Addendum to Flambeau Mine Ground Water Model

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Addendum to
Flambeau Mine Ground Water Model

submitted to

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Executive Summary

Several ground water models have been developed for the Flambeau Mine in Ladysmith, Wisconsin. In 1989, a quasi-three dimensional model was used to predict the impacts of mining during permitting. In 1995, this model was converted to a true three dimensional model and used to predict the impacts of mining on ground water flow through the remaining life of the mine. New data became available that allowed updating of the model's assumptions. With these new data, the ground water model was recalibrated and used to predict the resaturation of the backfill and the postmining water table.

There were three significant changes in the model's parameters made as part of this addendum. A 1997 study by Hydro-Geo Consultants concluded that the Precambrian bedrock at the site should have horizontal anisotropy due to preferential jointing, faulting and fracturing. The direction of the major axis of the hydraulic conductivity tensor is along the orientation of the mine pit. The ground water model was recalibrated at steady state with horizontal anisotropy in the bedrock aquifer. The optimum calibration results were obtained with a horizontal anisotropy ratio of 5 to 1.

The second change was based on review of pit inflow data and monitoring well drawdown data. The previous ground water models had assumed the bedrock was impermeable below an elevation of 860 feet. Actual ground water inflows to the pit did not increase after the pit reached an elevation of approximately 950 feet. Monitoring well drawdown data showed water levels were generally above an elevation of 1000 feet. Transient calibration simulations with the ground water model resulted in a final bedrock aquifer bottom elevation of 980 feet.

The third change was additional information on the permeability of the backfill. Since the bedrock aquifer was horizontally anisotropic and the backfill was isotropic, it was necessary to modify the model (MODFLOW) code.

With the changes to model parameters, the model was recalibrated with data through March 1997. All other model parameters, except for some minor adjustments during the recalibration, were the same as documented in the February 1996 report. The model predicted it would take approximately 15 years to resaturate the backfill. The postmining steady state water table will be the same as the premining water table except for some increased ground water elevations over the northeastern end of the pit because of the lower permeability of the backfill.

I. Introduction

Engineering Technologies Associates, Inc. (ETA) and Thomas A. Prickett & Associates (TPA) were retained by Foth & Van Dyke of Green Bay, Wisconsin to update and verify the ground water model of the Flambeau Mine in Ladysmith, Wisconsin. The team of TPA and ETA developed a ground water model of the Flambeau Mine in 1989 as part of the permitting process. This quasi-three dimensional model was used to predict the impacts on ground water. In 1995, TPA and ETA were retained again to update the model, calibrate it with the actual data, and predict impacts on ground water flow. This model is documented in a report dated February 1996. During 1997, new data became available that necessitated changes to some of the assumptions of the model. These new data were used to recalibrate the 1996 model and predict the time necessary to resaturate the backfill and the postmining water table.

This report is an addendum to the February 1996 report on the ground water flow model. Only the changes to this previous model are described in this addendum.

II. Model Development

A. Summary of Previous Modeling

During 1989, Thomas A. Prickett and Associates and Engineering Technologies Associates modeled the ground water flow impacts of the proposed open pit copper mine that became the Flambeau Mine. The purposes of this previous modeling were to predict what the mining and reclamation plans of the Kennecott Flambeau Project would likely do to the water table in the area aquifers, predict ground water inflow rates into the open pit, and estimate impacts to wetlands and the Flambeau River.

A specially modified version of PLASM (Prickett-Lonnquist Aquifer Simulation Model) was used in this previous study. PLASM is a two dimensional, finite difference ground water flow model. The model was assembled by inputting field data collected and analyzed by Foth & Van Dyke of Green Bay, Wisconsin. The PLASM model is fully described in the Environmental Impact Report.

The model was calibrated at steady state using water levels collected from monitoring wells during 1989. The calibrated model was used to predict drawdowns, pit inflows, and surface water impacts for the open pit both during mining and reclamation. Out of ten wetlands analyzed, only five were predicted to be affected by mining activities. Pit inflow was predicted to range between 110 and 296 gallons per minute (gpm). The maximum extent of the drawdowns caused by pit dewatering was predicted to occur shortly after the end of mining. The extent of drawdown covered an area about 1800 feet either side of a line aligned with the pit axis from the Flambeau River to about 5400 feet northeastward of the river.

In 1995, the United States Geological Survey Modular Three-Dimensional Finite-Difference Ground-Water Flow Model (MODFLOW) (McDonald and Harbaugh, 1988) was used to predict pit inflow and drawdowns. MODFLOW is a true three dimensional flow model. MODFLOW has a limited capability to simulate an open pit mine. The MODFLOW code was modified to accurately represent a mine. These model modifications are fully described and documented in the report on the 1995 modeling (TPA and ETA, 1996).

Initial parameter estimates for the 1995 model were taken from the 1989 model. The model grid had 63 columns and 64 rows. Grid spacings varied from 200 feet square at the edges of the modeled area to 50 feet by 100 feet in the river pillar area between the mine pit and the Flambeau River. Figure 1 shows the model grid.

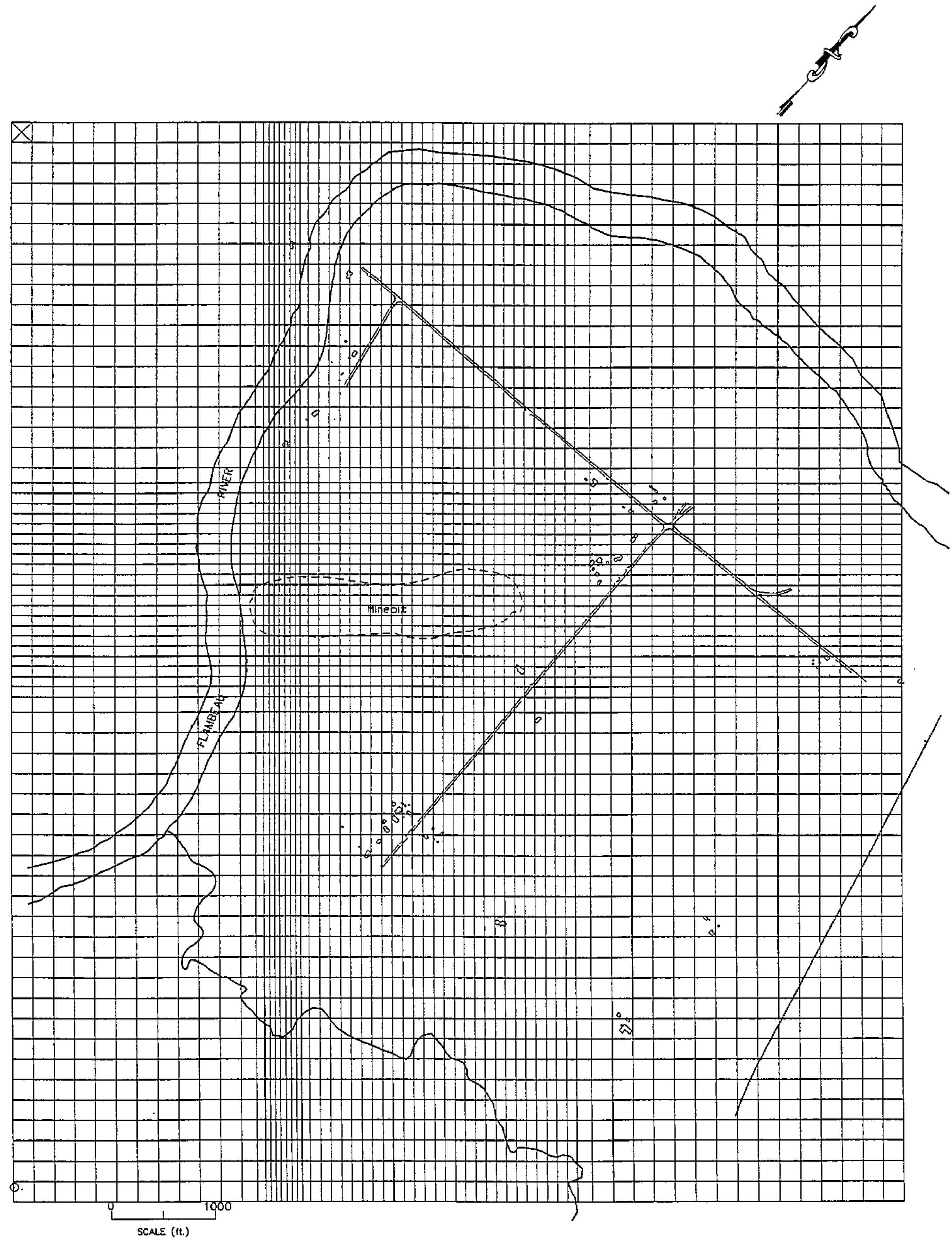

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FIGURE 1
MODFLOW GRID

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The MODFLOW model had three layers. The top layer was the glacial drift aquifer, which included both glacial outwash, consisting of sand and gravel, and glacial till. The second layer was the sandstone aquifer. The third layer was the bedrock. The bottom of the model was an elevation of 860 feet. Beneath this elevation the bedrock was assumed to be relatively impermeable. The elevations of each layer were the same as the changes in hydraulic conductivity (which represented the aquifer layering) in the PLASM model.

The bedrock aquifer had a horizontally isotropic hydraulic conductivity of 0.027 ft/day (0.2 gpd/ft^2), except in the ore body which had a horizontally isotropic hydraulic conductivity of 1.42 ft/day (10.6 gpd/ft^2). The ore body occupied rows 30 and 32 between columns 10 and 47. The glacial drift and sandstone aquifers had horizontally isotropic hydraulic conductivities that varied throughout the model extent. Small adjustments were made to these hydraulic conductivities during calibration. Specific yields for the three aquifers were 0.05 in the glacial drift, 0.1 in the sandstone, 0.05 in the ore body, and 0.001 in the remaining bedrock.

Recharge varied over the area of the model between 0 and 8.5 inches per year. Potential evapotranspiration from ground water was set to 22 inches per year. The extinction depth was 3.5 feet. These and other model parameters were based on the 1989 modeling (TPA and ETA, 1996).

The model was calibrated at steady state using the 1989 monitoring well water level data. A transient calibration was then performed using data between 1989 and March 1995. Recharge was estimated for each quarterly stress period from precipitation data. The mine pit was discretized for each quarterly stress period. Adjustments to hydraulic conductivity, specific yield and recharge were made so that the drawdowns predicted by the model and the pit inflow were similar.

The period from March of 1995 through the projected end of mining, July 1997, was simulated. Pit inflows were estimated to range from 180 to 310 gallons per minute (gpm). Drawdowns and impacts on wetland areas were predicted. At the end of mining, the five foot drawdown contour was predicted at about 1000 feet from the mine.

New data on the hydraulic conductivity of the backfill became available in 1995. These new data were used with the BCF2 package of MODFLOW to predict that it would take 30 years to resaturate the backfill. The February 1996 report fully documents the predictions of this model.

B. Recalibration

In 1997, additional data indicated the need for recalibration of the ground water model. There was a geologic study of the bedrock, pit inflow data, monitoring well water level data, and additional estimates of the backfill hydraulic conductivity.

A study by Hydro-Geo Consultants (1997) concluded that the Precambrian bedrock at the site should have horizontal anisotropy due to preferential jointing, faulting and fracturing. The direction of the major axis of the hydraulic conductivity tensor is along the orientation of the mine pit. A preliminary estimate of the horizontal anisotropy was 10 to 1. This report is shown in Appendix A.

Monitoring well data were available through July 1997. Pit inflow data were available through December 1996. Review of the pit inflow data through the end of 1996 indicated that the bedrock aquifer was not permeable to an elevation of 860 feet as previously assumed. Pit inflows did not increase as the mine pit deepened as would be expected if the bedrock aquifer was uniformly permeable with depth. Inspection of monitoring well drawdown data confirmed this interpretation; there was little drawdown observed in monitoring wells after the pit was deeper than an elevation of about 1000 feet.

The model was recalibrated using these new data interpretations. The bedrock horizontal anisotropy was initially assumed to be 10 to 1. Several steady state calibration attempts resulted in a horizontal anisotropy of 5 to 1 being selected as the most appropriate.

A series of transient calibration simulations were made to select the most appropriate bedrock aquifer bottom elevation. By adjusting bedrock hydraulic conductivity by the same proportion as bedrock thickness was changed, it was possible to preserve a steady state calibration. Since the bedrock aquifer is confined (without the drawdown caused by the mine pit) as long as heads and the transmissivity of the aquifer are the same, simulated ground water flow at steady state is the same. Transmissivity is the product of aquifer thickness and hydraulic conductivity. So if aquifer thickness decreases by 50 percent and hydraulic conductivity increases by 50 percent, the resulting steady state calibration simulation is identical.

The transient calibration was performed over the period from 1989 to July 1997. Quarterly stress periods were used to reasonably approximate mine pit changes and changes in recharge. For the period from January 1990 through March 1995, recharge was estimated for each quarterly stress period as described in the 1996 modeling report (TPA and ETA). The average 1989 recharge was used for the period from April 1995 through July 1997. Recharge was not a particularly sensitive parameter during the transient calibration based on review of monitoring well water level data. The result of the recalibration were the following changes to the parameters of the 1996 model (TPA and ETA, 1996).

- A horizontal anisotropy ratio of 5 to 1 was assumed for the bedrock aquifer.

- The bottom elevation of the bedrock aquifer was assumed to be at an elevation of 980 feet, except where this resulted in less than 50 feet of bedrock aquifer thickness in which case the bottom of the bedrock aquifer was 50 feet below the top of the bedrock aquifer.

- Leakance between the glacial drift and sandstone aquifers was reduced by a factor of 1000. Previously, leakance had reflected values of vertical hydraulic conductivities that were greater than the corresponding horizontal hydraulic conductivity. This change reduced the average ansiotropy (horizontal hydraulic conductivity/vertical hydraulic conductivity) to a value of 17. This value is consistent with the depositional environment, which is a sedimentary and glacio-fluvial environment.

- Leakance between the sandstone and bedrock aquifer was increased by a factor of 1.87. This change accounts for the reduced thickness of the bedrock aquifer. The leakance between the bedrock aquifer and the sandstone aquifer was assumed to be due to the small permeability of the bedrock and the large thickness of the bedrock aquifer. As the bedrock aquifer was assumed to be thinner, the leakance increases. The vertical hydraulic conductivities resulting from this change varied depending on location, but were generally the same as the horizontal hydraulic conductivities (vertical anisotropy of one).

- After the adjustments to hydraulic conductivity to account for the decreased thickness of the bedrock aquifer, the hydraulic conductivities were reduced by 13 percent to improve the calibration. The final geometric mean value for hydraulic conductivity in the bedrock aquifer outside the ore body was 0.061 ft/day (this value includes the increase because of the reduced thickness of the bedrock aquifer). The value along the principal axis of anisotropy (model row direction) was 0.14 ft/day and along the minor axis (model column direction), 0.028 ft/day. In the ore body the final geometric mean value was 3.3 ft/day. The value along the principal axis of anisotropy was 7.4 ft/day and along the minor axis, 1.5 ft/day.

Table 1 shows how the statistical comparison of the steady state model compared to observed water levels before mining (water levels collected between December 1987 and November 1988). Figures 2, 3, and 4 show the steady state water table and potentiometric surface elevations for the three layers of the model. There is no significant vertical gradient between layers.

Figure 5 shows pit inflow versus time for the part of the transient calibration period when there was inflow to the mine pit. The predicted mine inflow is generally the same order of magnitude but displays peaks that are not represented in the actual data. These peaks correspond to the quarterly changes in mine pit position. In reality, the mine pit changed almost continuously, thus there are no peaks in pit inflow rates except those caused by seasonal changes. Figure 6 shows the cumulative pit inflow versus time. The correlation between model and actual is excellent.

Figures 7 through 9 show the predicted water table and potentiometric elevations in the glacial drift aquifer (model layer 1), the sandstone aquifer (model layer 2), and the bedrock aquifer (model layer 3) in July of 1997 . There are no water table contours in layers 1 and 2 around the mine. These areas have been dewatered by the mine pit.

Table 1
Final Steady State Calibration Statistics

Column	Row	Layer	Observed Head	Modeled Head	Difference	Well
20	38	1	1112.48	1116.98	4.50	1001
34	14	1	1089.99	1090.64	0.65	1002
24	26	1	1108.58	1105.40	-3.18	1004
40	41	1	1137.91	1138.97	1.06	1005
46	35	1	1133.40	1139.22	5.82	1006G
18	37	1	1109.51	1106.21	-3.30	7
26	22	1	1093.76	1097.02	3.26	10
35	22	1	1108.58	1106.29	-2.29	12
44	21	1	1121.12	1121.87	0.75	14
20	25	1	1095.90	1098.36	2.46	31
23	22	1	1095.88	1093.75	-2.13	36
19	35	1	1099.06	1097.47	-1.59	39
17	30	1	1095.60	1095.44	-0.16	41
18	25	1	1094.08	1096.22	2.14	42
16	20	1	1087.41	1086.34	-1.07	43
30	16	1	1092.23	1090.33	-1.90	45
35	31	1	1112.47	1112.64	0.17	2
23	29	1	1108.63	1103.72	-4.91	19A
15	29	1	1094.95	1093.45	-1.50	S1
16	34	1	1091.41	1093.32	1.91	S2
39	33	1	1116.17	1114.13	-2.05	S4
16	31	1	1093.30	1093.57	0.27	R3
39	32	1	1115.41	1113.99	-1.42	R7
27	33	1	1111.67	1110.48	-1.19	K3
40	33	1	1116.34	1114.22	-2.12	K4
23	30	1	1107.88	1104.20	-3.68	K6
15	31	1	1092.09	1092.40	0.31	K8
28	34	1	1112.94	1111.29	-1.65	24
28	34	1	1112.84	1111.14	-1.70	S3
14	33	1	1088.91	1090.83	1.92	1000
22	35	1	1108.94	1106.27	-2.67	26
19	31	1	1097.39	1095.70	-1.69	28A
12	32	1	1084.85	1088.73	3.88	SP
32	46	1	1136.16	1137.78	1.62	1008
55	44	1	1141.16	1142.78	1.62	1009
26	40	1	1137.88	1146.95	9.07	SP6
31	43	1	1136.96	1139.12	2.16	SP8
35	27	2	1110.28	1111.55	1.27	1003
24	26	2	1108.41	1105.39	-3.02	1004S
34	34	2	1115.62	1113.24	-2.38	23
40	41	2	1137.51	1139.49	1.98	1005S
46	35	2	1131.92	1131.84	-0.08	1006S
52	23	2	1114.72	1118.17	3.45	1007S
20	38	3	1112.53	1109.84	-2.69	1001P
35	27	3	1110.34	1111.48	1.14	1003P
24	26	3	1106.17	1105.31	-0.86	1004P
40	41	3	1137.91	1139.48	1.57	1005P

Table 1 (continued)
Final Steady State Calibration Statistics

LAYER	WELLS	AVG DIFFERENCE	ROOT MEAN SQUARE
1	37	0.09	2.84
2	6	0.20	2.32
3	4	-0.21	1.71
TOTAL	47	0.08	2.70

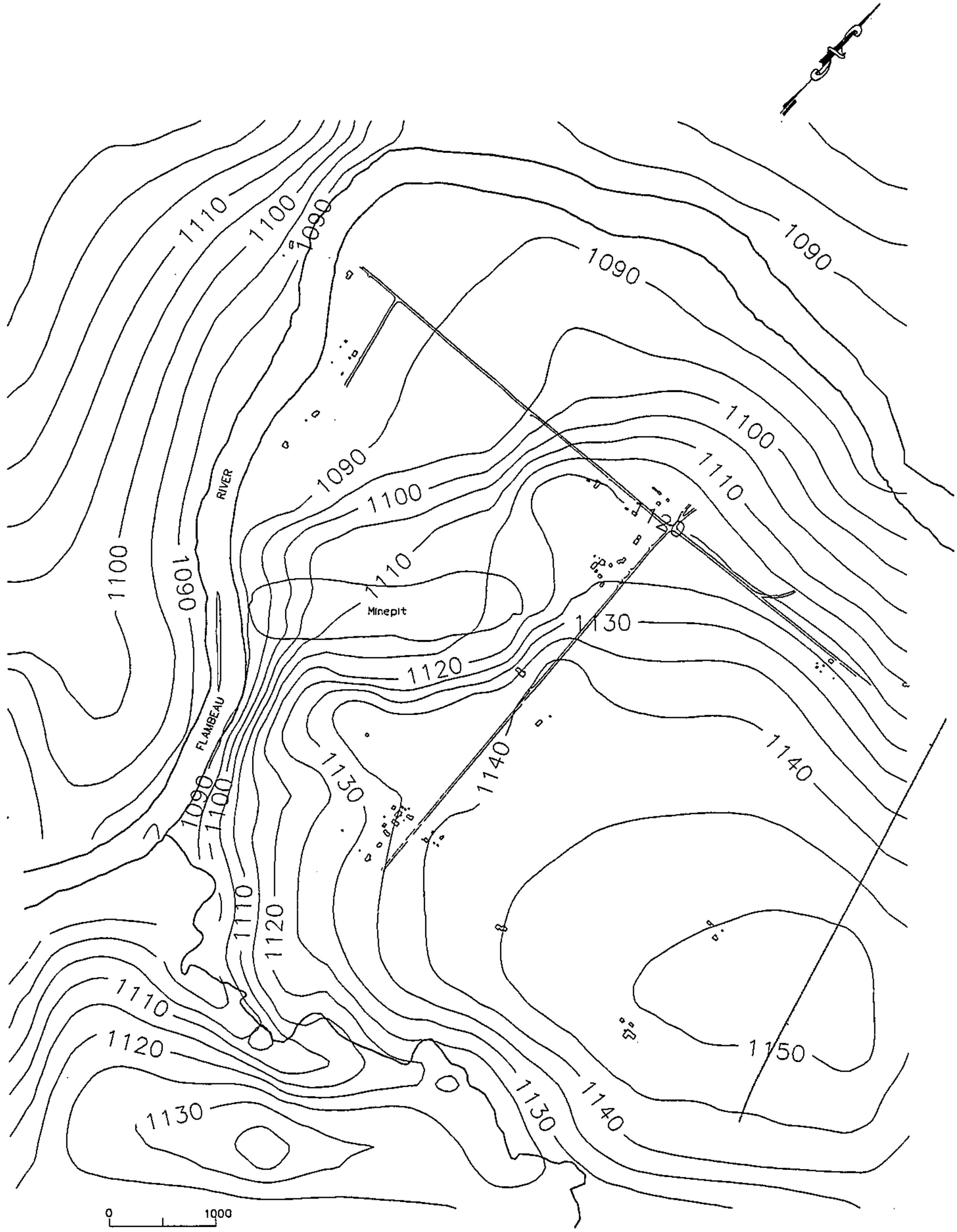

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FIGURE 2
STEADY STATE WATER LEVELS
LAYER 1

