FINAL REPORT

Minnesota Department of Natural Resources
Division of Lands and Minerals
Division of Waters

PROJECT SPONSORS
Cliffs-Erie Mining Company
Minnesota Power
City of Aurora
City of Hoyt Lakes
Minnesota Department of Natural Resources

FINAL REPORT

EAST RANGE
HYDROLOGY PROJECT

March, 2004

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Executive Summary

The East Range Hydrology Project was initiated in response to the need for a long-term watershed reclamation plan for the pits and tailing basin cells associated with Cliffs-Erie Mining Company (CE) (formerly LTV Steel Mining Company) mining property near Hoyt Lakes. Hydrologic changes to Colby Lake, Whitewater Reservoir, and St. James Pit were also included as part of the project.

Four recently abandoned CE pits were analyzed to determine time to fill, static water level elevation, and discharge characteristics. Three tailing basin cells were studied to determine static water level elevation with respect to dam safety requirements. Reclamation needs were assessed for both pits and tailing basin cells as they related to requirements in the permit to mine. Colby Lake and Whitewater Reservoir were analyzed concurrently to determine water level changes associated with various management options for the Diversion Works. The goal in analyzing St. James Pit was to predict static water levels for recommendations in pump placement. Important findings for each water body are summarized below.

Prediction of discharge quantities for pits 2E, 2W, 2WX, and 6 had two objectives: 1) to provide outlet structure design criteria and a flow conveyance system, and 2) to project downstream impacts. Pits 5N, 5S, 9, and 9S reached their static water levels prior to the project and were therefore not studied. No outlet channel construction is anticipated for these pits.

Pit 2E is predicted to fill in 16 to 18 years and have an open water area of 192 acres at its outflow elevation of 1535 ft-msl. Average pit discharge is predicted to be 0.3 cfs, while maximum discharge is predicted to reach 8.2 cfs. Pit 2E is not expected to need an outflow channel, as pit water should freely pass through existing road and railroad rock fill to Pit 2W. If this does not occur, and the road/railroad is threatened, an appropriately-sized culvert should be installed.

It is estimated Pit 2W will outflow in 11½ to 16½ years at elevation 1488 ft-msl where it will have an open water area of 287 acres. Average discharge is predicted to be approximately 2.0 cfs while maximum discharge could exceed 9.0 cfs. Although flows will be very low at times, the pit should not reach zero discharge. To carry runoff to an existing railroad ditch that drains to Second Creek, Pit 2W will need an outlet channel at an approximate elevation of 1488 ft-msl that is several hundred feet long. Spot improvements to the ditch will be necessary to remove constrictions.

Pit 2WX is predicted to outflow in 10½ to 14½ years. Once outflow begins, average discharge should be approximately 1.5 cfs while maximum discharge could exceed 12 cfs. Because of the large dependence on direct precipitation and storm runoff, there will also be times when flow from this pit will cease.

Outflow from Pit 2WX will follow an existing, remnant channel that flows to Colby Lake. Coarse rock fill and culverts associated with two crossings must be removed to at least the original channel dimensions to provide unimpeded outflow.

Pit 6 is predicted to outflow in 5½ to 6 years. Once pit water begins to outflow, average discharge should be about 3.9 cfs while maximum discharge should range between 9.7 cfs and 18.8 cfs. Although outflow will be very low at times, it should not reach zero discharge due to the strong influence of ground water inflow. Pit 6 will need an outlet channel located at the east-central side of the pit, along the north side of an existing road that runs approximately 600 feet due east, through a wetland to Second Creek. It is recommended the pit runout elevation be no more than 2.5 feet higher than the elevation of the bed of Second Creek where the channel enters the creek. This should result in an 800 foot-long channel.

Outlet channels for Pits 2W, 2WX, and 6 can all be constructed to the following configuration:

Bottom width = 5 ft
Side slopes = 3:1 (H:V)
Maximum channel gradient = of 0.003 ft./ft.

Pit outlet channels with the above configurations will have maximum storm runoff velocities of about 2.0 feet/second, minimizing potential erosion problems. Steeper channel gradients can be used provided it is demonstrated channel erosion will not be a problem. Outlet channels can be surveyed, designed, and constructed as soon as practical, however, they should be promptly vegetated with grasses to control side slope erosion and discourage establishment of woody vegetation in channel bottoms.

To control outflow from Pit 1 it is required the roads/railroad, overlying the seepage, be excavated to approximately elevation 1548 ft-msl, for a minimum width of 25 feet. This would provide an overflow channel in the event the rock fill becomes plugged with debris. It is also recommended that a 10-foot wide channel be constructed diagonally through the gravel road that is currently flooded with outflowing water from Pit 1. The cutoff ditch would be constructed from WNW to ESE, near the top of the gravel road, and designed to collect the majority of outflow and carry it to the east side of the road. Large rock should be placed along both sides of the channel to prevent motorized traffic from crossing.

Operational options for the Diversion Works structure provided a basis for predicting water level impacts on Colby Lake and Whitewater Reservoir. The two extremes of operation were *gate-closed*, thereby allowing no water to flow from Colby Lake to Whitewater Reservoir, and *gate-open 4.0 feet*, allowing a continuous flow of water from Colby Lake to Whitewater Reservoir. Under the *gate-closed* option Whitewater Reservoir water levels will stabilize between 1432 ft-msl and 1434 ft-msl, about five to seven feet below the normal pool elevation of 1439 ft.-msl. The *gate-open* option maintains water levels in Whitewater Reservoir between 1438 ft-msl and 1442 ft-msl. Between these extremes were three other management options: 1) placing a weir at the Diversion Works with a fixed crest at elevation 1439.8 ft-msl, 2) opening the gate 0.1-feet, and 3) opening the gate only when Colby Lake exceeded a water level of 1439.25 ft-msl. Water levels below 1439 ft-msl violate provisions of Minnesota Power's water appropriation permit. The elevations noted in options 1 and 3 were selected in an attempt to achieve compliance with the permit. For Colby Lake, water levels drop below 1439 ft-msl even under the *gate-closed* option but do not drop below the runout elevation of 1438.5 ft-msl. Since the *gate-closed* option is the most favorable for Colby Lake water levels it follows that any other management option evaluated for this project will result in water levels below 1439 ft-msl a greater percentage of time. During the *gate-open 4.0-feet* simulation, low water levels are consistently below the *gate-closed* simulation and drop below runout several times. High water levels are not affected by gate management options.

In an effort to increase water input to Colby Lake, diverting water from Second Creek into the lake was simulated. Second Creek would be diverted into Knox Pit then into Pit 2WX which would outflow into Unnamed Creek, and empty into Colby Lake just upstream of its outlet. For modeling purposes, it was assumed only 75% of Second Creek flow was diverted. This amount was added to flow from Pits 2E and 2W which will eventually contribute flow to Second Creek. Modeling results indicate this diversion did not appreciably raise Colby Lake water levels.

Tailing Basin Cell 2W did not hold any ponded water at the project's conclusion. Lack of a surface water body precluded the use of modeling techniques applied to the other two cells. Modeled water levels for tailing basin Cell 1E ranged between 1649 ft-msl and 1652 ft-msl. The result is that predicted water levels will remain at least seven feet below the dam safety threshold of 1659.5 ft-msl. Cell 2E predicted water levels ranged from 1557.8 ft-msl to 1560 ft-msl, the maximum level allowed by dam safety.

On Cell 2W, it was postulated that infiltrating water followed a circuitous route to the outside of the dike, contributing to the many seeps around the cell's base, but not reaching the cell's water table. Even the lowest infiltration rates, measured at the cell's surface, indicate water moves quite readily into tailing. Therefore, some water may temporarily accumulate on the basin every year after major storms, but will rapidly infiltrate. In addition, infiltration will increase with time as the basin becomes more vegetated and dead vegetation forms an organic layer. For these reasons, no outlet control structure is deemed necessary, and no dam safety permit is required for this cell. However, the concrete standpipe structure extending from Cell 2W to Cell 1E is a public safety problem. It is required that

Cliffs-Erie address this problem in their final closure plan. It is recommended that consideration be given to filling both ends with porous material, such as coarse tailing or crushed rock.

Several reclamation options exist for Cells 1E and 2E, depending on long-term DNR Dam Safety permit requirements and CE's management objectives. According to state regulations, CE must retain a Dam Safety permit for the cells if the dam is greater than six feet high at maximum storage capacity or contains more than 15 acre-feet of water. To eliminate the need for a Dam Safety Permit, outlet channels would have to be constructed at elevations that reduce the volume of water in each cell to less than 15 acre-feet. Two reclamation options exist whereby the owner of the dam would retain the Dam Safety permit. One option is to leave the dikes as they are and retain the Dam Safety permit. This would require continued monitoring, safety inspections, and associated costs and fees, paid by the owner of the structure. A second option involves retaining the Dam Safety permit, but constructing emergency spillways so that the permit can be re-written as a Class III, Low Hazard, No Outflow permit. The DNR does not require monitoring or an inspection fee for this class of dam, although provisions of the permit are subject to change if future hydrologic conditions warrant. An emergency spillway would need to be constructed in the dike between Cell 1E and 2E. Normal mineland reclamation standards for vegetation establishment would apply elsewhere.

Aurora's pump house is located along the south shore of St. James Pit, with a floor elevation of 1442.8 ft-msl. Water levels recorded during the project ranged from approximately 1439 ft-msl to 1441 ft-msl. The pit is presently gaining more water than it is losing, prompting the city to periodically discharge water at 400 gpm in order to protect their pump house from flooding. Modeled predictions suggest maximum future water level of St. James Pit, without water level control pumping, would be about elevation 1445 ft-msl, more than two feet above the pump house floor. To eliminate the need to discharge excess water from the pit, the pump house should be moved to a higher elevation. However, given uncertainty associated with the ground water component of the pit's water balance analysis, it is recommended the city use the 1445 ft-msl estimate with caution.

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Acknowledgements

This paper is dedicated to the late Dave Ford (1950 – 2003) of the Division of Waters' Hydrographics Unit for his creation of, and assistance with WATBUD modeling. Dave's assistance with adapting WATBUD to mine pit and tailing basin hydrology, and interpreting the results, was invaluable.

The authors of this report gratefully acknowledge the many people who contributed to this project.

Cliffs-Erie Mining Company, Minnesota Power, the cities of Aurora and Hoyt Lakes, and the Minnesota Department of Natural Resources provided funding.

Technical assistance came from a great number of sources including Greg Kruse, Carl Rundberg, and Lisa Bendtsen from the Division of Waters' Stream Hydrology Unit; Division of Lands and Minerals' Hibbing office staff, especially Matt Oberhelman, Tim Pastika, Dan Steinbrink, and Al Klaysmat; Evan Drivas from the Division of Waters' Ground Water Technical Analysis Unit; Dana Gauthier from the Division of Waters' Dam Safety Unit; Division of Waters' Ground Water Level Monitoring Program; Division of Lands and Mineral's Surveying Unit; Greg Spoden, Jim Zandlo, and Peter Boulay from the State Climatology Office; Joseph Maki, formerly of the Minnesota Department of Natural Resources; and Minnesota Power's Laskin Energy Center Staff.

Data was provided by Cliffs-Erie Mining Company, Minnesota Power's Laskin Energy Center, and the cities of Hoyt Lakes and Aurora. Data and technical assistance was provided by Northeast Technical Service (NTS) of Virginia, MN.

Special appreciation goes to Jim Solstad from the Division of Waters' Hydrographics Unit for his expertise in HEC-RAS modeling.

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I. INTRODUCTION/BACKGROUND

The East Range Hydrology Project (ERHP) was initiated after the closure of LTV Steel Mining Company (LTV) on May 24, 2000. Varied interests in understanding hydrologic consequences of mine closure, and the need to develop a long-term watershed reclamation plan for the land affected by mining defined the project area (Figure 1). Subsequent to closure, Cliffs-Erie Mining Company (CE) purchased LTV and is now responsible for reclamation of the property. Minnesota Power subsequently purchased extensive riparian property around Colby Lake (69-0249) and Whitewater Reservoir (69-0376) from CE, including the Diversion Works that is used to control water movement between the two bodies of water. Stakeholders in the project included: the Minnesota Department of Natural Resources (DNR), responsible for regulating mineland reclamation; CE, responsible for developing and implementing a watershed reclamation plan; Minnesota Power (MP), who operates the Laskin Energy Center on Colby Lake and is interested in knowing how watershed reclamation of the mineland will affect their operation; and the cities of Aurora and Hoyt Lakes, who own adjacent property that could be affected by watershed reclamation of the mineland. Data collection began in fall, 2001.

The DNR regulates mineland reclamation through the Mineland Reclamation Rules (Chapter 6130), and the Public Water Resources and Water Appropriations Rules (Chapter 6115). These rules reflect the intent of Minnesota Statute, Chapter 103G.297, Diversion or Drainage of Water for Mining, and Chapters 93.44 to 93.50, Policy for Mineral Development, which authorize the Commissioner to prescribe permit conditions necessary for restoring watersheds to the extent practical.

The purpose of the ERHP was to collect data and make reliable predictions of future hydrologic conditions that could serve the needs and interests of affected parties. The study was funded by financial and in-kind contributions from the five stakeholders.

Major objectives of the study included making predictions of the:

1) Ultimate static water level of each abandoned pit,
2) Time it will take each pit to reach its static water level,
3) Location of pit outflow and identification of receiving water,
4) Pit outflow hydrographs,
5) Effects of pit outflow on Colby Lake water levels,
6) Effects of Diversion Works management options on Colby Lake and Whitewater Reservoir water levels,
7) Long-term, static water level of each of the three tailing basin cells, and how water level relates to dam safety requirements and,
8) Long-term, static water level of the St. James Pit.

The ERHP addresses ten mine pits that were created by LTV. Six of the pits (1, 3, 5N, 5S, 9 and 9S) have reached static water levels, and were not studied for

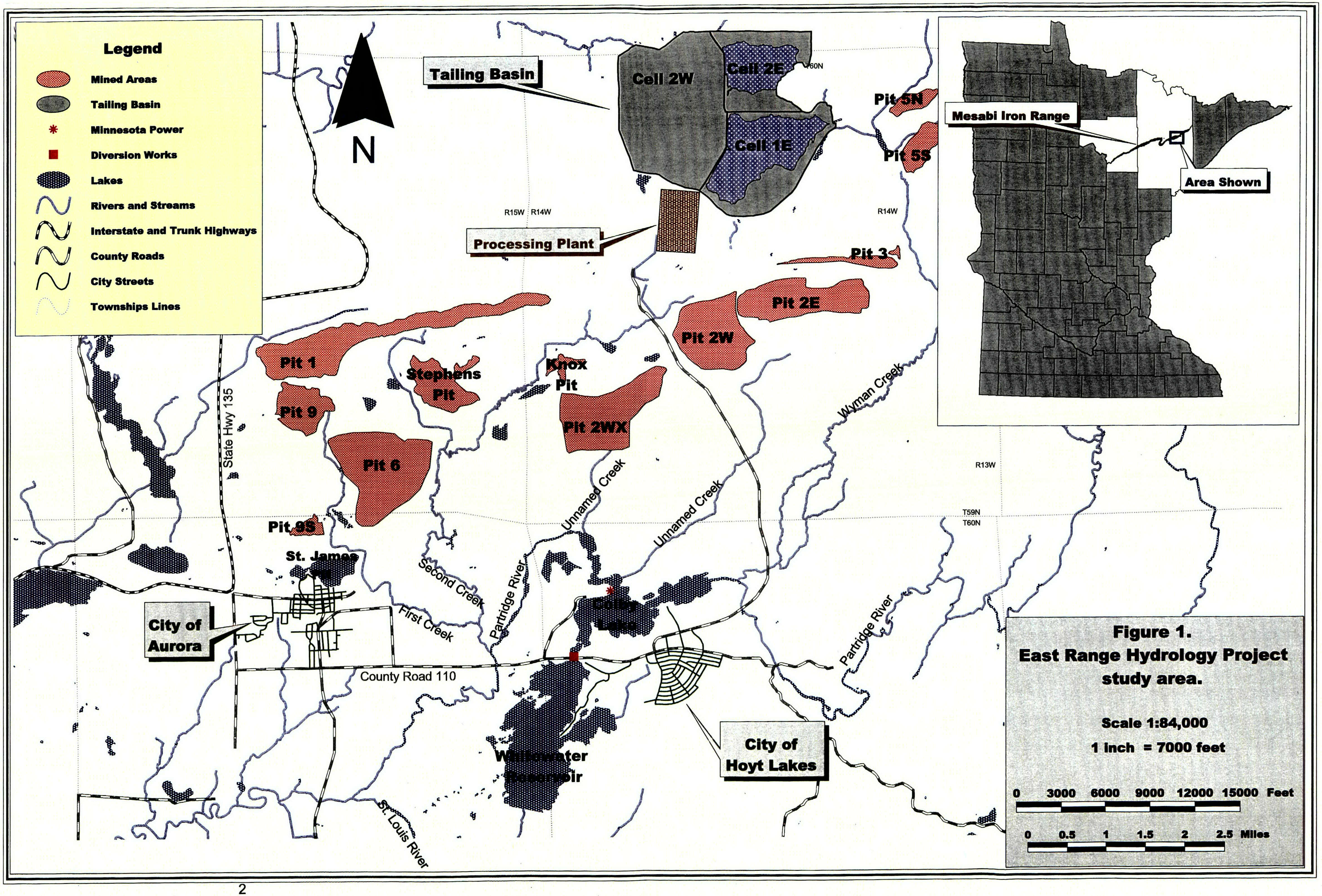


Figure 1.
East Range Hydrology Project study area.

hydrologic modeling purposes. Watershed reclamation recommendations for these pits are included in the report (Section V, page 95). The four remaining pits (2E, 2W, 2WX, and 6) were actively mined at the time of closure, are filling with water, and were studied to predict future hydrologic conditions. Pits 2E, 2W, and 2WX could have an effect on Colby Lake water levels and management of Whitewater Reservoir.

Colby Lake served as LTV's make-up water source. Several thousand gallons of water per minute were pumped from the lake on a continuous basis. Minnesota Department of Natural Resources Water Appropriation Permit 49-135 required LTV to maintain a minimum Colby Lake level of 1439.0 ft-msl (feet above mean sea level, NGVD 1929). In order to comply with this provision, LTV constructed Whitewater Reservoir and the Diversion Works. The Diversion Works contains three 8-foot gates that can be opened to release a large flow of water from Colby Lake to Whitewater Reservoir during high water levels. It also contains three high-volume pumps to move water back to Colby Lake during low water levels for compliance with the permit. After closure of the mine, MP purchased the Diversion Works and all of CE's riparian land around Colby Lake and Whitewater Reservoir, and had the appropriation permit transferred to them. As a result, MP was interested in knowing effects of various Diversion Works management options on Colby Lake and Whitewater Reservoir water levels. Water levels affect MP's Laskin plant operation and water quality permit requirements from the Minnesota Pollution Control Agency. Of further interest were long-term effects of outflow from Pit 2WX on Colby Lake, and potential effects of diverting flow from Second Creek to Colby Lake through Pit 2WX.

The CE tailing basin consists of three large cells, 2W, 1E and 2E. At the time of closure, each cell contained ponded water. Long-term, static water levels needed to be predicted to assess potential risks associated with dam safety, and evaluate wetland management opportunities.

St. James Pit has served as the city of Aurora's municipal water supply for many years. After cessation of mining in Pit 9S, located less than ½ mile north of St. James Pit, ground water inflow to the St. James Pit reportedly increased. Consequently, Aurora periodically pumped water from St. James Pit to prevent flooding of their pump house. The city was interested in knowing the long-term, static water level of the pit, without water level control pumping, so they may determine if moving their pump house is warranted.

Colby Lake serves as Hoyt Lake's municipal water supply. The intake pipe is deep enough that fluctuating water levels are not a concern to the city. Hoyt Lakes also discharges wastewater to Whitewater Reservoir and manages a public campground on the reservoir. Future reservoir water levels are a concern to the city.

II. SITE DESCRIPTION

Northeast Minnesota's Mesabi Iron Range is a 120-mile long, narrow belt of iron-rich ore know as the Biwabik Iron Formation (BIF). The Iron Range extends from Grand Rapids in Itasca County to Birch Lake on the eastern edge of St. Louis County. The thickness of the BIF in the project area varies from about 650 feet along the west side to about 435 feet along the east side (Graber 1993).

Natural iron ore mining began on the Iron Range in the late 1800's, and continued until reserves diminished in the late 1950's. Taconite mining began to replace natural ore mining, with Reserve Mining Company (now Northshore Mining Company) and Erie Mining Company (predecessor of LTV) initiating operations in 1955-1956. In the following ten years, six more taconite plants opened on the Iron Range. At peak production, the Iron Range produced nearly 75% of the total U.S. taconite production. Landscape of the Iron Range has been significantly altered by more than 100 years of open pit mining.

Cliffs-Erie property is located near the east-central part of the Iron Range, between and north of the towns of Aurora and Hoyt Lakes, in Townships 58 to 60 north, Ranges 14 and 15 west (Figure 1). It covers an area of nearly 65 square miles. Surface topography in the area originally included wetlands, forests, and gently rolling hills. Much of this area has been converted to mining features, including the tailing basin, mine pits, stockpiles of glacial till, waste rock and lean ore, and mine roads. Glacial drift is thickest in the western portion of the property where it may exceed 100 feet, but is generally very thin throughout the remainder of the property.

The tailing basin is located on the north side of the property and covers an area of approximately 3,033 acres. Cell 2W is the oldest, largest (1,447 acres), and highest (200 feet) of the three cells. Cell 1E is 970 acres and rises about 120 feet about ground; Cell 2E is about 616 acres and is the lowest cell, rising only about 30 feet above ground.

The mine pits are located generally along an east-west line, south of the tailing basin, and vary in size from 42 acres (Pit 9S) to 650 acres (Pit 6). The St. James Pit is located at the far southwest corner of the project area, immediately north of the city of Aurora. The pit has a water surface area of approximately 125 acres and a watershed of 360 acres.

Colby Lake and WWR are located along the south portion of the project area and straddle St. Louis County Highway 110. The Diversion Works is located on either side of the highway. Colby Lake has a surface area of 514 acres and a watershed of 81,771 acres. Partridge River flows through Colby Lake. Whitewater Reservoir has a water surface of 1196 acres at its normal pool elevation of 1439 ft-msl, and a watershed area of 3174 acres.

The entire project area is within the St. Louis River watershed, which is tributary to Lake Superior. The area receives about 28 inches of precipitation annually, of which about 5.5 inches falls as snow during the winter months. Average monthly temperature ranges from 8.3°F in January to 68.1°F in July.

III. GENERAL METHODOLOGY

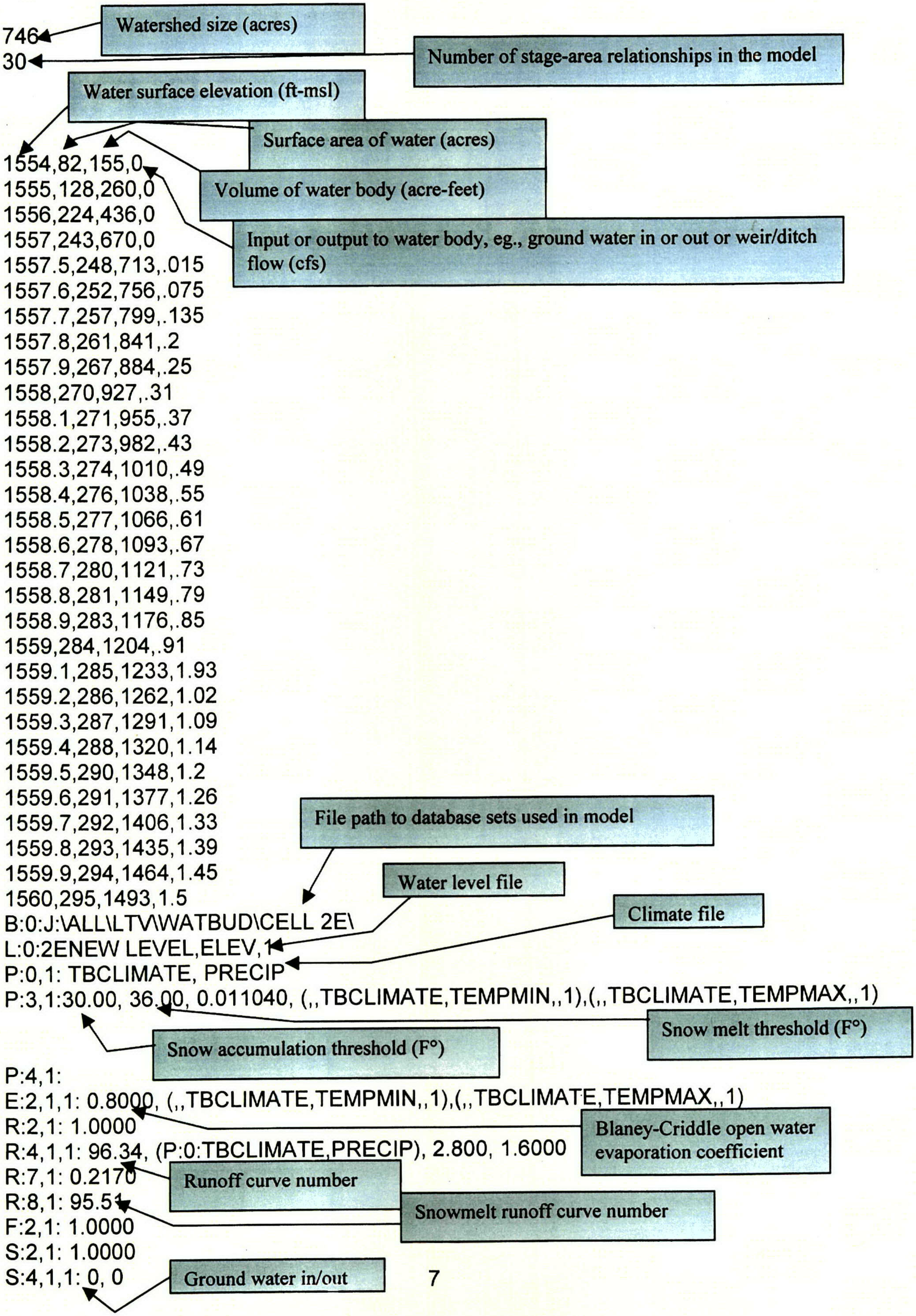
Modeling Procedure for Mine Pits

To accomplish project objectives, standard hydrologic study methods were applied. Appropriate historic data was supplemented with new data to calibrate a water balance model for each water body. The calibrated water balance model (WATBUD) was adjusted where necessary and used to estimate each pit's time to fill and outflow hydrograph. The Minnesota Department of Natural Resources, Waters Division, developed WATBUD in the 1980's. WATBUD is a physically based parameter model capable of optimizing and estimating selected water balance parameters by comparing simulated to known water level data. The Parameter File is the central mechanism driving WATBUD. Figure 2 shows a typical WATBUD Parameter File with its parts labeled.

