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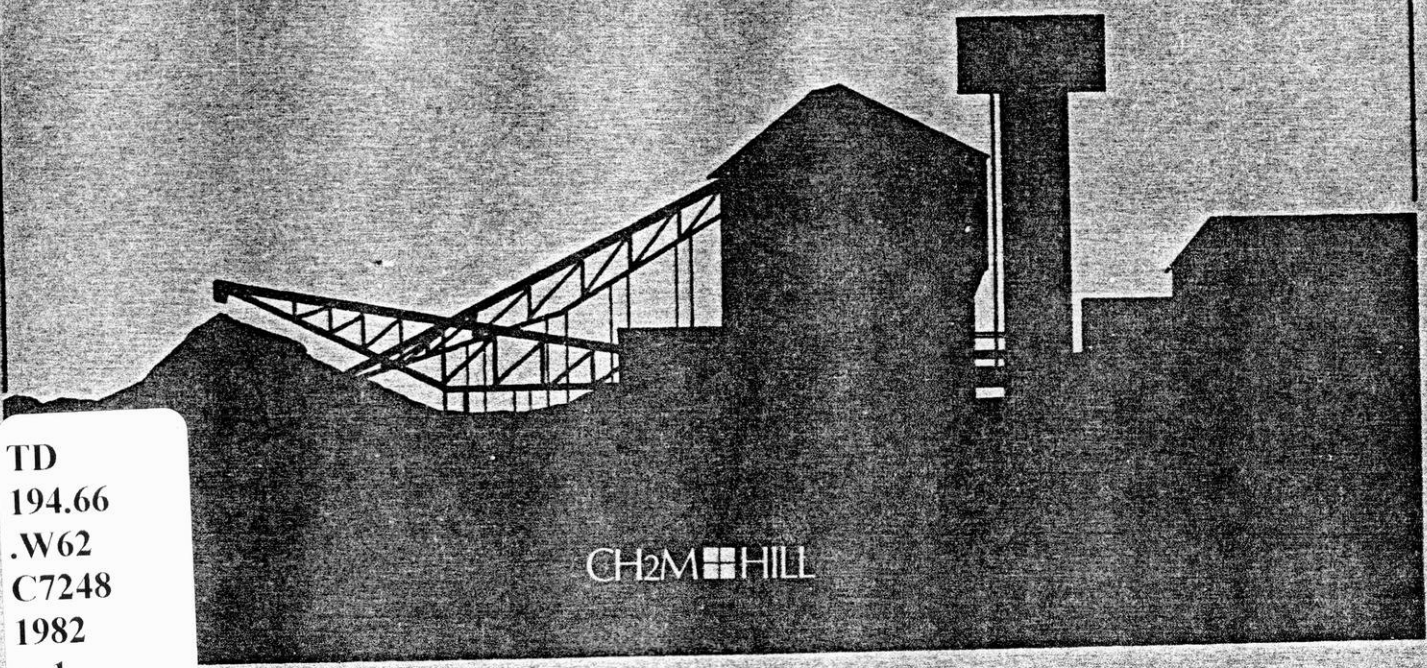
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PHASE III WATER MANAGEMENT STUDY

VOLUME 1 OF 3
WATER MANAGEMENT STUDY

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EXON MINERALS COMPANY
CRANDON PROJECT
CRANDON, WISCONSIN



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Exxon Minerals Company
P.O. Box 813
Rhineland, Wisconsin 54501

Attention: Mr. Curtis Fowler

Dear Mr. Fowler:

Subject: Phase III Water Management Study
Final Report
Exxon Contract: 21081
CH2M HILL No.: L15028.A0
Correspondence No.: L-022

We are pleased to submit this three-volume report summarizing CH2M HILL's findings during the Phase III Water Management Study for the Crandon Project.

It has been our sincere pleasure working with Exxon during this study. We look forward to working with you again on future phases of engineering work.

If we can provide further assistance, please feel free to call me at any time at 414/774-5530.

Sincerely,

Michael R. Harris

Michael R. Harris
Project Manager

jsm/GLT225/4

Enclosures

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 CRANDON PROJECT

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Section I
INTRODUCTION

BACKGROUND

Exxon Minerals Company is investigating the costs and feasibility of developing a copper/lead/zinc sulfide deposit located approximately 8 miles south of Crandon, Wisconsin, (Crandon Project), in the southwest portion of Forest County. A more precise location of the Crandon Project is the S 1/2 of Section 30, T35N, R13E. Figure 1 illustrates the site location.

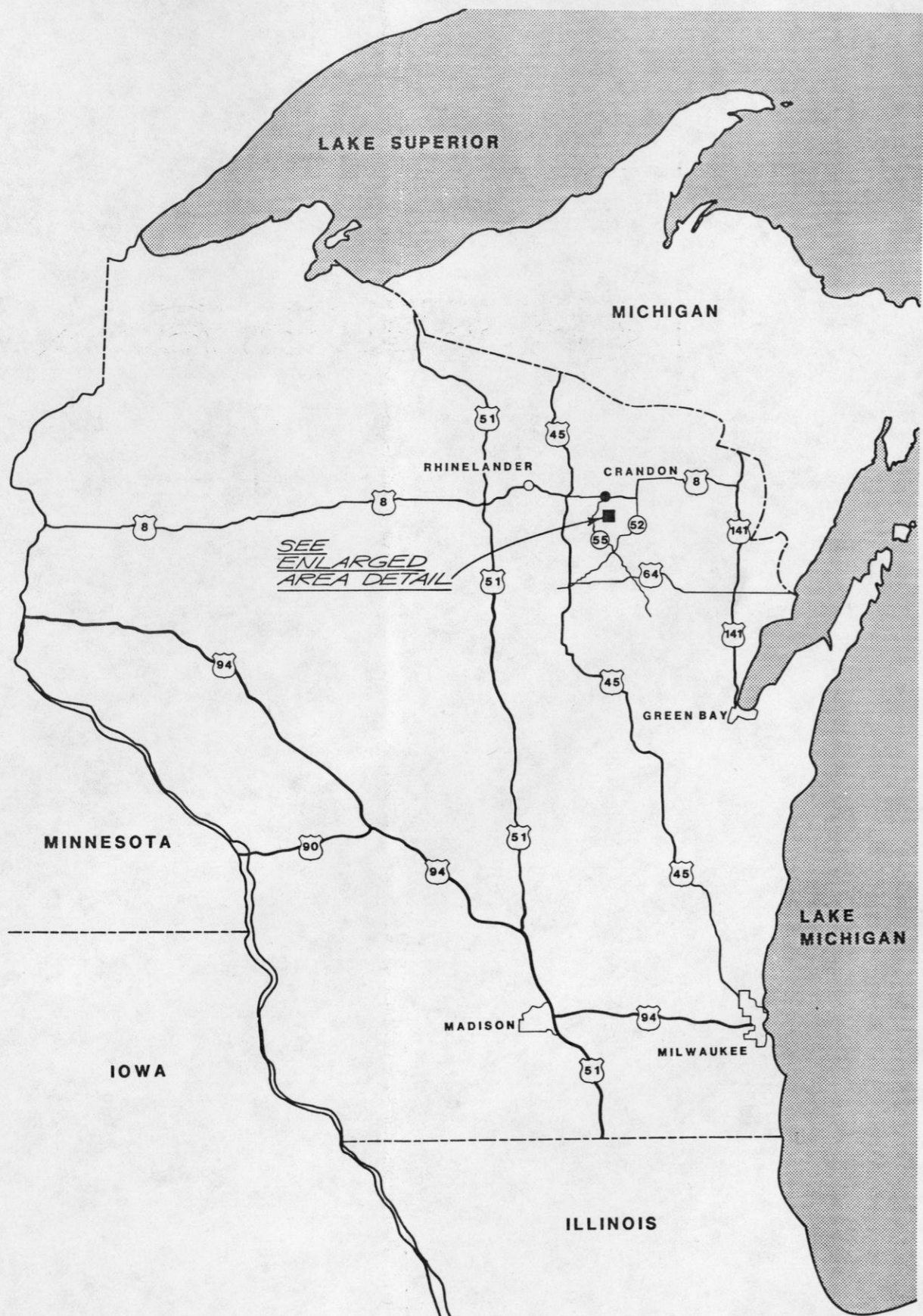
Since the discovery of the Crandon ore body in 1974, Exxon has undertaken a number of engineering studies¹ to determine the size and characteristics of the orebody, a proposed configuration of a mill complex to process the ore, alternate siting locations and sizing for the pond system associated with the mill, environmental impacts of the proposed mine/mill complex, and a variety of related studies.

Early in 1978, Exxon commissioned Kilborn Limited to perform a preliminary assessment² of water uses, sources, and losses at the Crandon Project. This preliminary water management study was completed in August 1978.

Late in 1978, Exxon commissioned the Ralph M. Parsons Company to perform preliminary engineering of the surface facilities for the Crandon Project.³ As part of this study, Parsons developed preliminary mill process flowsheets, a preliminary site plan, mill process equipment sizing criteria, and estimates of water consumption in each of the mill circuits.

In September 1979, Exxon commissioned CH2M HILL to prepare a Phase II Water Management Study²⁸ for the Crandon Project. The Phase II study was based on the output of a number of preliminary studies completed by other consultants working for Exxon. This study was terminated in late 1980 and an interim report, describing conclusions of the study, was submitted to Exxon on January 5, 1981. Section III of this report contains a more in-depth review of the reasons for termination of the Phase II study.

In May 1981, Exxon commissioned CH2M HILL to prepare this Phase III Water Management Study for the Crandon Project.



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Major concurrent engineering studies for the Crandon Project include:

- o Dames & Moore
 - Preparation of Baseline Studies for the Crandon Project.
- o Ralph M. Parsons Company
 - Phase III Conceptual Design of Surface Facilities.
- o Golder Associates
 - Siting and configuration studies for the tailings and reclaim pond system.
- o Lakefield Research of Canada, Ltd.
 - Metallurgical studies.
- o B.C. Research
 - Waste Characterization of Waste Rock.
- o Thomas A. Prickett & Associates and Klohn Leonoff
 - Analysis of anticipated mine seepage flow rates and potential mitigative measures.


PURPOSE OF STUDY

Water management is a vital part of Exxon's overall evaluation of the Crandon Project. The objectives of the Phase III Water Management Study are to define the overall water requirements and usage in the mine/mill complex, to define quantities and quality of water which might be discharged; and, if discharge is to occur, define the degree and type of treatment which is required to comply with current and potential regulations. This effort is intended to provide input to the Environmental Impact Report for the Crandon Project and to provide data to the Wisconsin Department of Natural Resources (DNR). The study will provide the basis for future design and engineering of certain water related aspects of the Crandon Project. The scope of the study included:

- o Review CH2M HILL's Phase II study and past reports and ongoing studies by Exxon and other consultants.
- o Consult with Exxon to assess potential water discharge regulations.
- o Review and assess available water treatment technologies.
- o Condense the list of available technologies to a group of "preferred" methods.
- o Prepare an up-to-date water balance for the entire mine/mill facility, taking into account all sources, uses, and losses of water, and prepare block flow diagrams.
- o Revise and/or prepare computer subroutines to describe the impact of mine/mill/pond/treatment unit operations on water quality.
- o Revise the Phase II Crandon Project Water Use Model for the entire mine/mill complex to demonstrate the interrelationships of water uses and to permit modeling of a greater variety of potential flow patterns than was possible with the model developed in Phase II.
- o Evaluate potential effluent treatment/process recycle options as necessary to optimize water management for the Crandon Project. Elements of this evaluation include:
 - Protect the environment.
 - Comply with state and Federal effluent regulations.
 - Maximize recycle and minimize discharges to the greatest possible extent.
 - Utilize proven and reliable treatment technologies.
 - Provide a cost-effective system which will not adversely affect overall project economics.
- o In consultation with Exxon, select several water treatment systems for evaluation.

- o In consultation with Exxon, select the water treatment system believed to be the best and most appropriate for the needs of the Crandon Project.
- o Prepare a conceptual design and layout of the preferred water treatment system.
- o Prepare capital and operating cost estimates for the preferred water treatment system.
- o Evaluate alternatives and formulate final recommendations for treatment of sanitary wastes which would be generated at the mine/mill facilities.
- o Prepare a summary report to Exxon describing all of the findings in the Phase III Water Management Study.

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 Section II
 SUMMARY AND CONCLUSIONS

This Phase III Water Management Study contains a comprehensive analysis of the entire water management system at Exxon's Crandon Project. The findings of this study are summarized as follows:

1. This Phase III study contains a number of significant revisions from CH2M HILL's earlier Phase II study. These revisions, based on the conclusions reached in a number of other studies by Exxon and other consultants, substantially strengthen and improve the data base upon which water management alternatives were evaluated.
2. The following sources will contribute water to the Crandon Project water system:

<u>Source</u>	<u>Quantity*</u>	
Fresh (well) water	22.5 m ³ /hr	(98.9 gpm)
Rainfall	104.8 m ³ /hr	(461.2 gpm)
Mine Seepage		
Contaminated	227.1 m ³ /hr	(1,000.0 gpm)
Uncontaminated**	227.1 m ³ /hr	(1,000.00 gpm)
Bound Water in Ore	16.6 m ³ /hr	(73.0 gpm)
TOTAL	598.1 m³/hr	(2,633.1 gpm)

*Flow rates based on mature mine/mill operation.

**Maximum predicted flow of ambient groundwater that is segregated and pumped to the surface separately.

3. The following uses of water have been identified in the Crandon Project water system (the quantities shown are based on operation of the mill at its design capacity of 9,555 MTPD):

<u>Use</u>	<u>Quantity</u> <u>m³/hr (gpm)</u>
Fresh (well) Water	
Potable Water - Surface	7.3 (31.9)
Potable Water - Mine	2.3 (9.9)
Lab and Shops	4.5 (20.0)
Boiler Makeup	8.4 (37.1)

Process Water Use in the Mill 1,340.3 (5,901.1)

(of this total use, 194.6 m³/hr is supplied with treated recycled water)

4. The following represent "losses" of water from the Crandon Project Water System (the quantities shown are based on operation of the mill at its design capacity of 9,555 MTPD):

<u>Use</u>	<u>Quantity m³/hr (gpm)</u>
Water Retained in Mine Backfill	31.7 (139.3)
Water Retained in Tailings	51.2 (225.3)
Effluent Discharge (including sludges and brines)	432.7 (1,905.4)
Seepage from Pond System	2.4 (10.6)
Evaporation from Pond System	60.1 (264.7)
Water in Ore Concentrates	6.0 (26.2)
Evaporation Losses	6.8 (29.7)
Sanitary Wastewater	<u>7.3 (31.9)</u>
TOTAL	598.2 (2,633.1)

5. Exxon, in consultation with CH2M HILL and other consultants, prepared a detailed water balance for the Crandon Mill operations.
6. A computer model was prepared for the entire Crandon Project water system. The entire Mine/Mill complex is represented in the model by a series of "links" (process streams) connecting "nodes" (unit operations). The model computes mass balance equilibrium concentrations of 64 water constituents throughout the entire water system. The model was constructed to be extremely flexible, allowing users of the model to assess overall water quality/quantity impacts of changes to the following user variables:
- o Backfill to surface storage or mine

- o Early (massive ore only) or Mature (massive and stringer ores) operation of the mill
 - o Ore tonnage processed in the mill
 - o Percent weight retention of solids in the mine or ponds
 - o Summer or winter operation
 - o Pond acreage
 - o Seepage rates from ponds
 - o Annual rainfall and evaporation rates
 - o The percentage of pond areas subject to evaporation
 - o Flow "splits" at 49 locations
 - o Water treatment systems in any of 27 locations
 - o The quantity and quality of water required for mill operations
7. The effluent discharge limitations which will be applied to effluent from the Crandon Project will depend on the location ultimately selected for discharge. To assist in evaluation and screening of treatment alternatives, Exxon identified potential limitations which could be applied to the effluent.
8. Exxon instructed CH2M HILL to identify a water treatment system capable of meeting the most stringent of a) New Source Performance Standards (NSPS), b) primary and secondary drinking water standards, and c) preliminary water quality based limitations developed by the Wisconsin Department of Natural Resources for a surface water discharge.
9. Forty water treatment technologies were screened for potential applicability to the needs of the Crandon Project. The purpose of this preliminary screening process was to develop a listing of technologies which would be evaluated in depth. The following

technologies were believed to be potentially applicable to the needs of the project:

- o Filtration
 - o Tailings Pond
 - o Lime Precipitation
 - o Sulfide Precipitation
 - o Carbonate Precipitation
 - o Coprecipitation with Tailings (Tailings Thickener)
 - o Ferrocyanide Precipitation
 - o Carbon Adsorption
 - o Alkaline Chlorination
 - o Ozonation
 - o Hydrogen Peroxide Oxidation
 - o Biological Oxidation
 - o Reclaim Pond
 - o Ion Exchange for Anion Removal
 - o Reverse Osmosis
 - o Vapor Compression Evaporation
 - o Ion Exchange for Calcium Removal
 - o Ion Exchange for Cation Removal
 - o pH Adjustment with H_2SO_4
 - o pH Adjustment with CO_2
 - o pH Adjustment with $Ca(OH)_2$
10. For each of the selected treatment technologies, and for each unit operation in the Mine/Mill complex, an "effect matrix" (computer subroutine) was prepared to describe the "effect" each unit process has on each of the 64 modeled water constituents.
11. The Crandon Project Water Use Model was used extensively to evaluate a number of alternative water management flow patterns. After evaluation of these alternatives it was decided that the water treatment system should be sized to treat all of the contaminated water pumped from the mine plus a sufficient volume of water from the Reclaim Pond to mitigate scaling in the mill water circuit. Uncontaminated mine water would be collected separately and monitored for direct discharge.
12. The water treatment needs of the Crandon Project will vary with time. To evaluate the required size of the water treatment system, three time periods were selected:
- o Mine Development Period (construction)

- o Early Mill Operation (first year of operation when only massive ore will be processed)
 - o Mature Mill Operation (remainder of mill operating life when both massive and stringer ores will be processed)
13. A "zero discharge" of water is not possible for the Crandon Project. Annual rainfall exceeds annual evaporation, causing an influx of water from the pond system. In addition, mine seepage water flow rates are expected to be substantial. Even with 100 percent recycle water use in the mill, a discharge of treated water will be necessary to maintain a water balance in the system.
14. In consultation with Exxon, a set of criteria were selected for screening potential water treatment systems for the Crandon Project. These screening criteria include:
- o Meet effluent limitations and/or standards
 - o Remove scale forming compounds
 - o Provide cost-effective treatment
 - o Use proven technology
 - o Be flexible with respect to influent water quality
 - o Remove thiosalts
 - o Remove metals
 - o Produce environmentally acceptable sludges
 - o If possible, produce a marketable byproduct
15. A final effluent/recycle water treatment system is necessary to treat contaminated mine water and Reclaim Pond water. Effluent from this system would be used as mill process water makeup to the maximum possible and excess treated effluent will be discharged to the environment.
16. There is a possibility that a cyanide oxidation process may be required for treatment of the overflow from the lead concentrate thickener. Exxon's Phase I₃ pilot plant data indicated that this small stream (13 m³/hr) contains the bulk of the cyanide exiting the mill. Effective in-plant control of reagent addition, however, should virtually eliminate cyanide in this stream. This type of control was not possible in the pilot

plant. It is not currently believed that a cyanide oxidation system will be necessary.

17. Ten final effluent/recycle water treatment alternatives were evaluated:

- System 1 - Lime Precipitation/Filtration/
pH Adjustment
- System 2 - Carbonate Precipitation/pH Adjustment/
Filtration
- System 3 - Sulfide Precipitation/Filtration/pH
Adjustment
- System 4 - Sodium Aluminate Precipitation/Filtration/
pH Adjustment
- System 5 - Sedimentation/Filtration/Ion Exchange for
Anion Removal/Carbonate Precipitation/pH
Adjustment/Filtration
- System 6 - Sedimentation/Filtration/Ion Exchange for
Anion Removal/Ion Exchange for Cation
Removal/pH Adjustment
- System 7 - Sedimentation/Filtration/Reverse Osmosis/
Vapor Compression Evaporation
- System 8 - Sedimentation/Filtration/Ion Exchange
for Calcium Removal/Reverse Osmosis/
Vapor Compression Evaporation
- System 9 - Carbonate Precipitation/pH Adjustment/
Filtration/Reverse Osmosis/Vapor Com-
pression Evaporation
- System 10 - Lime Precipitation/Filtration/pH Adjust-
ment/Vapor Compression Evaporation

18. Systems 1 through 8 were dropped from consideration either because they did not meet the screening criteria described above or because they are insufficiently flexible.

19. Systems 9 and 10 met all of the established criteria. Estimated capital and annual operating and maintenance costs of these two systems are summarized as follows:

<u>System</u>	<u>Estimated Cost*</u>	
	<u>Capital</u>	<u>Annual O&M</u>
9	21,161,000	3,087,000
10	24,830,000	4,809,000

*Comparative costs, including 25 percent contingency. Estimate is defined as being accurate within +50 to -30 percent.

20. System 9 was selected as the preferred water treatment system for final effluent/recycle treatment.
21. Four treatment technologies were evaluated for cyanide oxidation in the lead concentrate thickener overflow on the outside chance that a treatment system would prove to be necessary:
 - o Alkaline Chlorination
 - o Ferrocyanide Precipitation
 - o Ozone Oxidation
 - o Hydrogen Peroxide Oxidation
22. The treatment system believed most appropriate for cyanide oxidation, should it be necessary, is Hydrogen Peroxide Oxidation followed by a "polishing" Ozone Oxidation system. This system could be installed in a very short time if full-scale operating experience indicates it is necessary.
23. The preferred final effluent/recycle water treatment system is predicted to meet all potential effluent limitations. The predicted effluent concentrations of cadmium, mercury, and silver, however, are very close to the preliminary water quality based limitations provided by the DNR.
24. As a final check on the validity of the Crandon Project Water Use Model projections, data from two operating Mine/Mill facilities were compared with information developed for the Crandon Project. It appears that the effect matrices prepared for the Crandon Mill and pond system are realistic and reasonably close to actual measured effects at operating facilities.
25. Sanitary wastewaters generated at the Crandon site will be treated in a septic tank system. Treated wastewaters will be disposed of in a pressurized absorption field.
26. Based on the anticipated number of employees at the Crandon Project, a septic tank system and absorption field have been conceptually designed. Field percolation tests are necessary, however, before the absorption field can be accurately sized.

27. A conceptual design was prepared for the preferred final effluent/recycle treatment system including:
- o Preliminary Process Instrumentation Diagrams
 - o Preliminary Hydraulic Profile
 - o Conceptual Building Layout
 - o A description of process equipment sizing and/or design criteria
 - o A set of duty specifications for major process equipment
 - o A description of system control philosophy
 - o Annual chemical consumption rates
 - o A description of operating manpower requirements and key operational features
 - o A description of effluent testing requirements
28. A timetable was prepared to illustrate timing requirements for design and construction of the water treatment system.
29. Estimated capital and annual operating & maintenance costs for the two treatment systems were prepared:

<u>System</u>	<u>Estimated Capital Cost*</u>	<u>Estimated Annual O&M Cost*</u>
Final Effluent/ Recycle Treatment	\$19,953,000	\$3,510,000
Septic Tank System	\$ 234,000	\$ 19,000

*The cost estimates are based on July 1, 1982 prices. The estimates were prepared with an estimated accuracy of ±20 percent with a 50 percent probability of a 10 percent or greater overrun. (See Section XXII for other limitations on the estimate.)



Section III
REVIEW OF PHASE II WATER MANAGEMENT STUDY

GENERAL REVIEW

CH2M HILL began work on the Phase II Water Management Study for the Crandon Project in September 1979. During the same time period as the Phase II Water Management Study, a number of other engineering studies were underway, many of which had direct impacts on water management at the Crandon Project.

During the Phase II study, CH2M HILL:

- o Summarized all sources, uses and losses of water at the Crandon Project.
- o Prepared "base case" water balances for four potential configurations of the Crandon Mine/Mill.
- o Reviewed potential effluent regulations with Exxon.
- o Evaluated alternative treatment methods for sanitary wastewaters generated at the site.
- o Sized a septic tank treatment system and absorption field for treatment of sanitary waste.
- o Screened 30 water treatment technologies for applicability to the project.
- o Prepared a computer model for the entire water system. The model tracked 64 water constituents throughout the entire water system.
- o Prepared "effect matrices" (computer subroutines) to describe the "effect" each unit process in the Mine/Mill/Pond/treatment system has on each of the 64 modeled constituents.
- o Evaluated seven water treatment systems.
- o After preliminary screening of the seven treatment systems, prepared a conceptual design for four of the treatment systems.

- o Prepared capital and Operating & Maintenance cost estimates for each of the four water treatment systems.

As CH2M HILL's Phase II study approached completion, new information became available from other engineering studies (by Exxon and other consultants). This new information necessitated major revisions to the water use model developed for the Crandon Project and further revisions were made to the selection and sizing of a water treatment system for the project.

A decision was made to terminate CH2M HILL's Phase II study in an "interim report" summarizing the work completed during the study. Since, by the time the report was written, several basic assumptions were outdated, no attempt was made to reach definitive water management decisions in the report.

Following completion of the Phase II report, this Phase III Water Management Study was initiated.

MAJOR MODIFICATIONS

Later sections of this report include both information developed in the Phase II study and information developed and/or revised during this Phase III study. Table 1 has been prepared to illustrate a number of the more significant changes made between Phase II and Phase III. This table is included for the dual purpose of illustrating a) how the water management study has interacted with other ongoing studies, and b) how the data base for the water management study has been improved by acquisition of additional information.

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Table 1

MAJOR MODIFICATIONS TO WATER MANAGEMENT
STUDY BETWEEN PHASE II AND PHASE III

<u>Phase II Study</u>	<u>Phase III Study</u>	<u>Reason For Modification</u>
o Prediction of mill effects on water quality based on a single set of data points from a bench-scale test.	Mill effects on water quality based on a pilot scale, continuous flow test of the ore concentration process to be used at the Crandon Project.	Phase I pilot plant tests conducted by Lakefield Research.
o No detailed water quality available from an operating mill.	Mill effect matrices cross checked with data from an operating mill.	Testing program by Exxon at an operating mill. (see Section XVI of this report)
o Tailings pond effect matrix based on a single data point from a bench-scale test.	Tailings pond effect matrix based on data from an operating tailings pond.	Data acquired by CH2M HILL from other ongoing project work (client confidential).
o Mine seepage flow rate predicted to be 128 gpm.	Contaminated mine seepage flow rate predicted to be 1300 gpm during mine development and 1000 gpm during mature operation. Uncontaminated mine seepage predicted at an additional 1,000 gpm.	Engineering studies by Exxon, Camp Dresser & McKee, Thomas A. Prickett & Associates, and Klohn Leonoff.
o Mine seepage water quality predicted to be typical acid mine drainage. (This was consistent with low predicted seepage rates.)	Uncontaminated mine seepage water quality based on rock column leaching tests conducted B.C. Research.	Change in projected contaminated mine seepage water quality is consistent with predictions of increased flow rates (less contact time with ore body).
o Model predictions of CaSO ₄ scaling based on empirical formula [Ca (mg/l) x SO ₄ (mg/l) ≤ 900,000].	Model predictions for CaSO ₄ scaling based on the Marshall Slusher Model.	Additional sophistication of predictions.
o No byproduct recovery alternatives were evaluated.	Byproduct recovery (Na ₂ SO ₄) is incorporated into preferred wastewater treatment system.	Analysis of different treatment technologies.
o Definitive (numerical) effluent goals not defined.	Effluent goals set at equal to or better than the lower of a) Primary and Secondary Drinking Water Standards, b) NSPS standards, or c) Water quality based surface water discharge standards.	Exxon's commitment to protect the local environment led to selection of stringent effluent goals.
o The water use model link/node structure was rigidly fixed and had limited capability to model different or innovative flow patterns.	The link/node structure of the model was extensively revised to permit more flexibility in selection of flow patterns.	Additional sophistication in evaluation of alternatives.

Table 1
(Continued)

<u>Phase II Study</u>	<u>Phase III Study</u>	<u>Reason For Modification</u>
o Winter oxidation of thiosalts was not addressed.	Evaluation of thiosalts incorporated into analysis of Phase II alternatives.	Phase II study was terminated before this issue was addressed.
o The water use model was based on a fixed production of 9,100 MTPD.	Water use model was revised to permit modeling of two different ore grades and to address operations at different ore throughput.	Additional sophistication in evaluation of treatment needs.
o Water management during the mine development period was not addressed.	Water management during the mine development period is addressed.	Insufficient information was available during the Phase II study period.
o Tailings were routed directly to the tailings ponds.	Tailings thickeners have been added to the flowsheet. In addition to thickening the tailings, this unit process can be used to precipitate metal hydroxides.	This change permits direct recycle of water from the tailings thickener to the backfill preparation area.
o Reclaim Pond area assumed to be 113 acres.	Reclaim Pond size reduced to 61 acres.	By increasing internal mill recycle, less water is routed to the Reclaim Pond.
o Mill water balance based on preliminary design of surface facilities.	Mill water balance based on updated design of surface facilities.	Slight revisions to the design (by Parsons) were dictated by results of the Phase I pilot plant (by Lakefield Research) and updated predictions of the composition of the ore body (by Exxon).
o Total seepage from pond system predicted to be 129 gpm.	Total seepage from pond system predicted to be less than 10 gpm.	Design of a more sophisticated pond liner and seepage collection system by Golder Associates.
o The primary mill configuration studied in Phase II involved pyrite flotation and separation.	Pyrite flotation is no longer under consideration. Backfill preparation area is designed as a conventional zinc tails desliming system.	Process decision by Exxon. This change results in only one active tailing pond, rather than two as in Phase II.

■ ■ Section IV
■ ■ SITE WATER SOURCES

FRESH WATER SUPPLY

Based on work completed by others^{1,2} it is assumed that all fresh water needs at the Crandon Project will be met with well water or treated recycle water.

The following variables will influence the quantity of fresh water required for the Crandon Project:

- o Quantity of ore processed at the mill.
- o Amount of water recycled to the mill from the Reclaim Pond and/or final effluent treatment system.
- o Number of employees working at the site (potable water use).
- o Quantity of reagents used in the mill.

One of the primary goals of this water management study has been to identify ways to minimize the volume of well water required for the operation of the Crandon Mine/Mill.

MINE SEEPAGE

Groundwater which seeps into the mine will be pumped to the surface. Mine seepage can be controlled, to a certain extent, by grouting or sealing of major inflow points detected in the mine.

Water which will seep into the underground development can be separated into two distinct categories:

1. Some seepage of groundwater will be intercepted before it contacts any ore-grade rock.³¹ Exxon estimates that this water will have essentially the same water quality as area average groundwater. For the purpose of this study, it is assumed that this "uncontaminated mine seepage water" can be discharged directly without treatment, other than, possibly, neutralization.
2. Seepage which passes through the ore body or enters the active working area within the mine will contact ore-grade rock and other mine water and will become contaminated. This "contaminated mine

seepage water" will have to be treated prior to discharge and/or recycle within the mill.

Exxon and other consultants¹ have completed a number of studies to predict the flow rate of mine seepage water. Extensive evaluations have been completed to assess information obtained from borings in the glacial drift and the ore-body. A number of grouting plans have been analyzed.

Based on these studies, Exxon projects the following maximum flow rates of mine seepage water³¹:

<u>Time Period</u>	<u>Mine Seepage Water</u>	<u>Description</u>
First 18 Months of Construction	11.36 m ³ /hr (50 gpm)	Shaft construction seepage and tool water. If treatment is required, will be retained for later treatment.
Month 19 through Month 24	113.55 m ³ /hr (500 gpm)	Seepage from initial mine level development plus tool water.
Month 25 through Month 36	227.1 m ³ /hr (1,000 gpm)	Increasing mine seepage from overburden as mine level development expands laterally and to depth. Includes depletion of the ore body in-situ water storage
Month 37 through Month 42	340.7 m ³ /hr (1,500 gpm)	Increasing mine seepage from overburden as mine level development expands laterally and to depth. Includes depletion of the ore body in-site water storage
Month 43 through Operating Life of Mine	227.1 m ³ /hr (2,000 gpm)	Steady state mine seepage. (Includes 1,000 gpm contaminated mine seepage water and up to 1,000 gpm of segregated ambient uncontaminated groundwater.)

PRECIPITATION

Rainfall records from the Nicolet College Weather Station⁴ were reviewed to estimate precipitation rates at the Crandon Project site. The records span the 68-year period from 1908 to 1977.

Based on these records, average annual rainfall at the site is anticipated to be 780 mm (30.77 inches). During the period covered by the records, the extreme high and low annual rainfall totals were 1179 mm (46.41 inches) and 370 mm (14.58 inches), respectively.

Two "classifications" of precipitation must be considered for the Crandon Project: a) that which falls into the tailings and reclaim pond system and/or storage areas where runoff may be contaminated and b) that which falls on the surface facilities in locations where there is no potential for contamination.

All precipitation entering the pond system will contact tailings and/or process water and will enter the mill's process water circuit. The quantity of precipitation entering the ponds is directly proportional to the size of the ponds.

Three surface storage areas with potential for runoff contamination have been identified:

- o A 5-acre area in front of the mill shops will be used as a laydown area for equipment. Parsons' conceptual design of the surface facilities¹ will include an oil/water separator to remove oil from runoff in this area. The surface facilities design will contain provisions to pump collected runoff to the Reclaim Pond.
- o Waste rock will be stored in a 15-acre area near Tailings Pond No. 4. Runoff from this area will be pumped to the Reclaim Pond.
- o A 5-acre area near the mill will be used to store sands during short periods when the mine backfilling operation is shut down. Runoff from this area will be pumped to the Reclaim Pond.

The remainder of the surface facilities will be designed such that no ore will be exposed to precipitation; (i.e., all ore processing will be done in enclosed structures). Runoff from the surface facilities will, therefore, resemble urban runoff from buildings and parking areas¹.

Parsons' preliminary design of the surface facilities includes provisions for collection and disposal of runoff from the surface facilities¹. This category of precipitation is not considered further in this study.

Golder's design of the Tailings and Reclaim Pond system allows for excess freeboard in the ponds to "accumulate" excess water from storms and/or "wet" years (e.g., when net precipitation is greater than the long-term average).²⁹ Design of the water management system is based, therefore, on handling long-term average flow rates from precipitation.

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Section V
SITE WATER USES

PROCESS WATER

Water is used in the Crandon mill process. The Ralph M. Parsons Company has completed its Phase III conceptual design of the surface facilities. That Phase III design incorporates the results of bench-scale and pilot tests of the proposed ore concentration process (by Lakefield Research) and Exxon's revised estimates of the grades of ore which will be mined.

As part of Parsons' work, a series of process flowsheets and water balances were developed for individual unit operations within the mill. Two drawings from the Parsons' study (Drawing numbers 051-1-L-002 and 010) are included in this report as Figures 2 and 3 to show process water uses within the proposed Crandon Mill.

Figure 2 illustrates a complete metallurgical and material balance for the mill, and Figure 3 presents a summary of the water uses within the mill. Both of these flowsheets are based on steady state operation of the mill at its design capacity of 9,555 MTPD.

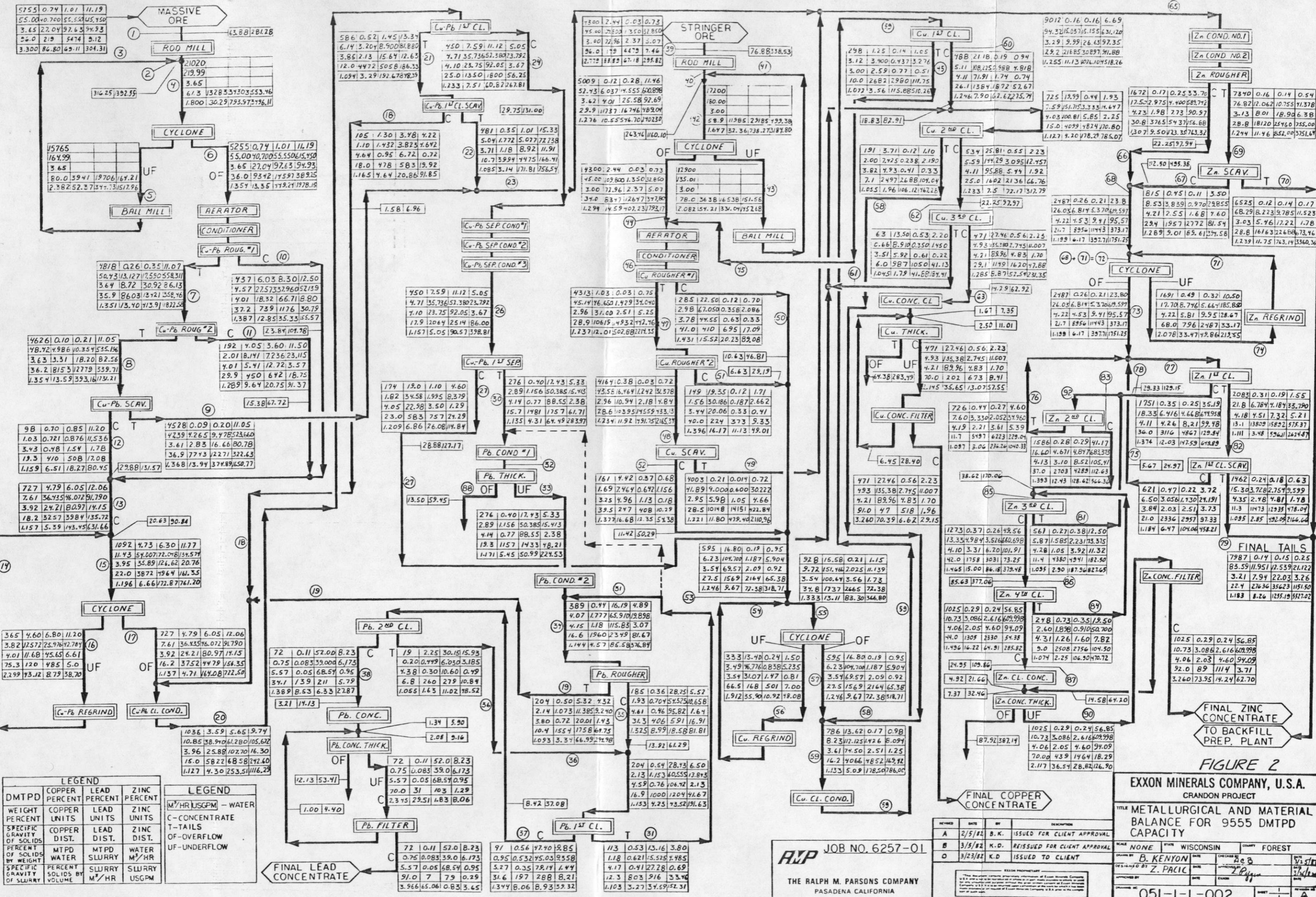
MISCELLANEOUS AND UTILITY WATER

Fresh and/or recycle water is required for several miscellaneous uses around the Mine/Mill complex.

The mill laboratory and shop area will require fresh water for various cleanup activities. Exxon staff estimates that a total²⁹ of 4.5 m³/hr (20 gpm) will be required in these areas. Drains in these¹ areas would be tied into the mill process water circuit¹ and routed to the Reclaim Pond.

A small quantity of fresh water will be required in the mine for drinking water, cleanup activities, and other miscellaneous clean water uses. Exxon staff estimates¹ that about 2.3 m³/hr (10 gpm) of fresh water will be required in the mine.