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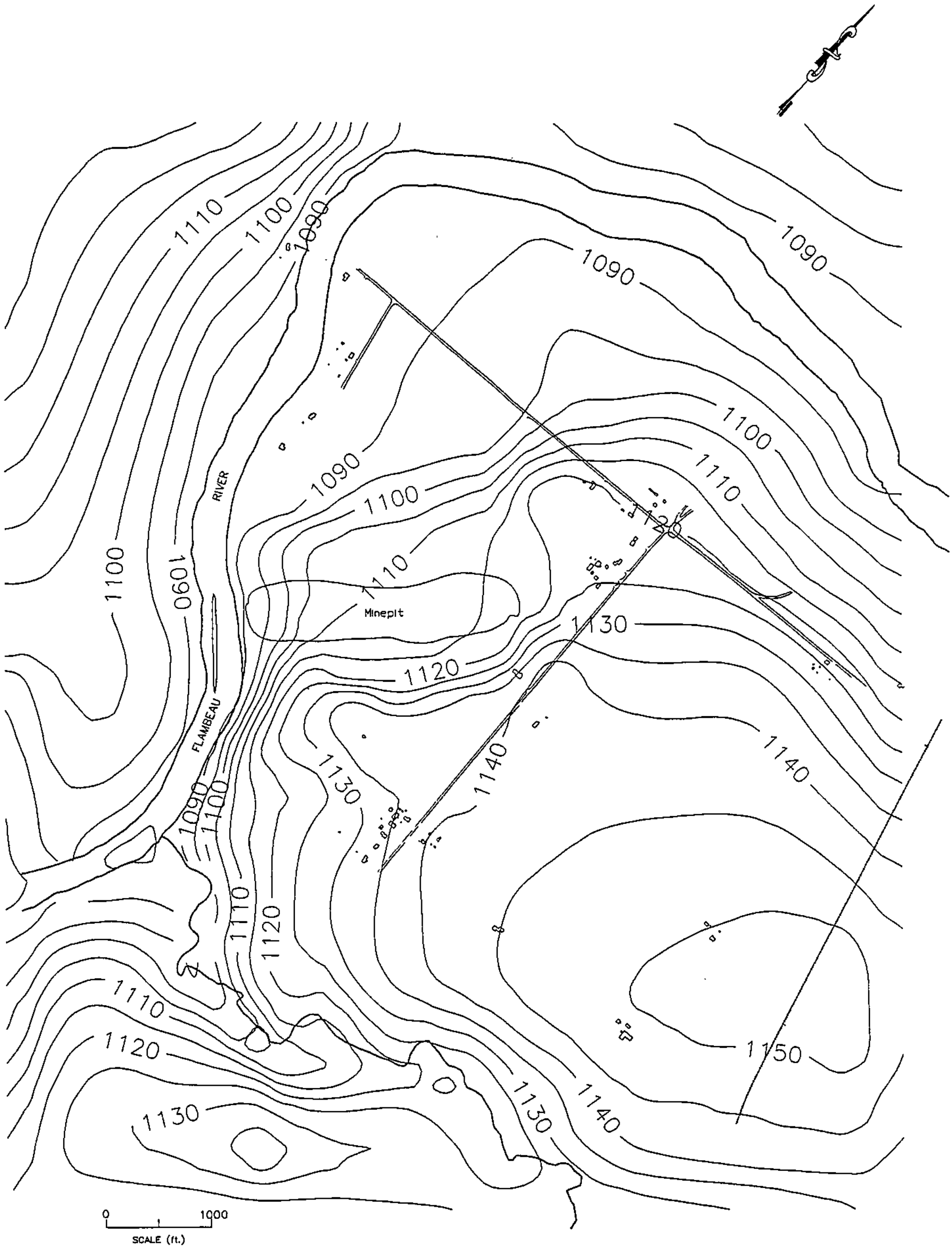

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FIGURE 3
STEADY STATE WATER LEVELS
LAYER 2

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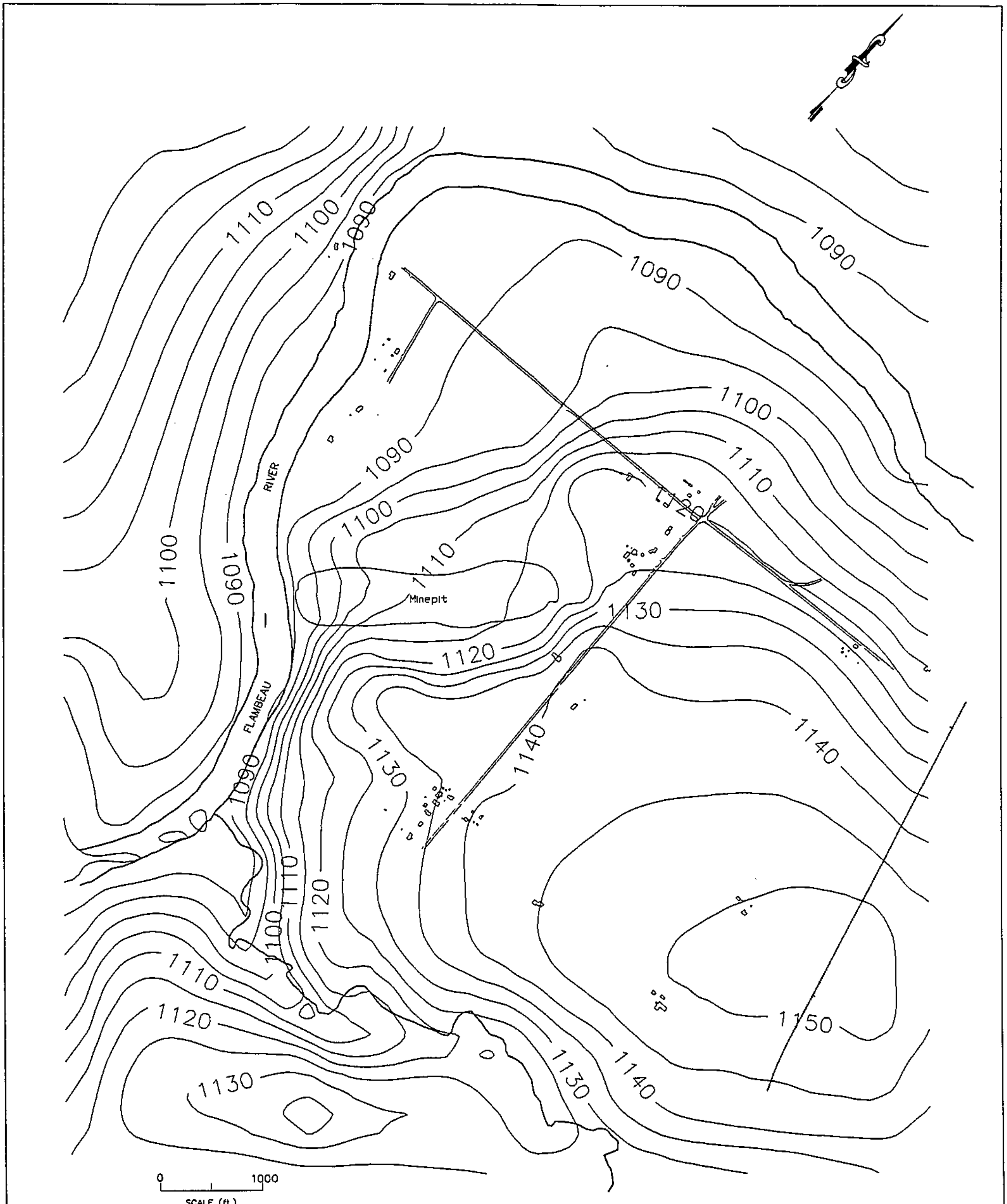

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FIGURE 4
STEADY STATE WATER LEVELS
LEVEL 3

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Figure 5
Calibrated Pit Inflow Rates

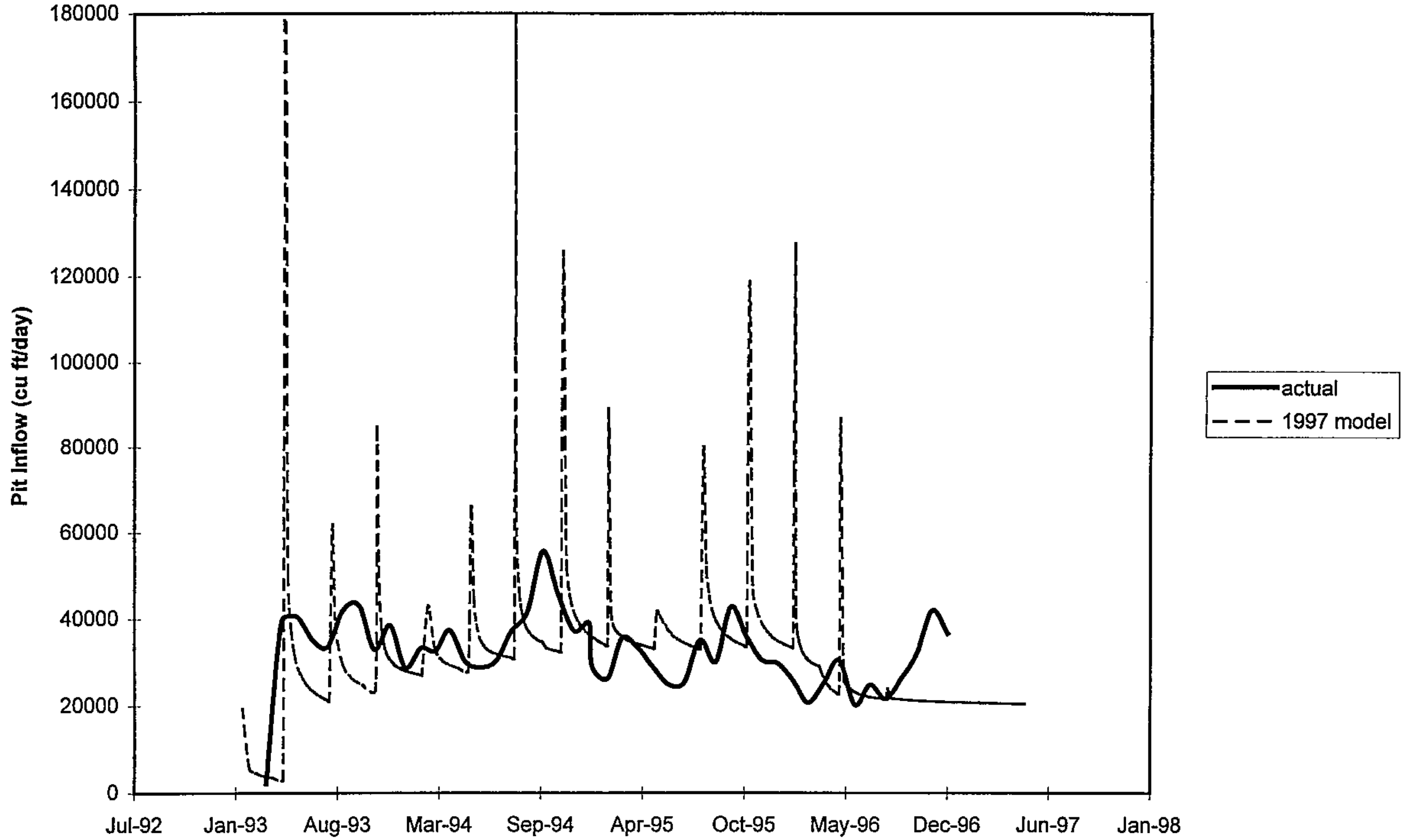
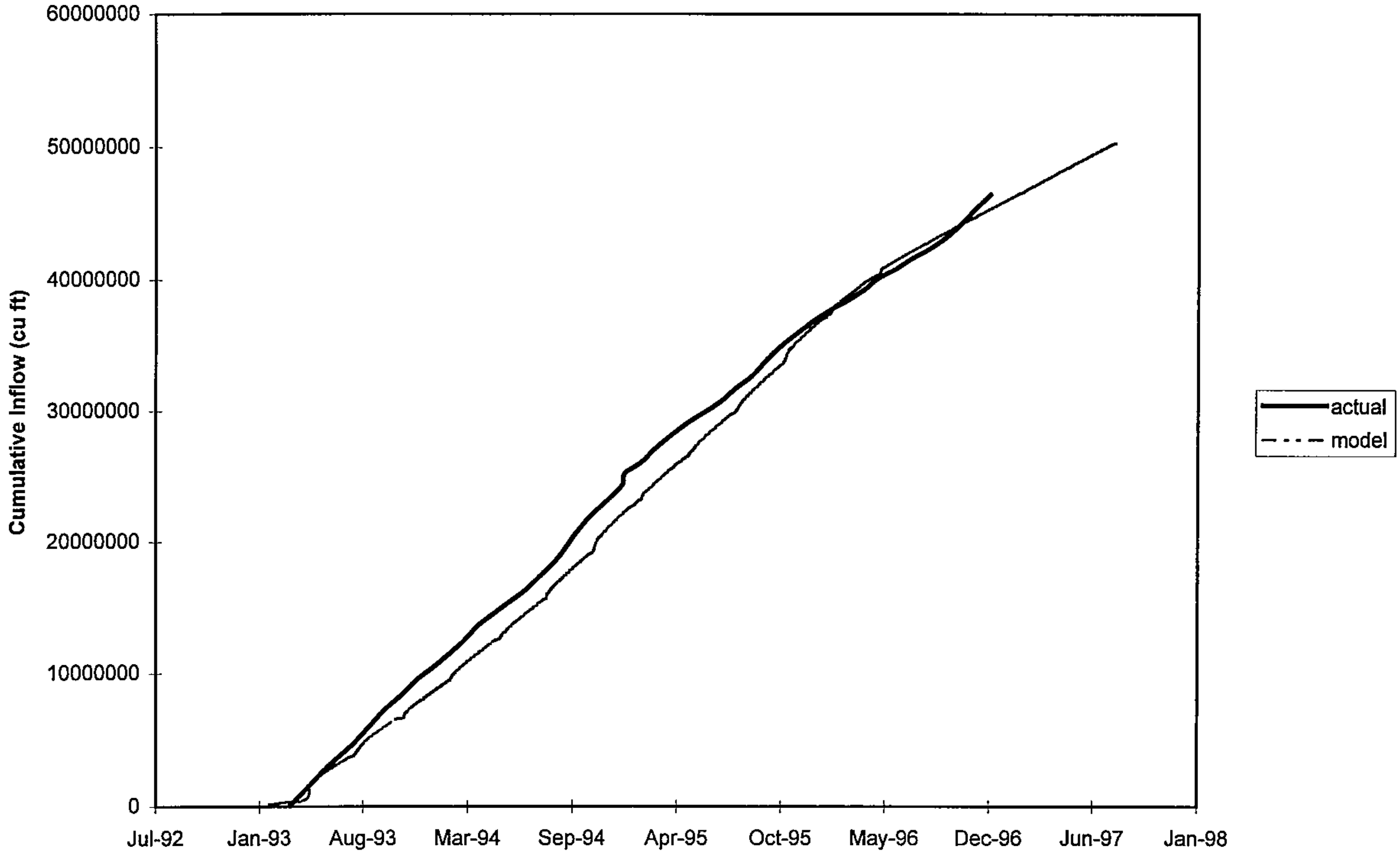


Figure 6
Cumulative Inflow versus time



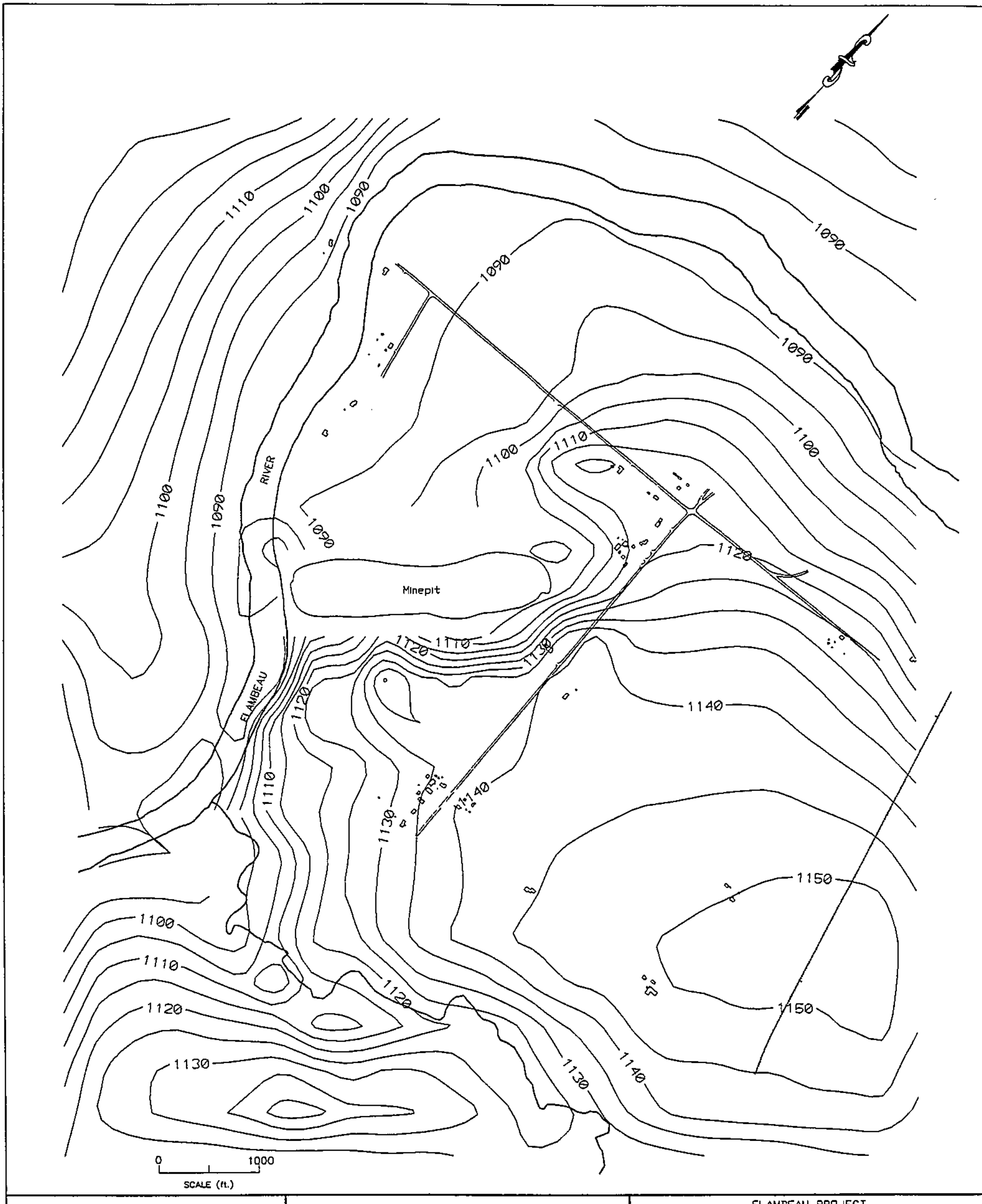


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FIGURE 7
MODELED WATER LEVEL ELEVATIONS
JULY 1997
LAYER 1

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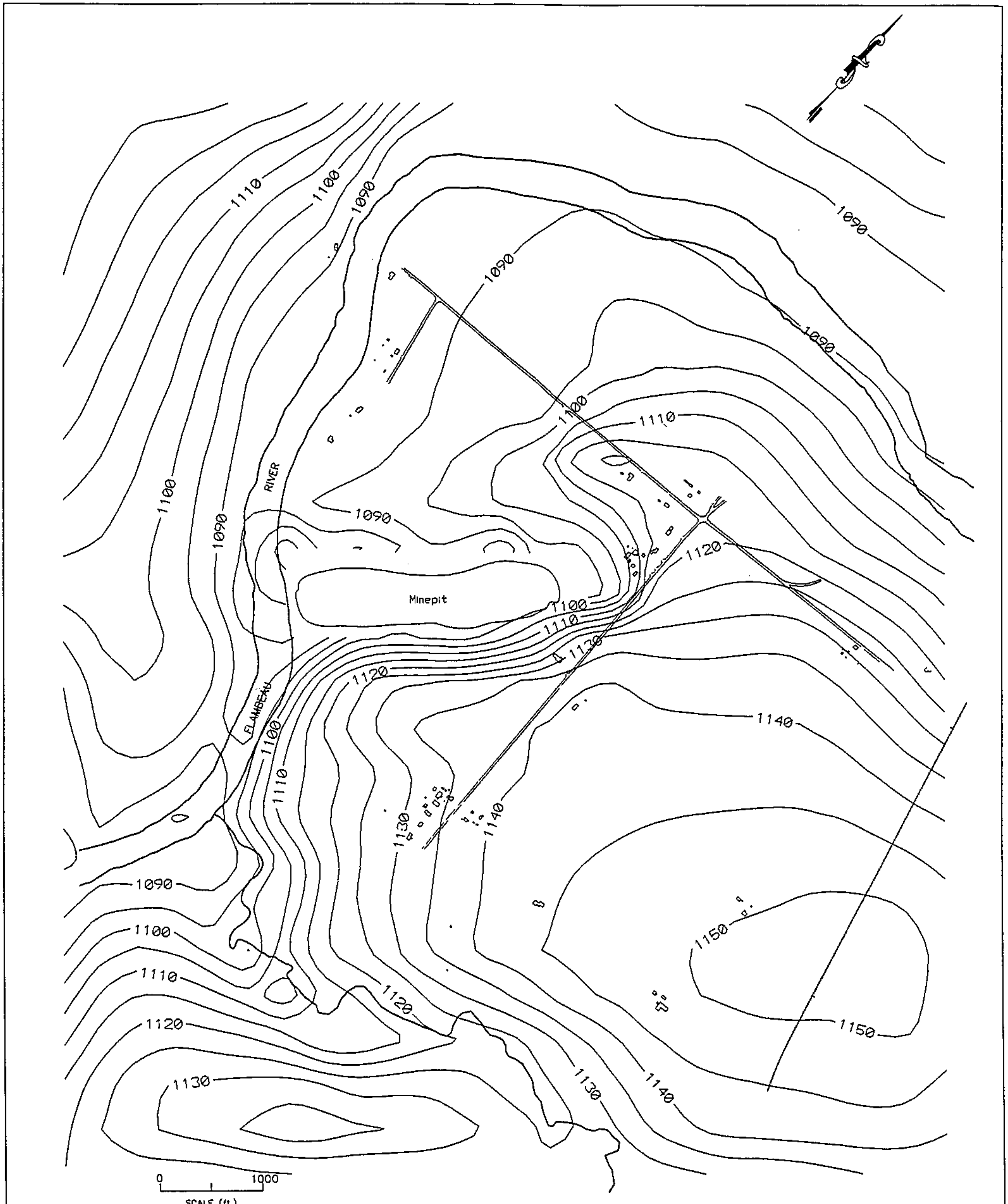