Recorded pit water levels and local climate data were used to calibrate WATBUD. As predicted water levels rise, the calibrated model automatically adjusts for most changing water balance relationships, such as water surface area and volume, water evaporation, watershed area, and runoff to the pit. The calibrated model produces a "seepage constant", the model's best estimate of net ground water or the difference between ground water inflow and outflow. Although labeled as "net ground water", the seepage constant for recently-abandoned mine pits is normally all ground water inflow. Ground water inflow and outflow can change considerably as water levels rise, so the calibrated models needed adjustment for these relationships to make defensible predictions of future water levels. Ground water inflow can come from two sources, the BIF or glacial drift. The source(s) of ground water inflow must be identified so the proper reduction in ground water inflow can be made as the pit water level rises. As detailed in the Hydrologic Setting and Methods sections for each pit, it was concluded that ground water inflow, where present in substantial quantity, was predominantly from surficial sources. Ground water inflow from the BIF is likely present for each pit, but in negligible quantities. A sub model was therefore developed for each pit, where appropriate, to account for reducing ground water inflow with rising water level. It was also concluded that ground water outflow will not be part of any pit's water balance until the water level exceeds the lowest down-gradient water table elevation in the glacial drift. Ground water outflow through the BIF can occur only if the subject pit is hydraulically connected to an adjacent pit with a lower water level. After proper adjustments were made to each calibrated model, long-term climatic records were used as input to make predictions of the range of future pit water levels and outflow hydrograph.

Climatic data used for WATBUD calibration and predictions were acquired from the State Climatology web site, http://climate.umn.edu/ under the label "Allen Junction". Precipitation data for the Allen Junction site was collected by MP at their Laskin Power Plant on the west side of Colby Lake. On-site precipitation data was also collected for better calibration of WATBUD to tailing basin Cells 1E and 2E.

Figure 2. A typical WATBUD parameter file.



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Pit water levels were measured using a surveyor's level and temporary benchmarks tied to mean sea level elevation of known benchmarks, or satellite-acquired elevations of temporary benchmarks. Pit water levels were measured 27 times between 14 May 2001 and 14 May 2003. They were transferred to an Excel spread sheet and compared graphically as new data were collected.

Bathymetric relationships for each pit were developed using five-foot contour data produced from aerial photography flown in 2001 after closure of LTV. Watershed delineation utilized the same contour data. Watersheds were drawn on digital orthoquads (DOQs) with contour overlays, and then field checked for accuracy.

Pit Outlet Channel Criteria

Prediction of pit discharge quantities had two objectives: 1) provide criteria for outlet channel design, and 2) quantify downstream impacts. To address the first objective the following ditch configuration was included in each WATBUD model for the pits:

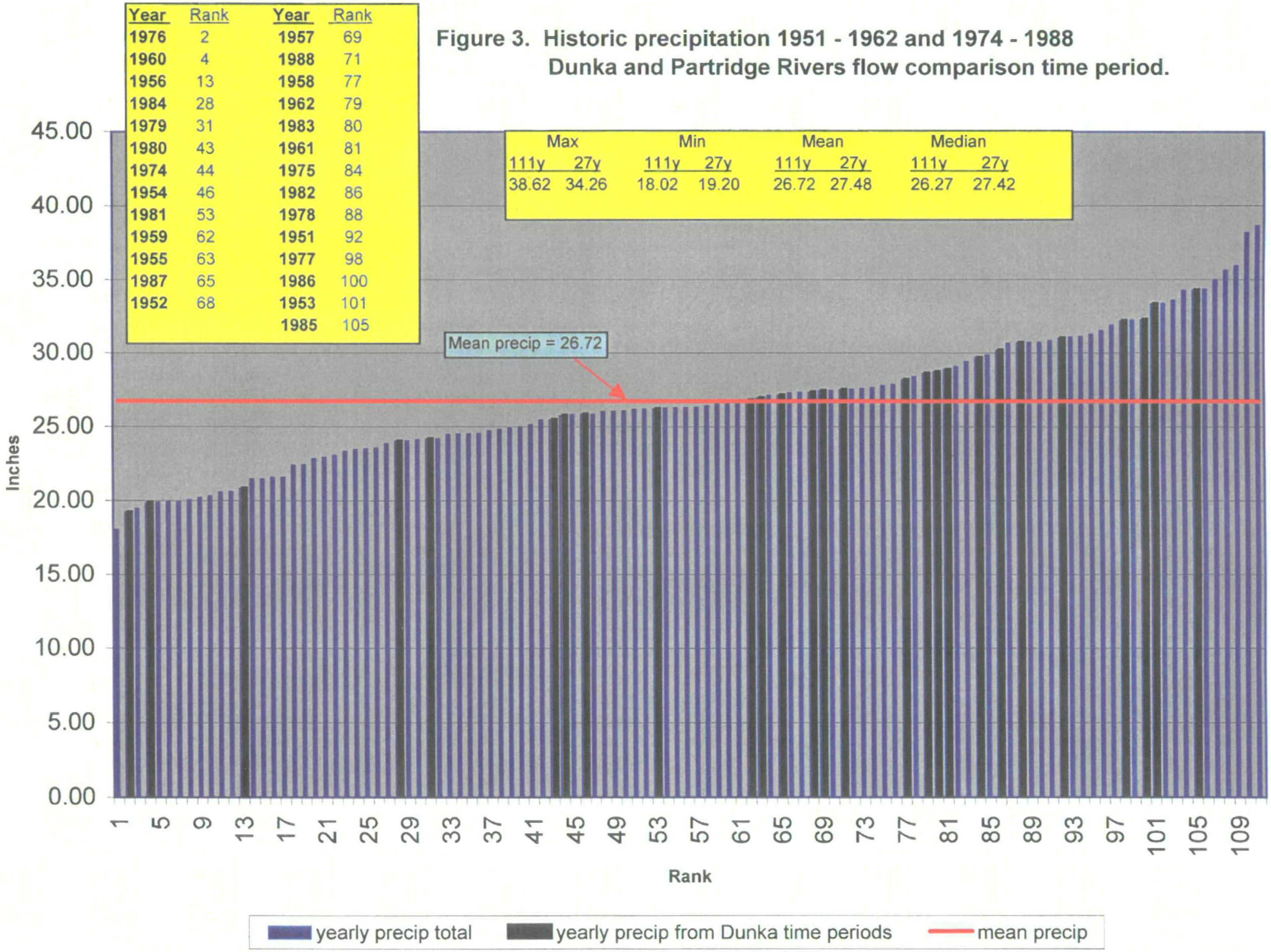
Channel slope = 0.003 ft/ft
Mannings' n roughness = 0.03
Channel bottom width = 5.0 ft.
Channel side slope = 3:1 (H:V)

Predicting discharge from the pits was accomplished using climatic data from October 1951 through September 1962, and February 1975 through November 1988. These two climatic periods were chosen since they coincide with the Dunka River flow data used to predict inflows to Colby Lake. These two time periods are subsequently referred to as the two "Dunka time periods". To test the normality of precipitation data during the Dunka time periods, yearly precipitation totals for a period of 111 years, starting in the year 1890, were graphed in ascending order (Figure 3). The 111 years of data are an historic sequence for the Hoyt Lakes area, produced using the Kriging Method. Some of the data were extrapolated from nearby stations (Spoden 2004). The Dunka time periods are highlighted in black so it can be seen how these data compare to the 111 years of data. It is evident from the graph the 24-year period contains some very wet and dry years. The median amount for the 111-year period is 26.27 inches, compared to 27.46 inches for the 24-year period. Data from the 24-year period are distributed across the range of the 111 years, making the data acceptable for prediction purposes.

Modeling Procedure for Colby Lake and Whitewater Reservoir

The water balance model used for Colby Lake was HEC-RAS, a state-of-the art, multi-component hydrologic model designed by the U.S. Army Corp of Engineers. The steady-flow, water-surface profile computation component was used for this project. Unlike WATBUD, HEC-RAS did not use climatic data as an input; rather, it was calibrated to measured water levels using collected or simulated flow data for all Colby Lake inflows and outflows, and a newly-determined Colby Lake outlet rating table (Table 1).

Figure 3. Historic precipitation 1951 - 1962 and 1974 - 1988
Dunka and Partridge Rivers flow comparison time period.



Year	Rank	Year	Rank
1976	2	1957	69
1960	4	1988	71
1956	13	1958	77
1984	28	1962	79
1979	31	1983	80
1980	43	1961	81
1974	44	1975	84
1954	46	1982	86
1981	53	1978	88
1959	62	1951	92
1955	63	1977	98
1987	65	1986	100
1952	68	1953	101
		1985	105

Max		Min		Mean		Median	
111y	27y	111y	27y	111y	27y	111y	27y
38.62	34.26	18.02	19.20	26.72	27.48	26.27	27.42

The predictive phase of HEC-RAS used long-term known or simulated inflow/outflow records for the 24-year Dunka time periods. Partridge River contributes the largest inflow to Colby Lake. U.S. Geological Survey (USGS) flow records exist for the Partridge River (04015475) for only a ten-year period (October 1978 to September 1988). To facilitate a longer-term prediction period, USGS Dunka River flow records (05126000), which cover two time periods totaling 16 years, were used to simulate Partridge River inflows for the 24-year Dunka time periods. Runoff from Whitewater Reservoir for the Dunka time periods was simulated using WATBUD, after calibration to collected water levels.

Modeling Procedure for the Tailing Basin Cells

Basin water levels for model calibration of Cells 1E and 2E were recorded using data loggers. The calibrated models were modified to account for the changing relationship between water level and net ground water. Bathymetric relationships for Cells 1E and 2E were developed using a GPS unit and depth finder. Watershed areas were delineated using 5-foot contour data. Predictions of future water levels were made using the 30-year normal climatic record.

The small volume of water present in tailing basin Cell 2W at initiation of the project was rapidly lost to infiltration and evaporation. This lack of ponded water prevented application of WATBUD, however, the need to assess the cell's long-term potential to accumulate water still existed. An alternative approach involving observation wells and infiltration tests was employed.

Table 1. Colby Lake outlet rating table.

			Discharge in cfs			(standard precision)					
Stream stage (ft)	0	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	Difference in Q per 0.1 units
1438.6	1.0*	1.2	1.4	1.6	1.8	2.1	2.3	2.5	2.7	2.9	2.1
1438.7	3.1	3.3	3.5	3.7	3.9	4.2	4.4	4.6	4.8	5.0*	2.2
1438.8	5.3	5.7	6	6.3	6.7	7	7.3	7.7	8	8.3	3.4
1438.9	8.7	9	9.3	9.7	10.0*	10.5	11	11.5	12	12.5	4.3
1439	13	13.5	14	14.5	15.0*	15.8	16.5	17.3	18.1	18.8	6.6
1439.1	19.6	20.4	21.1	21.9	22.7	23.5	24.2	25	25.8	26.5	7.7
1439.2	27.3	28.1	28.8	29.6	30.4	31.2	31.9	32.7	33.5	34.2	7.7
1439.3	35.0*	36.2	37.5	38.7	40	41.2	42.5	43.7	45	46.2	12.5
1439.4	47.5	48.7	50	51.2	52.5	53.7	55	56.2	57.5	58.7	12.5
1439.5	60.0*	61.6	63.3	65	66.7	68.3	70	71.6	73.3	75	16.6
1439.6	76.6	78.3	80	81.6	83.3	85	86.6	88.3	90	91.6	16.7
1439.7	93.3	95	96.7	98.3	100	102	103	105	107	108	16.7
1439.8	110*	113	115	118	121	124	126	129	132	134	27
1439.9	137	140	143	145	148	151	153	156	159	162	27
1440	164	167	170	172	175	178	181	183	186	189	27
1440.1	191	194	197	200	202	205	208	210	213	216	28
1440.2	219	221	224	227	229	232	235	238	240	243	27
1440.3	246	248	251	254	257	259	262	265	267	270	27
1440.4	273	276	278	281	284	286	289	292	295	297	27
1440.5	300*	305	310	315	320	325	330	335	340	345	50
1440.6	350	355	360	365	370	375	380	385	390	395	50
1440.7	400	405	410	415	420	425	430	435	440	445	50
1440.8	450	455	460	465	470	475	480	485	490	495	50
1440.9	500	505	510	515	520	525	530	535	540	545	50
1441	550	555	560	565	570	575	580	585	590	595	50
1441.1	600	605	610	615	620	625	630	635	640	645	50
1441.2	650	655	660	665	670	675	680	685	690	695	50
1441.3	700	705	710	715	720	725	730	735	740	745	50
1441.4	750	755	760	765	770	775	780	785	790	795	50
1441.5	800*										

*indicates a rating descriptor point

IV. RESULTS AND DISCUSSION

A. Cliffs-Erie Mine Pits

1. Pit 2E

Objective
Analyses objectives for Pit 2E were to determine the ultimate static water level, time it will take the pit to fill, and pit outflow hydrograph.

Hydrologic Setting
Pit 2E has a surface watershed of 507 acres (Figure 4). The stair-step configuration of water levels (Figure 5) is a distinct signature of a pit that is hydrologically dominated by storm runoff with little or no contribution from ground water. This characteristic makes sense as Pit 2E's watershed is the topographic high point of surrounding pits and is largely made up of bare rock with virtually no surface overburden. In addition, winter water levels drop slightly. Pit 2E is separated from Pit 2W by a relatively thin column of BIF rock, about 600 feet wide, providing a relatively short travel distance for seepage loss from Pit 2E to Pit 2W. Pit 2E's present water level is approximately 100 feet higher than that of Pit 2W, suggesting seepage loss to Pit 2W is small, probably accounting for the slight drop in winter water level. It was concluded that ground water inflow was an inconsequential part of the pit's water balance. Pit water level has risen approximately 14 feet during the course of this project and will need to rise another 55 feet before outflow occurs.

Methodology
Water level data from 16 July 2001 through 14 May 2003 were used to calibrate WATBUD. Interpretation of calibrated model results, and examination of borehole data around the pit concluded no adjustment of the calibrated model was warranted to make predictions. To determine time it will take the pit to fill, the Exceedance Calculations routine in WATBUD was run using the calibrated model and 30-year normal climate record. Climatic data from the two Dunka time periods were used to make predictions of future pit outflow.

Calibrated Model
The calibrated WATBUD model results and parameter file for Pit 2E are presented in Figures 5 and 6. Results include a small, negative seepage constant of – 0.2025 acre-feet/day, and a high runoff curve number of 97.32. These results, along with the stair-step configuration of water levels, are indicative of a surface water system.

Predictive Model
It was concluded that ground water inflow from all sources, including the BIF, was inconsequential. The small net seepage value (-0.2025 acre-feet/day) suggests minor seepage loss to Pit 2W. Pit 2E is predicted to outflow through coarse rock

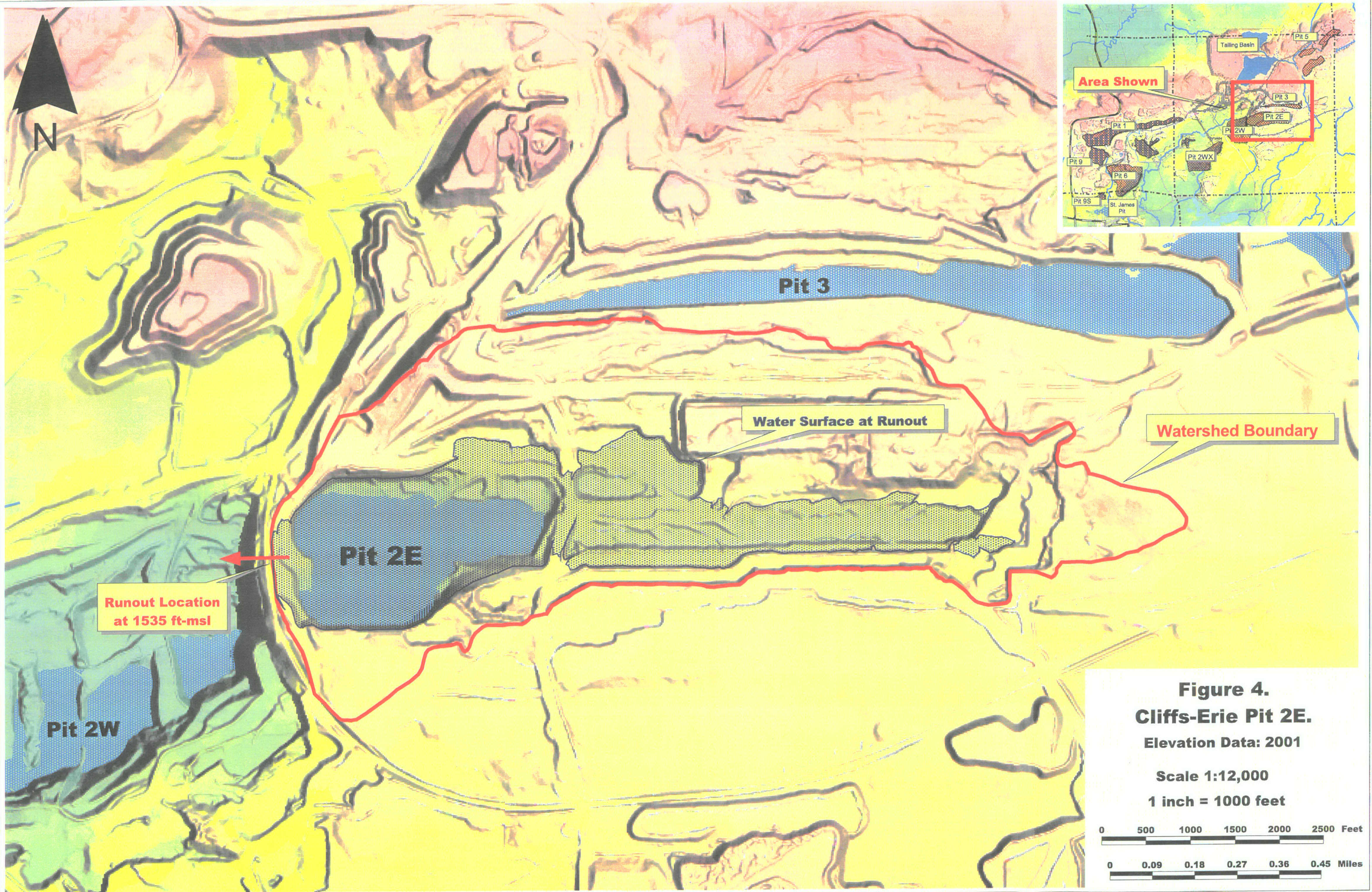


Figure 4.
Cliffs-Erie Pit 2E.
Elevation Data: 2001

Scale 1:12,000
1 inch = 1000 feet

Figure 5. Pit 2E calibrated model and recorded water levels.

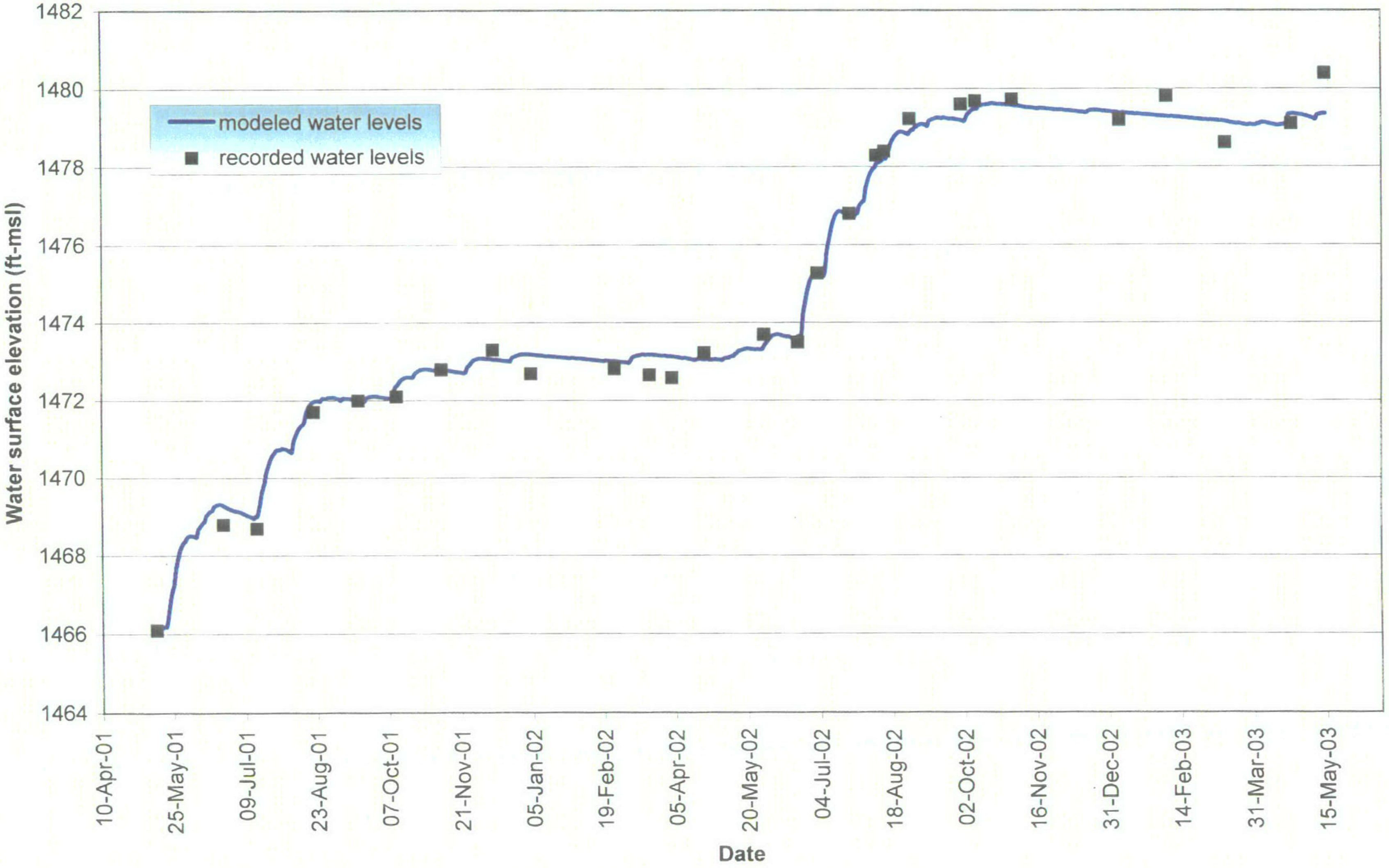


Figure 6. Pit 2E WATBUD parameter file for calibrated model.
(see Figure 2 for detailed description of components)

```
507
14
1470,69,250,0
1480,75,720,0
1490,83,1510,0
1500,86,2355,0
1510,92,3245,0
1520,98,4195,0
1530,105,5210,0
1535,190,6000,0
1535.1,190.3,6015,.3
1535.3,190.9,6045,1.94
1535.5,191.5,6075,4.77
1535.7,192.1,6105,8.8
1536,193,6152,17.21
1540,207,6760,168
B:0:J:\ALL\LTV\WATBUD\PIT 2E\
L:0:PIT2ELEVS,ELEV,1
P:0,1:NEWCLIM,PRECIP
P:3,1: 30.00, 37.00, 0.011040, ( ,,NEWCLIM,TEMPMIN,,1),
(,,NEWCLIM,TEMPMAX,,1)
P:4,1:
E:2,1,1: 0.8000, (,,NEWCLIM,TEMPMIN,,1), (,,NEWCLIM,TEMPMAX,,1)
R:2,1: 1.0000
R:4,1,1: (97.32,1), (P:0:NEWCLIM,PRECIP), 2.708, 1.6179
R:7,1: 0.2170
R:8,1: (96.60,1)
F:2,1: 1.0000
S:2,1: 1.0000
S:4,1,1: (-0.2025,1), 0
```

on its western end into Pit 2W. Bedrock elevations in that area are presumed to control runout at approximately elevation 1535 ft-msl into Pit 2W. Pit water at elevation 1535 ft-msl will not encounter any glacial drift, eliminating the potential for ground water outflow, other than that which may occur to Pit 2W. When Pits 2E and 2W are discharging water, the difference in water levels will have decreased from the present 100 feet to 50 feet. This reduced gradient could result in a reduction in ground water outflow from 2E to 2W. However, since ground water outflow is not a significant part of the pit's water balance, the potential slight change was ignored. Results from this analysis are shown in Figure 7 and indicate the pit will fill to its projected outflow elevation of 1535 ft-msl in 16 to 18 years, and have an open water area of 192 acres.

Although no outlet channel is anticipated, the channel configurations outlined on page five were used for predicting outflow to serve as input to Pit 2W modeling. Predicted discharge, utilizing the two Dunka time periods of climate data, is presented in Figures 8 and 9. Average pit discharge was 0.25 cfs while maximum discharge was 8.2 cfs.

2. **Pit 2W**

Objective

Analyses objectives for Pit 2W were to determine ultimate static water level, time it will take to fill the pit, and pit outflow hydrograph. It also included examination of an outlet route to Second Creek.

Hydrologic Setting

Pit 2W has a surface watershed of 495 acres (Figure 10). As with Pit 2E, bare rock is the dominant surface cover. Pit 2W was one of the last pits mined by LTV. Water levels collected between 14 May 2001 and 14 May 2003 show a rise of nearly 80 feet. As opposed to the stair-step configuration of Pit 2E water levels, the steady water rise in Pit 2W indicates major ground water inflow (Figure 11).