Drilling operations in the mine will require approximately 36.3 m³/hr (160 gpm) of water.¹ Drilling operations will not require high quality water, so this water need can be



LEGEND

DMPD	COPPER PERCENT	LEAD PERCENT	ZINC PERCENT
WEIGHT PERCENT	COPPER UNITS	LEAD UNITS	ZINC UNITS
SPECIFIC GRAVITY OF SOLIDS	COPPER DIST.	LEAD DIST.	ZINC DIST.
PERCENT OF SOLIDS BY WEIGHT	MTPD WATER	MTPD SLURRY	WATER M ³ /HR
SPECIFIC GRAVITY OF SLURRY	PERCENT SOLIDS BY VOLUME	SLURRY M ³ /HR	SLURRY USGPM

LEGEND

IM³/HR USGPM - WATER

C - CONCENTRATE
T - TAILS
OF - OVERFLOW
UF - UNDERFLOW

FIGURE 2

EXXON MINERALS COMPANY, U.S.A.
CRANDON PROJECT

TITLE METALLURGICAL AND MATERIAL BALANCE FOR 9555 DMPD CAPACITY

REVISED	DATE	BY	DESCRIPTION
A	2/5/82	B.K.	ISSUED FOR CLIENT APPROVAL
B	3/5/82	K.D.	ISSUED FOR CLIENT APPROVAL
O	3/23/82	K.D.	ISSUED TO CLIENT

SCALE NONE STATE WISCONSIN COUNTY FOREST

DESIGNED BY B. KENYON DATE 3/2/82

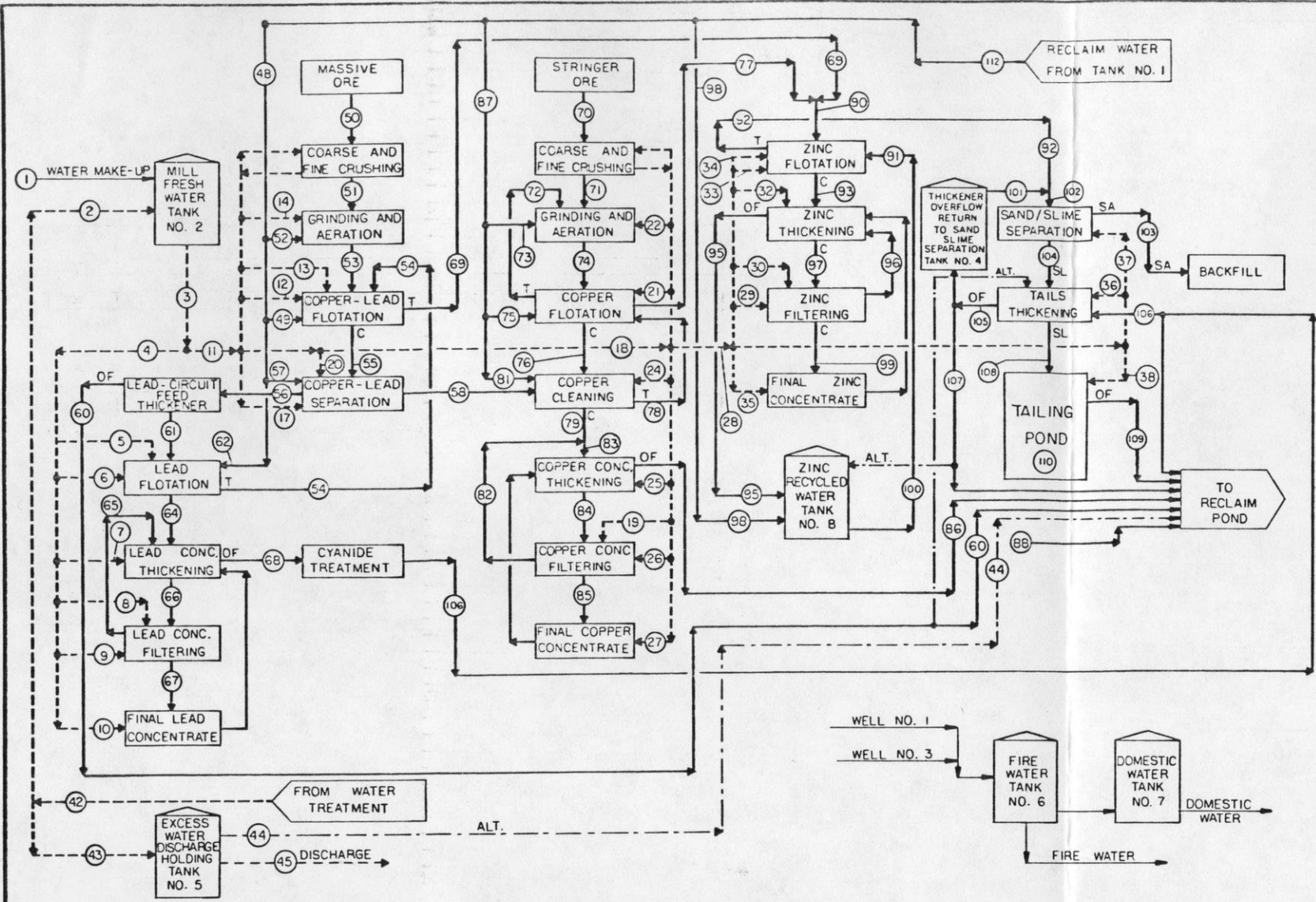
CHECKED BY Z. PACIC DATE 3/2/82

APPROVED BY DATE EXAMINER DATE

PROJECT NO. 051-1-L-002

RMP JOB NO. 6257-01

THE RALPH M. PARSONS COMPANY
PASADENA CALIFORNIA



WATER BALANCE MTPD			
FLOW NO.	DESCRIPTION	WATER ADDED TO CIRCUIT	WATER RECOVERED
1	MASSIVE ORE ROD MILL FEED	219	
1	WATER IN ROD MILL	1,533	
3	WATER TO BALL MILL	7,590	
10	Cu-Pb RO. #1 CONC. LAUNDER WATER	572	
11	Cu-Pb RO. #2 CONC. LAUNDER WATER	369	
12	Cu-Pb SCAVENGER LAUNDER WATER	717	
14	Cu-Pb REGRIND CIRCUIT	495	
24	Cu-Pb 1-ST CLEANER CONC. LAUNDER WATER	714	
18	Cu-Pb 1-ST CLNR. SCAV. CONC. LAUNDER WATER	38	
27	Cu-Pb 1-ST SEPARATION CONC. LAUNDER WATER	693	
88	Pb THICKENER OVERFLOW		324
35	Pb ROUGHER CONC. LAUNDER WATER	334	
37	Pb 1-ST CLNR. CONC. LAUNDER WATER	202	
38	Pb FINAL CONC. LAUNDER WATER	77	
38	Pb THICKENER OVERFLOW		311
32	Pb CONC. THICKENER SPRAY WATER	32	
32	Pb CONC. FILTER CLOTH WASH WATER	50	
33	Pb FINAL CONCENTRATE		7
39	STRINGER ORE ROD MILL FEED	179	
39	WATER IN ROD MILL	1,845	
41	WATER IN BALL MILL	6,323	
50	Cu ROUGHER #1 CONC. LAUNDER WATER	255	
51	Cu ROUGHER #2 CONC. LAUNDER WATER	159	
52	Cu SCAVENGER CONC. LAUNDER WATER	274	
60	Cu 1-ST CLEANER CONC. LAUNDER WATER	452	
62	Cu 2-ND CLEANER CONC. LAUNDER WATER	534	
63	Cu 3-RD CLEANER CONC. LAUNDER WATER	343	
63	Cu CONCENTRATE THICKENER OVERFLOW		1580
63	Cu CONCENTRATE THICKENER SPRAY WATER	40	
63	Cu CONCENTRATE FILTER CLOTH WASH WATER	60	
63	Cu FINAL CONCENTRATE		47
66	Zn ROUGHER CONC. LAUNDER WATER	534	
67	Zn SCAVENGER CONC. LAUNDER WATER	2,700	
71	Zn REGRIND CIRCUIT		
78	Zn 1-ST CLEANER CONC. LAUNDER WATER	704	
75	Zn 1-ST CLNR. SCAV. CONC. LAUNDER WATER	136	
83	Zn 2-ND CLEANER CONC. LAUNDER WATER	927	
86	Zn 3-RD CLEANER CONC. LAUNDER WATER	2,055	
87	Zn 4-TH CLEANER CONC. LAUNDER WATER	599	
87	Zn CONCENTRATE THICKENER OVERFLOW		2,155
87	Zn CONCENTRATE THICKENER SPRAY WATER	118	
87	Zn CONC FILTER CLOTH WASH WATER	177	
90	Zn FINAL CONCENTRATE		89
80	SAND/SLIME SEPARATIONS AND FINAL TAILS FINAL CYCLONE UNDERFLOW		2,534
	TAILING THICKENER OVERFLOW		22,089
	WATER RECOVERED FROM THE POND		1,808
	WATER LOST IN THE TAILING POND		1,205
	WATER TO DUST COLLECTORS (CONC. AREA)		100
	TOTAL BALANCE		
	TOTAL WATER IN/OUT	32,149	28,267
			3,882

WATER BALANCE MTPD			
FLOW NO.	DESCRIPTION	WATER ADDED TO CIRCUIT	WATER RECOVERED
1	MAKE-UP WATER	3059	
88	FROM SURFACE (RUN-OFF)	425	
50	IN MASSIVE ORE	219	
70	IN STRINGER ORE	179	
67	IN LEAD CONCENTRATE		7
85	IN COPPER CONCENTRATE		47
99	IN ZINC CONCENTRATE		89
103	IN BACKFILL SAND		2534
110	IN TAILING POND		1205
	TOTAL BALANCE		
	TOTAL WATER IN/OUT	3,882	3,882

NOTE: FLOW NUMBERS CORRESPOND TO THIS DWG.

FRESH WATER CONSUMPTION = $\frac{3059 \text{ MAKE UP WATER MTPD}}{9555 \text{ TOTAL ORE MTPD}}$

= 0.3201 TONS OF WATER PER TON OF ORE

FOR COMPLETE MATERIAL (PULP & WATER) BALANCE SEE DWG. NO. 051-I-L-002

FLOW NUMBER	DESCRIPTION	WATER MTPD	WATER M ³ /HR	WATER USGPM
1	TOTAL MAKE-UP WATER FROM WATER TREATMENT TANK NO. 2	3059	127.46	561
2	TOTAL FRESH WATER FROM TANK NO. 2	3691	153.79	677
3	FRESH WATER TO LEAD CIRCUIT	675	281.24	1238
4	GLAND WATER TO LEAD FLOTATION	98	27.21	120
5	FRESH WATER TO LEAD FLOTATION	453	18.88	83
6	LEAD CONC. THICKENER SPRAY WATER	32	1.33	6
7	FRESH WATER TO LEAD CONC. FILTER	30	1.25	6
8	GLAND WATER TO LEAD CONC. FILTER	20	0.83	4
9	FRESH WATER FOR DUST COLLECTOR	20	0.83	4
10	FRESH WATER TO C4-Pb CIRCUIT (MASSIVE ORE)	1352	54.33	248
11	FRESH WATER TO C4-Pb CIRCUIT (STRINGER ORE)	923	38.46	169
12	GLAND WATER TO C4-Pb FLOTATION	92	3.83	17
13	GLAND WATER TO C4-Pb FLOTATION	215	8.88	39
14	GLAND WATER TO GRINDING			
15				
16				
17	FRESH WATER TO SEPARATION	124	5.17	23
18	FRESH WATER TO C4 CIRCUIT (STRINGER ORE)	751	32.29	142
19	GLAND WATER TO C4 FILTER	20	0.83	4
20	GLAND WATER TO C4-Pb FLOTATION	22	0.92	4
21	GLAND WATER TO C4-Pb FLOTATION	60	2.50	11
22	GLAND WATER TO GRINDING	191	7.96	35
23	FRESH WATER TO C4 CLEANING	343	14.29	63
24	SPRAY WATER TO C4 CONC. THICKENER	40	1.67	7
25	FRESH WATER TO C4 CONC. FILTER	40	1.67	7
26	FRESH WATER TO DUST COLLECTOR	35	1.46	6
27	FRESH WATER TO ZN CIRCUIT	3578	143.08	656
28	FRESH WATER TO ZN FILTER	129	5.38	24
29	GLAND WATER TO ZN FILTERING	48	2.00	9
30				
31				
32	SPRAY WATER TO ZN CONC. THICKENER	118	4.92	22
33	FRESH WATER TO ZN FLOTATION	2582	104.67	547
34	GLAND WATER TO ZN FLOTATION	256	10.67	47
35	GLAND WATER TO ZN FLOTATION	45	1.88	8
36	GLAND WATER TO ZN FLOTATION	20	0.83	4
37	GLAND WATER TO TAILING THICKENERS	371	15.46	68
38	GLAND WATER TO TAILING POND AREA	25	1.04	5
39				
40				
41				
42				
43				
44				
45				
46				
47				
48	RECLAIM WATER TO MASSIVE REGRIND CIRCUIT	11409	475.38	2053
49	RECLAIM WATER TO C4-Pb FLOTATION	1890	78.75	347
50	MASSIVE ORE TO CRUSHING PLANT AND AERATION AREA FEED	219	9.13	40
51	RECLAIM WATER TO GRINDING AND AERATION AREA FEED	219	9.13	40
52	RECLAIM WATER TO BRANDING AND AERATION AREA FEED	8910	371.25	1635
53	RECLAIM WATER TO C4-Pb FLOTATION	9342	389.25	1714
54	ROUGHER Pb FLOTATION TAILS	1554	64.75	285
55	C4-Pb FLOTATION CONCENTRATE	2064	86.00	379
56	Pb CIRCUIT FEED	1481	61.71	272
57	RECLAIM WATER TO C4-Pb SEPARATION	547	22.79	100
58	C4 CLEANER FEED	1276	53.17	234
59	Pb CIRCUIT THICKENER OVERFLOW	324	13.50	59
60	Pb FLOTATION FEED	1157	48.21	212
61	RECLAIM WATER TO Pb FLOTATION	62	2.58	11
62	Pb CONC. TO Pb THICKENER	216	9.00	40
63	Pb FILTERATE THICKENER	74	3.08	14

FLOW NUMBER	DESCRIPTION	WATER MTPD	WATER M ³ /HR	WATER USGPM
66	Pb CONC. FILTER FEED	31	1.29	6
67	FINAL Pb CONCENTRATE	7	0.29	1
68	Pb CONC. THICKENER OVERFLOW	311	12.56	57
69	C4-Pb FLOTATION TAILS	11731	489.34	2153
70	STRINGER ORE FEED	179	7.46	33
71	GRINDING AREA FEED	179	7.46	33
72	C4 SCAVENGER CLEANER TAILS	2682	111.75	492
73	RECLAIM WATER TO GRINDING	7577	332.38	1464
74	C4 FLOTATION FEED	11029	455.54	2024
75	RECLAIM WATER TO C4 FLOTATION	1080	45.00	198
76	C4 CLEANER FEED	1836	76.50	337
77	C4 FLOTATION TAILS	10142	422.83	1862
78	C4 CLEANER TAILS	2497	104.04	458
79	C4 CLEANER CONCENTRATE	1492	62.17	274
80				
81	RECLAIM WATER TO C4 CLEANER	534	22.25	98
82	C4 FILTERATE	215	8.96	39
83	C4 CONC. THICKENER FEED	1707	71.13	313
84	C4 CONC. FILTER FEED	202	8.42	37
85	FINAL C4 CONCENTRATE	47	1.96	9
86	C4 CONCENTRATE THICKENER OVERFLOW	1580	65.83	290
87	RECLAIM WATER TO STRINGER ORE CIRCUIT	9591	395.63	1760
88	SURFACE RUN-OFF PLUS FROM SAND/SLIME STORAGE	425	17.71	78
89	Zn CIRCUIT FEED	21885	911.88	4015
90	RECLAIM WATER TO Zn CIRCUIT	4417	184.04	810
91	Zn FLOTATION TAILING	27636	1151.50	5070
92	Zn FLOTATION CONCENTRATE	1504	73.33	345
93				
94	Zn CONC. THICKENER OVERFLOW	2155	89.79	395
95	Zn FILTERATE	527	21.96	97
96	Zn FILTERATE	439	18.29	81
97	Zn FILTERATE	2262	94.25	415
98	RECLAIM WATER TO Zn CIRCUIT TANK NO. 8	89	3.71	16
99	FINAL Zn CONCENTRATE	4417	184.04	810
100	RECLAIM WATER FROM TANK NO. 8	9938	444.08	1823
101	THICKENER OVERFLOW RETURN TO SAND/SLIME SEPARATION TANK NO. 4	37574	1565.58	6894
102	SAND/SLIME SEPARATION FEED	2534	105.58	445
103	SAND PRODUCT	35411	1475.46	6497
104	SLIME PRODUCT	32729	1363.71	6005
105	TAILINGS	311	12.56	57
106	WATER AFTER CYANIDE TREATMENT	22791	949	4182
107	THICKENER OVERFLOW	3013	125.54	553
108	RECLAIM WATER TO TAILING POND	1833	76.38	336
109	WATER IN TAILING POND	1205	50.21	221
110	TAILING POND	24858	1020.79	4935
111	FROM RECLAIM POND TO TANK NO. 1	23242	969.25	4268
112	RECLAIM WATER FROM TANK NO. 1 TO TANK NO. 2	3591	149.63	659
113				
114				
115				
116				
117				
118	FRESH WATER TO WATER TREATMENT	3591	149.63	659
119				

LEGEND

1. GLAND AND FRESH WATER - - - - -

2. RECLAIM WATER - - - - -

3. ALTERNATE - - - - -

FIGURE 3

EXXON MINERALS COMPANY
CRANDON PROJECT

SURFACE PLANT
PROCESS FLOWSHEET
WATER BALANCE

DATE: 3/23/82 BY: K.D. ISSUED TO CLIENT

DATE: 3/8/81 BY: K.D. ISSUED FOR CLIENT APPROVAL

SCALE: NONE STATE: WISCONSIN COUNTY: FOREST

DESIGNED BY: K. DISON DATE: 3/3/82 CHECKED BY: ACB DATE: 3/5/82

DRAWN BY: Z. PACIC DATE: 2/23/82 CHECKED BY: R. J. GILMAN DATE: 3/15/82

PROJECT NO: 051-I-L-010 SHEET NO: 1

RMP JOB NO. 0257-01

THE RALPH M. PARSONS COMPANY
PASADENA, CALIFORNIA

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met with mine seepage water. No separate water supply from the surface will be required.

Allowance has been made for use of a small closed-loop boiler/cooling tower system to provide steam for process and heating needs. Approximately $8.4 \text{ m}^3/\text{hr}$ (37 gpm) of fresh water will be required as makeup for the boiler. It has been assumed that approximately 80 percent of this water will evaporate and be lost to the atmosphere. Approximately 20 percent, or $1.67 \text{ m}^3/\text{hr}$ (7.33 gpm), will enter the Mine/Mill water circuit as blowdown from the circuit (5 cycles of concentration were assumed) and will be routed to the Reclaim Pond.

POTABLE WATER

During full operation, the Crandon Mine/Mill will employ a maximum of 893 persons. In addition, up to 20 visitors per day can be expected at the mill. Potable water will be supplied to the facilities from the fresh water wells. Categories of potable water consumption by the employees will include toilet use, handwashing, and showering. Table 2 illustrates several per-capita potable water consumption estimates available in the literature.

Many employees of the Crandon Project will shower before leaving the site after each shift, resulting in a moderately high per capita design flow rate. A per capita flow rate of $0.19 \text{ m}^3/\text{day}$ (50 gal/day) has been selected as the basis for design.

The total predicted average potable water consumption (for sanitary purposes) at the Crandon Project is $7.3 \text{ m}^3/\text{hr}$ (31.9 gpm).

REAGENT PREPARATION

A variety of reagents are required in the flotation circuits of the mill. These reagents are added at various locations throughout the mill.^{1,3,5} The categories of reagents required for the mill processes include pH modifiers, frothers, collectors (promoters), activating agents, depressing agents, dispersants, and coagulants.

Most reagents will be mixed with water for use in the process. Since the use of reagents is critical to the perform-

Table 2

POTABLE WATER FLOW RATE ESTIMATES

(These numbers are presented for comparison only)

<u>Type of Source</u>	<u>Flow Rate, m³/day/person (gal/day/person)</u>
Factory ⁶	0.057 to 0.132 (15 - 35)
Labor camp ⁶	0.132 to 0.189 (35 - 50)
Factory ⁷	0.114 (30)
Construction camp ⁷	0.189 (50)
Migrant labor camp ⁸	0.114 (30)
Construction camp ⁹	0.189 (50)
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Table 3

DAILY CONSUMPTION OF WATER FOR REAGENT PREPARATION²⁹

Reagent	Reagent Use ¹ (Kg/day)	Clean Water		Recycle Water		Total	
		m ³ /hr	(gpm)	m ³ /hr	(gpm)	m ³ /hr	(gpm)
Lime (CaO)	16,000	3.57	(15.7)	11.32	(49.8)	14.88	(65.5)
Sulfur Dioxide	3,000	2.57	(11.3)	0	(0)	2.57	(11.3)
Copper Sulfate (CuSO ₄)	3,200	2.38	(10.5)	0	(0)	2.38	(10.5)
Zinc Sulfate (ZnSO ₄)	550	0.33	(1.4)	0	(0)	0.33	(1.4)
Sodium Cyanide (NaCN)	190	0.11	(0.49)	0	(0)	0.11	(0.49)
Activated Carbon	750	--	--	--	--	--	--
Sodium Dichromate	500	0.57	(2.5)	0	(0)	0.57	(2.5)
Sodium Silicate (Na ₂ SiO ₃)	1,400	0.57	(2.5)	0	(0)	0.57	(2.5)
Sodium Ethyl Xanthate (NaEX)	230	0.09	(0.4)	0	(0)	0.09	(0.4)
Potassium Amyl Xanthate (PAX)	130	0.05	(0.2)	0	(0)	0.05	(0.2)
Sodium Isopropyl Xanthate	250	0.21	(0.9)	0	(0)	0.21	(0.9)
Methyl Isobutyl Carbinol (MIBC)	390	--	--	--	--	--	--
Carboxy Methyl Cellulose	260	0.55	(2.4)	0	(0)	0.55	(2.4)
Sodium Sulfide (Na ₂ S)	2,250	5.86	(25.8)	0	(0)	5.86	(25.8)
Poly Propylene Glycol Methyl Ether (PPE)	30	--	--	--	--	--	--
Sodium Carbonate	100	<u>2.44</u>	<u>(10.7)</u>	<u>0</u>	<u>(0)</u>	<u>2.44</u>	<u>(10.7)</u>
TOTAL		19.29	(84.9)	11.32	(49.8)	30.61	(134.7)

¹ Does not include water treatment reagent consumption.

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ance of the mill flotation processes, Exxon's metallurgical staff advise that all reagents should be mixed with fresh (or highly purified) water to ensure proper performance of the mill.

Table 3 illustrates the reagents to be used in the mill and lists the daily water requirements for preparation of the reagents.^{2,9} It is assumed that Milk-of-Lime (MOL) will be slaked at an 18-percent solids concentration using fresh water and then diluted to 5 percent with untreated recycle water from the Reclaim Pond.

PUMP GLAND WATER

The mill water circuit will contain a number of pumps which will require gland seal water. It is recommended that pump gland water be supplied by either well water or highly purified, treated recycle water. No attempt should be made to use untreated recycle water for this critical use. Parsons' estimates¹ that 84.1 m³/hr (370.2 gpm) will be required to supply seal water to all pumps on the surface.

FIRE PROTECTION

Fire protection water will be supplied to the Crandon Project from the fresh water tank.^{1,3} Since fire protection water use should be extremely rare, it has not been considered further.

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Section VI
WATER LOSSES FROM SITE

SANITARY WASTEWATER

All sanitary wastewater generated at the site will be collected, treated, and discharged. Sanitary wastewater treatment is discussed in Section XVII, TREATMENT OF SANITARY WASTES.

The anticipated flow rate of sanitary wastewater is $7.3 \text{ m}^3/\text{hour}$ (31.9 gpm), based on the assumption that all potable water used at the site will be discharged as sanitary wastewater. (See Section V, SITE WATER USES for basis of design flow rate.)

RETENTION IN MINE BACKFILL SANDS

Sands from the mill will be slurried with water and pumped back to the mine to backfill mined-out stopes. The majority of transport water will drain from the backfill and exit the mine with other water collected in the mine. Some water, however, will be trapped between sand particles and will remain in the mine. Exxon estimates that sands will drain to approximately 85 weight percent solids in the mine.

During mature operation of the mine, approximately 4,305 metric tons of sand will be backfilled each day. At this design backfill rate, approximately $31.65 \text{ m}^3/\text{hr}$ (139.3 gpm) of water will be lost from the mill water circuit as retained water in the backfill.

RETENTION IN SAND STORAGE ON SURFACE

From time to time the mine backfilling operation may be out of operation for short periods. During these periods, sands may be stored on the surface in a sand storage area. Sand storage on the surface would likely occur intermittently throughout the Mine/Mill operational life.

As with mine backfilling operations, sands stored on the surface will retain water between sand particles. Exxon's mining engineers estimate that sands stored on the surface will also drain to approximately 85 percent solids by weight.

The quantity of water retained in sand storage is identical to that described earlier for retention in mine backfill sands.

RETENTION IN TAILINGS IMPOUNDMENTS

Fines in the underflow from the tailings thickeners will be pumped to the tailings impoundment and will likewise retain water. Exxon estimates that fines deposited in the tailings impoundments will settle to an average solids concentration of 75 percent by weight.

During mature operation of the mill, approximately 3,682 metric tons of fines will be routed to the tailings impoundment each day. At this design rate, approximately 51.3 m³/hr (225 gpm) of water will be lost from the mill water circuit as retained water in the tailings impoundment.

RETENTION IN ORE CONCENTRATES

Final ore concentrates (lead, zinc, and copper) will be dewatered and shipped from the Crandon Mill in a damp condition rather than being dried. Some water, therefore, will leave the site with the concentrates.

Based on current projections of ore grade and Parsons' Phase III design of the surface facilities, the following "flow rate" of water will leave the site in the concentrates:

<u>Concentrate</u>	Dry Solids (MTPD)	<u>Water</u>		
		<u>MTPD</u>	<u>m³/hr</u>	<u>gpm</u>
Lead	72	7	0.29	1
Zinc	1,025	89	3.71	16
Copper	471	<u>47</u>	<u>1.96</u>	<u>9</u>
TOTAL		143	5.96	26

EVAPORATION

The closest point to the Crandon Project for which long-term evaporation rates are available is the station at Rainbow Reservoir in north central Oneida County. In a preliminary report to Exxon¹, Dames and Moore presented 20 years of data from this station indicating an average pan evaporation rate for the months of May through October of 608.6 mm (23.96 inches). To extrapolate this data to an annual lake evaporation rate, CH2M HILL examined the Climatic Atlas of the United States, published by the Natural Oceanic and Atmosphere Administration of the United States Department of

Commerce. This reference indicates that, for the general area of the Crandon Project, May to October evaporation is approximately 80 percent of the annual. It also indicates that, for this same general area, lake evaporation is 78 percent of pan evaporation. Therefore,

$$\frac{608.6}{0.8} \times 0.78 = 593.4 \text{ millimeters} = \text{average annual lake evaporation}$$

$$\frac{23.96}{0.80} \times 0.78 = 23.36 \text{ inches} = \text{average annual lake evaporation}$$

Evaporative water losses will occur from all standing water surfaces in the pond system, and to some extent from the surface of beached tailings. Table 4 illustrates the projected sizes of each of the tailings ponds to be constructed during the life of the Crandon Project and of the two cells of the Reclaim Pond. The table further illustrates the approximate percentage of the total pond areas which will be subject to evaporation.

The two-cell Reclaim Pond will be constructed at the beginning of the project and will remain active for the duration of the operational life of the facility. The tailings impoundments will be constructed sequentially and as each pond is filled with deposited fines, the next cell will be activated. Table 4 also illustrates the planned years of construction, operation, and reclamation of each pond.²⁹

Total evaporation water losses from the site are discussed further in later sections of this report.

INFILTRATION (SEEPAGE)

The Tailings and Reclaim Pond system for the Crandon Project will occupy a substantial land area. Infiltration (seepage) from the ponds will percolate to the groundwater under the site. To reduce the rate of seepage from the ponds, Exxon and other consultants have conceptually designed a sophisticated liner/underdrain system to capture and pump the majority of seepage to the Reclaim Pond.

Table 4

WATER MANAGEMENT CRITERIA
TAILINGS AND RECLAIM PONDS²⁹

<u>Pond</u>	<u>Construction Period¹</u>	<u>Operation Period¹</u>	<u>Reclamation Period¹</u>	<u>Area Inside Crest (Acres)³</u>	<u>% of Area Subject to Evaporation</u>
Tailings #1	1986/1987	1989-1994	1994/1995	83	80
Tailings #2	1993/1994	1994-2001	2001/2002	104	80
Tailings #3	2000/2001	2001-2007	2007/2008	100	80
Tailings #4	1985 ² /2006/2007	2007-2010	2010/2011	92	80
Reclaim #1	1985	1989-2010	2010/2011	29	92
Reclaim #2	1988	1989-2010	1020/2011	32	92

¹ Dates shown are based on beginning of construction in 1985. If start of construction is delayed, all dates shown would slip.

² Partial construction of a laydown area in Tailings Pond No. 4 for storing waste rock and production ore.

³ May be subject to adjustment during final design of tailings ponds and Reclaim Pond.

CH2M HILL was advised by Exxon²⁹ that seepage to the groundwater from the Pond/Liner/Underdrain system will be as follows:

<u>Pond</u>	<u>Seepage Rate</u>
Tailings Ponds	5 gpm per 100 acres
Reclaim Ponds	1 gpm per 100 acres

FINAL DISCHARGE

One of the most important goals of this study has been to define the quantity of water which must be discharged from the Crandon Project, and to define the quality of discharge water from various water treatment processes.

The overall discharge of water from the Crandon Project will be comprised of:

- A) Direct discharge of uncontaminated seepage water intercepted at ambient groundwater quality.
- B) Discharge of excess treated water from the mine/mill water treatment system.

The quality of discharged treated water depends on the type of treatment system used. The quantity of discharged water is influenced by a number of interrelated parameters. The following sections of this report describe the rationale and methods by which estimated discharge flow rates were computed.

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Section VII
CRANDON WATER BALANCE

The proposed Crandon Mine/Mill facilities represent a complex and interrelated series of unit processes and operations. As discussed previously, there are a variety of water sources, uses and losses to and from the mill water circuit. A number of separate studies by Exxon and various consultants have been necessary to define the overall facilities.

One of the major tasks in this Water Management Study was to develop a computer model to predict the flow rate and quality of water at various locations around the Mine/Mill complex. To establish a series of "base case" conditions to enter into the model, it was first necessary to formulate an overall water balance around the mill/pond system and to identify minimum fresh (or treated and purified recycle) water requirements.

During the first year of operation (Early), Exxon intends to process only massive ore. During subsequent years (Mature), a blend of massive and stringer ores will be processed. Since both water quality and quantity within the mill water circuit will be different during these two time periods, both were evaluated in this Water Management Study.

Figure 4 illustrates a mill/pond water balance for Mature operation of the Crandon Mill. This water balance, prepared by Exxon staff, incorporates work by the Ralph M. Parsons Company (surface facilities design), Lakefield Research (pilot plant test results), Golder Associates (pond sizing), CH2M HILL (rainfall and evaporation rates), and other miscellaneous work by Exxon.

The water and solids material balances illustrated on Figure 4 are based on the "design" operating rates of the Crandon Mill (9,555 MTPD during Mature operation). Although, the actual tonnage of ore processed at the mill may vary slightly from day to day, most water flows are fixed by pump sizes, pipeline velocity requirements and so forth. For the purpose of this study, it has been assumed that overall water requirements in the mill will be relatively constant despite fluctuations in ore throughput.

Several clarifying notes are appropriate to explain the water balance shown on Figure 4.

- o Although the flow rates of reagents to mill unit operations are not specifically called out, they are included in the makeup flow rates of recycle water shown for each unit operation.
- o Precipitation and evaporation rates at the Tailings Pond are based on the use of Tailings Pond Nos. 2 and 3 during Mature operations.
- o These water balances were prepared without regard to scaling in the mill water circuit, so do not necessarily represent "real world" water balances. (See later discussions regarding scaling conditions.) For example, the flow rate shown in stream "96" is insufficient to prevent scaling conditions. This figure has been updated by Exxon based on final results of this study. The updated balance is not included in this report.
- o Only a limited number of fresh (or highly purified) water uses are shown. The fresh water usage points shown are the minimum number of points where such water is required from a process or mechanical performance standpoint.

Exxon staff manually adjusted the water balance in Figure 4 to obtain data on water management during Early operation of the Mill. Although a detailed water balance was not drawn up, Early operations were considered during development of water management plans. (See Section XII - EVALUATION OF WATER TREATMENT NEEDS)

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■ ■ Section VIII
■ ■ PREPARATION OF CRANDON PROJECT WATER USE MODEL

The following discussion describes in general terms how the Crandon Water Use Model was prepared. For a detailed technical description, the reader is referred to the system and user manuals prepared for the model.

PURPOSE OF MODEL

The Crandon Water Use Model was developed to assist CH2M HILL and Exxon staff in evaluating water management alternatives for the Crandon Project.

Exxon has contracted with a variety of consultants, each working on projects which influence the overall water balance for the project. The Water Use Model has enabled Exxon and CH2M HILL to quickly incorporate design refinements into this study and estimate their effects on water quality and quantity. The model has demonstrated the interrelationships between water systems. With the exception of uncontaminated mine seepage, the model predicts the flow rate and water quality of all water in the mine/mill water circuit. CH2M HILL has constructed the model to allow for modifications to the Mine/Mill configuration or water chemistry as new information becomes available. It has been instrumental in the evaluation of numerous treatment options which would probably not have been explored without its development.

MODEL STRUCTURE

The Crandon Water Use Model is a FORTRAN coded program which is run interactively from a Cathode Ray Terminal (CRT) or hard copy computer terminal. The model has been constructed in a modular form comprised of 74 subroutines, a link/node data file, and an initializing data file. The data file is converted into a link/node representation of the Mine/Mill facility. In addition, the model will incorporate user supplied information, define the water quality effects of each unit process in the facility, simulate water treatment processes, and prepare a final output report.

The program EXXON is the main program in the Water Use Model. It performs the major tasks of the model by controlling the order in which the subroutines are executed. A generalized flow chart outlining the function of the EXXON program is shown in Figure 5.

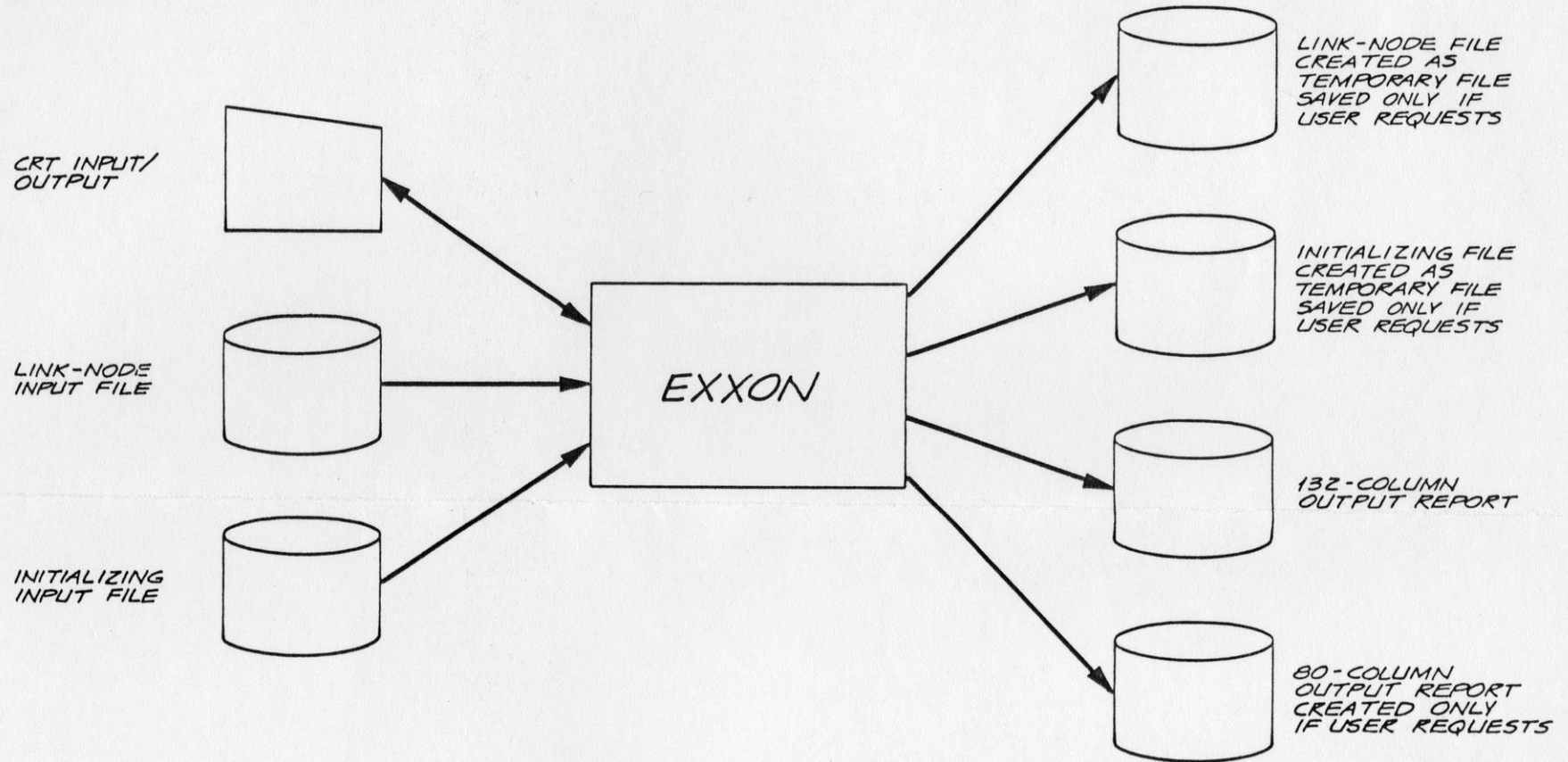


FIGURE 5

EXXON MINERALS COMPANY			
CRANDON PROJECT			
TITLE			
GENERALIZED SYSTEM FLOWCHART FOR EXXON WATER USE MODEL			
SCALE	STATE	COUNTY	
NONE	WISCONSIN	FOREST	
DRAWN BY	DATE	CHECKED BY	DATE
D.L.A.	6-5-82		
APPROVED BY	DATE	APPROVED BY	DATE
M.R.H.			
APPROVED BY	DATE	EXXON	DATE
DRAWING NO			SHEET
051-7-L-001			OF
			REVISION NO



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VII-3**

It was decided by Exxon staff that the pyrite flotation configurations were not needed and were, therefore, dropped from further model development in this Phase III Study. Currently, the model will simulate Configurations B and D only. These two configurations, shown in Figures 6 and 7, are the master configurations which can be modified by the user into desired link/node configurations.

SELECTION OF CONSTITUENTS TO BE MODELED

In consultation with the Exxon staff¹ and Lakefield Research⁵, a list of water constituents was developed for the modeling effort. The list of modeled constituents is presented in Appendix B. The list includes:

<u>Type of Constituent</u>	<u>Number</u>
Soluble Cations	18
Particulate Cations	15
Soluble Anions	13
Particulate Anions	6
Nonionic	<u>12</u>
Total	64

Flow rates of water are also tracked by the model and reported in both English and metric units.

EFFECT MATRICES

Each node in the model represents a unit process which will have an "effect" on water quality as water "passes through" the node. "Effect matrices" (computer subroutines) were developed for each node in the model and for a variety of water treatment processes. Each matrix describes the changes to each of the 64 modeled constituents as water is passed through the node. Each node in the model is represented with a distinct effect matrix. These effect matrices range in complexity from a relatively simple process, such as a flow summer, to the complex mill node. Development of the model effect matrices is described in Section XI.