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FIGURE 8
MODELED WATER LEVEL ELEVATIONS
JULY 1997
LAYER 2

SCALE:	CONTRACT NO.: 96303.11	DATE: Apr. 1998	SHEET:

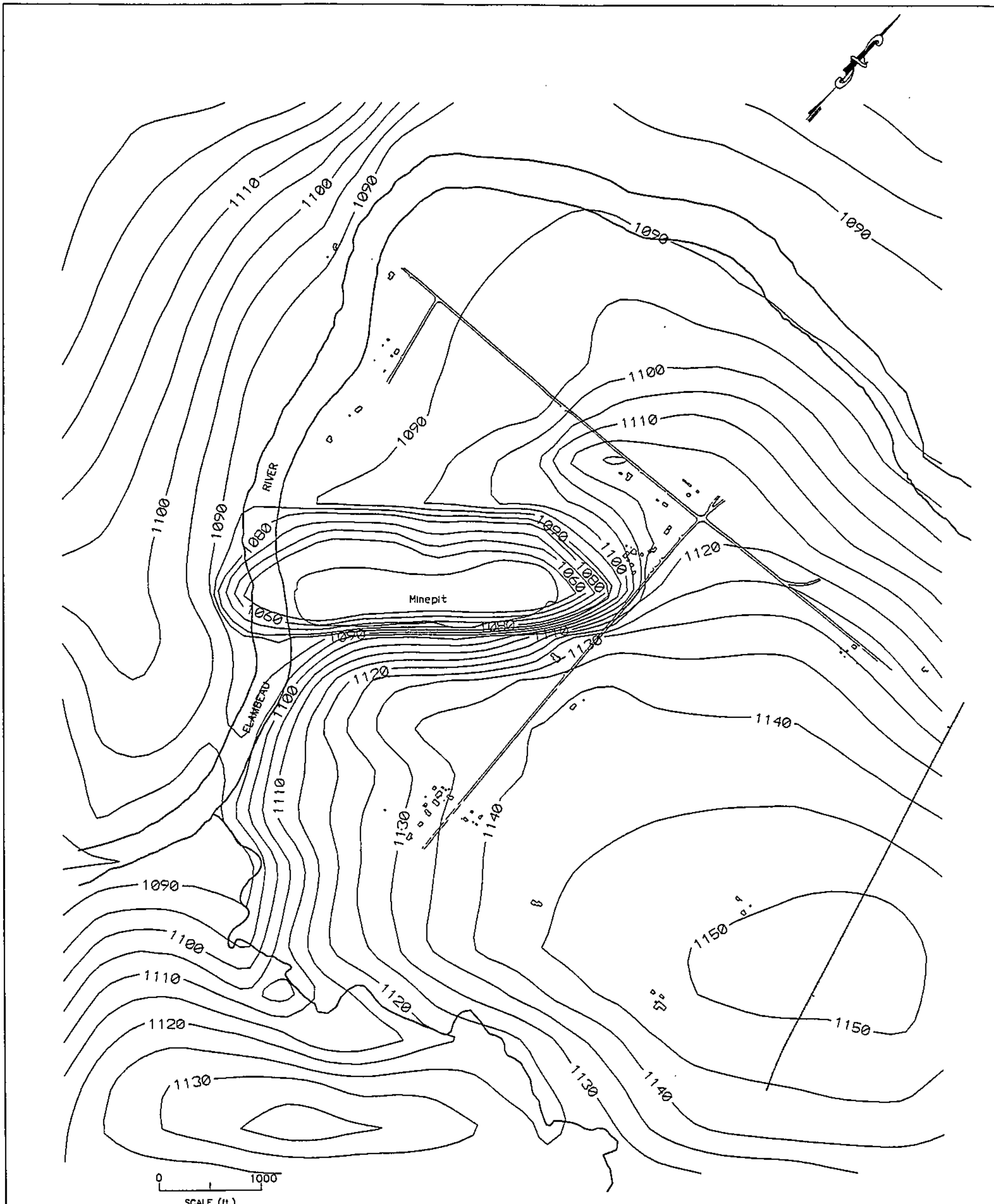

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FIGURE 9
MODELED WATER LEVEL ELEVATIONS
JULY 1997
LAYER 3

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Figures 10 through 23 show plots of model predicted water levels and those in the monitoring wells for the period from 1990 to the spring of 1997. The model generally predicts the drawdowns observed. There are differences between the model and observed water levels because of the assumptions inherent in the modeling as explained below.

There are several reasons that the modeled water levels shown in Figures 10 through 23 do not match the observed. One is a consequence of the assumptions used to simulate the mine pit. The flow to the mine pit was calculated by MODFLOW using a linearization of the Dupuit-Forcheimer assumption for water table aquifers. The Dupuit-Forcheimer assumption is an exact solution for the one dimensional flow in a water table aquifer given the heads, but it does not calculate the exact position of the water table around the excavation. The elevation of the seepage face is ignored. Thus, predicted water levels in the grids around the mine pit are over predicted. The inflow to the pit is correctly predicted. Drawdowns away from the pit are correctly predicted (see model testing section in Appendix C of the 1996 report). The model does not, however, accurately predict water levels around the pit because the model ignores the seepage face.

A second reason is the gradational nature of the contact between permeable bedrock and impermeable bedrock. Flow through the bedrock is through fractures. It was assumed that the bedrock aquifer is impermeable below an elevation of 980 feet. In reality, there are likely to be some fractures below this elevation, and some unfractured (and thus impermeable) blocks of rock above this elevation. The elevation of 980 was chosen during calibration as the best typical or average value.