Given the negligible ground water inflow to Pit 2E from all sources, and the similarity in geology between the two pits, it was concluded that ground water inflow to Pit 2W from the BIF was negligible. Rather, the source of ground water is believed to be from the north where borehole data indicate overburden up to 40-feet deep exists in the Second Creek headwaters. This bedrock valley is believed to act as a ground water conveyance system, transporting Second Creek water to Pit 2W. Second Creek water elevation varies from a low of about 1485 ft-msl near the northwest corner of the pit to as high of 1500 ft-msl near the northeast corner of the pit. Unless ground water outflow becomes high enough to balance inflows, an uncontrolled surface water outflow will occur through or over the mine road along the northwest side of the pit at about elevation 1490 ft-msl. When pit water level rises above 1485 ft-msl, ground water flow direction will begin to reverse and ground water outflow will become part of the water balance. At uncontrolled outflow elevation 1490 ft.-msl, ground water outflow will not be large enough to

Figure 7. Pit 2E exceedance calculations to determine time to fill pit.

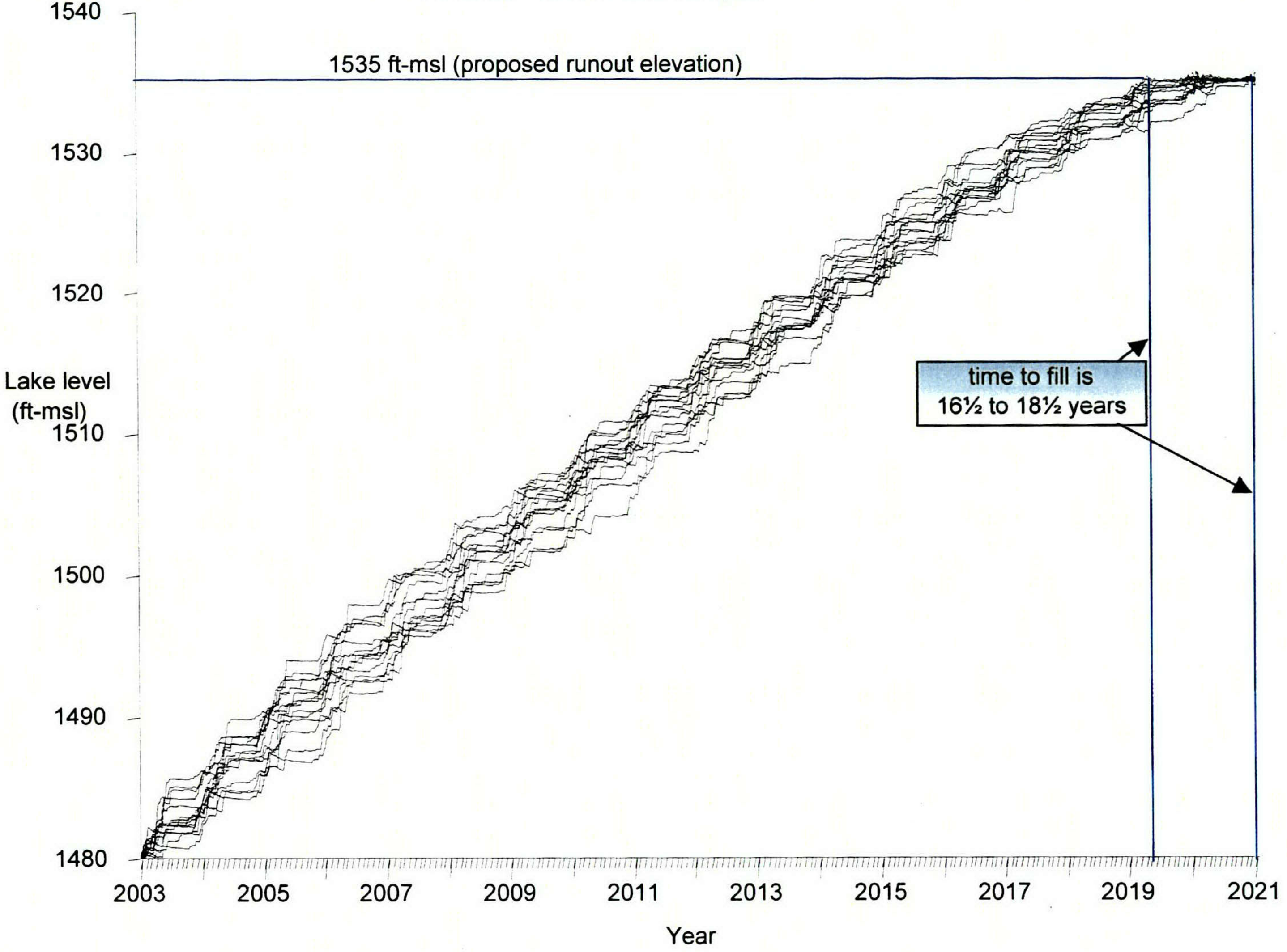


Figure 8. Predicted discharge from Pit 2E using a climate file covering 01 December 1951 - 29 September 1962.

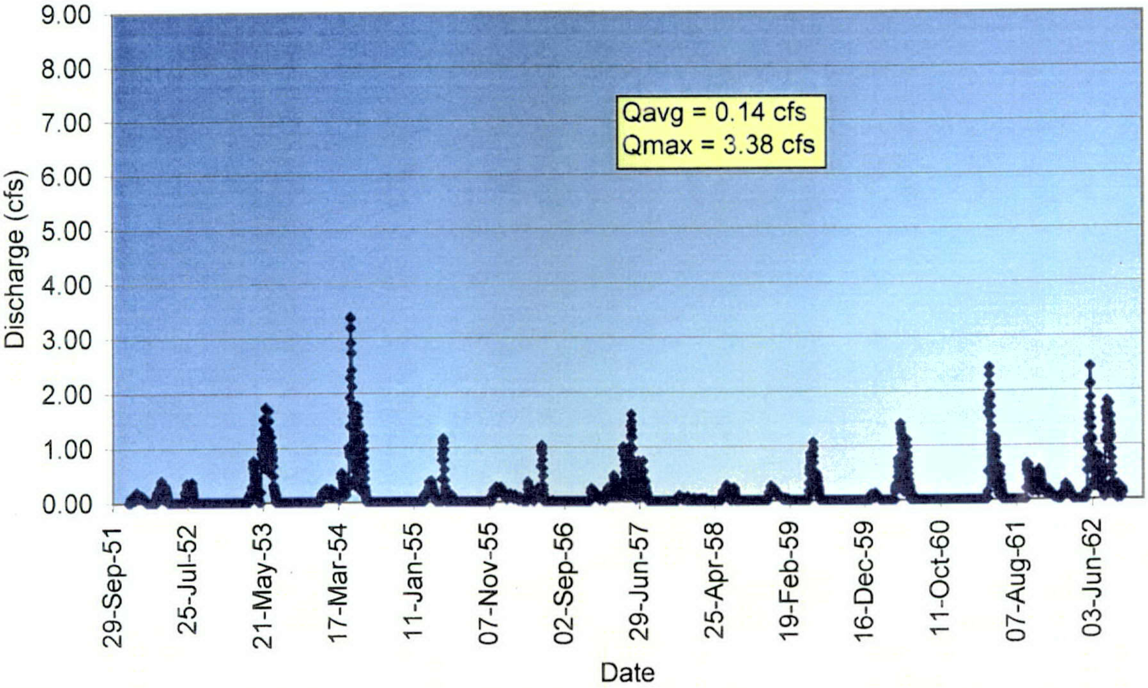
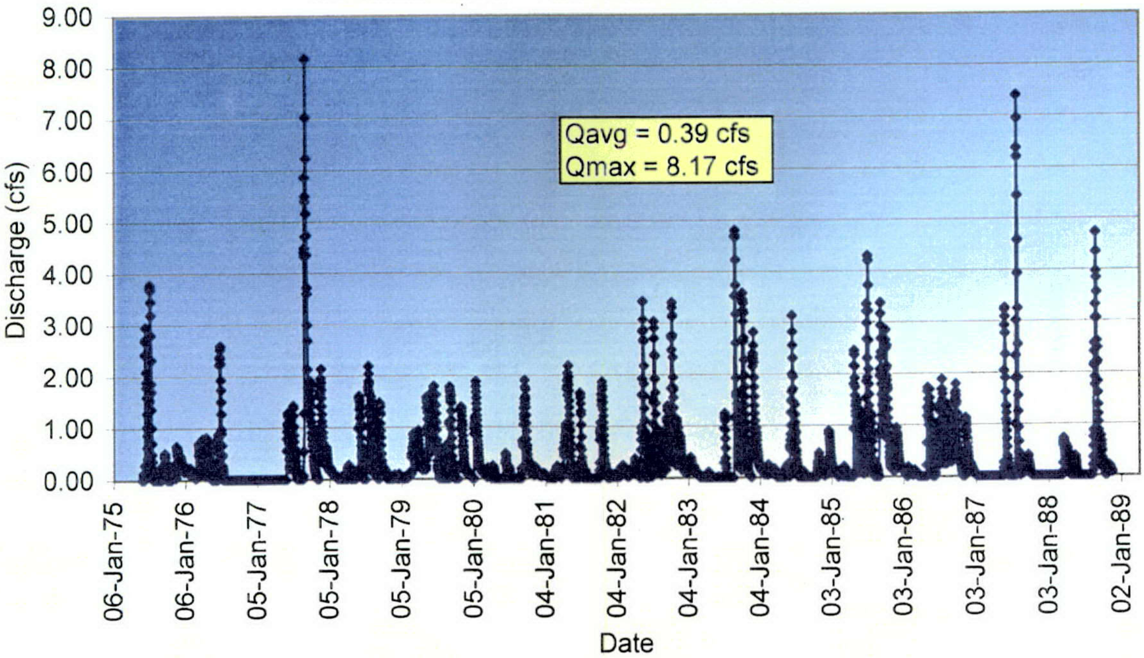


Figure 9. Predicted discharge from Pit 2E using a climate file covering 01 June 1975 - 15 November 1988.



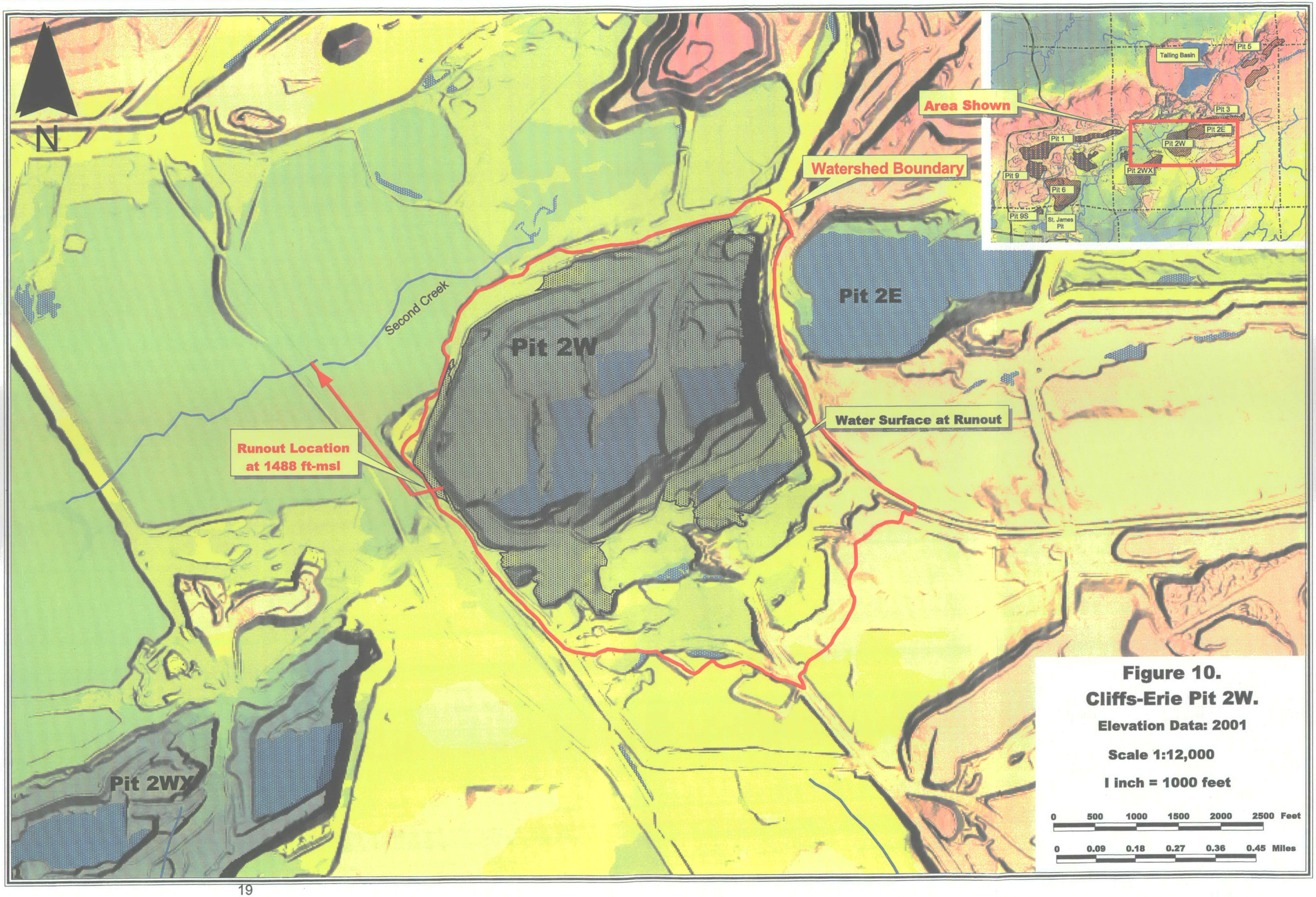


Figure 10.
Cliffs-Erie Pit 2W.

Elevation Data: 2001

Scale 1:12,000

I inch = 1000 feet

balance inflows, resulting in the formation of an uncontrolled surface outflow. An outlet channel could be cut through the road and for about 1000 feet across a wetland to Second Creek. To avoid wetland impacts, an alternative location was selected at the west end of the pit where the outlet channel would connect to an existing railroad ditch that flows to Second Creek. The runout elevation of this channel must be low enough to prevent uncontrolled outflow through the road. However, if constructed at too low an elevation, say 1485 ft-msl, the channel would be about 1300 feet long before daylighting in the railroad ditch. Therefore, the recommended runout elevation is 1488 ft-msl, which would shorten the channel length to a few hundred feet, yet prevent uncontrolled outflow.

Methodology

Pit water levels prior to 11 December 2001 were influenced by unmetered pumping of water from tailing basin Cell 1E to Pit 2W. Therefore, the calibrated WATBUD model used only water levels and climate data from 11 December 2001 through 14 May 2003. Estimating time it will take the pit to fill used the 30-year normal climate record in the Exceedance Calculations routine in WATBUD.

In contrast to the predictive model used for Pit 2E, it was necessary to modify the Pit 2W calibrated model to account for decreasing ground water inflow. Ground water inflow was diminished following the principle of Darcy's Law as described in *Ground Water and Wells* (Driscoll 1986):

> Darcy's experiments show that flow in saturated sand varies directly with hydraulic gradient. If the hydraulic gradient (head loss per unit length of travel) is doubled, the rate of flow in a given sand is also doubled. The slope of the water table or potentiometric surface is the hydraulic gradient under which groundwater movement takes place.

Using this principle, a time series file was developed that reflected a linear decrease in ground water input as pit water level rose above the floor of the bedrock valley. Ground water inflow may not decrease linearly with rising pit water level due to changes in aquifer hydraulic conductivity or width. Possible error introduced by this assumption would be a minor adjustment in the time needed for the pit to fill. WATBUD's Run Forward Once routine was executed several times to create the time series file relating each one foot rise in pit water to its associated decrease in ground water inflow. The time series file was utilized in a Flow In/Flow Out submodel for subsequent Run Forward Once runs and essentially subtracted flow from the water balance equation to simulate a decrease in ground water inflow. This relationship was incorporated into the WATBUD model to predict pit fill time and the outflow hydrograph.

Ground water outflow to Second Creek at the recommended runout elevation of 1488 ft.-msl will be a negligible part of the pit's water balance, and was therefore ignored in the predictive model. Potential error resulting from this assumption could be a slight under-estimation of the time required for the pit to fill, and a slight over-estimation of pit outflow rates.

Estimation of discharge from Pit 2W necessitated incorporating expected flow from Pit 2E. This was accomplished using a second Flow In/Flow Out submodel in WATBUD. Even though Pit 2E will take a few years longer to fill than Pit 2W, calculations of predicted outflow assumed Pit 2E was filled and contributing water to Pit 2W.

Calibrated Model

Figures 11 and 12 show the calibrated model and associated parameter file. The model's positive net seepage constant of 4.92 acre-feet/day (2.46 cfs) is interpreted to be all ground water inflow originating from Second Creek.

Predictive Model

The bottom of the bedrock valley that controls ground water inflow is at elevation 1460± ft-msl, while the recommended pit outlet channel elevation is approximately 1488 ft-msl. Once pit water levels exceed elevation 1460 ft-msl, ground water inflow was linearly reduced in proportion to the decrease in hydraulic head between Second Creek and Pit 2W. At outflow elevation 1488 ft-msl, net ground water is predicted to reduce to 2.0 acre-feet/day or 1.0 cfs. This estimate may be slightly high, given the probability of a small amount of ground water outflow to Second Creek in the vicinity of the recommended outlet channel. The small head differential (maximum 3 feet) over a minimum horizontal distance of 1200 feet will limit ground water outflow. The resultant error is expected to be within the limits of modeling accuracy.

Results of Exceedance Calculations in WATBUD estimated Pit 2W will fill to the recommended runout elevation of 1488 ft-msl in 11½ to 16½ years (Figure 13). At runout, the pit will have a surface water area of 287 acres.

Average discharge was predicted to be approximately 2.0 cfs while maximum discharge could exceed 9.0 cfs (Figures 14 and 15). These estimates were based on the two Dunka time periods' climate files and assumed outlet channel dimensions outlined on page five. Although flows will be very low at times, pit outflow should not cease.

3. **Pit 2WX**

Objective

Analyses objectives for Pit 2WX were to determine ultimate static water level, time it would take the pit to fill, and pit outflow hydrograph. It also included identification of an outlet route to Colby Lake.

Figure 11. Pit 2W calibrated model and recorded water levels.

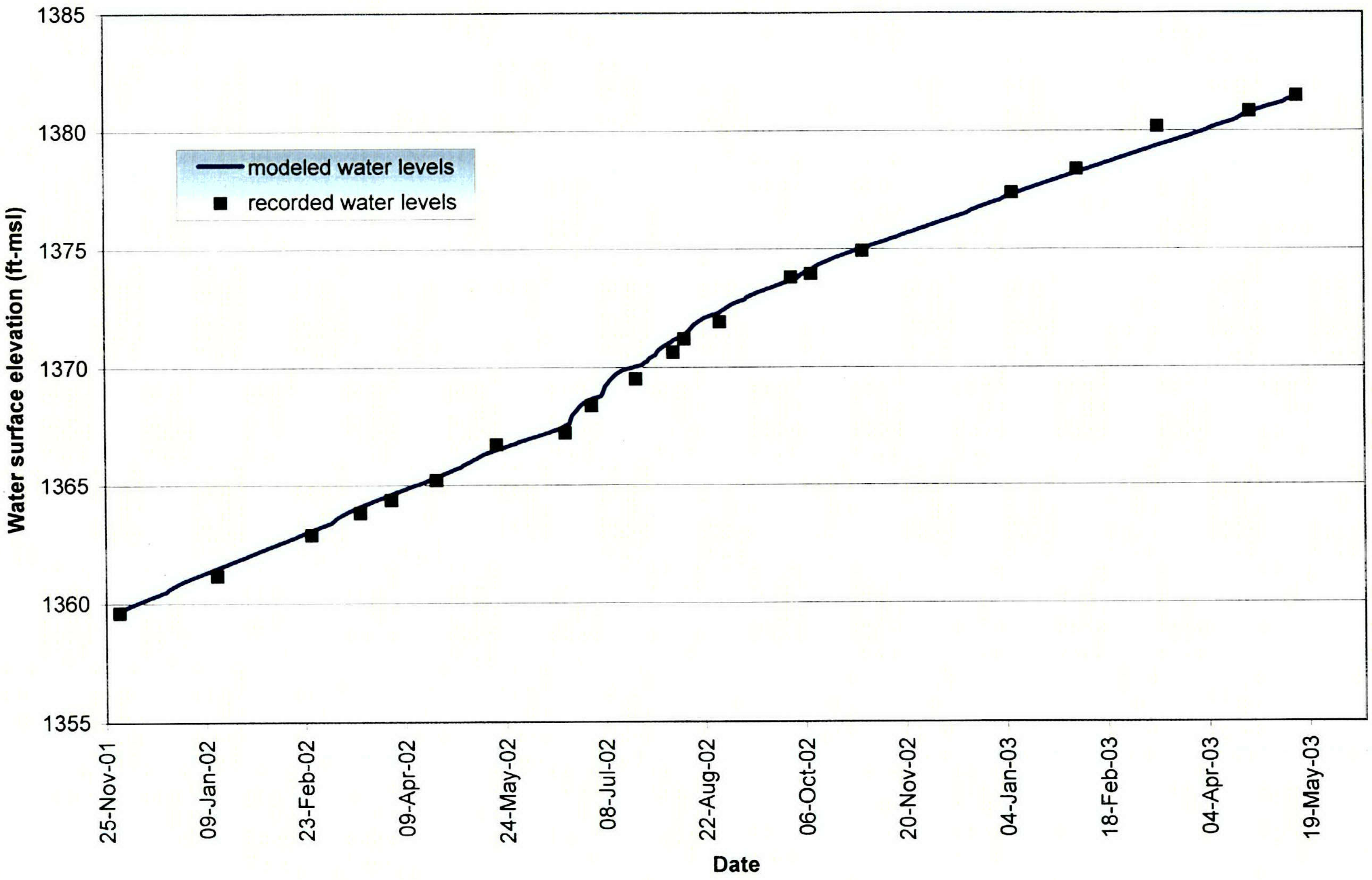


Figure 12. Pit 2W WATBUD parameter file for calibrated model.
(see Figure 2 for detailed description of components)

```
495
24
1330,86,1701,0
1340,102,2644,0
1350,119,3748,0
1360,132,5001,0
1370,141,6368,0
1380,151,7931,0
1390,161,9493,0
1400,170,11150,0
1410,180,12867,0
1420,191,14755,0
1430,200,16710,0
1440,209,18755,0
1450,224,20919,0
1460,233,23202,0
1465,238,25554,0
1470,245,27966,0
1480,278,30741,0
1485,287,32174,0
1485.1,287.4,32203,.3
1485.3,287.7,32260,1.94
1485.5,288.1,32317,4.77
1485.7,288.4,32375,8.8
1486,288.8,32461,17.21
1486.5,289.7,32604,38.24
B:0:J:\ALL\LTV\WATBUD\Pit 2W\
L:0:LEV012W,ELEV,1
P:0,1:2WCLIMB,PRECIP
P:3,1: 31.00, 40.00, 0.011040, (,,2WCLIMB,TEMPMIN,,1), (,,2WCLIMB,TEMPMAX,,1)
P:4,1:
E:2,1,1: 0.8000, (,,2WCLIMB,TEMPMIN,,1), (,,2WCLIMB,TEMPMAX,,1)
R:2,1: 1.0000
R:4,1,1: 99.37, (P:0:2WCLIMB,PRECIP), 2.699, 1.8271
R:7,1: 0.2170
R:8,1: 90.00
F:0:2JUL03A,Q
F:2,1: 1.0000
F:0:GW_LOSSPIT2W,GW
F:2,1: 1.0000
S:2,1: 1.0000
S:4,1,1: (4.921,1), 0
```

Figure 13. Pit 2W exceedance calculations to determine time to fill pit.

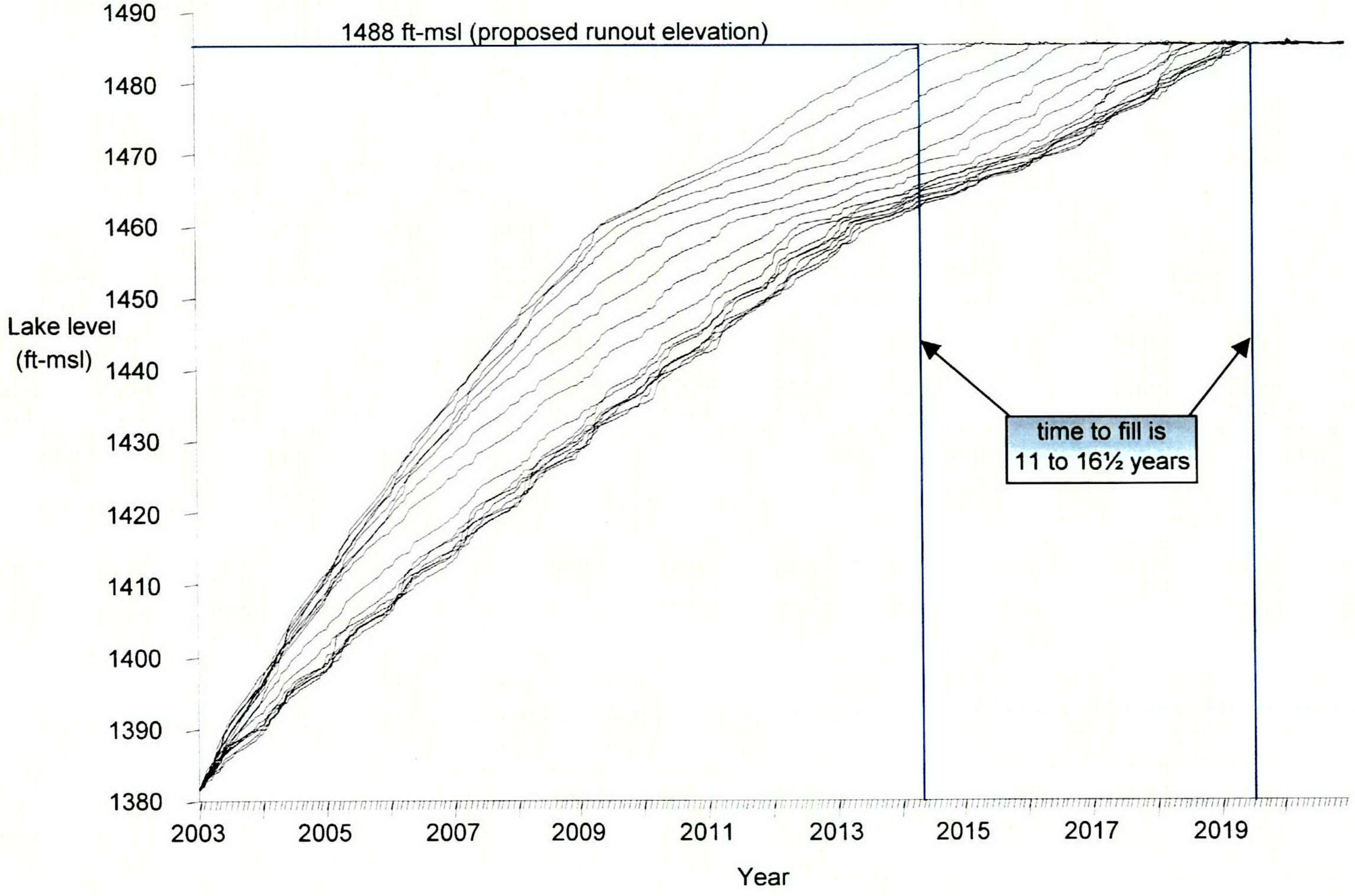


Figure 14. Predicted discharge from Pit 2W using a climate file covering 01 December 1951 - 29 September 1962.

