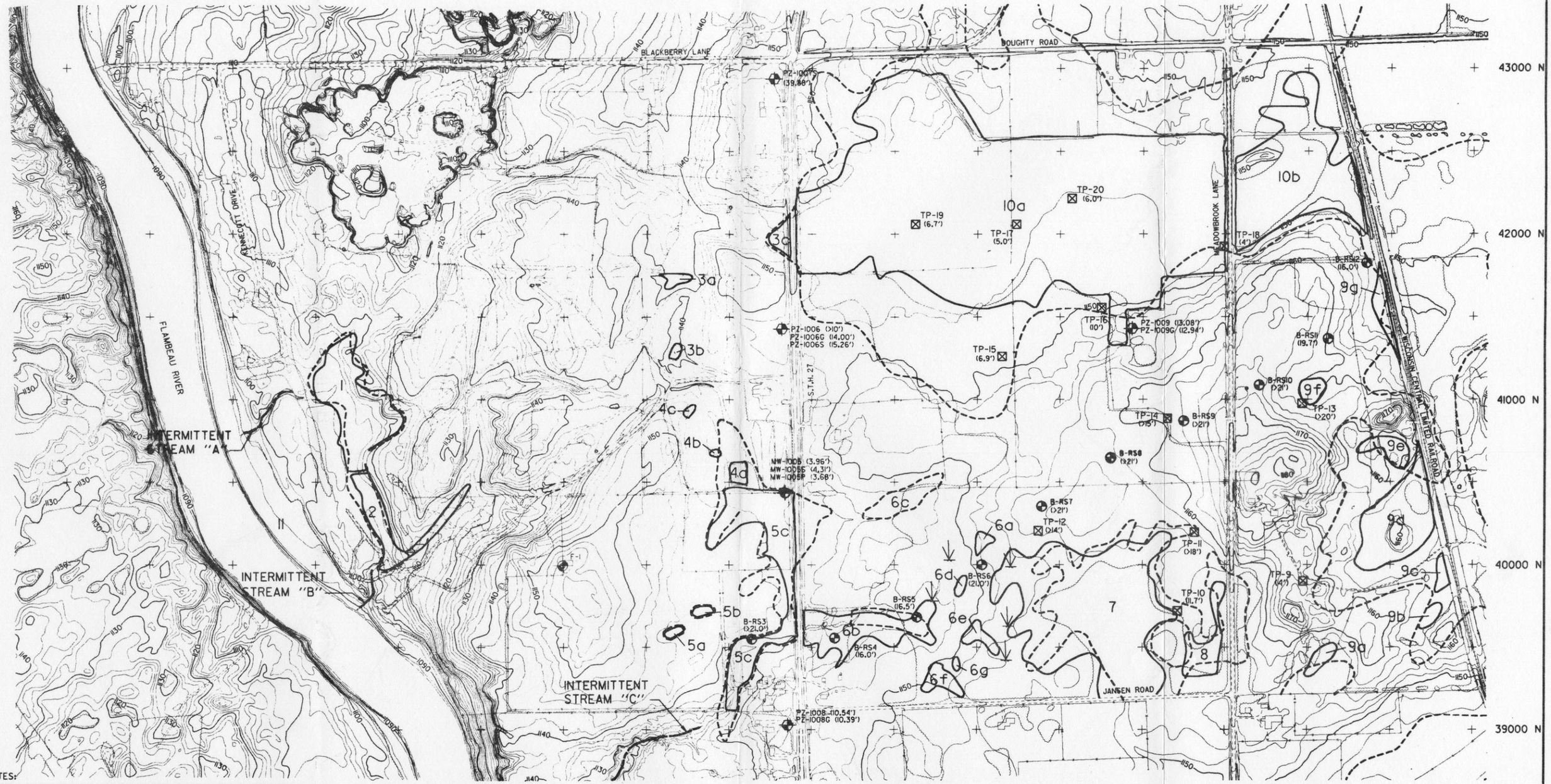
Job No	Dwg No	REV



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	FIGURE NO 3.6-19 HYDROGRAPH OW 7, 12, AND 14