Figure 10
WELL: MW1004

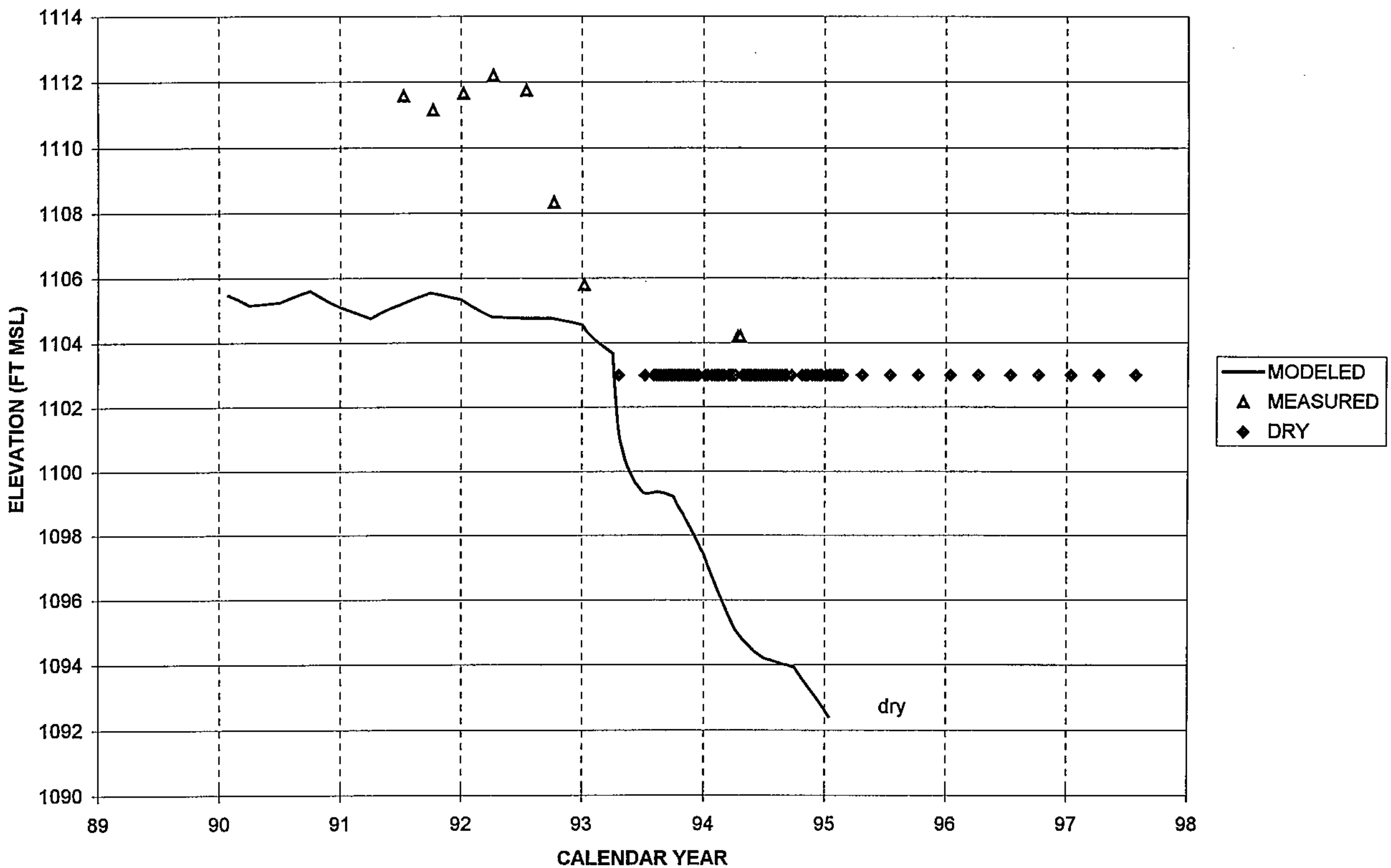


Figure 11
WELL: MW1004S

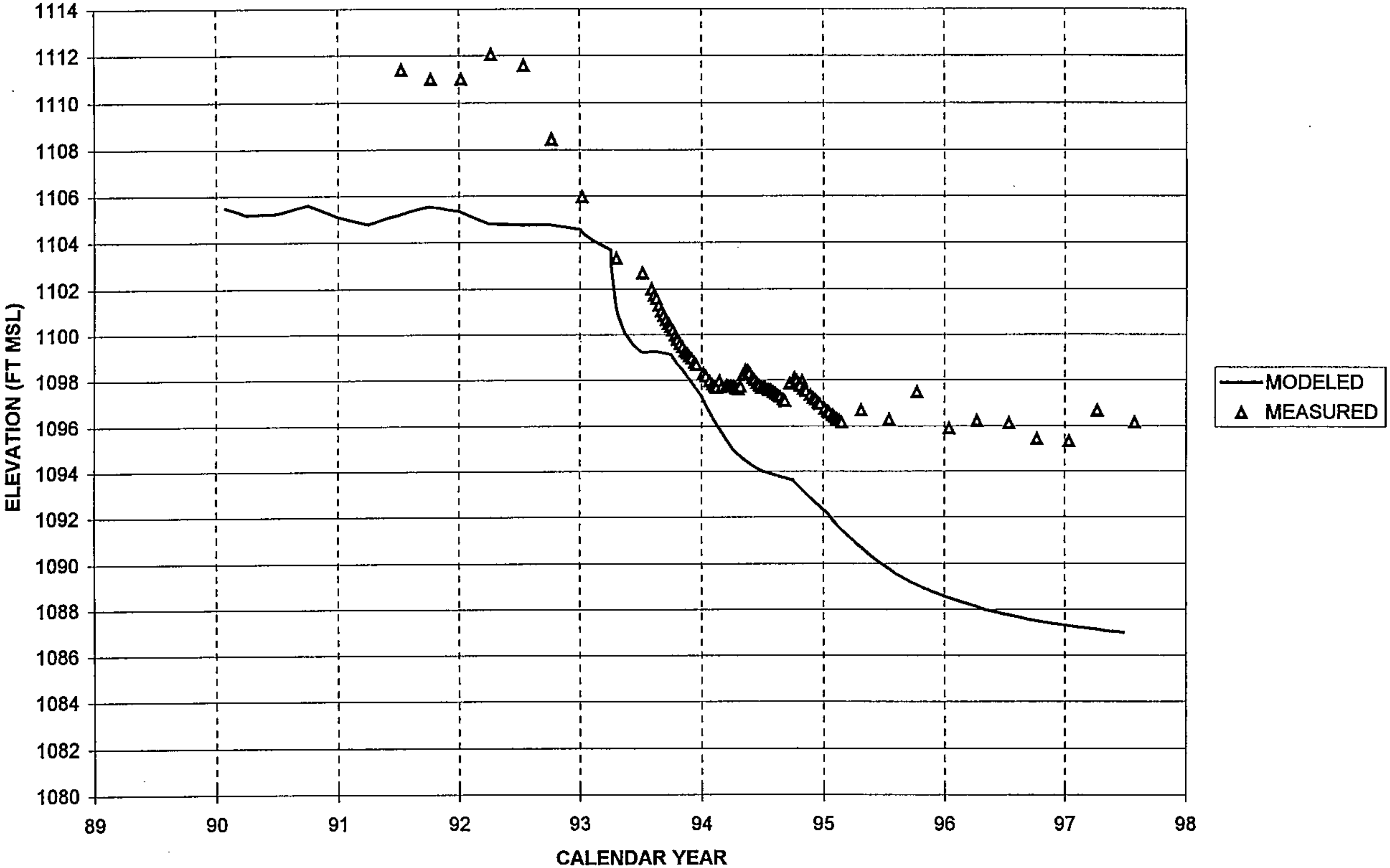


Figure 12
WELL: MW1004P

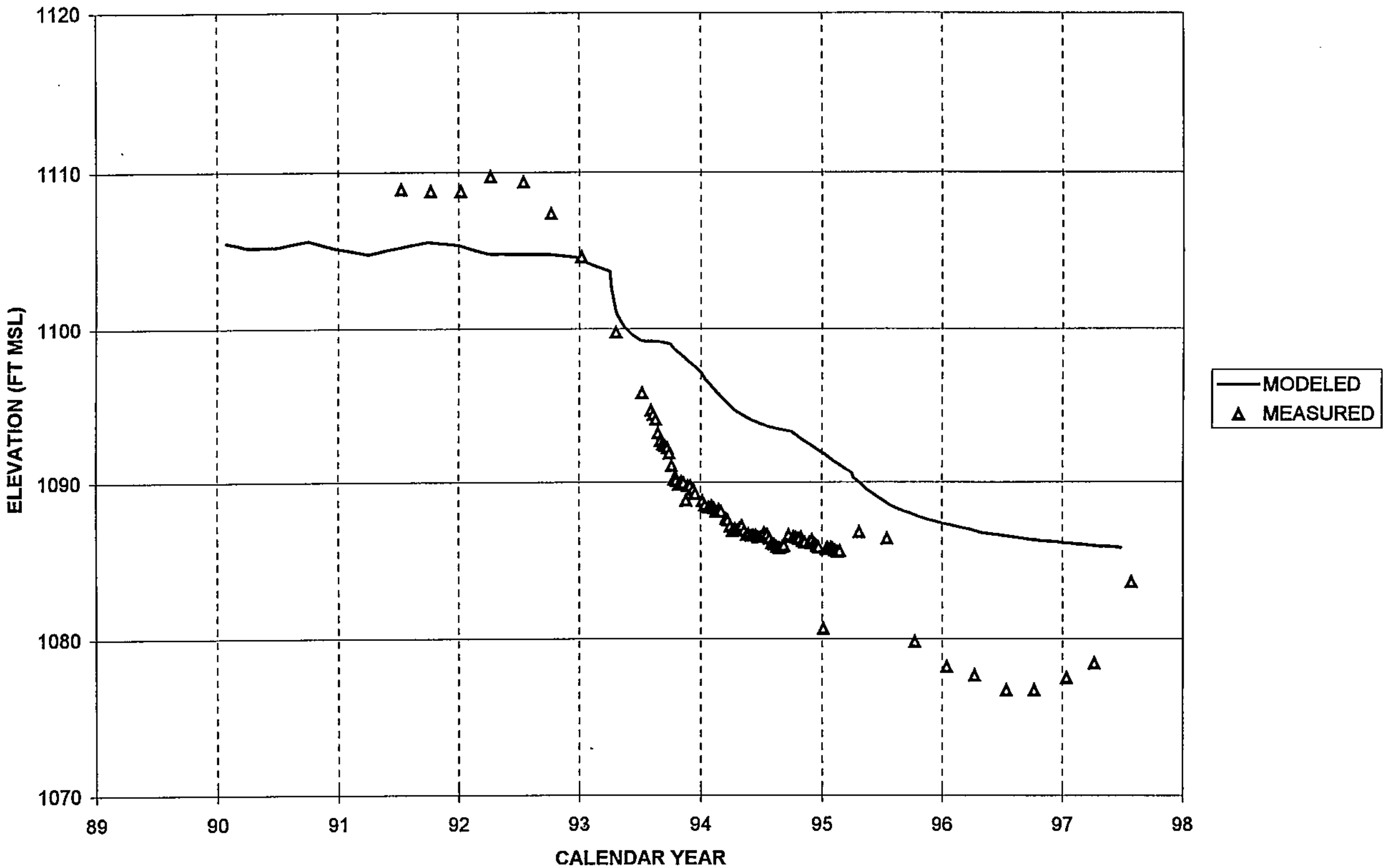


Figure 13
WELL: MW1001P

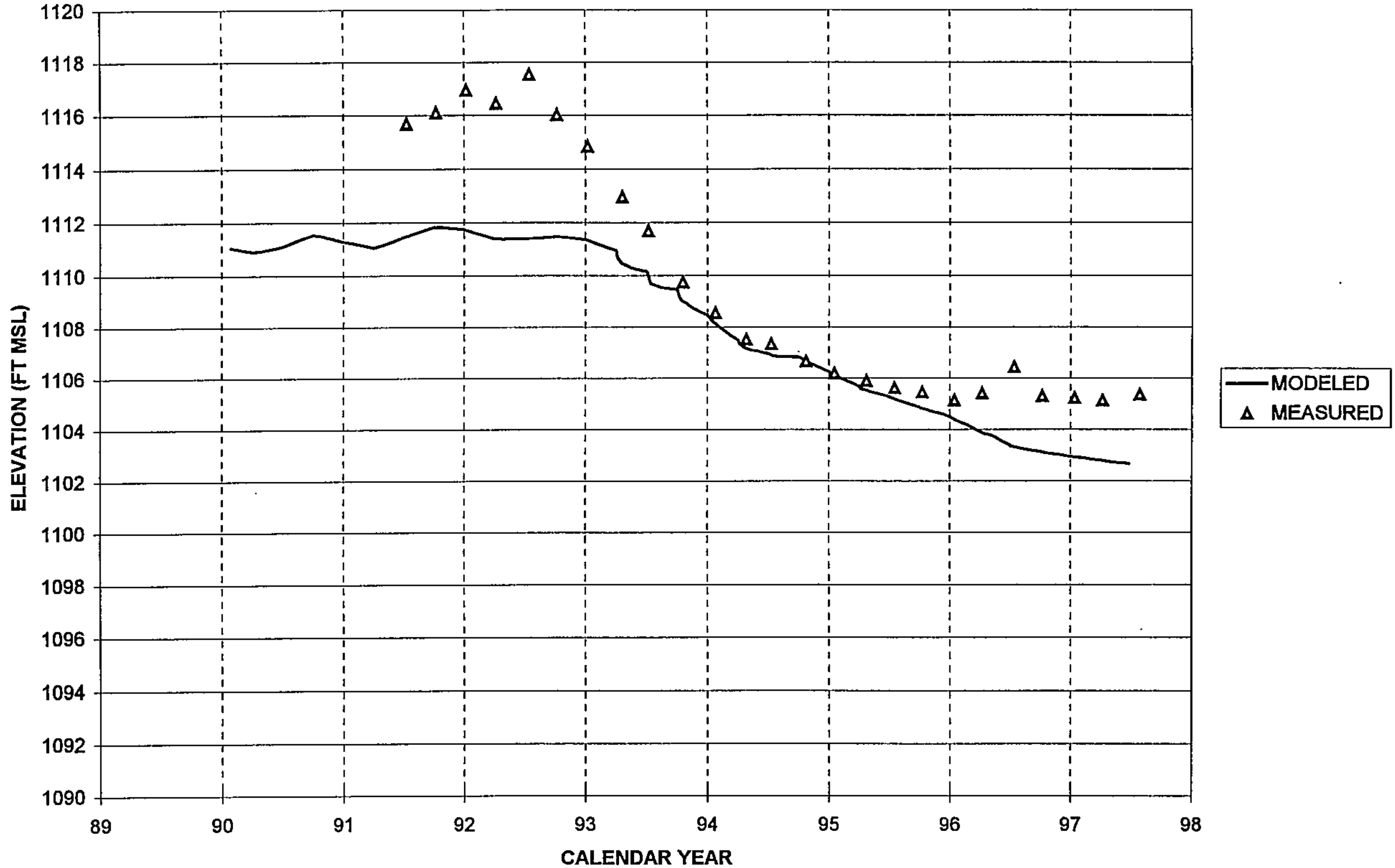


Figure 14
WELL: MW1003

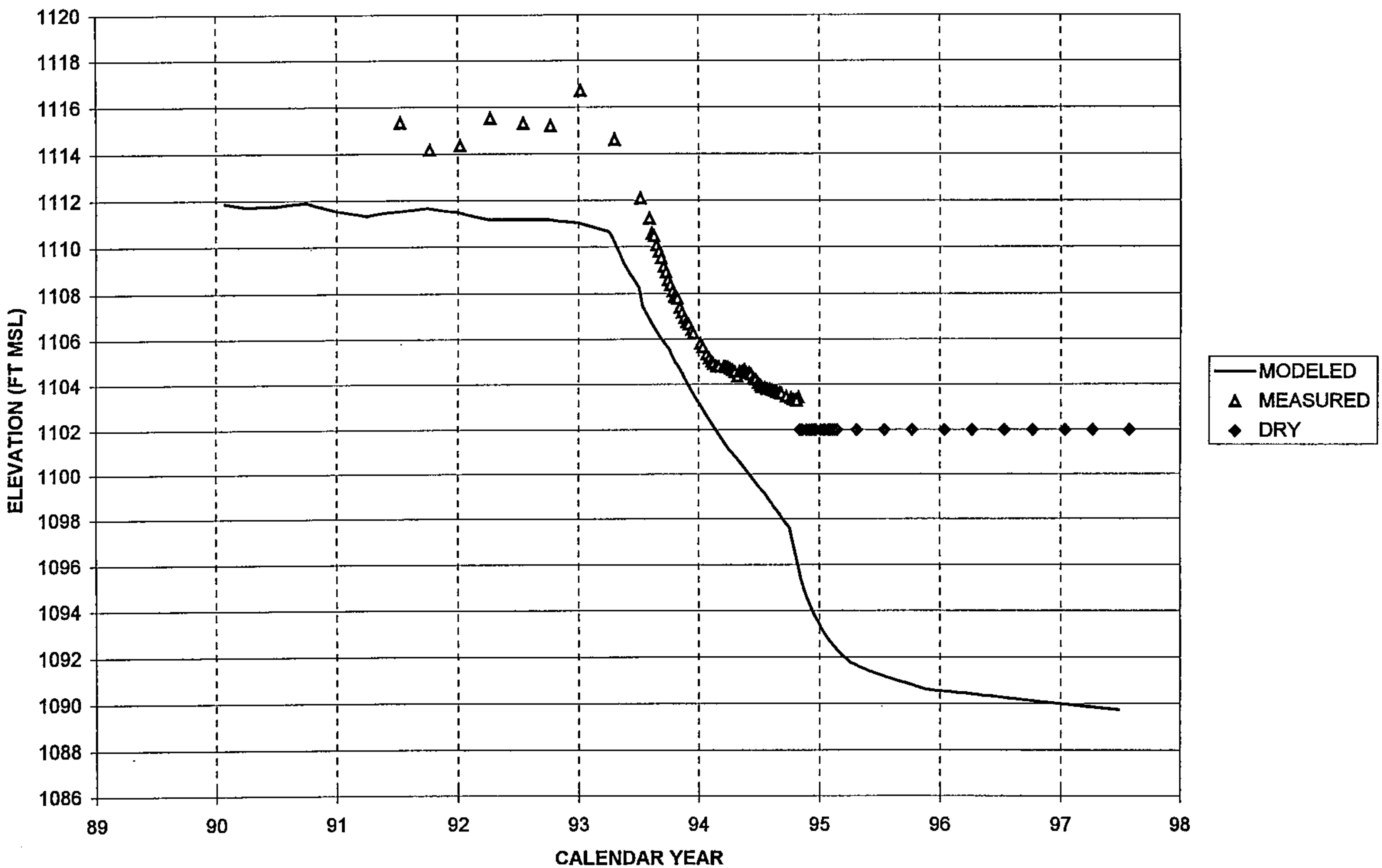


Figure 15
WELL: MW1003P

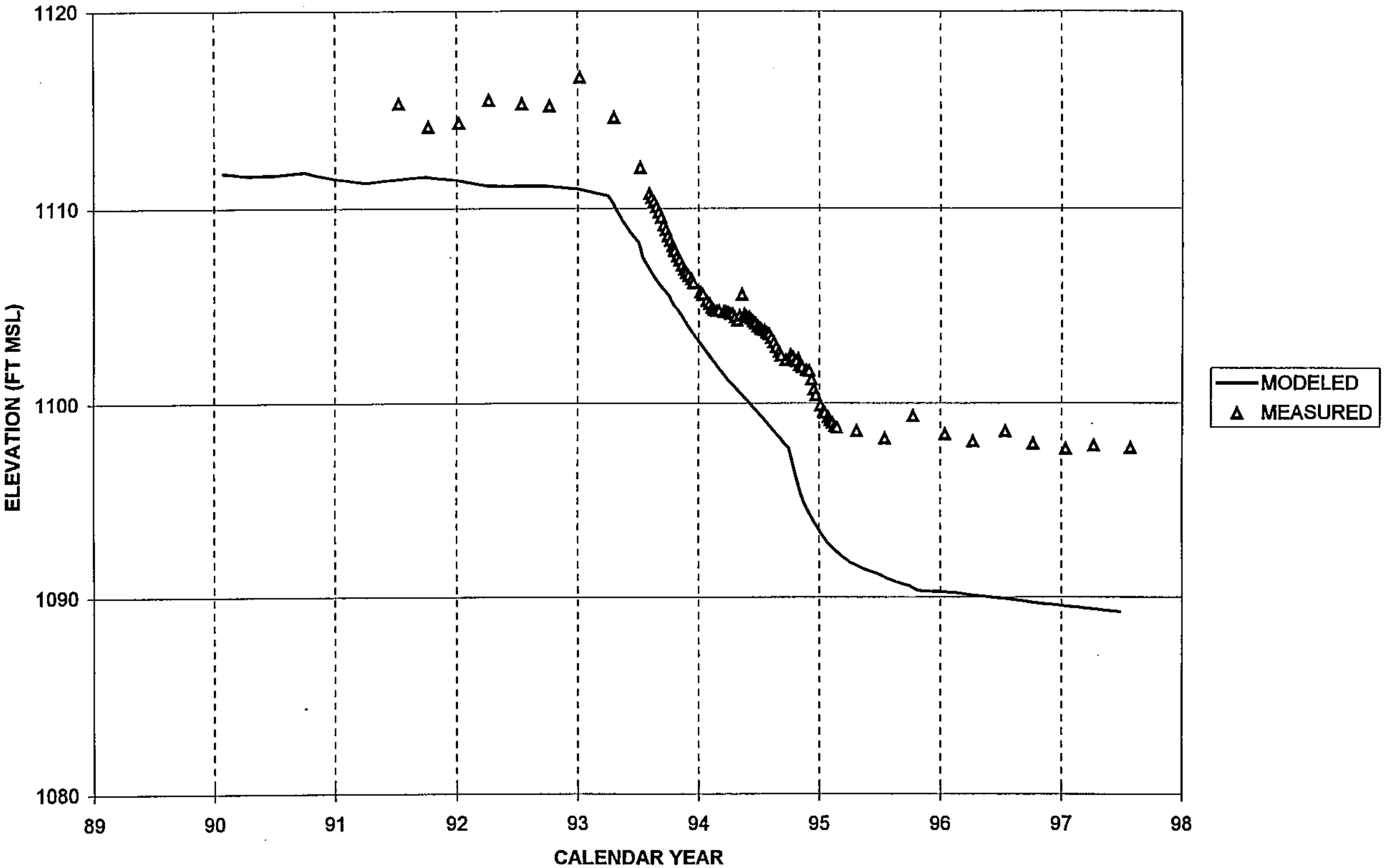
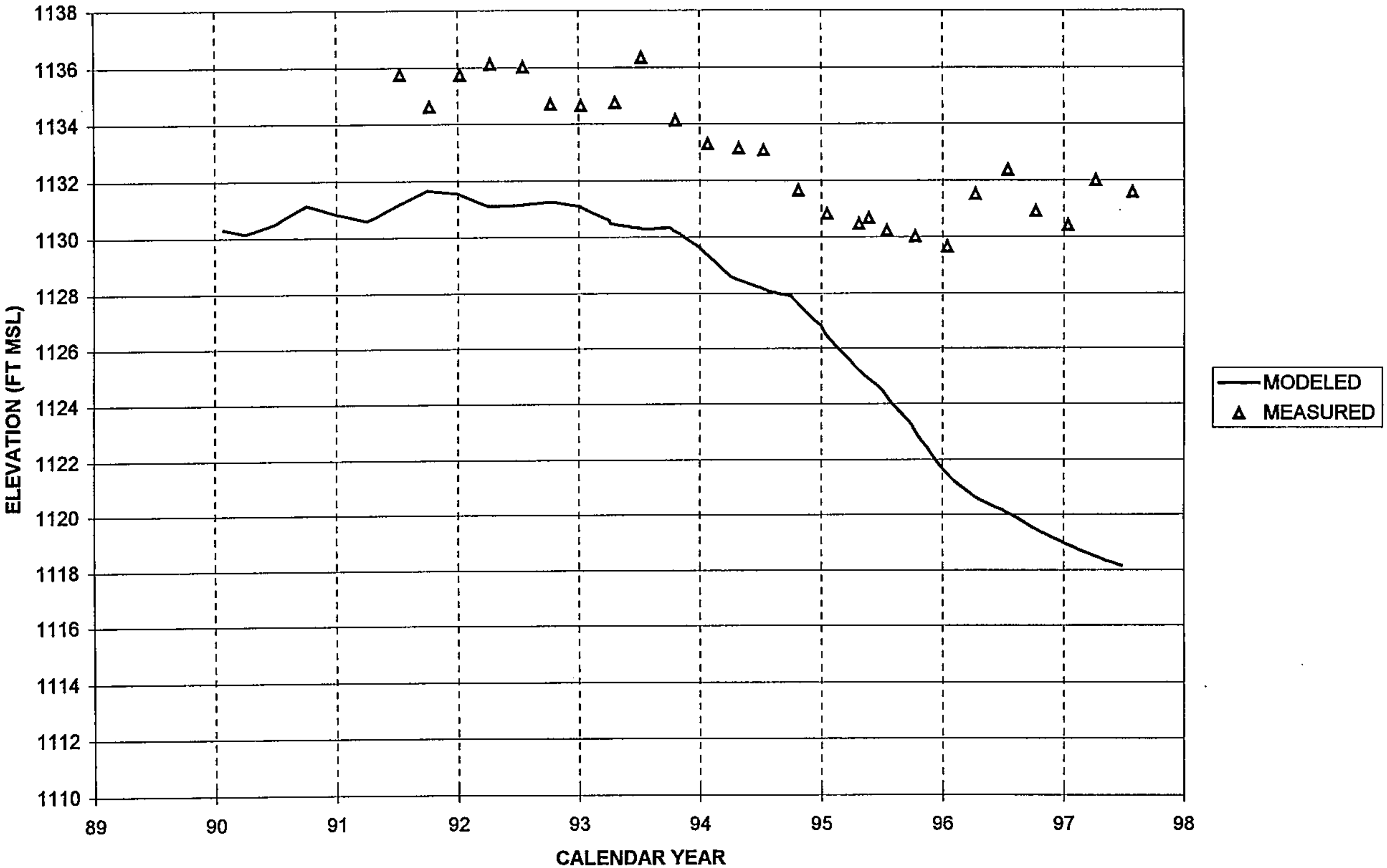


Figure 16
WELL: PZ1006S



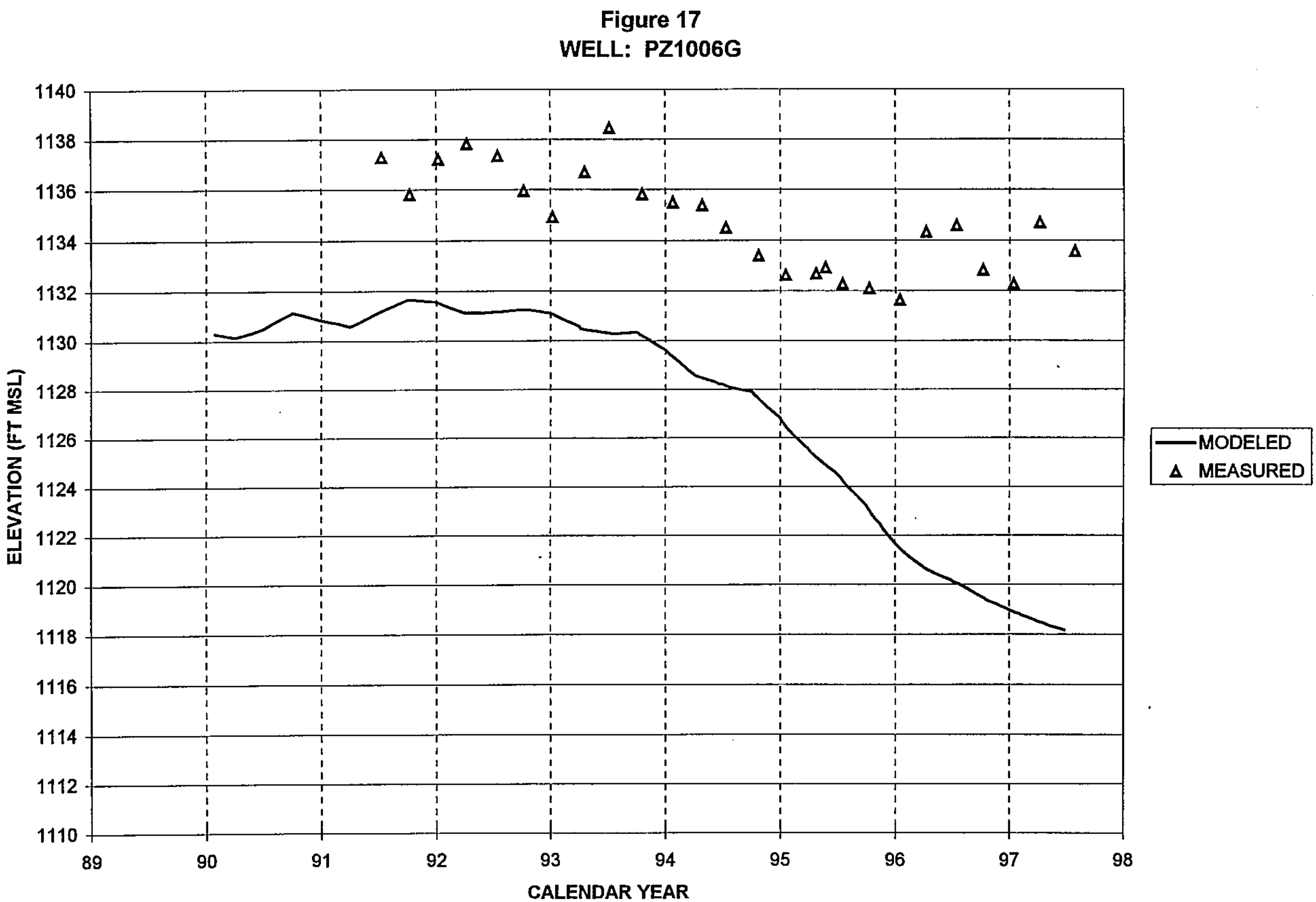


Figure 17
WELL: PZ1006G
1140
1138
1136
1134
1132
1130
1128
1126
1124
1122
1120
1118
1116
1114
1112
1110
ELEVATION (FT MSL)
89
90
91
92
93
94
95
96
97
98
CALENDAR YEAR
MODELED
MEASURED

