Description and summary of results. 1989

Urbana, Illinois ; Ellicott City, Maryland: T.A. Prickett & Associates : Engineering Technologies Associates, 1989

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Kennecott

July 28, 1989

Gordon H. Reinke, Chief
Mine Reclamation Section
Bureau of Solid Waste Management
Wisconsin Department of Natural Resources
101 S. Webster St., GEF II
P. O. Box 7921
Madison, WI 53707

Dear Mr. Reinke:

RE: Kennecott Flambeau Project
Groundwater Flow Model

Kennecott Minerals Company (Kennecott) is pleased to provide the Wisconsin Department of Natural Resources with the enclosed copy of the report and appendices titled Groundwater Model for the Kennecott Flambeau Project at Ladysmith, Wisconsin - a Description and Summary of Results, produced jointly by Thomas A. Prickett and Associates, Inc. of Urbana, Illinois, and by Engineering Technologies Associates, Inc. of Ellicott City, Maryland.

With the submittal of this report, plus the Environmental Impact Report in April, and the two groundwater quality modeling reports from Foth & Van Dyke and Associates, Inc. earlier this month, Kennecott feels that the issue of the proposed project's groundwater impact has been thoroughly evaluated.

The reports collectively show no adverse impact to the public health, welfare, and the environment in relation to any changes the project will have on groundwater flow systems.

The enclosed report shows that maximum groundwater drawdowns due to the presence of the open pit will be almost entirely confined to Kennecott-owned land. Impacts to non-Kennecott owned water supplies will be insignificant. Along with data presented in the Environmental Impact Report, the report shows that the bulk of the wetland area is not connected to the water table and, thus, will also not be impacted by drawdowns. Finally, the report shows that the amount of steady-state water flowing into the mine during the maximum extent of the open pit will be limited to just over 100 gallons per minute, an amount dwarfed by the more than 800,000 gallons per minute that flow by the site, on average, in the Flambeau River.

The first of the two Foth & Van Dyke reports submitted earlier this month concluded that there would be no significant groundwater quality impacts from either the Type I or Type II stockpiles. The other Foth & Van Dyke report concluded that the reclaimed pit would produce no significant groundwater quality impact.

The reason these conclusions have been reached is that we have carefully designed the project in a manner that is intended to protect the environment and the interests of the residents of the area.

We are confident that the Department will agree that the investigation of these groundwater issues has been satisfactorily completed. We are confident, too, that the Department will agree with our conclusion that the impacts to groundwater will be negligible.

If you have any questions or comments as you review this report, please contact us at your convenience.

Sincerely,

KENNECOTT

Lawrence E. Mercando

Lawrence E. Mercando
Director, Process Development

LEM/gm

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GROUNDWATER MODEL FOR THE KENNECOTT FLAMBEAU PROJECT AT LADYSMITH, WISCONSIN
A Description and Summary of Results

by

Thomas A. Prickett & Associates, Inc.
Urbana, Illinois

and

Engineering Technologies Associates, Inc.
Ellicott City, Maryland

submitted to
Kennecott Minerals Company
Salt Lake City, Utah

July 1989

Table of Contents

Appendix List

List of Figures

List of Exhibits

Executive Summary

This modeling report predicts the impacts of contemplated open pit copper mining and reclamation plans on the water resources of the area. The main purposes of the impact analysis were to 1) predict what the mining and reclamation plans of the Kennecott Flambeau Project would likely do to the water table in the area aquifers; 2) predict what the groundwater inflow rates would likely be into the open pit during and after the mining activities; 3) make estimates of the changes in groundwater flow rates to the Flambeau River and Meadowbrook Creek due to the mining/reclamation plans; 4) make estimates of the changes in groundwater flow rates connected to the wetlands of the area; and 5)present the results of a sensitivity analysis on selected high and low aquifer parameters on the above four project purposes.

The groundwater model was assembled by inputting field data collected and analyzed by Foth & Van Dyke of Green Bay, Wisconsin and fully described in the Environmental Impact Report. A modification of the computer program called PLASM was used to predict groundwater conditions during premining, mining, reclamation, and post reclamation.

Ten wetlands were analyzed to determine if mine dewatering would affect them. Out of the ten wetlands analyzed, only five were affected by the mining activities. A table is presented below summarizing the premining, mining/reclamation, and post reclamation steady-state groundwater flows in the affected wetlands.

Summary Table of Groundwater Flow Rates to the Mining Pit, Wetlands, and Surface Waters near the Kennecott Copper Mine (Using Best Engineering Judgement Aquifer Parameters)

All values below are in gallons per minute (gpm)

Item	Premining	End of Mining	Minimums During Reclamation	Post Reclamation
Wetland 1	1.5	0.0	0.0	0.6
Wetland 2	1.4	0.0	0.0	0.7
Wetland 5	1.3	0.3	0.3	1.1
Wetland 6	0.1	0.05	0.03	0.1
Wetland 9	2.2	2.2	2.1	2.2
Meadowbrook	19.4	19.4	19.4	19.5
Flambeau (adj/mine)	60.8	46.8*	---	60.5

Peak Pit inflow at start of mining is about 296 gpm
Pit inflow at end of mining is about 110 gpm

*An additional 46.8 gallons per minute is being infiltrated toward the mine by induced infiltration from Flambeau River.

The maximum extent of the drawdowns caused by pit dewatering occurs shortly after the end of mining. The extent of the drawdown covers approximately the area about 1800 feet either side of a line from the Flambeau River to about 5400 feet northeastward of the river. The alignment of this line is in the same direction as that of the final pit.

An analysis of the groundwater flows in the vicinity of the mine indicates premining flows through the main permeable portions of the orebody of only about 4 gallons per minute. Post reclamation groundwater flows through selected parts of the reclaimed backfill materials and remaining deeper orebody deposits total about 6 gallons per minute.

Meaningful residual effects of the mining and reclamation activities are small and include small depressions in the water table in the immediate vicinity of the reclaimed area and slightly smaller groundwater runoff to nearby wetlands 1 and 2.

I. Introduction

Thomas A. Prickett and Associates, Inc. in cooperation with Engineering Technologies Associates, Inc. were hired to construct a groundwater model of the area in the vicinity of the Kennecott Flambeau Project. The main purpose of this model was to aid in understanding the groundwater conditions at the mine site and to predict the future impacts of mine dewatering and reclamation on the surrounding aquifers, wells and wetlands.

This work assignment started in the month of April 1989 from the ending point of field data collection and aquifer-mapping work accomplished by Foth and Van Dyke of Green Bay, Wisconsin. This data base and mapping work formed the major part of the input to the groundwater model of this report.

Numerous meetings were held among Kennecott personnel, Foth and Van Dyke, the Wisconsin Department of Natural Resources and associated agencies, and Prickett & Associates prior to initiating the modeling work. The purpose of the model, the scheduling of the work, and the staffing of this study were discussed in detail.

The written discussion below outlines the main purpose and scope of the work that this modeling assignment encompasses, includes a short description of the modeling theory and design, a detailed presentation of the basic data base used as the input to this analysis, the calibration procedures of comparing the model response to the field measured aquifer response, and the estimated impacts the contemplated mining and reclamation plans would have on the nearby groundwater, surface water resources, and wetland areas.

A. Purpose and Scope of Work

The purpose of this modeling assignment was to predict the impacts of contemplated open pit copper mining and reclamation plans on the water resources of the area. Figure 1 outlines the general area of the project including the mining site and the surrounding area near Ladysmith, Wisconsin.

The overall scope of work involved incorporating field data and mapping results of Foth and Van Dyke into a groundwater computer model of the area, using that model to analyze the mining and reclamation plan impacts, and then summarizing the results of that analysis.

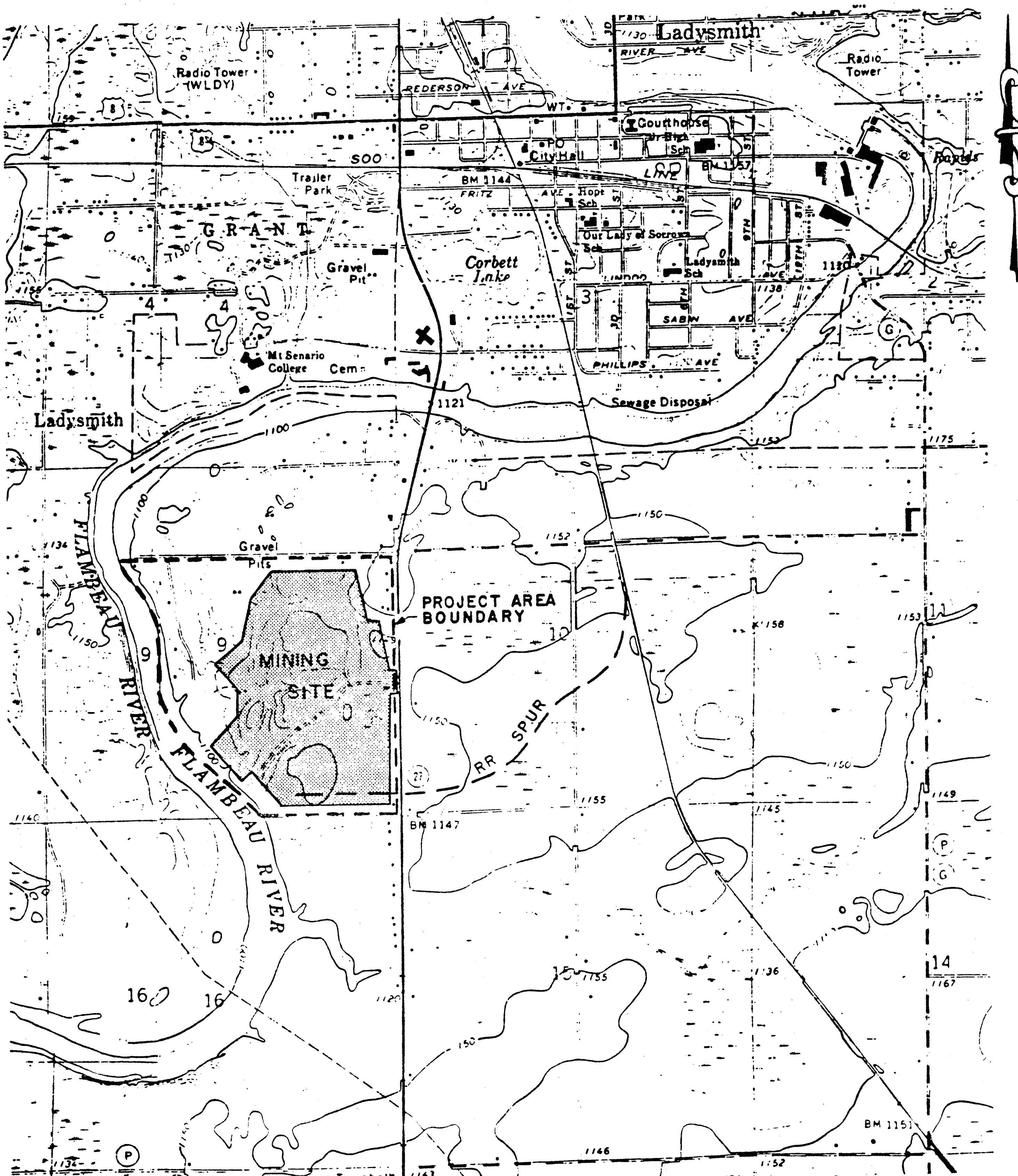


Figure 1 Scale: 1"=2000'

Project Area

The main purposes of this modeling exercise falls into the following five categories of impacts:

1) Predict the drawdown that the mining and reclamation plans would cause in the area aquifers. These drawdowns would be expressed in terms of water-table drawdowns, both in areal extent and giving consideration to the timing of the various mining/reclamation activities.

2) Predict what the groundwater inflow rates would likely be in the open pit during the mining activities, including the time variations over the life of the mine.

3) Make estimates of the changes in groundwater flow rates that are likely to be experienced either going to or coming from the Flambeau River and Meadowbrook Creek due to the mining/reclamation plans.

4) Make estimates of the changes in groundwater flow rates that are likely to occur in connection with the wetlands of the area, again, as a function of the mining/reclamation plans.

5) And finally, display the limits of uncertainty in the above estimates via a sensitivity analysis of major aquifer parameters including high and low combinations of aquifer permeabilities and groundwater recharge rates.

In addition to the above five categories of analyses, the scope of work included keeping basic computer files of data and results as the analysis took place. Although not everything was kept, most starting and major ending positions, aquifer parameters (node for node values), and resulting water-table histories were to be formed and saved in computer disk format for future reference. In this fashion, if anyone would like to change parameters, review aquifer results, or combine special area water balance information not previously enumerated, then at least several outputs and starting positions would be available to short cut reanalysis or making new calculations.

B. Acknowledgements

Several firms, groups, and people were instrumental in assembling the work done herein. We would like to acknowledge the help from Kennecott representatives Larry Mercando and Steve Richtel who provided basic data and mining/reclamation information on demand.

Probably the most comprehensive data input information and patience came from Boyd Possin and Fred Doran of Foth and Van Dyke---their help and suggestions were greatly appreciated throughout this modeling project. The data base, in both map and machine readable form was compiled by Foth and Van Dyke. Mr. Doran spent months of hard work prior to the modeling effort putting the basic data together. His work was superior and provided the initial input to this modeling exercise. Without those data, and in the excellent form that they were, this project would have been postponed significantly.

We want to point out that Tom Prickett was the major project director in this effort. Mr. Donald Koch, of Engineering Technologies Associates was the major computer analyst. Mr. Koch's work forms the major part of this report. Joe Yano and Peter Mattejat of Engineering Technologies Associates assisted Mr. Koch in the computer modeling effort.

II. Model Capabilities and Theory

A. The PLASM Flow Model

The model used in this assignment is the two-dimensional flow model called the Prickett-Lonnquist Aquifer Simulation Model (PLASM) (see Prickett and Lonnquist, 1971). This model was modified to account for the vertically varying hydraulic conductivities of the Flambeau project area, the interaction of the groundwater table and the wetland areas, the mining plan, and the reclamation plan. The details of each of these modifications follows in this section of the report.

The overall capabilities of the PLASM model include the following features:

1) Heterogeneous two-dimensional aquifer with groundwater recharge, evapotranspiration, leakance, flow from springs and net withdrawal rate features.

2) The transmissivity at every node of the model is calculated as a function of the depth of flow and an appropriate function of hydraulic conductivity (permeability) distribution keyed to the hydrogeology of the area. An explanation of this is given in the section below on PLASM modification details.

3) Boundaries of the model have the capability of no flow (modeled by zero leakance) on up to constant head via high leakance.

4) River and creek nodes are handled by riverbed leakance/river level/bottom elevation control as outlined in Prickett and Lonnquist, 1971.

5) Special water balance output on model edges, selected wetland areas, Flambeau River sections, Meadowbrook Creek, and pit inflow rates.

6) Special printout of water levels in category printout form, disk file storage capabilities for selected water level and aquifer parameter arrays, node for node arrays of water outlet flow rates of the model.