USER VARIABLES

There are a number of model variables which can be modified by the user when using the model. All of the variables are

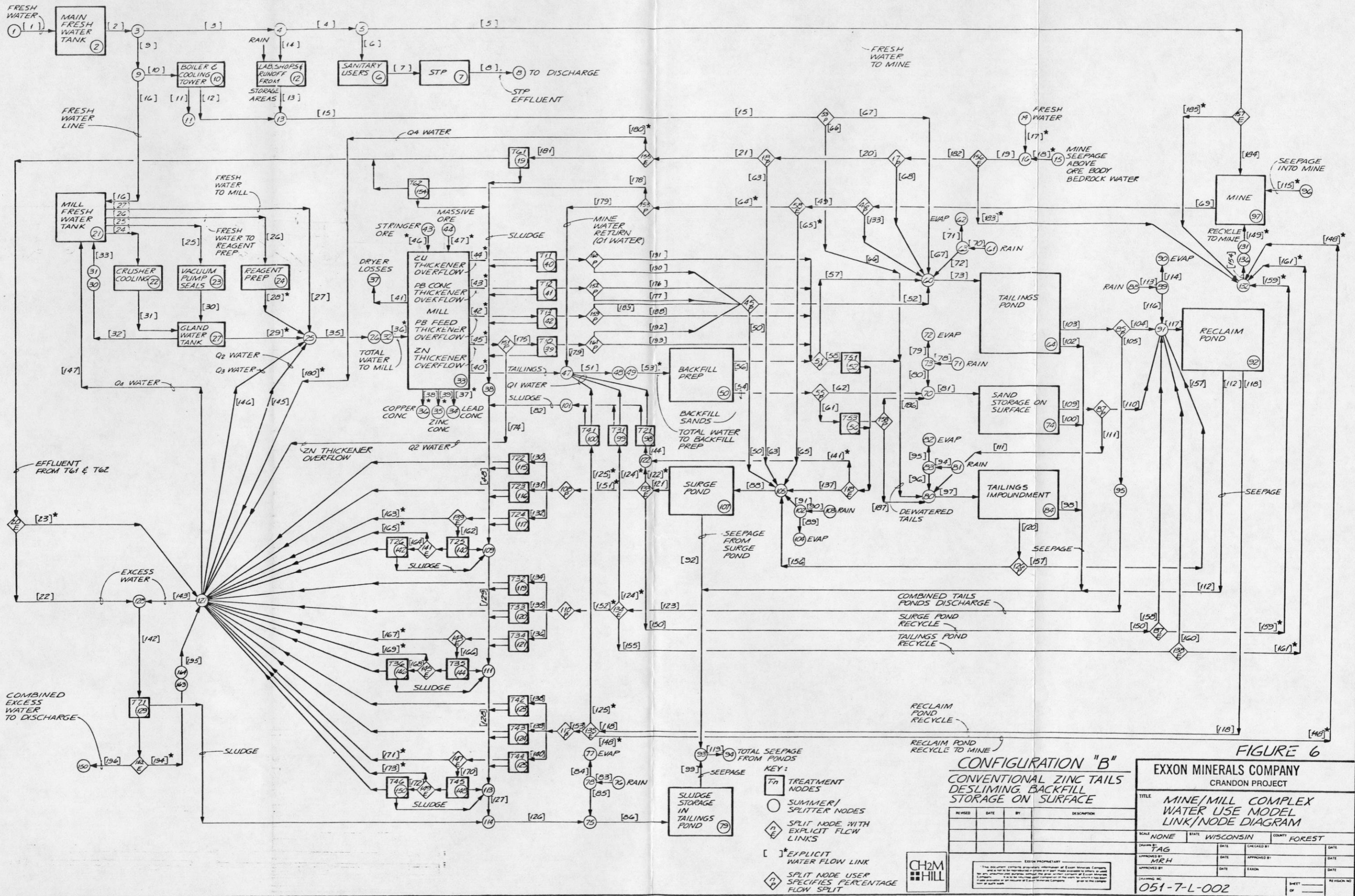


FIGURE 6

CONFIGURATION "B"
 CONVENTIONAL ZINC TAILS
 DESLIMING, BACKFILL
 STORAGE ON SURFACE

REVISED	DATE	BY	DESCRIPTION

EXXON MINERALS COMPANY
 CRANDON PROJECT

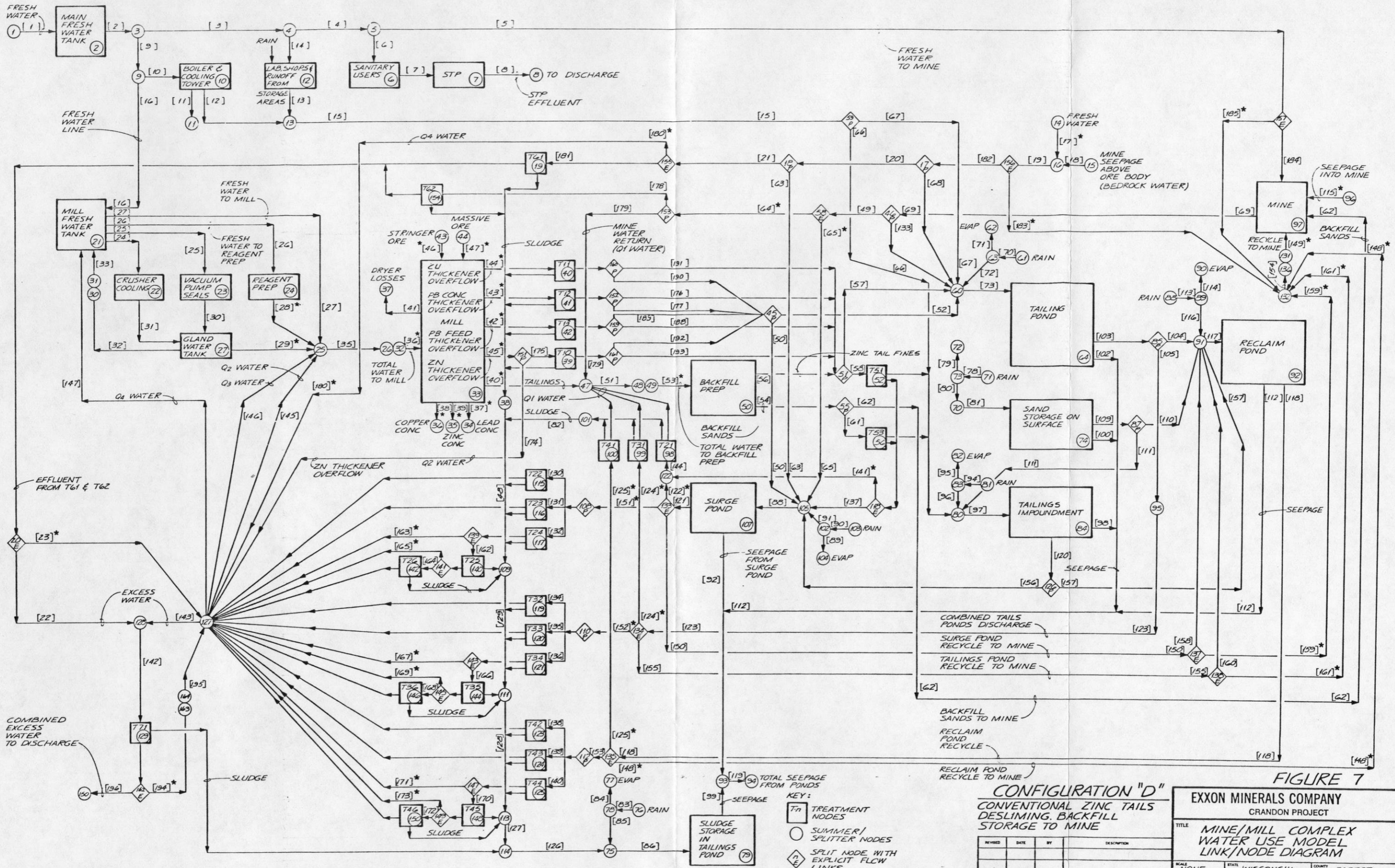
TITLE: **MINE/MILL COMPLEX WATER USE MODEL LINK/NODE DIAGRAM**

SCALE: NONE	STATE: WISCONSIN	COUNTY: FOREST
DESIGNED BY: FAG	DATE:	CHECKED BY:
APPROVED BY: MRH	DATE:	APPROVED BY:
APPROVED BY:	DATE:	APPROVED BY:

051-7-L-002



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CONFIGURATION "D"
 CONVENTIONAL ZINC TAILS
 DESLIMING, BACKFILL
 STORAGE TO MINE

- KEY:
- Tn TREATMENT NODES
 - SUMMER/ SPLITTER NODES
 - ◇ SPLIT NODE WITH EXPLICIT FLOW LINKS
 - [] EXPLICIT WATER FLOW LINK
 - ◇ SPLIT NODE USER SPECIFIES PERCENTAGE FLOW SPLIT

REVISED	DATE	BY	DESCRIPTION

FIGURE 7

EXXON MINERALS COMPANY
 CRANDON PROJECT

TITLE: **MINE/MILL COMPLEX WATER USE MODEL LINK/NODE DIAGRAM**

SCALE: NONE	STATE: WISCONSIN	COUNTY: FOREST
DRAWN BY: TAG	DATE:	CHECKED BY:
APPROVED BY: WJH	DATE:	APPROVED BY:
APPROVED BY:	DATE:	DATE:

051-7-L-003



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entered at the computer terminal when using the model. The following is a summary of user-defined inputs.

1. General Inputs or Variables

- o Two Mine/Mill configurations:
 - Backfill Storage on Surface
 - Backfill to Mine
- o Type of ore to be processed:
 - Massive and stringer ore (Mature operation)
 - Massive ore only (Early operation)
- o Design capacity of the Mill
- o Tonnage of ore to be processed in the specified mill
- o Water and solids flow rates for all streams entering and leaving the Mill
- o Annual rainfall and evaporation rates
- o Water and solids flow rates for all streams entering and leaving the backfill preparation area
- o Percent weight retention of solids in the Mine
- o Summer or winter operation
- o pH control at the Reclaim Pond
- o Number of iterations allowed for model convergence
- o Output format
 - hard copy printout
 - CRT display

2. Pond Variables

The user can specify acreage, seepage, evaporation factor and solids weight percent retention in each of the following:

- o Tailings Pond
- o Sand Storage Pond

- o Sludge Storage Area
- o Reclaim Pond
- o Tailing Disposal Area (for thickened tailings)
- o Surge Pond

3. User-Defined Percent Flow Splits

Currently, there are 22 nodes which have been defined as percent splitter nodes. The nodes can be located on Configurations B or D link/node diagrams (Figures 6 and 7). At each node, the user can specify the percentage flow split between links exiting the nodes.

4. User-Defined Flow Rates

Currently, there are 27 links (excluding the mill node) where the user can define "explicitly" (numerically) the flow rate in each link exiting the node. The explicit links are identified on the Configurations B or D link/node diagrams (Figures 6 and 7).

5. User-Defined Water Treatment Unit Operations

The model contains 22 water treatment effect matrices. Up to eight treatment processes in series can be specified at any of the 27 treatment nodes identified in the link/node diagrams as "T" nodes. A description of each treatment effect matrix is presented in Appendix A.

6. Recycle Water Quality

In consultation with Exxon staff, the following five classes of water qualities have been defined within the Mine/Mill facility:

- o Q1 - Backfill Preparation Use (Lowest Water Quality)
- o Q2 - Mill Use (Low Water Quality)
- o Q3 - Mill Use (Moderate Water Quality)
- o Q4 - Mill Use (Highest Water Quality)
- o QD - Water to Discharge

The model user is able to define the total quantity of water required by the mill and to further define how much of each water quality type the mill or backfill operation will require. The quality of the water recycled back to the mill is defined at the terminal by the user as either Q1, Q2, Q3 or Q4. The model will then match the water quality requirements of the mill with the quality of water being recycled.

If insufficient water is available, fresh water will be used to make up the deficit. Water that is designated QD is routed by the model to discharge.

After all user variables are defined, the model performs several iterations to achieve a mass balance equilibrium of water quality throughout the entire link/node "water circuit." When equilibrium is achieved a final report is printed out to illustrate water quality in each link in the system being simulated.

Initializing Data Files

To use the model, two data files are required: a link/node file and an initial data file. These two files exist for each configuration stored in the computer and are generated automatically for each run of the model. The model will prompt the user to specify a name for each set of data files.

The link/node file is the master file describing the Mine/Mill in terms of links and nodes. It contains information describing the function and location of each link and node in the model.

The initial data file contains the constituent names and qualities for each of the "boundary nodes." Boundary nodes are defined as nodes with no influent stream. An example of a boundary node is the mine seepage node. The water quality of the mine seepage is defined in the initial data file.

Flexibility and Utility

The model has been constructed with a great deal of flexibility. This is demonstrated, in part, by the large number of variables which can be modified by the user. The large array of variables has given the project team the ability to react to project refinements.

The modular construction of the model facilitates changes to the program and is an important feature if changes to the link/node configurations, process effect matrices or water quality data are required.

MODEL VERIFICATION

Verification of the model was done by carefully reviewing each program module to ensure that the effect matrices are properly implemented in the computer program. Model

verification has centered on the close examination of the predicted chemical makeup in every link of the model, to ensure that the process at every node has been correctly programmed. Given the large number of links and nodes used for the Crandon project, and the number of effect matrices and operating assumptions to check, this in itself was a major task.

The model requires an initial estimate of the chemical make-up in all recycle circuits. The model then completes several iterations of all processes until the predicted makeup of these recycle circuits reaches an equilibrium state. The model was further validated by comparing runs using extreme conditions as initial estimates of water quality at each of the recycle circuits.

An initial run was completed using well water quality as the initial makeup water quality in links 36 (total water to the mill) and 53 (total water to backfill). A second run was completed, identical to the first, except that the initial water quality values assumed in links 36 and 53 were changed to an estimate of highly contaminated quality similar to acid mine drainage. These two runs represented two extreme initial conditions. Comparison of the results indicated that, with the exception of pH, all predicted concentrations in the two runs were reasonably close. The pH discrepancy may be explained by the extremely low pH value used in links 36 and 53 in the second run. With this exception, the model did converge to a similar solution from the two widely divergent starting conditions.

OPERATION OF THE MODEL

The Crandon Water Use Model is stored on the CH2M HILL computer system. Simulations can be made from either a CRT or hard copy computer terminal by executing the EXXON program. The model will then prompt the user for the required information.

The model is a complex program that requires some knowledge of the link/node configurations and water treatment processes. Before model runs are made, it is recommended that the user outline the configuration to be modeled on the link/node diagram and read the user manual.

OVERALL ASSESSMENT OF MODEL

The model has proven to be a valuable tool in the evaluation of water treatment options. It has been essential in evaluating the effects of treatment processes, climatic conditions, mill operation, and mine seepage on water qualities throughout the Crandon Mine/Mill facility. The model is structured to allow the user to create numerous link/node configurations and save them for future simulations. The ability to define categories and qualities of water enables the user to optimize treatment needs with water quality requirements. Reports generated by the model include an extensive executive summary describing all user variables in the run.

The model includes a number of error checks and diagnostic messages to assist the user. These error conditions check for excessive or negative flows, calcium sulfate scaling conditions in each link of the model, errors in the input data files and influent concentration limits for some treatment subroutines. When an error is encountered during a run, a message with the appropriate corrective action is displayed at the user's terminal.

The development of the Crandon Water Use Model is, to CH2M HILL's knowledge, the first attempt ever to predict water quality throughout an entire Mine/Mill water circuit. It is realistic to assume that both the quantity and quality of water in the full-scale mine/mill will be somewhat different than predicted by the model. To the maximum extent possible, CH2M HILL and Exxon have cross checked the predictions of Mill "effects" on water quality with testing results from a full-scale operating Mine/Mill complex (see Section XVI). The model matrices prepared for Crandon appear reasonable and realistic, but only after startup can the matrices be totally verified. Development and use of the model, however, resulted in an extremely thorough evaluation of options.

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Section IX
EFFLUENT REGULATIONS

INTRODUCTION

The location and method of discharge of treated effluent from the Crandon Project has not yet been determined. This issue is the subject of ongoing evaluations by Exxon staff.

Effluent regulations and/or standards may be different, depending on the location ultimately selected for the discharge. At the present time, two methods of effluent discharge are under consideration:

- o Discharge to groundwater
- o Discharge to surface water

To assess treatment requirements for the Crandon Project, it has been necessary to estimate effluent quality goals (potential standards) against which to judge the use of alternative water treatment technologies.

Under Wisconsin law, permits are required for discharge from point sources to waters of the state. Waters of the state include both surface waters and groundwater. Applicable discharge standards are determined by first considering whether any applicable new source performance standards exist for the point source categories applicable to the Crandon project. Secondly, the quality of the receiving water is analyzed to determine what level of effluent discharge it can carry in the vicinity of the discharge point and still maintain its designated water quality classification. As a general rule, the stricter of the two standards will be used in establishing the discharge limits. With respect to the Crandon Project, no applicable Federal or state new source performance standards currently exist.

NEW SOURCE PERFORMANCE STANDARDS

By statute, the state must adopt EPA established new source performance standards (NSPS) once the EPA adopts these. Where the EPA has failed to establish an NSPS, the state may adopt an NSPS: ". . . which shall reflect the greatest degree of effluent reduction achievable through the application of the best available demonstrated control technology processes, operating methods, or other alternatives. Where practicable, a standard of performance permitting no discharge of pollutants shall be adopted . . . When establishing or revising standards of performance under this section, the department

shall consider the cost of achieving such effluent reductions and the nonwater quality environmental impact and energy requirements of such reductions."

The EPA has promulgated final NSPS standards in the Friday, December 3, 1982, Federal Register:

§440.104 New Source Performance Standards (NSPS)

"...any new source subject to this subsection must achieve the following NSPS representing the degree of effluent reduction attainable by the application of the best available demonstrated technology (BADT):

(a) The concentration of pollutants discharged in mine drainage from mines that produce copper, lead, zinc,...bearing ores or any combination of these ores from open-pit or underground operations other than placer deposits shall not exceed:

Effluent characteristic	Effluent limitations	Average of daily values
	Maximum for any 1 day	for 30 consecutive days
	<u>Milligrams per liter</u>	
Cu	0.30	0.15
Zn	1.5	0.75
Pb	0.6	0.3
Hg	0.002	0.001
Cd	0.10	0.05
pH	*	*
TSS	30.0	20.0

*Within the range 6.0 to 9.0.

(b) (1) Except as provided in paragraph (b) (2), there shall be no discharge of process wastewater navigable waters from mills that use the froth-flotation process alone, or in conjunction with other processes, for the beneficiation of copper, lead, zinc,....ores or any combination of these ores.

(2) (i) In the event that the annual precipitation falling on the treatment facility and the drainage area contributing surface runoff to the treatment facility exceeds the annual evaporation, a volume of water equal to the

difference between annual precipitation falling on the treatment facility and the drainage area contributing surface runoff to the treatment facility and annual evaporation may be discharged subject to the limitations set forth in paragraph (a) of this section.

(ii) In the event there is a build up of contaminants in the recycle water which significantly interferes with the ore recovery process and this interference cannot be eliminated through appropriate treatment of the recycle water, the permitting authority may allow a discharge of process wastewater in an amount necessary to correct the interference problem after installation of appropriate treatment. This discharge shall be subject to the limitations of paragraph (a) of this section. The facility shall have the burden of demonstrating to the permitting authority that the discharge is necessary to eliminate interference in the ore recovery process and that the interference could not be eliminated through appropriate treatment of the recycle water..."

DISCHARGE TO SURFACE WATERS

For discharge into water bodies in the general vicinity of the Crandon Project, it can be reasonably assumed that discharge standards will be stricter than the New Source Performance Standards. The Wisconsin DNR will establish water quality related effluent standards for the Crandon Project by examining the effluent concentrations the receiving water can assimilate and still remain fishable and swimmable.

Wisconsin's Water Quality Standards for Surface Waters (NR 102) further states that "if it is determined that there is no reasonable relationship between the economic and social cost of achieving such limitation, . . . and the social and economic benefits to be obtained by achieving such water quality, variances from the . . . water quality criteria goal shall be provided."

The Water Quality Standards are also subject to an antidegradation policy which states: "No waters of the state shall be lowered in quality unless it has been affirmatively demonstrated to the Department that such a change is justified as a result of necessary economic and social development, provided that no new or increased effluent interferes with or becomes injurious to any assigned uses made of or presently possible in such waters." (NR 102.03)

To assist Exxon in evaluating treated water discharge alternatives, the Wisconsin DNR Water Quality Evaluation Section calculated preliminary effluent limitations for a discharge of treated water from the Crandon Project to Swamp Creek at County Highway "M." These preliminary limitations are set out in Table 5. The discussions with the DNR on the water quality standards are continuing. The surface water quality standards in Table 5 are preliminary.

DISCHARGE TO GROUNDWATER

If final effluent from the Crandon Project is discharged to groundwater, the provisions of Wisconsin's Metallic Mineral Mining regulations (NR 132) and the land disposal regulations (NR 214) would apply. It is believed that the DNR would, through the application of NR 132 and NR 214, adopt the NR 182 groundwater protection standards as discharge standards. The NR 182 groundwater protection standards are incorporated by reference in NR 132.

NR 182 requires that groundwater quality at the compliance boundary (generally 1,200 feet from the site or at the boundary of the property, whichever is closer) be maintained at a certain level. Water quality standards at the compliance boundary are a) primary or secondary drinking water standards, or b) background water quality, whichever is higher. The regulation also establishes the DNR's right to set additional standards for "substances toxic to humans" for which drinking water standards have not been established. Likewise, the primary and secondary drinking water standards can be lowered when necessary to protect public health, safety and welfare.

EFFLUENT GOALS

Table 5 summarizes several sets of standards which may be applicable to final effluent from the Crandon Project. Exxon instructed CH2M HILL to identify a water treatment system which will produce an effluent quality capable of meeting the most stringent of any of the identified potential effluent limitations that could be reasonably adopted by the state for the Crandon Project.

WASTEWATER TREATMENT FACILITIES REVIEW

Wisconsin regulations provide for submission of plans and specifications for any industrial wastewater facility (NR 108).¹⁶
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Table 5

POTENTIAL EFFLUENT LIMITATIONS/STANDARDS FOR THE
CRANDON PROJECT

POTENTIAL EFFLUENT LIMITATIONS/STANDARDS ¹			
<u>Compound</u>	<u>Proposed NSPS Standards (Mills and Mines)²</u>	<u>Primary & Secondary Drinking Water Standards³</u>	<u>Surface Water Quality Based Limitations⁴</u>
Chromium (+3)	--	--	0.09
Chromium (+6)	--	--	0.001
Chromium (Total)	--	0.05	--
Arsenic	--	0.05	0.09
Barium	--	1.0	11
Cadmium	0.05	0.01	0.0016
Lead	0.3	0.05	0.18
Mercury	0.001	0.002	0.0001
Selenium	--	0.01	0.08
Nitrate	--	10.0	--
Silver	--	0.05	0.0002
Fluoride	--	2.2	13.6
Chloride	--	250	1100
Copper	0.15	1	0.05
Iron	--	0.3	1.0
Manganese	--	0.05	--
Sulfate (SO ₄)	--	250	210
Zinc	0.75	5	0.31
pH	6-9	6.5-8.5	6-9
Cyanide	--	--	0.03
Total Dissolved Solids	--	500	2000
Total Suspended Solids	20	500	20

¹ All values except pH in mg/l.

² 30-day average values from EPA's NSPS standards.

³ NR182 requires that these standards be met in the groundwater at the "compliance boundary," not in the actual discharge.

⁴ Based on Preliminary Limits set forth in DNR letter to Exxon's Mr. Barry Hansen dated March 14, 1982, and subsequent discussions.

INTRODUCTION

Evaluation of water treatment alternatives for the Crandon Project involved a series of screening steps.

First, a list of available treatment technologies (unit operations) was prepared based on the needs of the Crandon Project. This preliminary assessment of technologies considered both existing and new, or developing, technologies. The goal of this technology assessment was to select several promising technologies for further consideration. This section of the report contains the preliminary assessment of wastewater treatment technologies.

Following the initial screening of technologies, extensive literature reviews were conducted to document the performance capabilities of each of the technologies selected for consideration. Information obtained in this literature review was used to prepare computer subroutines ("effect matrices") describing the performance capability of each technology. These effect matrices were then incorporated in the Crandon Project Water Use Model for evaluation of water management alternatives (see Section XI - PREPARATION OF EFFECT MATRICES, and APPENDIX A, Computer Model Effect Matrices).

After all computer effect matrices were prepared, computer modeling runs were completed to determine the performance capabilities of various treatment "trains" or "systems" comprised of the various treatment technologies. Computer projections of final effluent quality and estimates of system costs were then used to select a recommended water treatment system for the Crandon Project (see Section XIV - EVALUATION OF WATER TREATMENT ALTERNATIVES).

TECHNOLOGY ASSESSMENT

Figure 8 illustrates a brief overview of key features of the water treatment technologies evaluated in the preliminary screening process.

PROCESS TYPE AND DESCRIPTION	STATE OF DEVELOPMENT	CAPITAL COST	O&M COST	REMOVAL EFFICIENCY				EFFICIENCY				OVERALL EFFLUENT QUALITY	COMMENTS	
				TSS	ORGANICS	METALS	CYANIDE	SULFATE	THIO SALTS	NITRATE	PHOSPHATE			
PHYSICAL/CHEMICAL SEPARATION														
* FILTRATION	COMMERCIAL INSTALLATIONS	MODERATE	LOW	VERY HIGH	NIL	LOW (TSS REMOVAL)	NIL	NIL	NIL	NIL	NIL	NIL	VERY LOW TSS	SUSPENDED SOLIDS REMOVAL POLISHER
* TAILING PONDS	IN GENERAL USAGE	HIGH	VERY LOW	HIGH	LOW	LOW	NIL	NEGATIVE	LOW	NIL	NIL	NIL	UNSUITABLE FOR DISCHARGE	LARGE AREA REQUIREMENTS
* LIME PRECIPITATION	IN GENERAL USAGE	MODERATE	MODERATE	LOW	NIL	HIGH	NIL	NIL	NIL	NIL	NIL	NIL	LOW IN HEAVY METALS	MOST COMMONLY USED METHOD FOR HEAVY METAL REMOVAL
ELECTRO-FLOTATION	ONE MINING INSTALLATION - CLIMAX - 2000 GPM	HIGH	HIGH	LOW	NIL	HIGH	NIL	NIL	NIL	NIL	NIL	NIL	SIMILAR TO LIME PRECIPITATION	3% SOLIDS IN FLOAT
SULFIDE PRECIPITATION														
SODIUM	COMMERCIAL INSTALLATIONS (NO MINE - MILLING)	MODERATE	MODERATE	LOW	NIL	VERY HIGH	NIL	NIL	NIL	NIL	NIL	NIL	BETTER THAN LIME PRECIPITATION	POTENTIAL H ₂ S PROBLEMS
* IRON	COMMERCIAL INSTALLATIONS (NO MINE - MILLING)	MODERATE	MODERATE	LOW	NIL	VERY HIGH	NIL	NIL	NIL	NIL	NIL	NIL	BETTER THAN LIME PRECIPITATION	SULFEX PROCESS
BARIUM	BENCH SCALE	MODERATE	MODERATE	LOW	NIL	VERY HIGH	NIL	NIL	NIL	NIL	NIL	NIL	BETTER THAN LIME PRECIPITATION	BARIUM SULFIDE NOT READILY AVAILABLE
* CARBONATE PRECIPITATION	IN GENERAL USAGE	MODERATE	MODERATE	LOW	NIL	HIGH	NIL	NIL	NIL	NIL	NIL	NIL	LOW IN HEAVY METALS	SIMILAR TO LIME PRECIPITATION
IONIC FLOTATION	BENCH SCALE	UNKNOWN	UNKNOWN	NIL	NIL	HIGH	NIL	NIL	NIL	NIL	NIL	NIL	LOW IN HEAVY METALS	TIED-UP METALS ARE FLOATED
NAGAHM	COMMERCIAL FLOTATION PROCESS	UNKNOWN	UNKNOWN	HIGH	MODERATE	HIGH	LOW	UNKNOWN	UNKNOWN	NIL	NIL	NIL	HIGH CN	NOT SUITABLE FOR WASTEWATER TREATMENT
* COPRECIPITATION WITH TAILINGS	IN GENERAL USAGE	MODERATE	MODERATE	LOW	NIL	HIGH	NIL	NIL	NIL	NIL	NIL	NIL	LOW IN HEAVY METALS	THICKENER DESIGN WILL HAVE TO BE REVIEWED
SOLVENT EXTRACTION	THEORETICAL	UNKNOWN	UNKNOWN	LOW	HIGH	HIGH	LOW	LOW	LOW	LOW	LOW	LOW	POOR, FURTHER TREATMENT REQUIRED	PROBABLY BETTER SUITED TO MINERAL PROCESSING THAN WASTE TREATMENT
DAF	COMMERCIAL INSTALLATIONS	MODERATE	HIGH	VERY HIGH	UNKNOWN	LOW	NIL	NIL	NIL	NIL	NIL	NIL	FAIR	NO INSTALLATIONS FOR FROTHER REMOVAL
* FERRO CYANIDE PRECIPITATION		MODERATE	MODERATE	HIGH	NIL	NIL	HIGH	NIL	NIL	NIL	NIL	NIL	PRIMARYLY FOR CYANIDE REMOVAL	
ADSORPTION														
* CARBON (GRANULAR)	COMMERCIAL INSTALLATIONS	VERY HIGH	HIGH	HIGH	HIGH	HIGH	NIL	NIL	NIL	NIL	NIL	NIL	HIGH (IF PROPERLY PRETREATED)	CARBON REGENERATION FACILITY REQUIRED
POWDERED ACTIVATED CARBON	COMMERCIAL INSTALLATIONS	VARIABLES	HIGH/VERY HIGH	HIGH	HIGH	HIGH	NIL	NIL	NIL	NIL	NIL	NIL	HIGH	APPLICABILITY QUESTIONABLE
PEAT MOSS	VERY LIMITED	HIGH	HIGH	LOW	HIGH	HIGH	UNKNOWN	NIL	UNKNOWN	NIL	NIL	NIL	LOW IN HEAVY METALS	PEAT MOSS DISPOSAL SITE REQUIRED
STARCH XANTHATE	BENCH SCALE	MODERATE	MODERATE	LOW	NIL	HIGH	NIL	NIL	NIL	NIL	NIL	NIL	LOW IN HEAVY METALS	POTENTIAL BIOLOGICAL GROWTH
XANTHATED SAWDUST	BENCH SCALE	UNKNOWN	UNKNOWN	LOW	NIL	HIGH	NIL	NIL	NIL	NIL	NIL	NIL	LOW IN HEAVY METALS	POTENTIAL BIOLOGICAL GROWTH
CHEMICAL OXIDATION/REDUCTION														
* CHEMICAL OXIDATION	COMMERCIAL INSTALLATIONS	MODERATE	VERY HIGH	NIL	HIGH	LOW	HIGH	NEGATIVE	HIGH	NIL	NIL	NIL	LOW C.O.D.	ONLY PRACTICAL FOR POLISHING
* ALKALINE CHLORINATION	COMMERCIAL INSTALLATIONS	MODERATE	HIGH	LOW	HIGH	HIGH	VERY HIGH	NEGATIVE	HIGH	NIL	NIL	NIL	NO CN; HIGH pH	MOST COMMONLY USED METHOD FOR CYANIDE DESTRUCTION
* OZONATION	COMMERCIAL INSTALLATIONS (NO MINE - MILLING)	VERY HIGH	VERY HIGH	LOW	VERY HIGH	MODERATE	VERY HIGH	NEGATIVE	HIGH	NIL	NIL	NIL	LOW C.O.D.	ONLY PRACTICAL FOR POLISHING
CARO'S ACID	PILOT	MODERATE	VERY HIGH	MODERATE	VERY HIGH	LOW	UNKNOWN	NEGATIVE	HIGH	NIL	NIL	NIL	LOW C.O.D.	PERSULFURIC ACID (H ₂ SO ₅)
H ₂ S REDOX	COMMERCIAL INSTALLATIONS (NO MINE - MILLING)	MODERATE	MODERATE	NIL	NIL	MODERATE	NIL	UNKNOWN	HIGH	NIL	NIL	NIL	LOW IN THIO SALTS	PRODUCES ELEMENTAL SULFUR
* HYDROGEN PEROXIDE	COMMERCIAL INSTALLATIONS (NO MINE - MILLING)	VERY LOW	VERY HIGH	LOW	VERY HIGH	LOW	HIGH	NEGATIVE	HIGH	NIL	NIL	NIL	LOW C.O.D.	FACILITY EASILY ENLARGED
BIOLOGICAL TREATMENT														
OXIDATION PROCESSES	IN GENERAL USAGE	VARIABLES	HIGH	LOW	HIGH	LOW	MODERATE	NEGATIVE	HIGH	NIL	NIL	NIL	LOW OXYGEN DEMAND	ACTIVATED SLUDGE, HIGH PURITY OXYGEN ACTIVATED SLUDGE
* RECLAIM POND	IN GENERAL USAGE	HIGH	VERY LOW	MODERATE	MODERATE	NIL	NIL	NEGATIVE	HIGH	NIL	NIL	NIL	UNSUITABLE FOR DISCHARGE	SENSITIVE TO SEASONAL CHANGES
SULFATE REDUCTION	PILOT PLANT	UNKNOWN	UNKNOWN	NIL	MODERATE	NIL	NIL	HIGH	UNKNOWN	NIL	NIL	NIL	REDUCED SO ₄ LEVEL	ANAEROBIC PROCESS
AIR OXIDATION														
MECHANICAL AERATION (NO BIO ACTIVITY)	BENCH SCALE	MODERATE	LOW	NIL	NIL	NIL	NIL	NIL	LOW	NIL	NIL	NIL	VIRTUALLY UNCHANGED	INEFFECTIVE FOR MINE/MILL WASTEWATER
WET AIR OXIDATION														
ZIMPRO	COMMERCIAL INSTALLATIONS (NO MINE - MILLING)	VERY HIGH	VERY HIGH	HIGH	VERY HIGH	UNKNOWN	HIGH	NEGATIVE	VERY HIGH	NIL	NIL	NIL	LOW ORGANICS/THIO SALTS	HIGH HEATING COSTS
VTR	PILOT PLANT	HIGH	HIGH	HIGH	VERY HIGH	UNKNOWN	HIGH	NEGATIVE	VERY HIGH	NIL	NIL	NIL	LOW ORGANICS/THIO SALTS	EXPERIMENTAL PROCESS
DESALINIZATION/SULFATE REMOVAL														
* ION EXCHANGE (DESAL)	COMMERCIAL INSTALLATIONS	VERY HIGH	VERY HIGH	HIGH	NIL	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH TDS	LARGE VOLUMES OF SPENT REGENERANT
* REVERSE OSMOSIS	COMMERCIAL INSTALLATIONS	VERY HIGH	HIGH	VERY HIGH	VERY HIGH	HIGH	HIGH	VERY HIGH	HIGH	MODERATE	VERY HIGH	VERY LOW TDS	VERY LOW TDS	LIKELY SO ₄ FOULING
ELECTRODIALYSIS	PILOT PLANT	VERY HIGH	HIGH	NIL	HIGH	MODERATE	MODERATE	MODERATE	MODERATE	MODERATE	MODERATE	MODERATE	VERY LOW TDS	LIKELY SO ₄ FOULING
* VAPOR COMPRESSION EVAPORATION	COMMERCIAL INSTALLATIONS	HIGH	HIGH	VERY HIGH	LOW	VERY HIGH	VERY HIGH	VERY HIGH	VERY HIGH	VERY HIGH	VERY HIGH	VERY HIGH	VERY HIGH QUALITY	HIGH TDS BRINE PRODUCED
* SODIUM ALUMINATE	BENCH SCALE	HIGH	HIGH	LOW	NIL	HIGH	NIL	HIGH	UNKNOWN	NIL	NIL	NIL	HIGH TDS	PRESENCE OF Fe DEPRESSES SO ₄ REMOVAL
FLYASH TREATMENT	THEORETICAL	MODERATE	MODERATE	LOW	NIL	HIGH	NIL	UNKNOWN	NIL	NIL	NIL	NIL	LOW IN HEAVY METALS	UNTESTED, UNPROVEN
* ION EXCHANGE (CATION/Ca REMOVAL)	COMMERCIAL INSTALLATIONS	VERY HIGH	VERY HIGH	HIGH	NIL	HIGH	NIL	NIL	NIL	NIL	NIL	NIL	LOW IN ALL CATIONS	LARGE VOLUMES OF SPENT REGENERANT
DISPOSAL METHODS														
SOLAR EVAPORATION	COMMONLY PRACTICED IN ARID REGIONS	LOW	VERY LOW	—	—	—	—	—	—	—	—	—	CONTAMINANTS CONCENTRATED IN BRINE, NO EFFLUENT	NOT FEASIBLE AT CRANDON
DEEP WELL INJECTION	WIDELY PRACTICED IN SOME AREAS	MODERATE	LOW	—	—	—	—	—	—	—	—	—	UNCHANGED, DISCHARGE TO GROUND	PROBABLY UNACCEPTABLE IN WISCONSIN
OTHER														
* PH ADJUSTMENT	IN GENERAL USAGE	LOW	MODERATE	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NEUTRAL pH	OFTEN USED IN CONJUNCTION WITH OTHER TREATMENT PROCESSES
NATURAL BIOLOGICAL SYSTEMS	IN USAGE	LOW	LOW	LOW	LOW	HIGH	NIL	NIL	LOW	NIL	NIL	NIL	LOW IN HEAVY METALS	ALGAE, CATTAILS, WATER HYACINTHS - NOT PRACTICAL FOR YEAR-ROUND USE AT CRANDON

* RECOMMENDED FOR IN-DEPTH EVALUATION

FIGURE 8

EXXON MINERALS COMPANY			
CRANDON PROJECT			
TITLE ASSESSMENT OF TREATMENT METHODS AND TECHNOLOGIES			
SCALE NONE	STATE WISCONSIN	COUNTY FOREST	
DESIGNED BY M.J.L.	DATE	CHECKED BY	DATE
APPROVED BY M.R.H.	DATE	APPROVED BY	DATE
APPROVED BY	DATE	EXXON	DATE
EXXON INC.			
DRAWING NO. 051-7-L-004			SHEET OF



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The following paragraphs describe general features of each technology and describe the rationale for selection or rejection of the technology from further consideration.

Physical/Chemical Separation

Filtration. Passing water through a finely divided barrier such as a screen, cloth, or sand or gravel bed will reduce suspended solids concentrations. In treating mine/mill waters, this unit operation would normally follow chemical precipitation treatment processes and/or precede treatment processes that are adversely affected by even moderate concentrations of suspended solids.

Filtration is a common, state-of-the-art treatment process which would be required as a pretreatment step upstream from a reverse osmosis system or required as an effluent polishing step in most land disposal options. It may not be needed in some zero discharge scenarios.

A filtration effect matrix was developed in CH2M HILL's Phase II study and was retained for use in the current study.

Tailings Pond. This type of facility is the most common treatment used in the ore mining and dressing industry today. The primary function of a tailings pond is for suspended solids removal, requiring retention time and quiescent conditions conducive to settling. In most cases, the pond provides perpetual storage for the materials settled from the water. If properly designed, and if retention time and surface area are sufficient, a tailings pond may also effect, to some degree, the stabilization of oxidizable constituents in the tailings water.

Suspended solids concentrations in tailings pond effluents have been reported in the range of 10 to 30 mg/l.

An effect matrix for the Tailings Pond was developed in Phase II and was retained for use in the current study.

To reduce land requirements, tailings can be thickened prior to placement in the pond. An effect matrix was developed in this study for a Tailings Impoundment area which receives thickened tailings.

Lime Precipitation. Use of lime to form insoluble metal hydroxides is considered state-of-the-art treatment¹⁴ for

metals removal in the mining and ore dressing industry. Concentrations of metals actually attainable are a function of lime dosage, operating pH, the presence of complexing agents, such as ammonia and organics, and the means used to remove the insoluble metal hydroxides from the water. A lime precipitation effect matrix was prepared during the Phase II study and was retained for use in the current study.

Electro-Flotation. Electro-flotation is a metals removal process in which lime and polymer are added while passing an electrical current through the water. Gas bubbles which are formed attach to and carry insoluble metal hydroxides to the surface where they are collected. Partial destruction of cyanide is also achievable. Total metals removal is on the order of that produced with conventional lime precipitation, while capital and operating costs are significantly higher. A 2,000-gpm facility is in operation in Colorado on excess water from a tailings impoundment facility.

The effluent water quality from an electro-flotation treatment system is similar to that from a lime precipitation system but with the distinct disadvantage of very high electrical power costs. An effect matrix was developed in Phase II, but was eliminated from consideration during the current study.

Sulfide Precipitation. Almost all metal sulfides are less soluble than metal hydroxides. The use of sulfide ion as a precipitant for removal of heavy metals can, therefore, accomplish more complete removal than the use of hydroxide for precipitation. Although sulfide precipitation is widely used for metals removal from high-strength wastewater in the inorganic chemical industry, it is not presently employed in the mining and ore dressing industry.

Various sulfide compounds can be used as the sulfide source. The use of sodium sulfide (Na_2S) requires precise control; if too little is added, all the metal will not precipitate. If too much is added, H_2S gas may be generated.

The Sulfex Process, developed by Permutit, claims to overcome this control requirement by using iron sulfide to provide the sulfide ion. Sufficient iron sulfide is added to convert all of the heavy metals present to metal sulfides. Excess iron sulfide precipitates. By maintaining pH in the 8 to 9 range, excess iron in the system will precipitate as iron hydroxide. The Sulfex Process is, however, generally

less cost-effective than lime precipitation when total influent metal concentrations exceed 50 mg/l.

Barium sulfide (BaS) can also be used for sulfide precipitation. Its advantage is that barium will not persist in the treated water, being completely precipitated as BaSO_4 .

The performance of all three systems discussed above would be similar, but operating data from Sulfex installations is more readily available.

An effect matrix for the Sulfex process was developed in Phase II and was retained for use in the current study.

Carbonate Precipitation. Another process for heavy metal removal by chemical precipitation involves the use of soda ash (Na_2CO_3) to form insoluble metal carbonates. As with hydroxide and sulfide precipitation, solubilities of the metallic salts vary with pH.

This process provides about the same removal rates as lime precipitation for heavy metals. However, in waters with potential for CaCO_3 or CaSO_4 scaling, the process has merit since it also removes calcium as CaCO_3 .

Carbonate precipitation is commonly used as the second stage in lime-soda softening of drinking water supplies. This technology could be applicable for the treatment of selected brine streams, mill recycle water, or as a pretreatment step for other unit processes.

This technology was evaluated in Phase II and dropped from consideration. After more extensive review in the current study, however, an effect matrix was developed for this technology.

Ionic Flotation. Ionic flotation is a metals removal process in which a collector ion is used to react with an ionic form of the metal to be removed. The resulting compound is then air floated. Primary aliphatic amines are often used as collectors.

Bench-scale tests indicate the potential suitability of this process for removing/recovering tungsten, molybdenum, and uranium compounds from mine and tailings water. The majority of research appears to have been performed in Russia. Removal efficiencies are highly dependent on solution pH and the specific collector used. The process

does not appear attractive for treating waste streams containing numerous heavy metals because specific collector reagents are required for each metal to be removed.

Ionic flotation was reviewed and dropped from consideration.