No	REVISIONS	NOTES	APPROVAL		DATE
			DESIGNED BY		
			DRAWN BY	RDM	3/89
			CHECKED BY	PNP	3/89
			APPROVED BY		
			CAD No.	SCALE	

Job No	Dwg No	REV



NOTES:

1. SITE LOCATION: SECTIONS 9, 10, 15 & 16, T34N, R6W, RUSK COUNTY, WISCONSIN.
2. TOPOGRAPHIC BASE MAP PREPARED FROM AERIAL SURVEY BY SURDEX CORPORATION, CHESTERFIELD, MISSOURI. DATE OF PHOTOGRAPHY - APRIL 24, 1970. ROADS, TREES AND BUILDINGS WERE UPDATED AS PER AERIAL PHOTOGRAPH TAKEN BY MARKHURD CORPORATON, MINNEAPOLIS, MINNESOTA. DATE OF PHOTOGRAPHY - SEPTEMBER 14, 1987.
3. ELEVATIONS BASED ON MEAN SEA LEVEL DATUM. CONTOUR INTERVAL IS TWO FEET.
4. HORIZONTAL DATUM BASED ON PROJECT SITE GRID SYSTEM. SITE GRID COORDINATES CORRELATION TO STATE PLANE COORDINATES DERIVED AS FOLLOWS:

SITE GRID COORDINATES CONTROL MONUMENT F-1	STATE PLANE COORDINATES
40000 N =	587,357.8087 N
40000 E =	1,713,516.1229 E

THE ANGULAR ROTATION FROM STATE PLANE BEARINGS TO SITE GRID BEARINGS IS 359°-13'-23" RIGHT WITH CONTROL POINT F-1 AS THE BASE POINT.

LEGEND

- 1100 — EXISTING CONTOUR
- EXISTING PAVED ROADWAY
- EXISTING TRAIL/GRAVEL SURFACE
- TREES AND/OR BRUSH
- FENCE
- F-1 CONTROL MONUMENT
- TP-10 (10.3') TEST PIT LOCATION AND DEPTH TO GROUNDWATER
- PZ-R3 (12.3') PIEZOMETER LOCATION AND DEPTH TO GROUNDWATER
- B-RS3 (18.7') SOIL BORING LOCATION AND DEPTH TO GROUNDWATER
- HYDRIC SOILS
- HYDROPHYTIC VEGETATION
- 7 WETLAND AREA DESIGNATION

0 300' 600'
SCALE

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155 MINERAL SQUARE
SALT LAKE CITY, UTAH
84112

FIGURE NO. 3.6-20
LOCATION OF WETLANDS, TEST PITS, AND BORINGS IN SECTIONS 9 & 10

	BY	DATE
PROJ. ENG'R		
MGR. PROCESS ENGR.		
ENG'R MGR.		
DESIGN		
DRAWN	M.J.O.	3/89
CHK'D	B.N.P.	3/89
DES. ENG'R		
SECT ENG'R		

MICROFILM | JOB
DRAWING NO. | REV.
DIVISION DRAWING NO.
SCALE | SEE BAR SCALE

REFERENCES

DWG. NO.	DESCRIPTION

NO.	DATE	REVISIONS	BY	CHK'D	ENG'R	ENG'R MGR.