Figure 18
WELL: SANDPOINT

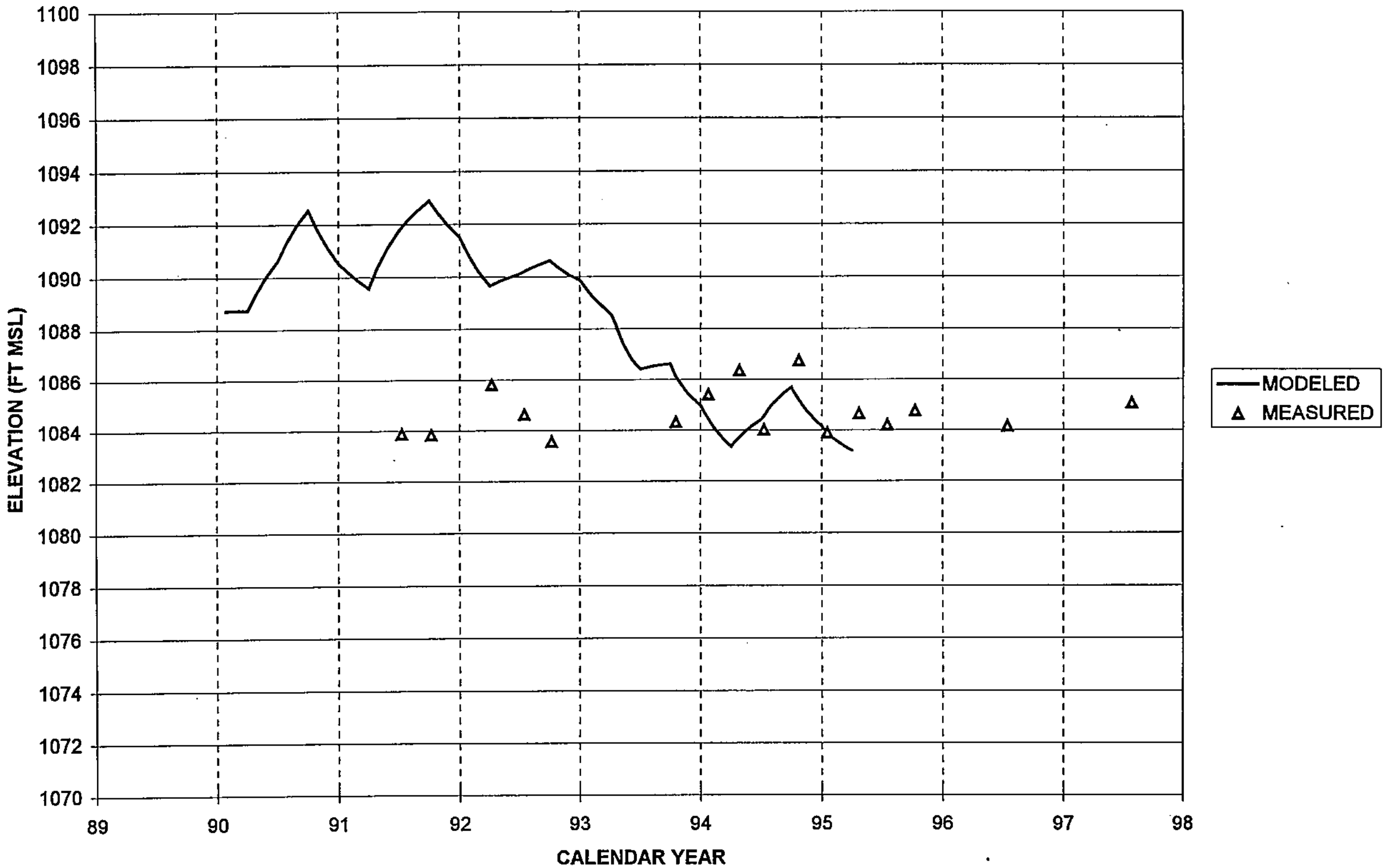


Figure 19
WELL: OW-10

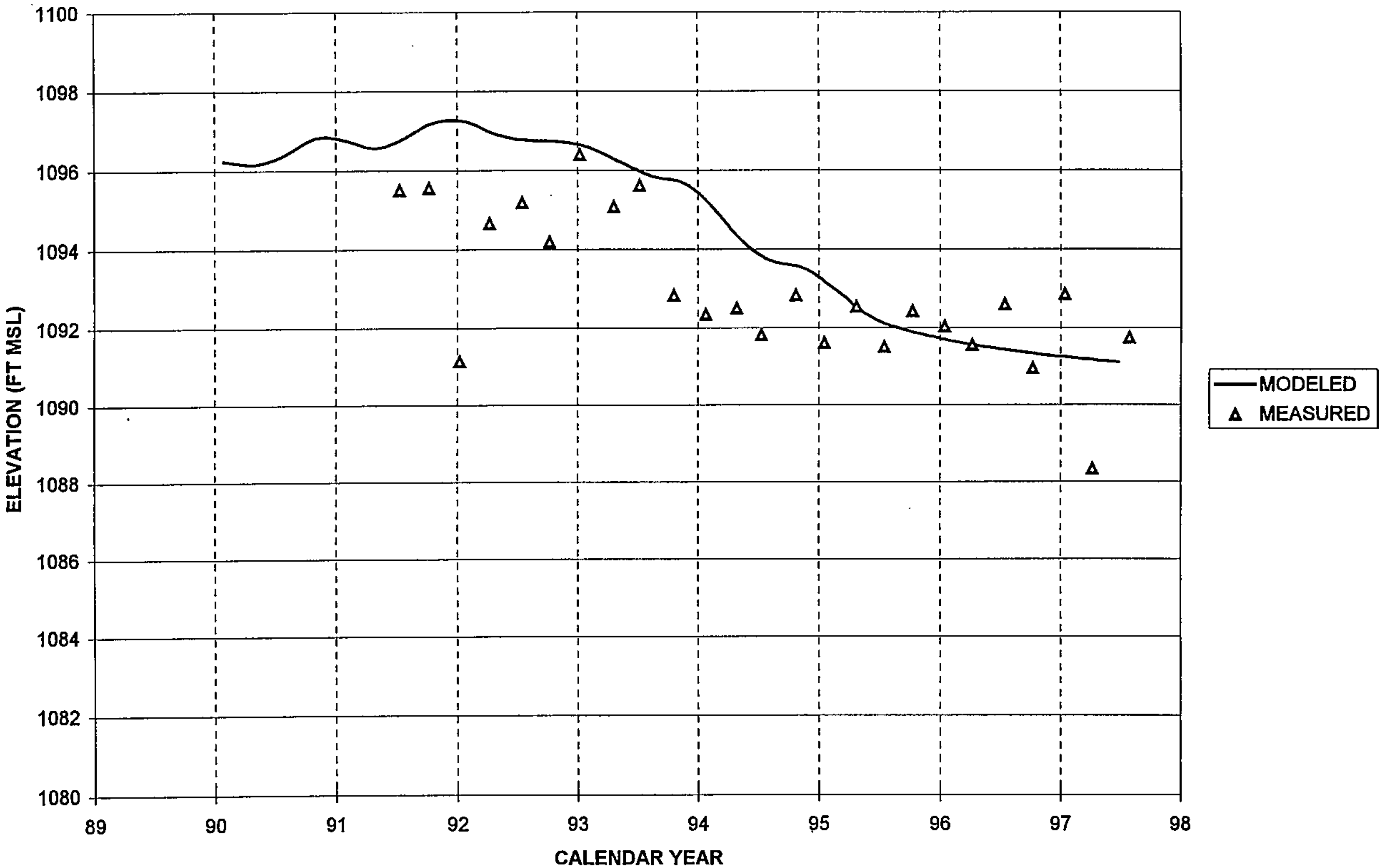


Figure 20
WELL: PZR1

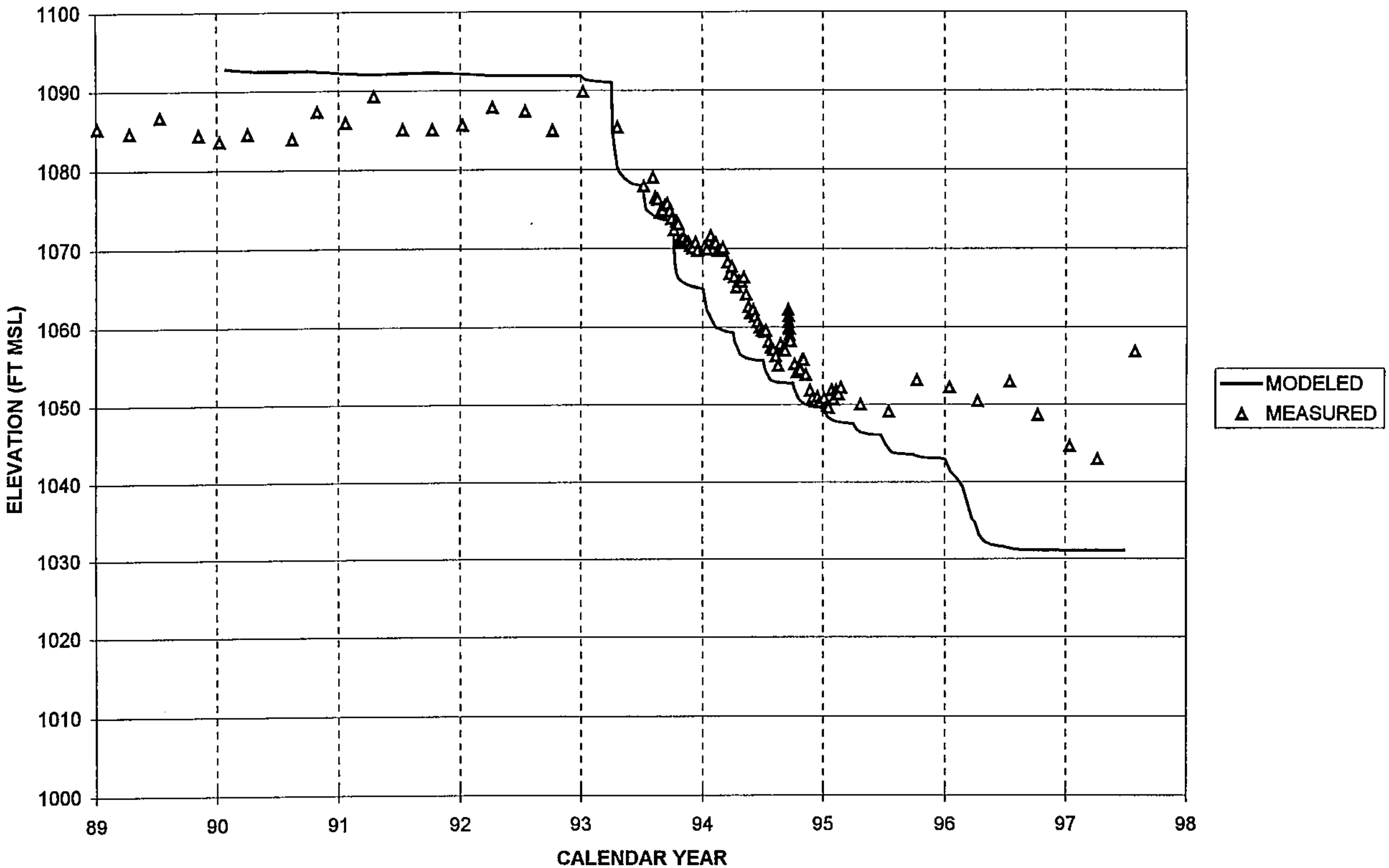


Figure 19
WELL: OW-10

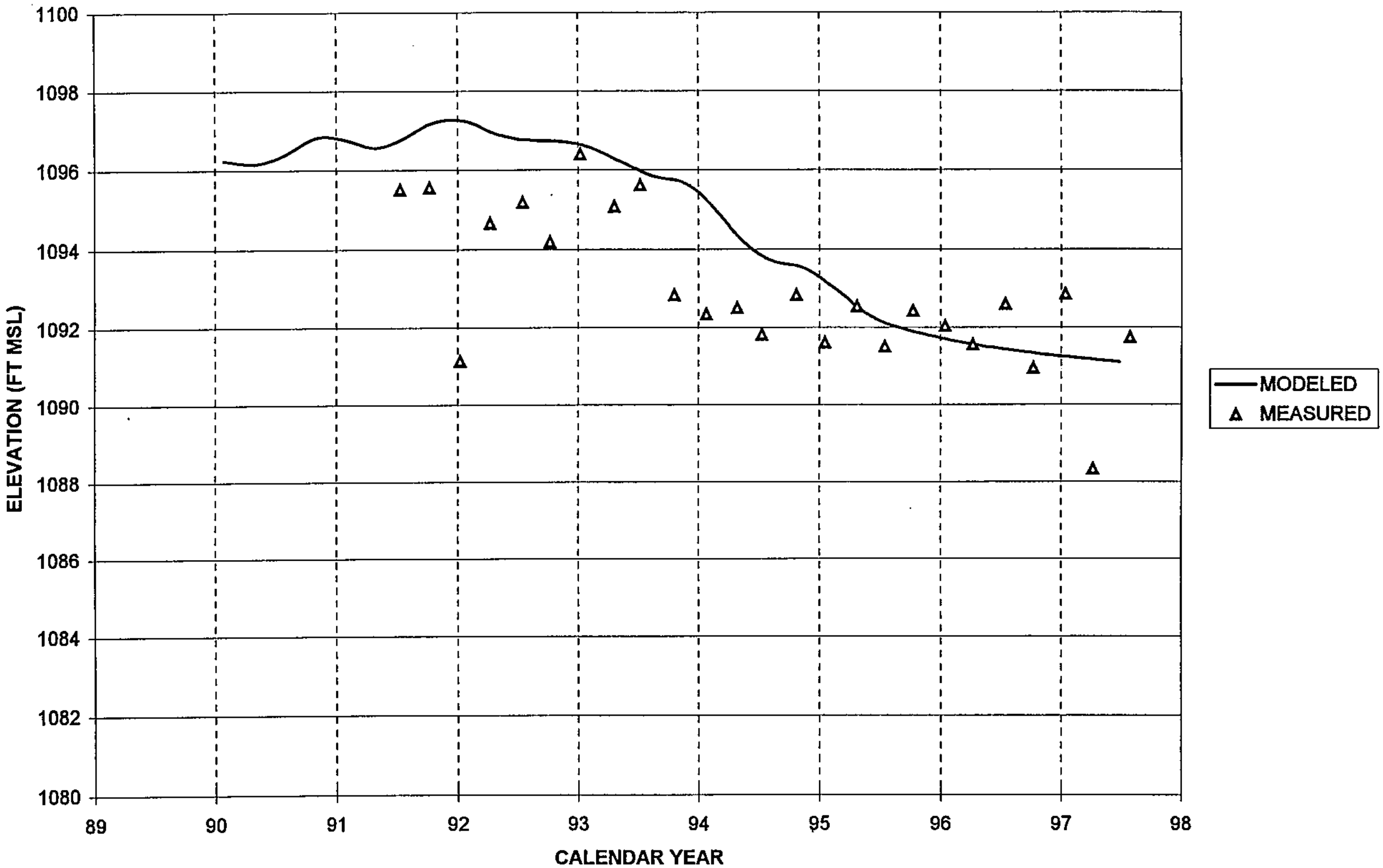


Figure 20
WELL: PZR1

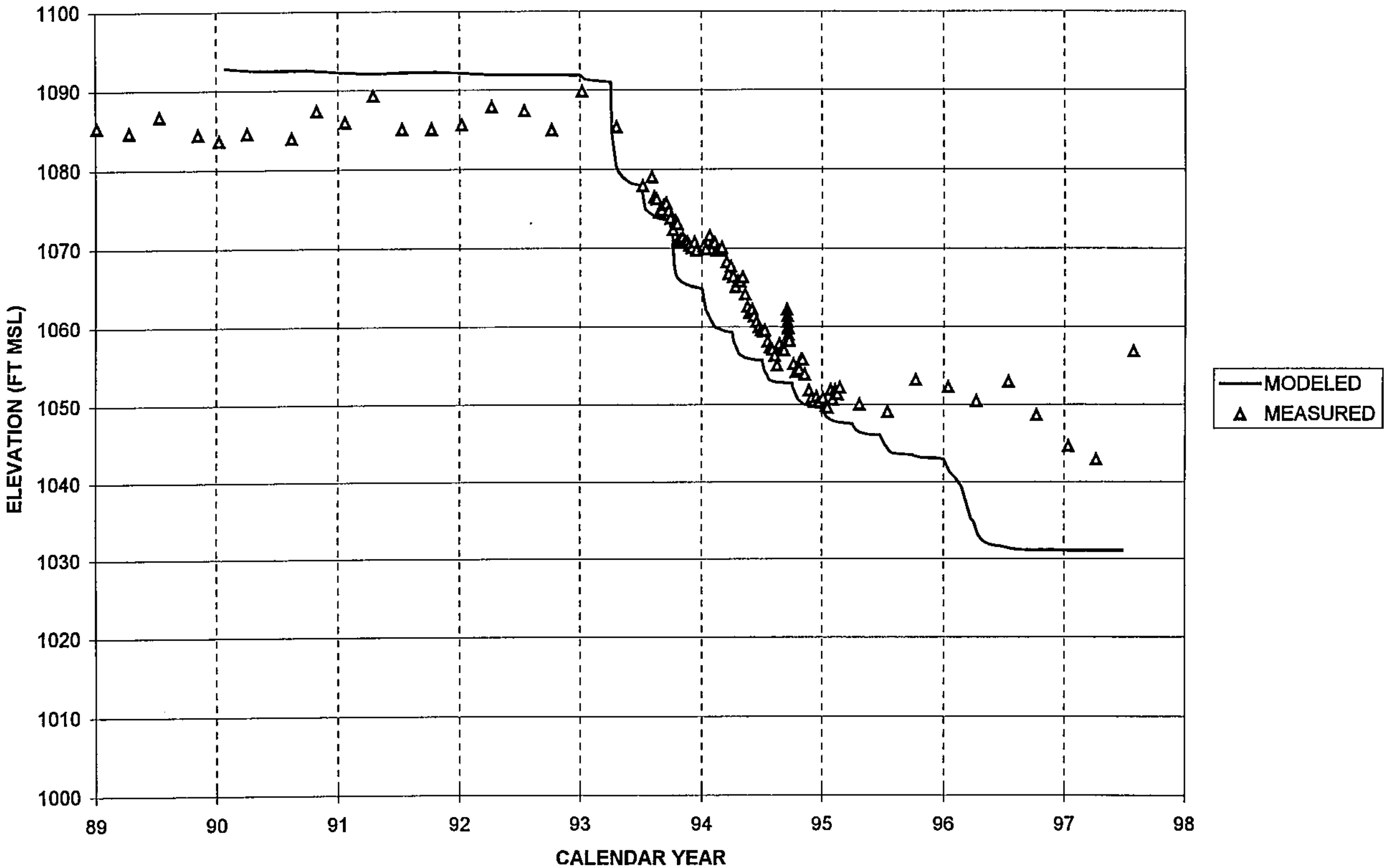


Figure 21
WELL: PZ1008

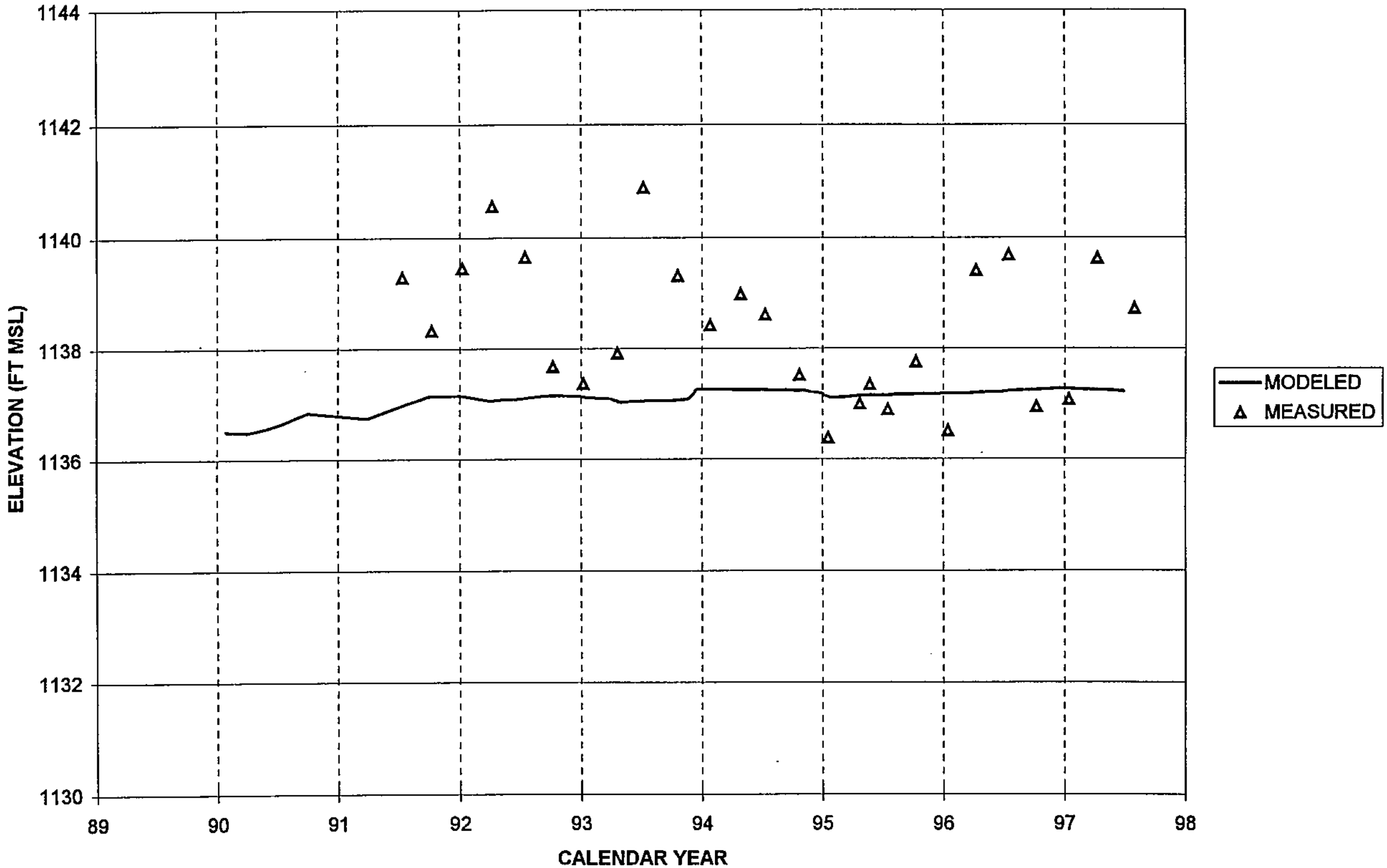


Figure 22
WELL: MW1005

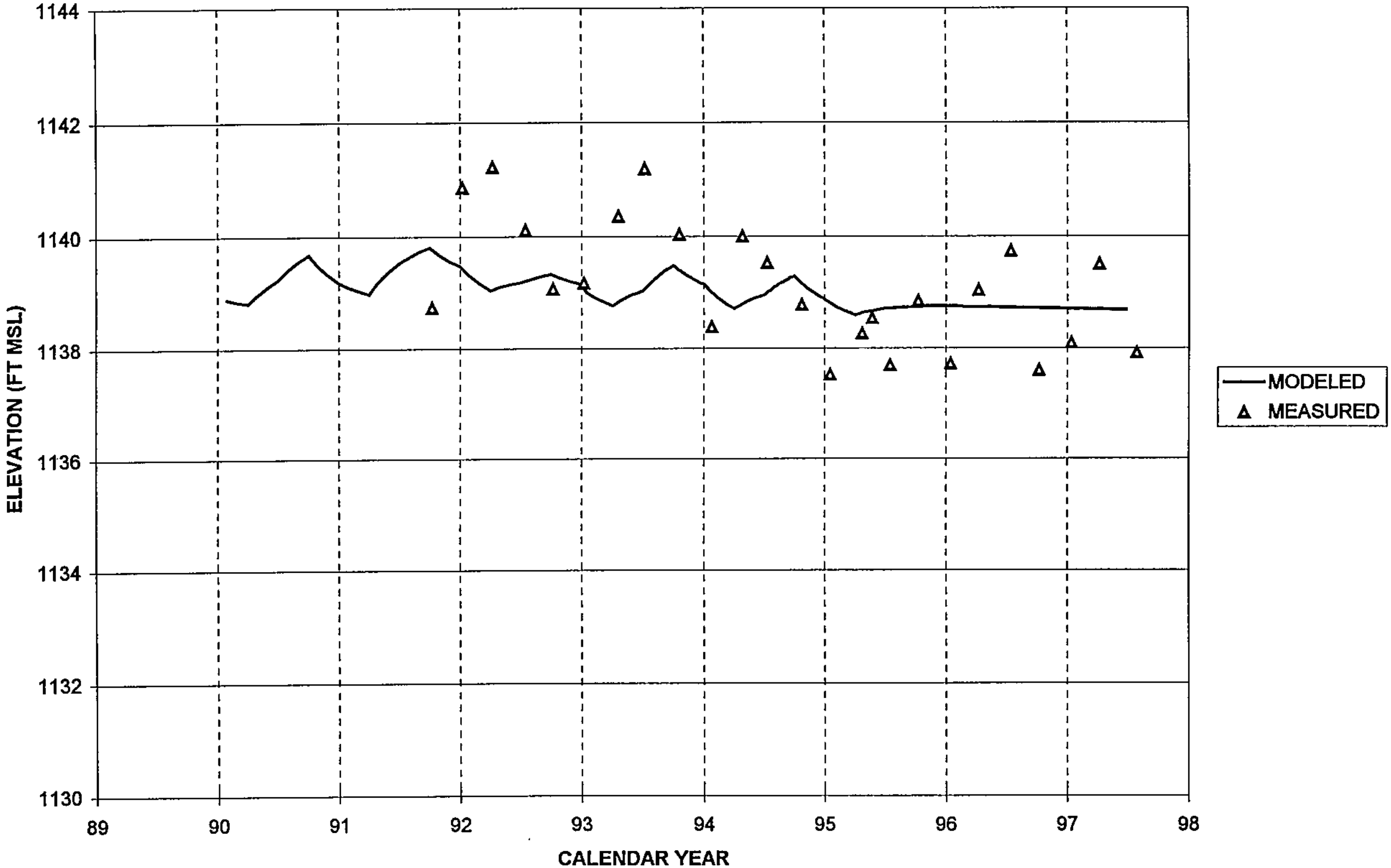
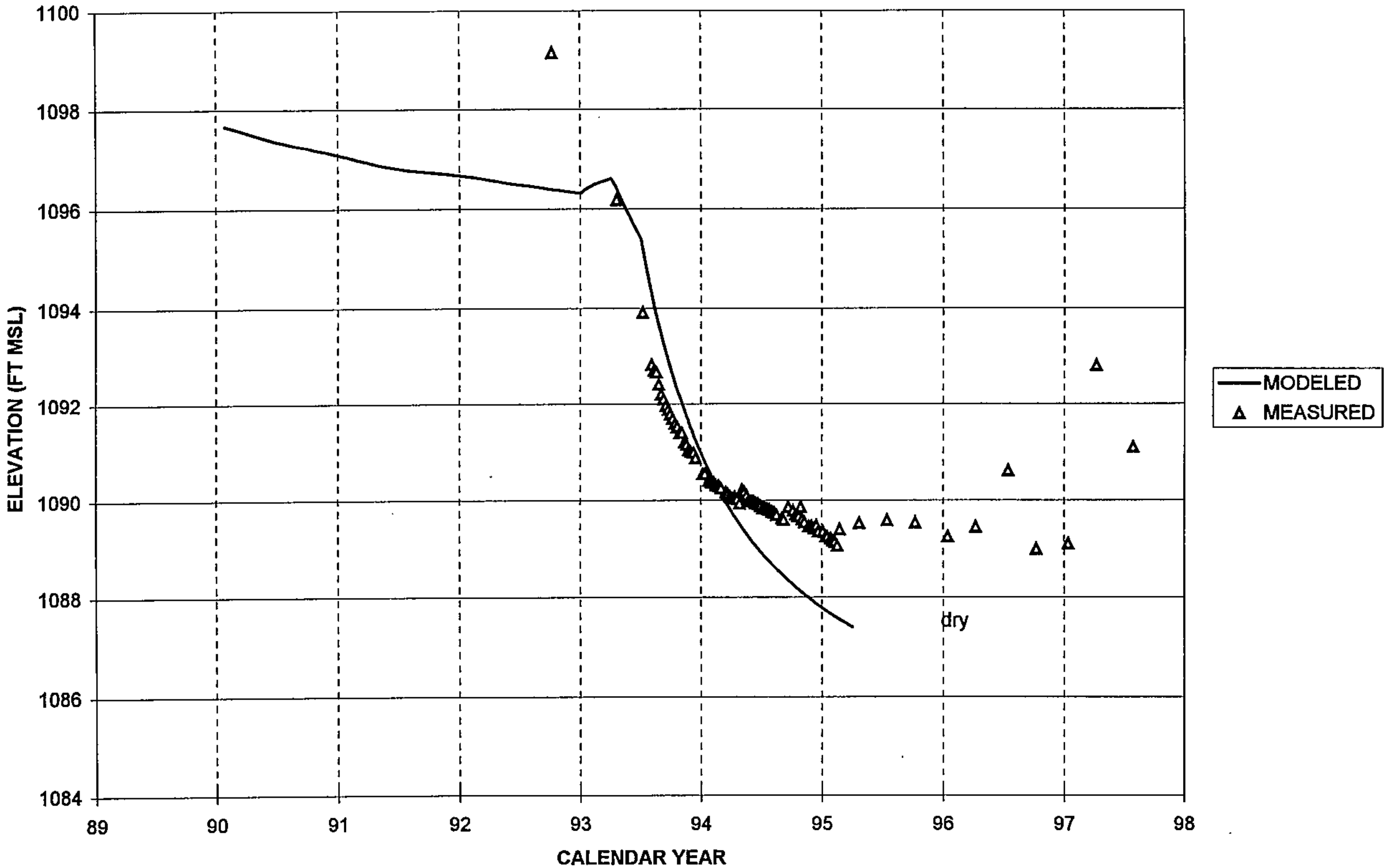