The PLASM model is a standard "finite-difference" formulation of the equations of groundwater flow. The inputs to the model are the aquifer properties, the wetland relationships to the groundwater reservoir, the connections between the rivers and creeks to the aquifer under study, the mining and reclamation plans (including permeability of the reclaimed materials), and the groundwater recharge rates expected in the area. The main outputs are time related estimates of the elevation of water- levels of the aquifer under study and the rates of groundwater flow throughout the aquifer.

The solution of the equations of flow is accomplished with the aid of a computer. In this study, an Everex 386/20 Mhz machine in the Engineering Technologies Associates and a Compaq 386 computer in the Prickett & Associates offices were used to organize and make the computations of water levels and flow rates of the model area.

The source code of the PLASM model, with modifications, is called BALPOND.BAS and is presented in Appendix A of this report. The reader should have this Appendix A available while studying the next few paragraphs.

The details of the modifications to the above model description is included in the following section.

B. Major Modifications of the PLASM Model For This Project

The original PLASM model was designed for studying the typical aquifer development and water level impact problems associated with wells pumping in a heterogeneous aquifer with various hydrologic and complex geometric shape boundary conditions. Modifications were made to PLASM to simulate the mining and reclamation plan, its timing, and the wetlands.

First, the vertical distribution of permeable materials in this project area was more complex than the basic PLASM was originally programmed to handle. Second, special input/output data routines were needed to handle the massive data requirements related to this project. Third, the interest in wetland area, river and creek, and model edge flow information required modifications to PLASM to keep track and printout special water balances. Fourth, special preprocessing and post processing routines were needed to manipulate and evaluate the model data. In particular, the processing codes helped printout and compare model predicted water levels with those actually measured in the aquifer under study. The details of these four modification areas are described now.

1) Transmissivity and Storage Coefficient Functions

There has been sufficient information generated by Foth and Van Dyke that indicate variations in permeable deposits with depth of flow. These data indicate that vertical distribution of permeability (hydraulic conductivity) can be broken into three main types from top to bottom: First, there are glacial/fluvial materials composed of sands, gravels, or tills; second, there is a sandstone unit (SS); and third there are the bedrock materials composed of the orebody itself and the slightly permeable surrounding Precambrian rocks (PC) which extend over the entire project area. The vertical integration of these permeable deposits was accounted for in the model by summing the transmission properties as a function of depth of flow and the thicknesses of the appropriate individual deposit, node by node, for the entire modeled area.

Therefore, the PLASM model was modified to make these integrated calculations given the permeability distributions dictated by the basic data as outlined by Foth and Van Dyke. Reference should now be directed to Figure 2.

Figure 2 illustrates three typical curves of transmissivity versus water-level elevation for three nodes of the computer model for different areas of the project area including Figure 2A which shows a typical vertical sequence of Precambrian rocks overlayed by sandstone and till. Figure 2B illustrates the transmissivity function for a sequence of orebody footwall or hanging wall deposits overlayed by sandstone and till deposits. Finally Figure 2C shows how transmissivity varies in an area where ordinary Precambrian rocks are overlayed by sandstone and sands and gravels.

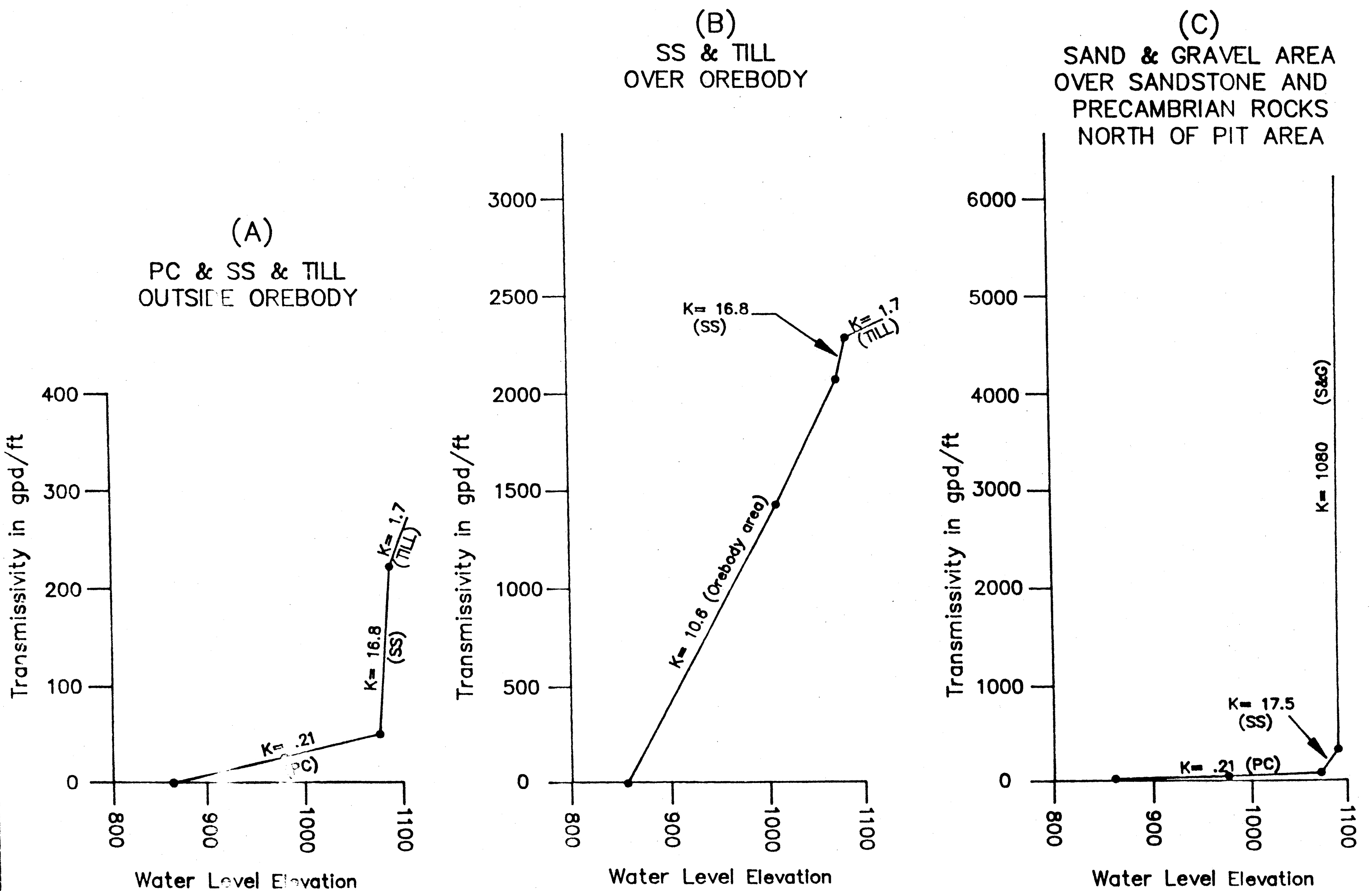
In each of the graphs in Figure 2, the transmissivity goes from zero when the water-level elevations are below 860 feet. As the water-level elevation increases, the transmissivity increases according to the permeability (hydraulic conductivity) of the saturated materials and the depth of flow. The computer was programmed to test for water-level elevation and then integrating (or summing up) the specified material thickness and permeabilities below that elevation. The results are aquifer transmissivities for each node of the model according to local permeability and saturated thickness of the multiple formations below the water table. Any changes in permeability, with time, are accounted for as the reclamation plan is completed.

Refer to the model code in Appendix A. The coding in lines 1490 through 1656 indicate the details of the transmissivity calculations.

Furthermore, as the water levels change, the appropriate storage coefficients are accounted for. Those changes are dictated by testing for the elevation of the water level and assigning the appropriate storage coefficient. The calibrated storage coefficients for the unconsolidated and bedrock formations are imbedded in the code within the lines 1490 through 1656 as well.

Figure 2

Transmissivity Functions



The storage coefficient values are given here as a sneak preview of the calibration results discussed later in this report. The storage coefficients for water-table conditions for the glacial, sandstone, orebody, and precambrian rocks are 0.05, .1, .05, and 0.001 respectively. The reclaimed storage coefficients are .1 and 01 for the types I and II materials, and the saprolite materials respectively.

2) Input/Output Routines

Modifications were made to the original PLASM model to allow interactive input, retrieval and running a text-edited data input file, and to save and retrieve any present position RESTART data file set. In addition, water-level, or head data for each time step, can be saved to disk for mapping with Golden Software or Prickett & Associates software. All of these routines were necessary to save and restart modeling efforts as the project calculations progressed. The reader can refer to subroutines in lines beyond 7140 and 4280 of the program source code of Appendix A for the details of how this is done.

In addition, the subroutine given in lines beyond 7140 gives the format of the input and output data that the reader will be reviewing in a later part of this report. For example, see the Appendix B listing of the calibration data results and input data.

Finally, an output routine has been written to memorize exit and entrant groundwater flow rates for each node of the model for each time step of all model runs. The reader can observe the major coding for this output routine near line 2750 and near line 3040 of the Appendix A source code.

3) Wetland Impact Theory

One of the prime interests of this assignment was to monitor and be aware of any changes in the groundwater flows of the area in relation to the wetlands. Any changes of the groundwater flowing to the wetlands due to mining or reclamation would be calculated and summarized. This situation was studied and programmed into the computer in the following manner.

King (1983) made a detailed study of the hydrologic balance of the project area and determined the following wetland field conditions. First, he calculated that there is a groundwater component feeding any wetland when the water table is within 3.5 feet of the land surface. If the water table is at a depth below 3.5 feet from the land surface, then the upward groundwater flow ceases and thus this component of the wetland hydrologic balance becomes isolated from the wetland. Thus, changes in groundwater levels below the 3.5 foot level do not affect the wetland hydrology.

If the water table is closer to the land surface than this 3.5 feet limit, then the groundwater reservoir contributes water to the wetland--including all of the cases up to the situation when springs occur when groundwater runs off at the land surface. As the water table approaches the level of the land surface, the upward rate of groundwater flow increases to a limit of 22 inches/year of water. This 22 inch rate of upward flow from the groundwater reservoir represents the potential evapotranspiration rate from the groundwater reservoir to the wetland for the case when the groundwater levels would be at the land surface.

A final component of groundwater flow exchange between the wetlands and the underlying aquifers is the downward recharge rate due to precipitation or ponded water at the land surface. As this rate is dependent upon climatic conditions and soil permeability and slope, the groundwater recharge rate is determined by calibration of the computer model rates and comparing the water-table levels in the computer model with those actually measured in the field.

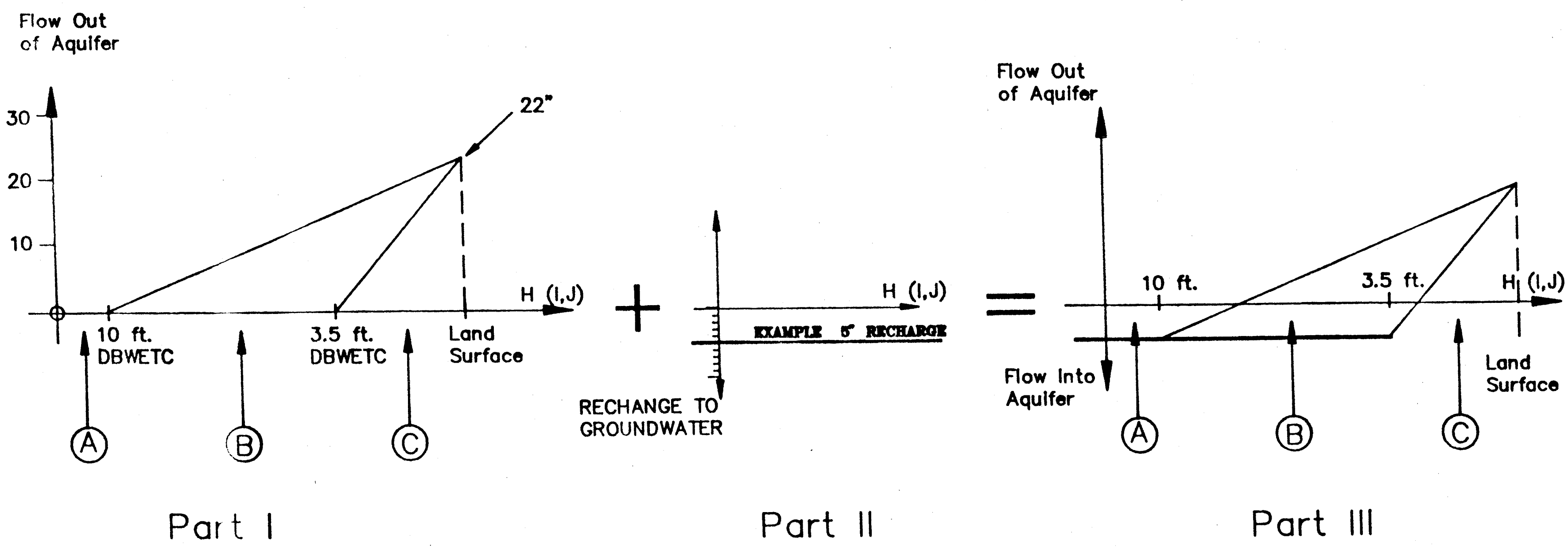
A pictorial and mathematical representation of the King results and theory is shown in Figure 3. The groundwater exchange rate mechanism is seen to be a summation of the upward component of groundwater flow (Part III of Figure 3) when water levels are within 3.5 feet of the land surface and the downward component of groundwater recharge through the bottom of the wetland. The upward component of groundwater flow, taken by itself is shown as in Part I of Figure 3. The downward groundwater recharge rate from the wetland is shown in Part II of Figure 3.

The consistent theory throughout this project and previous studies (particularly King's work) points to the 3.5 foot depth of the water table as the lower limit of the connection of groundwater flow to the wetlands. However, other interested agencies (DNR as an example) have asked for a sensitivity analysis based on a 10 foot depth of the water table. Therefore, that explains why the reader finds two sloping lines in Figure 3, one for the 3.5-foot depth and the other one for a 10-foot depth.

As it turns out, the original PLASM model had this groundwater/wetland function included in it as one of its standard features. The only addition to the PLASM code was a need to print out, for each wetland area of interest, the flow rate interchange values. This necessity was arranged via the water balance printouts explained in the next section of this report.

Figure 3

Leakance Functions for Wetlands



The general rule holds that all nodes of the model (except those associated with external boundaries, fivers, or creeks) have the 3.5 foot theory applied to them whether or not a water balance is printed.

4) Water Balance Printouts

The PLASM code was further modified to allow printout of several types of water balances and flow rates. In most cases, the flow rates of interest were calculated by summing, via Darcy-law type equations, the flows of interest. In the case of storage and groundwater recharge rates, the basic equations of flow were used to sum up those categories of the water balance. The computer code to accomplish printout of the special interest flows is given between lines 2720 and 3667 of the PLASM program of Appendix A.

To enumerate, the leakance values at the nodes of the model (model edges, Flambeau River and Meadowbrook Creek sections) allowed flow calculations out or into the aquifer along those lines. Balances were produced for the first and last columns and rows of the model plus three sections of the Flambeau River and three sections of Meadowbrook Creek. Furthermore, the first 10 wetland areas (see humic soil delineation on Exhibit 1) were included in water balance printouts. The wetland area water balance results were calculated from summation routines spoken of in the wetland theory section above and the mathematical curves of Figure 3.