Nagahm Process. A proprietary flotation process developed by Mitsui Mining and Smelting Company of Japan uses Ion-Precipitate-Ultrafine-Particle flotation (I.P.U. flotation) and Nagahm flotation machines to treat thickener overflow for reuse in the Pb-Zn differential flotation circuit. The process removes Cyanocopper complexes, ZnS, CdS, xanthate, and frother from the thickener water, rendering it suitable for reuse. Developers of the process claim improved mill recovery in the Pb-Zn circuit, additional recovery of copper, zinc, and cadmium from the thickener overflow, and reduction in reagent usage.

Nagahm flotation machines will remove a small fraction of the CN⁻ in the thickener overflow. Typical residual concentrations are in the range of 30 ppm or higher. Although this process could, in certain cases, have merit, it does not appear suitable as a water treatment technology.

Coprecipitation with Tailings. It has been demonstrated^{14,15} that mill tailings are able to enhance metal removal efficiencies at high pH. Many mine/mill operations currently add lime to their tailings thickeners for metals control. For some constituents, this type of treatment will remove metals to a concentration below that of a lime precipitation system operated at the same pH.

The proposed flowsheet for the Crandon Project includes thickening of tailings prior to disposal in a tailings impoundment. Since the tailings streams exit the mill at an alkaline pH, only minor modifications would be necessary to convert the tailings thickeners into modified "lime-precipitation" reactors. An effect matrix was prepared for the tailings thickeners, which are modeled in a similar fashion as a lime precipitation process.

Solvent Extraction. This technique is widely used for the separation and/or concentration of high concentrations of metallic and nonmetallic species in the mineral processing industry. Theoretically, this technology should be applicable to the removal of low levels of soluble metals from waste streams. However, the process has not been developed to the point of identifying optimum reagents or required

pretreatment. Post treatment to reduce effluent organic levels would likely be required also. This process was dropped from further consideration because of its limited development and lack of application as a water treatment process.

Dissolved Air Flotation (DAF). This process is commonly used to float solid particles by attaching air bubbles to the surface of the particles. The influent water is supersaturated with air under pressure. When the pressure is released, small bubbles are formed which then attach to the solids and cause them to rise to the surface.

This process was not selected for modeling primarily because it is not particularly applicable to metals removal processes. All of the chemical precipitation systems considered normally use gravity sedimentation as a solids/liquid separation technique.

Ferrocyanide Precipitation. Free cyanides in solution can be precipitated by adding ferrous and ferric salts to form an insoluble iron-cyanide complex. One form of the complex is commonly referred to as Prussian Blue $[\text{Fe}_4(\text{Fe}(\text{CN})_6)_3 \cdot 10\text{H}_2\text{O}]$.

The process has only been demonstrated on a bench-scale level and has not been used to treat complexed cyanides. The treatment would be an experimental one, but it does represent a potential cyanide treatment technology. An effect matrix was developed for this technology.

Adsorption

Carbon Adsorption (granular). Activated carbon has found widespread application in the treatment of drinking water, domestic wastewater, and a few industrial waste streams. It is usually applied after conventional treatment as a polishing operation for removal of trace concentrations of residual organics. Incidental removals of trace concentrations of heavy metals have been reported. Many organic compounds, such as phenolics, aromatics, surfactants, and chlorinated hydrocarbons are readily adsorbed on the surface of activated carbon. In addition, certain heavy metals such as cadmium, chromium, copper, nickel, lead, and zinc can be partially removed from water with carbon. The removal mechanism for metals is thought to involve both adsorption and filtration within the carbon bed. It is not known whether adsorbed metals can be

effectively removed during carbon regeneration, so use of this technology for metals removal would be considered experimental.

An effect matrix for carbon adsorption was developed in the Phase II study, and was retained for use in the current study.

Powdered Activated Carbon. The use of powdered activated carbon for adsorption of trace organic pollutants has been a well documented treatment technology for a number of years, both in raw water treatment (PAC) and wastewater treatment (PACT). The Powdered Activated Carbon Treatment (PACT) system has been marketed for several years as a method to protect biological treatment systems from toxic organic upsets and, further, as a method to enhance removal of certain organic compounds. The PAC or PACT processes do not appear to be as attractive as other treatment technologies available for the Crandon Project. The following are foreseen drawbacks:

1. With the PAC or PACT process, carbon is in contact with lower concentrations of organics than with conventional carbon columns.
2. With the PAC or PACT process, carbon is not normally recovered or regenerated. Carbon costs would be very high if this were the primary method used for organics removal. (Assuming, for comparative purposes, that granular carbon can be regenerated.)
3. The effect matrix for PAC or PACT would be essentially identical with "carbon adsorption." If carbon adsorption is ultimately incorporated into a treatment system, further work could be done to evaluate PAC or PACT.

Some permutation of the PAC or PACT process could be used as a "standby" measure to remove organics, but no further consideration is recommended at this time.

Peat Moss Adsorption/Filtration. A patented process utilizing the adsorptive and filtrative properties of peat moss to remove trace concentrations of heavy metals from wastewater has been developed in Canada and is currently being marketed in the United States. Peat moss possesses a strong affinity for soluble metals and insoluble metallic sulfides and hydroxides. Its low capacity makes it best suited as a

polishing treatment after lime or sulfide precipitation. Regeneration of saturated peat moss is not practical. One United States installation is treating a photo processing waste in New York. No operating data is available.

Disposal of depleted mass would be a solid waste disposal problem which would have to be addressed if this technology were to be used.

The technology was reviewed and dropped from consideration because of its limited state of development.

Starch Xanthate Treatment. Modified corn starch has the ability to adsorb trace concentrations of heavy metals from wastewater. Bench-scale evaluations indicate that very low concentrations of residual heavy metals are achievable. Removals can be further enhanced by using cationic polymers in conjunction with the starch xanthate. Treatment consists of mixing the xanthate in the waste stream followed by settling and separation. Required contact time is dependent on initial metal concentrations and required removals.

Although this treatment would remove dissolved heavy metals, it would not remove calcium or sulfate. This process would add organics to the wastewater, potentially necessitating further treatment for organics removal. In addition, the technology has not been demonstrated in a full-scale wastewater treatment system. This technology was dropped from consideration because of its limited state of development.

Xanthated Sawdust. Research conducted by the United States Bureau of Mines indicates that xanthated sawdust, like starch xanthate, has the capacity to adsorb heavy metals from wastewaters. This adsorbent is prepared by treating sawdust with aqueous NaOH and CS₂, followed by filtering, washing, and air-drying. Bench-scale laboratory tests in which metal-bearing waters were passed through columns of xanthated sawdust indicate preference for heavy metals over the more common lighter metals, such as Na, K, Mg, and Ca. Metals can be desorbed with complexing agents such as sodium cyanide or sodium-EDTA salt.

This treatment was dropped from further consideration because of its limited development and, further, because of concerns about introducing organic material into the wastewater.

Chemical Oxidation/Reduction

Alkaline Chlorination. Alkaline chlorination is the most frequently employed technology for the destruction of cyanide. In this process, free cyanide (CN^-) is oxidized to cyanate (CNO^-) and ultimately to CO_2 and N_2 . Destruction of metal-cyanide complexes is accomplished by oxidation of the complexed anion to form the metal cation and free cyanide. Chlorine or hypochlorite is used as the oxidant. Typically, rapid chlorination at a pH above 10 and, at least, 15-minute contact time are required to drive the reactions to completion. The degree of oxidation is, in part, dependent on the form of cyanide present in the wastewater. Nickel cyanide complexes are only partially oxidized and iron cyanide complexes are unaffected by chlorine oxidation. Thus, the specific forms of cyanide must be determined before this treatment is selected. It should be noted that chlorine will preferentially react with thiosalts before cyanide, which could significantly increase chlorine requirements.

The most important disadvantage of this technology is the residual chloride ion donated to the water stream. For example, oxidation of one mole of cyanide ion to carbon dioxide and nitrogen would add 5 moles of chloride ion to the solution.

This technology has been demonstrated in full-scale systems treating mining wastewaters. An effect matrix was prepared for alkaline chlorination during Phase II and was retained for use in the current study.

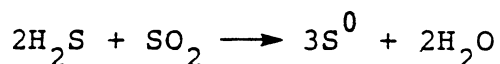
Ozonation. Another chemical oxidation process suitable for cyanide destruction, thiosulfate destruction, and the removal of some COD-producing compounds is ozonation. Although more expensive than alkaline chlorination, it is especially well suited to the treatment of high-volume, relatively low-cyanide concentration waste streams.

Recent developments in ozone generating equipment have reduced the operating costs of ozonation to near that of other chemical oxidants, but capital costs associated with an ozonation system are very high.

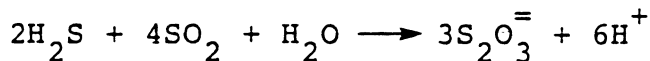
An effect matrix was prepared for ozonation during Phase II and was retained for use in the current study.

Caro's Acid. Caro's acid (H_2SO_5), also known as persulfuric acid, is a strong oxidant which theoretically could be used to destroy thiosulfate, COD, and cyanide. Its usage requires special handling and storage provisions, however. A disadvantage to its use at the Crandon Project is the fact that the acid, in addition to forming sulfate in the oxidation of thiosulfate ($\text{S}_2\text{O}_3^{=}$), will itself contribute sulfate to the waste stream. For these reasons, and because of its undeveloped nature, this treatment was dropped from further consideration.

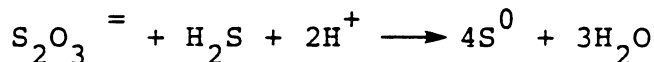
Hydrogen Sulfide Redox. H_2S is frequently used to reduce SO_2 to elemental sulfur by the Claus reaction:



Actually, the reaction proceeds in two steps with the first step producing various thiosalts and thiosulfate:



Hydrogen sulfide then reacts with polythionates and thio-sulfate to form elemental sulfur:



The sulfur is removed from suspension by air flotation and the froth is partially dewatered using a vacuum filter.

A commercial plant using this technology for removal of SO_2 from stack gas was completed in October 1979, through a joint venture between the U.S. EPA, the U.S. Bureau of Mines and industry. The working solution has a concentration of about one mole percent $\text{S}_2\text{O}_3^{=}$ (30,000 mg/l), much stronger than would be expected in a mine/milling complex. It is unknown whether the process would work as well with lower concentrations of thiosalts. This process was dropped from further consideration because other, more proven, methods are available.

Hydrogen Peroxide. H_2O_2 is a strong oxidizer which can be used to treat waste streams containing cyanide and thio-sulfate. Some organic oxidation is also possible. The process has been demonstrated on a pilot-scale at several mine/mill installations. It has relatively high operating costs but capital investment is minimal as only a storage tank, mixing reactor and delivery system would be required.

Hydrogen peroxide operates best at an alkaline pH and the reaction rate is sensitive to catalysts such as copper, formaldehyde and UV light. Cyanide complexes, however, are typically oxidized only to cyanate (CNO). Iron cyanide complexes and thiocyanates are not oxidized by hydrogen peroxide.

An effect matrix was prepared for H_2O_2 oxidation for use in this study.

Biological Treatment

High Rate Biological Treatment. Suspended or attached microbial cultures can be used to oxidize thiosulfates and organic reagents used in the mill. Oxygen requirements can be met by transferring air into the water using mechanical aerators, dispersed air injection or pure oxygen treatment.

This type of process is quite common for treatment of sanitary wastewaters and a large number of industrial waste streams. It has also been recognized within the mining industry that similar types of biological reaction can occur in a reclaim or tailings pond.

During the past several years, a great deal of research has been conducted by the Canadian mining industry on the biological oxidation of thiosalts. To date, this research has all been bench- and pilot-scale. Research has centered on the use of Rotating Biological Contactors (RBC), aerated lagoons, activated sludge, rock packed towers, or lagoons.

All of the tests indicate that thiosalts can be effectively removed in a biological treatment system and that, in general, rock packed towers or lagoons achieve higher reaction rates than conventional aeration tanks.

Despite the promising research efforts, there are several significant drawbacks and/or unknowns to biological oxidation of thiosalts which impact its immediate consideration for the Crandon Project.

1. Research to date has centered on thiosalt removal rates. Very little work has been done on solids-liquid separation techniques to remove biomass from the treated effluent.
2. The literature does not describe any test results indicating required "recovery time" of such systems from process upsets.

3. Researchers uniformly agree that, at low temperatures (less than about 6 to 10°C) reaction rates fall drastically.
4. In a December 1979 report, Noranda indicated that, in bench-scale tests, colloidal sulphur deposited on the packing of both packed rock and polyurethane reactors and columns. This deposition of solids could prove disastrous in a full-scale system if plugging or short circuiting occurred. This phenomena could make an "open" lagoon (i.e., a Reclaim Pond) much more attractive.
5. Both phosphorus and nitrogen addition systems are necessary to provide nutrients for biological growth.
6. Data obtained to date does not adequately define oxygen requirements and/or optimum dissolved oxygen concentrations required for the process, especially with regard to oxygen requirements and biological reaction rates for organics removal.
7. Data between researchers conflicts, in some cases, regarding the necessity of dissolved ferrous iron for successful thiosalt oxidation.
8. Researchers agree that CO₂ enhances the oxidation of thiosalts, but precise definition of required addition rates are not yet available.

Available data indicates that biological thiosalt oxidation may someday prove to be an effective technology for removal of organics and thiosalts from mining and milling wastewaters. The technology, however, has not been developed to the point that it could be permittable without a standby physical-chemical treatment system for thiosalt removal during process upsets and/or winter months. Any full-scale design based on available data would be subject to a number of gross assumptions and would potentially require extensive modifications after construction and startup. Use of a conventional "Reclaim Pond" is recommended for organic and thiosalt oxidation at the Crandon Project, but an effect matrix for biological oxidation was prepared for consideration in this study.

Reclaim Pond. The effectiveness of reclaim or retention ponds for reducing suspended solids, organics, and thiosalt concentrations in decant water from tailings ponds has been

widely demonstrated. These reductions are attributable to the combined effects of evaporation, oxidation from natural aeration, biological oxidation, photo-decomposition, and extended quiescent settling. Oxidation rates are, however, somewhat reduced during winter months. A reclaim pond also provides surge volume for normal fluctuations in water use in the Mill and for seasonal variations in precipitation over the Tailings and Reclaim Ponds.

Reaction rates in a reclaim pond are slow and require residence times of 30 or more days to stabilize mine/mill wastewaters. Ice cover during the winter months retards normal oxidation mechanisms resulting in increased organic and thiosulfate concentrations in the pond effluent. Reclaim or retention ponds have been demonstrated in both cold and warm climates as state-of-the-art technology in mine/mill installations to reliably treat water for disposal and reuse. It is recommended that a reclaim pond be used at the Crandon Project because of proven track records and low operating cost.

Biological Reduction of Sulfate. Biological reduction of sulfate has been demonstrated on pilot-scale. Treatment consists of a two-stage anaerobic process in which SO_4 is first reduced to sulfide by the organism Desulfovibrio desulfuricans. The sulfide is then reoxidized to elemental sulfur by the photosynthetic bacteria Chlorobium thiosulfatophilum. Conversion of sulfate to sulfur is highly dependent on pH, concentration stability, and substrate availability. Optimum means of physically separating the final sulfur product from the living bacterial culture has not been developed. Sulfate reductions naturally occur in some anaerobic sections of ponds. However, to design and reliably operate this type of system would require extensive pilot testing. Because of the experimental nature of the technology, it was dropped from further consideration.

Mechanical Aeration (No Biological Activity). In some cases, COD can be partially oxidized in waste streams by vigorous contact with air. The equipment used for mechanical aeration is thoroughly tested and transport rates are well documented. Oxidation of thiosalts by contact with air has been attempted in bench-scale equipment and has not been demonstrated to be effective. For this reason, mechanical aeration without biological activity was not considered further in this study.

Wet Air Oxidation - Zimpro. Zimpro has marketed a wet air oxidation process for a number of years, primarily for the treatment of high strength organic wastes. In a wet air oxidation system, wastewater is subjected to high oxygen concentrations, high temperature, and high pressure, thereby oxidizing (combusting) organic materials. If a thiosalt bearing stream were to be subjected to the same conditions, thiosalts would be rapidly converted to sulfates. The Zimpro process has been largely restricted to high strength organic wastes because the heat of combustion of organics reduces the heating requirements necessary to raise the temperature of the wastewater. Even with an efficient heat transfer system (say a 20°F approach between influent and effluent) heating costs could be substantial if the Zimpro process were applied to a milling wastewater. To heat 500 gpm by 20°F for example, would require approximately 120×10^6 BTU/day (approximately \$400/day in fuel costs). Although wet air oxidation is undoubtedly a high cost treatment option, it offers the potential benefit of both thiosalt and organic removals and could probably be made to work regardless of climatic conditions. This technology would be considered only as a last resort. An effect matrix was not prepared for modeling purposes.

Two other types of air oxidized thiosulfate treatments were briefly reviewed. These included a copper-catalyzed air oxidation process and a alkaline oxidation at high temperature and pressure process (autoclave oxidation). Both of these methods have been demonstrated in the laboratory as technically feasible but no full-scale installations have been built. They were dropped from consideration because of their limited development.

Vertical Tube Reactor (VTR). The Vertical Tube Reactor Corporation, headquartered in Englewood, Colorado, markets a new and innovative treatment technology known as the Vertical Tube Reactor (VTR). The VTR system is also a wet air oxidation process. A wastewater and air mixture is pumped down the central shaft of a deep well (as deep as 5,000 to 6,000 feet). Organic materials in the wastewater combust at high temperatures (650°F±) and pressure (1,800 psig±) to form inert ash. The manufacturer reports that dissolved metals will form metal oxides in the reactors as well. Effluent rises through the annular area between the reactor shaft and the downcomer. Solids (ash and metal oxides) are removed from the effluent in a conventional dissolved air flotation unit.

The VTR is still in the development stage. One pilot scale unit has been operated on municipal primary and biological sludge but no full-scale units have been designed or constructed. Although this technology potentially holds future promise as a technology for both metals and organics removal, it was dropped from further consideration because no full-scale units have ever been designed or built, corrosion and/or scaling could cause severe problems with this system, and it is unproven technology.

Desalinization/Sulfate Removal

Ion Exchange for Anion Removal (DESAL). Ion exchange resins are in common use for the removal of undesired constituents from water. Ion exchange (IX), resins have been developed for the preferential removal of both cations and anions. Performance of these IX resins is dependent on pH, temperature and the concentration of the components to be removed. Pretreatment or preconditioning of waste streams is often required to ensure satisfactory operation.

Regeneration of the resin is periodically required and large quantities of spent regenerant can be produced.

Sulfate control has been identified as an important requirement to maximize water recycle at the Crandon Project. Rohm and Haas has developed an ion exchange system, DESAL, which can remove sulfates from water by exchanging them for bicarbonates. This process has been demonstrated in full-scale on brackish waters and in pilot-scale on acid mine drainage. The resin has a very high regeneration efficiency which results in a low volume high strength regenerant stream. Recovery of the ammonia regenerant is also possible.

The DESAL process has been demonstrated in full-scale system, addresses a key wastewater problem and, therefore, should be considered for the Crandon Project. An effect matrix for "Ion Exchange for Anion Removal" was developed for use in this study.

Reverse Osmosis (RO). This process involves the application of an external pressure to a solution in contact with a semipermeable membrane. The pressure forces water through the membrane and rejects soluble and insoluble solution constituents. In most instances, extensive pretreatment and conditioning for pH, temperature, and TSS is required for successful RO operation. RO membranes may be fouled if the concentration of scale forming compounds in the brine

streams exceed their solubility. Care must be exercised to ensure that the concentrations of CaSO_4 , CaCO_3 , BaSO_4 , and similar scale forming compounds do not exceed their solubility. This consideration usually dictates the degree of concentration achievable in the brine or reject stream. Other potential problems with RO membranes are fouling with iron or with organic growths, further emphasizing the need for effective pretreatment.

Although calcium sulfate scaling may limit the brine stream flow rate, RO represents a proven process to produce high quality water. An effect matrix was developed in Phase II and was retained for use in this current study.

Electrodialysis. This technology employs a combination of semipermeable membranes to separate soluble impurities from water, and an electrical field to provide a driving force for ion migration through the membranes. The concentration limitations and pretreatment requirements associated with reverse osmosis are also applicable to electrodialysis. Suitability of this process for mining/milling wastewater has not been demonstrated, however, and this treatment was dropped from further consideration.

Vapor Compression Evaporation (VCE). This treatment process produces a concentrated brine stream and a clean condensate suitable for reuse and/or discharge. This is the only system considered that produces an effluent with sufficient purity to offset/replace critical fresh water uses and which, further, can reduce the brine reject stream to a low volume, high concentration stream that can be economically disposed of. Fuel economy is achieved by using compressed evaporator product steam to vaporize evaporator contents. (Other types of evaporators are available, but a VCE is believed to be most appropriate to the needs of the Crandon Project.) An effect matrix for this technology was developed in Phase II and was retained for use in this current study.

Sodium Aluminate Precipitation. Both calcium and sulfate concentrations in wastewater can be reduced through treatment with sodium aluminate and lime. In this process, a calcium sulfoaluminate precipitate is formed which is then removed as a sludge. This treatment has only been demonstrated on a bench-scale level. Limited data available indicates that sulfate removal is highly sensitive to the molar ratios of aluminum, calcium, and sulfate maintained in the reactor.

Although reagents are much more costly than for a lime precipitation system, this technology can remove calcium sulfate and dissolved metals. An effect matrix for this technology was developed in Phase II and was retained for use in this current study.

Fly Ash Treatment. Fly ash from coal fired power plants contains significant quantities of aluminates which could potentially be used as a reagent substitute in the sodium aluminate precipitation treatment system. Research in the utilization of fly ash has demonstrated that the reactions that occur when lime is added to fly ash are very similar to those in the sodium aluminate precipitation process.

In addition to aluminates, however, fly ash contains significant quantities of sulfates that would be leached into solution unless they are stabilized by large quantities (up to 30 percent by weight) of lime. In addition, there is no clear evidence demonstrating, that even after stabilization, additional reactive aluminates are available. For these reasons, the use of fly ash as a substitute reagent for the experimental sodium aluminate precipitation process was dropped from further consideration.

Ion Exchange (Cation/Calcium Removal). Ion exchange resins have been developed that will remove all or portions of cations in solution. Typically they operate by exchanging a H⁺ (hydrogen form resins) or Na⁺ (sodium form resins) ion for the cation being removed. After the resin has been exhausted, the resin must be regenerated with either a strong acid or a saturated sodium chloride solution. Ion exchange systems have been used in numerous industrial applications including treating water from a mine/mill operation but the vast majority of ion exchange systems are used as a "polishing" process to remove low residual concentrations of contaminants.

Ion exchange is a proven technology for cation removal and could be effective as a single treatment unit or as a pre-treatment step for a reverse osmosis system. Effect matrices were prepared for both a hydrogen form resin for complete cation removal and for a sodium form resin for calcium removal.

Disposal Methods

Solar Evaporation. Many mining and milling operations in the western and southwestern United States use solar

evaporation as a principal means of water treatment and sludge/brine disposal. This process is not applicable in the Crandon area because of the excess of average annual rainfall over average annual evaporation (30.77 inches rainfall versus 23.36 inches evaporation). This technology is not feasible for the site and was dropped from consideration.

Deep Well Injection. This is a disposal method rather than a treatment process. It requires little land, eliminates the surface discharge of wastes, and has moderate capital and operating costs. However, its applicability is limited by geological factors, pretreatment is frequently required to prevent clogging of the disposal aquifer, and there is potential for contamination of ground and surface waters by the injected wastes. Deep well injection is not considered feasible in the northern Wisconsin area and was dropped from consideration as a disposal option.

Other Methods

pH Adjustment. This is the most common chemical treatment practiced in the mining and milling industry today. The pH adjustment of a waste stream will influence the form of suspended and dissolved constituents in the water. This treatment is often the initial stage of a larger treatment process which utilizes this modified behavior to remove, change, or destroy certain constituents in the water. pH adjustment, with acid or caustic, is also often used as a final treatment just prior to discharge to bring the effluent to within permit pH limitations. Two pH adjustment effect matrices (H_2SO_4 , CO_2) were developed in Phase II and were retained for use in this study. In addition a third matrix, pH adjustment with lime, was developed for use in this study.

Natural Biological Systems. Use of natural biological systems (water hyacinths, cattails, etc.) for organic removal has been demonstrated in several southern locales. Some installations also report that uptake of heavy metals has been observed in such systems. The climate at the Crandon Project, however, is believed to be too cold to permit effective year-round treatment with this kind of treatment system, so it was dropped from consideration.

SUMMARY

The following water treatment technologies were judged to be potentially applicable to the needs of the Crandon Project and were retained for further consideration:

- o Filtration
- o Tailings Pond
- o Lime Precipitation
- o Sulfide Precipitation
- o Carbonate Precipitation
- o Coprecipitation with Tailings (Tailings Thickener)
- o Ferrocyanide Precipitation
- o Carbon Adsorption
- o Alkaline Chlorination
- o Ozonation
- o Hydrogen Peroxide Oxidation
- o Biological Oxidation
- o Reclaim Pond
- o Ion Exchange for Anion Removal
- o Reverse Osmosis
- o Vapor Compression Evaporation
- o Sodium Aluminate Precipitation
- o Ion Exchange for Calcium Removal
- o Ion Exchange for Cation Removal
- o pH Adjustment with H_2SO_4
- o pH Adjustment with CO_2
- o pH Adjustment with $Ca(OH)_2$

GLT53/20

■ ■ Section XI
■ ■ PREPARATION OF MODEL EFFECT MATRICES

INTRODUCTION

Each node in the Crandon Water Use Model represents an "effect matrix" (e.g., computer subroutine). The purpose of an effect matrix is to compute the water quality in the link or links exiting each node. The model contains numerous mill "process" nodes which are described by separate effect matrices. In addition, there are 22 treatment system effect matrices which can be inserted into any of 27 special treatment nodes. The effect matrices range in complexity from the relatively simple summer/splitter routines to the complex mill effect matrix. All of the effect matrices used in the model were developed by CH2M HILL and Exxon specifically for the Crandon Project. Figures 9 through 13 summarize the effect of each subroutine on water quality.

This section includes a brief discussion of how the matrices were developed and their effects on water quality. For a detailed description of each effect matrix and the data sources used, refer to Appendix A.

MILL

When the model is run, one of the first user inputs is the decision to model Early or Mature operations. These two mill operating modes required the development of two effect matrices: Early operation for processing massive ore only and Mature operation for processing a 55-percent massive, 45-percent stringer ore blend. Both effect matrices were developed from Exxon's Phase I pilot plant results.

The mill and the associated flotation circuits are, perhaps, the most important processes affecting water quality. They are also the most difficult and complex operations to model. Modelling the complex chemical reactions that occur in individual milling operations is beyond the scope of this project. Modelling of the mill operation, therefore, was simplified by assuming that, for each constituent tracked, the combined mill influent water quality will be changed by a fixed increment in each effluent stream. Each mill effluent stream is modelled as having a unique set of water quality "effects."

(EARLY OPERATION)
MASSIVE ORE ONLY

MILL EFFECT MATRIX SUMMARY

(MATURE OPERATION)
MASSIVE & STRINGER ORE

COMPONENT	Cu THICKENER OVERFLOW	Pb FEED THICKENER OVERFLOW	Pb CONCENTRATE THICKENER OVERFLOW	Zn THICKENER OVERFLOW	Zn TAILS TO BACKFILL PREP	BACKFILL PREP	Cu THICKENER OVERFLOW	Pb FEED THICKENER OVERFLOW	Pb CONCENTRATE THICKENER OVERFLOW	Zn THICKENER OVERFLOW	Zn TAILS TO BACKFILL PREP	BACKFILL PREP
CATIONS	10 ⁻⁸	10 ^{-8.5}	10 ^{-11.5}	10 ^{-10.8}	10 ^{-11.3}		10 ^{-6.8}	10 ^{-8.5}	10 ^{-11.5}	10 ^{-9.5}	10 ^{-11.0}	
Ag	+0.004	NO CHANGE	+0.13	NO CHANGE	+0.004		+0.002	NO CHANGE	+0.13	NO CHANGE	+0.002	
Al	+0.08	+0.03	+0.15	+0.05	+0.5		+0.04	+0.03	+0.15	+0.03	+0.3	
Ba	+0.02	+0.02	+0.03	NO CHANGE	NO CHANGE		+0.01	+0.02	+0.03	NO CHANGE	NO CHANGE	
Ca	+3.3	+5.0	+100	+3.4	+114		+5.0	+5.0	+100	+0.9	+96	
Cd	+0.004	+0.003	+0.002	NO CHANGE	NO CHANGE		+0.005	+0.003	+0.002	NO CHANGE	NO CHANGE	
Cr	+31.8	+4.0	+22.04	NO CHANGE	+0.05		+17.5	+4.0	+22.04	NO CHANGE	+0.03	
Cu	+0.07	+0.46	+27.5	+0.05	+0.13		+0.06	+0.46	+27.5	+0.04	+0.07	
Fe ²⁺	+0.28	-0.02 (0.01)	-0.02 (0.01)	-0.03 (0.01)	+0.01		+0.27	-0.02 (0.01)	-0.02 (0.01)	-0.02 (0.01)	+2.4	
Fe ³⁺	+0.77	+0.02	-0.008 (0.2)	-0.03 (0.2)	+0.01		+0.52	+0.02	-0.008 (0.2)	-0.02 (0.2)	(0.2)	
Hg	NO CHANGE	+0.0004	+0.0002	NO CHANGE	NO CHANGE		+0.0002	+0.0004	+0.0002	NO CHANGE	NO CHANGE	
K	+1.4	+2.6	+1.25	+0.16	+4.1		+1.0	+2.6	+1.25	+0.13	+4.2	
Mg	+0.23	+0.47	-2.1 (10)	-2.03 (10)	+0.21		+0.3	+0.47	-2.1 (10)	-1.4 (10)	-1.1 (10)	
Mn	+0.08	+0.04	-0.002 (0.03)	-0.003 (0.03)	+0.001		+0.3	+0.04	-0.002 (0.03)	-0.021 (0.03)	+0.03	
Na	+38.3	+133.0	+209	+0.8	+98.3		+24.4	+133.0	+209	+0.7	+136	
Pb	+0.59	NO CHANGE	+0.05	NO CHANGE	NO CHANGE		+0.32	NO CHANGE	+0.05	NO CHANGE	+0.02	
Se	NO CHANGE	NO CHANGE	NO CHANGE	+0.003	+0.28		+0.34	NO CHANGE	NO CHANGE	+0.003	+0.25	
Zn	+0.25	-0.03 (0.06)	+113.9	-0.08 (0.06)	+0.10		+0.52	-0.032 (0.06)	+113.9	-0.04 (0.03)	+0.11	
ANIONS												
OH	10 ⁻⁶	10 ^{-5.5}	10 ^{-2.5}	10 ^{-3.2}	10 ^{-2.7}		10 ^{-7.2}	10 ^{-5.5}	10 ^{-2.5}	10 ^{-4.5}	10 ⁻³	
AS	+0.006	NO CHANGE	NO CHANGE	+0.007	+0.119		+0.005	NO CHANGE	NO CHANGE	+0.006	+0.067	
CO ₃	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE		NO CHANGE	NO CHANGE	NO CHANGE	+17	+131	
Cl	-0.9	+2.1	+4.0	-0.9	+1.0		-0.5	+2.1	+4.0	-0.5	+3.0	
CN	+0.04	+2.99	+152.3	NO CHANGE	+0.022		+0.02	+2.99	+152.3	(0.0)	+0.014	
F	+0.5	NO CHANGE	-0.14 (8.0)	-0.21 (8.0)	+0.38		+0.3	NO CHANGE	-0.14 (8.0)	-0.15 (8.0)	+0.52	
HCO ₃	NO CHANGE	+136.0	0.0	NO CHANGE	NO CHANGE		+40	+136.0	0.0	+4.0	NO CHANGE	
NO ₃	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE		NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	
PO ₄	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE		NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	
SO ₄	+34.1	+88	+264	+11	+290		+27.0	+88	+264	+10	+230	
S	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE		NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	
S ₂ O ₃	+39.0	+74.0	+412.5	+58	+179		+21.0	+74.0	+412.5	+32	+100	
NON-IONIC												
CO ₂	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE		NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	
NH ₃	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE		NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	
O ₂	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE		NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	
SiO ₂	-3.0 (15)	-2.6 (15)	-2.4 (15)	-1.1 (15)	-2.06 (15)		-1.5 (15)	-2.6 (15)	-2.4 (15)	+0.8	+0.19	
BOD	+59	NO CHANGE	+53	+7	NO CHANGE		+44	NO CHANGE	+53	+18	+28	
COD	+164	NO CHANGE	+427	+104	+217		+97	NO CHANGE	+427	+65	+146	
HARD	SUM OF Ca ²⁺ Mg ²⁺ & Fe ²⁺	SUM OF Ca ²⁺ Mg ²⁺ & Fe ²⁺	SUM OF Ca ²⁺ Mg ²⁺ & Fe ²⁺	SUM OF Ca ²⁺ Mg ²⁺ & Fe ²⁺	SUM OF Ca ²⁺ Mg ²⁺ & Fe ²⁺		SUM OF Ca ²⁺ Mg ²⁺ & Fe ²⁺	SUM OF Ca ²⁺ Mg ²⁺ & Fe ²⁺	SUM OF Ca ²⁺ Mg ²⁺ & Fe ²⁺	SUM OF Ca ²⁺ Mg ²⁺ & Fe ²⁺	SUM OF Ca ²⁺ Mg ²⁺ & Fe ²⁺	
pH	8.0	8.5	11.5	10.8	11.3		6.8	8.5	11.5	10.8	11.0	
TDS	SUM OF SOLUBLE COMPONENTS	SUM OF SOLUBLE COMPONENTS	SUM OF SOLUBLE COMPONENTS	SUM OF SOLUBLE COMPONENTS	SUM OF SOLUBLE COMPONENTS		SUM OF SOLUBLE COMPONENTS	SUM OF SOLUBLE COMPONENTS	SUM OF SOLUBLE COMPONENTS	SUM OF SOLUBLE COMPONENTS	SUM OF SOLUBLE COMPONENTS	
TEMP	+7 (MAX 30°C)	+7 (MAX 30°C)	+7 (MAX 30°C)	+7 (MAX 30°C)	+7 (MAX 30°C)		+7 (MAX 30°C)	+7 (MAX 30°C)	+7 (MAX 30°C)	+7 (MAX 30°C)	+7 (MAX 30°C)	
TOC	+20.1	NO CHANGE	+95.4	+2.7	+5.0		+13.0	NO CHANGE	+95.4	+7.0	+7.0	
TSSA	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	
TSSN	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE		NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	

NO CHANGE IN CHEMICAL COMPOSITION
SOLIDS DISTRIBUTED INTO SANDS AND SLIMES
SOLIDS FLOW PROPORTIONAL TO ORE THROUGHPUT

NO CHANGE IN CHEMICAL COMPOSITION
SOLIDS DISTRIBUTED INTO SANDS AND SLIMES
SOLIDS FLOW PROPORTIONAL TO ORE THROUGHPUT

- NOTE:
- THIS SUMMARY DESCRIBES THE EFFECTS OF EACH UNIT PROCESS ON SOLUBLE WASTEWATER CONSTITUENTS. EACH EFFECT MATRIX COMPUTES PARTICULATE CONSTITUENTS BASED ON INFLUENT WATER QUALITY, PROCESS-SPECIFIC WATER CHEMISTRY, AND ASSUMED EFFLUENT TSS CONCENTRATIONS
 - UNITS mg/L EXCEPT H₂O WHICH ARE MOLAR, TEMP IS IN °C AND pH NO UNITS
 - VALUES IN PARENTHESES ARE MINIMUM EFFLUENT CONCENTRATIONS.
 - IF INFLUENT CONCENTRATION IS LESS THAN PREDICTED EFFLUENT SOLUBLE CONCENTRATION, EFFLUENT CONCENTRATION WILL EQUAL THE INFLUENT CONCENTRATION

FIGURE 9

EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE WATER USE MODEL
EFFECT MATRIX SUMMARY
MILL EFFECT MATRIX

REVISED	DATE	BY	DESCRIPTION

SCALE NONE STATE WISCONSIN COUNTY FOREST

APPROVED BY: BAK DATE: _____

APPROVED BY: MRH DATE: _____

APPROVED BY: _____ DATE: _____

APPROVED BY: _____ DATE: _____

051-7-L-005



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GENERAL FACILITIES MATRIX SUMMARY

COMPONENT	EVAPORATION	FRESH WATER	CONTAMINATED MINE SEEPAGE	RAINFALL	WATER ASSOCIATED W/ MASSIVE ORE	WATER ASSOCIATED W/ STRINGER ORE	BOILER & COOLING TOWER BLOWDOWN	CRUSHER COOLING	FRESH WATER TANKS	GLAND WATER TANK	LAB SHOPS, & RUNOFF FROM SURFACE STOR AREA	MINE	REAGENT PREP
CATIONS		10 ⁻⁷⁷	10 ^{-5.7}	10 ^{-4.54}	10 ^{-5.6}		NO CHANGE				10 ^{-2.8}		
H		0.001	0.001	0	0.001						0.002		
Ag		0.53	0.53	0	1.9						25.4		
Al		0.02	0.02	0	0.1						0.01		
Ba		298	44.8	0.33	92						21.4		
Cd		0.002	0.07	0	0.26						0.018		
Cr		0.002	0.1	0	0.10						0.033		
Cu		0.007	0.07	0	0.68						3.69		
Fe ⁺²		1.74	1.74	0	0		x5				156.		
Fe ⁺³		0	0	0	0.07						0		
Hg		0.0001	0.0004	0	0.001						0.0001		
K		1.31	1.31	0.042	15						0.65		
Mg		120	19.3	0.054	39						47.3		
Mn		0.423	0.423	0	1.0						3.88		
Na		4.11	4.11	0.069	20						2.03		
Pb		0.01	0.34	0	1.62						0.06		
Se		0.001	0.001	0	0.06						0.001		
Zn		0.052	20.4	0	71						11.5		
ANIONS		10 ^{-6.3}	10 ^{-8.3}	10 ^{-9.46}	10 ^{-8.4}		NO CHANGE				10 ^{-11.2}		
OH		0.001	0.01	0	0.05						0.461		
AS		0	0	0	0						0		
CO ₃		4	4	0.152	5.8						2.4		
Cl		0.001	0.001	0	0.01						0.001		
CN		0.20	0.20	0	5						0.1		
F		152	30	0	52		x5				0		
HCO ₃		164	1.64	1.953	5.8						0.8		
NO ₃		0.06	0.61	0.003	1.81						0		
PO ₄		9	200	2.298	484						749.		
SO ₄		0	0	0	1						0		
S		0	0	0	0						0		
S ₂ O ₃		0	2	0	2		NO CHANGE				0.3		
NON-IONIC CO ₂		0	0	0.534	0		NO CHANGE				0		
NH ₃		5	5	0	5		NO CHANGE				2.		
O ₂		9	9	0	50		x5				5.7		
SiO ₂		2	2	0	5		NO CHANGE				1.		
BOD		29	29	0	10		NO CHANGE				14.		
COD		SUM OF Ca ⁺² Mg ⁺² & Fe ⁺²	SUM OF Ca ⁺² Mg ⁺² & Fe ⁺²	SUM OF Ca ⁺² Mg ⁺² & Fe ⁺²	SUM OF Ca ⁺² Mg ⁺² & Fe ⁺²		SUM OF Ca ⁺² Mg ⁺² & Fe ⁺²				SUM OF Ca ⁺² Mg ⁺² & Fe ⁺²		
HARD		7.7	5.7	4.54	5.6		NO CHANGE				2.8		
pH		SUM OF SOLUBLE COMPONENTS	SUM OF SOLUBLE COMPONENTS	SUM OF SOLUBLE COMPONENTS	SUM OF SOLUBLE COMPONENTS		SUM OF SOLUBLE COMPONENTS				SUM OF SOLUBLE COMPONENTS		
TDS		7	7	20	20		20				8		
TEMP		1	1	0	5		NO CHANGE				1		
TOC		0	0	0	0		0				0		
TSSA		0	0	0	50		x5				50.		
TSSN													

ASSUMED TO BE PURE WATER

SAME AS WATER WITH MASSIVE ORE

NO CHANGE

x5

NO CHANGE IN WATER QUALITY

NO CHANGE IN WATER QUALITY

NO CHANGE IN WATER QUALITY

A SUMMER ADD OF SOLUBLE INEFFLUENT STREAMS TO COMPLETE QUALITY OF MINE RETURN WATER. ADDS 12 MT/D OF SOLIDS AND 18.5 KG/CLAY DEMANDS

CHANGES IN WATER QUALITY DUE TO REAGENT ADDITION ARE PREDICTED IN THE MILL EFFECT MATRIX

- NOTE:
- THIS SUMMARY DESCRIBES THE EFFECTS OF EACH UNIT PROCESS ON SOLUBLE WASTEWATER CONSTITUENTS. EACH EFFECT MATRIX COMPUTES PARTICULATE CONSTITUENTS BASED ON INFLUENT WATER QUALITY, PROCESS-SPECIFIC WATER CHEMISTRY, AND ASSUMED EFFLUENT TSS CONCENTRATIONS
 - UNITS mg/L EXCEPT H, OH WHICH ARE MOLAR, TEMP IS IN °C AND PH NO UNITS
 - IF INFLUENT CONCENTRATION IS LESS THAN PREDICTED EFFLUENT SOLUBLE CONCENTRATION, EFFLUENT CONCENTRATION WILL EQUAL THE INFLUENT CONCENTRATION