NOTES:

1. SITE LOCATION: SECTIONS 9, 10, 15 & 16, T34N, R6W, RUSK COUNTY, WISCONSIN.
2. TOPOGRAPHIC BASE MAP PREPARED FROM AERIAL SURVEY BY SURDEX CORPORATION, CHESTERFIELD, MISSOURI. DATE OF PHOTOGRAPHY - APRIL 24, 1970. ROADS, TREES AND BUILDINGS WERE UPDATED AS PER AERIAL PHOTOGRAPH TAKEN BY MARKHURD CORPORATON, MINNEAPOLIS, MINNESOTA. DATE OF PHOTOGRAPHY - SEPTEMBER 14, 1987.
3. ELEVATIONS BASED ON MEAN SEA LEVEL DATUM. CONTOUR INTERVAL IS TWO FEET.
4. HORIZONTAL DATUM BASED ON PROJECT SITE GRID SYSTEM. SITE GRID COORDINATES CORRELATION TO STATE PLANE COORDINATES DERIVED AS FOLLOWS:

SITE GRID COORDINATES CONTROL MONUMENT F-1	STATE PLANE COORDINATES
40000 N =	587,357.8087 N
40000 E =	1,713,516.1229 E

THE ANGULAR ROTATION FROM STATE PLANE BEARINGS TO SITE GRID BEARINGS IS 359°-13'-23" RIGHT WITH CONTROL POINT F-1 AS THE BASE POINT.

LEGEND

- 1100 — EXISTING CONTOUR
- EXISTING PAVED ROADWAY
- EXISTING TRAIL/GRAVEL SURFACE
- TREES AND/OR BRUSH
- FENCE
- F-1 CONTROL MONUMENT
- MW-1005 MONITORING WELL
- PZ-S4 PIEZOMETER
- ST-9-2 SOIL BORING
- — 20 — DEPTH TO WATER ISOPACH CONTOUR