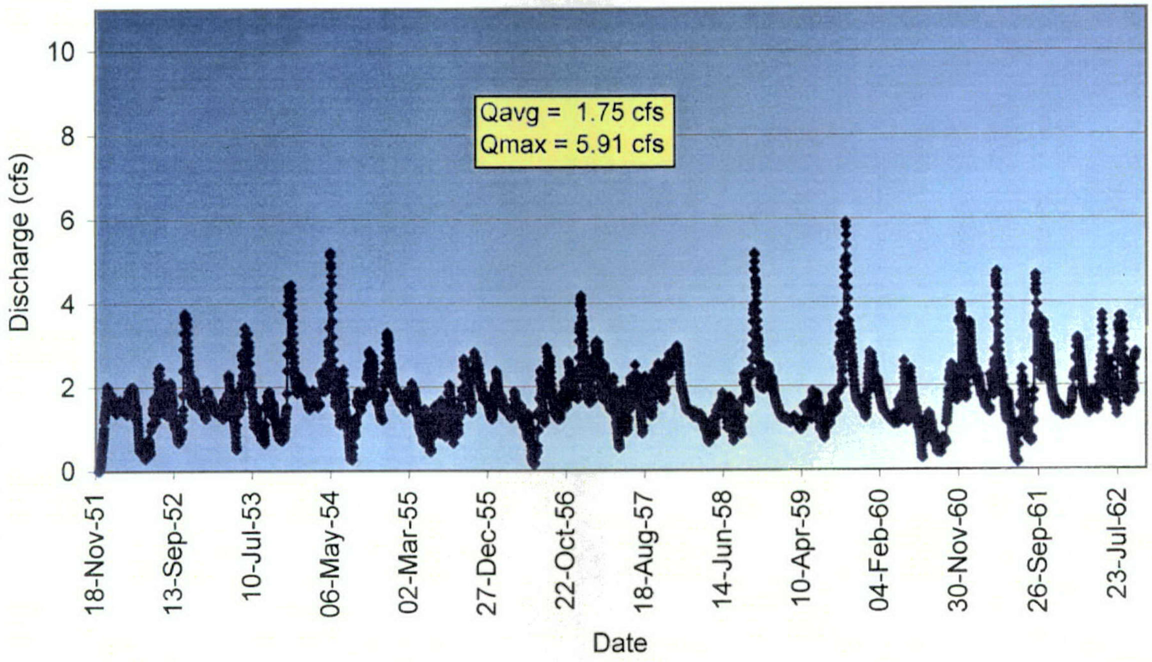
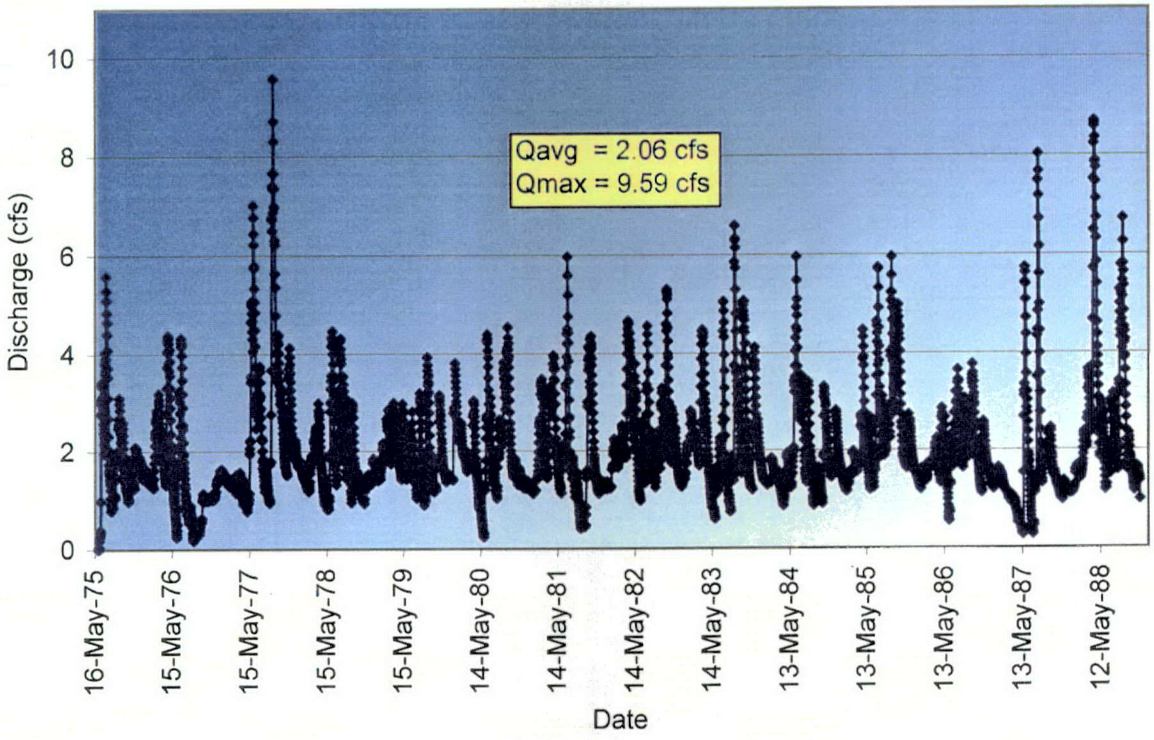


Figure 15. Predicted discharge from Pit 2W using a climate file covering 01 June 1975 - 15 November 1988.



Hydrologic Setting

Pit 2WX consists of two separate mining areas below approximately elevation 1410 ft-msl. Above this elevation the areas merge to form one pit. The larger, western area has a watershed of 915 acres while the smaller, eastern area has a watershed of 112 acres, totaling 1027 acres (Figure 16). Water levels were collected from 14 May 2001 to 14 May 2003 and from 1 July 2002 to 14 May 2003, for the western and eastern areas, respectively. A 40-feet increase in water levels occurred in the western area during the study, while water in the eastern area increased only six feet.

Methods

Developing the calibrated model for Pit 2WX involved first calibrating a seperate model for the east and west areas, then weighting the runoff curve number and snowmelt curve number based on watershed size. In addition, the seepage constant for both areas was added to account for total ground water inflow. The weighted calibrated model was used for predictive purposes. As with Pit 2W, it was concluded all ground water inflow to Pit 2WX originates from Second Creek, with inconsequential BIF inflow. It was therefore necessary to modify the Pit 2WX calibrated model to account for decreasing ground water inflow as pit water level rises above the bedrock valley that controls ground water inflow. Application of the principle of Darcy's Law, as described in the discussion for Pit 2W, was utilized in the predictive model for Pit 2WX. This relationship was incorporated into the WATBUD model to predict time to fill. The 30-year normal climate record was used in the WATBUD Exceedance Calculations routine for this prediction.

The pit discharge will utilize an existing, remnant surface water channel that crosses an area dominated by wetland vegetation with an apparent high water table. The thickness of glacial drift in this area is as much as 22-feet. The drift could serve as a ground water outflow zone, stabilizing the pit water level below 1455 ft.-msl. The area was not accessible for installation of observation wells for aquifer characterization. This low-gradient area appears to be saturated, and not likely to transport significant volumes of ground water. It was concluded that a surface water discharge through this area would likely occur.

Calibrated Model

Figures 17 & 18 show the calibrated model and parameter file for Pit 2WX. Using one model for the two areas combined caused predictions of water levels below 1410 ft-msl to be inaccurate. However, after water levels equalize, predicted pit water levels should be accurate. Exceedance Calculations in WATBUD indicate it will take about 4 years for water levels to reach elevation 1410 ft-msl.

The calibrated model's positive net seepage constant of 2.87 acre-feet/day (1.43 cfs) was interpreted to be all ground water inflow. As with Pit 2E, the source of ground water is believed to be from the north, where borehole data indicate a bedrock valley with an average elevation of about 1440 ft-msl. It was concluded

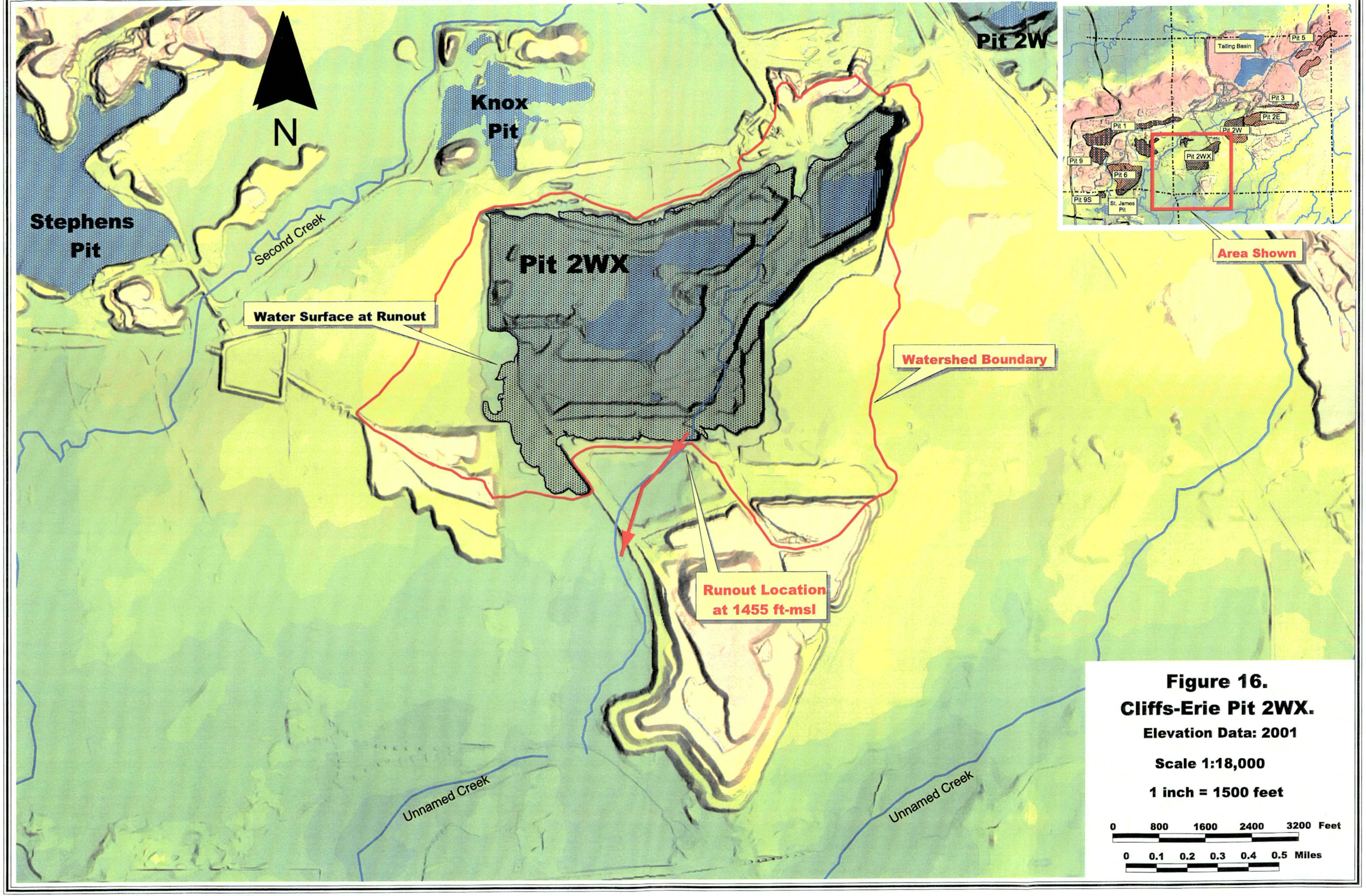


Figure 16.
Cliffs-Erie Pit 2WX.
Elevation Data: 2001

Scale 1:18,000

1 inch = 1500 feet

Figure 17. Pit 2WX calibrated model and recorded water levels.

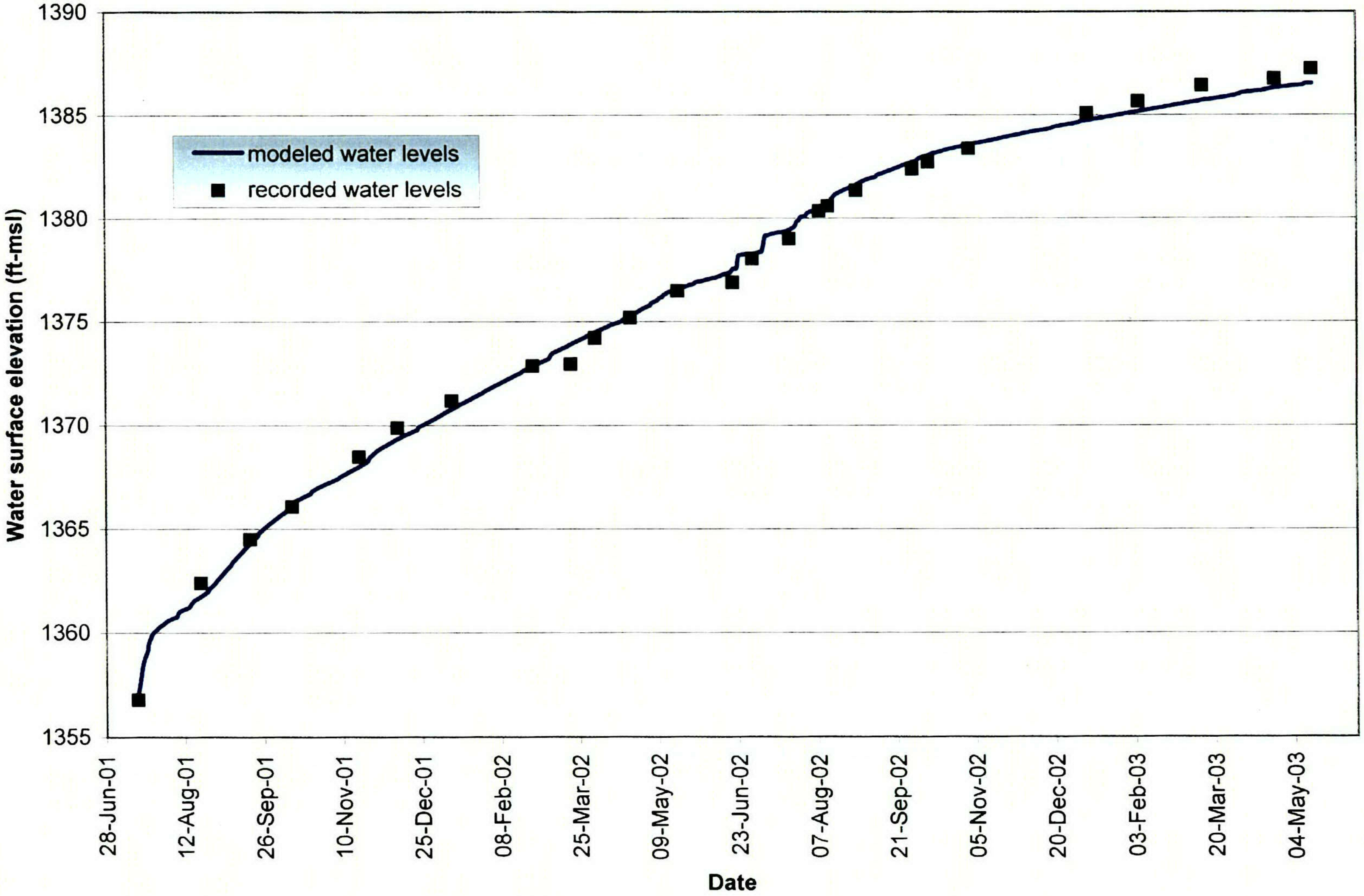


Figure 18. Pit 2WX WATBUD parameter file for calibrated model.
(see Figure 2 for detailed description of components)

```
1027
19
1350,50,750,0
1360,100,1010,0
1370,154,1797,0
1380,206,2530,0
1390,249,4495,0
1400,303,6905,0
1410,341,10855,0
1420,387,13038,0
1430,417,15221,0
1440,452,17404,0
1450,487,19587,0
1455,507,20679,0
1455.1,507.4,20701,.3
1455.3,508.2,20744,1.94
1455.5,510,20788,4.77
1455.7,510.8,20832,8.8
1456,511,20897,17.21
1456.5,513,21006,38.24
1460,527,21770,0
B:0:J:\ALL\LTV\WATBUD\PIT 2WX\
L:0:2WX LEVEL,ELEV,1
P:0:,1:WWRCLIMAT,PRECIP
P:3,1: 31.00, 37.00, 0.011040, (,,WWRCLIMAT,TEMPMIN,,1),
(,,WWRCLIMAT,TEMPMAX,,1)
P:4,1:
E:2,1,1: 0.8000, (,,WWRCLIMAT,TEMPMIN,,1), (,,WWRCLIMAT,TEMPMAX,,1)
R:2,1: 1.0000
R:4,1,1: (96.22,1), (P:0:WWRCLIMAT,PRECIP), (1.3588,1), (11.665,1)
R:7,1: 02170
R:8,1: 95.00
F:2,1: 1.0000
S:2,1: 1.0000
S:4,1,1: (2.870,1), 0
```

this bedrock valley acts as a ground water conveyance system to Pit 2WX, with the source of water being a large wetland through which Second Creek flows. During mining, Pit 2WX was expanded into this wetland, thereby establishing a conduit for ground water to flow from the wetland into the pit. Once water levels exceed elevation 1440 ft-msl, the present ground water inflow of 1.43 cfs will begin to decrease.

Predictive Model

When pit water level reaches runout elevation 1455 ft-msl, ground water inflow is predicted to decrease to 0.6 cfs.

Exceedance Calculations estimated Pit 2W outflow in 10½ to 14½ years (Figure 19). At runout, the pit's water surface area will be 507 acres. Average outflow discharge should be approximately 1.5 cfs while maximum discharge could exceed 12 cfs (Figures 20 and 21). Because of Pit 2WX's larger dependence on surface runoff, there will be times when outflow will cease.

4. **Pit 6**

Objective

Analyses objectives for Pit 6 were to determine ultimate static water level, time it would take the pit to fill, outlet channel location, and pit outflow hydrograph.

Hydrologic Setting

Pit 6's watershed is also characterized by very little glacial overburden. It has a watershed area of 7886 acres (Figure 22). Pit 6 has two major, visible sources of ground water inflow, seeps from Second Creek along the pit's eastern wall, and seeps from the direction of Pit 9S along its southwestern wall. Ground water inflow from the BIF may also be present, however, field estimates suggest that virtually all of the calibrated model's net seepage value is accounted for in the two visible seepage sources. Seepage inflow from Second Creek is controlled by bedrock elevation about 1445 ft.-msl. Seepage inflow from the direction of Pit 9S enters Pit 6 well above the proposed runout elevation and will therefore not be affected be Pit 6 water level. Water levels collected from 14 May 2001 through 14 May 2003 show an increase of 80 feet. Rapidly rising water levels are attributed mostly to the two major seepage sources.

Methods

As with the predictive models for Pits 2W and 2WX, Pit 6's calibrated model needed to be modified to account for decreasing ground water inflow as water levels increase. Based on field observations, it was estimated approximately 50% of total ground water inflow (calibrated model seepage constant) originated from Second Creek. Starting at bedrock control elevation of 1445 ft.-msl, this figure was reduced linearly in proportion to the reduction in head differential between the pit water surface and Second Creek. The remainder of the seepage was attributed to the large seeps along the southwest wall, which enter Pit 6

Figure 19. Pit 2WX exceedance calculations to determine time to fill pit.

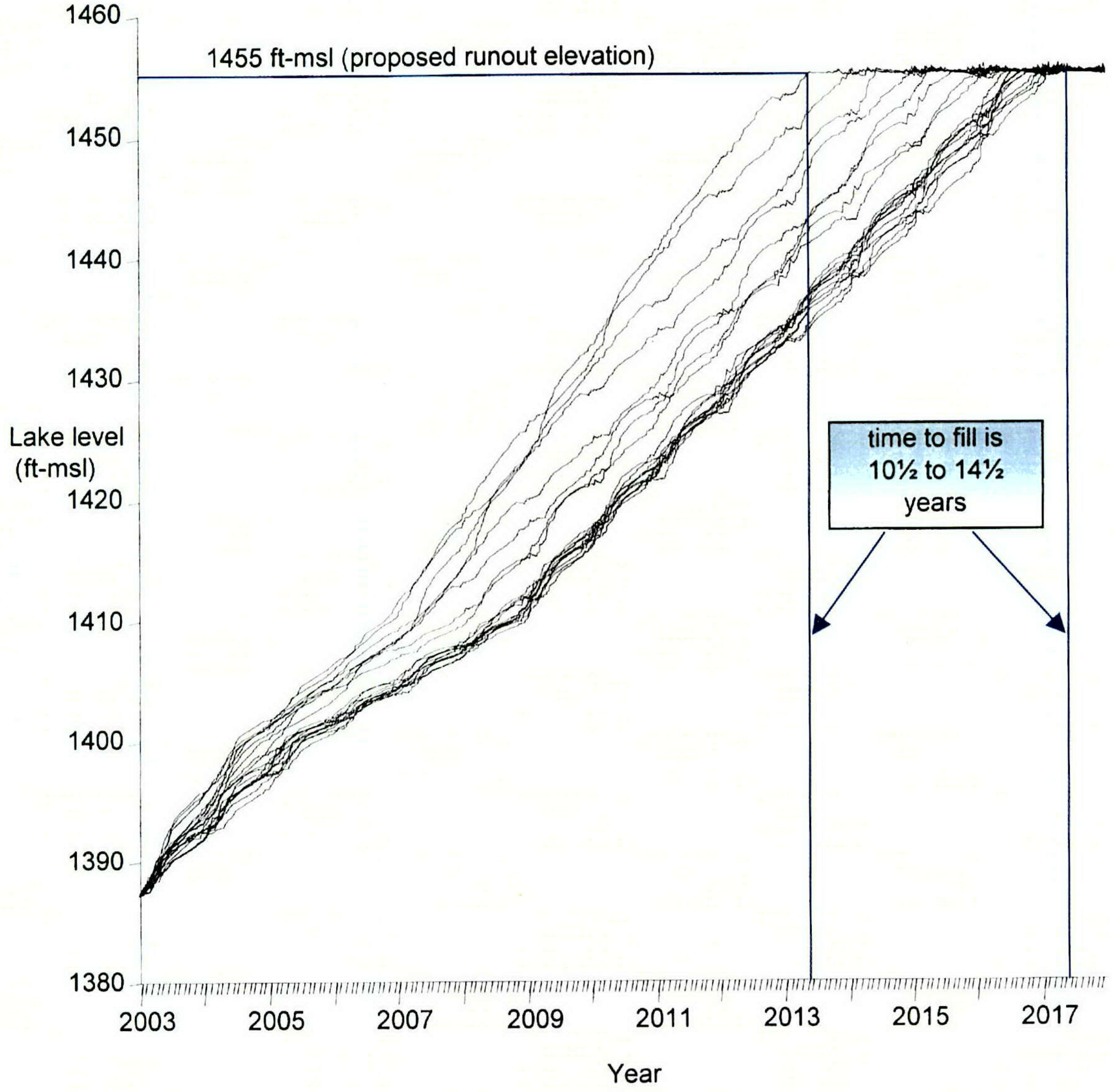


Figure 20. Predicted discharge from Pit 2WX using a climate file covering 01 December 1951 - 29 September 1962.