FIGURE 10

EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE: **WATER USE MODEL EFFECT MATRIX SUMMARY GENERAL FACILITIES**

SCALE: NONE STATE: WISCONSIN COUNTY: FOREST

DESIGNED BY: TAG DATE: _____ CHECKED BY: _____ DATE: _____

APPROVED BY: MRH DATE: _____ APPROVED BY: _____ DATE: _____

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051-7-L-006



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GENERAL FACILITIES EFFECT MATRIX SUMMARY

CATIONS	RECLAIM POND		SAND STORAGE RUNOFF	SANITARY SYSTEM USERS	SANITARY TREATMENT SYSTEM	SURGE POND	TAILINGS IMPOUNDMENT		VACUUM PUMP SEALS			
	SUMMER	WINTER					SUMMER	WINTER				
H	+2[ΔS ₂ O ₃]	+2[ΔS ₂ O ₃]	10 ^{-5.6}				+2[ΔS ₂ O ₃] 10 ⁻³ MAXIMUM	NO CHANGE				
Ag	NO CHANGE - LIME ADDITION OPTION AVAILABLE FOR pH CONTROL AT MINU = 7.0		0.001				NO CHANGE	SAME AS SUMMER TAILINGS IMPROVEMENT				
Al			1.9				HYDROXIDE SOLUBILITY					
Ba			0.1				NO CHANGE					
Ca			92				LIME ADDED TO MAINTAIN pH 9.0					
Cd			0.26				0.02 mg/l					
Cr			0.1				0.05 mg/l					
Cu			0.68				0.02 mg/l					
Fe ⁺²			0				NO CHANGE					
Fe ⁺³			NO CHANGE				0.2 mg/l					
Hg			0.001				0.3 mg/l					
K	15				NO CHANGE							
Mg	39				HYDROXIDE SOLUBILITY							
Mn	1.0				2.03 mg/l							
Na	20				NO CHANGE							
Pb	1.62				0.08 mg/l							
Se	0.06				40% REMOVAL							
Zn	71				0.05 mg/l							
ANIONS												
OH	10 ⁻¹⁴ [H ⁺]	10 ⁻¹⁴ [H ⁺]	10 ^{-8.4}				10 ⁻¹⁴ [H ⁺]	NO CHANGE				
AS	NO CHANGE	NO CHANGE	0.05	NO CHANGE	NO CHANGE	NO CHANGES IN WATER QUALITY	0.01	0.01	NO CHANGES IN WATER QUALITY			
CO ₃	NO CHANGE		0					DEPENDENT ON pH & CaCO ₃ , CaCO ₄ PPT				
Cl	NO CHANGE		5.8					NO CHANGE				
CN	0.01		0.01					NO CHANGE				
F	NO CHANGE		5					NO CHANGE				
HCO ₃	NO CHANGE		52					DEPENDENT ON pH & CaCO ₃ , CaCO ₄ PPT				
NO ₃	NO CHANGE		5.8					NO CHANGE				
PO ₄	NO CHANGE		1.81					NO CHANGE				
SO ₄	+2[ΔS ₂ O ₃]		+2[ΔS ₂ O ₃]				484				+2[ΔS ₂ O ₃]	NO CHANGE
S	NO CHANGE		NO CHANGE				1				NO CHANGE	NO CHANGE
S ₂ O ₃	90% REMOVAL	10% REMOVAL	0			50% REMOVAL	NO CHANGE					
NON-IONIC CO ₂	NO CHANGE	NO CHANGE	2			DEPENDENT ON pH & CaCO ₃ , CaCO ₄ PPT	SAME EFFECTS AS SUMMER IMPROVEMENT					
NH ₃	INCREASE FROM CN DESTRUCTION	NO CHANGE	0			INCREASE FROM CN DESTRUCTION						
O ₂	NO CHANGE	NO CHANGE	5			NO CHANGE						
SiO ₂	NO CHANGE	NO CHANGE	50			NO CHANGE						
BOD	90% REMOVAL	90% REMOVAL	5 mg/l	+357 mg/l	50 mg/l	NO CHANGE		SAME EFFECTS AS SUMMER IMPROVEMENT				
COD	90% REMOVAL	90% REMOVAL	10			0.57% COD REMOVED PER % SO ₃ REMOVED						
HARD	SUM OF Ca ⁺² Mg ⁺² & Fe ⁺²	SUM OF Ca ⁺² Mg ⁺² & Fe ⁺²	SUM OF Ca ⁺² Mg ⁺² & Fe ⁺²			SUM OF Ca ⁺² Mg ⁺² & Fe ⁺²						
pH	-LOG[H]	-LOG[H]	5.6			-LOG[H]						
TDS	SUM OF SOLUBLE COMPONENTS	SUM OF SOLUBLE COMPONENTS	SUM OF SOLUBLE COMPONENTS			SUM OF SOLUBLE COMPONENTS						
TEMP	20	20	20			NO CHANGE						
TOC	90% REMOVAL	90% REMOVAL	5 mg/l			NO CHANGE						
TSSA	0	0	0			15 mg/l						
TSSN	30	30	50	+357 mg/l	50 mg/l	15 mg/l						
SLUDGE CONCENTRA.	NO SLUDGE STREAM	NO SLUDGE STREAM	NO SLUDGE STREAM	NO SLUDGE STREAM	NO SLUDGE STREAM	TSSN: 80% TSSA: 25%						

NOTE:

- THIS SUMMARY DESCRIBES THE EFFECTS OF EACH UNIT PROCESS ON SOLUBLE WASTEWATER CONSTITUENTS. EACH EFFECT MATRIX COMPUTES PARTICULATE CONSTITUENTS BASED ON INFLUENT WATER QUALITY, PROCESS-SPECIFIC WATER CHEMISTRY, AND ASSUMED EFFLUENT TSS CONCENTRATIONS
- UNITS mg/l EXCEPT H, OH WHICH ARE MOLAR, TEMP IS IN °C AND pH NO UNITS [ΔS₂O₃] INDICATES MOLAR CHANGE
- IF INFLUENT CONCENTRATION IS LESS THAN PREDICTED EFFLUENT SOLUBLE CONCENTRATION, EFFLUENT CONCENTRATION WILL EQUAL THE INFLUENT CONCENTRATION

FIGURE 11

EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE: **WATER USE MODEL EFFECT MATRIX SUMMARY GENERAL FACILITIES**

SCALE: NONE	STATE: WISCONSIN	COUNTY: FOREST
DESIGNED BY: TAG	DATE:	CHECKED BY:
APPROVED BY: MRH	DATE:	APPROVED BY:
APPROVED BY:	DATE:	EXXON:

DRAWING NO: **051-7-L-007**

SHEET: _____ OF _____

CH2M HILL

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TREATMENT PROCESS EFFECT MATRIX SUMMARY

	A. TAILINGS THICKENER	B. TAILINGS THICKENER/DEWATERING	C. PH ADJUSTMENT H ₂ SO ₄	D. PH ADJUSTMENT CO ₂	E. PH ADJUSTMENT Ca(OH) ₂	F. LIME PRECIPITATION	G. CARBONATE PRECIPITATION	H. SULFIDE PRECIPITATION	I. SODIUM ALUMINATE PRECIPITATION	J. ALKALINE CHLORINATION	K. FERRO CYANIDE PRECIPITATION	L. H ₂ O ₂ OXIDATION	M. OZONATION	N. BIOX OF THIOSALTS	O. IX-CATION REMOVAL			
CATIONS	10 ^{-11.0}		10 ^{-7.5}	10 ^{-7.5}	10 ^{-7.5}	10 ^{-10.5}		10 ^{-9.0}	10 ^{-12.0}	10 ^{-8.0}	10 ^{-6 (MIN)}	10 ^{-10.5}	10 ^{-10.5}	2x MOLES OF S ₂ O ₃ OXIDIZED	COMPUTED BASED ON METALS REMOVAL			
Ag						0.03 mg/l	SAME AS LIME PRECIPITATION	0.01 mg/l	NO CHANGE	NO CHANGE	NO CHANGE	0.03 Mg/l	0.03 mg/l		0.0			
Al						HYDROXIDE SOLUBILITY		HYDROXIDE SOLUBILITY	35.0 mg/l	HYDROXIDE SOLUBILITY	NO CHANGE	NO CHANGE	HYDROXIDE SOLUBILITY	HYDROXIDE SOLUBILITY		0.0		
Ba						NO CHANGE		NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE		0.0			
Ca			OH PARTICULATES IN THE INFLUENT ARE CONVERTED TO SOLUBLE COMPONENTS	OH PARTICULATES IN THE INFLUENT ARE CONVERTED TO SOLUBLE COMPONENTS	SAME EFFECT AS H ₂ SO ₄ EXCEPT NO SOLUBILIZATION OF PARTICLES	INCREASE COMPUTED CARBONATE AND DUE TO LIME ADDITION	30 mg/l	CARBONATE AND SULFATE SOLUBILITY	30.0 mg/l	CARBONATE AND SULFATE SOLUBILITY	SULFATE SOLUBILITY	CARBONATE AND SULFATE SOLUBILITY	CARBONATE AND SULFATE SOLUBILITY	CARBONATE AND SULFATE SOLUBILITY		0.0		
Cd									0.02 mg/l		0.01 mg/l	0.02 mg/l		NO CHANGE	0.02 Mg/l	0.02 mg/l		0.0
Cr									0.05 mg/l		0.05 mg/l	0.05 mg/l		NO CHANGE	0.05 Mg/l	NO CHANGE		0.0
Cu									0.02 mg/l		0.01 mg/l	0.02 mg/l		NO CHANGE	0.02 Mg/l	0.02 mg/l		0.0
Fe ⁺²									0.00 mg/l OKIDIZED TO Fe ⁺³		0.05 mg/l	0.00 mg/l OKIDIZED TO Fe ⁺³		+15 Mg/l	0.00 mg/l OKIDIZED TO Fe ⁺³	0.00 mg/l OKIDIZED TO Fe ⁺³		0.0
Fe ⁺³									0.2 mg/l		0.20 mg/l	0.2 mg/l		+15 Mg/l	0.2 Mg/l	0.2 Mg/l		0.0
Hg									0.3 mg/l		0.005 mg/l	0.3 mg/l		NO CHANGE	0.3 Mg/l	0.3 mg/l		0.0
K									NO CHANGE		NO CHANGE	NO CHANGE		NO CHANGE	NO CHANGE	NO CHANGE		0.0
Mg									HYDROXIDE SOLUBILITY		HYDROXIDE SOLUBILITY	10.0 mg/l		NO CHANGE	HYDROXIDE SOLUBILITY	HYDROXIDE SOLUBILITY		0.0
Mn									0.03 mg/l		HYDROXIDE SOLUBILITY	0.03 mg/l		NO CHANGE	0.03 Mg/l	0.03 mg/l		0.0
Na						NO CHANGE	+2x MOLES Ca IN INFLUENT	ADDED IN PROPORTION WITH FES	INCR FROM NaOH & SODIUM ALUMINATE		NO CHANGE	NO CHANGE	NO CHANGE		0.0			
Pb						0.08 mg/l		0.01 mg/l	0.08 mg/l		NO CHANGE	0.08 Mg/l	0.08 mg/l		0.0			
Se						40% REMOVAL		0.05 mg/l	40% REMOVAL		65% REMOVAL	40% REMOVAL	40% REMOVAL		0.0			
Zn						0.05 mg/l		0.01 mg/l	0.05 mg/l		NO CHANGE	0.05 Mg/l	0.05 mg/l		0.0			
ANIONS			10 ^{-6.5}	10 ^{-6.5}	10 ^{-6.5}	10 ^{-3.5}		10 ^{-5.0}	10 ⁻²	10 ^{-6.0}	10 ^{-8.0 (MAX)}	10 ^{-3.5}	10 ^{-3.5}	10 ^{-14/H+}	10 ^{-4/H+}			
AS	0.01		NO CHANGE	NO CHANGE		0.03 mg/l		0.05 mg/l	0.03 mg/l	0.03 mg/l	NO CHANGE	0.03 Mg/l	0.03 mg/l	NO CHANGE	NO CHANGE			
CO ₃		NOT USED	ADJUST TO REFLECT PH CHANGE	ADJUST TO REFLECT PH CHANGE		DEPENDENT ON PH & CaCO ₃ PRECIP	45 mg/l	DEPENDENT ON PH & CaCO ₃ PRECIP	DEPENDENT UPON PH	INCREASED BY CN DESTRUCTION	DEPENDENT UPON PH	DEPENDENT UPON PH & CaCO ₃ PRECIP	INCREASED BY CN DESTRUCTION	DEPENDENT ON pH & CaCO ₃ PRECIPITATION	0.00			
Cl			NO CHANGE	NO CHANGE		NO CHANGE		NO CHANGE	NO CHANGE	BASED ON INFLUENT CN & S ₂ O ₃ CONCENT.	INCR DUE TO FeCl ₂ ADDN	NO CHANGE	NO CHANGE	NO CHANGE				
CN			NO CHANGE	NO CHANGE		NO CHANGE		NO CHANGE	NO CHANGE	0.01 mg/l	10 Mg/l	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE			
F			NO CHANGE	NO CHANGE		NO CHANGE		NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE			
HCO ₃			ADJUST TO REFLECT PH CHANGE	INCR BASED ON PH & CO ₂ ADDITION		DEPENDENT ON PH & CaCO ₃ PRECIP		DEPENDENT ON PH & CaCO ₃ PRECIP	DEPENDENT UPON PH	DEPENDENT ON PH & CaCO ₃ PRECIP	DEPENDENT UPON PH	DEPENDENT ON PH & CaCO ₃ PRECIP	DEPENDENT ON PH & CaCO ₃ PRECIPITATION	DEPENDENT ON pH & CaCO ₃ PRECIPITATION	0.00			
NO ₃			NO CHANGE	NO CHANGE		NO CHANGE		NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE				
PO ₄			NO CHANGE	NO CHANGE		NO CHANGE		NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	1.0 mg/l			
SO ₄			DEPENDENT ON CaSO ₄ SOLUBILITY	DEPENDENT ON CaSO ₄ SOLUBILITY		DEPENDENT ON CaSO ₄ SOLUBILITY		INCREASE BY REAGENT ADDITION	ADJUSTED TO 170 mg/l	INFLUENT PLUS 2x MOLES OF S ₂ O ₃ OXIDIZED	+1/2x MOLES OF INFLUENT CN + ADD FOR PH ADJUST	INFLUENT PLUS 2x MOLES OF S ₂ O ₃ OXIDIZED	INFLUENT PLUS 2x MOLES OF S ₂ O ₃ OXIDIZED	INFLUENT PLUS 2x MOLES OF S ₂ O ₃ OXIDIZED	NO CHANGE			
S			NO CHANGE	NO CHANGE		NO CHANGE		NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	0.0	0.0	NO CHANGE				
S ₂ O ₃			NO CHANGE	NO CHANGE		NO CHANGE		NO CHANGE	NO CHANGE	90% REMOVAL	NO CHANGE	95% REMOVAL	95% REMOVAL	MAX. EFFLUENT CONCENTRATN 50 mg/l				
NON-IONIC CO ₂			ADJUST TO REFLECT PH CHANGE	INCR BASED ON PH & CO ₂ ADDITION		DEPENDENT ON PH & CaCO ₃ PRECIP		DEPENDENT ON PH & CaCO ₃ PRECIP	DEPENDENT UPON PH	DEPENDENT ON PH & CaCO ₃ PRECIP	DEPENDENT ON PH	DEPENDENT ON PH & CaCO ₃ PRECIP	DEPENDENT ON PH & CaCO ₃ PRECIPITATION	DEPENDENT ON pH & CaCO ₃ PRECIPITATION	0.47 mg/l			
NH ₃			NO CHANGE	NO CHANGE		NO CHANGE		NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	1.0 mg/l				
O ₂			NO CHANGE	NO CHANGE		NO CHANGE		NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE				
S ₂ O ₂			NO CHANGE	NO CHANGE		NO CHANGE		NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE			
BOD			NO CHANGE	NO CHANGE		NO CHANGE		NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE			
COD			NO CHANGE	NO CHANGE		NO CHANGE		NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE			
HARD			SUM OF Ca ²⁺ , Mg ²⁺ & Fe ²⁺	SUM OF Ca ²⁺ , Mg ²⁺ & Fe ²⁺		SUM OF Ca ²⁺ , Mg ²⁺ & Fe ²⁺		SUM OF Ca ²⁺ , Mg ²⁺ & Fe ²⁺	SUM OF Ca ²⁺ , Mg ²⁺ & Fe ²⁺	SUM OF Ca ²⁺ , Mg ²⁺ & Fe ²⁺	SUM OF Ca ²⁺ , Mg ²⁺ & Fe ²⁺	SUM OF Ca ²⁺ , Mg ²⁺ & Fe ²⁺	SUM OF Ca ²⁺ , Mg ²⁺ & Fe ²⁺	SUM OF Ca ²⁺ , Mg ²⁺ & Fe ²⁺	0.0			
pH	11		7.5	7.5	7.5	10.5		9.0	12.0	8.0	6.0 (MAX)	10.5	10.5	-LOG[H ⁺]	-LOG[H ⁺]			
TDS			SUM OF SOLUBLE COMPONENTS	SUM OF SOLUBLE COMPONENTS		SUM OF SOLUBLE COMPONENTS		SUM OF SOLUBLE COMPONENTS	SUM OF SOLUBLE COMPONENTS	SUM OF SOLUBLE COMPONENTS	SUM OF SOLUBLE COMPONENTS	SUM OF SOLUBLE COMPONENTS	SUM OF SOLUBLE COMPONENTS	SUM OF SOLUBLE COMPONENTS	SUM OF SOLUBLE COMPONENTS			
TEMP			NO CHANGE	NO CHANGE		NO CHANGE		NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE	NO CHANGE			
TOC			NO CHANGE	NO CHANGE		NO CHANGE		NO CHANGE	NO CHANGE	50% REMOVAL	NO CHANGE	50% REMOVAL	50% REMOVAL	90% REMOVAL	NO CHANGE			
TSSA	USER VARIABLE 25-250 Mg/l		0.0	0.0		MAXIMUM OF 50 mg/l	MAXIMUM OF 50 mg/l	MAXIMUM OF 50 mg/l	MAXIMUM OF 50 mg/l	SUM OF INSOLUBLE COMPONENTS	MAX OF 50 Mg/l	SUM OF INSOLUBLE COMPONENTS	SUM OF INSOLUBLE COMPONENTS	0.0	0.0			
TSSN	USER VARIABLE 25-250 Mg/l		NO CHANGE	NO CHANGE		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	MAX EFFLUENT CONCENTRATN 15 mg/l	0.0			
SLUDGE CONCENTRA.	USER VARIABLE		NO SLUDGE STREAM	NO SLUDGE STREAM	NO SLUDGE STREAM	6.0%		1%	10%	6%	6%	NO SLUDGE STREAM	NO SLUDGE STREAM	12%	10% HCl REGEN SOLN 200 mg/l HCl REMOVED 10% HCl REGEN SOLN			

NOTE:
 1. THIS SUMMARY DESCRIBES THE EFFECTS OF EACH UNIT PROCESS ON SOLUBLE WASTEWATER CONSTITUENTS. EACH EFFECT MATRIX COMPUTES PARTICULATE CONSTITUENTS BASED ON INFLUENT WATER QUALITY, PROCESS-SPECIFIC WATER CHEMISTRY, AND ASSUMED EFFLUENT TSS CONCENTRATIONS.
 2. UNITS mg/l EXCEPT H, OH WHICH ARE MOLAR, TEMP IS IN °C AND PH NO UNITS.
 3. IF INFLUENT CONCENTRATION IS LESS THAN PREDICTED EFFLUENT SOLUBLE CONCENTRATION, EFFLUENT CONCENTRATION WILL EQUAL THE INFLUENT CONCENTRATION.

FIGURE 12

EXXON MINERALS COMPANY
 CRANDON PROJECT

TITLE WATER USE MODEL
 EFFECT MATRIX SUMMARY
 TREATMENT PROCESSES A-O

SCALE NONE STATE WISCONSIN COUNTY FOREST

DATE DATE DATE DATE DATE DATE DATE DATE

051-7-L-008



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TREATMENT PROCESS EFFECT MATRIX SUMMARY

COMPONENT	P IX - CALCIUM REMOVAL	Q IX ANION REMOVAL	R CARBON ADSORPTION	S FILTRATION	T. REVERSE OSMOSIS (RO)	U. VAPOR COMPRESSION EVAPORATION (VCE)	V. RO/VCE	W. SPARE	X SPARE	Y SPARE	Z. SPARE
CATIONS	10 ⁻⁷	10 ⁻⁷	COMPUTED BASED ON METALS REMOVAL	NO CHANGE	COMPUTED BASED ON HCO ₃ & CO ₂	1x 10 ⁻⁷					
H											
Ag		NO CHANGE	50% REMOVAL		0.05X INFLUENT	0.0					
Al			NO CHANGE		0.0	0.0					
Ba			NO CHANGE		0.05X INFLUENT	0.0					
Ca	10 mg/l		NO CHANGE		0.04X INFLUENT	0.0					
Cd			50% REMOVAL		0.05X INFLUENT	0.0					
Cr			75% REMOVAL		0.05X INFLUENT	0.0					
Cu			50% REMOVAL		0.05X INFLUENT	0.0					
Fe ⁺²			NO CHANGE		0.02X INFLUENT	0.0					
Fe ⁺³	NO CHANGE		NO CHANGE		0.00	0.0					
Hg			50% REMOVAL		0.05X INFLUENT	0.0					
K			NO CHANGE		0.1X INFLUENT	0.0					
Mg			NO CHANGE		0.04X INFLUENT	0.0					
Mn			NO CHANGE		0.05X INFLUENT	0.0					
Na	Z x [Ca] REMOVED		NO CHANGE		0.1X INFLUENT	0.0					
Pb			50% REMOVAL		0.05X INFLUENT	0.0					
Se			25% REMOVAL		0.05X INFLUENT	0.0					
Zn			NO CHANGE		0.05X INFLUENT	0.0					
ANIONS	10 ⁻¹⁴ /H ⁺	10 ⁻¹⁴ /H ⁺	10 ⁻¹⁴ /H ⁺		10 ⁻¹⁴ /H ⁺	1x 10 ⁻⁷					
OH											
AS		97% REMOVAL	NO CHANGE		0.15X INFLUENT	0.0					
CO ₃		ADJ TO REFLECT PH 7 CHANGE	NO CHANGE		0.5X INFLUENT	0.0					
Cl		95% REMOVAL	NO CHANGE		0.1X INFLUENT	0.0					
CN		NO CHANGE	NO CHANGE		0.1X INFLUENT	0.0					
F		NO CHANGE	NO CHANGE		0.5X INFLUENT	0.0					
HCO ₃		2X MOLES OF ANIONS REMOVED	DEPENDENT ON METALS REMOVAL		.375 (CO ₃ + HCO ₃)	0.0					
NO ₃		50% REMOVAL	NO CHANGE		0.15X INFLUENT	0.0					
PO ₄		97% REMOVAL	NO CHANGE		0.02X INFLUENT	0.0					
SO ₄	NO CHANGE	97% REMOVAL	NO CHANGE		0.04X INFLUENT	0.0					
S		NO CHANGE	NO CHANGE		0.1X INFLUENT	0.0					
S ₂ O ₃		95% REMOVAL	NO CHANGE		0.1X INFLUENT	0.0					
NON-IONIC CO ₂		ADJ TO REFLECT PH 7 CHANGE	DEPENDENT ON METALS REMOVAL		.75 (CO ₃ + HCO ₃) + CO ₂	0.0					
NH ₃		NO CHANGE	NO CHANGE		NO CHANGE	0.0					
O ₂		NO CHANGE	NO CHANGE		NO CHANGE	0.0					
S ₁ O ₂		NO CHANGE	NO CHANGE		0.15X INFLUENT	0.0					
BOD		NO CHANGE	63% REMOVAL		NO CHANGE	NO CHANGE					
COD		0.57 Kg COD REMOVED PER Kg S ₂ O ₃ REMOVED	67% REMOVAL		0.57 Kg COD REMOVED PER Kg S ₂ O ₃ REMOVED	0.57 Kg COD REMOVED PER Kg S ₂ O ₃ REMOVED					
HARD	SUM OF Ca ²⁺ , Mg ²⁺ , AND Fe ²⁺	NO CHANGE	NO CHANGE		SUM OF Ca ²⁺ , Mg ²⁺ & Fe ²⁺	0.0					
pH	7.0	7.0	-LOG [H ⁺]		-LOG [H ⁺]	7.0					
TDS	SUM OF SOLUBLE COMPONENTS	SUM OF SOLUBLE COMPONENTS	SUM OF SOLUBLE COMPONENTS		SUM OF SOLUBLE COMPONENTS	10.0 mg/l					
TEMP	NO CHANGE	NO CHANGE	NO CHANGE		NO CHANGE	85°C					
TOC	NO CHANGE	NO CHANGE	72% REMOVAL		NO CHANGE	NO CHANGE					
TSSA	0.0	NO CHANGE	76% REMOVAL		0.0	0.0					
TSSN	0.0	NO CHANGE	76% REMOVAL		0.0	0.0					
SLUDGE CONCENTRA.	10% COMPUTED BASED ON 10% SURCI REGEN RATES	2% (NH ₄) ₂ SO ₄	NO SLUDGE STREAM	3% SOLIDS IN FILTER BACKWASH	COMPUTED BASED ON SOLUBILITY OF LIMITING COMPOUND	MAX TDS IN BRINE = 200,000 mg/l					

NO CHANGE TO SOLUBLE COMPONENTS PROPORTIONAL REMOVAL OF INFLUENT PARTICULATES

RESIDUAL CONCENTRATIONS ARE EXTREMELY SMALL
COMBINED TREATMENT SYSTEM OF RO & VCE UNITS EFFLUENT AS A COMBINATION OF RO & VCE EFFECT MATRICES AND BRINE IS THE INFLUENT STREAM TO THE EVAPORATOR

- NOTE:
- THIS SUMMARY DESCRIBES THE EFFECTS OF EACH UNIT PROCESS ON SOLUBLE WASTEWATER CONSTITUENTS. EACH EFFECT MATRIX COMPUTES PARTICULATE CONSTITUENTS BASED ON INFLUENT WATER QUALITY, PROCESS-SPECIFIC WATER CHEMISTRY, AND ASSUMED EFFLUENT TSS CONCENTRATIONS
 - UNITS mg/l EXCEPT H, OH WHICH ARE MOLAR, TEMP IS IN °C AND pH NO UNITS
 - IF INFLUENT CONCENTRATION IS LESS THAN PREDICTED EFFLUENT SOLUBLE CONCENTRATION, EFFLUENT CONCENTRATION WILL EQUAL THE INFLUENT CONCENTRATION

FIGURE 13

EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE
WATER USE MODEL EFFECT MATRIX SUMMARY TREATMENT PROCESSES P-Z

SCALE NONE STATE WISCONSIN COUNTY FOREST

DRAWN BY TAG DATE _____ CHECKED BY _____ DATE _____

APPROVED BY MRH DATE _____ APPROVED BY _____ DATE _____

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051-7-L-009



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The development of these net effects required a detailed analysis of Exxon's Phase I pilot plant data to achieve an ion balance. The net effect of the Mill on water quality was computed as the difference in concentration between the particular pilot plant effluent stream and the pilot plant makeup water. Figure 9 shows the predicted net effects of the mill on mill effluent streams for both Early and Mature operations.

BACKFILL PREPARATION

Although backfill preparation is actually part of the mill, the model treats the backfill preparation area as a special type of splitter node where the tailing stream is split into two effluent streams, sands and fines. It has been assumed that no chemical reactions occur during backfill preparation.

Water and solids flow rates for both sands and fines are user supplied variables.

MINE

The mine is modelled as a modified summer node in which several solids and water streams are mixed to produce an output stream called mine discharge water. The subroutine also computes solids/water retention during backfilling and adjusts effluent ammonium and nitrate concentrations for predicted quantities of residual explosives. Potable and externally supplied tool water flow rates are user variables and are also incorporated as user supplied inputs to the mine matrix.

Contaminated water seeping into the mine will be a significant fraction of total flow pumped from the mine. The quality of this water will, in part, depend on the type of rock to which it is exposed and the time of exposure. The quality of the contaminated mine seepage water has been estimated by Exxon³¹ based on test work completed by Lakefield Research. The flow rate of contaminated mine seepage is a user variable.

The mine effect matrix does not consider uncontaminated mine seepage water (see Section IV). Since this water will be intercepted separately and discharged directly, it was decided to exclude the stream from the modeling efforts.

PONDS

The model has six nodes which are defined as ponds. These six include:

- o Tailings Pond or Impoundment
- o Reclaim Pond
- o Sand Storage on Surface
- o Surge Pond
- o Sludge Storage

Tailing Pond

The model contains two nodes where tailings can be disposed: the Tailings Pond and the tailings impoundment. The model uses the same effect matrix for each node. The effect assumes alkaline conditions will be maintained in the pond and metal solubilities will parallel those assumed in the "coprecipitation with tails" effect matrix. Summer and winter effects have also been modelled.

Reclaim Pond

Two effect matrices describing the Reclaim Pond were developed: a summer and a winter matrix. Both matrices treat the Reclaim Pond as an oxidizing reactor to remove organics and thiosulfates. Thiosulfate oxidation is reduced from 90 percent during summer months to 10 percent during the winter months. The Reclaim Pond matrix also includes an optional "pH adjustment with lime" feature to neutralize the effluent prior to being recycled. Use of this feature is a user variable.

Tailings Impoundment

When a tailings thickener is used in the model, the underflow (thickened tailings) is sent to the Tailing Impoundment node. As with the Reclaim Pond, summer and winter conditions can be modelled. The effect matrix is similar to the "coprecipitation with tails" effect matrix because it is assumed that lime will be added at the pond to maintain alkaline pH in the pond. Solids will be deposited in the pond at a user specified percent weight retention.

Sand Storage on Surface

If sands are ever stored on the surface it would be an intermittent operation. No changes in water quality, except for rain water dilution, have been assumed.

Surge Pond

No effects on water quality have been assumed for this node.

Sludge Storage

Sludge generated from water treatment is combined into a single stream and "stored." This is a "dead end" node and no effects are predicted because, in the model, the material never enters the mill circuit.

WATER TREATMENT PROCESSES

The model currently contains 22 water treatment options which can be inserted into various locations within the flow pattern. A variety of data sources were used in developing the treatment subroutines. The preferred sources of information were operating records from full-scale treatment systems at Mine/Mill complexes similar to the proposed Crandon facility. When needed information could not be obtained from these sources, it was necessary to expand the data base to include wastewater treatment results from other similar industries, pilot- or lab-scale results, and, as a last resort, theoretical predictions from engineering handbooks. Appendix A contains a complete description of the sources used in developing each of the treatment subroutines available for the Crandon Mine/Mill model.

GLT53/16

Section XII
EVALUATION OF WATER TREATMENT NEEDS

INTRODUCTION

Water requiring treatment will be generated at the Crandon Project starting at the time shaft sinking operations commence and ending some time after shutdown of the mill. Obviously, during the life of the project, both the quality and quantity of wastewater will vary.

For the purpose of sizing and confirming the capacity and design of a proposed water treatment system for the Crandon Project, three time periods were selected for evaluation:

- o Mine Development
- o Early Mill Operation
- o Mature Mill Operation

A system sized to treat waters generated in these three time periods will have adequate capacity for all other foreseen conditions.

MINE DEVELOPMENT

During the first 3 years of construction, the primary source of contaminated water will be water pumped from the mine as it is developed. The mill will be under construction during this period so will not be in operation.

The Crandon Water Use Model was set up to model the full-scale Mine/Mill operation. Assessments of wastewater quality and quantity during the mine development period, therefore, were computed manually. Through use of a special "stand-alone" subroutine, it was possible to use the computer treatment effect matrices to predict treatment system performance during this time period.

Sources of contaminated wastewater during the mine development period are summarized as follows:

- o Contaminated mine seepage will start at approximately 18 months after commencement of shaft sinking. Exxon projects that this flow rate will start at approximately 113.5 m³/hr (500 gpm) during the second year of construction, and increase to 227.1 m³/hr (1,000 gpm) during the third year of construction. After the third year, the maximum predicted seepage potential is about

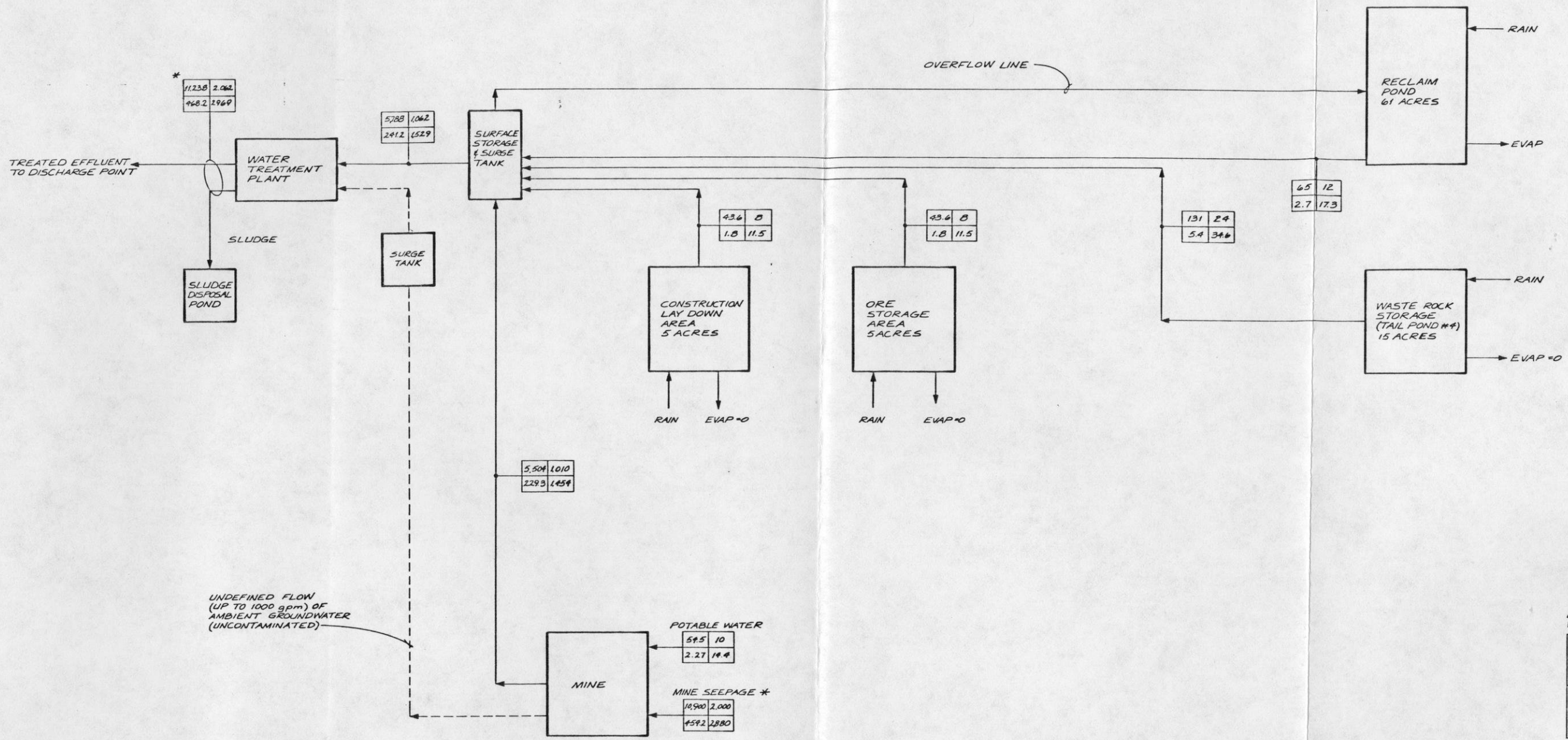
2,000 gpm, including up to 1,000 gpm of ambient groundwater (uncontaminated mine seepage) and 1,000 gpm of contaminated mine seepage. The uncontaminated mine seepage was not considered in the model studies.

- o Ten gpm of potable water will be used in the mine.¹
- o Ore rock brought to the surface during the mine development period will be stored on a 5-acre site near the mine. This area will also be used for equipment laydown. Runoff from this site will be collected and routed to the treatment system.²⁹
- o Waste rock (and potentially some excess ore rock) will be stored on a 10-acre site in the vicinity of Tailings Pond No. 4. During the mine development period, runoff from this site will be collected and routed to the treatment system.²⁹
- o During the mine development period, a 5-acre site near the mine will be used for equipment laydown. Ore or waste rock may also be present. During the mine development period, runoff from this site will be collected and routed to the wastewater treatment system.
- o After the Reclaim Pond is constructed, it will be used as a surge pond. Rainfall into the pond will be collected and routed to the wastewater treatment system.

The estimated quality of contaminated mine seepage water is as described earlier. Exxon's projections of water quality for the miscellaneous runoff areas are summarized in Appendices C and F.

Figure 14 illustrates a block flow diagram of water collection and treatment during the mine development period. The flow rates shown are representative of construction year 3, when mine seepage is projected to peak.

Surge volume will have to be provided upstream from the water treatment system to attenuate short-term fluctuations in mine water flow rates. By the second year of construction, when mine seepage flow rates are expected to start rising, the Reclaim Pond will be ready to provide additional surge volume.



UNDEFINED FLOW (UP TO 1000 gpm) OF AMBIENT GROUNDWATER (UNCONTAMINATED)

* INCLUDES UP TO 1000 gpm OF UNCONTAMINATED SEEPAGE

LEGEND: WATER FLOW RATES

MTPD	GPM
m ³ /hr	TGD

AVERAGE ANNUAL RAINFALL = 30.77 IN/YR.
 AVERAGE ANNUAL EVAPORATION = 23.36 IN/YR.

FIGURE 14

EXXON MINERALS COMPANY
 CRANDON PROJECT

TITLE
 MINE DEVELOPMENT PERIOD
 WATER BALANCE

REVISED	DATE	BY	DESCRIPTION



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DRAWN BY: DLA	DATE: _____	CHECKED BY: _____
APPROVED BY: MKH	DATE: _____	DATE: _____
APPROVED BY: _____	DATE: _____	DATE: _____
DATE: _____	DATE: _____	DATE: _____
051-7-L-010	SHEET OF _____	REVISION NO. _____

Each surface area with potentially contaminated runoff will be designed to contain runoff from storm events, so the treatment system surge tanks need not be sized for containment of peak runoff volumes. The runoff flow rates shown on Figure 14 are shown as annual average flow rates.

EARLY MILL OPERATION

During approximately the first year of mill operation, it is possible that only massive ore will be processed. As described in Section XI, the anticipated water chemistry in the mill water circuit is expected to be different in this time period than in subsequent years when both massive and stringer ores will be processed.