As a check on the total model numerics and equation solving accuracy, a global water balance was calculated and a mass balance of flows in and out of the model compared with change in storage was assembled. In this particular respect most global mass balances account for much greater than 99 percent of the water circulating in the project area.

5) Preprocessing and Post Processing Codes

Several additional modifications were made to the PLASM program. A special category printout routine was written to display the model heads in a graphic format. The category printout is a symbolic representation of the water-table elevations in the aquifer. The coding for this modification is given in the Appendix A PLASM program within lines 3710 through 3860.

According to the category printout of water-table levels, a symbol is printed for each node of the model. The symbol represents a range of groundwater levels. The symbols used in the category printout for this version of the model are:

Printed Symbol	When Water Table is less than (ft)
!	900
@	905
#	910
$	915
%	920
^	925
&	930
(	935
)	940
_	945
1	950
2	955
3	960
4	965
5	970
6	975
7	980
8	985
9	990
0	995
A	1000
B	1005
C	1010
D	1015
E	1020
F	1025
G	1030
H	1035
I	1040
J	1045
K	1050
L	1055
M	1060
N	1065
O	1070
P	1075
Q	1080
R	1085
S	1090
T	1095
U	1100
V	1105
W	1110
X	1115
Y	1120
Z	1125
<	1130
>	1135
.	1140
/	1145
	1150

Finally, a computer program for calibrating the model was also prepared. This program, called HEADSTAT reads in the heads predicted by the model, compares them to the actual measured observation well water level elevations, and computes the average difference and the standard deviation of those differences about the mean. This program allows evaluation of the goodness of fit of the model compared with the actual field measured data. This HEADSTAT program source code is given in Appendix C.

III. Basic Data Set for Model

The basic data on aquifer parameters were assembled by Foth & Van Dyke based on their field data. Foth & Van Dyke had constructed a preliminary groundwater model which was based upon a gridded area measuring 68 columns by 79 rows by 4 layers deep. This accounting system grid covered an area of approximately 8500 feet wide by about 10000 feet in length from the water table downward to a rock elevation of about 860 feet. Based upon a Foth & Van Dyke study of the hydrologic system, the formations below an elevation of 860 feet were assumed to be essentially impermeable and thus formed the bottom of the flow system under study here. The area mapped by Foth & Van Dyke was the same area modeled by the PLASM model of this report as shown in the PLASM grid configuration of Exhibit 1.

Foth and Van Dyke had assembled their data in this area and included positional elevations of the glacial/fluvial deposits, the sandstone unit, the orebody, the remaining bedrock, and the land-surface topography. Furthermore, they had analyzed field information on deposit permeabilities, groundwater recharge rates, and storage coefficients. Their data base also included Flambeau River and Meadowbrook Creek surface-water levels, plus estimates of model edge water-table elevations. Finally, a table of piezometer and observation well water level elevations and their locations were included that provided the basic model calibration target data base.

Based upon the Foth & Van Dyke gridded data base, a PLASM grid was chosen that would allow adequate representation of the Kennecott mining and reclamation plan impacts. The results of an analysis of the hydrologic system, the numeric requirements concerning likely area and distance impacts, and the detail required by the involved agencies, the grid intervals shown in Exhibit 1 were specified. All of the grid intervals are less than 200 feet on a side and gridding details as small as 50 by 100 feet are used near the mining and reclamation activities in the center of the modeled area.

After the PLASM grid system was specified, then the process of inputting the Foth & Van Dyke gridded data was initiated. The following section of this report gives a brief description of how that was accomplished.

A. Transformation of Foth & Van Dyke Data to the PLASM Grid

The Foth & Van Dyke data base was displayed on a 68 by 79 column and row grid system. The chosen PLASM grid system contained 63 columns by 64 rows as shown in Exhibit 1. As a reminder, the Foth & Van Dyke gridded area was the same as the PLASM area.

The transfer of data was accomplished by several techniques, one of which involved the Golden Software (package called SURFER, version 4.0, 1989) gridding and contouring routines. The following general procedure was used to load the Foth & Van Dyke data base into the PLASM model grid:

1) Each Foth & Van Dyke parameter was gridded using the Golden Software SURFER code called GRID on a uniform 50-foot grid basis. The parameters gridded were the hydraulic conductivities of the glacial materials (top layer) and the sandstone (second layer) aquifer, the bottom elevations of the glacial and sandstone aquifers, and the land-surface topography. An ASCII format grid file was created. Golden Software's kriging algorithm was used in this process.

2) The ASCII grid data was converted to a column, row, elevation format using the GRIDTODAT computer program given in Appendix D.

3) The column, row, and elevation data were transformed into the PLASM model array format using the Engineering Technologies Associates program called GRID (See Appendix E). Since the data were gridded to a constant interval of 50 feet, and the PLASM grid intervals were all at even multiples of 50 feet, it was possible to select the model column and row values from the output of the Golden Software GRID program.

4) The model arrays were then read into the PLASM program using a special version of the PLASM program modified to read the data generated from steps 1 through 3 above. The relevant section of the PLASM program code is shown in Appendix F. A PLASM external file was saved after reading in these arrays.

5) The above procedure was modified for inputting the groundwater recharge array. The procedure compared the PLASM grid to the Foth & Van Dyke model grid and the recharge value of the Foth & Van Dyke model nearest to the PLASM model grid node was used. This procedure avoided problems of interpolation inherent with Golden Software in regions containing sharp differences in grid parameters.

6) The leakance terms of the PLASM nodes different than the model boundaries, rivers, and creeks were set according to the Figure 3 straight-line slope related to the 3.5 foot wetland function and the local land-surface elevation array.

B. Display of PLASM Input Data

Exhibit 2 is a contour plot of the top of the sandstone aquifer (elevation of the bottom of the glacial aquifer). Exhibit 3 is a contour plot of the top of the bedrock (elevation of the bottom of the sandstone aquifer). Exhibit 4 shows the land surface topography. These values were not changed during the calibration procedures discussed below. The permeability of the glacial/fluvial and sandstone materials were input to the PLASM model from the above procedure but only as initial starting points in the model calibration process. The contoured hydraulic conductivities of these deposits are given later in this report as calibration results.

IV. Model Calibration Procedures and Model Results

The following section describes how the PLASM model was calibrated to the average water levels measured in the field (average calculated for the period December 1987 through November 1988). The calibration process results in the best engineering judgement (BEJ) values for all of the groundwater flow parameters that are controlling the groundwaters in the project area. A discussion and display of the calibration results is followed, however, by the results of a sensitivity analysis wherein a range of aquifer parameters, including permeability, groundwater recharge, and depth of groundwater/wetland communication were tested and compared with the BEJ hydrologic system parameters obtained from calibration.

This section is thus broken into three sections of procedures, best engineering judgement parameter results, and sensitivity analyses.

A. Calibration Procedure

PLASM was calibrated by running the model to steady state with reasonable estimates of aquifer parameters and comparing the predicted heads to the average actual observation well water level measurements. This procedure was repeated numerous times until the fit of the model to the field data was deemed adequate. The model parameters adjusted during the calibration process were glacial and sandstone permeabilities and specific yields, river and creek leakances, and groundwater recharge rates. Based on our experience in Wisconsin and other areas hydrogeologically similar to this project, an upper limit of 8 inches per year of groundwater recharge was assumed.

Water balance results were inspected throughout the calibration procedure for reasonableness. There were no quantitative discharge data that could be used in the model calibration process.

B. Best Engineering Judgement Calibration Results

1) Water Levels in Piezometers

Table 1 shows the results of the model calibration. The average difference between predicted and actual head is negligible and the standard deviation is 2.08 feet. Two wells were excluded from the statistical comparison. Well PZ-SP6 had an average water level 10.9 feet above the water level predicted by the model. Well OW-7 had an average water level 8.2 feet above the water level predicted by the model. These wells are anomalies and are either completed

TABLE 1
FLAMBEAU MINE PROJECT - STEADY STATE CALIBRATION

WELL NAME	I	J	MODEL	WELL	DIFFERENCE
1001	20	38	1111.278	1112.48	-1.202271
1002	34	14	1090.583	1089.99	.5935059
1004	24	26	1105.702	1108.58	-2.878296
1005	40	41	1138.336	1137.91	.4257813
1006G	46	35	1130.496	1133.4	-2.904175
10	26	22	1098.853	1093.76	5.092773
12	35	22	1106.229	1108.58	-2.350586
14	44	21	1117.947	1121.12	-3.172729
31	20	25	1098.079	1095.9	2.178833
36	23	22	1093.091	1095.88	-2.789063
39	19	35	1101.551	1099.06	2.490601
40	18	32	1097.684	1095.28	2.403931
41	17	30	1096.307	1095.6	.7073975
42	18	25	1096.093	1094.08	2.012573
43	16	20	1086.43	1087.41	-.9802246
45	30	16	1090.118	1092.23	-2.112427
2	35	31	1113.505	1112.47	1.034912
19A	23	29	1105.309	1108.63	-3.321045
23	34	34	1113.664	1115.62	-1.955566
26	22	35	1107.027	1108.94	-1.912476
28A	19	31	1098.923	1097.39	1.532959
29A	15	33	1093.508	1093.99	-.4821777
SP*	12	32	1088.846	1084.85	3.996094
1008	32	46	1136.865	1136.16	.7050781
1009	55	44	1141.607	1141.16	.4472656
SP8	31	43	1136.009	1136.96	-.9512939
1003	35	27	1112.867	1110.28	2.587158
1004S	24	26	1105.702	1108.41	-2.708374
1005S	40	41	1138.336	1137.51	.8258057
1006S	46	35	1130.496	1131.92	-1.424194
1007S	52	23	1117.515	1114.72	2.795166
24	28	34	1111.683	1112.94	-1.25708
S3	28	34	1111.683	1112.84	-1.157104
1000	14	33	1092.096	1088.91	3.185669
1001P	20	38	1111.278	1112.53	-1.252319
1003P	35	27	1112.867	1110.34	2.527222
1004P	24	26	1105.702	1106.17	-.4683838
1005P	40	41	1138.336	1137.91	.4257813
S1	15	29	1093.669	1094.95	-1.28064
S2	16	34	1094.979	1091.41	3.568726
S4	39	33	1114.979	1116.17	-1.191162
R3	16	31	1094.843	1093.3	1.542725
R7	39	32	1114.9	1115.41	-.5097656
K3	27	33	1110.267	1111.67	-1.402588
K4	40	33	1115.32	1116.34	-1.020264
K6	23	30	1104.954	1107.88	-2.92627
K8	15	31	1093.46	1092.09	1.370361

AVERAGE DIFFERENCE = -2.468418E-02
STANDARD DEVIATION = 2.125341

* sand point next to river

in multiple zones (OW-7) and have steep hydraulic gradients, or have deficient frequency of data (PZ-SP6) to determine average water levels throughout the year.

2) General Configuration of Water Table

Exhibit 5 shows the predicted steady state water table elevation. The water table generally follows the topography with the Flambeau River and Meadow Brook Creek being areas of groundwater discharge. Depth to water for the calibrated model was contoured and is presented as Exhibit 6.

3) Conditions at Model Boundaries and Wetlands

Appendix G shows the model printout with the model at steady state. The printout shows the model water balance as a whole and for each specific element. There are ten wetland areas in the model. Wetlands 1 and 2 are areas of groundwater discharge; the remaining wetlands are generally isolated above the steady state water table, although there are small parts of wetlands 5, 6, and 9 that are predicted to be in contact with the water table. Predicted groundwater discharges to these wetland areas are:

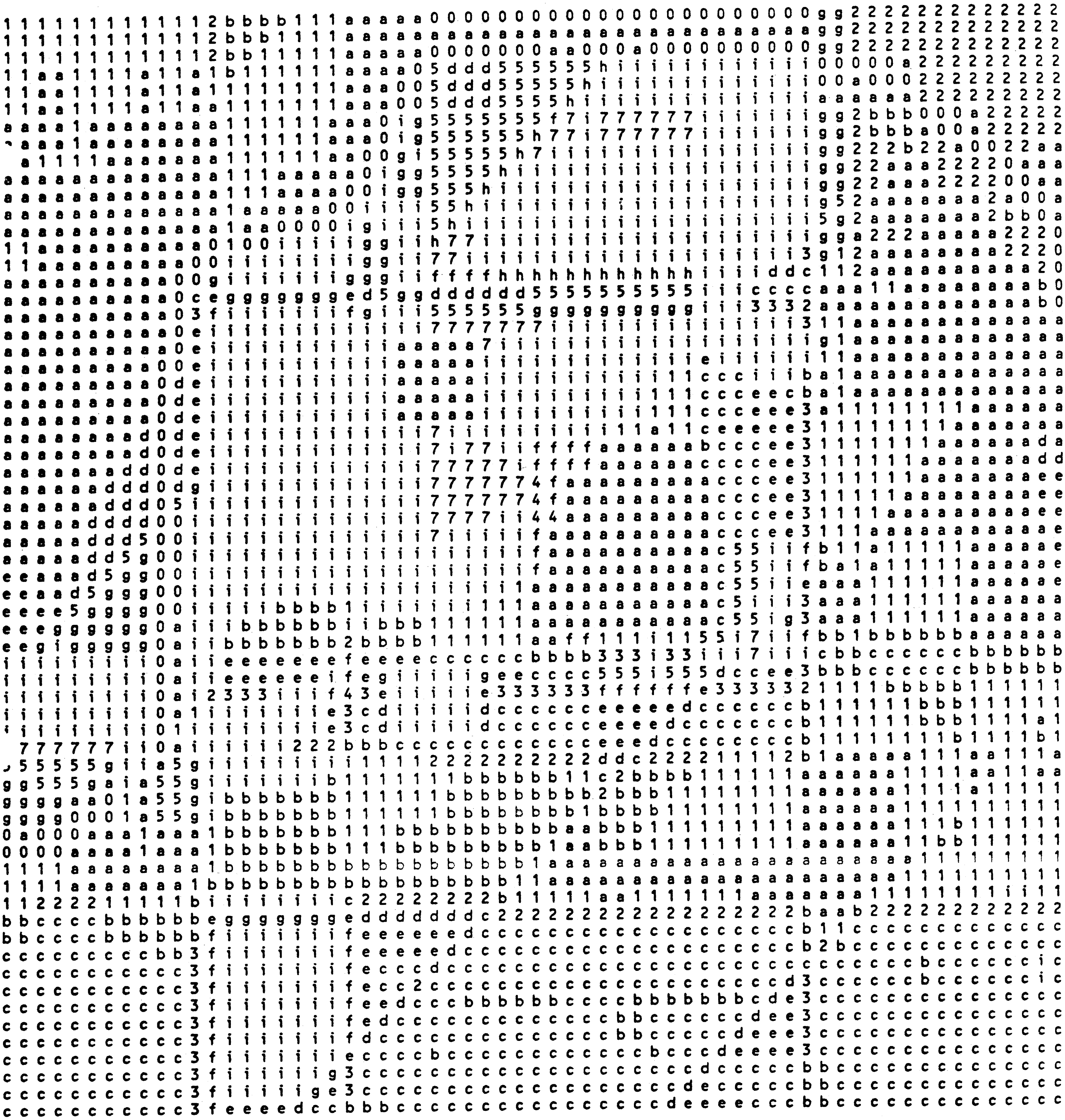
wetland 1	1.5 gpm
wetland 2	1.4 gpm
wetland 5	1.3 gpm
wetland 6	0.1 gpm
wetland 9	2.2 gpm

Groundwater also discharges to the Flambeau River and Meadow Brook Creek. Total discharge to Meadow Brook Creek is 19.4 gpm. Total discharge to the Flambeau River adjacent to the mine is 60.8 gpm. Depending on hydraulic gradients, groundwater flows are in or out of the first row and column of the model and in or out of the last row and column of the model.