0 300' 600'
SCALE

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SALT LAKE CITY, UTAH
84112

FIGURE NO. 3.6-21
DEPTH TO WATER
ISOPACH MAP

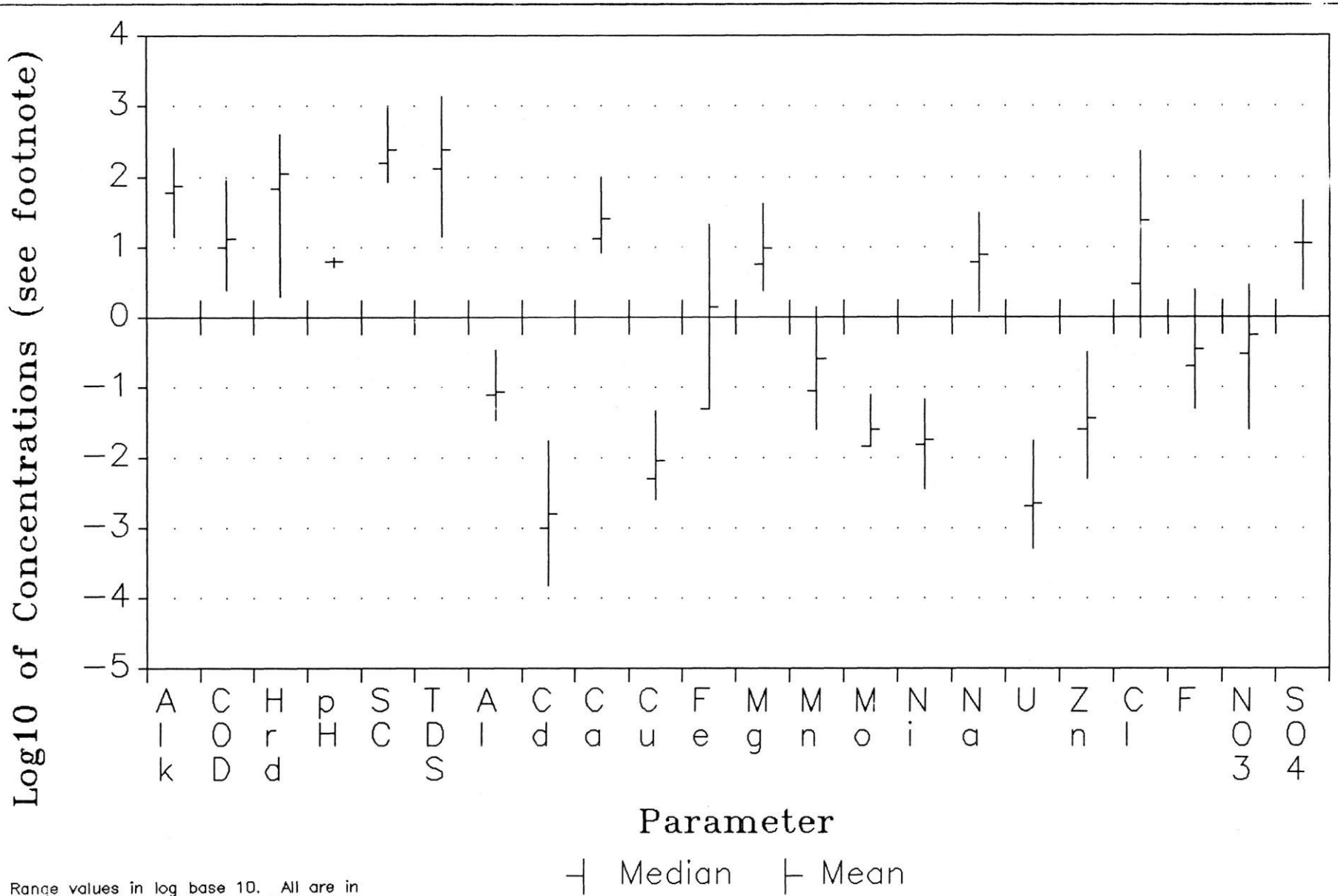
REFERENCES	DWG. NO.	DESCRIPTION

NO.	DATE	REVISIONS	BY	CHK'D	ENG'R	ENG'R MGR.

	BY	DATE
PROJ. ENG'R		
MGR. PROCESS ENG'R		
ENG'R MGR.		

	BY	DATE
DESIGN		
DRAWN	M.J.O.	3/89
CHK'D	B.N.P.	3/89
DES. ENG'R		
SECT ENG'R		

MICROFILM	JOB
DRAWING NO.	REV.
DIVISION DRAWING NO.	
SCALE	SEE BAR SCALE



Range values in log base 10. All are in mg/l except specific conductivity (umho/cm) and pH (Standard Units).