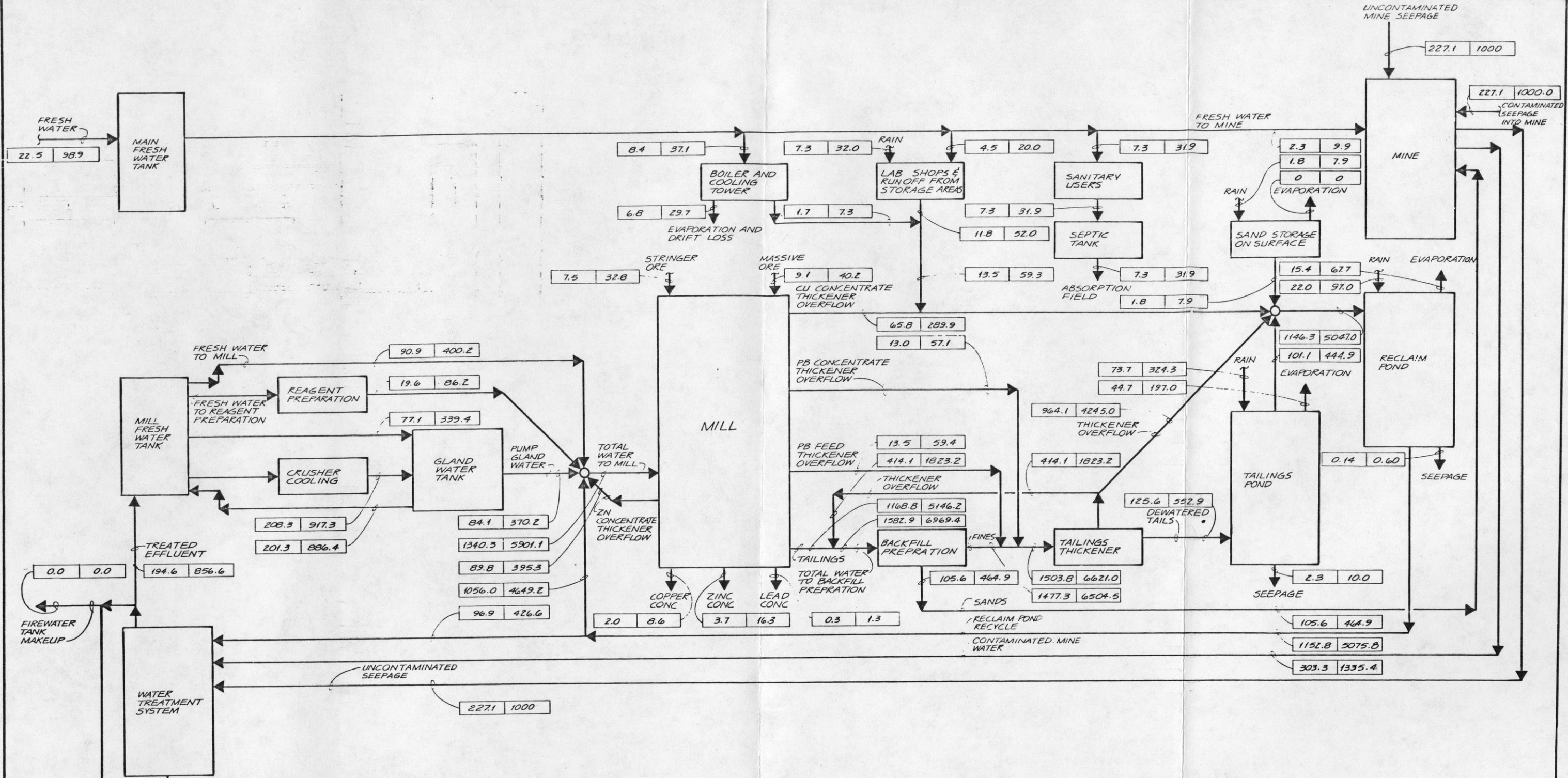
Figure 15 illustrates a block flow diagram for the Mine/Mill water system during Early operation of the mill. The flow rates illustrated are based on preliminary runs of the water use model. Final "blowdown" from the mill water circuit to a) the mine via backfill water and b) directly to the water treatment system from the Reclaim Pond have been optimized to mitigate scaling within the mill water circuit. As shown in Figure 15, all process water requirements are met with either untreated or treated recycle water. No fresh water (other than potable, lab, and boiler makeup) is used in the mill.

For the purposes of predicting precipitation rates on the tailings ponds, it was assumed that only Tailings Pond No. 1 would be active during Early mill operation.

MATURE MILL OPERATION

Figure 16 illustrates a block flow diagram for the Mine/Mill water system during Mature operation of the mill. The flow rates illustrated are based on preliminary runs of the water use model. Final blowdown from the mill water circuit has been optimized to mitigate scaling within the mill circuit. As shown on Figure 16, all process water requirements are again met with either treated or untreated recycle water.

For the purpose of modeling Mature operation of the mill, it was decided to select the time period when both Tailings Pond Nos. 2 and 3 are active (i.e., the brief period when pond No. 2 is virtually full and ready for reclamation and pond No. 3 has been completed and is or is about to be placed in service). In this period of time, the maximum pond area will be "open" to collect precipitation.



NOTE: THIS DOES NOT INCLUDE ALLOWANCE FOR WATER ADDED WITH REAGENTS

KEY
 m³/hr gpm ALL FLOWS SHOWN ARE ANNUAL AVERAGE RATES

FIGURE 16

EXXON MINERALS COMPANY		CRANDON PROJECT	
TITLE OVERALL WATER BALANCE FOR CRANDON PROJECT - MATURE SUMMER OPERATION			
SCALE NONE	STATE WISCONSIN	6/2/77 FOREST	
DESIGNED BY DLA	DATE	CHECKED BY	DATE
APPROVED BY MRH	DATE	APPROVED BY	DATE
APPROVED BY	DATE	EXXON	DATE
DRAWING NO. 051-7-L-012	SHEET	OF	



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SUMMER VERSUS WINTER OPERATION

All preliminary model runs, as necessary to establish treatment system sizing criteria, were made assuming "summer" conditions. Under summer conditions, thiosalt oxidation in the Reclaim Pond is maximized, thereby maximizing sulfate buildup within the mill water circuit (See Section XIII).

The water treatment system selected for the Crandon Project will also operate in winter months when thiosulfate oxidation rates are reduced. Since less sulfate will be generated (i.e, less thiosulfate is oxidized) less blowdown may be required during winter months. The treatment system selection process must, however, consider the fact that increased concentrations of thiosulfate must be dealt with in the winter months.

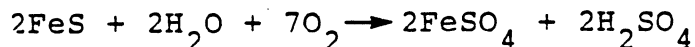
GLT53/17

FACTORS INFLUENCING RECYCLE RATE

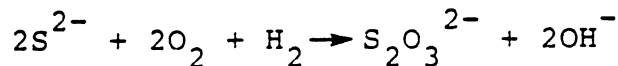
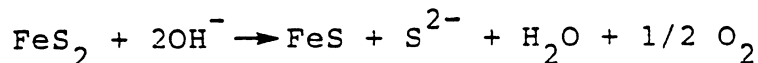
Recycling of water, in the context of this report, means the direct reuse of process water or the reuse of treated water. One hundred percent recycle would mean that all process water requirements are made up with water recycled directly within the mill facility, water recycled from the Reclaim Pond, or treated water from the treatment facility. With this definition of "recycle rate," it is possible to have 100 percent recycle and still have a discharge of excess water.

The "base case" Mill water balance presented in Section VII was formulated without regard for water chemistry in a high-recycle water circuit. Fresh water influent flow rates to the Mill were based on the absolute minimum requirements for fresh (or highly purified) water. The "base case" water balance was prepared prior to modeling of water chemistry at equilibrium conditions.

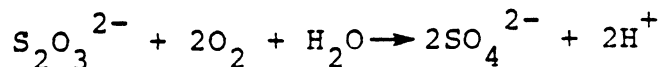
The Crandon orebody contains high concentrations of pyrite (FeS₂). Water which contacts the ore leaches out sulfates in accordance with the following reaction:²⁵



Alkaline grinding and flotation of sulfide ores have also been shown to generate partially oxidized sulphur compounds known as thiosalts.²² Production of thiosulfate occurs through the following reactions:²³



When thiosulfate (S₂O₃²⁻) is discharged to the tailings/reclaim pond system, it is biologically oxidized in accordance with the following reaction:²⁴



Milk-Of-Lime [Ca(OH)₂] will be added for pH adjustment in numerous locations throughout the Crandon Mill.³ Some lime will be rejected from the water system in the ore concentrates and in retained water in tailings and sands. A large

fraction of the total calcium added, however, will remain in solution as soluble Ca^{2+} .

As evidenced by the above reactions, water within the Mine/Mill system gains an incremental increase in the concentrations of Ca^{2+} and SO_4^{2-} each time water passes through the system. The effect matrices developed for the Mill and pond system predict this anticipated increase of these two constituents. In a completely closed-loop system, the concentrations of Ca^{2+} and SO_4^{2-} would rise until the solubility product of CaSO_4 (calcium sulfate) would be exceeded.²⁶ If this were to occur, severe scaling problems could occur in the Mill's piping system.

The water use model is set up to check the scaling potential of CaSO_4 in each link in the Mine/Mill model based on the Marshall Slusher³⁰ scaling model.

Manual checks for scaling conditions due to buildup of BaSO_4 (barium sulfate), silica (SiO_2), CaCO_3 (calcium carbonate),⁴ and CaF_2 (calcium fluoride) have also³ been completed. The predicted concentrations of these compounds, however, are quite low and do not appear to create the same degree of scaling problems as does calcium sulfate.

In addition to scaling problems, high recycle rates will result in a buildup of reagents or degradation products within the Mill water circuit. An exact definition of the permissible "buildup" of spent reagent concentrations is very difficult, but several Canadian mills report¹ that, at a recycle rate of raw, untreated water of approximately 70 to 80 percent, performance of the concentration processes are impaired. These other mills report that the problems are probably caused by a buildup of xanthates, frothers, copper, and potentially cyanides, all of which interfere with the ore flotation processes in the mill.

EVALUATION OF ZERO DISCHARGE

One of the primary goals of the Water Management Study was to identify potential treatment technologies to achieve, as closely as technically practical, a "zero discharge" of water from the Mine/Mill operation, or to produce an effluent for discharge that will meet or exceed effluent limitations.

Zero discharge of water from the Crandon Project cannot be achieved. Since public perceptions of proposed water

management policies may be important to acceptance of the EIR for the Crandon Project, it is important to explain why a discharge of treated effluent is absolutely necessary.

Under mature Mine/Mill operating conditions (See Figure 16, Section XII), and an ore throughput of 9,555 MTPD, water "sources" (See Section IV) to the Mine/Mill water circuit include:

<u>Stream</u>	<u>Flow Rate</u> <u>m³/hr (gpm)</u>
Well water to boiler and cooling tower	8.4 (37.1)
Well water to potable water system	7.3 (31.9)
Well water used in labs	4.5 (20.0)
Well water used in the Mine	2.3 (9.9)
Rainfall on tailings/reclaim ponds	95.7 (421.3)
Rainfall on miscellaneous surface storage areas	9.1 (39.9)
Mine seepage	454.2 (2,000.0)
Bound water in unprocessed ore from the Mine	<u>16.6 (73.0)</u>
TOTAL	598.1 (2,633.1)

Water "retained" within the Mine/Mill/Pond system includes:

<u>Stream</u>	<u>Water Retained</u> <u>m³/hr (gpm)</u>
Tailings Pond	51.2 (225.3)
Mine backfill	<u>31.7 (139.3)</u>
TOTAL	82.9 (364.6)

Water "lost" or "discharged" from the system includes:

<u>Stream</u>	<u>Flow Rate</u> <u>m³/hr (gpm)</u>
Effluent discharge (including sludges and/or brines)	432.7 (1,905.4)
Seepage from pond system	2.4 (10.6)
Evaporation from pond system	60.1 (264.7)
Water in ore concentrates	6.0 (26.2)
Evaporation losses, boiler, and cooling tower	6.8 (29.7)
Sanitary wastewater	<u>7.3 (31.9)</u>
TOTAL	515.3 (2,268.5)

In the previous summary of the Mature Mine/Mill water balance, the only uses of fresh well water are for potable water, laboratory use, and boiler makeup (a total of only 22.5 m³/hr). All mill process water requirements are met with internal recycle, Reclaim Pond effluent recycle, or with recycled treated effluent. Even with 100 percent recycle, there is a net discharge of over 200 m³/hr. This net discharge is a result of net precipitation over evaporation on the pond system and of the predicted flow rates of mine seepage water. There is no technically feasible method to achieve zero discharge from the site.

CRITERIA FOR EVALUATION OF TREATMENT SYSTEMS

Potential effluent discharge limitations (Section IX) necessitate a sophisticated water treatment system for the Crandon Project. The goal of maximizing recycle to the mill imposes additional constraints on the types of technologies which may be used.

Since there are a variety of treatment technologies which could be used at the Crandon Project, it was necessary to establish a set of screening criteria to determine which potential treatment systems meet the needs of the Crandon Project.

In consultation with Exxon, it was agreed that the treatment system selected for the Crandon Project must:

- o Produce an effluent which meets or exceeds the higher quality of a) water quality based effluent limits proposed by the Wisconsin DNR, b) NSPS standards, or c) primary and secondary drinking water standards; and further satisfy all other identified State and Federal regulations.
- o Provide for removal of scale forming compounds (such as Ca, SO₄, and SiO₂) to permit 100 percent recycle water use in the mill, thereby minimizing the volume of effluent discharged to the environment.
- o Provide a cost-effective solution to water treatment needs which will not adversely affect overall project economics. Performance of the water treatment system must be ensured to protect Exxon's investment in the project.

- o Use proven technology, for ease of permit acquisition for the facilities.
- o Be flexible with respect to influent water quality, (i.e., the treatment system should be capable of meeting effluent quality goals even if influent water quality were different than projected).
- o Be compatible with various stages of Mine/Mill development.
- o Remove thiosalts from the water during winter operations.
- o Remove organics (unoxidized or partially oxidized reagents) from the water if they prove to be a problem with performance of the system.
- o Remove all metals to trace concentrations.
- o Produce sludges which can be disposed of in an environmentally acceptable manner.
- o If possible, produce a marketable byproduct.

RISK ANALYSIS

Regardless of the treatment system selected for the Crandon Project, it is important to recognize that this Water Management Study is based on a number of engineering judgments and assumptions. After identification of viable alternatives (as defined by the criteria above), it was believed appropriate to perform a "risk analysis" to further screen alternatives.

The "risk analysis" was designed to protect Exxon from both "ends" of the risk spectrum:

- o If full-scale operations prove that key assumptions were optimistic, the system should still meet the desired goals, and
- o If full-scale operations prove that key assumptions were too conservative, the system should be capable of meeting the desired goals at a reasonable cost.

The major items identified as appropriate for the risk analysis are summarized as follows:

- o What key assumptions have been made which, if in error, would or could change the selection of treatment unit processes? Examples include:
 - mine seepage water quality
 - thiosalt generation rate in the Mill and/or oxidation rate in the Reclaim Pond
 - mill "effect" on water quality
 - organic concentrations in Reclaim Pond effluent
 - metals removal in tailings thickener

- o If key assumptions are in error, what compounds could pass through the treatment system which could adversely affect the environment? Examples include:
 - water quality based surface water discharge limitations
 - primary drinking water standards
 - secondary drinking water standards
 - NSPS standards
 - Hexavalent chrome
 - Ca or SO₄ (i.e., compounds which could cause post precipitation of CaSO₄ or CaCO₃)
 - Thiosalts
 - Organics

- o If key assumptions are in error, what compounds could pass through the treatment system which could adversely affect performance of the mill? Examples include:
 - Organics
 - Copper
 - Thiosalts
 - Any corrosive and/or scale forming compounds

- o Is the treatment system sufficiently flexible that, with minor modifications, it can meet treatment goals even if influent water quality is different than anticipated?

- o If key assumptions regarding influent water quality are incorrect, would the method of sludge/brine/residue disposal have to be changed?



Section XIV
EVALUATION OF WATER TREATMENT ALTERNATIVES

INTRODUCTION

The Crandon Project Water Use Model was used extensively to evaluate alternative recycle options within the Mine/Mill complex. A final effluent/recycle treatment system is required to treat water for discharge to the environment and to control scaling in water recycled to the mill. After evaluating several treatment schemes, it was jointly agreed between Exxon and CH2M HILL that the treatment system should be sized to treat a) all water pumped from the mine, and b) sufficient water from the Reclaim Pond to reduce scaling within the mill circuit. This particular flow pattern (see Figures 15 and 16, Section XII) was selected because:

- o By treating all water pumped from the mine (rather than recycling it to the Reclaim Pond), the size of the Reclaim Pond can be kept to a minimum, thereby reducing environmental impacts of the pond
- o By treating only a small fraction of the water from the Reclaim Pond, it is possible to "contain" the maximum quantity of reagents within the mill circuit. Although organic reagents should be oxidized or otherwise decomposed in the Reclaim Pond, high concentrations could potentially be troublesome at the treatment system.

A cyanide oxidation process may be required for treatment of the lead concentrate thickener overflow. This stream is only 13 m³/hr (57.1 gpm), and Exxon's Phase I pilot plant data indicated that it contained a relatively high concentration of cyanide. Effective in-plant control of reagent addition, however, should virtually eliminate cyanide in this stream. This type of control was not possible in the pilot plant. It is not currently believed that cyanide oxidation will be necessary, but treatment options were evaluated in case a retro-fit treatment system were to be required.

A large number of individual treatment technologies were evaluated for potential application to the Crandon Project. In combination, these various technologies can be used to form a number of treatment "trains" or "systems" to provide water treatment.

This section of the report describes the various water treatment systems evaluated for the Crandon Project and further describes the logic used in making the final selection of the preferred treatment system.

TREATMENT ALTERNATIVES FOR FINAL EFFLUENT/RECYCLE

By far the most important consideration in the water management plan for the Crandon Project is the water treatment system selected for treatment of final effluent. Treated water from this system will be used as mill process water makeup to the maximum extent possible and excess treated water will be discharged to the environment.

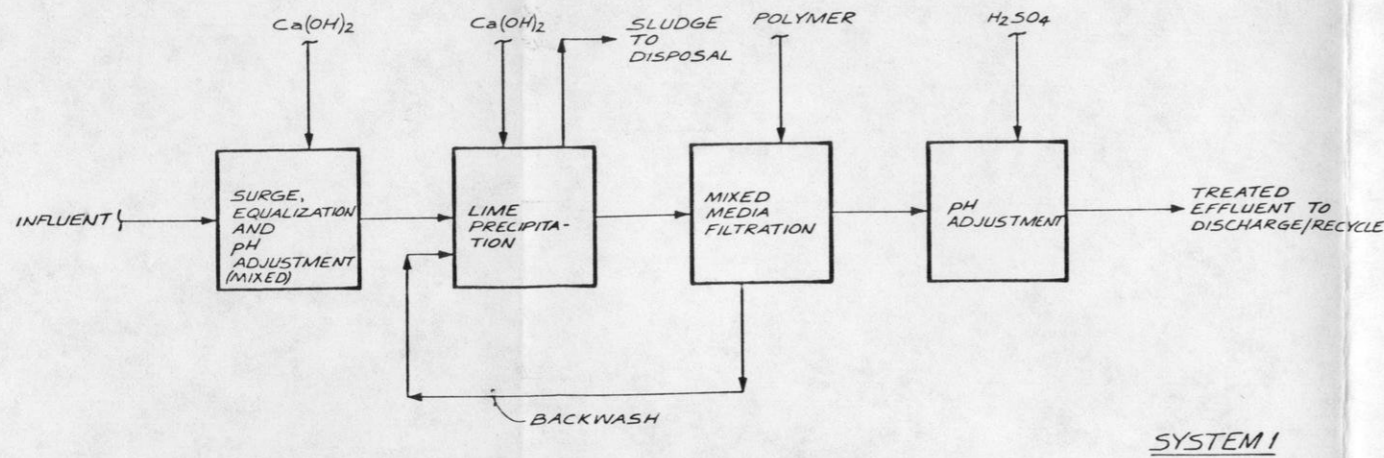
Figures 17 and 18 illustrate block flow diagrams of ten potential treatment systems which could be used at the Crandon Project. These systems range from simple state-of-the-art treatment to complex and/or innovative treatment systems which are more sophisticated than normally used for treatment of Mine/Mill waters.

PRELIMINARY SCREENING OF TREATMENT ALTERNATIVES

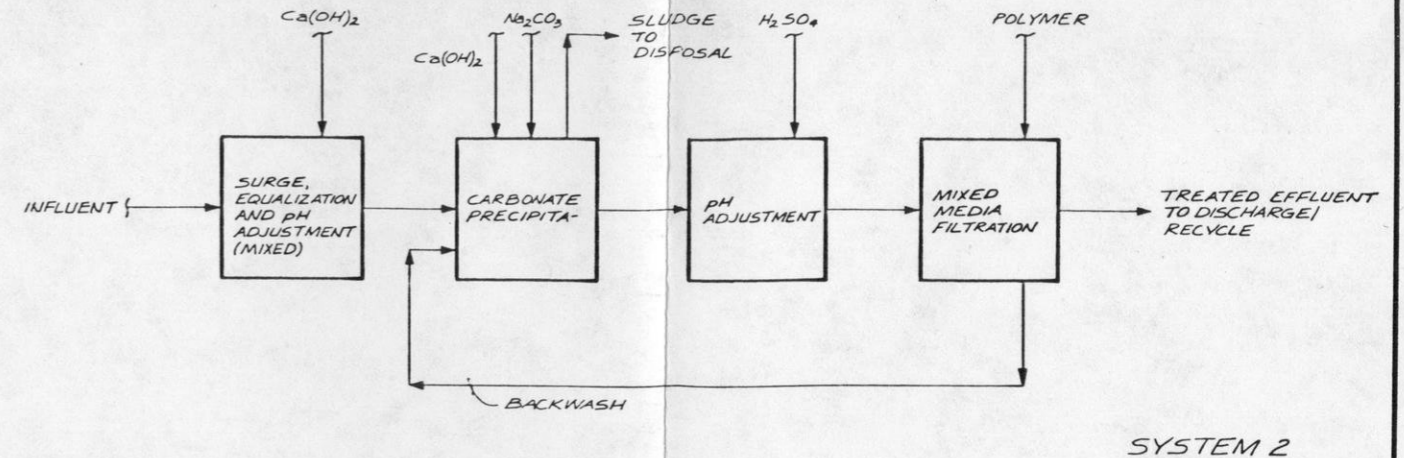
As discussed in Section XIII, the treatment system selected for the Crandon Project must meet a stringent set of criteria developed for evaluation of water treatment alternatives. Figure 19 illustrates a comparison of each of the considered treatment systems with the criteria developed previously.

Figure 19 contains a subjective comparison of the capital and annual O&M costs of the various systems. Throughout the Phase III Water Management Study, a number of cost comparisons and estimates were prepared for different treatment systems and different overall recycle flow patterns. Not all of the considered systems were estimated for each recycle option. The costs presented in Figure 19, therefore, are shown as "relative" costs between the systems rather than "absolute" costs.

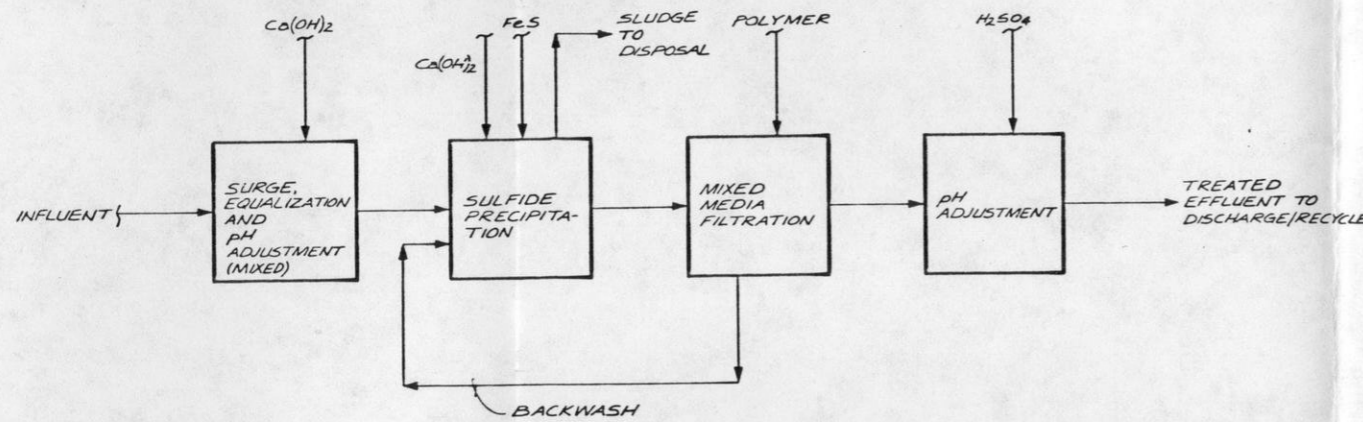
The following paragraphs present a discussion of each system in terms of the criteria developed for the selection of a treatment system for the project.



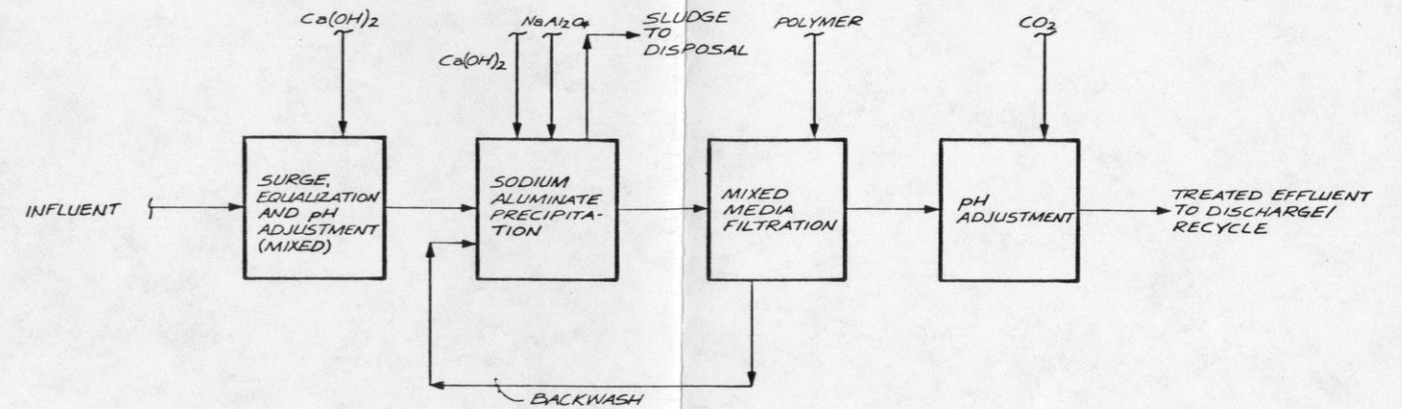
SYSTEM 1



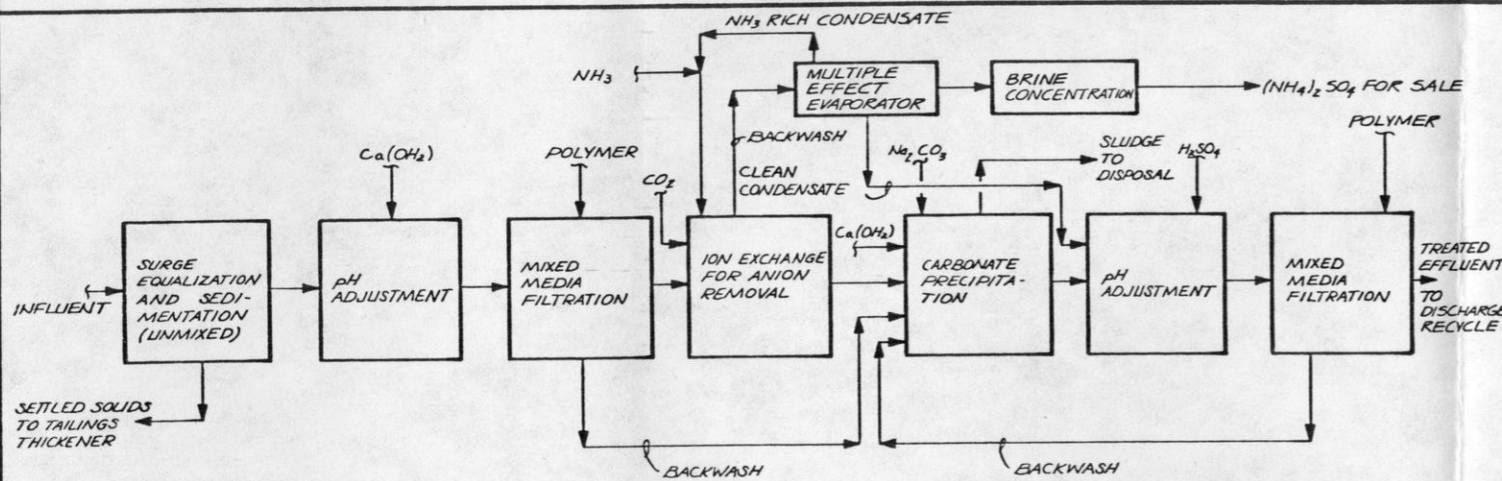
SYSTEM 2



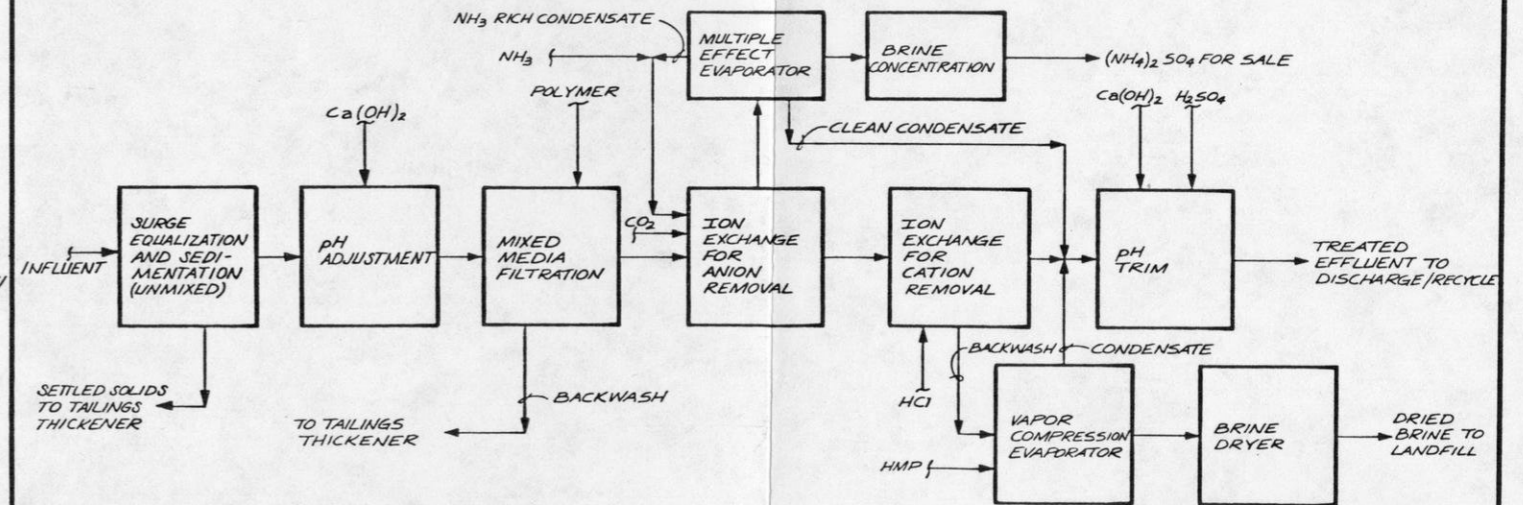
SYSTEM 3



SYSTEM 4



SYSTEM 5



SYSTEM 6 FIGURE 17

EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE
BLOCK FLOW DIAGRAMS
WATER TREATMENT
ALTERNATIVES 1-6

REVISED	DATE	BY	DESCRIPTION

SCALE NONE STATE WISCONSIN COUNTY FOREST

DRAWN BY MJL DATE CHECKED BY DATE

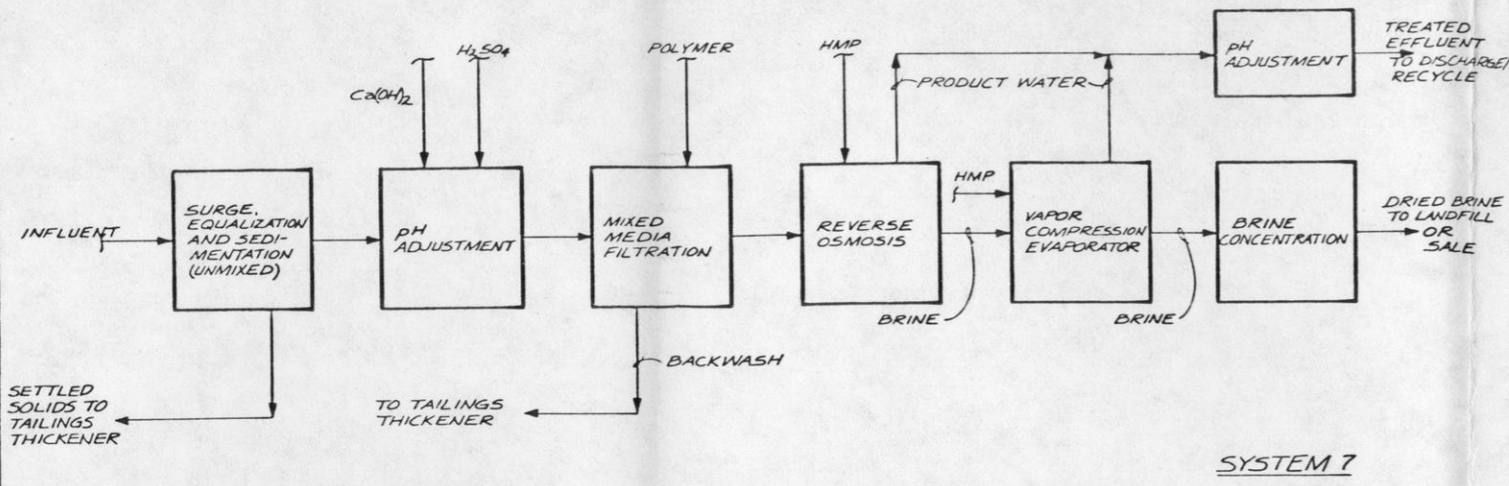
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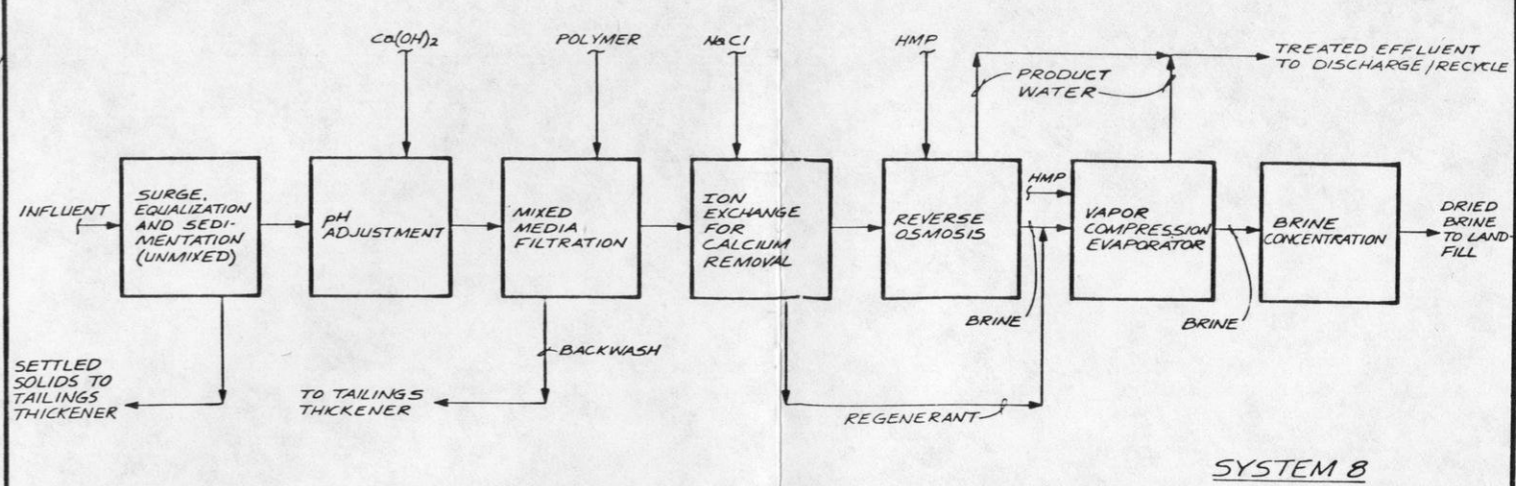
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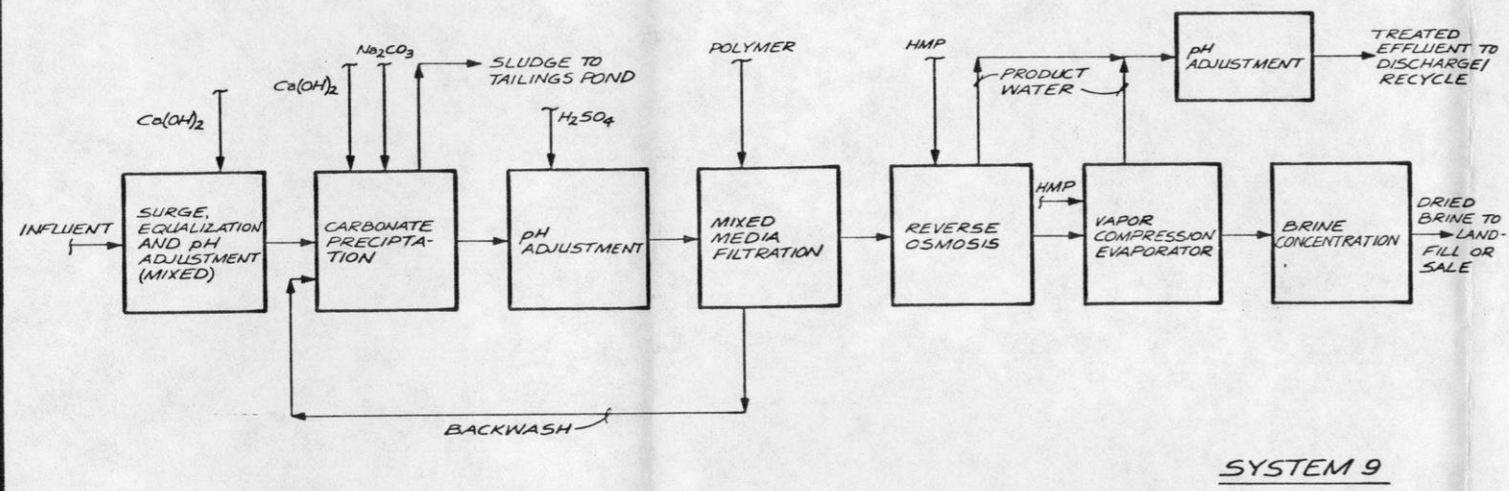
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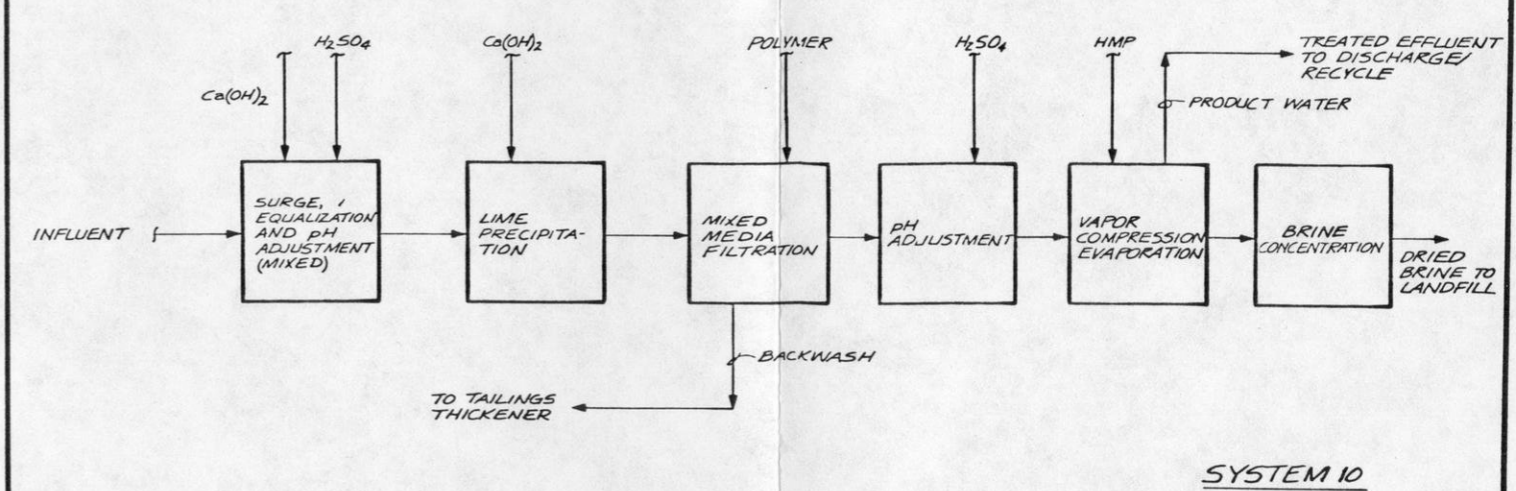
SYSTEM 7