Net withdrawal rates at all nodes are shown in Appendix H.

4) Calibrated Parameters

Exhibit 7 is a contour plot of the glacial aquifer hydraulic conductivity distribution produced by the calibration. Exhibit 8 is a contour plot of the final calibrated values of sandstone aquifer hydraulic conductivity. Figure 4 shows a category printout of the distribution of the calibrated values of recharge in the model. This display of the recharge distribution is easier to understand than a contour plot.



Label	Range
0 -	$Q = 0$
a -	$0 < Q \leq 0.5$
1 -	$0.5 < Q \leq 1$
b -	$1 < Q \leq 1.5$
2 -	$1.5 < Q \leq 2$
c -	$2 < Q \leq 2.5$
3 -	$2.5 < Q \leq 3$
d -	$3 < Q \leq 3.5$
4 -	$3.5 < Q \leq 4$
e -	$4 < Q \leq 4.5$
5 -	$4.5 < Q \leq 5$
f -	$5 < Q \leq 5.5$
6 -	$5.5 < Q \leq 6$
g -	$6 < Q \leq 6.5$
7 -	$6.5 < Q \leq 7$
h -	$7 < Q \leq 7.5$
8 -	$7.5 < Q \leq 8$
i -	$8 < Q \leq 8.5$

Figure 4

Calibrated values of groundwater recharge rates

5) Specific Yield

Choosing a specific yield to use in the model was based both on model response and professional judgement. The summer of 1988 was a drought and observation well water levels declined. A 90 day period with no recharge was simulated with the model to compare the predicted decline in well water levels with the actual declines. Assuming a specific yield of 0.05 in the glacial aquifer and 0.1 in the sandstone aquifer resulted in a average predicted decline in water level at the observation wells of 1.43 feet. This decline is representative of the declines actually measured in observation wells in the summer and fall of 1988. Figures 5 and 6 show the predicted versus actual declines. Precambrian specific yields were assigned (as 0.001) on the basis of typical values found in the literature.

C. Sensitivity Analysis

Sensitivity analysis is an important part of any modeling study. Sensitivity analysis defines how the uncertainty in the input parameters affects the conclusions of the study. The sensitivity of hydraulic conductivity, recharge, and the extinction depth for evapotranspiration were examined by changing these parameters and running the model to steady state.

1) High recharge and high permeability

Transmissivity and recharge were both increased by 50 percent and the model run to steady state conditions. As predicted from Darcy's law, predicted heads were at the same position as when using the best engineering judgment parameters. The total flows in the model did increase by 42 percent. Appendix I shows the model results including water balances for each wetland, river, and boundary. Discharges to wetlands that are in contact with the water table and the major surface water features are:

wetland 1	1.8 gpm
wetland 2	1.8 gpm
wetland 5	1.9 gpm
wetland 6	0.2 gpm
wetland 9	3.4 gpm
Meadow Brook Creek	29.9 gpm
Flambeau River (adjacent to mine)	93.7 gpm

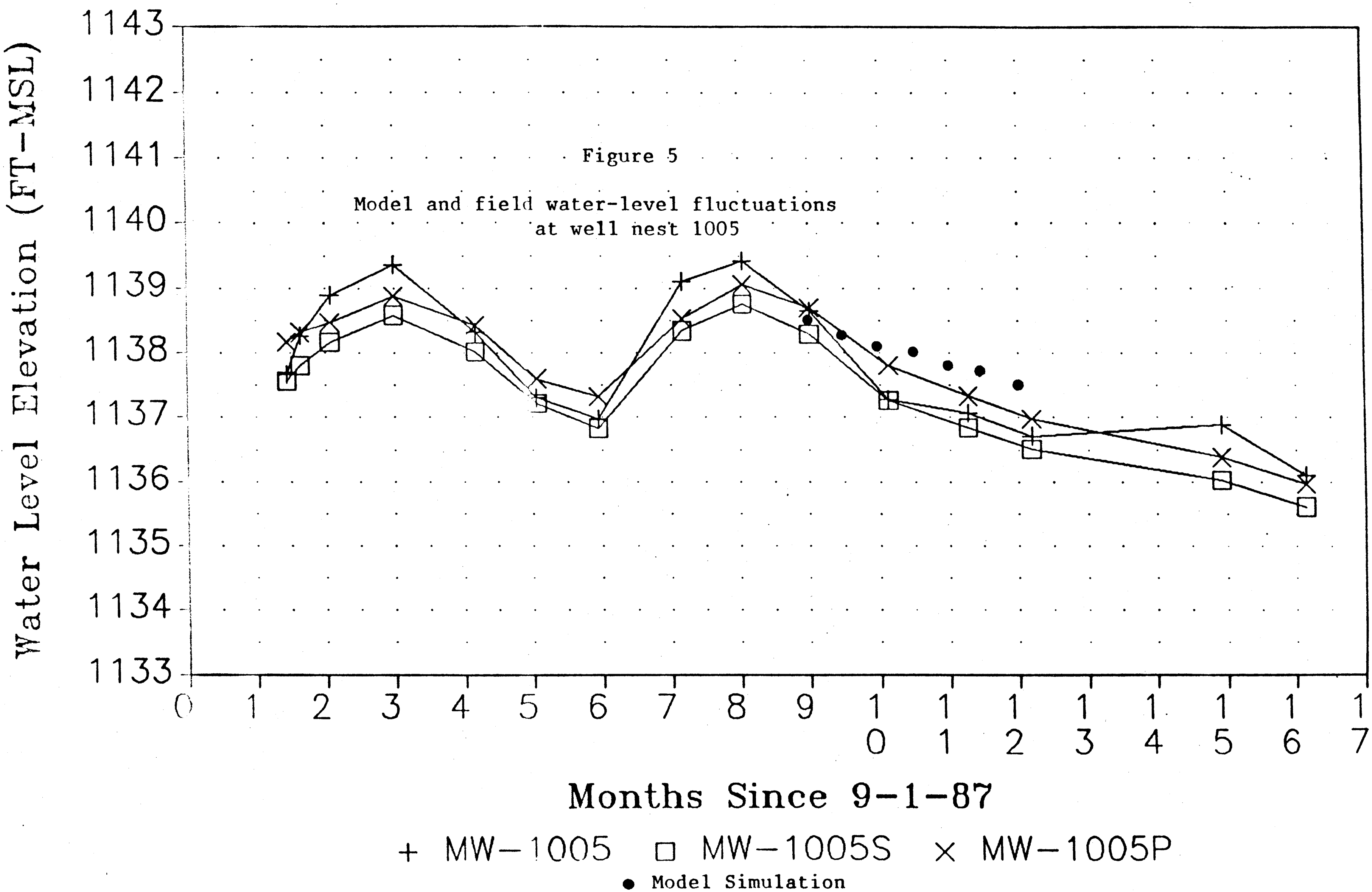


Figure 5

Model and field water-level fluctuations at well nest 1005

FOTH & VAN DYKE GEOSCIENCES & ENVIRONMENTAL MANAGEMENT DIVISION GREEN BAY, WISCONSIN				KENNECOTT MINERALS COMPANY FLAMBEAU PROJECT LADYSMITH, WISCONSIN
No	REVISIONS	NOTES	APPROVAL	DATE
			DESIGNED BY	
			DRAWN BY RDM	3/89
			CHECKED BY BNP	3/89
			APPROVED BY	
			CAD No. SCALE	

HYDROGRAPH
WELL NEST 1005

Job No | Dwg No | REV

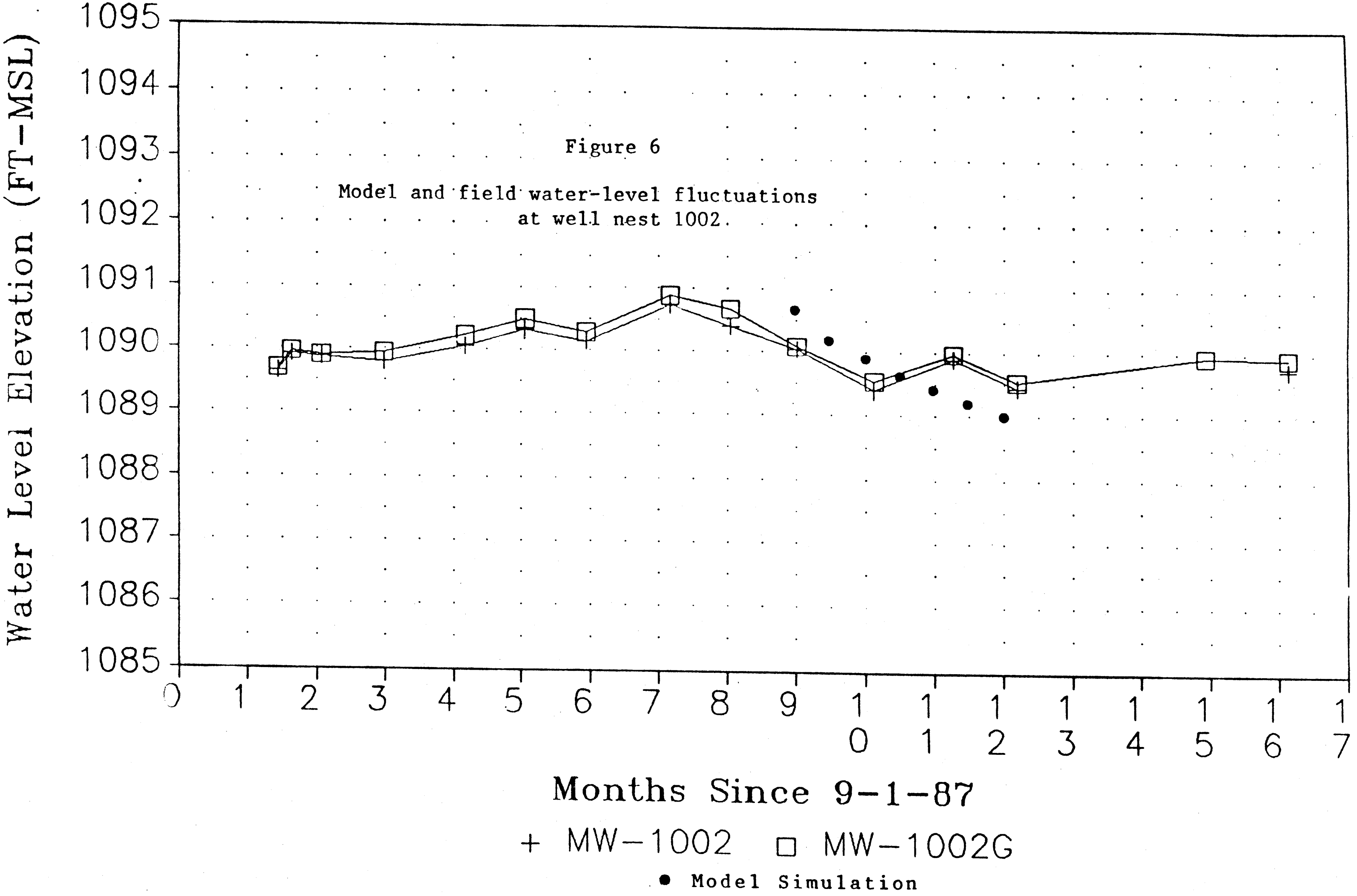


Figure 6

Model and field water-level fluctuations at well nest 1002.

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

KENNECOTT MINERALS COMPANY
FLAMBEAU PROJECT
LADYSMITH, WISCONSIN

HYDROGRAPH
WELL NEST 1002

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

Job No	Dwg No	REV

2) Low recharge and low permeability

Transmissivity and recharge were both decreased by 50 percent and the model run to steady state conditions. As predicted from Darcy's law, predicted heads were at the same position as when using the best engineering judgment parameters. The total flows in the model decreased by 48 percent. Appendix J shows the model results including water balances for each wetland, river, and boundary. Discharges to wetlands that are in contact with the water table and the major surface water features are:

wetland 1	1.1 gpm
wetland 2	0.9 gpm
wetland 5	0.7 gpm
wetland 6	0.03 gpm
wetland 9	1.1 gpm
Meadow Brook Creek	9.4 gpm
Flambeau River (adjacent to mine)	29.4 gpm

3) Wetland Function Isolation Depth

The best engineering judgement parameter on the 3.5 foot depth below which the water-table contributions upward to the wetlands cease was, as mentioned before, based upon the work of King (1983). However, an isolation depth of 10 feet below the land surface was also simulated to see what the impact of changing this assumption would be on the water table and wetland area flows. Changing the isolation depth while assuming a constant rate of potential evapo-transpiration (22 inches per year) changes the slope of the model groundwater/wetland function (see Figure 3). That slope factor was input to the model along with the 10- foot depth. Based on these input data the model was rerun and results presented in the water table map of Exhibit 9.

The overall simulated water table with this new 10-foot depth function was lowered. Comparing the predicted heads to the actual well heads, using the same statistical comparison as was previously used, yielded an average difference of -2.4 feet and a standard deviation of 3.4 feet. The deeper isolation depth lowered the water table significantly (on the average in the area where there are observation wells) 1.9 feet and does not fit the field situation at all. Increasing groundwater recharge and decreasing aquifer permeabilities to attempt a new calibration would require the upper limits of recharge to be in the range of 12 inches and more or the permeabilities to be lowered drastically. In our opinion, this readjustment of permeability and recharge is excessive and is inconsistent with field measured water balance values in this area, and therefore is not appropriate.

V. Simulation of the Mining Plan

A. Definition of Plan

The entire sequence of stripping overburden, pit excavating, stockpiling wastes into Type I and Type II areas, and the reclamation process has been outlined in detail in the Foth & Van Dyke report entitled "Kennecott Mineral Company Mining Permit Application for the Kennecott Flambeau Project", dated April 1989 and, in pictorial form can be found in the sequence drawings in Figures 4-28 through 4-37. The reclamation and backfilling procedures can be found in the same report as shown in their Figures 5-2 through 5-4. Other than those figures, the backfill elevations and permeability distributions within the reclaimed pit area are shown in this report in cross-sectional Figure 7.

We are not going to repeat that report here, nor are we going to reproduce the voluminous sequencing Figures. It is suggested that a copy of that report be made a companion to this modeling assignment. The methods, procedures, and PLASM modification programming to include these plans are discussed below.