Figure 23
WELL: OW-39



III. Predictions

A. Resaturation

After mining was completed in 1997, the backfilling of the pit began. Type II stockpile material was placed at the bottom of the pit, followed by Type I material, saprolite, sandstone and glacial drift. The 1996 modeling assumed the following hydraulic conductivities for the backfill.

material	layer	hydraulic conductivity (ft/day)
bedrock	3	0.076
sandstone	2	0.59
glacial drift	1	2.83

Additional testing was performed by Foth & Van Dyke on actual compacted backfill in 1996 and 1997 resulting in a recommended isotropic hydraulic conductivity for the Type II backfill of 1E-5 cm/sec. The details of the backfill analysis are shown in Appendix B.

Based on the testing of backfill described above, the following hydraulic conductivity values were used for simulating the resaturation of the backfill.

material	layer	hydraulic conductivity (ft/day)
bedrock	3	0.028
sandstone	2	0.59
glacial drift	1	2.83

Specific yields were assumed to be similar to premining values except for the bedrock where the granular nature of the backfilled rock would be much higher than that assumed for the fractured rock. A specific yield of 0.2 was assumed for all layers. Storage coefficients for layers 2 and 3 were assumed to be the same as their premining values, 0.0001.

Resaturation was simulated using MODFLOW with the BCF2 package. The BCF2 package permits resaturation of dry grid cells (McDonald et al, 1991). It was necessary to modify MODFLOW so the horizontally isotropic backfill and the horizontally anisotropic bedrock could be simulated. Standard MODFLOW provides for horizontal anisotropy constants applicable to each layer of the model. Ground water flow previous to and during mining was simulated with MODFLOW by using a horizontal anisotropy factor for the bedrock aquifer (layer 3) as described in Section II of this report. The resaturation simulation required horizontal anisotropy in the unmined bedrock and horizontal isotropy in the backfill. MODFLOW uses a one dimensional array, TRPY, to store the horizontal anisotropy factors for each layer of the model. To simulate a spatially variable horizontal anisotropy, this array becomes a three dimensional array, storing a horizontal anisotropy factor for each model grid (node). Array TRPY was expanded in size throughout the BCF2 package code.

Figure 24 shows the water level elevations as they increase with time at grid column 24, row 32 during the resaturation of the mine. This is at the middle of the mine pit. The water table effectively recovered to its premining value after about 15 years. Water level elevations are identical in all three layers. Layers one and two are not resaturated until near the end of the water level recovery.

The recovery of the water table shown in Figure 24 ignores the backfill below the bottom elevation of the bedrock aquifer. There will be backfill between an elevation of 880 feet and the bottom of the bedrock aquifer at 980 feet. An approximate time to resaturate this backfill was estimated by calculating the volume below an elevation of 980 feet (11.6 millon ft^3), assuming a porosity of 0.2, and assuming the inflow to the pit at the end of mining (120 gpm) would remain constant until the backfill below the bottom of the bedrock aquifer resaturated. The resulting estimate is 100 days. This calculation assumes that the backfill hydraulic conductivity is not controllling the rate of resaturation.

Figure 25 shows the drawdowns six years after reclamation of the pit begins when the impact of mining is at its maximum extent (as evidenced by the five foot drawdown contour). After the pit is backfilled with compacted backfill, ground water continues to flow towards the pit to provide the water to resaturate the backfill. Drawdowns will continue to increase away from the mine pit until the recovery of the water table is nearly complete.

B. Flow through Reclaimed Mine Backfill

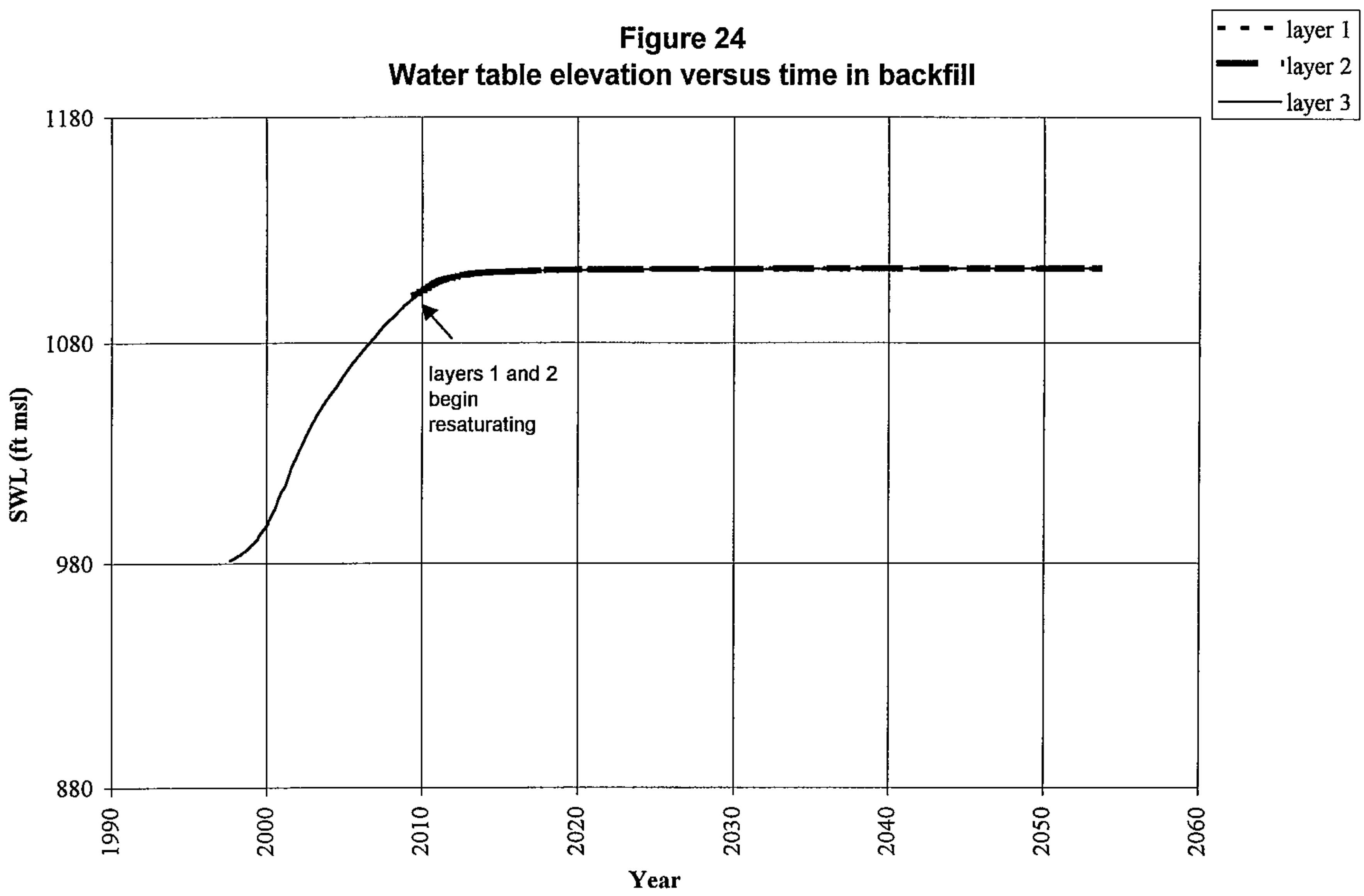
After the resaturation of the mine backfill is complete the water table is similar to that before mining. There is a small mound in the water table over the pit position. This mound is caused by the smaller backfill hydraulic conductivities and to a small degree the diaphragm wall. Figures 26, 27, and 28 show the steady state postming water tables and potentiometric surfaces for the glacial drift (layer 1), sandstone (layer 2), and bedrock (layer 3) aquifers, respectively. Figure 29 shows a plot of the difference between the premining and postmining steady state water table (the negative contours in Figure 29 represent buildup in the postmining water table).

C. Diaphragm Wall Analysis

There is a concrete diaphragm wall and slurry wall in the glacial drift and sandstone aquifers between the mine pit (backfill) and the Flambeau River that were installed to control the inflow of water from the river into the pit during mining. These walls were simulated as a small hydraulic conductivity in the ground water flow models that simulated the impact of the mine pit and backfill. An analysis of the impact of removing the diaphragm and slurry wall system was performed with the ground water flow model.

The walls were removed from the postmining steady state flow simulation by replacing the small hydraulic conductivities representing the walls in layers one and two with the hydraulic conductivities of the adjacent columns. Figure 30 shows the change in the water table resulting from the removal of the walls compared to the postmining steady state water table (Figure 26). The water table would be 1.7 feet lower in the mine backfill behind the wall at the point of greatest change. This maximum change only occurs in a single model grid. Ground water flows directly to the river in layers one and two, thus causing the point of greatest difference to be 1000 feet back from the diaphragm and slurry wall system rather than directly behind it.

Figure 24
Water table elevation versus time in backfill



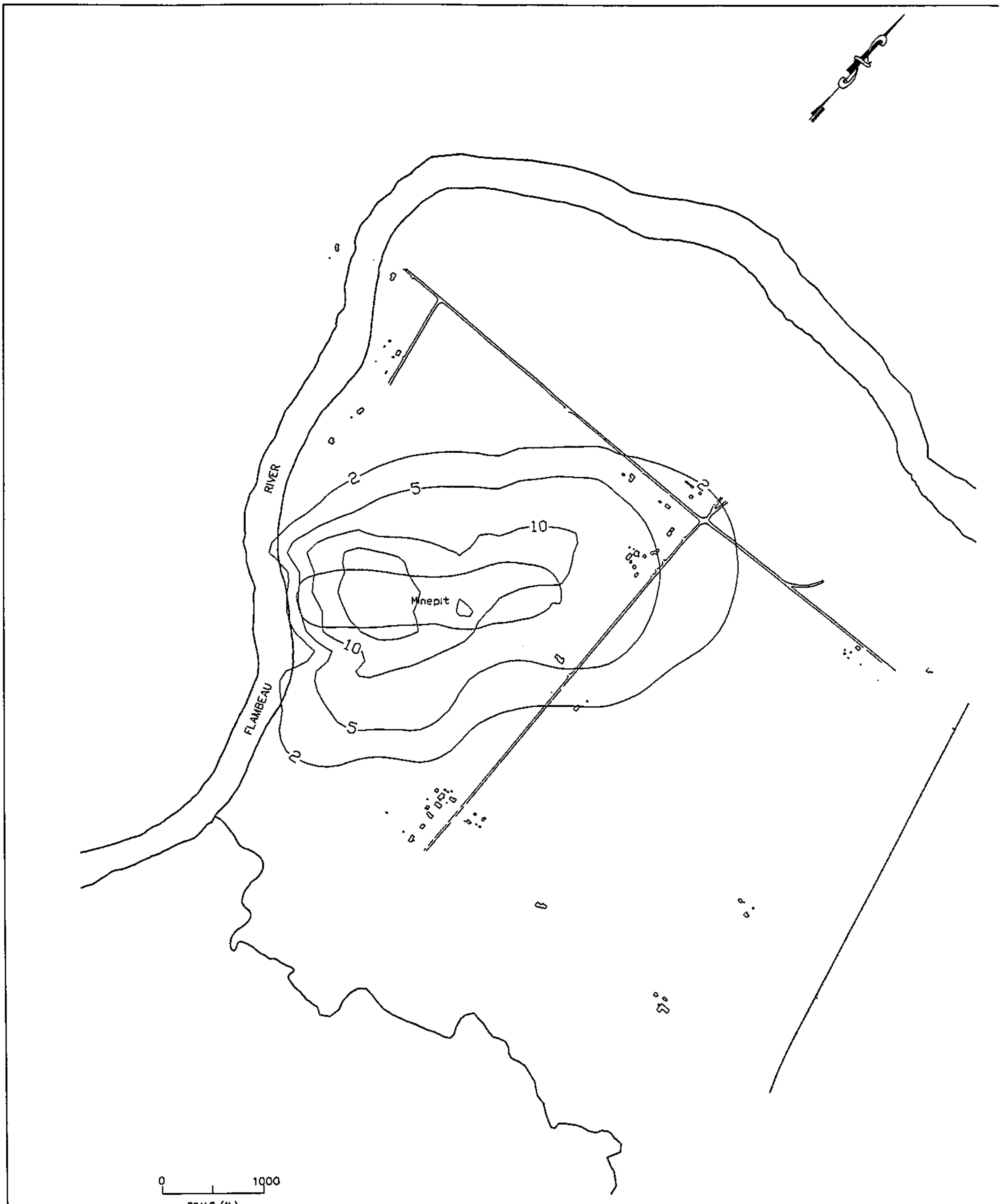


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FIGURE 25
MODELED DRAWDOWN AT MAXIMUM EXTENT
LAYER 3

SCALE:	CONTRACT NO.: 96303.11	DATE: Apr. 1998	SHEET:

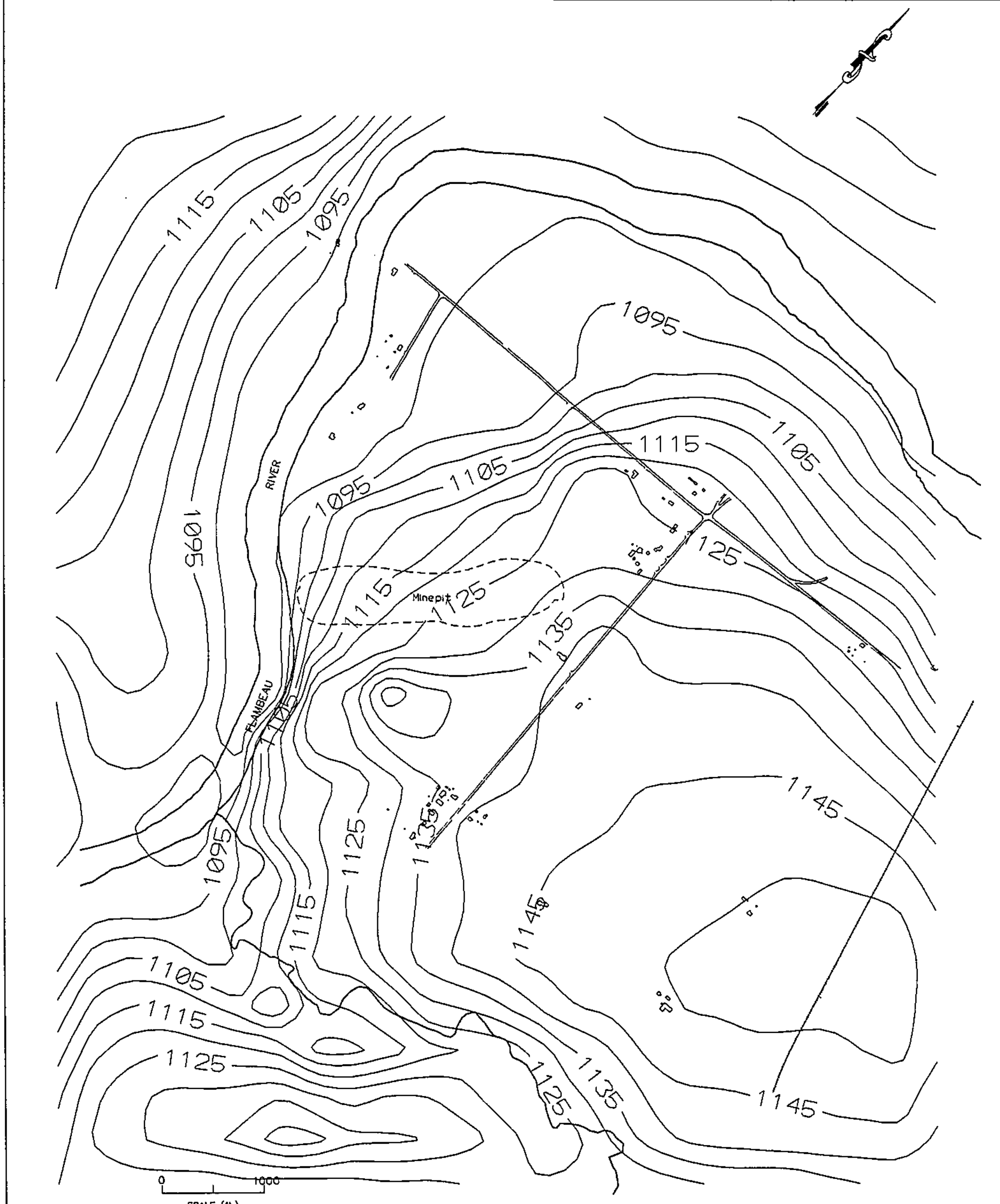

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FIGURE 26 POSTMINING STEADY STATE WATER LEVELS AND POTENTIOMETRIC HEAD LAYER 1			
SCALE:	CONTRACT NO.: 96303.11	DATE: Apr. 1998	SHEET:

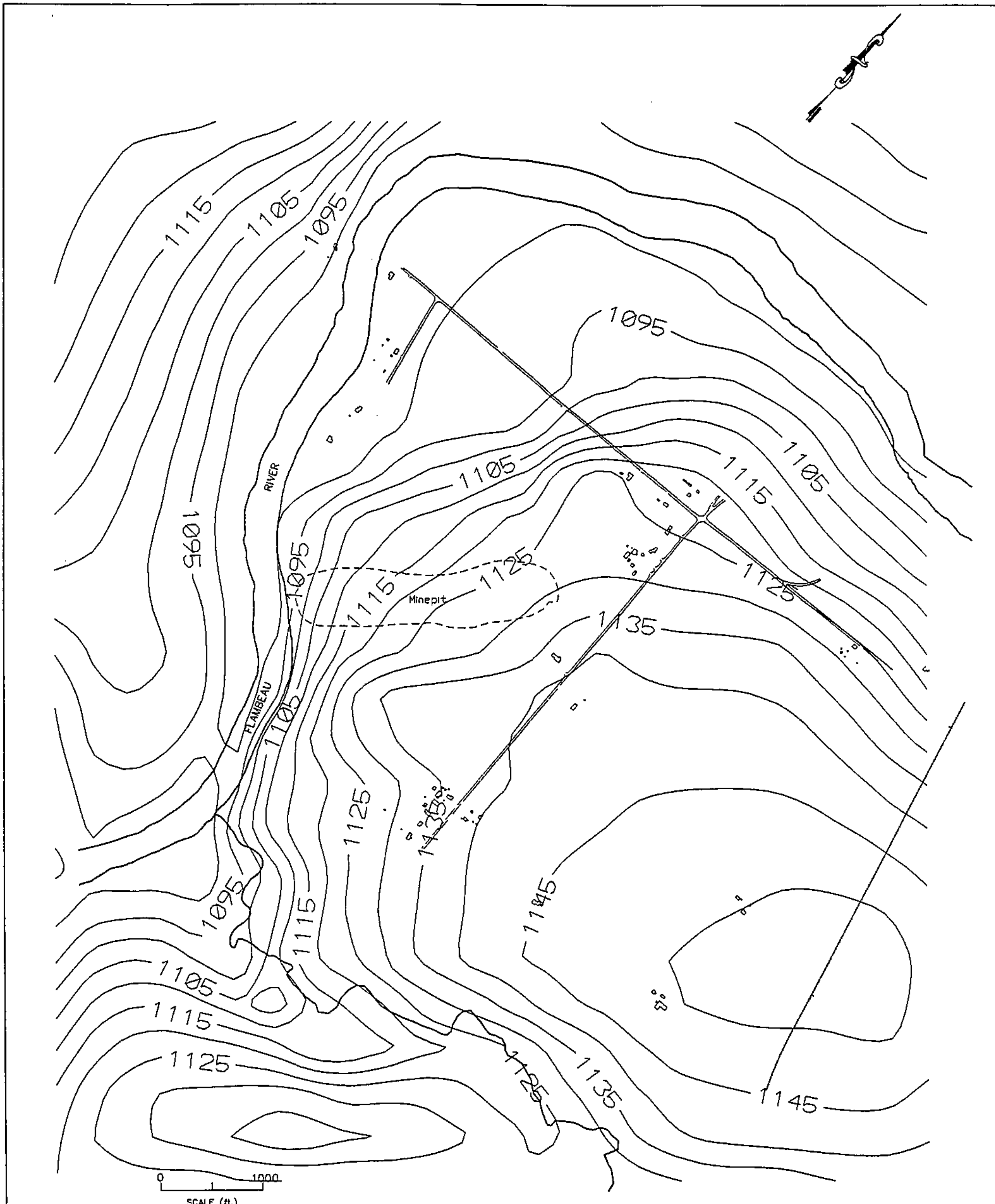

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FIGURE 27
POSTMINING STEADY STATE WATER LEVELS AND POTENTIOMETRIC HEAD
LAYER 2