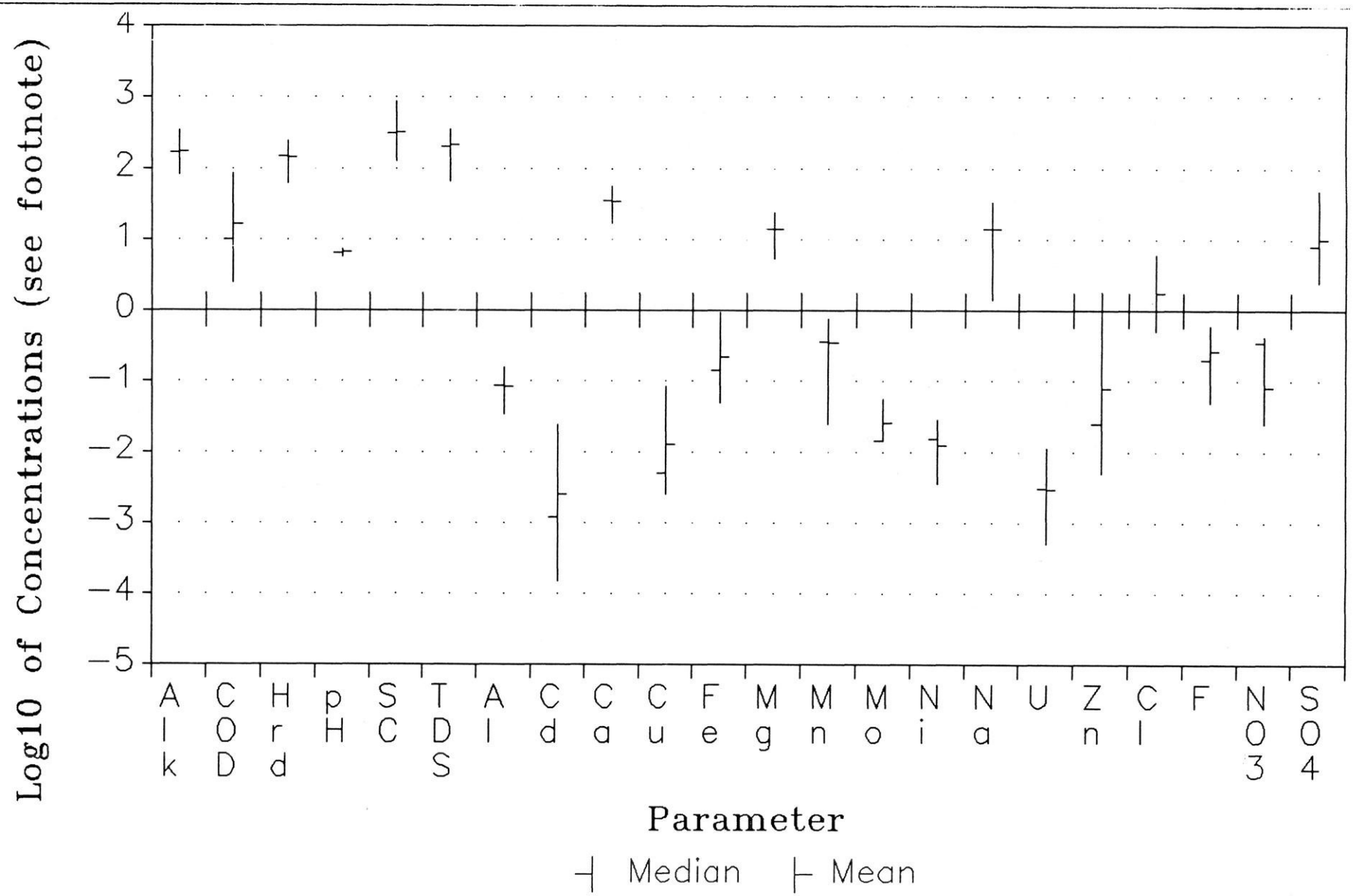
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			APPROVED BY	
			CAD No.	SCALE

FIGURE NO 3.6-22
OVERBURDEN
GROUNDWATER QUALITY RANGES

Job No	Dwg No	REV



Range values in log base 10. All are in mg/l except specific conductivity (umho/cm) and pH (Standard Units).