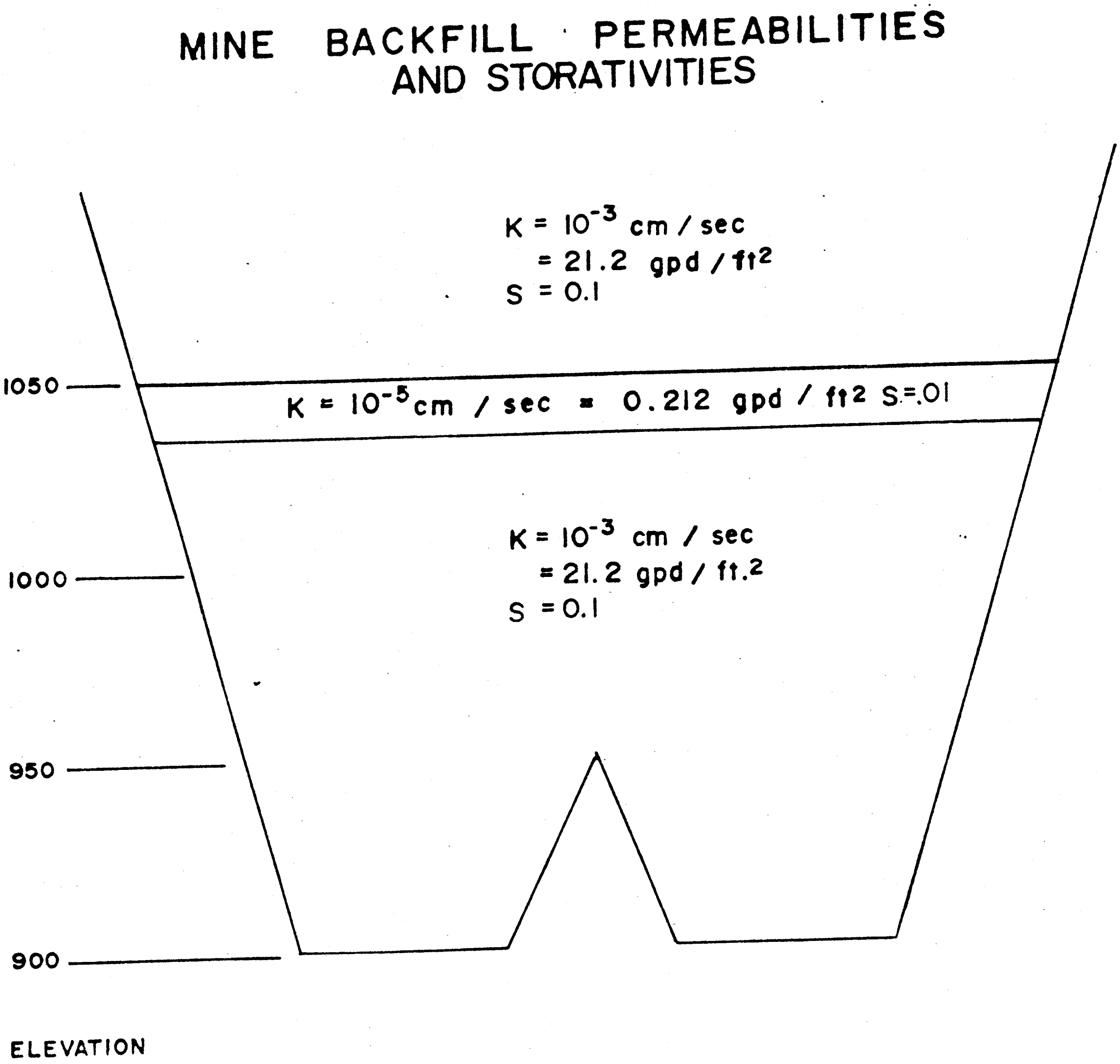
The source code (modified PLASM computer program) for the mining and reclamation sequencing is given in Appendix A prior to the discussion below. The actual model input data for the mining and reclamation plan are given in Appendix K. These input data are essentially the calibrated hydrologic system parameters plus an accounting of where (model column and row number) the lowest elevations of the pit bottom are in one-year increments. As will be described later, this discretization of time results in a stepped pit inflow and drawdown pattern whereas the real mine will show a more consistent inflow and drawdown pattern because the pit is continuously excavated. If desired, the reader can follow along with the coding and data sequencing as the next few sections are read.

B. Modification of PLASM model for mining

1) Theory

A mine is simulated in the PLASM model as a constant head node. This convention simulates a pit where groundwater inflow is pumped out at whatever rate is necessary to keep the bottom of the pit dry. Reclamation of the pit is simulated by removing the constant head assumption and programming a new transmissivity function that represents the backfill strata permeabilities.

Figure 7



MINE BACKFILL PERMEABILITIES AND STORATIVITIES
K = 10-3 cm / sec
= 21.2 gpd / ft2
S = 0.1
K = 10-5 cm / sec = 0.212 gpd / ft2 S=.01
K = 10-3 cm / sec
= 21.2 gpd / ft.2
S = 0.1
1050
1000
950
900
ELEVATION

2) Procedures

PLASM was modified to simulate the proposed mine by adding code to the model that permitted the creation and removal of constant head nodes to the model at specified column and row locations, elevations, and steps. The functioning of this routine is similar to the code used to simulate variable pumping rates at wells.

Modifications were made to PLASM to permit interactive entry of the schedule of mining, and to save these entries in an external file. Modifications were also made to the model to permit simulation of groundwater flow through the backfill. Figure 7 shows the assumed hydraulic conductivity in the different backfill strata.

The mine plan was discretized at one year intervals. The elevation of the bottom of the mine pit at the end of each year was tabulated. A total of 41 grid nodes were affected by mining. The mining operation was assumed to take seven years, with backfilling of the pit in the eighth year.

The stockpiling of overburden at the mine was also assumed to impact the hydrologic balance at the site. The Type II stockpile will be lined, so recharge in this area was assumed to be zero for the seven years of mining and one year of reclamation. The Type I stockpile and especially the associated sediment ponds increase groundwater recharge. Based on our experience, we estimate that recharge in this area will be higher by 50 percent during the seven years of mining and one year of reclamation.

A slurry wall is proposed for the unconsolidated material between the pit and the Flambeau River. The slurry wall would be four feet wide with a permeability of 10^{-6} cm/sec. The slurry wall would be constructed just before mining starts, would penetrate to the Precambrian bedrock, and be approximately 250 feet long. The slurry wall covers four grid nodes in the model and remains there in perpetuity. Hydraulic conductivities in these grid nodes were set to .023 gpd/sq ft to account for the slurry wall.

Reclamation was simulated by running the model until approximate steady state conditions were reached.

C. Model predictions during mining and reclamation

The following discussion summarizes the results of the mining and reclamation plans and their impacts on the hydrologic system. Appendix L shows the model printout for the mining phase and the first year of reclamation. Appendix M contains printouts of the water-level recovery after reclamation. Appendix N gives model net withdrawal rates for all nodes at the end of mining. Appendix O gives model net withdrawal rates for all nodes for the end of the post reclamation period. The reader should refer to these printouts for the details of the simulations.

1) Pit inflows

Figure 8 shows the predicted pit inflows. Inflows range from about 296 gpm at the initial removal of overburden to about 110 gpm at the end of mining. The simulated stepped dropping of the pit bottom is evident in the figure, an artifact of the time discretization previously described. Because the pit will not be excavated in these large blocks (resulting in the simulated step water level declines), the actual pit inflows would be less than the peak inflow rates shown, but eventually approach the flow rates shown for each period. Figure 9 shows the average yearly inflow over the life of the mine. Average yearly inflows gradually increase as the pit becomes deeper and more widespread.

2) Impacts on water table

a) During mining

Exhibit 10 shows the drawdowns caused by mining at the end of the mining period (seven years). Exhibit 11 shows the water table at the end of mining. The two foot drawdown contour is approximately 2750 feet from the mine pit at its furthest extent. Figure 10 shows the predicted aquifer head as a function of time over the life of the mine and during reclamation at a point approximately 100 feet from the mine pit. The maximum depression of the water table is reached when the mine pit is a its lowest point. Figure 11 shows the predicted aquifer head as a function of time at a point approximately 1200 feet from the mine pit. Figure 12 shows the predicted aquifer head as a function of time at a point approximately 2400 feet from the mine pit. Figure 13 shows the predicted aquifer head as a function of time at a point beneath wetland 3.

b) During reclamation

During reclamation, groundwater flows from the aquifer into the backfilled mine spoil. Water levels continue to fall away from the mine during this process. The maximum extent of the drawdown caused by mining as defined by the two feet drawdown contour, is thus not at the end of the mining period, but during the reclamation period. Exhibit 12 shows the maximum extent of drawdowns caused by mining which occurs 2.3 years after mining operations cease and backfilling of the pit begins. Exhibit 13 presents the elevation of the water table at that point in time.