SCALE:	CONTRACT NO.: 96303.11	DATE: Apr. 1998	SHEET:

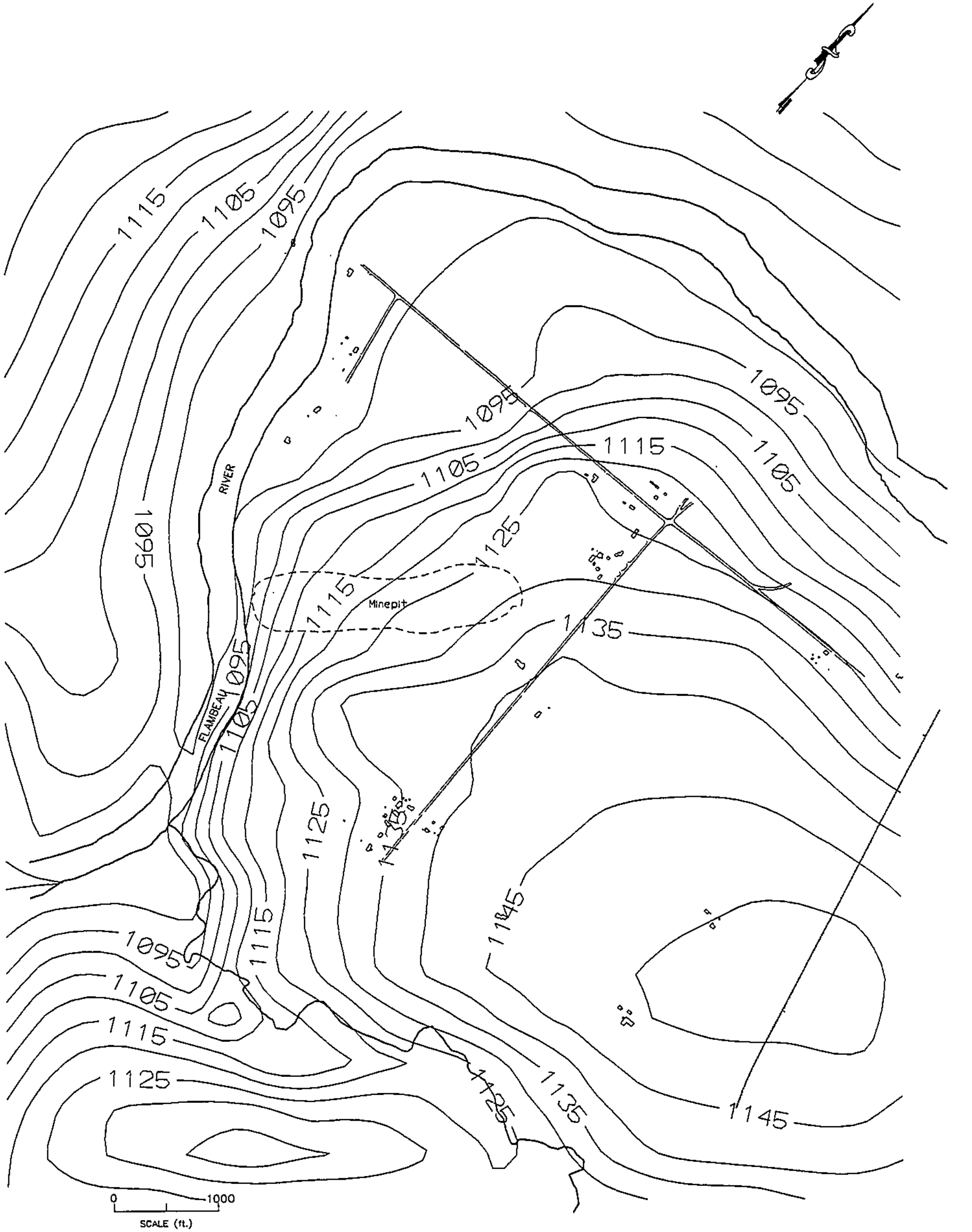

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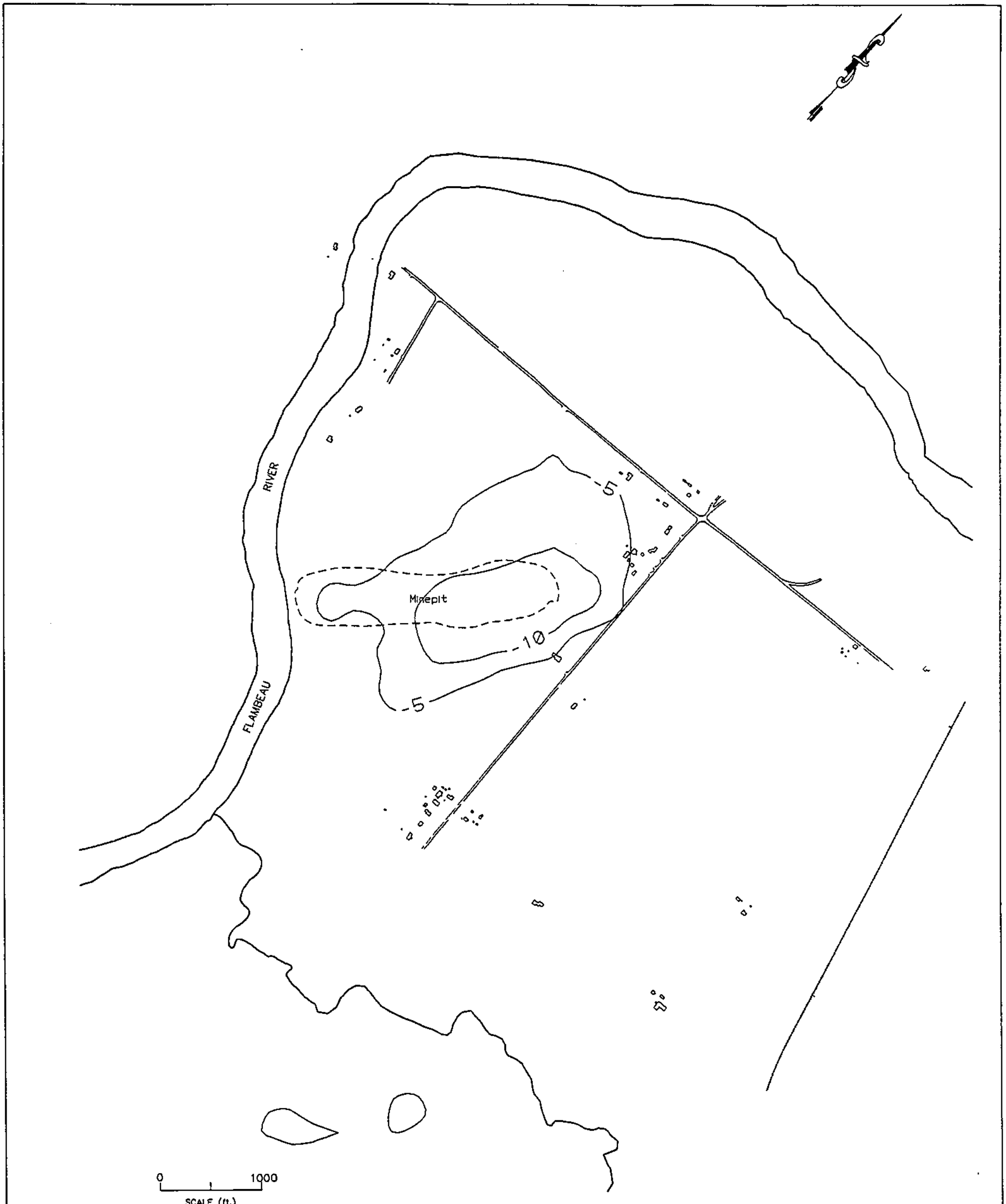
	FIGURE 28 POSTMINING STEADY STATE WATER LEVELS AND POTENTIOMETRIC HEAD LAYER 3
	SCALE: / CONTRACT NO.: 96303.11 / DATE: Apr. 1998 / SHEET:



	ENGINEERING TECHNOLOGIES ASSOCIATES, INC. ENGINEERS • PLANNERS • SURVEYORS 3458 ELLICOTT CENTER DRIVE SUITE 101 ELLICOTT CITY, MARYLAND 21043 BALTO. 461-9920 WASH. 621-4660	FLAMBEAU PROJECT FIGURE 29 POSTMINING DRAWDOWN AT STEADY STATE SCALE: CONTRACT NO.: 96303.11 DATE: Apr. 1998 SHEET:

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FIGURE 30
DRAWDOWN FROM REMOVAL OF DIAPHRAGM AND SLURRY WALL

SCALE:	CONTRACT NO.: 96303.11	DATE: Apr. 1998	SHEET:

IV. Conclusions

The previously developed three dimensional, finite difference model of the Flambeau Mine was recalibrated. Two major changes in the conceptual model of ground water flow at the site were made based on the data that became available between 1995 (when the previous three dimensional modeling was performed) and 1997. The first was the horizontal anisotropy of the bedrock aquifer. A geologic study concluded that the Precambrian bedrock at the site should have horizontal ansiotropy due to preferential jointing, faulting, and fracturing. The second change was the decrease in the permeable thickness of the bedrock. Previously, the bedrock aquifer was assumed permeable to an elevation of 860 feet above mean sea level. Review of monitoring well drawdown and pit inflow data indicated that this assumption was incorrect. A bedrock aquifer bottom at an elevation of 980 feet best fit the data. With these two assumptions, and some other minor changes, the ground water flow model was recalibrated.

Additional data on the hydraulic conductivity of the backfill became available in 1997. With these new estimates of backfill hydraulic conductivity, the model predicted backfill resaturation in slightly over 15 years. The previous three dimensional model had predicted resaturation in 30 years. The faster resaturation estimate was because of the smaller thickness of saturated bedrock which limits the drawdown and thickness of aquifer that has to be resaturated.

After the resaturation of the mine backfill is complete the water table is similar to that before mining. There is a small mound in the water table over the pit position. The postmining direction of ground water flow through the backfill changes slightly from the premining direction.

V. References

Hydro-Geo Consultants, Inc., 1997, Review of Hydrogeologic Conditions and Bedrock Geology at Flambeau Mine Near Ladysmith, Wisconsin.

McDonald, M. Harbaugh, A., Orr, B., and Ackerman, D., 1991, A Method of Converting No-flow Cells to Variable-head Cells for the U.S. Geological Survey Modular Finite-Difference Ground-Water Flow Model, USGS Open File Report 91-536.

McDonald, M. and Harbaugh, A., 1988, A Modular Three-dimensional Finite-difference Ground-water Flow Model, USGS Techniques of Water Resources Investigations, Book 6, Chapter A1.

Thomas A. Prickett & Associates, Inc. and Engineering Technologies Associates, Inc., Draft Final Flambeau Mine Groundwater Model, February 12, 1996.

Thomas A. Prickett & Associates, Inc. and Engineering Technologies Associates, Inc., Groundwater Model for the Kennecott Flambeau Project at Ladysmith, Wisconsin, report for Kennecott Minerals, July 1989.

Appendix A

Review of Hydrogeologic Conditions and Bedrock Geology at Flambeau Mine Near Ladysmith, Wisconsin

TECHNICAL MEMORANDUM

REVIEW OF HYDROGEOLOGIC CONDITIONS AND BEDROCK GEOLOGY AT FLAMBEAU MINE NEAR LADYSMITH, WISCONSIN

August 12, 1997

HYDRO-GEO CONSULTANTS, INC.

TECHNICAL MEMORANDUM

REVIEW OF HYDROGEOLOGIC CONDITIONS AND BEDROCK GEOLOGY AT FLAMBEAU MINE NEAR LADYSMITH, WISCONSIN

August 12, 1997

Submitted to :

Foth & Van Dyke
2737 South Ridge Road
Green Bay, Wisconsin 54307

Submitted by:

Hydro-Geo Consultants, Inc.
165 S. Union Blvd., Suite 400
Lakewood, Colorado 80228

TECHNICAL MEMORANDUM

REVIEW OF HYDROGEOLOGIC CONDITIONS AND BEDROCK GEOLOGY AT FLAMBEAU MINE NEAR LADYSMITH, WISCONSIN

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TECHNICAL MEMORANDUM

REVIEW OF HYDROGEOLOGIC CONDITIONS AND BEDROCK GEOLOGY AT FLAMBEAU MINE NEAR LADYSMITH, WISCONSIN

1.0 INTRODUCTION

At the request of Mr. Stephen V. Donohue of Foth & Van Dyke, Vladimir Straskraba of Hydro-Geo Consultants, Inc. visited the Flambeau Mine and reviewed the materials pertinent to geology and hydrogeology of the mine area. The scope of the mine visit and the review of material was to express an opinion on the hydrogeologic characteristics of the mine area and on the potential for preferential direction of ground water flow in the Precambrian bedrock in particular.

Prior to the site visit several reports describing the baseline hydrogeologic investigation and computer simulation of ground water mine inflow during and after the conclusion of mining operations were reviewed. A complete listing of the reviewed documents is presented in References.

Hydrogeologic investigations conducted for the Flambeau Mine permitting consisted of the installation of numerous monitoring wells and piezometers, testing for permeability, and monitoring of water levels and water quality. Computer modeling with the application of finite-difference ground water flow model "MODFLOW" simulated mine inflow and development of drawdown in the pit area during and after mining.

The ore recovery from the Flambeau open pit mine was practically completed by June 1997. The pit bottom reached an elevation of 860 feet, which is approximately 220 feet below the ground surface. The backfilling operation was initiated in March, 1997, and should be completed by October, 1997.

2.0 SITE VISIT

A site visit to the Flambeau Mine was made on June 26, 1997. Mr. Stephen V. Donohue of Foth & Van Dyke participated in the visit with Mr. Vladimir Straskraba. The visit consisted of an overview of the mine, the backfilling operation, an inspection of the surrounding area, and brief discussions with the mine management, Mr. Jeff Earnshaw, and Ms. Jana E. Murphy. A conference call with Mr. Gerald W. Sevick of Foth & Van Dyke to discuss the preliminary conclusions of the site visit was held at the conclusion of the site visit. During the mine tour we were accompanied by Ms. Nicole Hindal, mine geologist.

The mine inspection concentrated on observations of the fracture systems in the ore zone, footwall, and hangingwall, along with water seepage from various formations, and the backfilling operation. The following observations pertinent to the scope of visit were made:

Fracture systems - Numerous open fractures were observed in the ore zone, footwall, and hangingwall. It seemed that more open fractures were observed in the footwall than in the ore zone or hangingwall. Most of the open fractures are perpendicular to the pit wall. However, fractures with other orientation patterns, including horizontal, were observed. The foliation of mostly schist strata is also more pronounced on the west part of the footwall. It is believed that blasting caused increased fracturing, and opened pre-existing fractures in a narrow zone (9 to 11 feet) around the pit walls. The zone of increased fracturing at the pit walls due to blasting depends on the rock type, explosives used and blasting method. However, a maximum extension of this zone is approximately 66 to 72 times the radius of the blasting borehole (U.S. Bureau of Mines, 1961). This would amount to approximately 9.6 to 10.5 feet. The indicated probable extension of the zone with higher permeability along the pit walls was also confirmed in a discussion with Prof. John F. Abel Jr. (1997). A somewhat higher fracture frequency appears to occur in the footwall.

Seepage - Most of the seepage in the upper (not yet backfilled) portion of the pit occurs from the ore zone (both A and B orebodies) on the west wall. The seepage from the ore zone was estimated as 40 to 60 gpm, (based on personal observation at the time of the mine visit).

Seepage on the hangingwall occurs mostly at the contact between saprolite and the bedrock. Highest seepage was observed near the northwest corner of the pit. Several horizontal drains installed in the bedrock of the western sector of the hangingwall had a slight discharge of water (dripping). The area of slope failure, about 500 feet from the west corner of the pit was relatively dry, probably due to the presently operating two dewatering wells.

Several fractures, mostly horizontal, on the footwall had a slight seepage, and water was dripping from one of the horizontal drains during the site visit. Most of the observed seepage was located in the western sector of the unbackfilled pit. However, the western section of the pit was observed more carefully than the central and eastern sectors of the pit, and, therefore, some seepage occurring in the eastern portion of the mine pit could have been missed. The eastern sector of the pit was not inspected in detail because of the ongoing backfilling operation.

The Flambeau River is located approximately 140 feet from the west end of the pit. Although a slurry wall has been installed along the west extremity of the pit through the unconsolidated sediments and into the bedrock, it would be expected that in the western sector of the pit a higher rate of seepage should occur due to the high hydraulic gradient between the river and the pit and also because of generally higher permeability of the ore zone than the permeability of the waste rock.

Backfilling Operation - At the time of the site visit, the bottom half of the pit (about 100 feet) had been already backfilled with Type II fill. This fill consists of waste rock generally with sulfur content higher than 1%. The backfill above the Type II fill will be Type I fill consisting of waste rock without acid generating potential, saprolite, sandstone, and glacial materials.

The backfilling operation is very impressive by its organization, equipment utilization, and close supervision. However, it would be difficult to achieve the same degree of compaction of the backfill near the pit walls as in the central portion of the pit. It is anticipated that a narrow zone of slightly higher permeability, in comparison with the rest of the backfilled area, will develop in the backfill along the pit walls.

Hydraulic conductivity testing on the compacted backfill in the Flambeau pit was conducted by C.H. Benson and T. H. Hill from the Department of Civil and Environmental

Engineering at the University of Wisconsin. One sealed double-ring infiltrometer test and seven two-stage borehole tests were conducted in April, 1997.

Based on the test results, the following hydraulic conductivities of the backfill as-placed in the pit, are considered as representative of the andalusite biotite schist backfill (Benson and Hill, 1997):

- andalusite biotite schist (vertical): 5×10^{-6} cm/sec
- andalusite biotite schist (horizontal): 2×10^{-5} cm/sec

and for sericite schist backfill:

- sericite schist (vertical): 1×10^{-4} cm/sec
- sericite schist (horizontal): 1×10^{-2} cm/sec

The presence of the andalusite biotite schist is prevalent in the backfill, and therefore, the overall permeability of the backfill will be in the range of 10^{-5} to 10^{-6} cm/sec.

3.0 SITE HYDROGEOLOGIC CHARACTERISTICS

The Flambeau ore deposit is composed of Precambrian metamorphosed volcanics (mostly schists), Cambrian sandstone, and glacial sediments. All three of these formations are water-bearing. The sandstone strata of the Mt. Simon Formation is 20 to 30 feet thick. Ground water flow direction in the pre-mining conditions followed the local topography and the water flowed from southeast toward northwest, with discharge occurring into the Flambeau River.

The Flambeau deposit is structurally and stratigraphically within a thick felsic unit. It is a steeply dipping (75 to 80 degrees NW), sheared, and recrystallized conformable layered sulfide sheet enveloped by a semiconformable disseminated sulfide halo. Host rocks are a quartz-sericite schist unit, and the massive sulfide mineralization dominates the upper 600 feet of the deposit. The center of the deposit has been regionally deformed by isoclinal folding and shearing, and is moderately to strongly metamorphosed (DeMatties, 1994). Regional structural trends are northeast or east-northeast.

The hydrogeological investigation of the Flambeau deposit has been conducted in several phases. The first phase of the investigation was conducted between 1970 and 1976 for the Environmental Impact Statement (EIS) and mine permitting. It consisted of the installation and testing of 42 monitoring wells and piezometers.

The second phase of hydrogeologic investigation was conducted in years 1987 through 1989. In this phase of investigation a total of 50 monitoring wells and piezometers were installed and tested for permeability. Numerous pumping tests were performed in wells installed in the glacial till and fluvial sediments (Foth & Van Dyke, 1989). The average values of hydraulic conductivities for the three main water-bearing strata obtained from pumping tests and bailing tests were as follows:

- Precambrian bedrock - Hydraulic conductivity (pumping tests & recovery): $9.1x10^{-4}$ cm/sec. In the MODFLOW model (Prickett, 1996) hydraulic conductivity of 9×10^{-6} cm/sec and 1.5×10^{-4} cm/sec were used for the country bedrock and the orebody respectively).
- Cambrian sandstone strata - Hydraulic conductivity (bailing test only): $1.0x10^{-3}$ cm/sec;
- Glacial till - Hydraulic conductivity $3.6x10^{-4}$ cm/sec.

The first computer modeling of the Flambeau deposit ground water flow was completed by King (1983). The subsequent modeling efforts by Prickett and Associates were completed in 1989 and in 1996. In the latest modeling effort the finite-difference ground water model "MODFLOW" has been used. The model consisted of three layers (glacial till, sandstone, and bedrock) and cells 50x100 feet within the pit western sector of the area.