SYSTEM 8



SYSTEM 9



SYSTEM 10

FIGURE 18

EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE
BLOCK FLOW DIAGRAMS
WATER TREATMENT
ALTERNATIVES 7-10

SCALE NONE STATE WISCONSIN COUNTY FOREST

DRAWN BY: M.J.L. DATE: _____ CHECKED BY: _____ DATE: _____

APPROVED BY: MRH DATE: _____ APPROVED BY: _____ DATE: _____

APPROVED BY: _____ DATE: _____ EXXON DATE: _____

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SYSTEM NUMBER	MAJOR UNIT PROCESSES IN TREATMENT SYSTEM	EFFLUENT QUALITY			REMOVAL OF SCALE FORMING COMPOUNDS	CAPITAL COST	ANNUAL O&M COST	STATUS OF TECHNOLOGY	FLEXIBILITY WITH INFLUENT WATER QUALITY	COMPATIBLE WITH VARIOUS MINE/MILL PHASES	REMOVAL OF THIOSALTS	REMOVAL OF ORGANICS	REMOVAL OF METALS	SLUDGE/BRINE PROPERTIES	POTENTIAL FOR BYPRODUCT RECOVERY	COMMENTS
		PRIMARY AND SECONDARY DRINKING WATER STANDARDS	NSPS STANDARDS	SURFACE WATER QUALITY BASED LIMITATIONS												
1	LIME PRECIPITATION FILTRATION pH ADJUSTMENT	WILL PROBABLY EXCEED SEVERAL PRIMARY STANDARDS AND SECONDARY STANDARDS FOR SO ₄ , TDS, Fe, Mn	SHOULD MEET ALL STANDARDS	WILL EXCEED SEVERAL STANDARDS	NO REMOVALS NET INCREASE OF Ca	LOWEST OF ALL SYSTEMS	VERY LOW	STATE-OF-THE-ART FOR MINE/MILL WASTEWATER	N.A. - DOES NOT MEET EFFLUENT GOALS	YES	NO	NO	GOOD	COULD BE ROUTED TO TAILINGS POND	NONE	DOES NOT MEET CRITERIA
2	CARBONATE PRECIPITATION pH ADJUSTMENT FILTRATION	WILL PROBABLY EXCEED SEVERAL PRIMARY STANDARDS AND SECONDARY STANDARDS FOR SO ₄ & TDS	SHOULD MEET ALL STANDARDS	WILL EXCEED SEVERAL STANDARDS	REMOVES Ca	LOW	LOW	WELL DEVELOPED TECHNOLOGY IN WIDESPREAD USE	N.A. - DOES NOT MEET EFFLUENT GOALS	YES	NO	NO	GOOD	COULD BE ROUTED TO TAILINGS POND	NONE	DOES NOT MEET CRITERIA
3	SULFIDE PRECIPITATION FILTRATION pH ADJUSTMENT	WILL PROBABLY MEET PRIMARY STANDARDS EXCEPT FOR Se BUT WILL PROBABLY EXCEED SECONDARY STANDARDS FOR SO ₄ , Fe, & TDS	SHOULD MEET ALL STANDARDS	WILL EXCEED SEVERAL STANDARDS	NO REMOVALS NET INCREASE OF SO ₄	LOW	LOW	LIMITED FULL SCALE APPLICATIONS	N.A. - DOES NOT MEET EFFLUENT GOALS	YES	NO	NO	VERY GOOD	COULD BE ROUTED TO TAILINGS POND	NONE	DOES NOT MEET CRITERIA
4	SODIUM ALUMINATE PRECIPITATION FILTRATION pH ADJUSTMENT	WILL PROBABLY EXCEED SEVERAL PRIMARY STANDARDS AND SECONDARY STANDARD FOR TDS	SHOULD MEET ALL STANDARDS	WILL EXCEED SEVERAL STANDARDS	REMOVES Ca & SO ₄	LOW	EXTREMELY HIGH	EXPERIMENTAL, NO FULL SCALE INSTALLATIONS	N.A. - DOES NOT MEET EFFLUENT GOALS	YES	NO	NO	GOOD	EXTREMELY LARGE VOLUME WOULD HAVE TO BE DEWATERED AND LANDFILLED	NONE	DOES NOT MEET CRITERIA
5	FILTRATION ION EXCHANGE - ANION REMOVAL CARBONATE PRECIPITATION pH ADJUSTMENT FILTRATION	WILL PROBABLY EXCEED SEVERAL PRIMARY STANDARDS AND SECONDARY STANDARD FOR Fe	SHOULD MEET ALL STANDARDS	WILL EXCEED SEVERAL STANDARDS	REMOVES Ca & SO ₄	MODERATE	MODERATE	LIMITED FULL SCALE APPLICATIONS. NONE ON MINE/MILL WASTEWATERS	N.A. - DOES NOT MEET EFFLUENT GOALS	YES	YES	SOME REMOVALS, BUT HIGH ORGANICS COULD FOUL RESINS	GOOD	OFFSITE DISPOSAL OF DRIED I-X REGENERATION BRINE. CARBONATE SLUDGE COULD BE ROUTED TO TAILINGS POND	BRINE FROM I-X ANION COULD BE SOLD AS FERTILIZER. CONTAINS (NH ₄) ₂ SO ₄	DOES NOT MEET CRITERIA
6	SEDIMENTATION FILTRATION ION EXCHANGE - ANION REMOVAL ION EXCHANGE - CATION REMOVAL pH ADJUSTMENT	SHOULD MEET ALL STANDARDS	SHOULD MEET ALL STANDARDS	SHOULD MEET ALL STANDARDS	REMOVES Ca, Ba & SO ₄	MODERATE	HIGHEST OF ALL SYSTEMS	DEMINERALIZER TECHNOLOGY IS IN WIDESPREAD USE, BUT APPLICATION TO CONCENTRATED WASTE STREAMS IS NOT	HIGHER THAN ANTICIPATED CONCENTRATIONS OF ORGANICS, Fe, S ₂ O ₃ COULD CREATE RESIN FOULING	YES	YES	SOME REMOVALS, BUT HIGH ORGANICS COULD FOUL RESINS	EXCELLENT	OFF-SITE DISPOSAL OF DRIED ANION I-X REGENERATED BRINE. CATION I-X BRINE WOULD REQUIRE SPECIAL LANDFILL SITE	BRINE FROM I-X ANION COULD BE SOLD AS FERTILIZER. CONTAINS (NH ₄) ₂ SO ₄	APPEARS TO MEET CRITERIA
7	SEDIMENTATION FILTRATION REVERSE OSMOSIS VAPOR COMPRESSION EVAPORATION	SHOULD MEET ALL STANDARDS	SHOULD MEET ALL STANDARDS	SHOULD MEET ALL STANDARDS	REMOVES ALL SCALE FORMING COMPOUNDS	VERY HIGH	HIGH	WELL DEVELOPED TECHNOLOGY IN GENERAL USE	HIGHER THAN ANTICIPATED CONCENTRATIONS OF Ca OR SO ₄ COULD LIMIT R.O. THROUGHOUT. HIGH INFLUENT Fe COULD FOUL MEMBRANE	YES	YES	GOOD REMOVALS IN R.O. BUT SOME CARRY-OVER COULD OCCUR IN VCE	EXCELLENT	DRIED BRINE WOULD REQUIRE A SEPARATE LANDFILL	NONE	MEETS MOST CRITERIA
8	SEDIMENTATION FILTRATION ION EXCHANGE - CALCIUM REMOVAL REVERSE OSMOSIS VAPOR COMPRESSION EVAPORATION	SHOULD MEET ALL STANDARDS	SHOULD MEET ALL STANDARDS	SHOULD MEET ALL STANDARDS	REMOVES ALL SCALE FORMING COMPOUNDS	HIGH	MODERATE	INDIVIDUAL TECHNOLOGIES ARE WELL DEVELOPED, BUT THIS IS A RELATIVELY UNIQUE COMBINATION NOT USUALLY USED ON RAW WASTEWATER	HIGHER THAN ANTICIPATED Fe OR ORGANICS COULD FOUL RESIN AND/OR RO MEMBRANE	YES	YES	HIGH ORGANICS COULD FOUL RESIN. GOOD REMOVALS IN R.O. BUT SOME CARRY-OVER COULD OCCUR IN VCE	EXCELLENT	DRIED BRINE WOULD REQUIRE A SEPARATE LANDFILL	NONE	MEETS MOST CRITERIA
9	CARBONATE PRECIPITATION pH ADJUSTMENT FILTRATION REVERSE OSMOSIS VAPOR COMPRESSION EVAPORATION	SHOULD MEET ALL STANDARDS	SHOULD MEET ALL STANDARDS	SHOULD MEET ALL STANDARDS	REMOVES ALL SCALE FORMING COMPOUNDS	HIGH	HIGH	WELL DEVELOPED TECHNOLOGIES. FULL SCALE WASTEWATER SYSTEMS IN OPERATION	VERY FLEXIBLE	YES	YES	GOOD REMOVALS IN R.O. BUT SOME CARRY-OVER COULD OCCUR IN VCE	EXCELLENT	CARBONATE SLUDGE COULD BE ROUTED TO TAILINGS POND. DRIED BRINE COULD BE LANDFILLED OR DISPOSED OFF-SITE	VCE BRINE IS ALMOST ALL SODIUM SULFATE (Na ₂ SO ₄). POSSIBLE MARKETS ARE KRAFT PULP AND PAPER MILLS AND THE DETERGENT INDUSTRY	MEETS ALL CRITERIA
10	LIME PRECIPITATION pH ADJUSTMENT FILTRATION VAPOR COMPRESSION EVAPORATION	SHOULD MEET ALL STANDARDS	SHOULD MEET ALL STANDARDS	SHOULD MEET ALL STANDARDS	REMOVES ALL SCALE FORMING COMPOUNDS	HIGHEST OF ALL SYSTEMS	EXTREMELY HIGH	TECHNOLOGY IS WELL DEVELOPED BUT IS USUALLY PRECEDED BY R.O. (EXTREMELY COSTLY IF USED ALONE)	PERFORMANCE ALMOST INDEPENDENT OF INFLUENT QUALITY	YES	YES	SOME CARRY-OVER COULD OCCUR IN VCE	EXCELLENT	DRIED BRINE WOULD REQUIRE A SEPARATE LANDFILL	NONE	MEETS ALL CRITERIA

FIGURE 19

EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE
COMPARISON OF TREATMENT ALTERNATIVES WITH PROJECT-SPECIFIC CRITERIA

SCALE NONE STATE WISCONSIN COUNTY FOREST

DRAWN BY ELS DATE CHECKED BY DATE

APPROVED BY MRH DATE APPROVED BY DATE

APPROVED BY DATE EASON DATE

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System 1 - Lime Precipitation/Filtration/pH Adjustment

This technology is acknowledged by the EPA¹⁴ as state-of-the-art for treatment of mine/mill wastewaters. This technology was used by the EPA in the development of BPCTCA and BATEA regulations for the mining/milling industry.

Although this is the least costly treatment system considered for the Crandon Project, it cannot be considered viable because:

- o Projected effluent quality would exceed several potential effluent limitations.
- o This system would not remove either calcium or sulfate and, therefore, could not be used to control scaling.
- o This system would not remove thiosalts, thereby creating the need for some "add-on" unit operation during winter months.

System 2 - Carbonate Precipitation/pH Adjustment/Filtration

This system is similar to System 1, except that carbonate precipitation (single stage lime-soda softening) is used instead of lime precipitation. Removal of metals would be similar to System 1 and, in addition, calcium would be removed as calcium carbonate.

This system is comparable in capital and O&M cost to System 1, but must also be dropped from consideration because:

- o Projected effluent quality would exceed several potential effluent limitations.
- o This system would not remove sulfate and localized scaling could become a problem where lime is added in the mill circuit.
- o This system would not remove thiosalts, thereby creating the need for some "add-on" unit operation during winter months.

System 3 - Sulfide Precipitation/Filtration/pH Adjustment

Sulfide precipitation can achieve lower concentrations of metals than can lime or carbonate precipitation. This

system is also comparable in capital and O&M costs with System 1, but must be dropped from consideration because:

- o Projected effluent quality would exceed several potential effluent limitations.
- o This system would not remove calcium or sulfate.
- o Although this system represents proven technology in other industries with low volume, high-concentration wastewater, there are no installations treating mining waters.
- o This system does not remove thiosalts.

System 4 - Sodium Aluminate Precipitation/Filtration/pH Adjustment

The primary "advantage" of this system over System 1, is that both calcium and sulfate would be removed. Performance with respect to metals would be comparable to lime precipitation.

This system is comparable in capital cost to lime precipitation, but annual reagent costs (primarily sodium aluminate) would be extremely high. In addition to high operating costs, the following factors dictate that this system be dropped from consideration:

- o Projected effluent quality would exceed several projected effluent limitations.
- o This technology is still experimental in nature. Without pilot-scale testing, system design could not be completed. This process has not been proven as a reliable treatment process.
- o This system does not remove thiosalts.
- o The volume of sludge from this process (primarily calcium sulfoaluminate) would be extremely large. Sludge dewatering properties are unknown. Proper design of sludge dewatering/disposal facilities would be impossible without pilot-scale testing.

System 5 - Sedimentation/Filtration/Ion Exchange for Anion Removal/Carbonate Precipitation/pH Adjustment/Filtration

This treatment process (a variation of the DESAL process marketed by Rohm and Haas) has been used in several full-scale installations but none in the mining industry.

In this process, influent waters would be passed through an ion exchange resin which exchanges HCO_3^- for anions present in the water. Effluent from the ion exchange process would then be passed through a carbonate precipitation stage where metal hydroxides and calcium carbonate are removed.

The regenerant from the ion exchange columns would be primarily ammonium sulfate, $(\text{NH}_4)_2\text{SO}_4$. The regenerant could be evaporated, dried, and possibly sold as a fertilizer by-product.

Although this system "comes closer" to meeting the stated criteria, it should be dropped from consideration because:

- o Projected effluent quality would exceed several potential effluent limitations.
- o If mine seepage water were to contain high concentrations of colloidal solids which would not settle in a simple sedimentation basin, the mixed media filtration unit would clog very quickly, thereby necessitating installation of a coagulant addition system.

System 6 - Sedimentation/Filtration/Ion Exchange for Anion Removal/Ion Exchange for Cation Removal/pH Adjustment

This system is similar to System 5, and is also a variation of the DESAL process. In this system, an ion exchange system for cation removal would follow the ion exchange system for anion removal. The system is based on the use of a hydrogen form cation exchange resin, regenerated with HCl. This type of resin was chosen over a sodium form resin (regenerated with NaCl) to reduce the concentration of dissolved solids in the effluent. (HCO_3^- from the anion exchange process would combine with H^+ from the cation exchange process to form H_2CO_3 , which would then flash off.)

Projected effluent quality from this system would meet or exceed all foreseen effluent standards. Annual operating

costs would be extremely high, however, because of the high cost of HCl for regeneration of the cation exchange resin.

Dual bed ion exchange systems are in widespread use, but the vast majority of such systems are used to "polish" or demineralize relatively clean water streams. There are very few full-scale installations operating on raw, highly contaminated effluents.

Based on model predictions of effluent water quality, it appears that this system meets most of the criteria established for the wastewater treatment system. It is appropriate, therefore, to further assess the "risks" which would be associated with installation of this system.

- o If mine seepage water were to contain high concentrations of iron, fouling of the resin beds would occur. The system does not contain any unit processes which could be used to remove iron.
- o If mine seepage water were to contain high concentrations of colloidal solids which would not settle in a simple sedimentation basin, the mixed media filtration unit would clog very quickly, thereby necessitating installation of a coagulant addition system.
- o If the concentration of organics were higher than anticipated in the influent, resin fouling could occur. The system does not contain any unit processes which could be used to remove organics.
- o The manufacturer of the resin proposed for the anion exchange system claims that it will remove thiosalts to trace concentrations. There have been several literature reports that thiosalts "poison" anion exchange resins, binding to the exchange sites and reducing exchange capacity. The manufacturer claims that this problem can be solved with occasional caustic rinsing of the resin, but cannot document a full-scale installation which has encountered and solved this potential problem.
- o The manufacturer of the anion exchange resin could not document performance of the resin on wastewaters containing high concentrations of calcium. There is a possibility that CaCO_3 precipitation could occur in the resin bed.

With pilot scale testing of this process, it is possible that the potential problems could be resolved. Since pilot testing is not possible until after startup, it is recommended that this system be dropped from consideration.

System 7 - Sedimentation/Filtration/Reverse Osmosis/Vapor Compression Evaporation

This treatment system involves the use of well developed technologies which are in use in a number of applications around the United States. Effluent quality from this system would be very good, meeting all foreseen effluent regulations.

The capital cost of this system would be higher than any of the previous six systems. Annual O&M cost would also be higher, but somewhat less than Systems 4 or 6.

Because of high projected influent concentrations of Ca and SO₄, the effectiveness of the reverse osmosis system is somewhat limited. Preliminary runs of the computer model indicated that at approximately 50 percent recovery through the RO system (i.e., 50 percent product water and 50 percent brine), calcium sulfate reaches its solubility limit in the brine stream.

The limited utility of the RO process dictates a large vapor compression evaporation unit, which is the most capital intensive unit operation in the system.

Based on model predictions of raw effluent water quality, it appears that this system meets most of the criteria established for the water treatment system. It is appropriate, therefore, to further assess the "risks" which would be associated with installation of this system:

- o If mine seepage water were to contain high concentrations of iron, fouling of the RO membranes could occur. The system does not contain any preliminary unit processes which could be used to remove iron.
- o If mine seepage water were to contain high concentrations of colloidal solids which would not settle in a simple sedimentation basin, the mixed

media filtration unit would clog very quickly, thereby necessitating installation of a coagulant addition system.

- o If the concentration of organics were higher than anticipated in the influent, it is possible that RO membrane fouling could occur. Furthermore, light organics could carry over in the evaporator and appear in the effluent. The system does not contain any unit process which could be used to remove organics.
- o If the concentrations of calcium and sulfate were higher than anticipated in the influent, the achievable of water through the RO would be less than projected. If this were to occur, the VCE unit would be undersized to treat the increased flow rate of RO brine.
- o If actual raw effluent water quality contains less Ca and SO_4 than projected, this system would "lock" Exxon into very high operating costs. If the RO system were sized for a 50-percent recovery and full-scale operating data proved that a higher recovery was possible, insufficient RO capacity and excess VCE capacity would be installed.

Despite the fact that this system meets most of the criteria developed for the wastewater treatment system, it is not sufficiently flexible to warrant further consideration. If actual water quality is worse than projected, the system could fail to meet operating goals, if actual water quality is better than anticipated, excessive ongoing O&M costs would be incurred. Because of these drawbacks, it is recommended that this system be dropped from consideration.

System 8 - Sedimentation/Filtration/Ion Exchange for Calcium Removal/Reverse Osmosis/Vapor Compression Evaporation

This system was evaluated as a potential configuration to eliminate the "risks" associated with System 7. A sodium form ion exchange system (regenerated with NaCl) was added upstream from the RO system. This added unit process would remove most calcium from solution before the water enters the RO process, thereby permitting more cycles of concentration in the RO before $CaSO_4$ reaches its solubility. This, in turn, would permit construction of a smaller VCE unit.

Although this system reduces the "risks" associated with calcium and sulfate, it does not substantially change the "risks" associated with projected concentrations of iron or organics.

- o If mine seepage water were to contain high concentrations of iron, iron precipitation and/or fouling would probably be encountered in the ion exchange resin. This system does not contain any unit processes which could be used to remove iron.
- o If mine seepage water were to contain high concentrations of colloidal solids which would not settle in a simple sedimentation basin, the mixed media filtration unit would clog very quickly, thereby necessitating installation of a coagulant addition system.

If operating experience were to indicate that a sophisticated flocculation/precipitation system is necessary to protect the filter and/or ion exchange system, it is likely that a lime or carbonate precipitation system would be installed. If a carbonate precipitation system were selected (see System 9), the need for the ion exchange system would be eliminated.

- o If the concentration of organics were higher than anticipated in the influent, it is possible that both resin and RO membrane fouling could occur. As with System 7, some light organics could carry over in the evaporator and appear in the effluent. This system does not contain any unit process which could be used to remove organics.
- o Ion exchange systems are typically applied in "polishing" applications. There are very few IX systems used to treat raw effluent streams. This alternative, therefore, would represent somewhat unproven technology.

Although this system has reasonable annual O&M costs with respect to other systems, it is somewhat inflexible with respect to influent water quality.

If full-scale operating data indicates that concentrations of iron and organics are equal to or less than projected, and mine seepage water does not contain colloidal solids,

this system could very likely compare favorably with other potential systems. If, on the other hand, concentrations of iron or organics were significantly higher than anticipated, or mine water continued high concentrations of colloidal solids, several potential problems could create severe operating difficulties.

It is recommended that this system be dropped from consideration at this time. After the Mill is started up and effluent quality stabilizes, this technology could be reevaluated. Potential reductions in annual operating costs could provide an attractive payback for retrofitting an ion-exchange system.

System 9 - Carbonate Precipitation/pH Adjustment/Filtration/Reverse Osmosis/Vapor Compression Evaporation

This system is similar to System 8, except that carbonate precipitation (single stage lime-soda softening) is used to remove calcium instead of an ion exchange process. Preliminary model runs indicated that this combination of processes permits 80 percent water recovery in the RO system, substantially reducing the size of the VCE unit in comparison to System 7.

This general treatment flow pattern, or similar variations, has been used in a number of locations throughout the United States and has proven to be a reliable and functional method of water treatment for a variety of industries.

Predicted effluent quality from this system would meet all foreseen effluent regulations. The system removes all scaling compounds, is proven technology, is extremely flexible with respect to influent water quality, can be easily constructed in modular fashion, and removes virtually all thio-salts and metals.

An additional benefit of this system is that the VCE brine could potentially be a saleable byproduct. The brine would be almost entirely sodium sulfate (Na_2SO_4), which is used extensively in the Kraft pulp and paper process and in the detergent manufacturing industry.

Since this system appears to meet all criteria established for the water treatment system, it is appropriate to assess the "risks" associated with installation of the system.

- o If the concentration of iron were higher than expected in the influent, no adverse impacts are

foreseen. Any Fe^{+2} present could be oxidized to Fe^{+3} in the influent surge/neutralization tank and subsequently be removed in the carbonate precipitation system.

- o If the concentration of organics were higher than expected in the influent, powdered activated carbon (PAC) could be added to the surge/neutralization tank. The carbon and adsorbed organics would then be removed in the carbonate precipitation system and incorporated in the carbonate sludge stream.
- o Regardless of influent calcium concentrations, the carbonate precipitation process will provide a relatively constant and low concentration (approximately 30 mg/l) of calcium in the feed stream to the RO process, thereby ensuring a relatively stable design basis for the achievable recovery of product water in the RO.
- o Effluent water quality from this system would be very high. No potential problems are foreseen with discharge or recycle of the effluent. The system would produce high quality effluent with a wide variation in influent water quality.

Of all the systems considered thus far, this is the first system which meets all of the established criteria and, in addition, will meet the criteria even if full-scale operating experience indicates the raw influent quality is different than projected in this study.

System 10 - Lime Precipitation/Filtration/pH Adjustment/Vapor Compression Evaporation

The last system considered for the Crandon Project is the most capital intensive. By eliminating any ion exchange or membrane processes upstream from the evaporator, concerns about influent water quality can be greatly reduced.

This system would produce effluent which would approach distilled water quality. Some full-scale installations report total effluent dissolved solids concentrations in the range of 5 to 10 mg/l.

Both capital and annual O&M costs of this system would be substantially higher than for System 9. Power costs for the

evaporator system would be extremely high. Since brine from the System 10 evaporator would be primarily calcium sulfate (CaSO_4), no potential for byproduct recovery is foreseen.

System 10 appears to meet all of the criteria established for the water treatment system. It is appropriate, therefore, to assess the "risks" associated with installation of this system.

- o If the concentration of organics were to be higher than anticipated in the influent, it is probable that some light organics could carry over in the evaporator and appear in the effluent. If this were to occur, powdered activated carbon could be added to the surge/neutralization tank and the carbon and adsorbed organics could be removed in the lime precipitation system and incorporated in the lime sludge.
- o If full-scale operating experience shows that influent water quality (especially Fe, Ca, SO_4) is equal to or better than anticipated, Exxon would be "locked" in to extremely high annual O&M costs which would not be warranted.

Of all the systems considered, this system is the least sensitive to variations in influent water quality, and would produce an extremely high quality effluent. The only foreseen drawback to this system is the extremely high cost to install and operate the system.

DISCUSSION OF VIABLE ALTERNATIVES

Of all the water treatment systems considered, only Systems 9 and 10 meet all of the criteria established for the treatment system and are further capable of meeting the criteria, even if full-scale operating experience indicates that influent water quality is different than projected in this study. These are the only two treatment systems believed to be feasible for the Crandon Project. Either system would provide consistently high effluent quality.

After screening the alternatives down to these two systems, computer modelling runs were performed on the final proposed mine/mill/pond/treatment system configuration to assess the relative costs of the two systems.

Following an analysis of computer predictions, comparative cost estimates were prepared for each of the two viable systems. These cost estimates were prepared based on simple scale-up of previous CH2M HILL cost estimates, cost curves, and other estimating guides, and include approximately a 25-percent contingency.

Capital Cost Comparison

Capital cost estimates for the two systems are as follows:

	<u>SYSTEM 9</u>	<u>SYSTEM 10</u>
	<u>Estimated Cost</u>	<u>Estimated Cost</u>
Carbonate Precipitation	\$ 2,214,000	\$ ---
Lime Precipitation	---	\$ 2,214,000
pH Adjustment	151,000	152,000
Filtration	1,074,000	1,082,000
Reverse Osmosis	9,546,000	---
Vapor Compression Evaporation	7,094,000	20,300,000
Brine Concentrator	<u>1,082,000</u>	<u>1,082,000</u>
TOTAL ESTIMATED COST	\$21,161,000	\$24,830,000

Annual Operating and Maintenance Cost Comparisons

Estimated annual costs to operate and maintain the two systems are summarized as follows:

	<u>SYSTEM 9</u>	<u>SYSTEM 10</u>
	<u>Estimated Cost</u>	<u>Estimated Cost</u>
CaO		
CaO/CO ₃ Precipitation	15,000	8,000
Na ₂ CO ₃	412,000	---
Polymer	111,000	111,000
H ₂ SO ₄	19,000	15,000
Hexametaphosphate	56,000	---
Electrical		
RO	231,000	---
VCE	594,000	2,998,000

	<u>SYSTEM 9</u> <u>(continued)</u>	<u>SYSTEM 10</u> <u>(continued)</u>
	<u>Estimated</u> <u>Cost</u>	<u>Estimated</u> <u>Cost</u>
Natural Gas	295,000	295,000
R-O Membrane Replacement	<u>156,000</u>	<u>---</u>
Annual Reagent Cost	\$ 1,889,000	\$ 3,427,000
Annual Labor	140,000	140,000
Annual Maintenance ¹	<u>1,058,000</u>	<u>1,242,000</u>
TOTAL ESTIMATED ANNUAL O&M COST	\$ 3,087,000	\$ 4,809,000

¹ Annual maintenance was computed as 5 percent of estimated capital cost.

Reliability of Unit Processes

The two treatment systems believed viable for the Crandon Project both involve the use of sophisticated unit operations which are not common to the mining and milling industry.

It is appropriate, therefore, to review each of the unit operations in the two systems and to discuss operating experiences at full-scale operating installations.

Lime Precipitation is the state-of-the-art treatment technology for treatment of mining and milling wastewaters (as defined by the EPA's Development Document). This technology has been employed for many years in a variety of industries.

Carbonate Precipitation (single stage lime-soda softening) is an extremely common technology utilized in numerous water softening systems throughout the U.S. This technology has been in widespread use for several decades.

Filtration technology is well documented in literally hundreds of systems throughout the U.S. Single media, dual media, and/or mixed media filters are utilized in virtually every water softening plant, and in a variety of industrial applications downstream from chemical precipitation systems.

Reverse Osmosis (RO) is a relatively new wastewater treatment technology. The first commercial reverse osmosis systems were built less than 20 years ago. As industrial demand for high purity demineralized water has risen during the past few years, the number of reverse osmosis systems in operation has increased dramatically. Increasing regulatory agency pressures for reduced effluent flow rates and increased recycle rates have increased industrial use of this technology for wastewater treatment as well. Reverse osmosis has also been applied to desalinization of salt waters to provide drinking water supplies to coastal cities. At present, there are over 1,000 reverse osmosis systems in operation worldwide. Table 6 has been prepared to illustrate several pertinent features of RO systems with which CH2M HILL is familiar.

Vapor Compression Evaporation is a well established technology. The first commercial scale vapor compression evaporators were built approximately 35-40 years ago. Because of the high capital and operating costs of this technology, its use has been limited. Vapor compression evaporators are in use in the pulp and paper industry (cooking liquor evaporation), the corn wet milling industry (corn syrup evaporation), the field of wastewater treatment (rejection of inorganic salts), and similar types of applications. Worldwide, there are more than 250 facilities using vapor compression evaporators in process and/or wastewater applications. Table 7 illustrates several pertinent features of evaporator installations with which CH2M HILL is familiar.

SELECTION OF PREFERRED SYSTEM FOR FINAL EFFLUENT/RECYCLE TREATMENT

Although both Systems 9 and 10 meet the established criteria for the final effluent treatment system, System 9 is more cost-effective. Full-scale operating installations, utilizing the same basic flow pattern as System 9, have proven to be reliable and produce consistently high effluent quality in a variety of applications.

It is recommended, therefore, that System 9 be selected as the preferred water treatment alternative for effluent/recycle treatment at the Crandon Project.

Table 6
REVERSE OSMOSIS INSTALLATIONS:
WASTEWATER TREATMENT*

	Owner	Startup	Wastewater Source	Wastewater Flow (gpm)	Wastewater IDS (mg/l)	Percent Recovery	Pretreatment**	Membrane Type and Manufacturer***	System Vendor	Comments
1.	R.D. Nixon Station Colorado Springs, Colorado	1980	Combined wastes from coal-fired power plant	700	5,000	50	Algicide, Cl ₂ , FeCl ₃ , cong. clarification, mixed media filtration	Spiral wound CA UOP Fluid Systems	UOP Fluid Systems	Operates as designed. Permeate reused in power plant. Award-winning plant.
2.	Bridgeport Brass Bridgeport, Connecticut	1974	Combined wastes from copper-brass mill	600	.350 total (45 mg/l heavy metals)	95	Equalization, caustic treatment, filtration	Spiral wound CA UOP Fluid Systems	UOP Fluid Systems	Early mechanical and process problems solved after 2 years. Operational.
3.	San Juan Station Public Service Co. of New Mexico Farmington, New Mexico	1977	Combined wastes from coal-fired power plant	400	4,000	80	Cl ₂ , dual media filtration	Spiral wound CA UOP Fluid Systems	El Paso Environmental Systemr	Included recycle of concentrate through CaSO ₄ precipitator clarifier. Serious membrane fouling due to algae, oil, CaSO ₄ scaling. Operation discontinued late 1978.
4.	San Juan Station Public Service Co. of New Mexico Farmington, New Mexico	1980	Combined wastes from coal-fired power plant	2,000	4,300	80	Lime-soda softening dual media filtration, dechlorination	Spiral wound PA UOP Fluid Systems	Resources Conservation Co.	Operational. Throughput limited by severe flux decline (probably due to algae and Cl ₂ attack). PA membranes being replaced with CA.
5.	Water Factory 21 Orange County Water District Fountain Valley, California	1977	Tertiary treated municipal effluent (for groundwater recharge)	3,500	1,400	85	Activated sludge, Cl ₂ lime softening, filtration, activated carbon	Spiral wound CA UOP Fluid Systems	UOP Fluid Systems	Operational. Early fouling problems with carbon fines reduced by downflow carbon units. Some first-stage organic fouling Award-winning plant.
6.	Burec Demonstration Yuma, Arizona (pilot plants)	1975	Irrigation return flow	600	3,100	85	Cl ₂ , lime-soda softening, dual-media filtration	Spiral wound CA and hollow fine PA Various manufacturers	Various	Long-term testing showed this pretreatment system and spiral wound CA membranes optimum.
7.	Burec RO Facility Yuma, Arizona (full-scale plant)	1984 (?)	Irrigation return flow	70,000	3,100	85	Cl ₂ , lime-soda softening, dual-media filtration	Spiral wound CA UOP Fluid Systems Hydranautics	UOP Fluid System Hydranautics	Funding problems.
8.	Denver Water Reuse Facility Denver Water Board Colorado	1983	Tertiary treated municipal effluent (for general reuse)	70	1,000	90	Activated sludge, Cl ₂ , lime softening, recarbonation, filtration, activated carbon, ozone, carbon	Spiral wound PA UOP Fluid Systems	UOP Fluid Systems	Demonstration plant.
9.	Rocky Flats Arsenal Denver, Colorado	1977	Combined wastes from munitions mfg.	250	3,900	95	Cl ₂ , lime-soda softening, filtration Dow.	Spiral wound and hollow fine	UOP Fluid Systems and	Status unknown.
10.	Wyadak Power Plant Gillette, Wyoming	1979	Tertiary treated municipal effluent (for boiler feedwater)	200	3,800	90	Cl ₂ , lime-soda softening, filtration	Spiral wound CA	Unknown	Operational. Algae fouling minimized by high lime doses.

*Note that these are wastewater applications only. A great many other RO installations exist in brackish water and seawater service that have constraints and configurations similar to the RO system proposed at Crandon.

**pH adjustment, scale inhibitor addition, and cartridge filters included in all cases.

***CA - cellulose acetate. PA - polyamide.

Table 7
EVAPORATOR INSTALLATIONS:
WASTEWATER TREATMENT*

	Owner	Startup	Wastewater Source	Flow (gpm)	Pretreatment	Evaporator Type	Manufacturer	Comments
1.	St. Jo Minerals Monaco, Pennsylvania	1981	SO ₂ scrubber wastes (citrate process)	7	Filtration	Forced circulation	Goslin-Envirotech	Operational.
2.	Potash Corp. of America Sussex, New Brunswick	1982	Mine effluent (CaCl ₂ , NaCl wastes)	1,500	Equalization, clarification, pH adjust.	Vapor compression	HPD	One body, dual compressors. Operational.
3.	Union Carbide Bishop, California	1974	Tungsten mine wastes (solvent extraction raffinate)	70	Equalization, clarification, pH adjust.	Forced circulation evaporator and crystallizer	HPD	Early heat exchanger materials problems. Operational.
4.	Union Carbide (UCAR) TBL South Africa	1978	Tungsten mine wastes (solvent extraction raffinate)	160	Equalization, clarification, pH adjust.	Forced circulation evaporator and crystallizer	HPD	Operational.
5.	Sulphide Corporation Boolaro, Australia	1979	Mining wastes (lead/zinc mine)	150	Equalization, clarification	Forced circulation	HPD	Operational. Na ₂ SO ₄ recovery.
6.	Thiokol Chemical Moss Point, Mississippi	1980	Caustic scrubber wastes	70	Equalization	Draft tube crystallizer	HPD	Operational.
7.	Chevron Perth Amboy, New Jersey	1980	SO ₂ scrubber wastes (Wellman Lord process)	70	Equalization, clarification	Forced circulation	HPD	Operational. Na ₂ SO ₄ and Na ₂ S ₂ O ₃ byproduct recovery.
8.	San Juan Power Plant Public Service Co.	1981	SO ₂ scrubber wastes (Wellman-Lord process)	50	Equalization, clarification	Forced circulation	HPD	Operational. Na ₂ SO ₄ and Na ₂ S ₂ O ₃ byproduct recovery.
9.	Texas Instruments Dallas, Texas	1979	Etching wastes from semiconductor mfg.	60	Equalization, clarification	Forced circulation	HPD	Operational. (NH ₃) ₂ SO ₄ and Na ₂ SO ₄ by- product recovery.
10.	Wycon Chemical (Colorado Interstate Gas) Tablerock, Wyoming	1979	SO ₂ scrubber wastes (Pfitchard process)	40	Equalization, clarification	Falling film	HPD	Operational. (NH ₃) ₂ S ₂ O ₃ byproduct recovery
11.	MHO Antwerp, Belgium	1979	Metals reduction plant wastes (segregated waste acids)	350	Equalization, clarification	Forced circulation (6 units)	HPD	Operational.
12.	Eli Lilly Motescarios, Brazil	1979	Pharmaceutical wastes	20	Equalization	Falling film and forced circulation	HPD	Operational.
13.	Diamond Shamrock Van Buren, Arkansas	1978	CaCl ₂ , NaCl wastes with heavy metals contamination	30	Confidential	Forced circulation	HPD	Operational.
14.	Northwest Alloys Addy, Washington	1981	Magnesium plant wastes	70	Equalization, pH adjust.	Vapor compression	Resources Conser- vation Company	Operational.
15.	Ray D. Nixon Station Colorado Springs, Colorado	1980	RO brine from treatment of power plant wastes (see Table 1, No. 1)	350	Equalization, pH adjust.	Vapor compression	Resources Conser- vation Company	Operational.
16.	Deerhaven Station Gainesville Regional Utilities Gainesville, Florida	1981	Power plant wastes	170	Equalization, pH adjust.	Vapor compression (and spray dryer)	Resources Conser- vation Company	Operational. Continuing problems with spray nozzle materials.
17.	San Juan Station Public Service Co. Farmington, New Mexico	1975	Power plant wastes (cooling tower blowdown)	170	Equalization, pH adjust.	Vapor compression	Resources Conser- vation Company	Operational. Recent scaling and corro- sion problems.

*Note that these are industrial wastewater applications only. Literally hundreds of other evaporator installations exist in services whose chemistries correlate to Crandon's (e.g., black liquor and red liquor evaporators in pulp mills, waste evaporators in nuclear plants, and various evaporation/crystallization processes in the inorganic chemicals industry).

Table 7
(continued)

EVAPORATOR INSTALLATIONS:
WASTEWATER TREATMENT*

	<u>Owner</u>	<u>Startup</u>	<u>Wastewater Source</u>	<u>Flow (gpm)</u>	<u>Pretreatment</u>	<u>Evaporator Type</u>	<u>Manufacturer</u>	<u>Comments</u>
18.	San Juan Station Public Service Co. of New Mexico Farmington, New Mexico	1980	RO brine (see Table 1, No. 4)	250	Equalization, pH adjust.	Vapor compression	Resources Conser- vation Company	Operational. Recent scaling and corro- sion problems.
19.	San Juan Station Public Service of New Mexico Farmington, New Mexico	1983	Combined power plant wastes	500	Equalization, pH adjust.	Vapor compression	Resources Conser- vation Company	(Station must like VCE's.)
20.	Pawnee Station Public Service of Colorado	1982	Combined power plant wastes	170	Equalization, pH adjust.	Vapor compression	Resources Conser- vation Company	Under construction.
21.	Clark Station Nevada Power Company Las Vegas, Nevada	1982	Combined power plant wastes	170	Equalization, pH adjust.	Vapor compression	Resources Conser- vation Company	Under construction.
22.	Four Corners Station Arizona Public Service	1982	Combined power plant wastes	600	Equalization, pH adjust.	Vapor compression	Resources Conser- vation Company	In startup.
23.	Navajo Station Salt River Project Page, Arizona	1975	Power plant wastes	170	Equalization, pH adjust.	Vapor compression	Resources Conser- vation Company	Opeational.
24.	Navajo Station Salt River Project Page, Arizona	1981	Power plant wastes	800	Equalization, pH adjust.	Vapor compression	Resources Conser- vation Company	Operational.
25.	Hayden Station Colorado Ute Hayden, Colorado	1976	Power plant wastes	170	Equalization, pH adjust.	Vapor compression	Resources Conser- vation Company	Operational.
26.	Craig Station Colorado Ute Craig, Colorado	1979	Power plant wastes	600	Equalization, pH adjust.	Vapor compression	Resources Conser- vation Company	Operational.
27.	Colstrip Station Montana Power and Light Colstrip, Montana	1976	Power plant wastes	340	Equalization, pH adjust.	Vapor compression	Resources Conser- vation Company	Operational.
28.	Huntington Station Utah Power and Light	1975	Power plant wastes	170	Equalization, pH adjust.	Vapor compression	Resources Conser- vation Company	Operational. Recent corrosion problems.
29.	Great Plains Coal Gasification Project	1983	Waste brines from coalgas plant	600	Equalization, pH adjust.	Spray film	Aqua-chem	Substantial pilot work, commercial units in fabrication.

*Note that these are industrial wastewater applications only. Literally hundreds of other evaporator installations exist in services whose chemistries correlate to Crandon's (e.g., black liquor and red liquor evaporators in pulp mills, waste evaporators in nuclear plants, and various evaporation/crystallization processes in the inorganic chemicals industry).

TREATMENT ALTERNATIVES FOR CYANIDE OXIDATION

The lead concentrate thickener overflow stream was the only stream in Exxon's Phase I pilot plant with appreciable cyanide concentrations. In the full-scale mill, tight control of reagents should virtually eliminate cyanide in this stream. Such control was not possible in the pilot plant.

Regardless of whether this small stream is treated for cyanide oxidation, it will be discharged to the tailings thickener and will ultimately be routed through the Reclaim Pond.

In evaluating whether treatment is necessary for this stream, two major considerations were kept in mind:

- o During summer months, natural degradation processes in the Reclaim Pond will likely reduce cyanide concentrations to below detection limits.^{14, 15}
- o The concentration of thiosulfate in the lead concentrate thickener overflow (Phase I pilot plant results) is projected to be in excess of 400 mg/l. Any oxidation processes used to oxidize cyanide will also oxidize thiosulfate. This means that reagent costs for oxidizing agents would be extremely high with respect to the amount of cyanide destroyed.

Four of the treatment technologies considered appropriate for the Crandon Project (see Section X) could be used to remove cyanide and thiosulfate from the lead concentrate thickener overflow if such treatment is judged to be necessary after startup of the plant.

- o Alkaline chlorination
- o Ferrocyanide precipitation
- o Ozone oxidation
- o Hydrogen peroxide oxidation

The following paragraphs present a discussion of the suitability of each technology.

Alkaline Chlorination

Alkaline chlorination is a state-of-the-art technology for removal of cyanide. For the Crandon Project, however, use

of this technology would result in the undesirable buildup of chlorides within the mill water circuit.