Figure 8

Pit Inflow for BEJ parameters

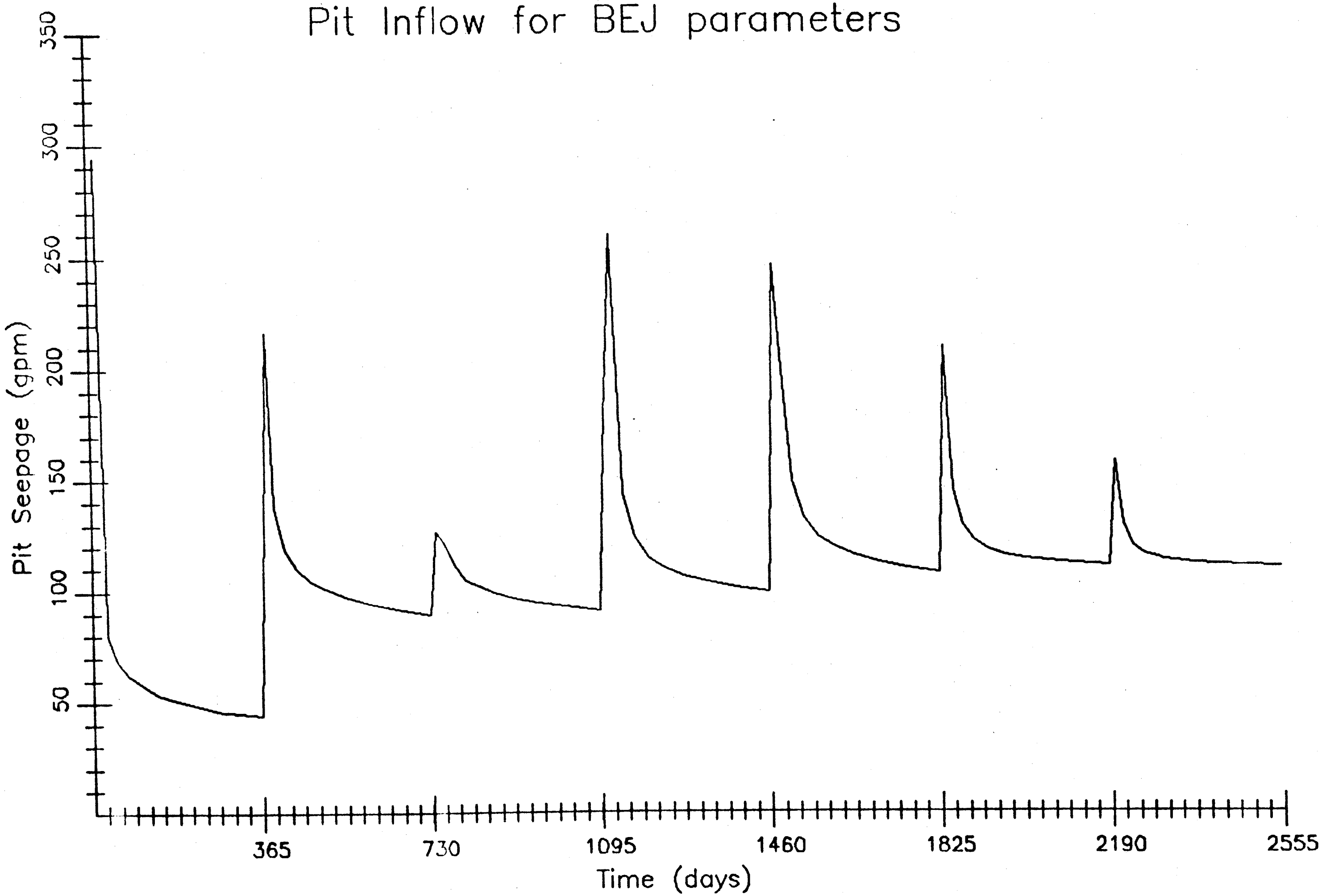


Figure 9

Average Annual Pit Inflow

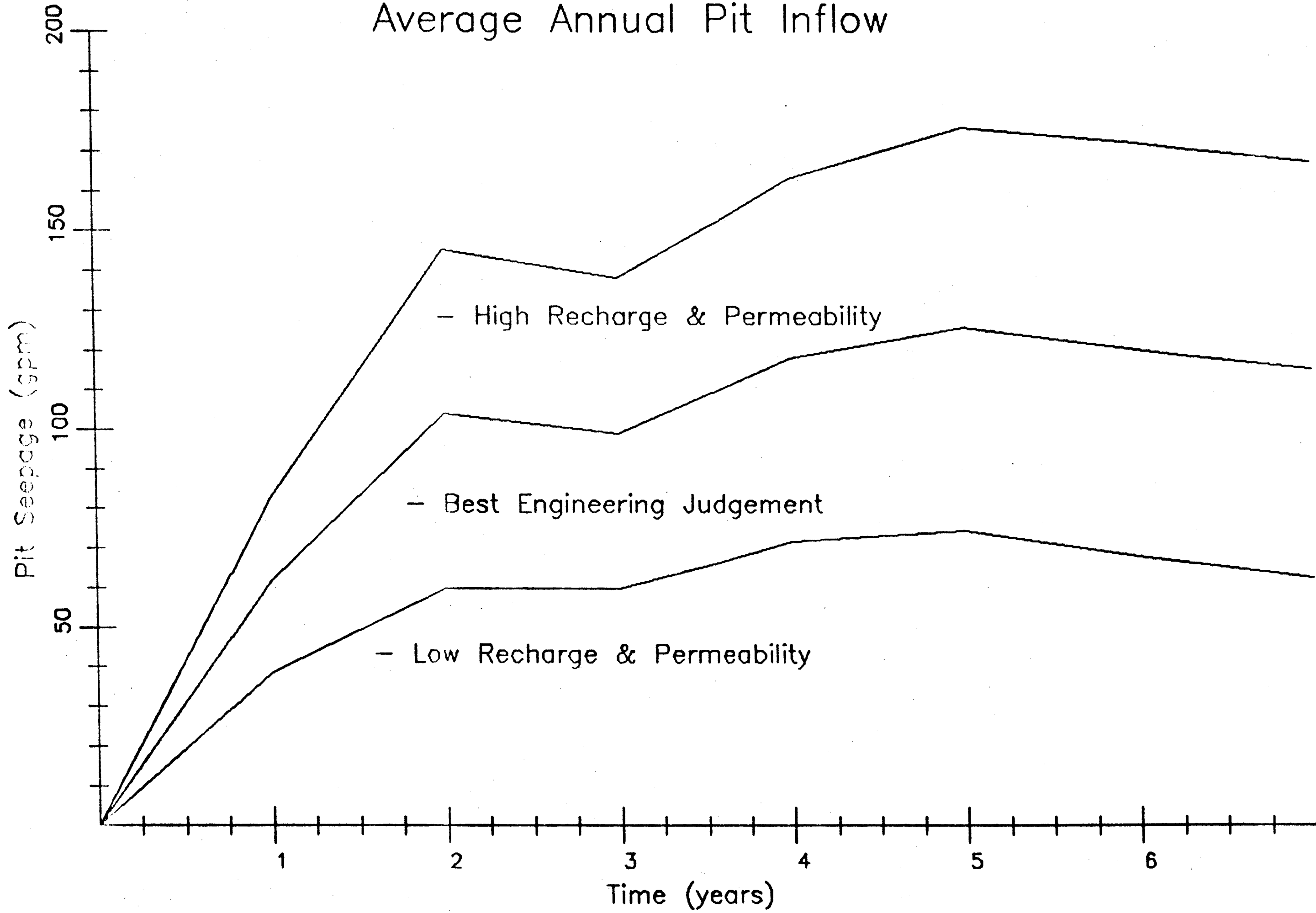
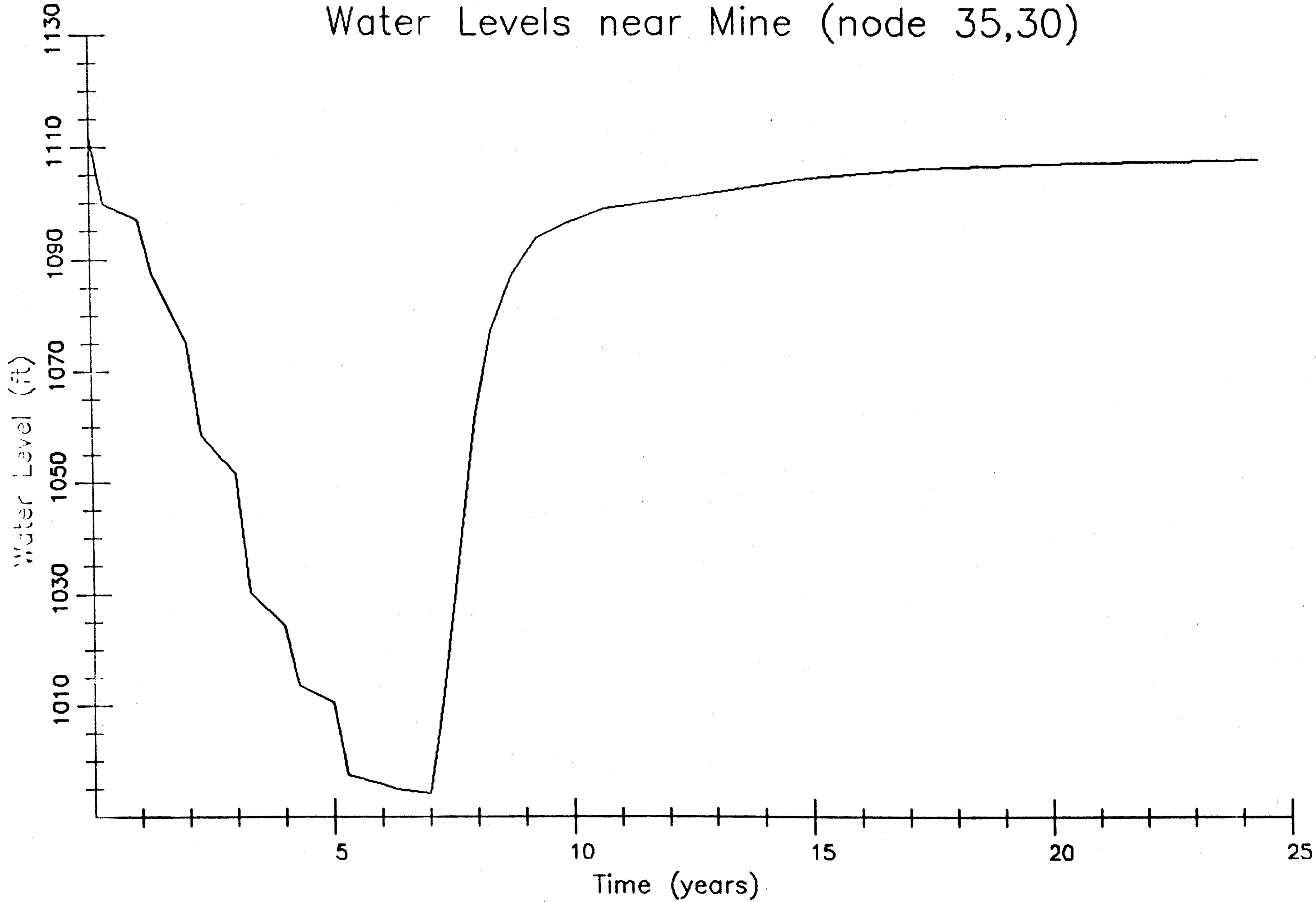


Figure 10



Water Levels near Mine (node 35,30)
1130
1110
1090
1070
1050
1030
1010
Water Level (ft)
5
10
15
20
25
Time (years)

Figure 11

Water Levels intermediate to Mine (node 51,31)

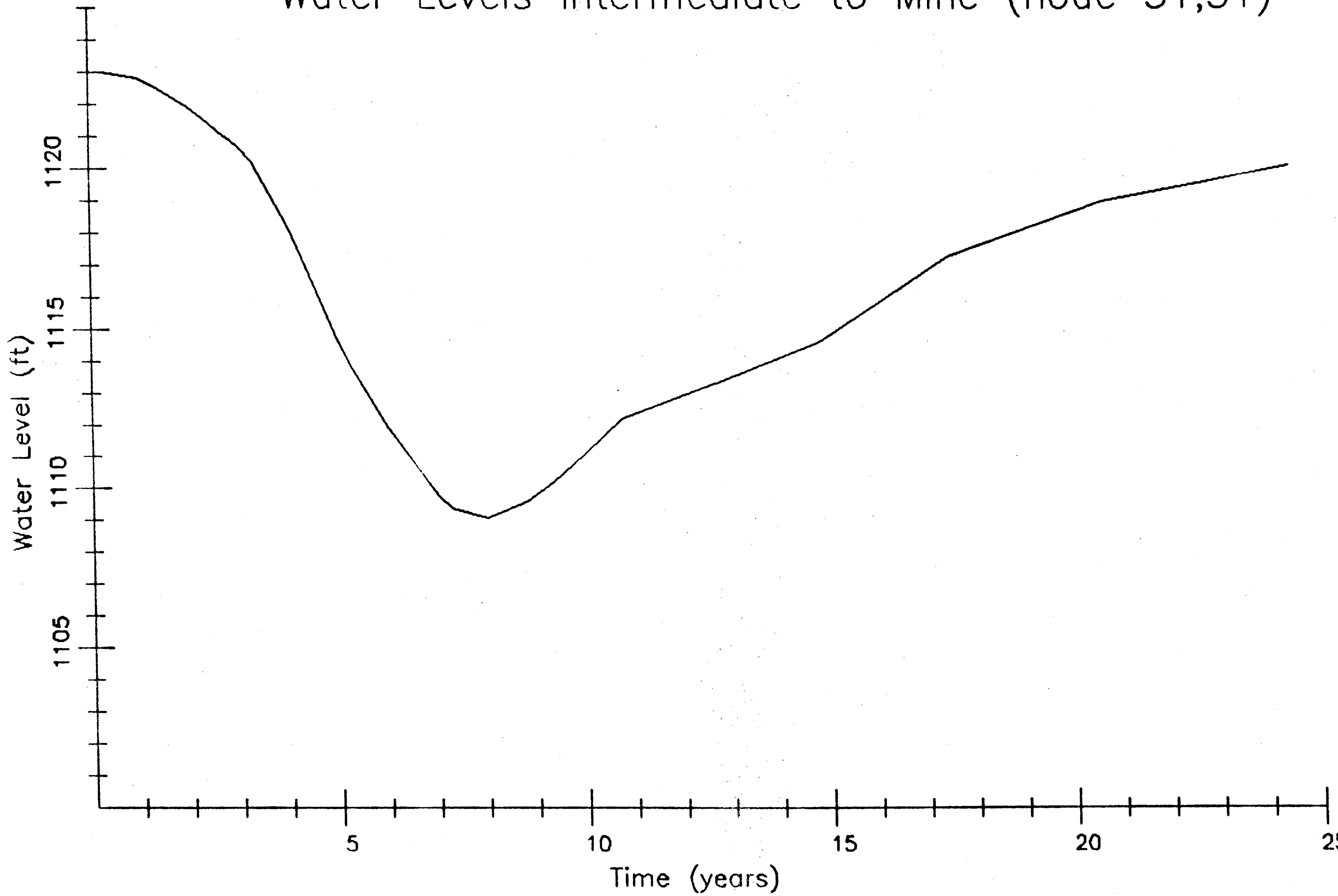


Figure 12

Water Levels remote from Mine (node 57,31)

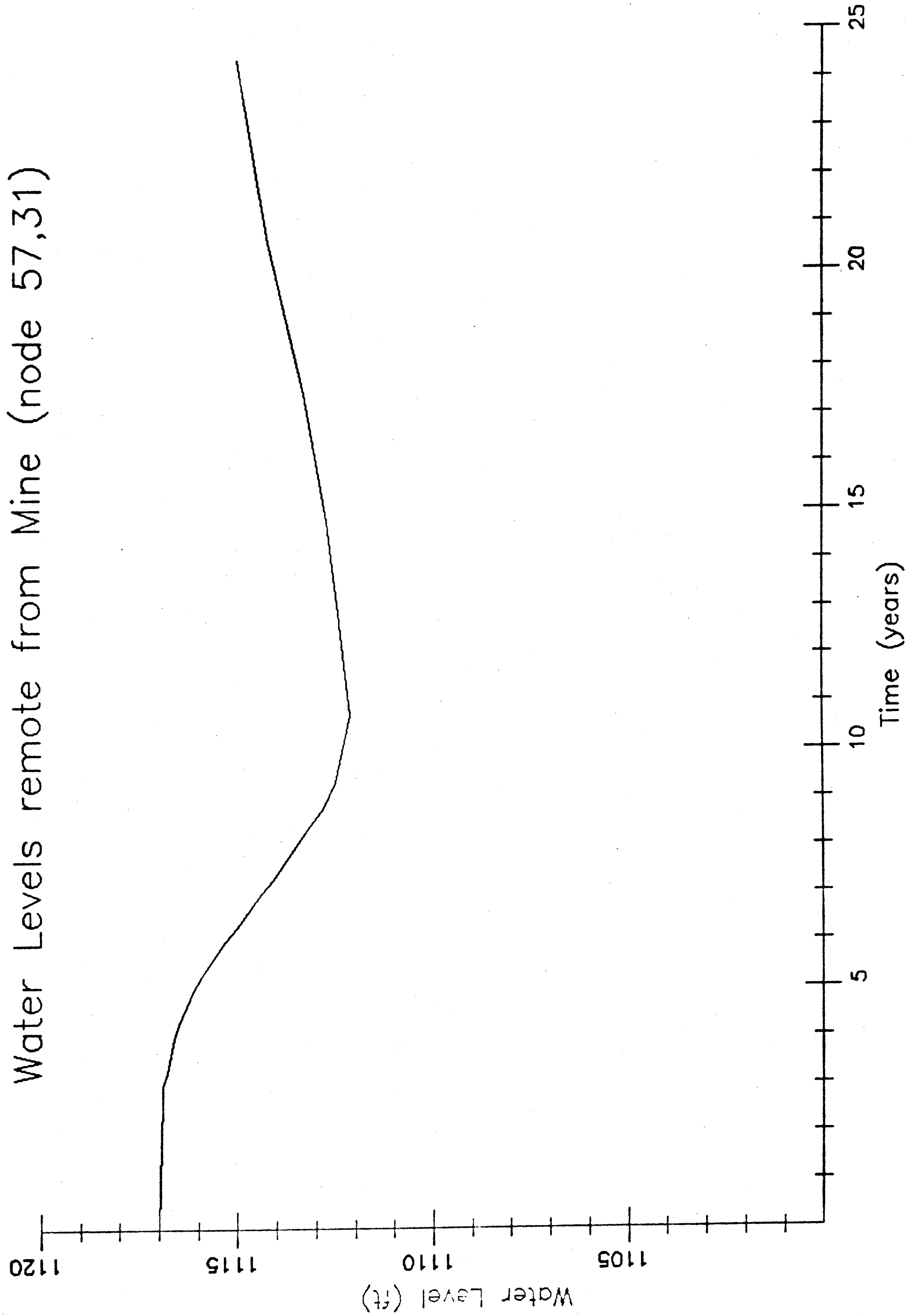
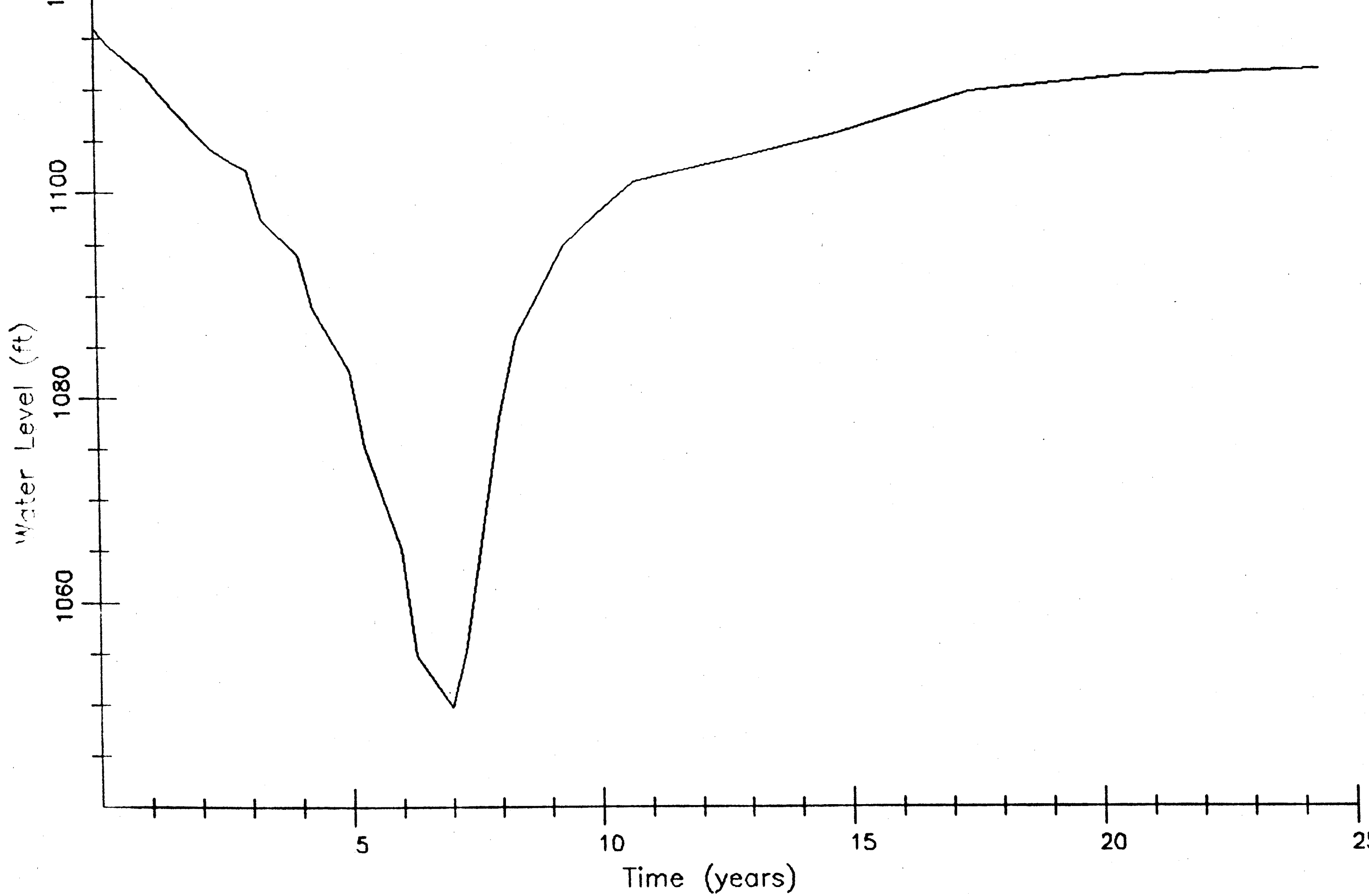


Figure 13

Water Levels at Wetland 3 (node 43,28)



Figures 10, 11, 12, and 13 also show the recovery of water table after mining at four selected points.

c) Steady-state post reclamation

Exhibit 14 shows the predicted water table contours after steady state conditions have been reached after reclamation. The water table is in approximately the same configuration as it was before mining, except in the immediate vicinity of the reclaimed mine. Exhibit 15 shows the residual water table differences calculated as the premining steady state water table (Exhibit 5) minus post reclamation water levels in Exhibit 14). Appendix P contains post reclamation steady state model data.