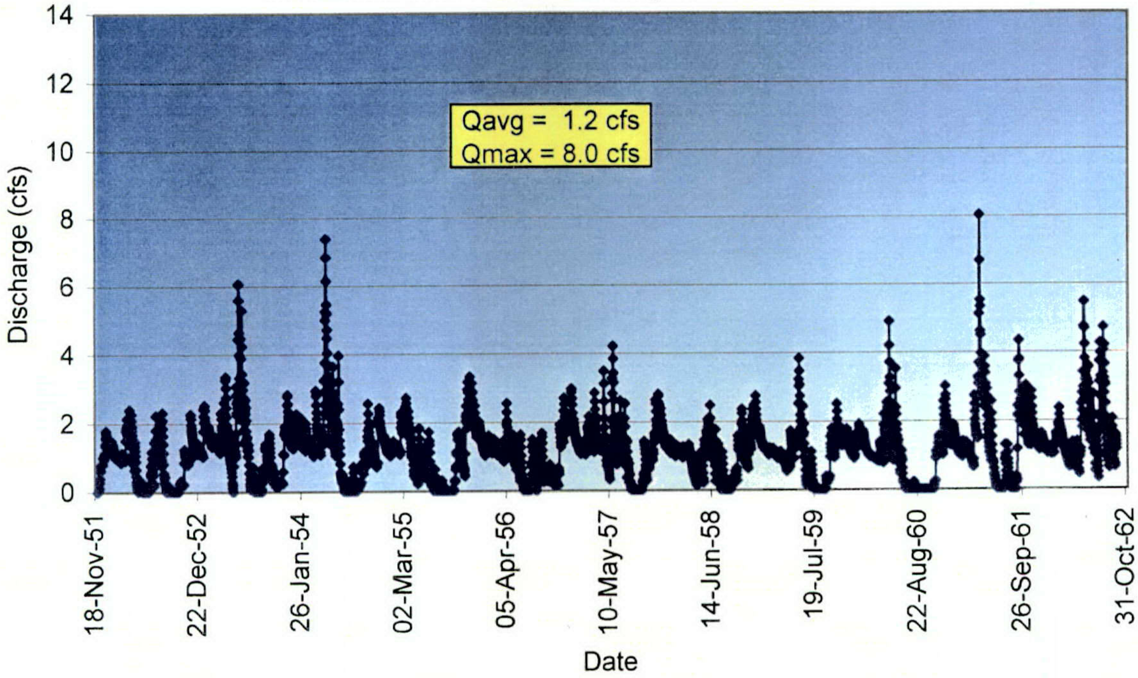


Figure 21. Predicted discharge from Pit 2WX using a climate file covering 01 June 1975 - 15 November 1988.

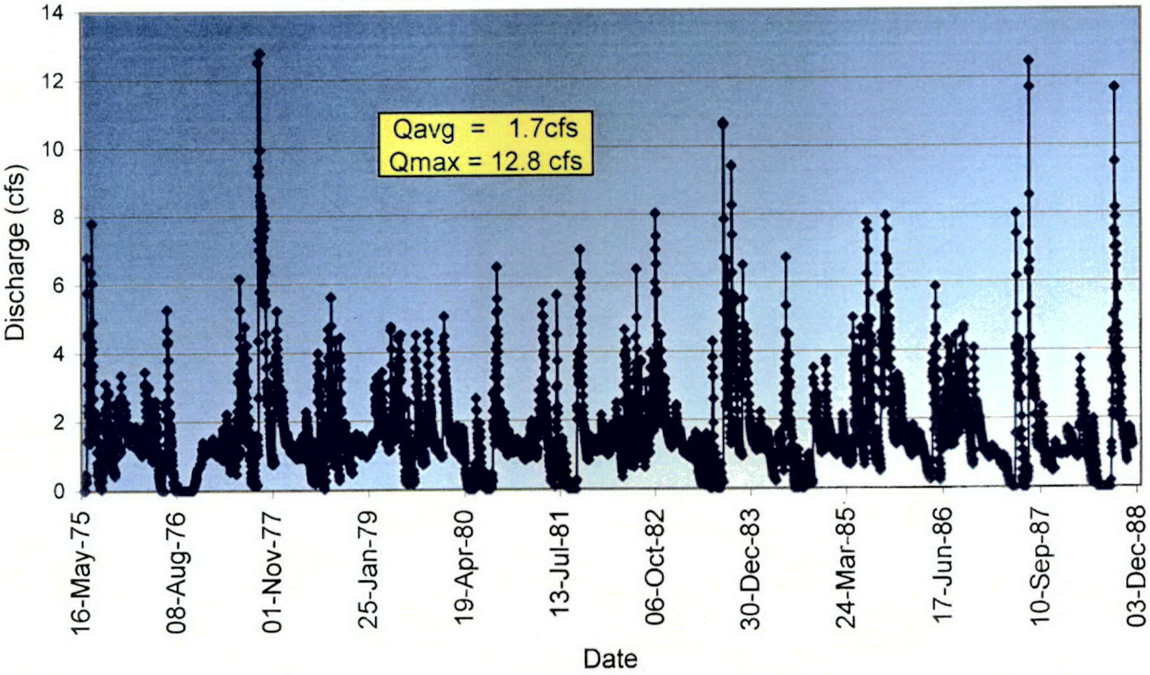


Figure 22.
Cliffs-Erie Pit 6.
Elevation Data: 2001
Scale 1:12,000
I inch = 1000 feet

above the pit's runout elevation and therefore remain constant in the predictive model.

Similar to Pit 2W, interpretation of borehole data indicates ground water outflow from Pit 6 will only occur in the vicinity of the recommended outlet channel where Second Creek water level will be slightly lower than the pit water level. This small amount of outflow was ignored in the predictive model. Resulting potential error could be a slight under-estimation of the time required for the pit to fill, and a slight over-estimation of pit outflow rates. It is recommended the pit runout elevation be no more than 2½ feet higher (approximately elevation 1455 ft.-msl) than the elevation of the bed of Second Creek where the channel enters the creek. This should result in a channel about 800 feet long with a low enough gradient to prevent erosion of the wetland's sandy soil substrate. At runout elevation 1455 ft-msl, substantial ground water inflow from Second Creek will persist along the north half of the east side of the pit.

Calibrated Model

Figures 23 and 24 show the calibrated model and parameter file for Pit 6. The calibrated model produced a net seepage constant of 10.2 acre-feet/day (5.1 cfs), the largest of the modeled pits. All of this seepage was attributed to ground water inflow from the two major visible sources.

Predictive Model

Total seepage inflow was predicted to reduce to 3.5 cfs at runout elevation 1455 ft.-msl. As with Pit 2W, this estimate may be slightly high, given the probability of a small amount of ground water outflow to Second Creek in the vicinity of the recommended outlet channel. The small head differential (maximum 2½ feet) over 800 feet horizontal distance, will limit ground water outflow. The resultant error is expected to be within the limits of modeling accuracy.

WATBUD Exceedance Calculations estimated that Pit 6 will fill and outflow in 5½ to 6 years (Figure 25). The 30-year normal climate record was used for this estimate. Average outflow discharge should be about 4 cfs, with maximum discharge about 19 cfs (Figures 26 and 27). Although outflow will be very low at times, it should not cease due to high ground water inflow. At runout, pit water surface area will be 268 acres.

B. Whitewater Reservoir and Colby Lake

Objective

A hydrologic model was calibrated for Colby Lake and Whitewater Reservoir to quantify effects of Pit 2WX outflow on Colby Lake and predict lake and reservoir water levels under different Diversion Works management options.

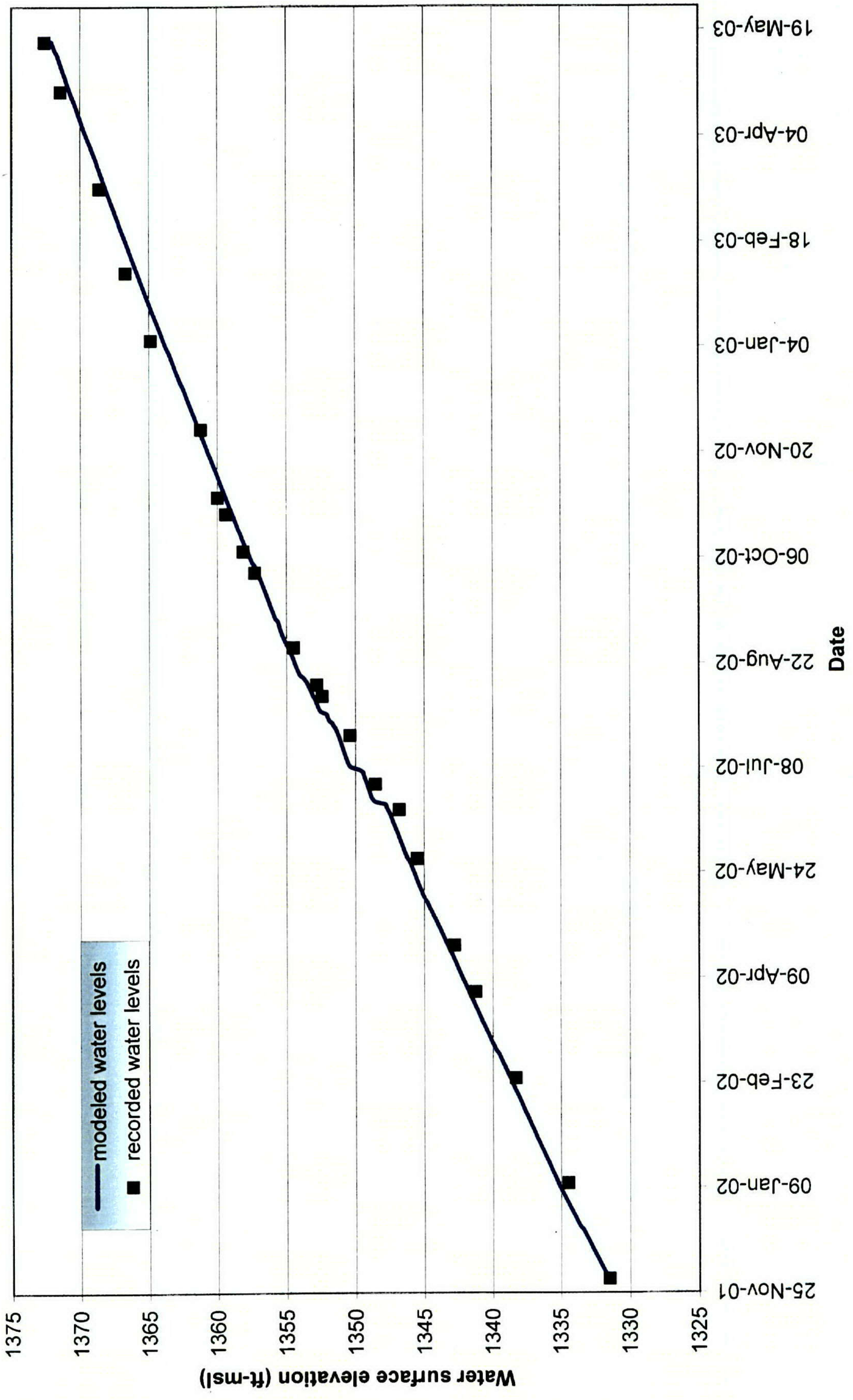


Figure 23. Pit 6 calibrated model and recorded water levels.