Ferrocyanide Precipitation

Based on bench-scale test work completed by CH2M HILL for other clients, this technology looks promising for the precipitation of cyanide as ferrocyanide ("prussian blue"). In CH2M HILL's test work, it was found that both ferric and ferrous iron were required for effective removal of cyanide. Although ferric chloride was used in CH2M HILL's test work, ferric sulfate could be used to eliminate the addition of chloride.

The primary drawbacks of this system are a) lack of operating experience with full-scale installations, and b) some degree of uncertainty about the fate of ferrocyanide precipitate in the alkaline tailings pond environment. (One literature report indicates that ferrocyanide may decompose to cyanide when exposed to ultraviolet light in a tailings pond; this is probably not of major concern because the EPA's Development Documents^{14,15} also describe photodecomposition to be one of the mechanisms of cyanide destruction in tailings ponds.)

Ozonation

Ozonation is a state-of-the-art, but expensive, technology which can be used for the destruction of cyanide. Ozone is a very strong oxidant which will convert cyanide to CO_2 and N_2 . Ozone will not affect iron complexed cyanide, but this is not of major concern because most of the cyanide present in the lead concentrate thickener overflow will be complexed with zinc and/or copper. These complexes would be destroyed by ozone.

Because ozone generation equipment is quite expensive, ozonation is best applied as a polishing step to remove residual cyanide.

Hydrogen Peroxide Oxidation

Hydrogen peroxide is a widely used oxidant in a variety of industrial applications. Literature reports indicate that H_2O_2 will destroy free cyanide and Cd/Zn complexes but that Cu/Ni complexes are only partially destroyed. Iron complexed cyanide and thiocyanate are not oxidized with H_2O_2 .

In our review of literature and in telephone conversations with a major U.S. manufacturer of H_2O_2 , it was further learned that hydrogen peroxide converts most cyanide only to cyanate (CNO^-) rather than complete oxidation to CO_2 and N_2 .

Because of the low capital costs and moderate chemical costs associated with a hydrogen peroxide system, it is attractive as a pretreatment stage upstream from ozonation. It could be used to destroy thiosulfate and to convert most cyanides to cyanate, thereby reducing the capital and O&M costs of a downstream ozonation system. The equipment required for an H_2O_2 oxidation system is very simple. If cyanide oxidation were to be necessary, such a system could be installed quickly.

SELECTION OF PREFERRED TREATMENT SYSTEM FOR CYANIDE REMOVAL

If necessary, the most cost-effective system for treatment of the lead concentrate thickener overflow would be to first treat the wastewater in a hydrogen peroxide oxidation system to oxidize thiosulfate and to convert the majority of cyanide to cyanate. Effluent from the H_2O_2 oxidation system could then be "polished" in an ozonation system to completely convert cyanate and residual cyanides to CO_2 and N_2 .

This system uses proven technology to oxidize cyanide, has reasonable capital and annual O&M costs, does not add undesirable chlorides (as would alkaline chlorination), and does not generate any sludges which would require disposal. If full-scale operating experience indicates that cyanide oxidation is necessary, this system could easily be retrofitted to the mill process.

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■ ■ . Section XV
■ ■ COMPLIANCE WITH EFFLUENT REGULATIONS

Table 8 shows a comparison between the projected quality of treated effluent from the preferred water treatment system and the potential effluent limitations described earlier in Section IX.

Based on computer model projections of water quality in the mill water circuit and of the estimated performance of the preferred water treatment system, all potential effluent limitations are met or exceeded by the system.

It is important to note, however, that projected effluent concentrations are extremely close to the surface water quality based standards for cadmium, mercury, and silver. With the exception of these limits, effluent quality should be far better than required by any of the potential limitations.

It is recommended that the surface water quality based standards for Cd, Hg, and Ag be evaluated further by the DNR. The proposed limits are very low, ranging from 1 to 2 orders of magnitude lower than other potential limitations for these three constituents. It is currently believed that the limitations can be met with the preferred system, but given the extremely low concentrations listed in the preliminary standards, CH2M HILL believes that compliance or noncompliance is literally "too close to call." A very small difference in influent water quality could cause occasional violations of these limits. This conclusion would hold true with both the preferred treatment system and with the only viable alternative system (see Section XIV - EVALUATION OF WATER TREATMENT ALTERNATIVES.)

Unless the proposed low limitations are shown to be absolutely necessary, it is recommended that the preliminary limits be negotiated upwards to values more in line with other potential limitations.

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Table 8

COMPARISON OF PROJECTED EFFLUENT QUALITY WITH
POTENTIAL EFFLUENT LIMITATIONS OR STANDARDS

Compound	<u>POTENTIAL EFFLUENT LIMITATIONS/STANDARDS¹</u>			
	<u>NSPS Standards (Mills and Mines)²</u>	<u>Primary & Secondary Drinking Water Standards³</u>	<u>Surface Quality Based Limitations⁴</u>	<u>Projected Effluent Quality</u>
Chromium (+3)	--	--	0.09	0.003
Chromium (+6)	--	--	0.001	--
Chromium (Total)	--	0.05	--	< 0.003
Arsenic	--	0.05	0.09	< 0.01
Barium	--	1.0	11	< 0.01
Cadmium	0.05	0.01	0.0016	< 0.001
Lead	0.3	0.05	0.18	< 0.01
Mercury	0.001	0.002	0.0001	< 0.0001
Selenium	--	0.01	0.08	< 0.01
Nitrate	--	10.0	--	0.5
Silver	--	0.05	0.0002	0.002
Fluoride	--	2.2	13.6	0.9
Chloride	--	250	1100	0.3
Copper	0.15	1	0.05	< 0.01
Iron	--	0.3	1.0	< 0.01
Manganese	--	0.05	--	< 0.01
Sulfate (SO ₄)	--	250	210	33
Zinc	0.75	5	0.31	< 0.1
pH	6-9	6.5-8.5	6-9	7.0
Cyanide	--	--	0.03	< 0.01
Total Dissolved Solids	--	500	2000	77
Total Suspended Solids	20	--	20	< 1

¹ All values except pH in mg/l.

² 30-day average values from EPA's NSPS standards.

³ NR182 requires that these standards be met in the groundwater at the "compliance boundary," not in the actual discharge.

⁴ Based on Preliminary Limits set forth in DNR letter to Exxon's Mr. Barry Hansen dated March 14, 1982, and subsequent discussions.



Section XVI

QUALITATIVE CALIBRATION OF MILL/POND EFFECT MATRICES

INTRODUCTION

The Water Use Model developed for the Crandon Project was used extensively to evaluate water management and water treatment alternatives. Since a number of decisions were based on model predictions of water quality throughout the system, it is appropriate to address the accuracy of model predictions.

Water chemistry in the mill water circuit is dependent on a great number of factors, including, but not limited to:

- o grade of ore being processed
- o reactivity of ore
- o retention time in various unit operations
- o degree of mixing and/or aeration
- o types and amounts of reagents used
- o pH of mill water in individual unit operations
- o percent recovery of metals in concentrates
- o degree of recycle water use

The effect matrices prepared for the Crandon Mill were based on analysis of water quality of individual effluent streams from a pilot test of the ore concentration process proposed for the mill. Since the pilot test (by Lakefield Research) used ore from the Crandon orebody and simulated the actual mill process proposed for Crandon, the predictions of mill "effects" on water quality should be close to anticipated "real-world" effects in the operating mill.

Both Exxon and CH2M HILL recognize that model predictions of water quality in the water circuit may not be precise. Until the mine and mill are in operation, however, there is no way to obtain more accurate predictions. Given the importance of the model's predictions, however, it was believed necessary to qualitatively assess whether predicted changes in

water quality are realistic. Two primary sources of data were used to make this assessment:

1. Exxon obtained permission to test water quality in various streams at an operating mine/mill complex. The mill selected bears close resemblance to the proposed Crandon Mill, but has several features which are different. Since mill impacts on water quality are so dependent on mine/mill-specific factors, it is appropriate to note the differences between the Crandon Mill and the mill selected for comparative testing.
 - o The ore at Crandon contains copper, lead, and zinc; the ore at the operating mill contains only copper and zinc in recoverable concentrations.
 - o The Crandon ore is less reactive because it contains no pyrrhotite.
 - o The Crandon Mill will have a different ore flotation process and will use different reagents. In particular, less SO₂ will be used.
 - o The Crandon Mill will have a high degree of water recycle. The tested mill had little or no recycle water use.
 - o The Crandon flowsheet will incorporate a tailings thickener. The operating mill super-limes their tailings stream for disposal in a tailings pond.
 - o The retention pond at the operating mill contains large quantities of old tailings. Since the Crandon Reclaim Pond will contain no tailings, data from the operating mill Reclaim Pond is not applicable to check predictions at Crandon.

2. CH2M HILL has worked for a variety of mining and milling clients. One recent project (client confidential) involved analysis of effluent from a tailings pond used to settle super-limed tailings. The results of this analysis can be used to further cross check the effect matrices prepared for the Crandon tailings thickener and tailings pond. This mill has a high water recycle rate, but recovers only copper from their ore.

Although these two sources of real-world operating data are not a perfect match to Crandon, they are the best source of

information available at this time. It is believed that comparison of the effect matrices prepared for the Crandon Project with data obtained from these similar operating installations should provide a qualitative check on the accuracy of the matrices.

MILL TAILINGS EFFECT MATRIX

Table 9 presents a comparison of the effect matrix prepared for the Crandon Project mill tailings stream with the effects at the operating mill. This stream was selected for comparison because it is by far the largest stream exiting the mill. It was not expected that the effects would match exactly; the primary purpose in obtaining the data from the operating facility was to qualitatively determine whether the effect matrix prepared for the Crandon Mill is realistically close to a real-life situation.

Considering the numerous differences between the two facilities, and that both sets of data are based on a single round of sampling and analysis, the data are very consistent.

Major differences between the two sets of data are assessed as follows:

- o Calcium (Ca) addition is higher in the Crandon effect matrix, but the projected pH of the Crandon tailings stream is much higher, requiring more lime addition.
- o Thiosulfate (S_2O_3) generation is higher in the Crandon effect matrix.
- o COD generation is higher in the Crandon effect matrix. This also makes model predictions conservative.
- o Carbonate (CO_3) addition is much higher in the Crandon effect matrix. The prediction is consistent with measured water quality in the pilot plant. Predicted increases in carbonate are also consistent with reports of calcium carbonate scaling problems in several U.S. mills. The difference between Crandon and the comparative mill is probably explained by process differences between the mills.

Table 9

MILL TAILINGS EFFECT MATRIX
COMPARISON OF CRANDON MATRIX WITH
MEASUREMENTS AT OPERATING MILL

<u>Component</u>	<u>Zinc Tailings Stream Effects*</u>	
	<u>Crandon</u>	<u>Operating Mill</u>
Ca	+96	+12.0
Cd	NC	NC
Cr	+0.03	NC
Cu	+0.07	-0.27
Fe ⁺²	+2.4	-0.50
Fe ⁺³	-1.1	+0.44
Hg	NC	+0.00012
K	+4.2	+5.83
Mg	-1.1	-0.5
Mn	+0.03	-0.04
Na	+136	+103.9
Pb	+0.02	+0.03
Se	+0.25	+0.147
Zn	+0.11	-0.46
CO ₃	+131	+1
Cl	+3.0	+5.68
CN	+0.014	NC
F	+0.52	NC
HCO ₃ ⁻	NC	-9.0
NO ₃	NC	-1.93
PO ₃	NC	NC
SO ₄	+230	+230.9
S ₄	NC	NC
S ₂ O ₃ ⁼	+100	+ 50 - 60
SiO ₂	+0.19	-0.2
COD	+146	+38
pH	11.0	9.4

* All effects except pH are shown as incremental changes (mg/l) in soluble water quality between mill influent and the tailings stream (i.e., these changes occur within the mill).

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- o Sodium (Na) addition is higher in the Crandon effect matrix. Actual measured effects in Exxon's Phase I pilot plant were somewhat lower. CH2M HILL "adjusted" the sodium addition rate to obtain an ionically balanced effect matrix.

In general, the effect matrix prepared for Crandon predicts larger increases of most metals than measured at the operating mill. The predicted increase in sulfate is nearly identical, and predicted thiosulfate increases for Crandon are higher than measured at the operating mill. It is concluded that the Crandon effect matrix is reasonably close to the measured effects at the operating mill, and, if anything, is slightly conservative in predictions of mill effects on the water quality in the mill tailings stream.

TAILINGS THICKENER AND TAILINGS POND EFFECT MATRICES

Operation of the Crandon Project tailings thickener at a high pH is expected to control the concentration of metals within the recycle water circuit (i.e., it is projected that metal hydroxides will co-precipitate with the tailings and be removed from the main water circuit).

Table 10 illustrates a comparison between:

- a) Computer model prediction of water quality in effluent from the Crandon tailings thickener.
- b) Measured water quality in effluent from the tailings pond (super-limed tailings) at the Mine/Mill evaluated by Exxon.
- c) Measured water quality in effluent from the tailings pond (super-limed tailings) evaluated by CH2M HILL for another client.

The data are all reasonably consistent. The compounds with the largest differences between the sets of data (Ca, K, Na, F, SO₄) are all compounds which are not removed by metal

Table 10

TAILINGS THICKENER OVERFLOW
COMPARISON OF PREDICTED CRANDON WATER QUALITY
WITH MEASURED QUALITY AT TWO OPERATING MILLS¹

<u>Component</u>	<u>Crandon Tails Thickener² Overflow</u>	<u>Operating Mill Tailings Pond Effluent</u>	<u>Tailings Pond Effluent (Confid. Client)</u>
Ag	0.01	NT ³	0.05
Al	2.5	NT	0.20
Ba	0.01	NT	NT
Ca	578	164	767
Cd	0.02	0.008	0.02
Cr	0.05	< 0.01	0.02
Cu	0.02	0.03	0.04
Fe ⁺²	16.7	< 0.1	-
Fe ⁺³	0.2	0.11	0.11 (total)
Hg	0.00015	0.00007	< 0.0002
K	21.5	7.69	28.2
Mg	10.0	0.2	2.2
Mn	0.03	0.2	0.03
Na	678	120	44.2
Pb	0.08	0.05	< 0.02
Se	0.32	0.19	0.002
Zn	0.05	0.05	0.06
As	0.01	NT	< 0.01
CO ₃	109	25	42
Cl	14.8	13.8	NT
CN	0.05	3.8 (CNS)	NT
F	5.0	< 0.02	4
HCO ₃	5.5	1	6
NO ₃	1.0	< 0.1	NT
PO ₃	0.2	< 0.03	NT
S ₄	0.04	177 (tot S)	0.8 (HS)
S ₂ O ₃	109	50	NT
SO ₃	1800	433	1915
SiO ₄	6.6	4.7	2.9
BOD	33	NT	< 2
COD	168	54	21
pH	11.0	11.54	10.3

¹ Soluble concentrations. All concentrations in mg/l.

² Results from model run with preferred water treatment system.

³ NT = Not Tested.

hydroxide precipitation and are more dependent on mill recycle and reagent addition rates. COD and S_2O_3 predictions are higher in effluent from the Crandon tailings thickener, but this is explained by the short residence time in the thickener as opposed to the long residence time (and, therefore, potential for oxidation) in the two tailings ponds.

It is concluded that the Crandon tailings thickener effect matrix is reasonably close to the measured effects at the two operating mills. (The tailings pond effect matrix is similar, so the same conclusion would hold for that matrix as well.)

THIOSULFATE OXIDATION IN TAILINGS AND RECLAIM PONDS

The effect matrices prepared for the pond system at the Crandon Project predict different percentage oxidation rates for thiosulfates in winter and summer operation.

The mill evaluated by Exxon has recorded thiosulfate concentrations in mill effluent, tailings pond effluents, and retention pond effluent for several years (other polythionates were not measured). Table 11 illustrates a comparison of predictions for the Crandon pond with actual data from the operating mill.

Both ponds at the operating mill have slightly higher retention times than the proposed ponds at Crandon, so it is appropriate that predicted oxidation rates are lower for the Crandon ponds, especially during winter operations (i.e., cold temperature). The data from the operating mill illustrate that predicted thiosulfate oxidation rates in the Crandon pond effect matrices are realistic.

ORE CONCENTRATE THICKENER OVERFLOW EFFECT MATRICES

Predicted water quality in the ore concentrate thickener overflows could not be reasonably checked against data from the operating mill. The projected use of reagents and operating pH at Crandon are very different than at the operating mill, greatly distorting water quality effects in these streams.

The ore concentrate thickener overflows are relatively small in comparison to the main tailings stream, so the lack of "real-world" calibration data was not judged to have any major impact on the validity of the Crandon Project Water Use Model.

Table 11

THIOSULFATE OXIDATION RATES

	<u>Percent of Thiosulfate Oxidized</u>	
	<u>Summer</u>	<u>Winter</u>
Crandon Effect Matrices*		
Tailings Pond	50%	0%
Reclaim Pond	90%	10%
Operating Mill Records**		
Tailings Pond	77%	0%
Reclaim Pond	91%	33%

* The Crandon Water Use Model treats S_2O_3 as representative of all polythionates

** Only S_2O_3 is measured. No records are available for the concentrations of other polythionates.

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SUMMARY

The effect matrices prepared for the mill/pond system at Crandon were qualitatively checked against data from full-scale operating installations. Although there are numerous differences between the Crandon effect matrices and the full-scale operating data, the projected effects of the Crandon Mill and ponds appear reasonable when compared to actual operating data.

Since the Crandon effect matrices were based on actual pilot test work on Crandon ore using the proposed Crandon concentration process, data from the operating mill was not used to change the effect matrices, only to check the reasonableness of the predictions.

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Section XVII
TREATMENT OF SANITARY WASTES

WASTEWATER QUANTITY

The average daily flow rate of sanitary wastewater is expected to be 7.25 m³/hour (31.9 gallons/min) (see Section IV). Total daily flow rate is, therefore, 173.8 m³/day (46,000 gal/day). On the basis of 272 showers per shift change, a peak hourly flow rate of 14.5 m³/hr (160 gallons/min) can be expected. The sanitary wastewater treatment system will be designed to handle sanitary wastes from surface activities as well as wastes from the dry or chemical toilets used in the mine. It has been assumed that wastes from the mine will be flushed into the sewer system within the confines of the concentrator.

WASTEWATER QUALITY

Typical domestic sanitary wastewater contains about 200 mg/l of BOD and about the same concentration of TSS.⁶ Because of the cafeteria food service at the surface facilities and concentrated wastes from the mine, Crandon sanitary wastewater will probably contain higher concentrations of BOD and TSS. Table 12 contains per capital BOD and TSS contributions listed in the literature. The sanitary wastewater contributions for the Crandon Project are estimated to be 0.7 kg BOD/person/day and 0.07 kg TSS/person/day. The corresponding concentrations are 357 mg/l BOD and 367 mg/l TSS, yielding average waste loads of 62.2 kg BOD/day (137 lbs/day) and 62.2 kg TSS/day (137 lbs/day).

SANITARY WASTEWATER TREATMENT ALTERNATIVES

During CH2M HILL's Phase II study, three treatment systems were identified as viable alternatives for the Crandon Project sanitary wastes. Primary criteria for selection of the three systems from available treatment technologies were: process stability, ease of operation, compatibility with effluent land disposal, space requirements, capital and operating costs, sludge disposal needs, and compatibility with the activities at the Crandon Project. The treatment alternatives selected on the basis of these criteria were a septic tank system, a rotating biological contactor plant and an extended aeration activated sludge plant.

Table 12

SANITARY WASTEWATER QUALITY

<u>Type of Source</u>	BOD kg/person/day <u>(lbs/person/day)</u>	TSS kg/person/day <u>(lbs/person/day)</u>
Domestic ¹⁷	0.04 - 0.07 (0.09 - 0.15)	0.04 - 0.07 (0.09 - 0.15)
Construction Camp - with Food Service ⁷	0.07 (0.15)	-- --
Factories - with No Food Service ⁷	0.03 (0.07)	-- --

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The septic tank system was chosen as the preferred alternative for the following reasons:

- o Lowest capital costs.
- o Fewest requirements for operation, maintenance, and monitoring, resulting in lowest operation and maintenance costs.
- o Best process stability, capable of treating shock hydraulic loads without additional surge controls.
- o Effluent quality suitable for absorption field disposal.
- o Compatible with the activities at the Crandon Project in terms of space requirements, cold weather conditions, and odor potential.

The Wisconsin Department of Industry Labor and Human Relations, Bureau of Plumbing reviewed the sanitary treatment section of CH2M HILL's Phase II Interim Report and concurred with the process selection. In a letter to Exxon Minerals Company, they indicated that a septic tank system would be permissible if it conforms to Wisconsin State Codes.

SEPTIC TANK SYSTEM

A generalized process diagram for the septic tank system is shown in Figure 20. Sanitary waste collected from the Crandon Project enters the septic tank where it is held for approximately one day. The wastewater passes from the septic tank into a dosing chamber. Two submersible pumps deliver the septic tank effluent to two soil absorption fields via a pressurized distribution system. A more detailed description of each component of the septic tank system follows.

Septic Tank

Septic tank systems are designed based on hydraulic loadings. The septic tank was designed in accordance with the Wisconsin Administrative Code Section H62.21(4) and with recommendations in the literature.^{9, 18} The septic tank will be a buried, rectangular concrete tank with a total liquid capacity of 223.3 m³ (59,000 gallons). The septic tank will provide a one day liquid retention time plus additional volume (13,000 gallons) for sludge storage. The tank will be divided into two compartments in series to maximize

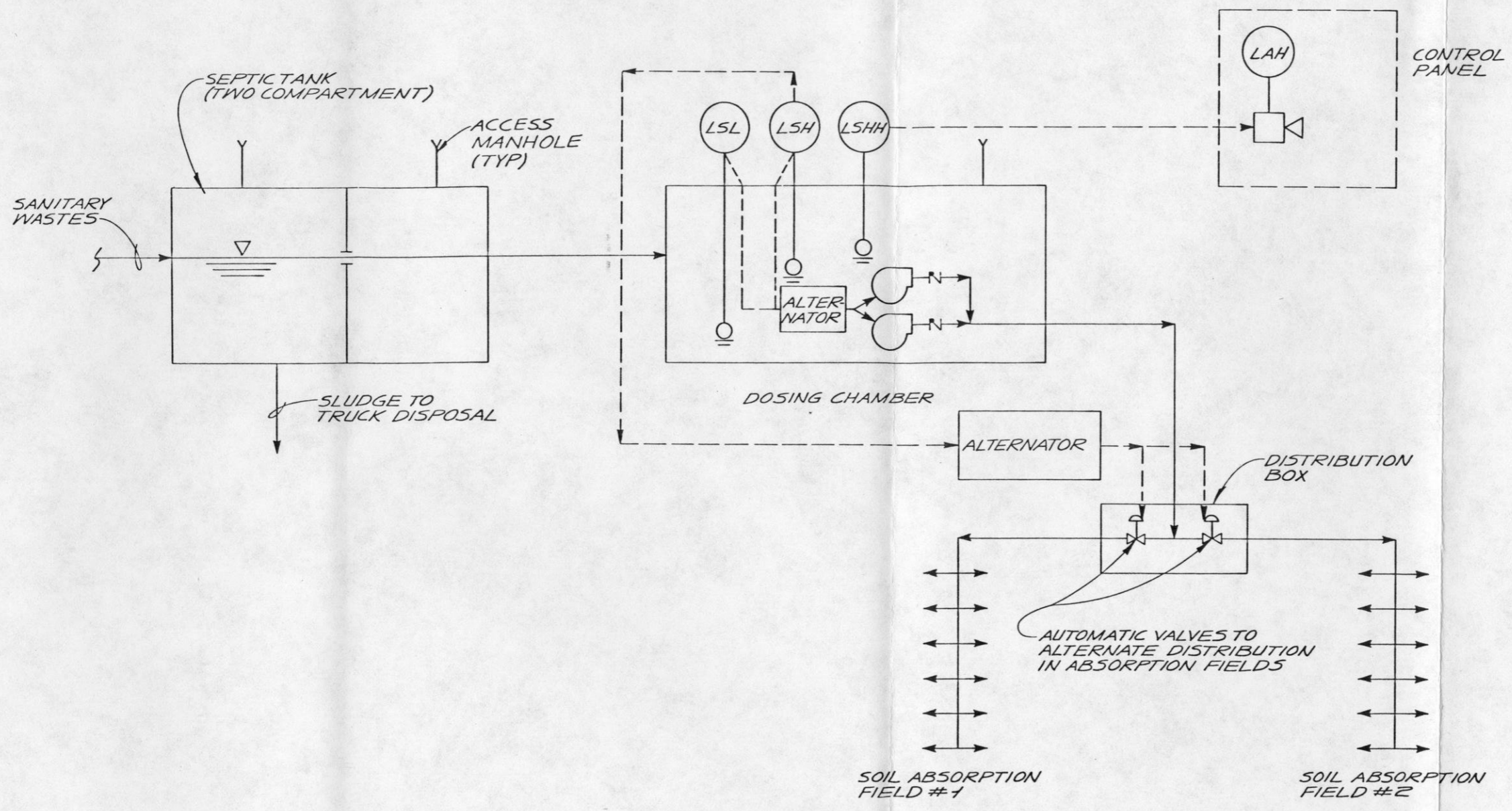


FIGURE 20

EXXON MINERALS COMPANY CRANDON PROJECT		
TITLE SEPTIC TANK SYSTEM, PRELIMINARY PROCESS DIAGRAM		
SCALE NONE	STATE WISCONSIN	COUNTY FOREST
DRAWN BY SAM	DATE	CHECKED BY
APPROVED BY WAE	DATE	DATE
APPROVED BY NRH	DATE	DATE
DRAWING NO. 051-7-L-016		SHEET OF

REVISED	DATE	BY	DESCRIPTION
1	6/5/82	NRH	FORMERLY 050-1-7-00-L035



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the solids removal from the wastewater. Manholes will provide access to both compartments for removing accumulated sludge. Both compartments will be equipped to vent gases to the atmosphere.

Dosing Chamber

The dosing chamber has been designed in accordance with Wisconsin Administrative Code Section H63.15(5)(b). The chamber will be constructed as an integral part of the septic tank structure, with a total liquid capacity of 217.6 m³ (57,500 gallons) which is equal to 1.25 times the expected daily flow rate. The dosing chamber will be equipped with two submersible pumps, controlled by float switches set to dose the absorption fields about four times per day. The dosing chamber will also be equipped with a high water level alarm and a vent to the atmosphere. A water-tight hatch will provide access to the dosing chamber for pump maintenance. Figure 21 shows a schematic plan and profile for the septic tank and dosing chamber.

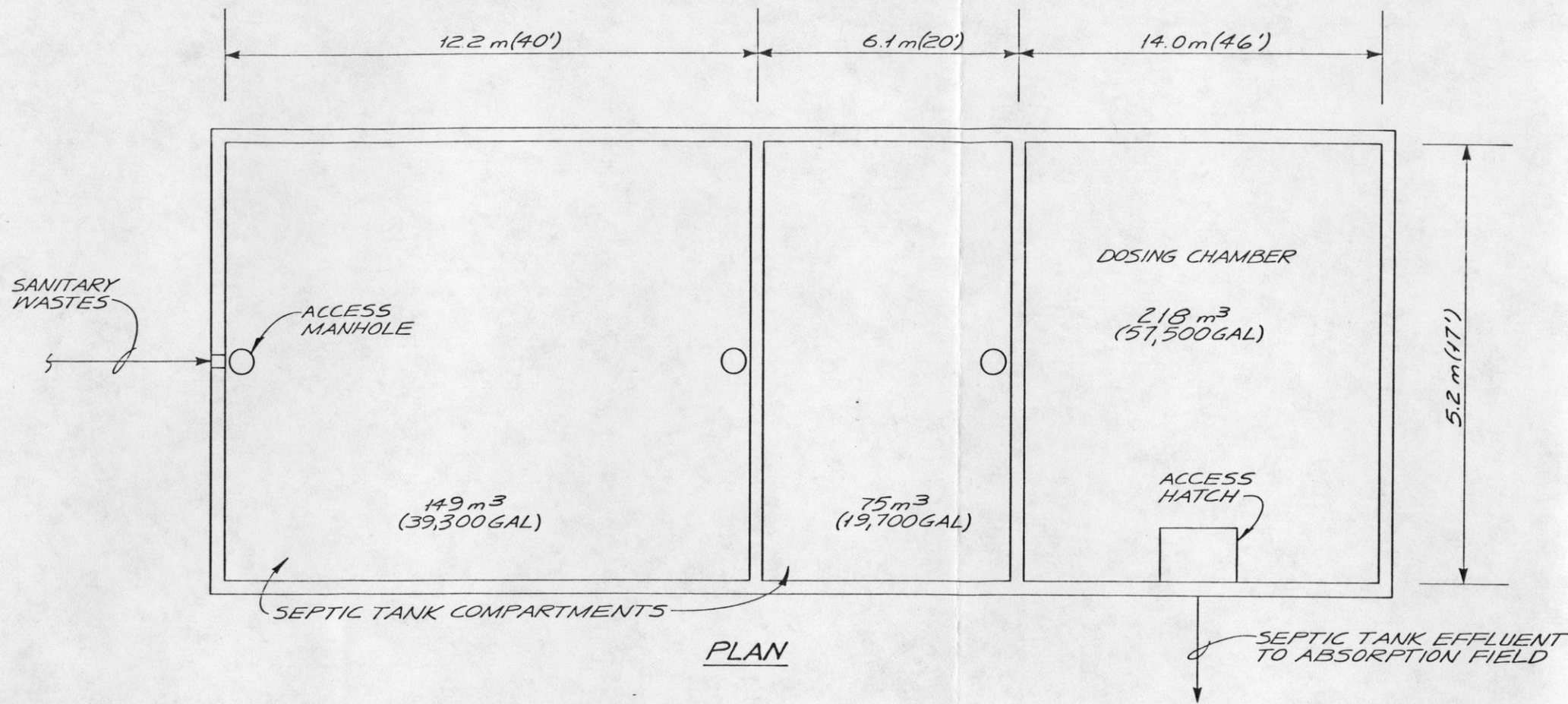
Soil Absorption Field

Area requirements for a soil absorption field using a pressurized distribution system are specified by Wisconsin Administrative Code Section H63.14(2). Area requirements are based on both wastewater flow rates and soil percolation rates. Field percolation tests at the Crandon site have not been completed. A definite field area cannot be specified until a percolation rate is established by a State approved soil tester. A range of field areas have been computed for the four classes of soils defined in the Code and are summarized in Table 13.

Wisconsin Code H62.20(2)(c) requires that an equivalent area must also be available onsite for a replacement absorption field.

The soil absorption field should be constructed as two beds, each with 50 percent of the required area. This is not required by code, but is recommended. A plan view of the proposed septic tank system is shown in Figure 22.

A pressure distribution system will deliver the septic tank effluent to the absorption fields. The size of the distribution system will depend on the area of the absorption field and must conform to H63.14(3) of the State Code. The system piping will evenly distribute septic tank effluent over the



DOSING PUMPS
 2 SUBMERSIBLE PUMPS
 EACH 341 m³/HR (1500 GPM)
 POWER AND PRESSURE REQUIREMENTS
 DEPENDENT ON FIELD SIZE

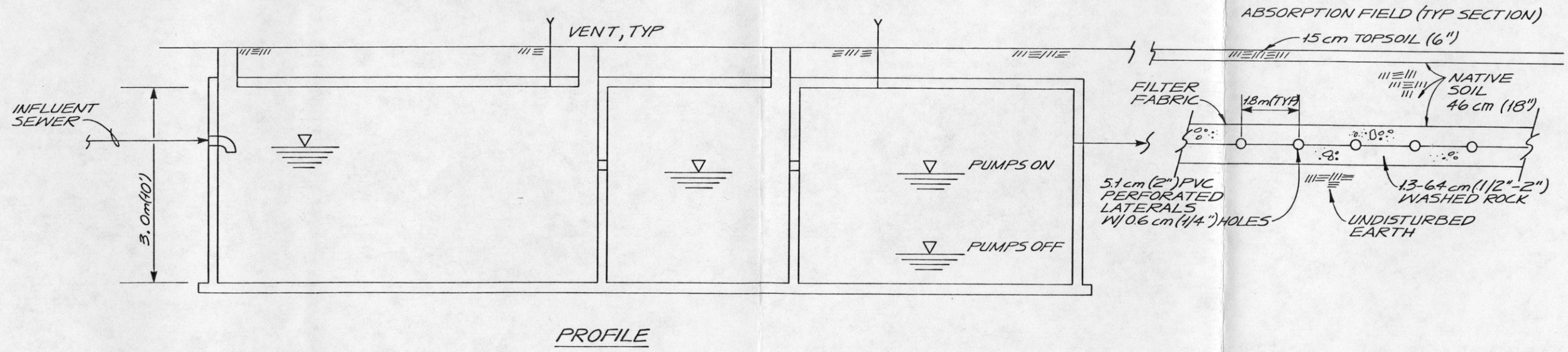


FIGURE 21

EXXON MINERALS COMPANY
 CRANDON PROJECT

TITLE
**SEPTIC TANK SYSTEM,
 PLAN AND PROFILE VIEWS**

SCALE	NONE	STATE	WISCONSIN	COUNTY	FOREST
DRAWN BY	SAM	DATE		CHECKED BY	
APPROVED BY	WAE	DATE		APPROVED BY	
APPROVED BY	MRH	DATE		EXXON	
DRAWING NO.	051-7-G-002				SHEET
					OF

REVISED	DATE	BY	DESCRIPTION
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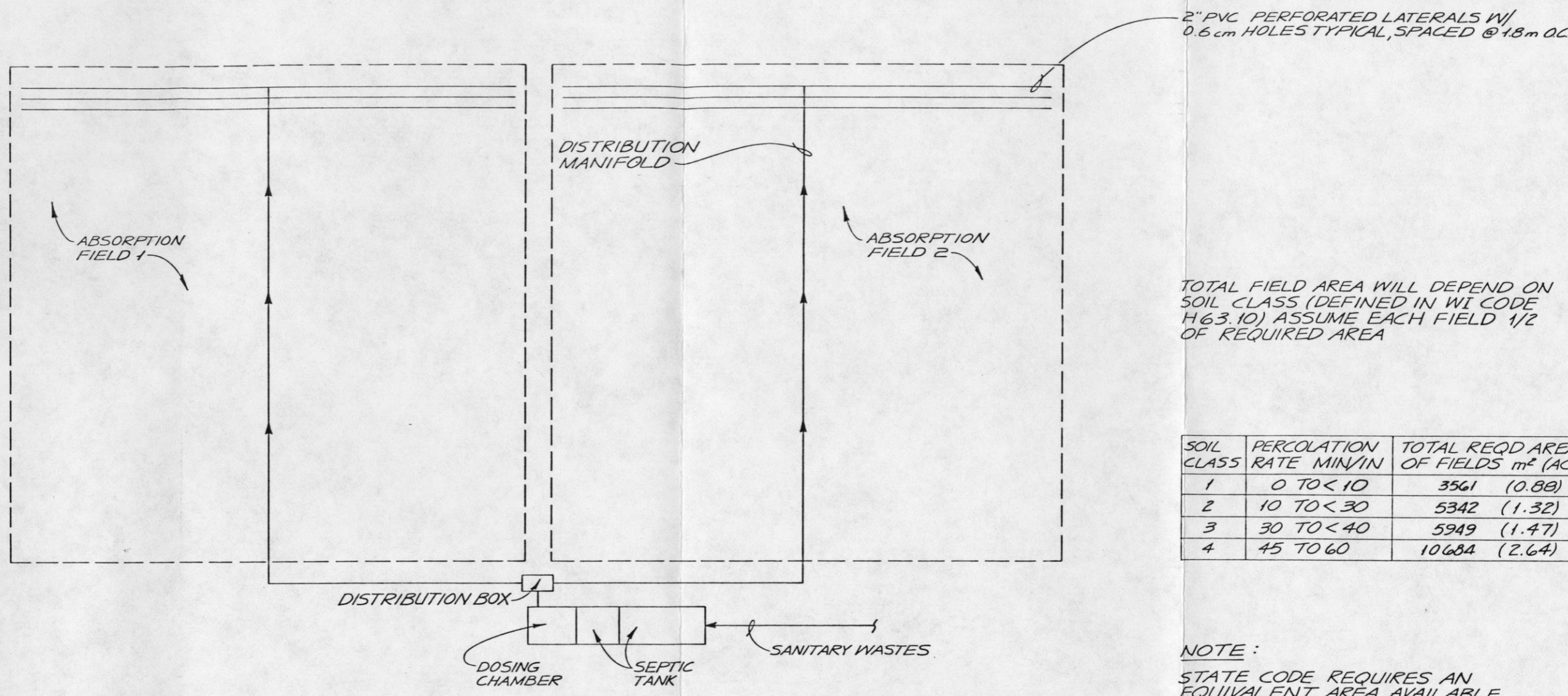
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Table 13

SOIL ABSORPTION FIELD AREA REQUIREMENTS

<u>Soil Class</u>	<u>Percolation Rate, min/in</u>	<u>Daily Flow gallons</u>	<u>Loading Factor gal/ft²/d</u>	<u>Required Area ft²</u>
1	0 to 10	46,000	1.2	38,340
2	10 to 30	46,000	0.8	57,500
3	30 to 45	46,000	0.72	63,890
4	45 to 60	46,000	0.4	115,000

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2" PVC PERFORATED LATERALS W/
0.6 cm HOLES TYPICAL, SPACED @ 1.8m OC

TOTAL FIELD AREA WILL DEPEND ON
SOIL CLASS (DEFINED IN WI CODE
H63.10) ASSUME EACH FIELD 1/2
OF REQUIRED AREA

SOIL CLASS	PERCOLATION RATE MIN/IN	TOTAL REQD AREA OF FIELDS m ² (ACRES)
1	0 TO < 10	3561 (0.89)
2	10 TO < 30	5342 (1.32)
3	30 TO < 40	5949 (1.47)
4	45 TO 60	10684 (2.64)

NOTE :
STATE CODE REQUIRES AN
EQUIVALENT AREA AVAILABLE
FOR REPLACEMENT OF THE
ABSORPTION FIELD

FIGURE 22

EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE
SEPTIC TANK SYSTEM,
PRESSURE DISTRIBUTION
SCHEMATIC PLAN

SCALE NONE STATE WISCONSIN COUNTY FOREST

DESIGNED BY	DATE	CHECKED BY	DATE
DRAWN BY	DATE	APPROVED BY	DATE
APPROVED BY	DATE	EXCHG	DATE

PROJECT NO
051-7-G-003

SHEET
OF

REVISION NO

REVISED	DATE	BY	DESCRIPTION
1	6/5/82	MRH	FORMERLY 050-1-7-00-6-006



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GLOSSARY OF TERMS USED IN REPORT

- BATEA - EPA defined "best available treatment economically achievable"
- BPCTCA - EPA defined "best practicable control technology currently available"
- Backfill
Drainage
Water - Water which drains from backfilled sands
- Bench Testing - Testing that is performed using laboratory scale testing apparatus
- Blowdown - The volume of water removed from a recycle water circuit.
- BOD - Biochemical Oxygen Demand
- COD - Chemical Oxidation Demand
- Concentrates - The valuable minerals or products obtained from the ore processing operation
- Concentrator - That portion of the surface facilities where ore is separated into concentrates and reject materials
- DNR - Wisconsin Department of Natural Resources
- Effect Matrix - A computer subroutine describing the "effect" a unit process has on a number of constituents as water passes through the unit process
- EPA - U.S. Environmental Protection Agency
- Fines - Fine crushed ore particles which are generated in the mill crushing operation, normally routed to the Tailings Pond
- Freeboard - The vertical distance between the water surface and top of a containment structure
- Flotation - The ore concentration process to be employed at the Crandon Mill
- gpm - Gallons per minute
- Ion - An electrically charged molecule
- Grout - A pumpable slurry of cement or other binding agent forced into a crevice to seal the crevice.

Link - A computer representation of process water flow stream

m³/hr - Cubic meters per hour

MTPD - Metric Tons Per Day, equal to 2,205 pounds per day

Massive Ore - A rock containing greater than 50 percent sulfide minerals

Mill - See concentrator

Mine Seepage - Water which seeps into the mine from surrounding areas

Node - A computer representation of a unit process

Ore - A mineral or minerals of sufficient quality and quantity which may be mined for profit

Orebody - Generally a solid and fairly continuous mass of ore

Pilot Testing - Testing that is performed using small scale testing apparatus

Reagents - Chemicals added to enhance the performance of a unit operation

Sands - Coarse rock particles which are generated in the mill crushing operation, normally used to backfill the mine

Sludge - Sediments or residue generated in the treatment of water

Stringer Ore - A rock containing 2 to 50 percent sulfide minerals

Stope - A segment of the orebody which has been or is being mined

Tailings - see Fines

TGD - Thousands of gallons per day

TSS - Total Suspended Solids

TSS_A and TSS_N - In development of the water use model, it was necessary to track two "classifications" of suspended solids. TSS_A describes solids formed as precipitates (i.e., metal hydroxides, metal sulfides, calcium sulfate, calcium carbonate, etc.) in treatment processes. TSS_N describes solids present in the water from mining and milling operations (fines, sands, etc.). Total suspended solids in any stream is the sum of TSS_A and TSS_N.

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