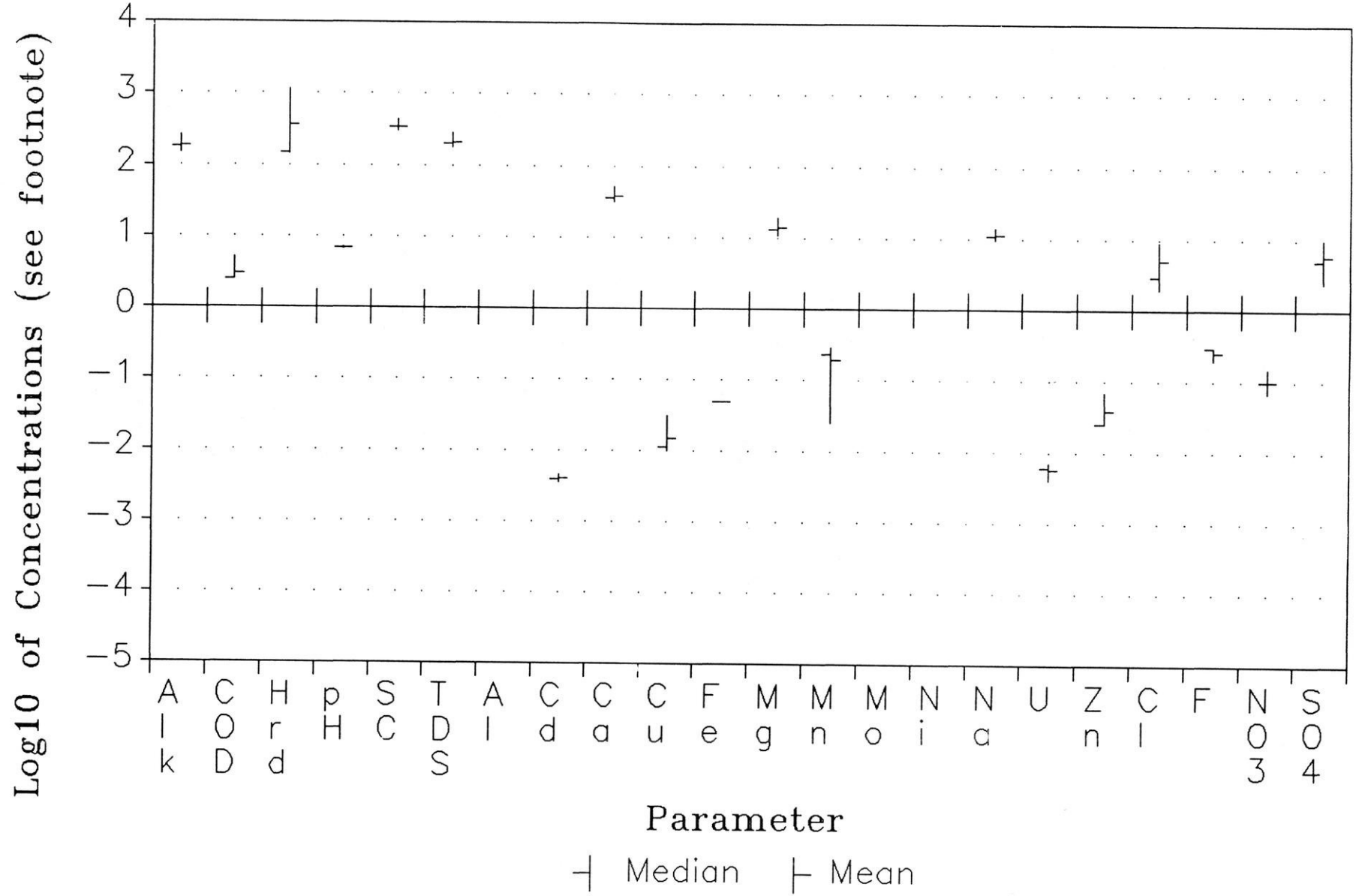
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			CHECKED BY BNP	3/89
			APPROVED BY	
			CAD No.	SCALE

FIGURE NO 3.6-23
SHALLOW PRECAMBRIAN
GROUNDWATER QUALITY RANGES

Job No | Dwg No | REV



Range values in log base 10. All are in mg/l except specific conductivity (umho/cm) and pH (Standard Units).