The model included a recharge rate of 0 to 8.5 inches/year, and an evapotranspiration of 22 inches/year to a depth of 3.5 feet. General head boundaries were assumed at the edges of the modeled area. The model was calibrated under transient conditions using monitoring well water levels and pit inflow data collected in the process of mine operation between 1989 and April 1995.

Pit inflows were estimated to range between 180 and 310 gpm, and the zone of influence predicted by the model ranged from approximately 600 feet (west of the pit) to 800 feet (south and east of the pit) and to 1,000 feet (north of the pit). The maximum predicted drawdown in the western section of the pit was at 175 feet. The model also predicted that the maximum drawdowns away from the mine will occur in about 10 years after the completion of mining, and that it will take about 30 years to completely resaturate the backfilled spoils.

It seems that the model overpredicted the drawdowns. The prediction of an eliptic cone of depression around the pit with an elongated axis toward north, northeast, may not conform with reality, because the model assumed an isotropic permeability of the bedrock. The available description of regional geology, and the available mapping of the bedrock fracture, foliation, and faults systems indicate a well pronounced directional permeability in the Precambrian bedrock.. The existence of well-developed foliation and joint systems in the bedrock would significantly impact the direction of ground water flow, during the post-mining period. The following discussion supports the above conclusion on the existence of directional permeability in the pit area.

The description of regional geological features, as presented in Sims (1977), DeMatties (1994), and Mudrey at al, (1982) indicate a well pronounced orientation of regional structures in a direction from northeast to southwest (Figure 1).

Geotechnical mapping in the pit area completed in several phases during the pit operation, mostly as studies for the design of stable pit slopes, also indicated the presence of well defined orientation of foliation and major joint systems. Attached with this report is a "Lower Hemisphere Schmidt Plot" (Figure 2) from a geotechnical study that was performed at Flambeau Mine, for slope stability in 1988 (Call and Nicholas, Inc.) and was based on the oriented core. This plot indicates a strong strike primary orientation in a northeast-southwest direction with a lump direction to the southeast for foliation. There is a prevalent orientation of joints in a northeast-southwest direction, with a plunge direction to the northwest confirming the regional trends. The majority of foliation orientations are found in Set 1, (Figure 2) and everything else can be representative of joints. The enclosed Table 1 is from a redesign of the Phase I hangingwall in 1996 (Call & Nicholas Inc.) This information, on Flambeau Joint Set Statistics obtained from cell mapping on the pit surface by R. Yost, represents statistics for each geologic set. The highest probability of occurrence (71.4%) is for joint set 5 with strike orientation northeast-southwest.

The best available information on the orientation of foliation, major joints systems and faults is presented on a recently completed map "Final Pit Wall Geology, Flambeau Mine,

TABLE 1
FLAMBEAU JOINT SET STATISTICS

Joint Set	Number	Dip (deg)		Dip Direction (deg)		Maximum Length (ft)	Mean Length (ft)	Spacing (ft)	Probably of Occurrence (%)
		Mean	S.D.	Mean	S.D.				
1	14	75.0	11.1	67.6	13.2	9.0	6.2	5.0	42.9
2	12	73.0	11.5	117.9	18.7	9.1	7.2	3.9	39.3
3	16	70.6	10.4	189.7	17.6	6.2	4.2	3.9	53.6
4	4	29.3	12.4	60.0	16.8	10.8	7.9	4.9	14.3
5	26	31.1	11.7	127.5	24.6	15.8	14.0	3.0	71.4
6	16	27.0	10.7	191.7	8.8	12.7	7.9	3.1	50.0
7	8	74.9	7.5	27.4	11.5	10.6	6.8	3.6	28.6
8	11	70.6	11.0	292.6	26.8	8.5	6.0	4.3	39.3
9	9	74.2	12.1	238.1	11.5	10.6	8.3	4.4	32.1
10	4	30.5	11.7	6.0	12.0	15.9	10.2	2.1	14.3
11	13	22.8	12.5	279.9	36.6	15.3	15.2	3.0	39.3

Reference: Flambeau Slope Design Update
North Wall - Phase 1.
April, 1996, Call & Nicholas, Inc.

Ladysmith, Wisconsin", May 29, 1997, completed by Raymond Yost. This map (Figure 3) contains numerous measurements of orientation (strike) and dip of faults, formations contacts, joints, and foliations in the ore zone, hangingwall, and footwall.

A statistical analysis of the orientation of joints, faults, and foliation, shown on the referenced map, was performed by Hydro-Geo. Results are presented in the following Table 2:

TABLE 2
FLAMBEAU OPEN PIT STRUCTURAL CHARACTERISTICS

Mapped Area	Joint Orientations		Fault Orientations		Foliation Orientation	
	Major %	Secondary %	Major %	Secondary %	Major %	Secondary %
FOOTWALL	245-271° 47% (ENE-WSW- to E-W)	129-133° 13% (NW-SE)	260-271° 33% (E-W)	181-195° 25% (N-S to NNE-SSW) 245-256° 25% (ENE-WSW)	217-235° 82% (NE-SW)	215-217° 11% (NE-SW)
HANGINGWALL	026-075° 55% (NE-SW)	348-352° 10% (N-S to NNW-SSE)	335-355° 50% (NNW-SSE to N-S) 145-155° 50% (NW-SE to NNW-SSE)	092-110° 25% (WNW-ESE to E-W)	225-250° 76% (NE-SW to ENE-WSW)	216-217° 8% (NE-SW)
ORE ZONE	030-050° 23% (NE-SW)	146-152° 18% (SSE-NNW to NW-SE)	222-260° 23% (ENE-WSW to NE-SW)	165-175° 14% (N-S)	217-235° 69% (NE-SW)	214-217° 16% (NE-SW)

NOTE: Major and secondary orientation of the strike is presented in degrees (and geographic orientation), with an indication of how may percent of the mapped joints, and faults, and foliations are oriented in the indicated range of degrees.

The statistical data presented in Tables 1 and 2 strongly support the opinion on the prevalent orientation of joints, faults, and foliation in northeast-southwest direction and that ground water flow in the Precambrian bedrock within the footwall, hangingwall, and ore zone, will be influenced by the orientation of major joint, foliation, and fault systems. As result, it is believed that a strong directional permeability along the orientation of the open pit, from east to west, and from northeast to southwest will govern the ground water flow direction in the Precabrian bedrock. In addition to the natural (pre-mining) orientation of directional permeability, ground water flow near the backfilled pit walls will be impacted by the blasting-enhanced permeability within a narrow zone along the pit walls, and by slightly less compacted backfill along the pit walls. Direction of this "man-enhanced "permeability will be similar to the natural directional permeability in the Precambrian bedrock.

Observations on the character of seepage from the ore zone, hangingwall, and footwall during the mining operation (Forth, 1993, 1994, and 1995), lends support to the conclusions on the directional ground water flow based on the geologic mapping. J. Forth (1994) observed that most of the seepage in the ore zone is impacted by the anisotropy of the schist formations, and that most of the seepage occurs in the east-west direction, with only limited seepage in the north-south direction. He also postulated that most of the flow is through discrete vertically separated paths which have no north - south continuity. It is believed that similar trends as observed within the pit area, could be extrapolated out of the pit area. Regional structural trends support this conclusion.

Modeling of fracture flow in the bedrock can be approached in two basic ways: discrete fracture model, which describes laminar flow in a fracture of known geometry; or a continuum model, which assumes a fracture network can be replaced by a representative continuum in which spatially defined hydraulic values can be assigned. and the fracture network behaves as if it were a porous media. Because of many problems associated with the discrete fracture model on a such large scale as is the Flambeau Mine, it is appropriate that the porous medium approach (as has been done with the MODFLOW model) be used, however, a more accurate definition of the directional permeability and the existence of the zone of higher permeability enveloping the pit walls could be included in the existing model. An initial minimal ratio of approximately 10:1 for E-W to NE-SW: N-S to NW-SE directional permeability is suggested, based on the observations in the pit during the site visit. Sensitivity analyses, performed during the modeling effort, could be used to verify the directional permeability that maybe slightly higher or lower than 10:1.

De Josselin de Jong and Way, (1972) developed equations that use probability theory to relate the dispersion of particles to fracture characteristics, hydraulic gradient, and directional hydraulic conductivity. This model assumes a pore canal system for the fracture network in which a certain particle will choose a certain path, taking into account the anisotropic nature of the media. Some of these studies could be applied to the proposed modeling of the post-mining ground water flow in the Flambeau Mine area.

Ground water flow through the backfilled pit will be greatly reduced by the low permeability of the partially weathered and well compacted (80 to 100% compaction and wet density mostly in a range of 125 to 165 pcf) spoils, and by the presence of a zone with higher permeability along the pit walls, both within the backfill and in the bedrock.

4.0 CONCLUSIONS AND RECOMMENDATIONS

Results of geological mapping within the Flambeau pit area, the available regional geological structure reviews, and the observations of seepage in the mine indicate that anisotropy exists in the Precambrian bedrock. This anisotropy is significantly impacting the direction of ground water flow, both during and after the completion of the mining and backfilling operations. To improve the knowledge of post-mining ground water flow patterns in the area of the backfilled pit, the following actions could be taken:

- Repeat the transient ground water flow modeling with an addition of directional permeability within the Precambrian bedrock. It will be necessary to recalibrate the model with the addition of new parameters. An initial ratio of E-W (NE-SW) N-S (NW-SE) permeability at minimum 10:1 is likely;
- The computer model should include a zone of higher permeability enveloping the pit walls, both in the backfill and in the bedrock. In our estimate the permeability of this zone could be one order of magnitude higher than permeability of the surrounding backfill and bedrock. This could be verified by the sensitivity analyses performed during the modeling effort, and also by testing several piezometers installed in various depths of the backfilled pit. Some of the piezometers could also be installed in the predicted zone of higher permeability along the pit walls, both in the backfill, and in the bedrock. The purpose of this installation of piezometers and testing would be to verify the presence of the zone of higher permeability along the pit walls.

* * * * *

We hope that this brief Technical Memorandum will satisfy your needs. Please let us know if you would like to expand on some parts of this document.

* * * * *

August 12, 1997

Hydro-Geo Consultants, Inc.

Vladimir Straskraba
Principal Hydrogeologist

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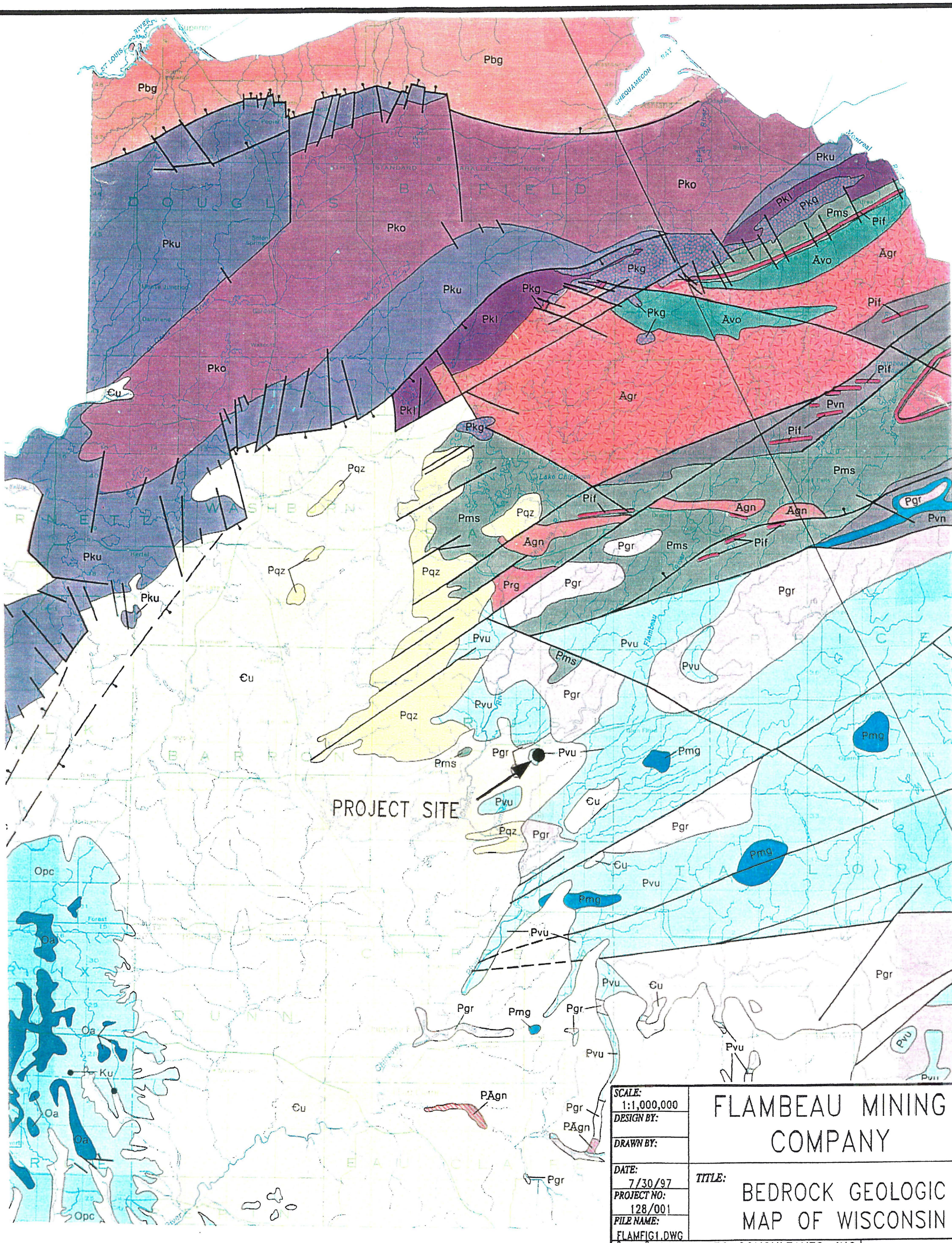
FIGURES



SCALE: 1:1,000,000
DESIGN BY:
DRAWN BY:
DATE: 7/30/97
PROJECT NO: 128/001
FILE NAME: FLAMFIG1.DWG

FLAMBEAU MINING COMPANY

TITLE: BEDROCK GEOLOGIC MAP OF WISCONSIN

HYDRO-GEO CONSULTANTS, INC.
165 S. UNION BLVD., STE. 400
LAKEWOOD, CO 80228

SHEET: 1 OF: 1

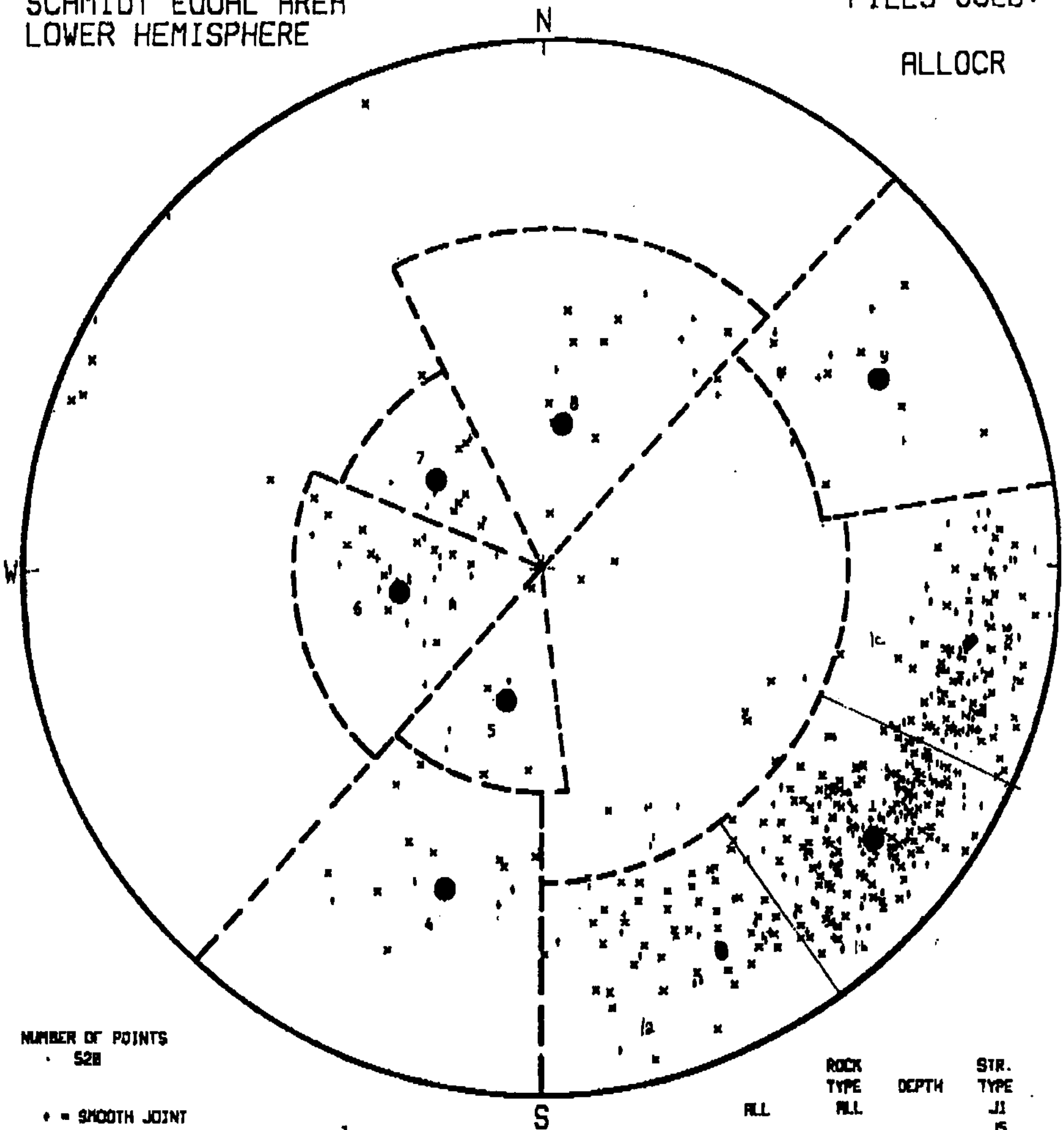
FIGURE 1

Reference: Mudrey, M.G., B.A. Brown, and J.K. Greenberg, 1982. University of Wisconsin-Extension.

SCHMIDT EQUAL AREA
LOWER HEMISPHERE

FILES USED:

ALLOCR



NUMBER OF POINTS
528

ROCK TYPE	DEPTH	STR. TYPE
ALL ALL		J1 J5

♦ = SMOOTH JOINT
✱ = ROUGH JOINT

1 ● - mean vector for geologic set #1

Set # 1 is foliation; Set #6 and possibly set # 7 are cross joints.

SCALE: No scale	FLAMBEAU MINING COMPANY
DESIGN BY:	
DRAWN BY:	
DATE: 7/30/97	TITLE:
PROJECT NO: 128/001	FLAMBEAU GEOLOGIC SETS
FILE NAME: FLAMFIG2.DWG	
HYDRO-GEO CONSULTANTS, INC. 165 S. UNION BLVD., STE. 400 LAKEWOOD, CO 80228	SHEET: 1 OF: 1 FIGURE 2

Reference: Call & Nicholos, 1988 from R. Yost, 1997

LEGEND

Rock Types

Footwall

- 11 – meta tuff
- 12 – quartz augen schist
- 13 – meta dacite
- 14 – chlorite/phyllite
- 15 – biotite schist

Ore Zone

- 20 – quartz sericite schist
- 30 – meta chert
- 40 – massive sulfide

Hangingwall

- 51 – quartz augen schist
- 52 – andalusite biotite schist
- 53/54 – meta dacite / chlorite/phyllite
- 56 – sericite clay schist

Other

- 60 – sandstone
- 70 – glacial till
- 90 – gossan

Structural Symbols

—	fault – located +/– 2'
---	fault – located +/– 5'
—	geologic contact – located +/– 2'
---	geologic contact – located +/– 5'
224/67	strike and dip of contact
276/78	strike and dip of fault
207/71	foliation strike and dip
104/32	major joint set strike and dip

FINAL PIT WALL GEOLOGY FLAMBEAU MINE LADYSMITH, WISCONSIN	mapping by Raymond Yost Aug. 1995 through Apr. 1997
	compilation and drafting by Raymond Yost Mar. 1997 through May 1997
	c:\ray\acad\final.dwg 5/29/97

prepared for Flambeau Mining Company May 29, 1997

Appendix B

Technical Memorandum on Backfill Hydraulic Conductivity

Foth & Van Dyke

Test Pad In situ Testing

Hydraulic conductivity tests were conducted as part of the compaction test pad work performed in June 1996. The tests were conducted to determine the horizontal and vertical hydraulic conductivities of the Type II wasterock in the testpad. Three sealed double-ring infiltrometer tests and 31 two-stage borehole tests were conducted. Based on the results, the geometric mean hydraulic conductivities of the weathered Type II wasterock were found to be:

* $K_{vertical} = 9x10^{-6}$ cm/sec
* $K_{horizontal} = 7x10^{-6}$ cm/sec

and fresh Type II wasterock:

* $K_{vertical} = 5x10^{-4}$ cm/sec
* $K_{horizontal} = 3x10^{-3}$ cm/sec

Pit In situ Testing

In situ hydraulic conductivity tests were performed in the pit on compacted, backfilled Type II material between April 17, 1997 and April 20, 1997. One sealed double-ring infiltrometer test and seven two-stage borehole tests were conducted. Based on the test results, the following hydraulic conductivities are representative of the backfill for biotite schist (weathered wasterock):

* $K_{vertical} = 5x10^{-6}$ cm/sec
* $K_{horizontal} = 2x10^{-5}$ cm/sec

and for sericite schist (less weathered wasterock):

* $K_{vertical} = 1x10^{-4}$ cm/sec
* $K_{horizontal} = 1x10^{-2}$ cm/sec

Conclusion

Based on the results of the field hydraulic conductivity tests, and the fact that most of the Type II wasterock (approximately 90%) was weathered, a reasonable conservative estimate of the Type II backfill hydraulic conductivity is approximately $1x10^{-5}$ cm/s, both horizontally and vertically.