Figure 24. Pit 6 WATBUD parameter file for calibrated model.
(see Figure 2 for detailed description of components)

```
786
28
1295,50,100,0
1300,64,250,0
1305,71,463,0
1310,78,783,0
1315,85,1190,0
1325,109,2160,0
1335,127,3340,0
1345,137,4660,0
1355,150,6095,0
1365,158,7635,0
1375,164,9245,0
1385,173,10930,0
1395,183,12710,0
1405,189,14570,0
1415,197,16500,0
1425,205,18510,0
1435,216,20615,0
1445,230,22845,0
1455,260,25295,0
1455.2,260.7,25350,.96
1455.4,261.4,25405,3.21
1455.6,262.1,25459,6.63
1455.8,262.8,25514,11.28
1456,263.5,25569,17.21
1456.2,264.2,25624,24.52
1456.4,264.9,25679,33.28
1456.5,265.3,25706,38.24
B:0:J:\ALL\LTV\WATBUD\PIT 6\
L:0:PIT 6 LEVEL,ELEV,1
P:0,1:WWRCLIMAT,PRECIP
P:3,1: 31.00, 37.00, 0.011040, (,,WWRCLIMAT,TEMPMIN,,1), (,,WWRCLIMAT,TEMPMAX,,1)
P:4,1:
E:2,1,1: 0.80000, (,,WWRCLIMAT,TEMPMIN,,1), (,,WWRCLIMAT,TEMPMAX,,1)
R:2,1: 1.0000
R:4,1,1: 96.00, (P:0:WWRCLIMAT,PRECIP), (3.556,1), (0.10092,1)
R:7,1: 0.2170
R:8,1: 95.00
F:2,1: 1.0000
S:2,1: 1.0000
S:4,1,1: (10.237,1), 0
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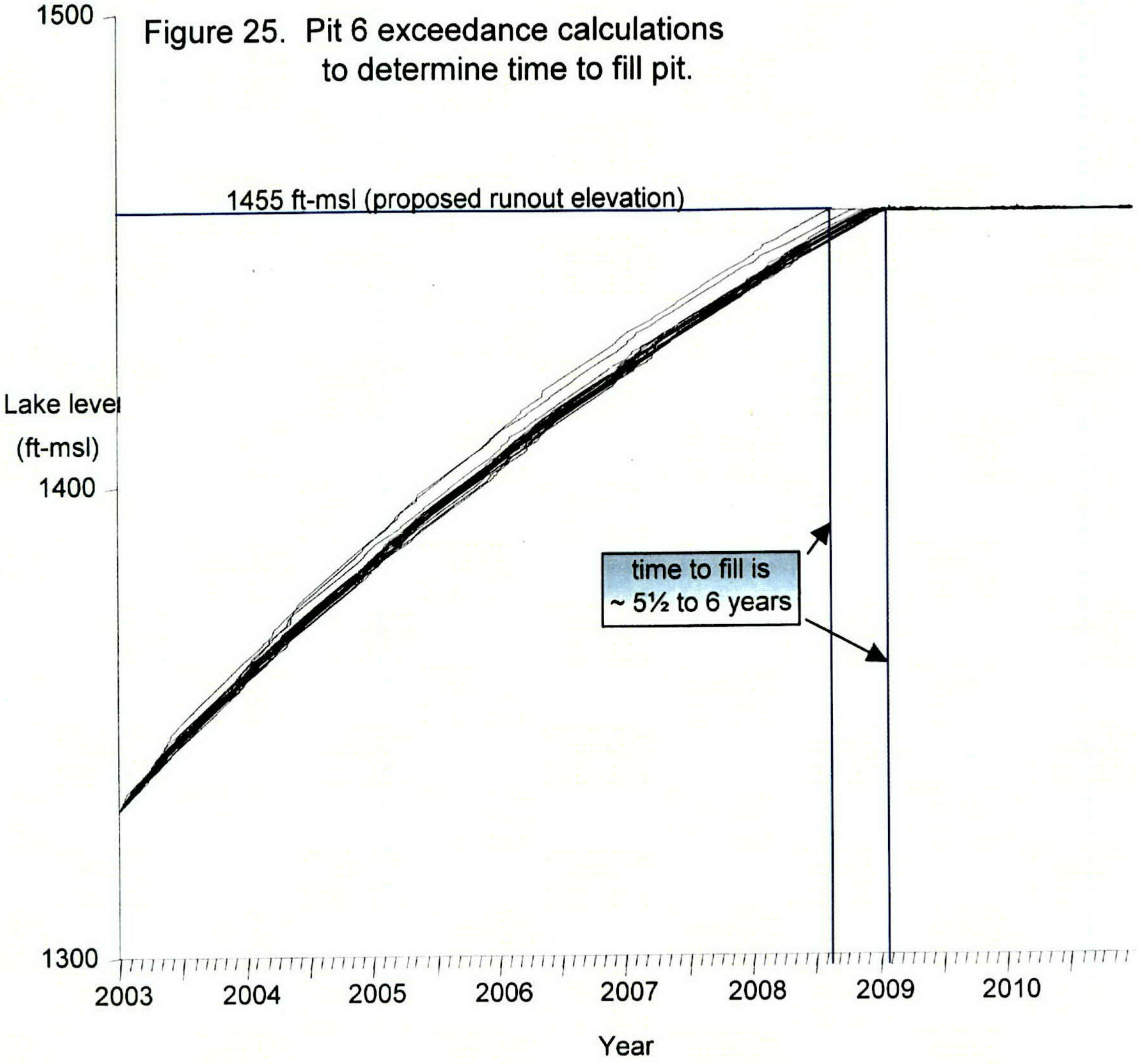


Figure 25. Pit 6 exceedance calculations to determine time to fill pit.

Figure 26. Predicted discharge from Pit 6 using a climate file covering 01 December 1951 - 29 September 1962.

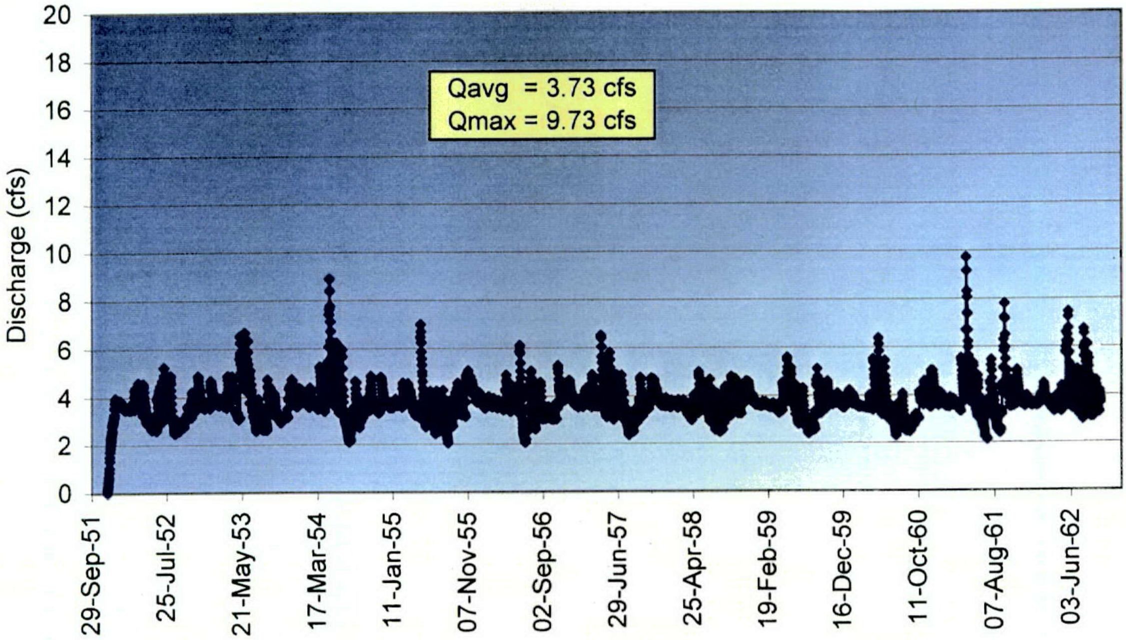
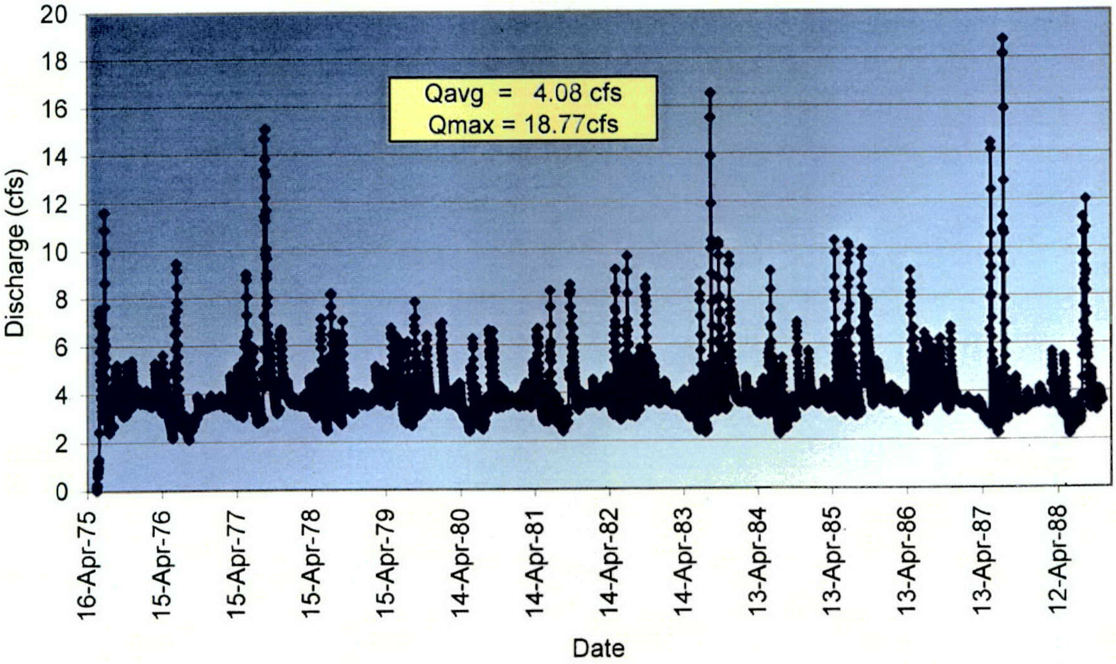


Figure 27. Predicted discharge from Pit 6 using a climate file covering 01 June 1975 - 15 November 1988.



Hydrologic Setting

Whitewater Reservoir and Colby Lake are located in the south portion of the study area adjacent to Hoyt Lakes (Figure 28). Whitewater Reservoir has a watershed area of 3174 acres. Two dikes were constructed to create the reservoir. The west dike is approximately 1800 ft long and the south dike is approximately 3000 ft long. Prior to LTV closing, water levels fluctuated in excess of 10 feet, mostly due to high seepage loss and operation of the Diversion Works.

Colby Lake, with a watershed area of 81771 acres (Figure 29), served as a source of water for taconite processing for more than 50 years, and continues to provide cooling water for MP's power plant. When Erie Mining Company was issued Permit 49-135 in 1950, remnants of a logging dam controlled outflow from the lake. The permit required Erie to maintain Colby Lake at elevation 1439.0 ft-msl or higher, which at the time equated to 13 cfs outflow. The logging dam deteriorated over time, resulting in progressively higher outflow at elevation 1439 ft-msl. Consequently, in 1976, Erie Mining Company was granted permission to construct a 13.5-foot wide concrete and rock broad-crested weir with a runout elevation of 1438.5 ft-msl (elevation at which outflow to Partridge River would cease). The weir was designed to re-create the outlet capacity that existed at the time Permit 49-135 was issued. A new rating table (Table 1) established during this project confirmed lake outflow is still 13 cfs at lake elevation 1439 ft-msl, although a survey of the outlet suggested portions of the concrete weir have deteriorated. Because MP now holds Permit 49-135, they are required to maintain a minimum Colby Lake elevation of 1439 ft-msl.

Methods

The U.S. Army Corps of Engineers, Hydrologic Engineering Center-River Analysis System (HEC-RAS) model was used for modeling Colby Lake and WWR water levels. Unlike WATBUD, which is driven by climatic records, HEC-RAS requires quantification of all inflows and outflows

Partridge River is the major water balance component of Colby Lake. Flow data from the USGS Partridge River gaging station (04015475) exists for only the time period 19 September 1978 to 02 November 1988. Since a longer record of flow was needed to cover a wider range of climatic conditions, it was necessary to estimate Partridge River flow based on flow data from another river. Dunka River was chosen because of its proximity to and similarity with Partridge River. Dunka River empties into Birch Lake near Babbitt, about 18 miles northwest of Colby Lake. USGS gaging-station flow data for the Dunka River (05126000) exists for periods 01 October 1951 to 30 September 1962, and 01 February 1975 to 05 November 1980.

A statistical analysis was performed on an approximate two-year period for which Dunka River and Partridge River average daily flow data overlap (19 September 1978 to 05 November 1980). Regression analysis resulted in an r^2 value of 0.96 (Figure 30). An r^2 value of at least 0.70 is considered desirable for predictive

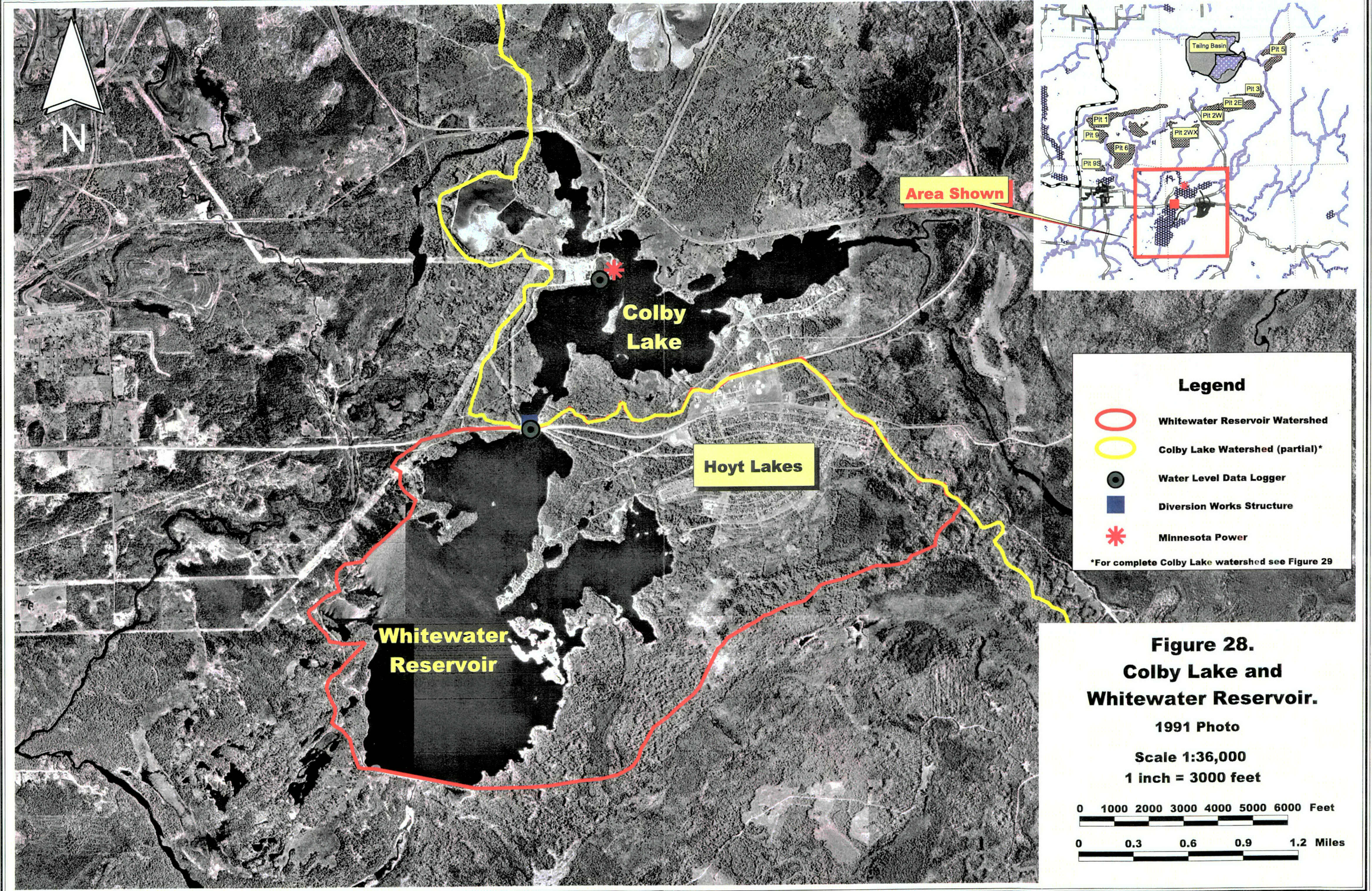


Figure 28. Colby Lake and Whitewater Reservoir.

1991 Photo

Scale 1:36,000
1 inch = 3000 feet

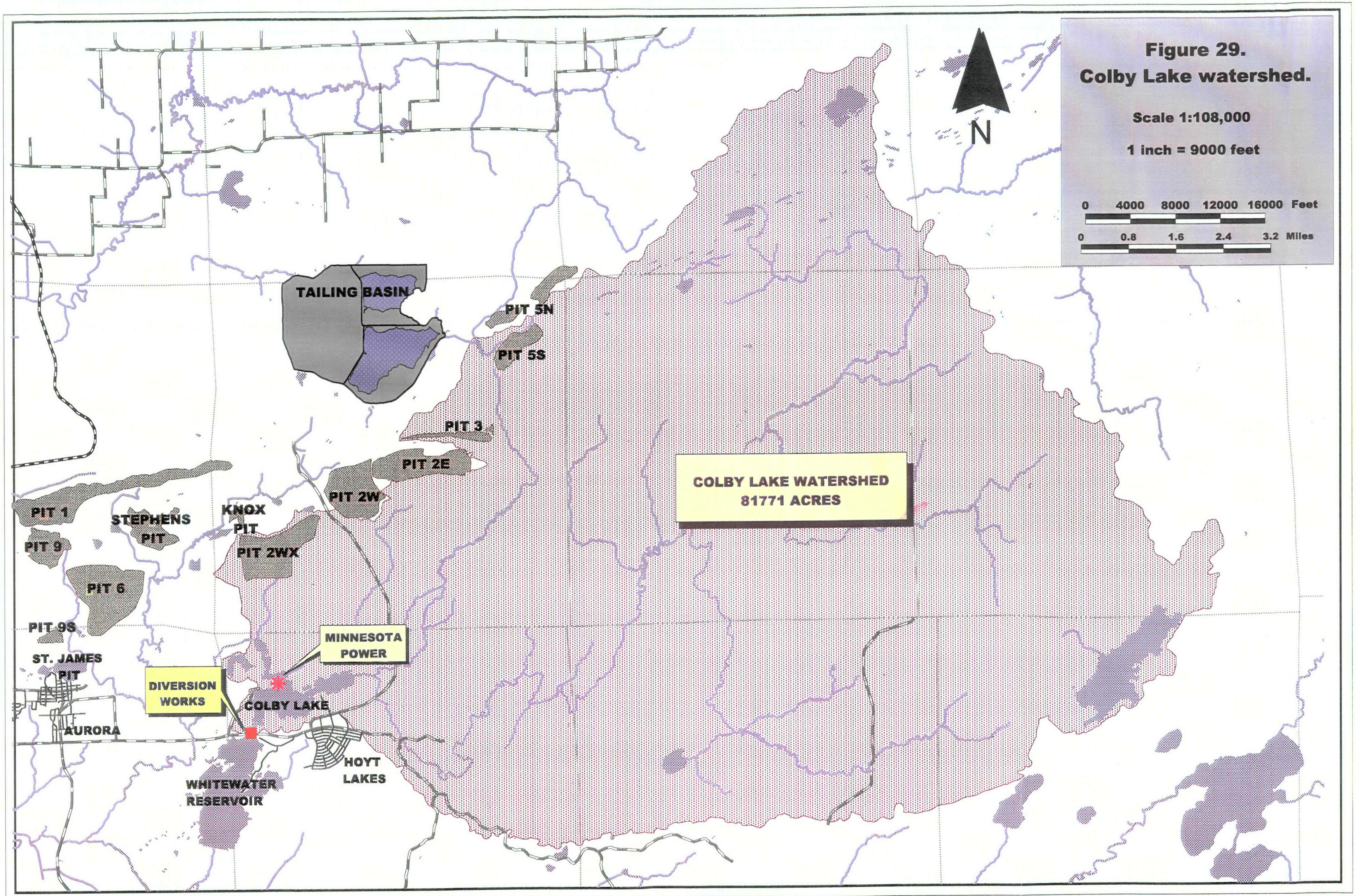
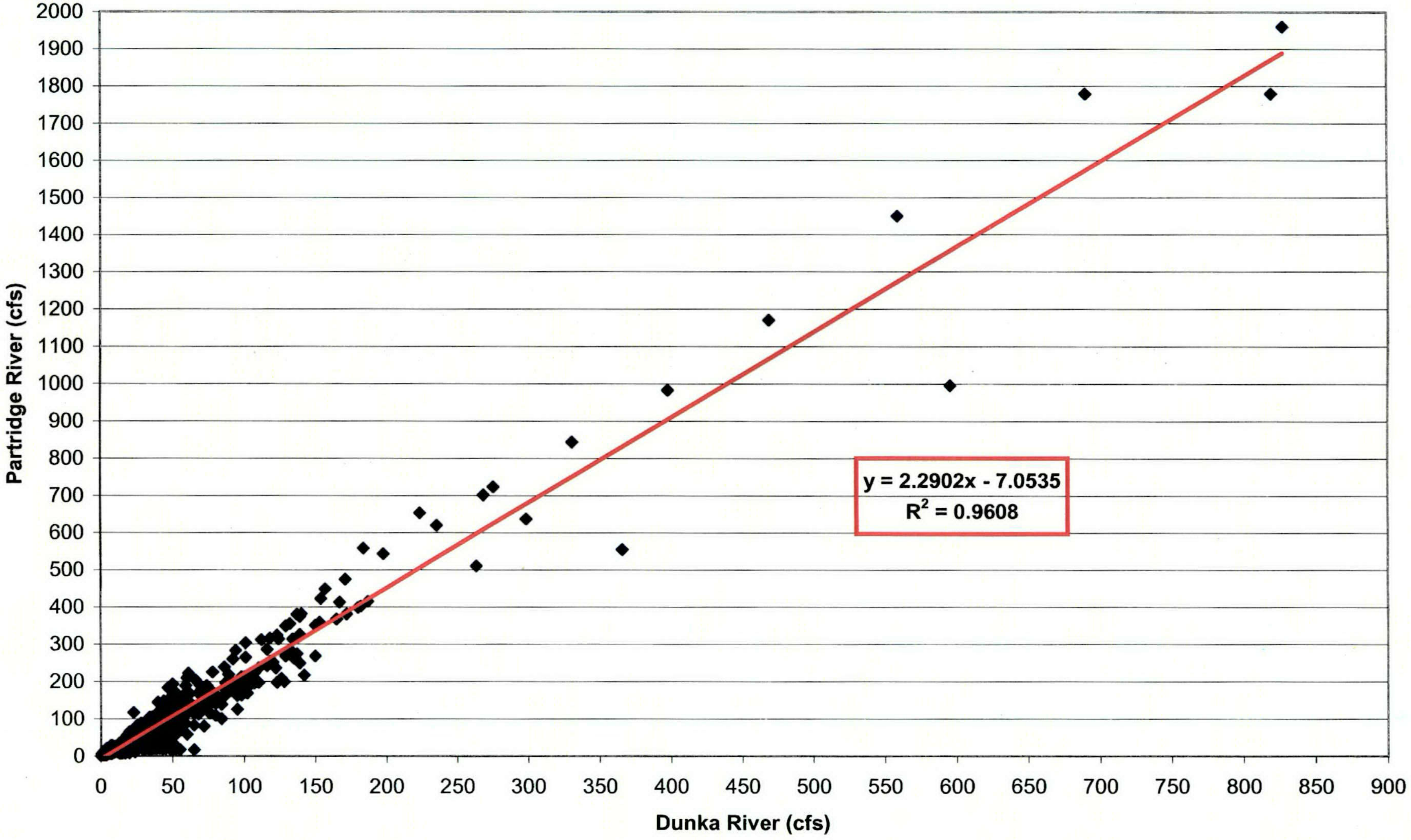


Figure 29.
Colby Lake watershed.

Figure 30. Dunka River vs. Partridge River daily flow data.



purposes, so it was concluded Dunka River data could be used to estimate Partridge River flow for the same time periods if further statistical tests were satisfied.

Using the handbook, *Linear Regression or if the Line Fits Can We Use it?* (Elsea 1977) as a guide the following four assumptions were tested: 1) Is the relationship significant? 2) Are errors independent? 3) Is the variance constant? 4) Are errors normal? Analysis confirmed flow data met all four assumptions. Further examination of the regression line suggested the relationship for low flow might differ from the relationship for high flow. To analyze this assumption, data were separated into two data sets, one for Dunka River flow less than or equal to 25 cfs and one for flow greater than 25 cfs (Figures 31 and 32). The r^2 values were 0.63 and 0.95, respectively, for low and high flows. Although these values were lower than the r^2 value for the entire data set, a review of residual errors showed improvement over results from the single data set.

The two regression equations were used to estimate average daily flows for the time periods 01 October 1951 to 30 September 1962, and 01 February 1975 to 18 September 1978. From 19 September 1978 to 02 November 1988, actual Partridge River data were used, resulting in a record of flow data for approximately twenty-four years.

In addition to predicting flow for Partridge River, it was necessary to predict flows for Wyman Creek, two Unnamed Creeks, and remaining local watershed. Daily flows for these ungaged watersheds were estimated using a unit-area extrapolation from Partridge River. In addition, WATBUD was used to estimate average daily runoff values for WWR for the Dunka time periods as input to HEC-RAS.

One of the most important components of the water balance for Whitewater Reservoir was seepage loss through the dikes. Barr Engineering calculated the amount of seepage loss in a 1964 report, *Rate of Seepage from Whitewater Reservoir – Hoyt Lakes, Minnesota*. Winter water levels collected during the project were analyzed to determine if the relationship Barr established between reservoir water levels and seepage loss was valid for present conditions. The range of water levels examined was not as great as for the five years analyzed by Barr. Project water levels ranged from 1436.33 to 1439.97, while the levels in Barr's report ranged from 1429.5 to 1440.3. Comparison of seepage loss was most important at high water levels where maximum seepage loss occurred. Seepage loss calculations during winters of 2001 and 2002 compared very favorably to Barr's calculations. Therefore, Barr's seepage relationship was used in the predictive model since it was anticipated water levels would fall below those collected during the project.

Other inputs to the HEC-RAS model included information on channel geometry for each of the input and output streams, bathymetric relationships for Colby

Figure 31. Dunka River vs. Partridge River daily low flow data (0-25 cfs).

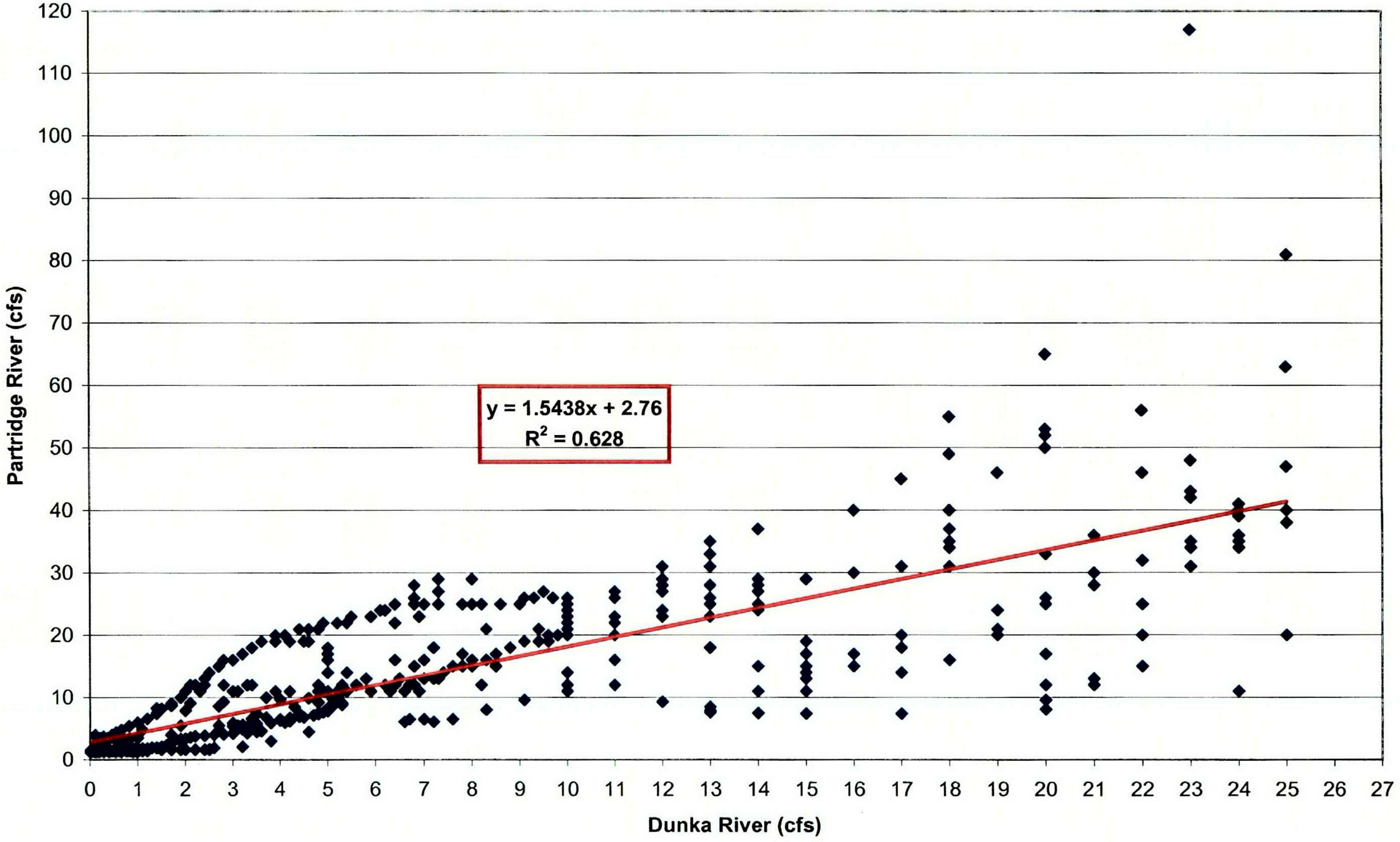
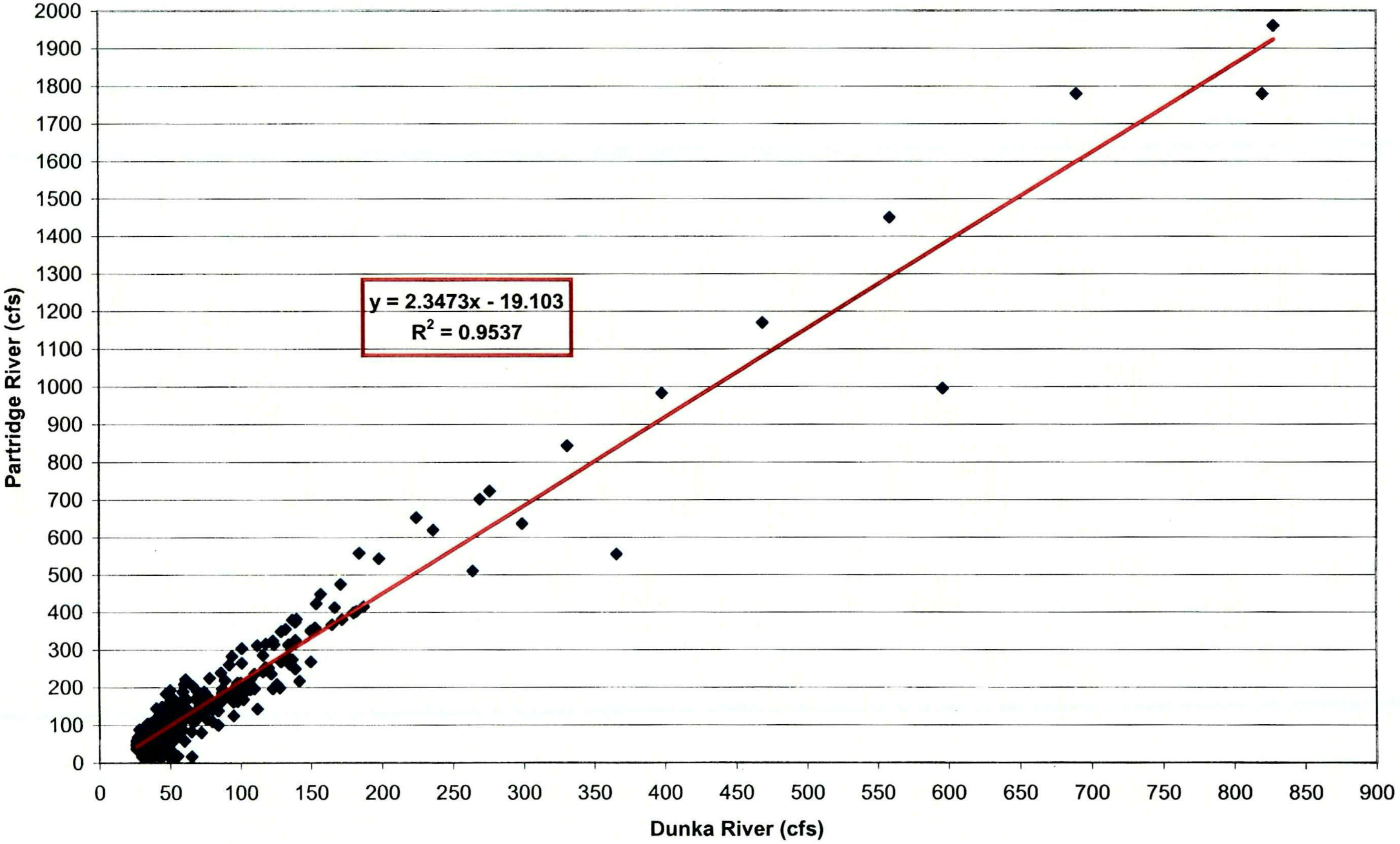


Figure 32. Dunka River vs. Partridge River daily high flow data (>25 cfs).



Lake and WWR, the hydraulic capacity of the Diversion Works gate, and a new Colby Lake rating table (Figure 3).

Calibrated Model

The WATBUD calibrated model and parameter file for Whitewater Reservoir are shown in Figures 33 and 34. The calibrated model does a good job of simulating actual water levels even during times of water transfer between Whitewater Reservoir and Colby Lake.

Figure 35 shows water balance components used in the HEC-RAS model calibration. Continuous water level data for Colby Lake, Partridge River, and Whitewater Reservoir from May 2002 through May 2003, along with estimates for inflows from ungaged watersheds, were used as the basis for calibration. Minnesota Power provided gate and pump operation details from Diversion Works records for this time period. Figures 36 and 37 show calibration results for Colby Lake and Whitewater Reservoir. The model does a good job of accurately simulating observed water levels.

Figure 33. Whitewater Reservoir calibrated model and recorded water levels.

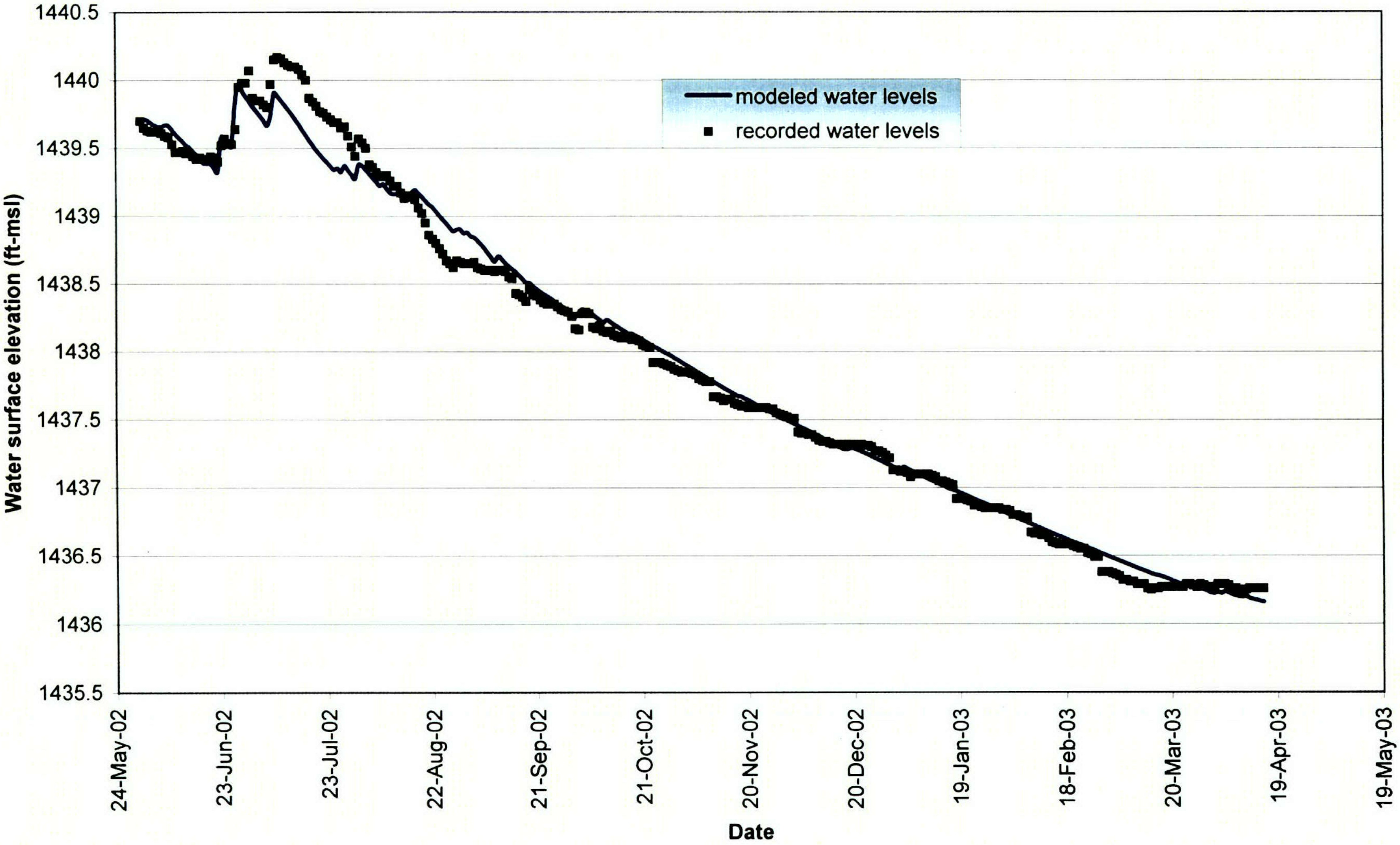


Figure 34. Whitewater Reservoir WATBUD parameter file for calibrated model. (see Figure 2 for detailed description of components)

```
3174
18
1425,792,23096,0
1426,820,23854,1.08
1427,849,24637,1.11
1428,878,25446,1.24
1429,907,26281,1.55
1430,936,27144,1.73
1431,965,28035,2.17
1432,994,28955,2.55
1433,1023,29906,3.1
1434,1051,30887,3.7
1435,1080,31901,4.8
1436,1109,32948,5.88
1437,1138,34030,7.43
1438,1167,35174,9.63
1439,1196,36301,12.38
1440,1225,37493,15.79
1441,1254,38723,0
1442,1282,39995,0
B:0:C:\WBLAKE\WWR\
L:0:WL_HECRAS,ELEV,1
P:0,1:WWRCLIMAT,PRECIP
P:3,1: 31.00, 38.00, 0.011040, (,,WWRCLIMAT,TEMPMIN,,1),
(,,WWRCLIMAT,TEMPMAX,,1)
P:4,1:
E:2,1,1: 0.8000, (,,WWRCLIMAT,TEMPMIN,,1), (,,WWRCLIMAT,TEMPMAX,,1)
R:2,1: 1.0000
R:4,1,1: 87.00, (P:0:WWRCLIMAT,PRECIP), (0.8256,1), (1.1676,1)
R:7,1: 1.2170
R:8,1: (100.00,1)
F:0:WWRCLIMAT,HLWW
F:2,1: 1.0000
F:0:WWRCLIMAT,PUMPGATE
F:2,1: 1.0000
S:2,1: 1.0000
S:4,1,1: (0.8781,1), 0
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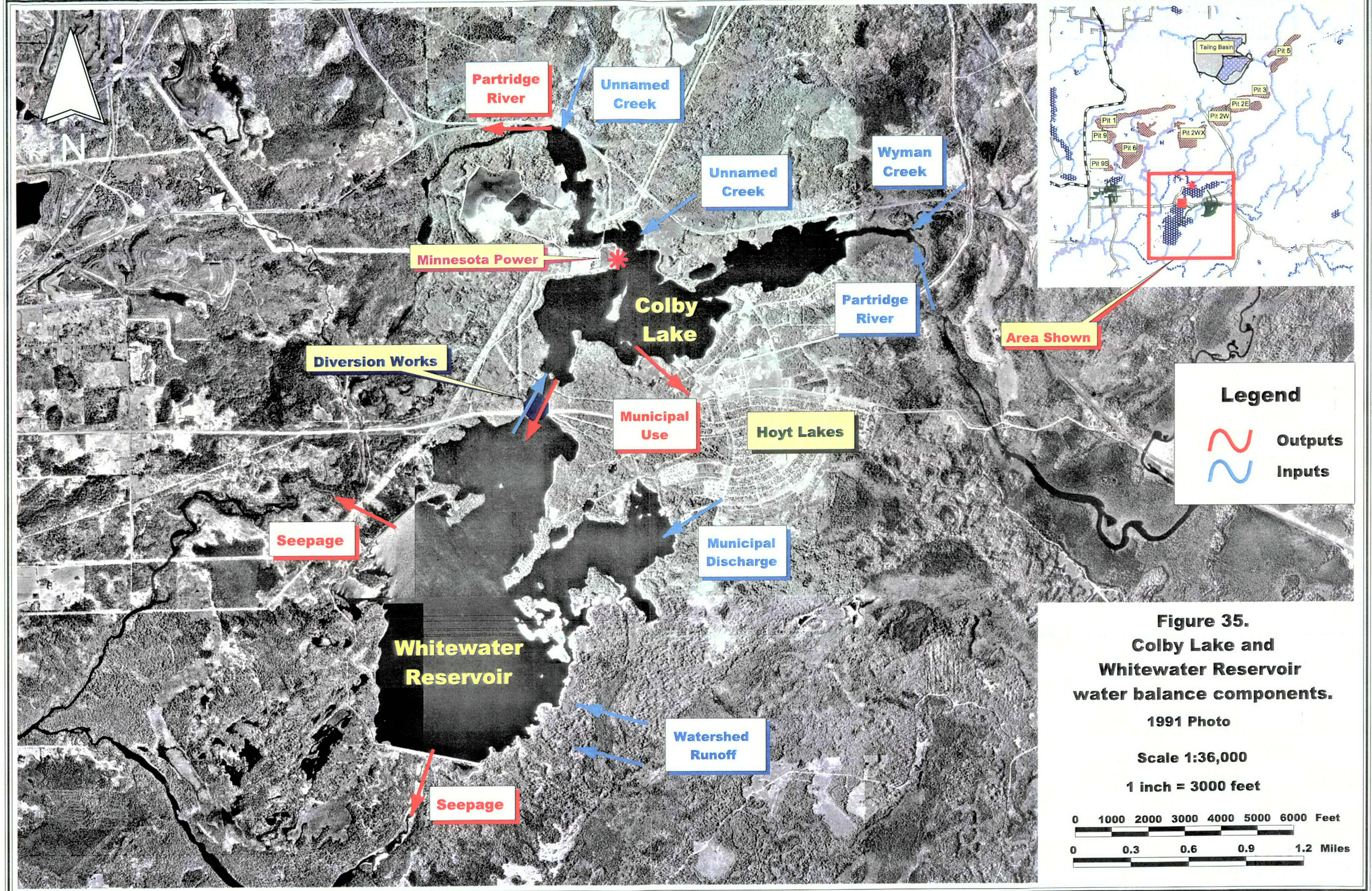


Figure 35.
Colby Lake and
Whitewater Reservoir
water balance components.
1991 Photo

Scale 1:36,000

1 inch = 3000 feet

Figure 36. Colby Lake HEC-RAS model calibration.