3) Effects on wetlands

a) During mining

Most of the wetlands are not expressions of the regional water table but rather poorly drained soils that are above the regional water table. Mining does effect the water table beneath wetlands 1 and 2 which are near the Flambeau River. Mining lowers the water table enough in these areas to prevent any groundwater discharge. Decreased flows to the wetlands with partial connection to the regional water table are limited. Predicted groundwater discharges at the end of mining are:

wetland 1	0.0 gpm
wetland 2	0.0 gpm
wetland 5	0.3 gpm
wetland 6	0.05 gpm
wetland 9	2.2 gpm

Figure 13 shows the drawdown and subsequent recovery of the water table under wetland 3. Wetland 3 is a isolated system, the wetland is not in contact with the regional water table.

b) During reclamation

Effects on wetlands during reclamation are similar to those during mining. No groundwater discharge occurs at wetland areas 1 and 2 until 9.5 years have elapsed after the backfilling of the mine pit. Maximum drawdowns and attendant decreased flow effects on partially connected wetlands occur at various times between 1 and 17 years after mining ends. Predicted worst case (at the point during the recovery of the water table when groundwater discharges to the wetland is a minimum) groundwater discharges are:

wetland 1	0.0 gpm
wetland 2	0.0 gpm
wetland 5	0.3 gpm
wetland 6	0.03 gpm
wetland 9	2.1 gpm

c) Post reclamation

After steady state water levels have been restored, all wetlands function as before, with the exception of wetland area 2, which is partially removed by mining.

4) Effects on surface-water bodies

a) Flambeau River

The maximum effect of mine dewatering on the Flambeau River adjacent to the mine occurs at the end of mining, when the mine pit is at its deepest point. At this point in time all of the groundwater flow (in this reach of river) normally discharging to the river flows to the mine pit and some water flows out of the river into the mine pit. Before mining, at the calibrated steady state position of the water table, there was 60.8 gpm of discharge from the aquifer to this reach of the Flambeau River. At the end of mining, there is 46.8 gpm of groundwater discharge to the pit and 46.8 gpm of groundwater leaking out of the river to the pit. The effect on the Flambeau River is negligible, since the average flow of the river in this area is about 1800 cfs (800,000 gpm), and all inflow is collected, treated, and discharged back to the Flambeau River, in any case.

b) Meadowbrook Creek

Effects of mine dewatering on groundwater discharge to Meadowbrook Creek are negligible. At the end of mining, groundwater discharge to Meadowbrook creek is the same as before mining, 19.4 gpm. At the worst time during reclamation, approximately one year after mining ends, discharge is essentially the same as before mining, 19.4 gpm.

D. Sensitivity Analysis

Sensitivity analysis of the mining effects were performed with the model by changing permeability and groundwater recharge values. The sensitivity analysis was done to span the Department of Natural Resources suggested range of uncertainty of the parameters. The following discussion therefore outlines the results of mining effects with permeability and recharge taking 50 percent higher and 50 percent lower values than those determined during calibration.

1) Pit Inflows

Figure 14 shows the predicted pit inflows over time for the high permeability scenario. Recharge and transmissivity were both 50 percent larger than the calibrated values. Pit inflows are 20 to 40 percent larger than for the calibrated case.

Figure 15 shows the predicted pit inflows over time for the low permeability scenario. Recharge and transmissivity were both 50 percent smaller than the calibrated values. Pit inflows are 20 to 40 percent smaller than for the calibrated case.

Figure 9 shows the predicted annual average inflows to the mine pit for the calibrated parameters, high permeability scenario, and low permeability scenario.

2) Effects on water table

Exhibit 16 shows the drawdowns caused by mining at the worst time under the low permeability scenario. The furthest extent of the two foot drawdown contour occurs approximately 2.3 years after mining ends and reclamation begins. Exhibit 17 shows the water table elevations at this same point in time. The two foot drawdown contour is approximately 2550 feet from the mine pit.

Exhibit 18 shows the drawdowns caused by mining at the worst time under the high permeability scenario. The furthest extent of the two foot drawdown contour occurs approximately 2.3 years after mining ends and reclamation begins. Exhibit 19 shows the water table elevations at this same point in time. The two foot drawdown contour is approximately 3000 feet from the mine pit.

3) Effects on wetlands

Under both the low and high permeability scenarios, groundwater discharges at wetlands 1 and 2 are eliminated at some point. Effects on the wetlands with partial connection to the regional water table are limited. Predicted worst case (at the point during the recovery of the water table when groundwater discharges to the wetland is a minimum) groundwater discharges are:

	permeability range		
	high	low	
wetland 1	0.0	0.0	gpm
wetland 2	0.0	0.0	gpm
wetland 5	0.2	0.2	gpm
wetland 6	0.01	0.02	gpm
wetland 9	3.2	1.1	gpm

Figure 14

Pit Inflow for High Recharge & Permeability

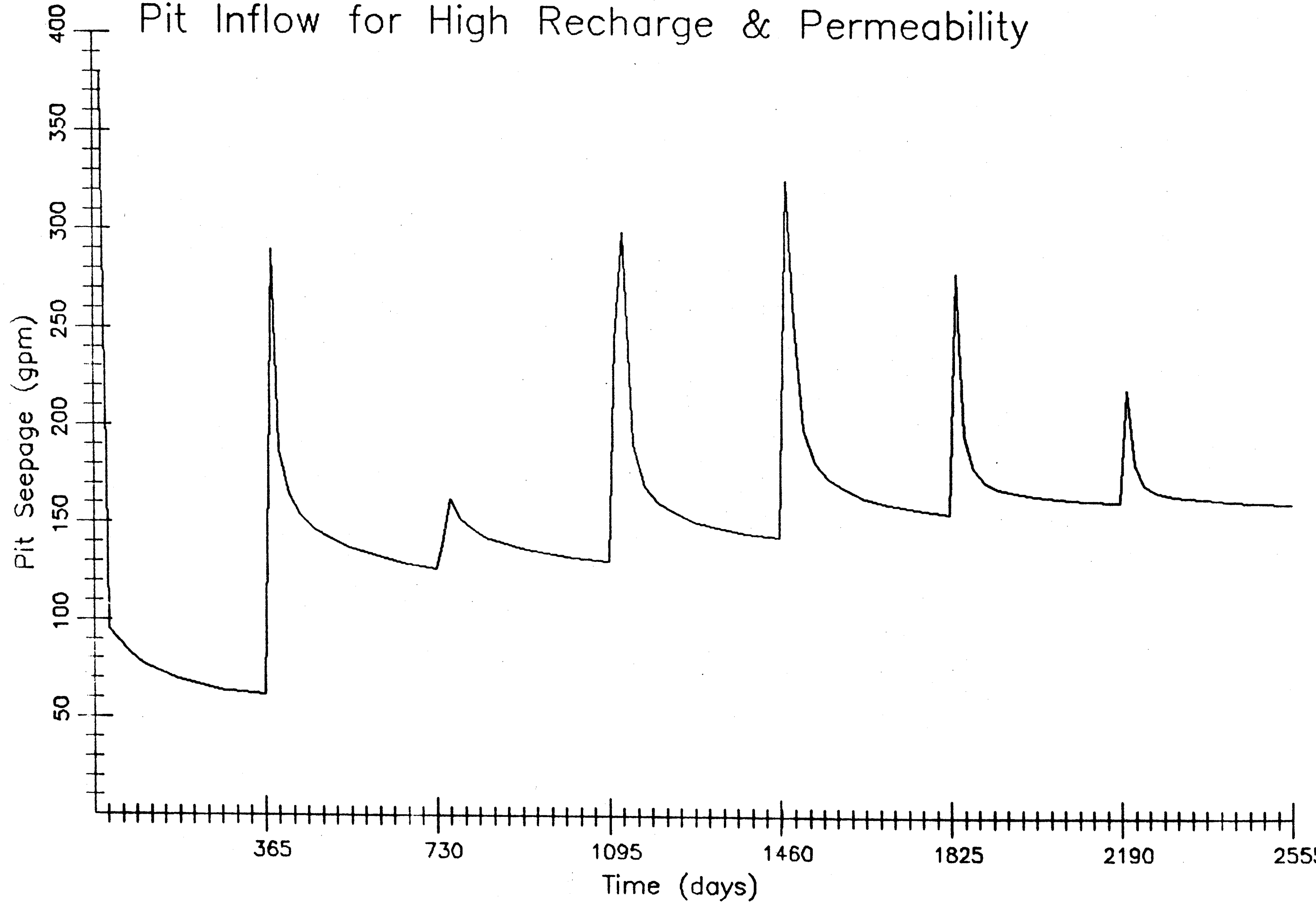
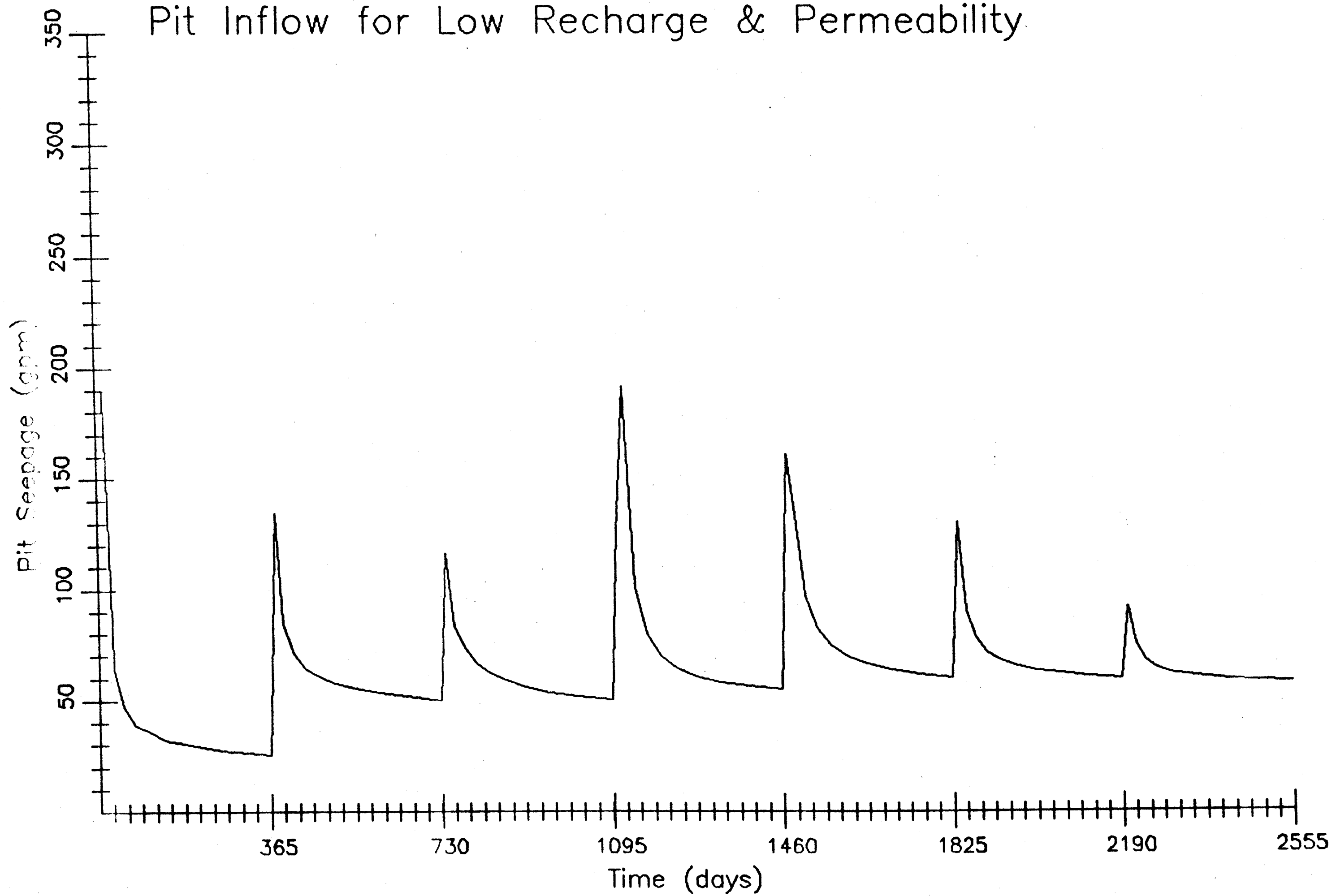


Figure 15

Pit Inflow for Low Recharge & Permeability



All other wetlands (3, 4, 7, 8, and 10) are unaffected by mining.

4) Effects on surface water

At the end of mining under the low permeability scenario, there is 23.2 gpm of groundwater discharge and 23.7 of groundwater leaking out of the river. The effects on the Flambeau River are negligible, since the average flow of the river in this area is about 1800 cfs (800,000 gpm). This effect is the maximum at any point in time under the low permeability scenario.

At the end of mining under the high permeability scenario, there is 70.3 gpm of groundwater discharge and 68.5 of groundwater leaking out of the river. The effect on the Flambeau River is negligible, since the average flow of the river in this area is about 1800 cfs (800,000 gpm). This effect is the maximum at any point in time under the high permeability scenario

At the worst time during reclamation under the low permeability scenario, discharge to Meadow Brook Creek is 9.3 gpm (9.4 gpm premining for comparison). Under the high permeability scenario, discharge to Meadow Brook Creek is reduced to 29.8 gpm (29.4 gpm premining for comparison).