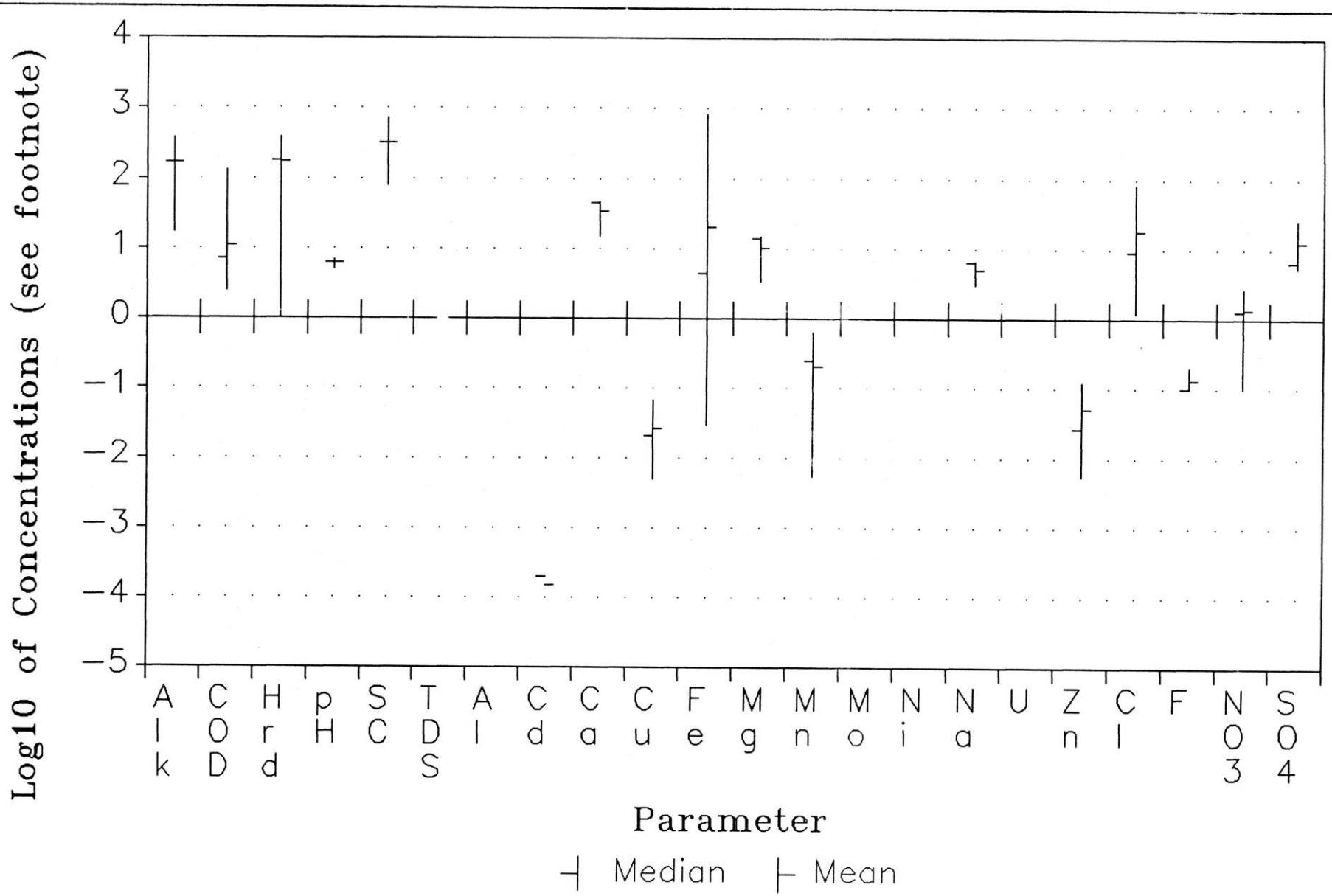
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			DRAWN BY RDM	3/89
			CHECKED BY BNP	3/89
			APPROVED BY	
			CAD No.	SCALE

FIGURE NO 3.6-24
DEEP PRECAMBRIAN
GROUNDWATER QUALITY RANGES

Job No | Dwg No | REV



Range values in log base 10. All are in mg/l except specific conductivity (umho/cm) and pH (Standard Units).

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FIGURE NO 3.6-25
PRIVATE WELL
GROUNDWATER QUALITY RANGES

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			CHECKED BY BNP	3/89
			APPROVED BY	
			CAD No.	SCALE

Job No	Dwg No	REV

UW-STEVENS POINT
3 1775 677584 5