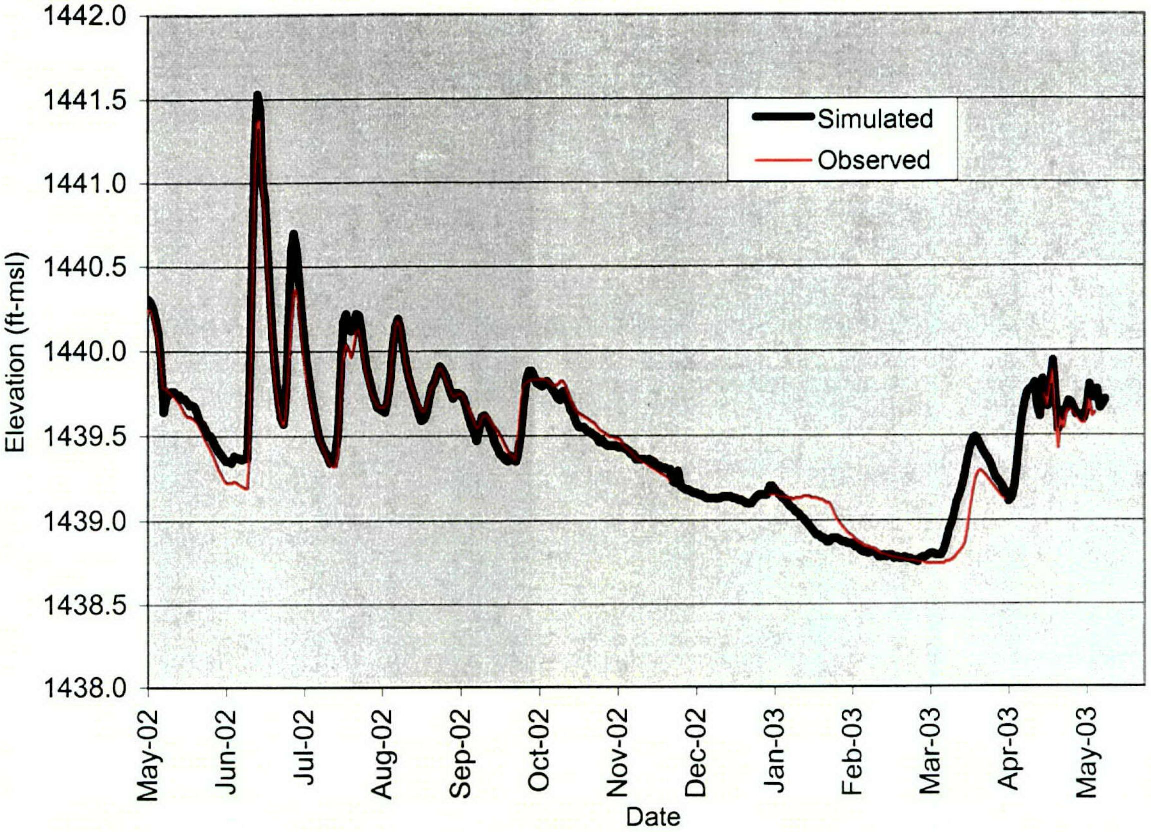
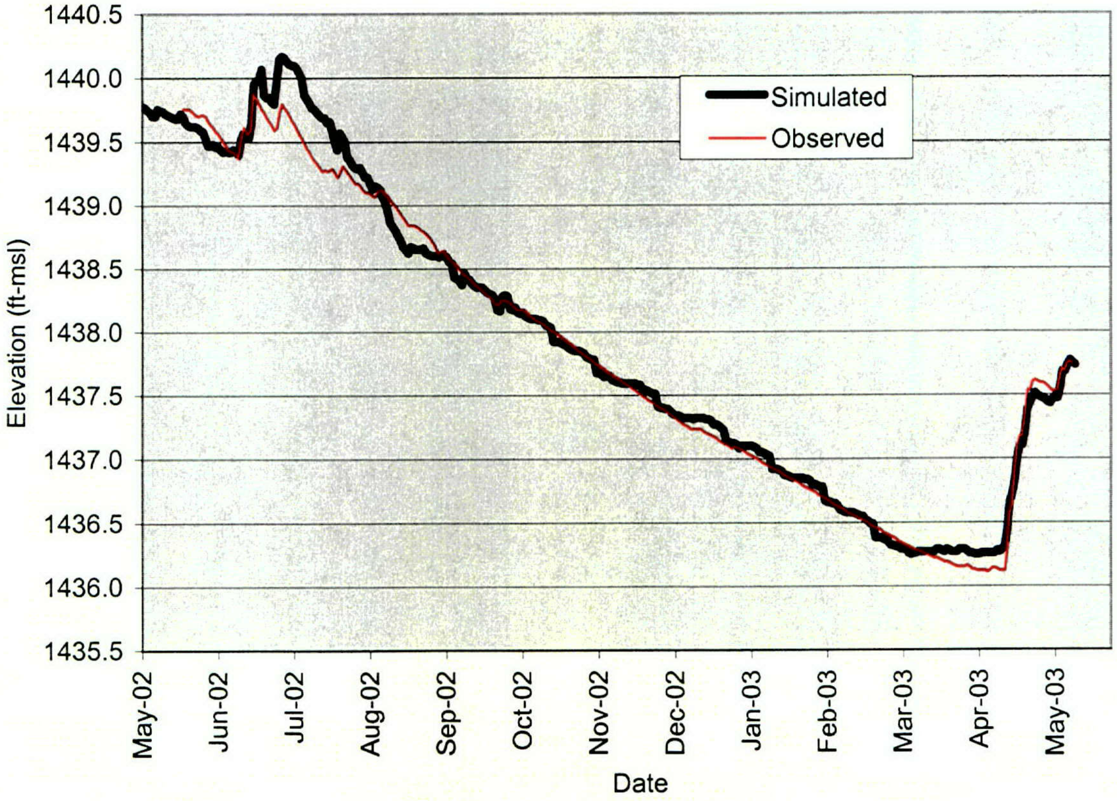


Figure 37. Whitewater Reservoir HEC-RAS model calibration.



Predictive Model

HEC-RAS was used to model effects on Colby Lake and Whitewater Reservoir water levels from selected Diversion Works gate management options, and future inflow from Pit 2WX. Although both Dunka time periods were modeled, a comparison of predicted water levels for the first Dunka time period (Figures 38 and 39) with those from the second Dunka time period (Figures 40 and 41) shows similarity in predicted water levels. The second time period was considerably wetter than the first time period, providing an excellent evaluation of water levels under wet conditions. It also contains the driest year (1976) for the combined time periods. Because of these characteristics, only predictions for the second time period are included in the remainder of this report.

The two extremes of operation used for modeling were *gate-closed*, thereby allowing no water to flow from Colby Lake to Whitewater Reservoir, and *gate-open 4 feet*, allowing a continuous flow of water from Colby Lake to Whitewater Reservoir. Figure 42 illustrates the resulting effect on Whitewater Reservoir. Under the *gate-closed* option, Whitewater Reservoir water levels stabilized between 1432 ft-msl and 1434 ft-msl. This is approximately 5 to 7 feet below the normal pool elevation of 1439 ft.-msl. The *gate-open 4 feet* option resulted in water levels fluctuating around the normal pool elevation, between 1438 ft-msl and 1442 ft-msl. Surface runoff is the dominant factor affecting water levels under this option, resulting in a wider range of levels.

Three other management options were modeled between these extremes (Figure 40). They were 1) *weir @ elevation 1439.8,* placing a weir in one of the gates with a fixed crest elevation of 1439.8 ft-msl, while keeping the other two gates closed, 2) *gate open 0.1 ft.,* opening one gate 0.1-feet, and 3) *elevation-gate,* opening one gate 4 feet whenever Colby Lake exceeded a water level of 1439.25 ft-msl. The elevations specified in options 1 and 3 were selected to provide reasonable inflow to Whitewater Reservoir while minimizing the probability of Colby Lake water levels falling below the 1439 ft.-msl threshold.

Colby Lake water levels resulting from the 5 management options are illustrated in Figures 43-46. Figure 43 and 44 show predicted water levels for the second Dunka time period, while Figures 45 - 46 focus on the years 1976 through 1978. Year 1976 is the second driest year in 111 years of record. Years 1977 and 1978 are the 13th and 23rd wettest years. These three years give a good range of response of Colby Lake water levels under extreme precipitation conditions.

Colby Lake water levels frequently drop below the lowest permitted elevation of 1439 ft-msl, even under the *gate-closed* option. Increased incidence of low Colby Lake water levels is demonstrated by a comparison between *gate-closed* and *gate-open 4 feet* (Figure 43). During the *gate-open 4 feet* simulation, low water levels are consistently below the *gate-closed* simulation and drop below Colby Lake's runout elevation (1438.5 ft.-msl) several times. High water levels are not appreciably affected by

Figure 38. Whitewater Reservoir HEC-RAS simulated lake levels.
(1952 - 1961)

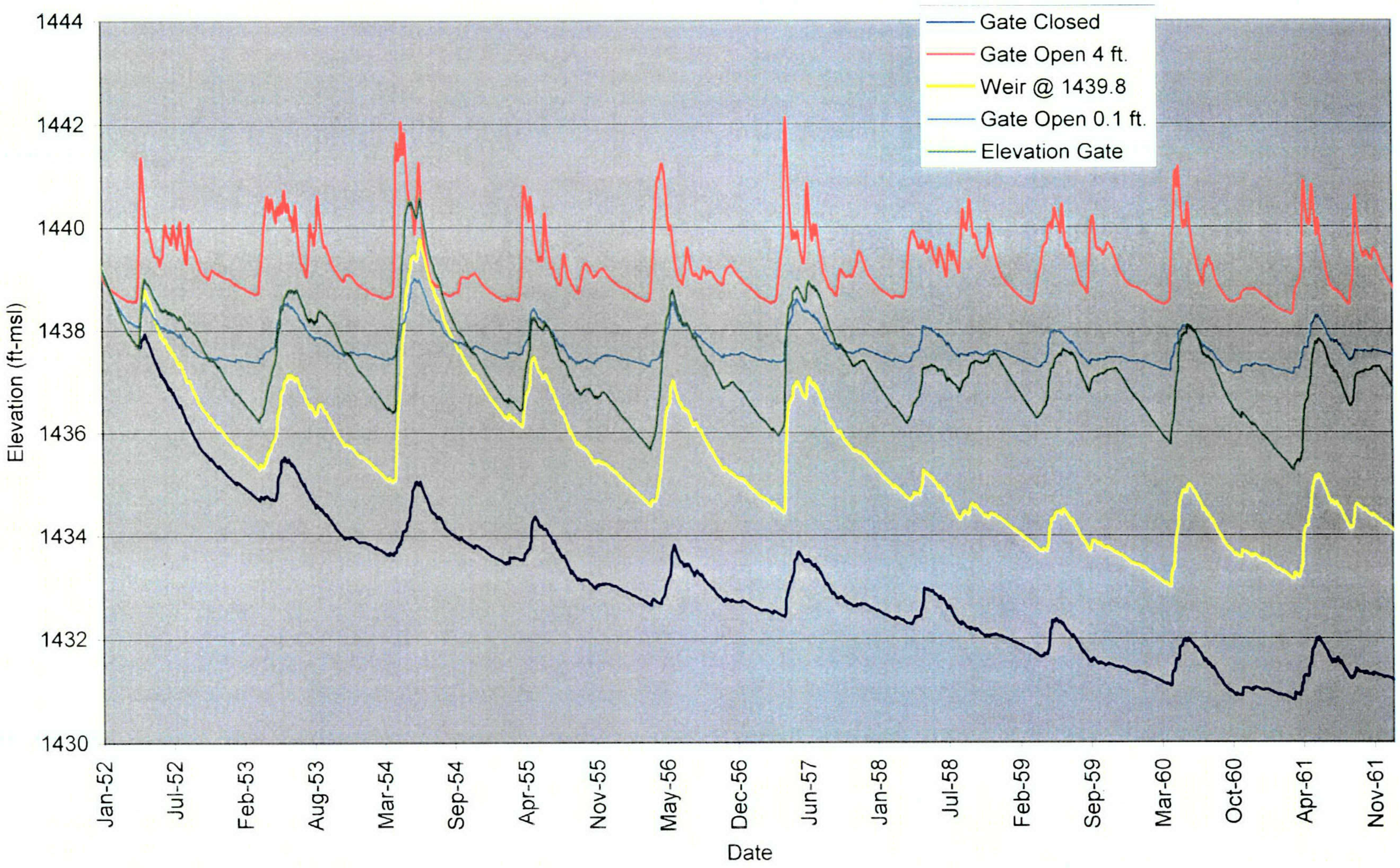


Figure 39. Colby Lake HEC-RAS simulated lake levels.
(1952 - 1962)

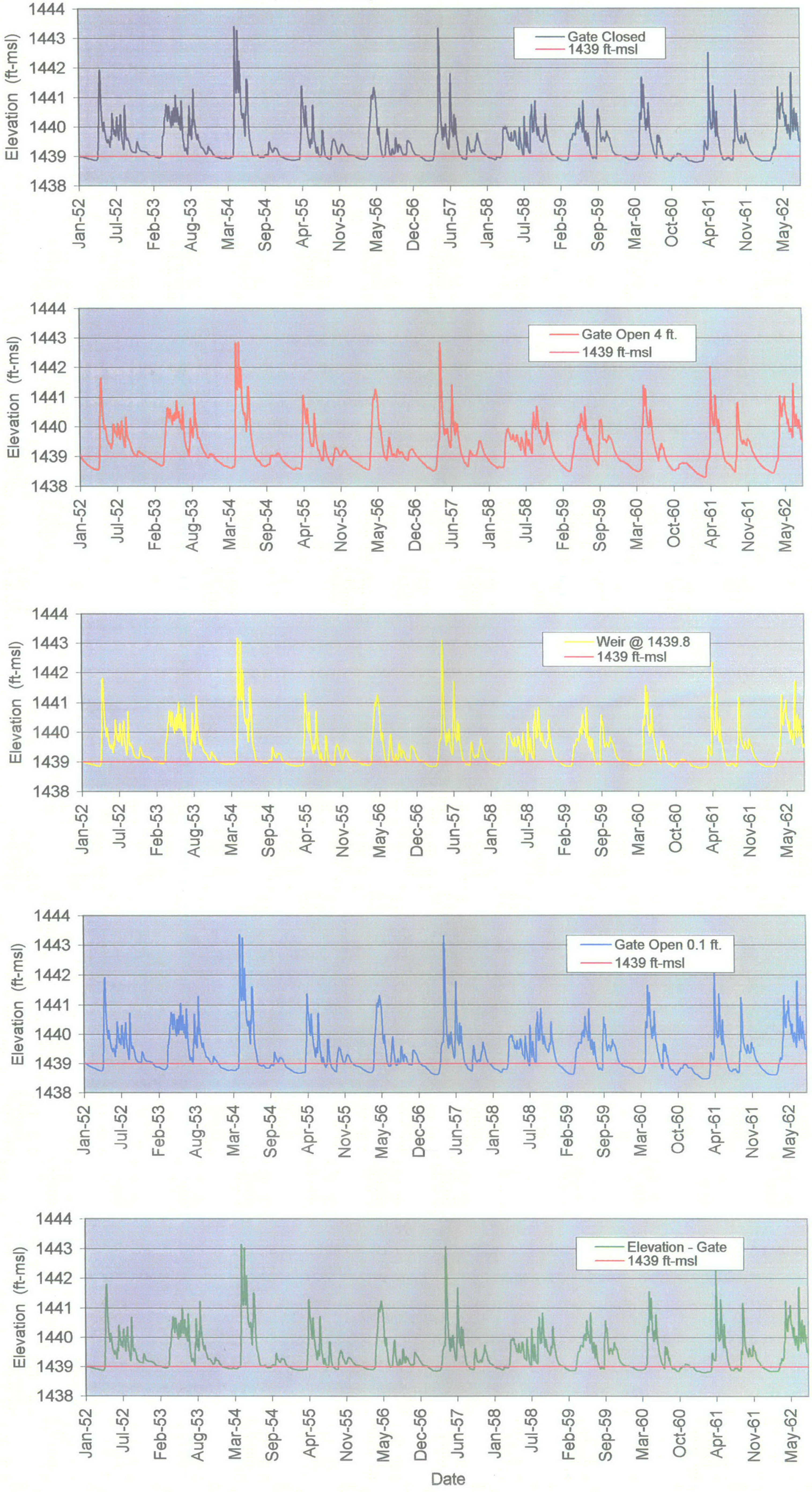


Figure 40. Whitewater Reservoir HEC-RAS simulated lake levels.
(1976 - 1988)

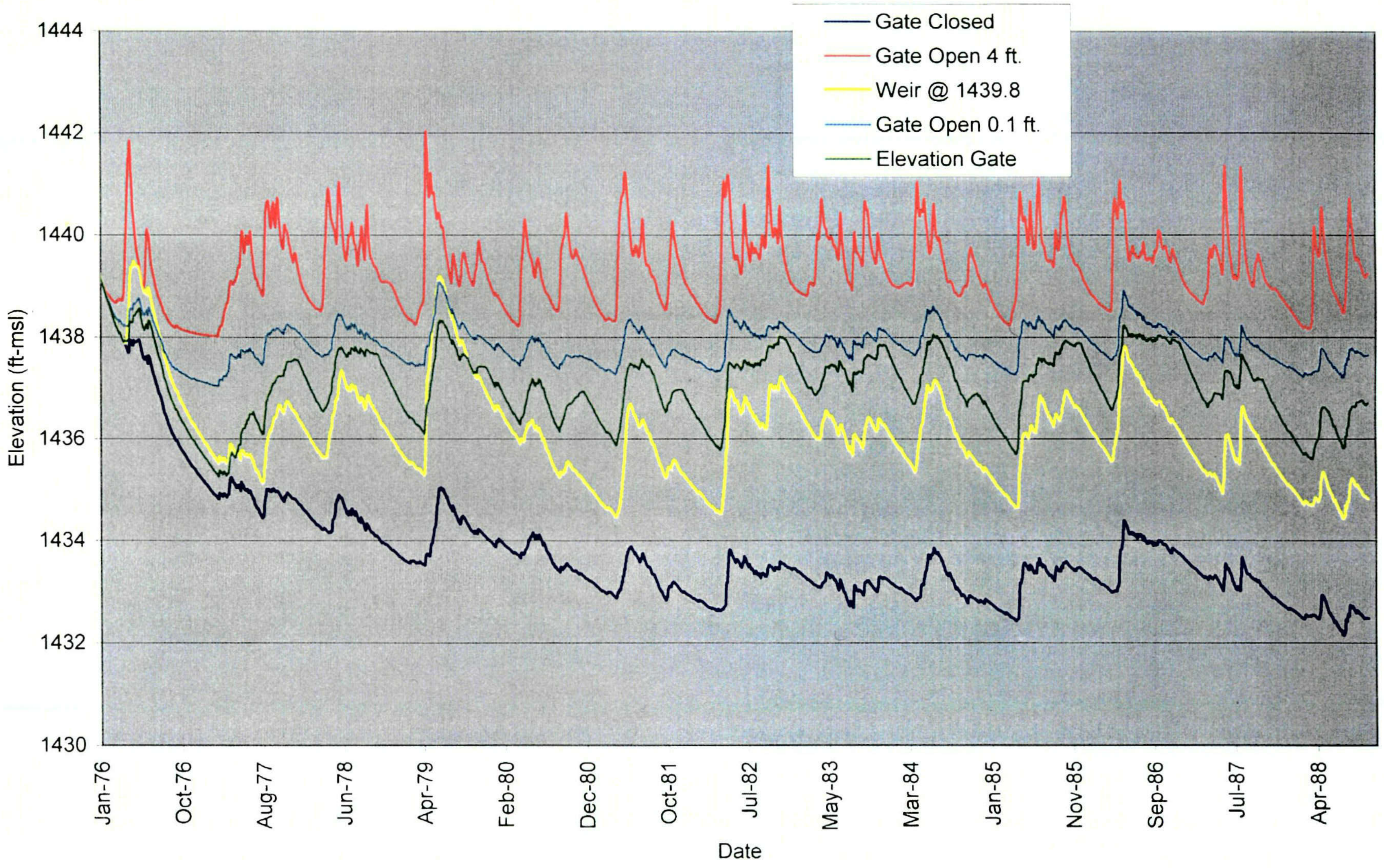


Figure 41. Colby Lake HEC-RAS simulated lake levels. (1976 - 1988)

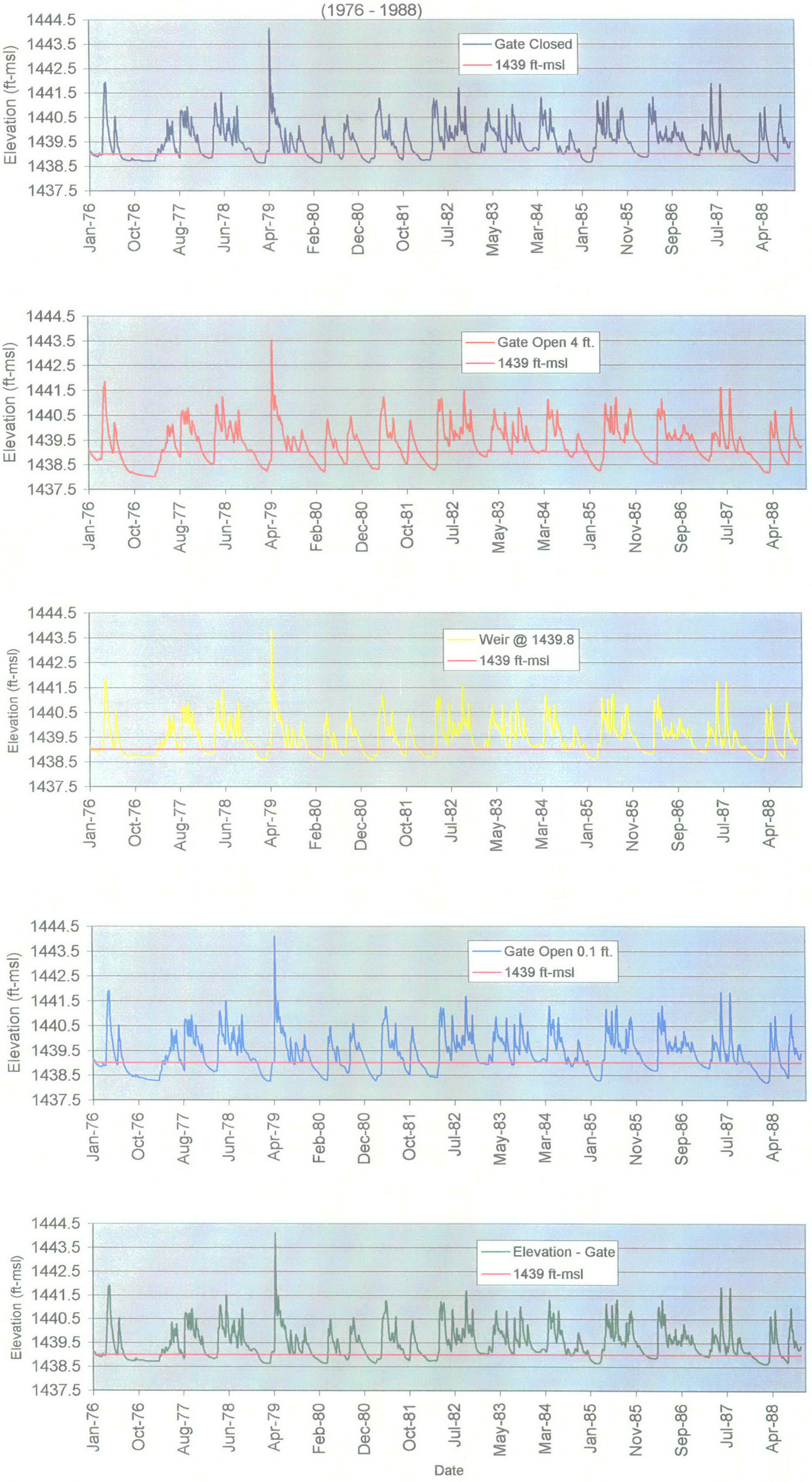


Figure 42. Whitewater Reservoir HEC-RAS simulated lake levels.
(1976 - 1988)