VI. An Analysis of Premining Orebody and Reclaimed Area Groundwater Flow Rates

There are interests, in the area of water quality impacts, that require making estimates of groundwater flow rates through the reclaimed mine pit area. Based upon an analysis of the water table elevation maps of Exhibits 5 (premining) and 14 (post mining), and the model grid shown in Exhibit 1, the main groundwater flow changes, due to the mining/reclamation activities, occurs along the alignment of the orebody. This alignment generally extends from the Flambeau River along model rows 30, 31, and 32 in a northeasterly direction out to just east of State Route 27.

As mentioned in the description of the calibrated model parameters, the main permeable zones of the orebody are aligned along the hanging wall and foot-wall zones of the 30th and 32nd rows of the model. This is the reason why the main groundwater flow rates in the orebody are along those rows also. It was along this alignment that cross-sectional modeling was undertaken to estimate groundwater flow directions and rates. The following discussion is broken into two parts, with the main emphasis being given to groundwater flow distributions after the reclamation is completed and the hydrology of the area has reached its equilibrium level.

A. Estimates of Premining Orebody Groundwater Flow

So as to provide a base for later calculation comparisons, an estimate of premining orebody groundwater flow was done.

Application of Darcy's law along the alignment of the hanging and foot-wall zones of the orebody provides an estimate of orebody flows prior to mining. Based upon pumping test results, the calibrated permeabilities and hydraulic gradients derived from the groundwater model, and the width and depth geometries of the permeable zones determined by drilling studies, the flow rate through the orebody was calculated as follows.

By using the BEJ pertinent parameters in Darcy's law we get 10.6 gpd/ft sq. for the permeability, (1115 - 1085)/2400 or 0.0125 ft/ft for the hydraulic gradient, and about 200 feet wide and 225 feet deep for the sum of the permeable areas of the orebody or 45000 sq ft. Inputting these BEJ data into Darcy's law gives an estimate of about 6000 gallons per day or about 4 gallons per minute. This flow originates in the higher water table areas to the northeast and eventually discharges upward from beneath the Flambeau River in the southwestern region of the orebody.

If one is interested in the range of possible flow rates through the orebody, then the same high and low permeability assumptions mentioned in the plan view model sensitivity analysis above, leads the reader to between a low of 2 gpm to a high of 6 gpm for the premining flow rate range through the orebody.

B. Groundwater Flows Through Reclaimed Area

Estimates of groundwater flow through the pit reclaimed area were of interest as input to water quality studies reported elsewhere. The following procedures and discussions outline how these flows were computed. First, several flow lines were drawn on the post-mining water-table map shown in Exhibit 14. While several flow paths indicate slightly different directions through which the groundwater flow was taking place in the area of the reclaimed pit, we chose a cross section for study which was the same as that mentioned in the premining orebody flow discussion above. This cross- sectional model is illustrated in Figure 16.

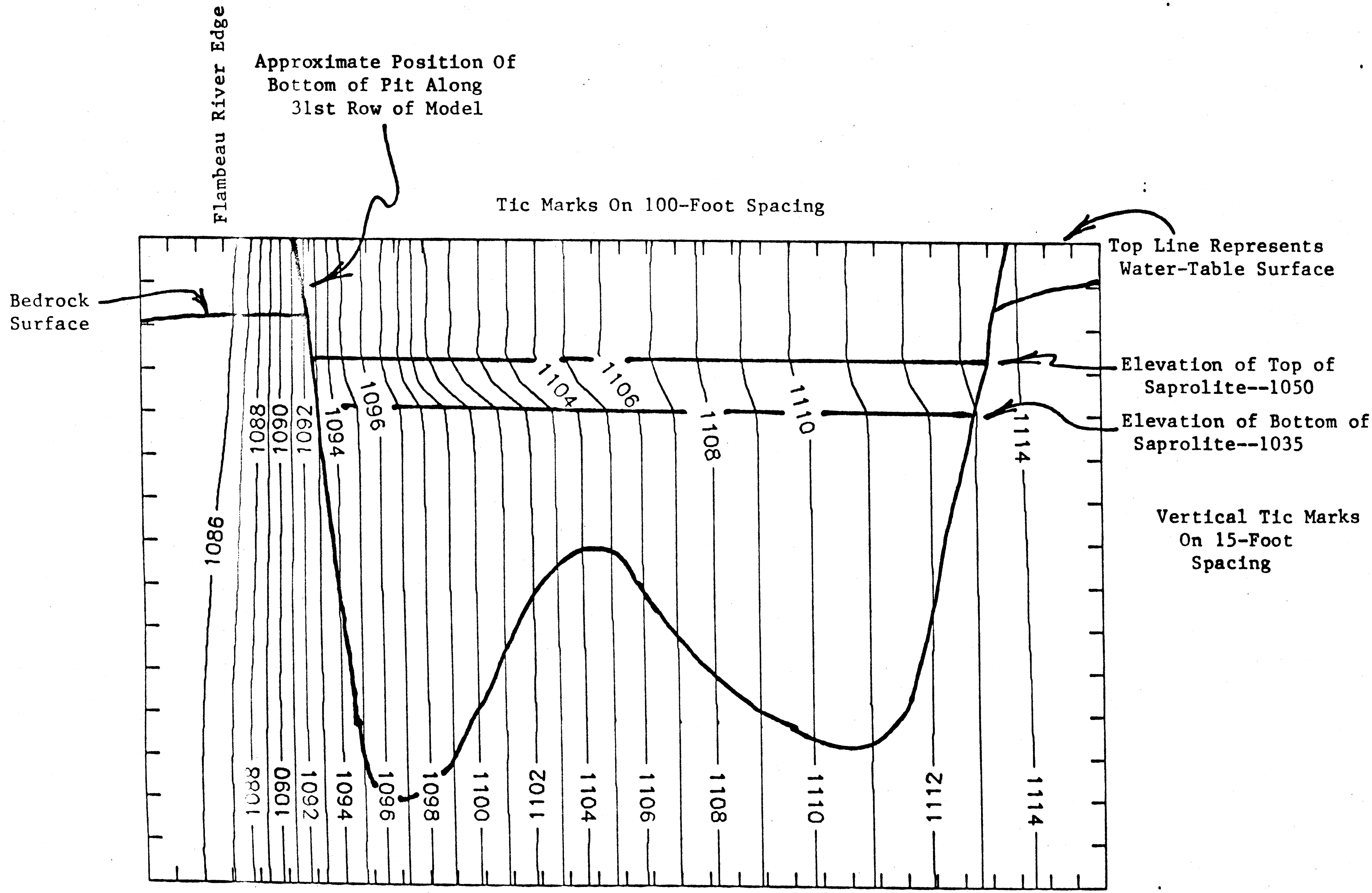
In the case of Figure 7, the model includes the permeable materials which extend from the post-mining water table downward to an elevation of 860 feet. An averaged cross sectional model data base was developed along rows 30, 31, and 32. However, the cross-sectional thickness in the zone of the reclaimed area above an elevation of 1050 (which is the top of the saprolite materials) was increased to 500 feet to account for the increased zone size of the shallow reclaimed materials. The permeabilities (hydraulic conductivities) of this cross sectional model were assigned based upon the calibrated permeabilities discussed earlier in this report and the description of the reclaimed Type I, saprolite, and Type II permeabilities shown in Figure 7.

A special note should be made of the vertical to horizontal scale exaggeration of the model of Figure 16. Each tic mark in the horizontal direction represents 100 feet. Each tic mark in the vertical direction represents only 15 feet. The total horizontal model dimension is 3500 feet while the total depth is about 250 feet. Furthermore, the Figure 16 graphics has a 10 times exaggeration on the vertical dimension. Thus for actual horizontal and vertical dimension analysis on the same scale, the reader should reduce the vertical dimension by a factor of 10 to obtain true scale visuals.

Figure 16 shows an approximate, or averaged position of the bottom of the pit at the end of mining, the water-table surface values at the post-mining/final reclamation equilibrium levels (see Exhibit 14), and the position of the top and bottom of the saprolite materials at the end of reclamation plan.

Figure 16

RESULTS OF CROSS—SECTION FLOW MODEL



1) Design of the PLASMCRS model for the above cross section

To estimate the groundwater flow rates and directions of vertical flow through the cross-sectional model of Figure 16, a second PLASM model was constructed. This model has the same groundwater theory as discussed for the plan view model of this project, but is much simpler. The actual source code used for this cross- sectional model is given in Appendix Q and is hereafter referred to the PLASMCRS model code.

The permeabilities, thicknesses, and widths discussed above were entered into this PLASM model. Based upon the calibration results of the plan-view model, the Flambeau River was made an outlet for groundwater flow at a fixed elevation of 1085 feet. The water-table along top of this cross section was fixed at the elevations dictated by the water levels shown in the post reclamation area of Exhibit 14. The data base thus formed for this model is printed out as shown in Appendix R.

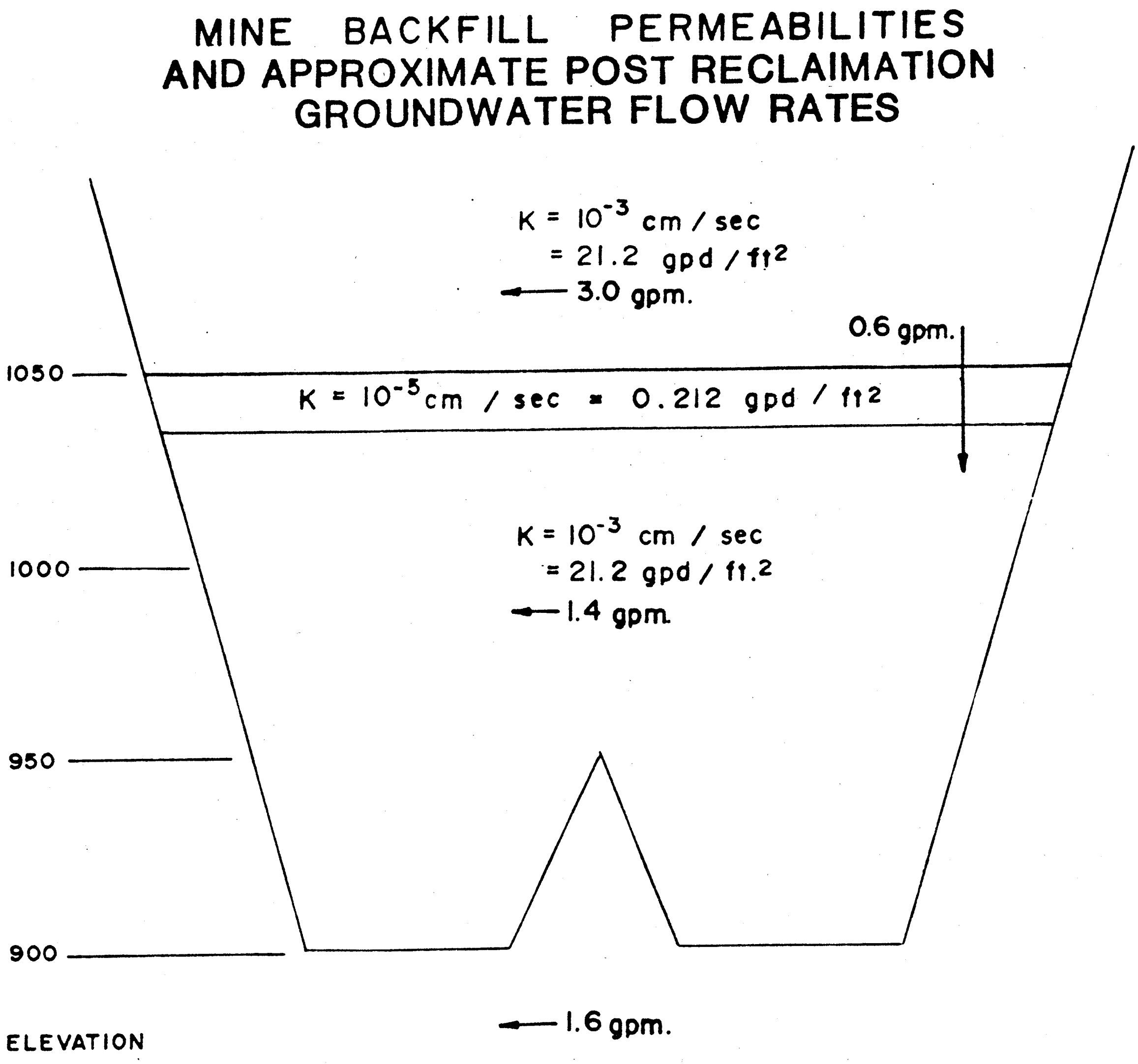
2) Results of the PLASMCRS modeling and Estimated Groundwater Flow Rates Taking Place Through the Reclaimed Area

The PLASMCRS model of Appendix Q and the input data as discussed above and shown in Appendix R was run to steady state or equilibrium conditions. The water-level contours of Figure 16 depict the results of that model run.

By taking into account the permeabilities, the appropriate cross- sectional widths and depths of flow, and the hydraulic gradients taken from Figure 16, calculations were made, via application of Darcy's law, what the approximate <u>average</u> groundwater flow rates were taking place in the reclaimed area. Hydraulic gradients within the reclaimed area vary from place to place and from flow positions upgradient to downgradient within the section. Therefore, the point to point flow rates vary above and below the averages shown in Figure 17.

Figure 17 illustrates and enumerates what the appropriate average groundwater flows are. First, an average of about 3 gpm is flowing horizontally through the shallow backfill materials above the saprolite. This shallow flow exits the area as flow to the Flambeau River. Some of this shallow flow seeps downward (0.6 gpm) through the saprolite into deeper backfilled materials. Approximately 1.4 gpm is flowing horizontally in the deeper backfilled materials and, it too, in addition to the 0.6 gpm exits to the Flambeau River via connections with permeable hanging wall and foot wall pathways (a total of 1.4 and 0.6 equals 2.0 gpm). Finally, there is about 1.6 gpm of

Figure 17



MINE BACKFILL PERMEABILITIES
AND APPROXIMATE POST RECLAIMATION
GROUNDWATER FLOW RATES
K = 10^-3 cm / sec
= 21.2 gpd / ft2
3.0 gpm.
0.6 gpm.
1050
K = 10^-5 cm / sec = 0.212 gpd / ft2
K = 10^-3 cm / sec
= 21.2 gpd / ft.2
1.4 gpm.
1000
950
900
ELEVATION
1.6 gpm.

underflow beneath the bottom of the reclaimed pit. This underflow exits to the Flambeau River as a result of upward hydraulic gradients.

If the reader is interested in sensitivity analysis with high/low permeability concerns, all of the above flows can be proportioned accordingly.

VII. References

Kennecott Mineral Company Mining Permit Application for the Kennecott Flambeau Project, Foth & Van Dyke, April 1989.

King,J.M., Hydrogeology and Numerical Modeling of the Flambeau Mine Site, Rusk County, Wisconsin, PhD thesis, Department of Geology, Indiana University, July 1983.

Prickett,T.A., and Lonnquist,C.G., Selected Techniques for Groundwater Resource Evaluation, Illinois State Water Survey Bulletin 55, Urbana, Illinois, 1971.

SURFER, Graphics Package, Golden Software, Inc., Version 4.0, 1989. Golden, Colorado.