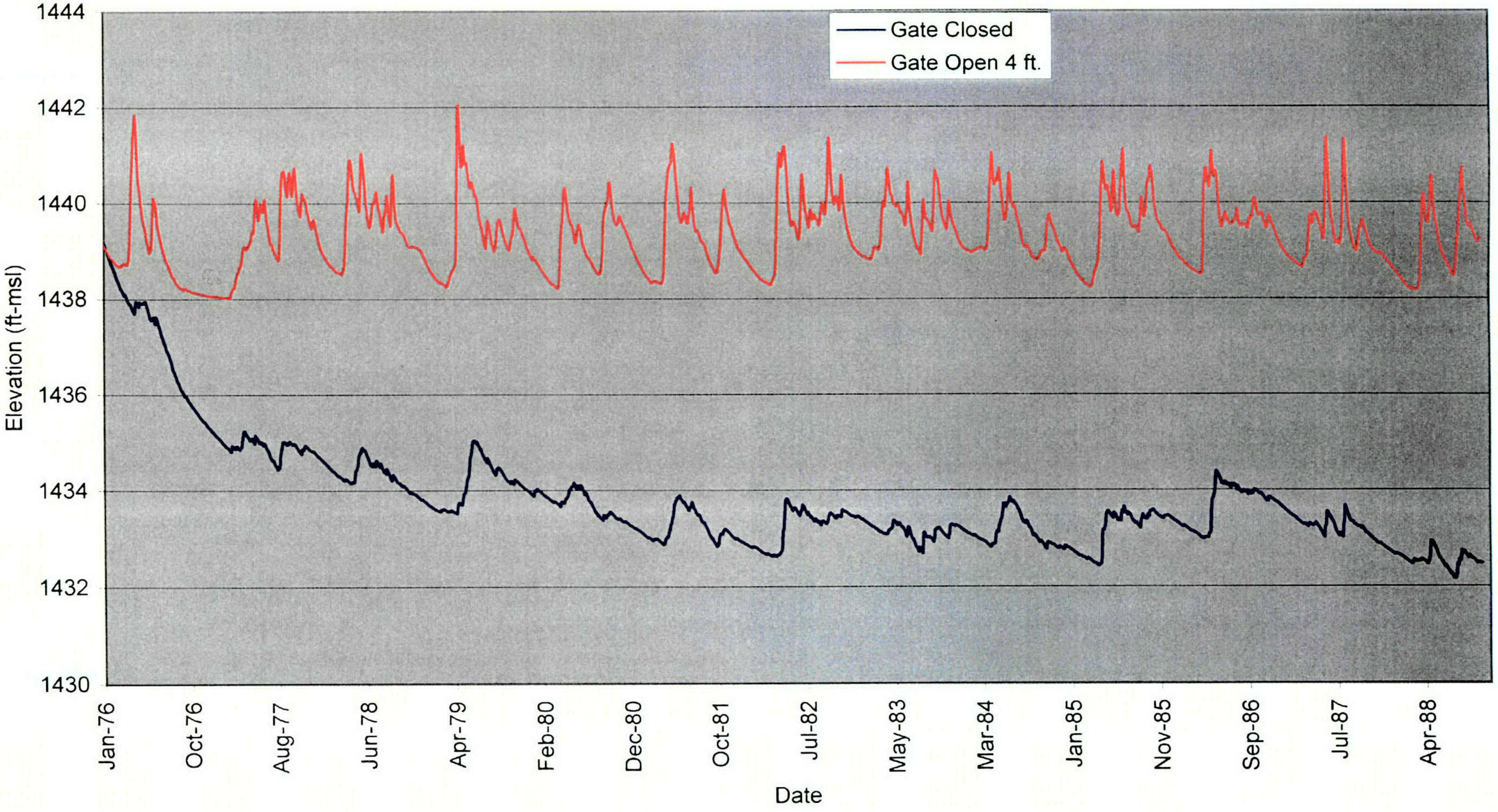


Figure 43. Colby Lake HEC-RAS simulated lake levels.
(1976 - 1988)

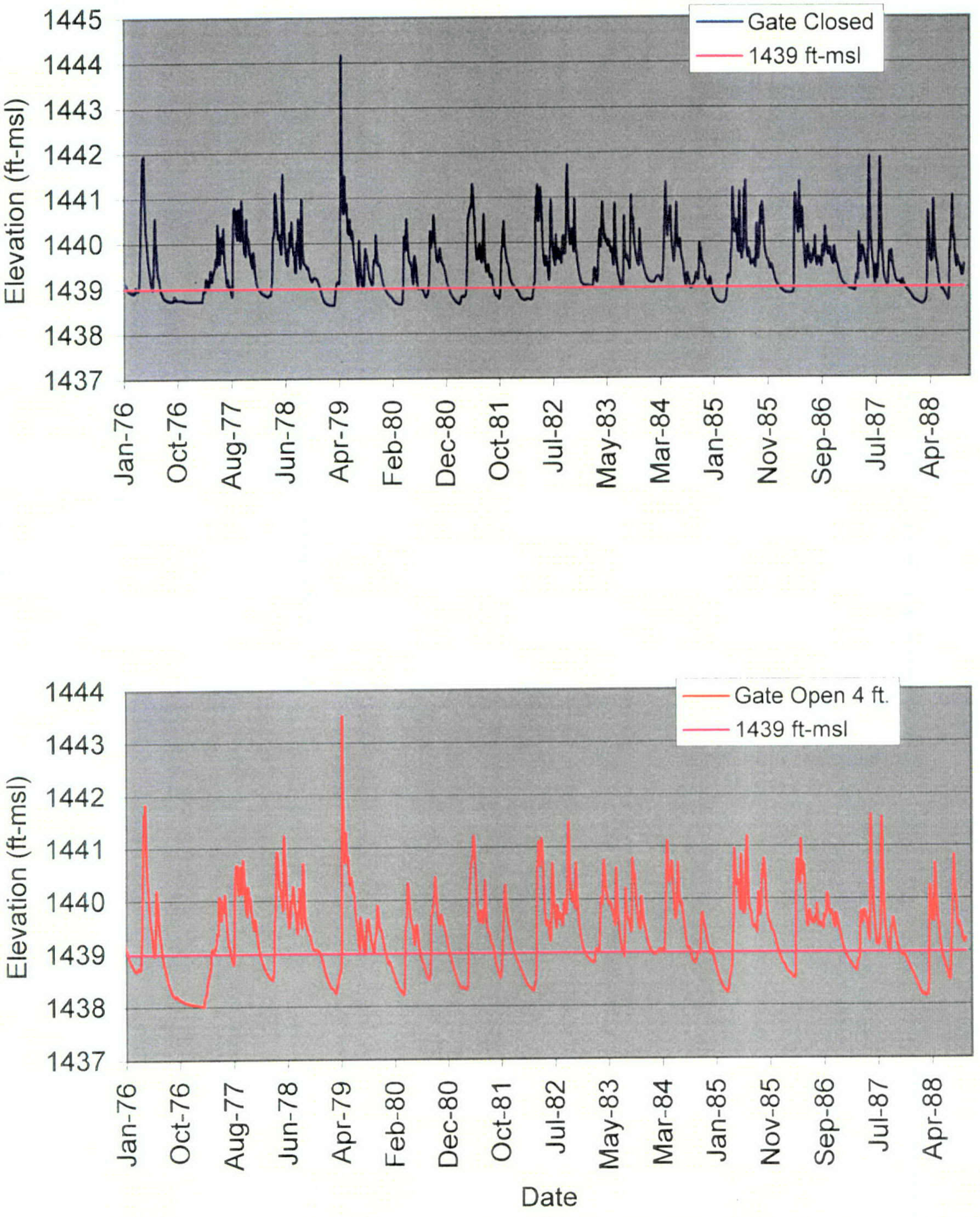
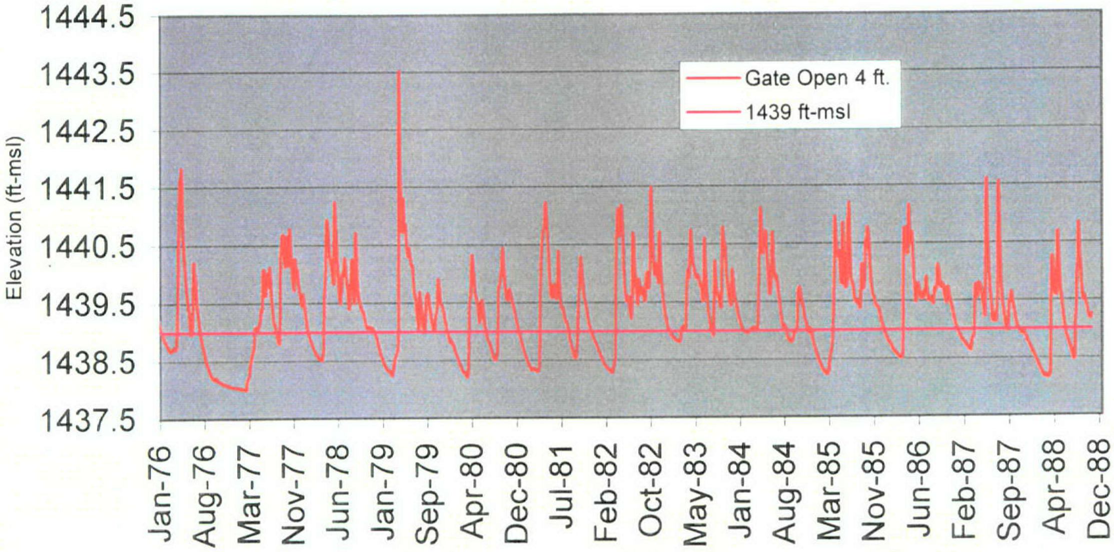


Figure 44. Colby Lake HEC-RAS simulated lake levels.
(1976 - 1988)



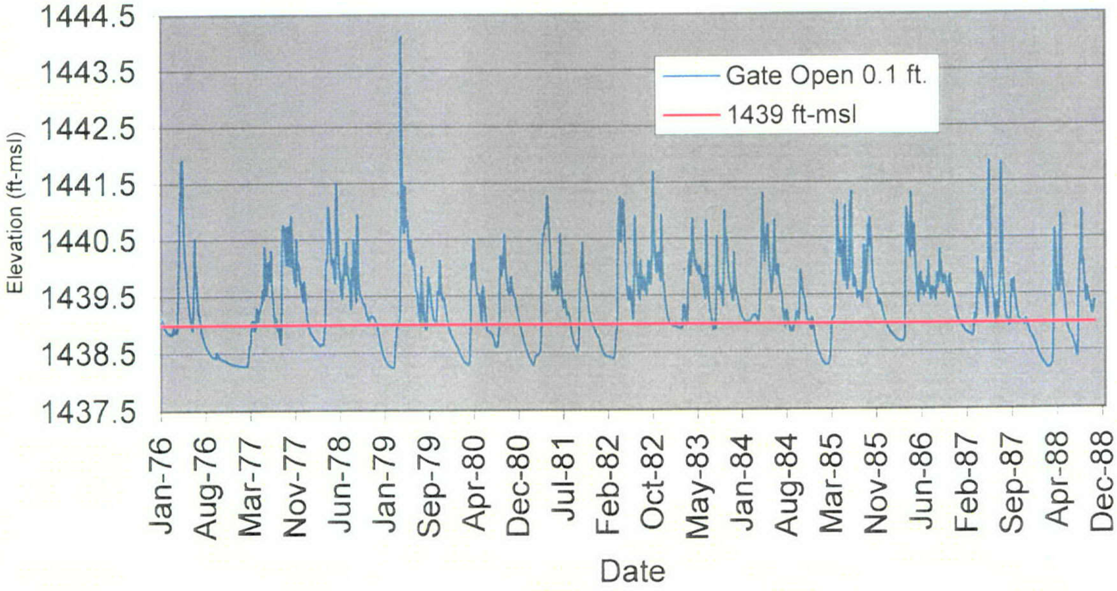


Figure 45. Colby Lake HEC-RAS simulated lake levels.
(1976 - 1978)

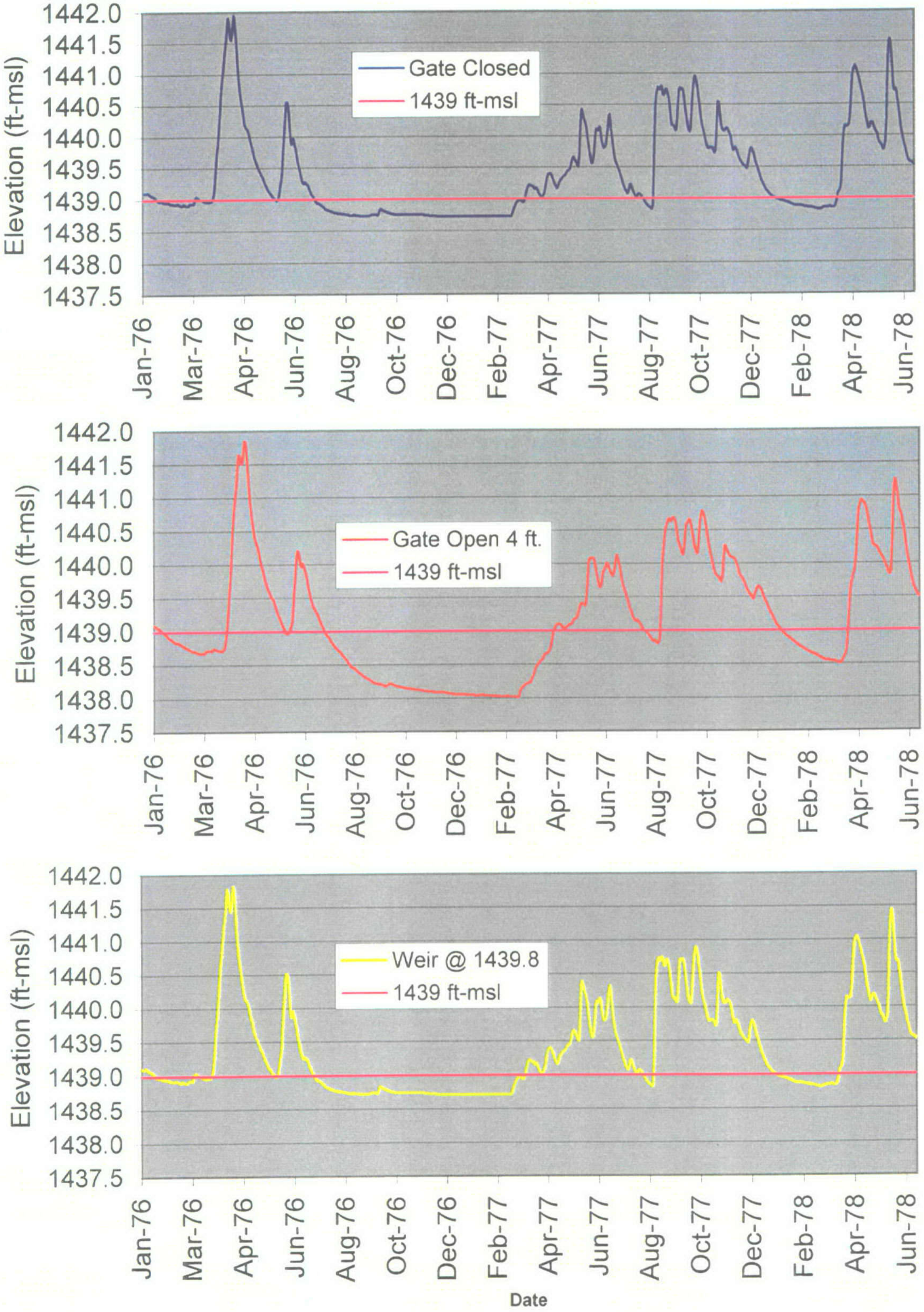
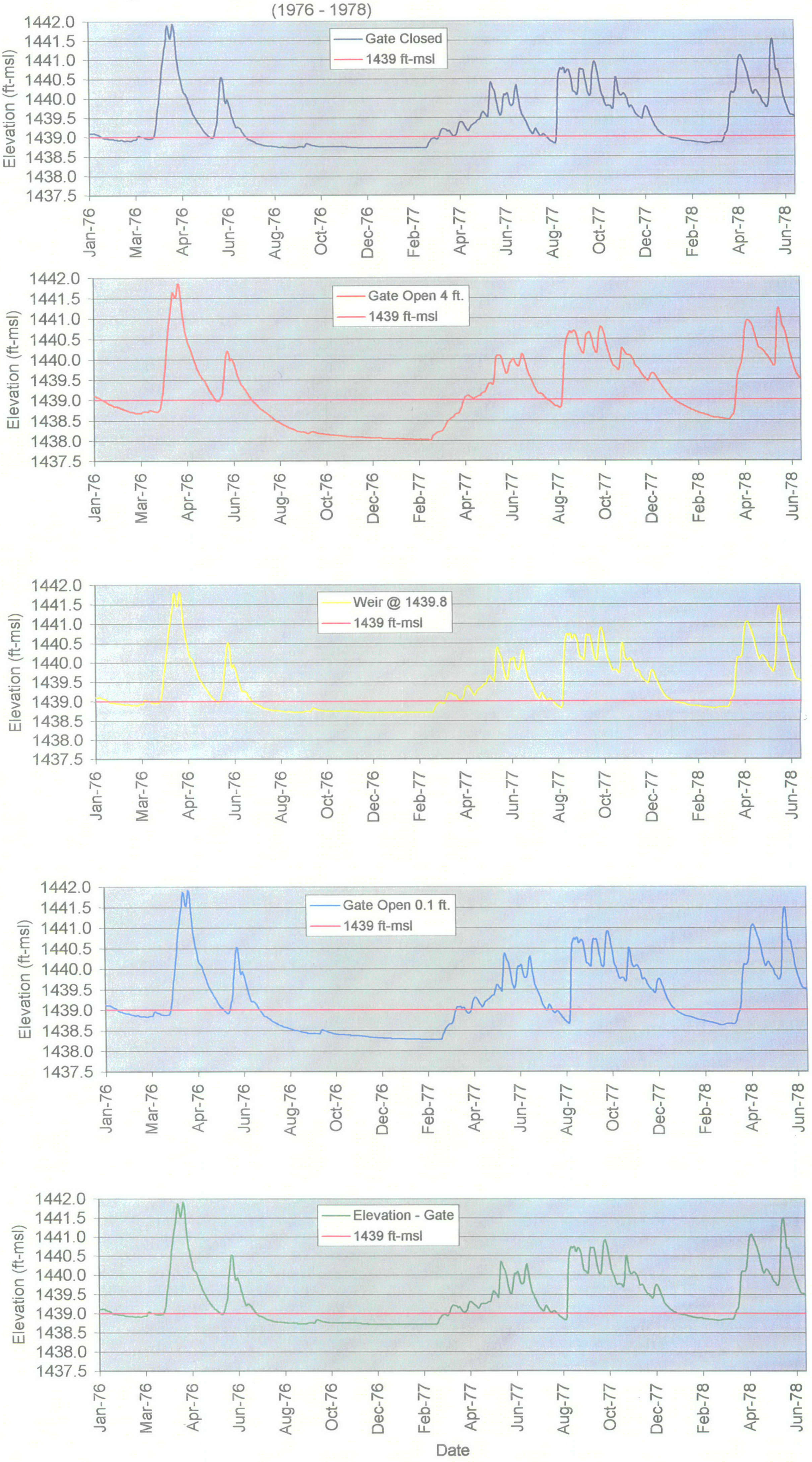


Figure 46. Colby Lake HEC-RAS simulated lake levels.
(1976 - 1978)



gate management options, which points out the low storage capacity of Colby Lake. It is essentially a pass-through system with a hydrograph that rises and falls quickly in response to precipitation or snowmelt events.

Water levels also drop below the lake's runout elevation for the *gate-open 0.1 ft.* option, resulting in no lake outflow (Figure 44). Since the *gate-closed* option is the most favorable for Colby Lake water levels, it follows that any other management option evaluated for this project will result in water levels below 1439 ft-msl a greater percentage of time.

Years 1976 through 1978 also illustrate disparity in low water levels between the *gate-open* and *gate-closed* options. Figure 45 shows how the *weir @ elevation 1439.8* ft-msl option is nearly identical to the *gate-closed* option except for the highest water levels. The *gate-open 0.1-feet* and *elevation-gate* options are included in Figure 46. The *elevation-gate* option is very similar to the *gate-closed* option during both wet and dry conditions. The *gate-open 0.1-foot* option is nearly the same as the *gate-open 4 feet* option with water levels dropping below runout for an extended period of time in 1976.

Diversion of Second Creek to Colby Lake

Minnesota Power has an interest in increasing flow to Colby Lake during dry periods. Higher lake levels would better enable them to meet permit requirements. One possible method for meeting their goal would be to divert the headwaters of Second Creek into Knox Pit, and then into Pit 2WX, which would outflow to Colby Lake (Figure 47).

Impacts on Colby Lake from this diversion were modeled using HEC-RAS. Second Creek flow estimates were made using a unit-area extrapolation from Partridge River data (Figure 48). It was assumed that only 75% of Second Creek flow was diverted. This amount was added to outflow from Pits 2E and 2W, and routed through Knox Pit to Pit 2WX. The combined outflow from Pit 2WX was then routed to Colby Lake.

Effects of Pit 2WX outflow alone on Colby Lake were not modeled because combined flows from Pits 2E, 2W, 2WX, and 75% of Second Creek flow did not appreciably raise Colby Lake water levels during dry periods (Figures 49).

C. Tailing Basin

Objective

The analysis objective for the tailing basin was to estimate future static water levels for the three cells. This information will provide the DNR and CE with information that allows them to produce an acceptable watershed reclamation plan.

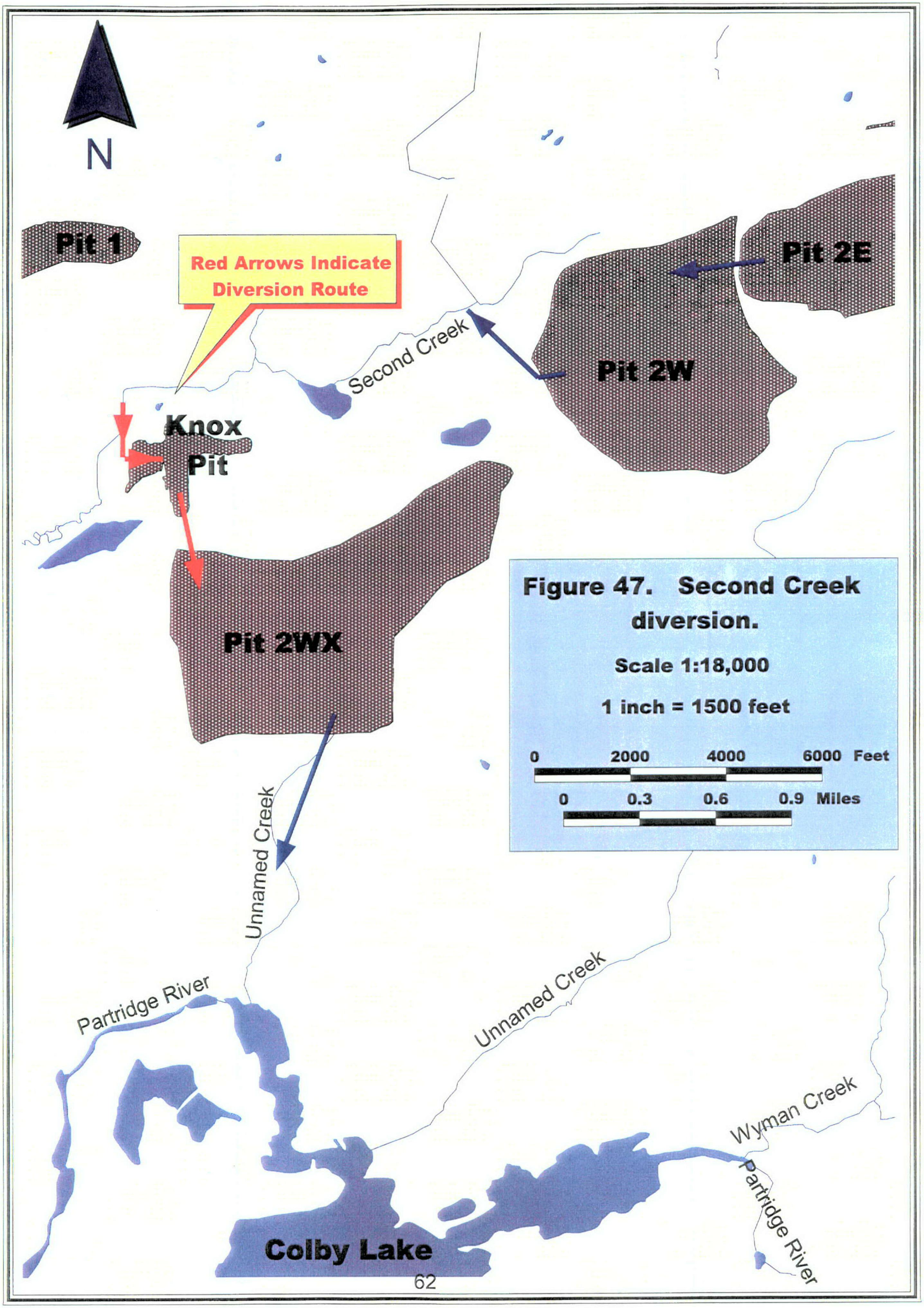


Figure 47. Second Creek diversion.

Figure 48. Predicted Second Creek flow monthly averages for Dunka Time Period 2
01 June 75 to 02 November 88.

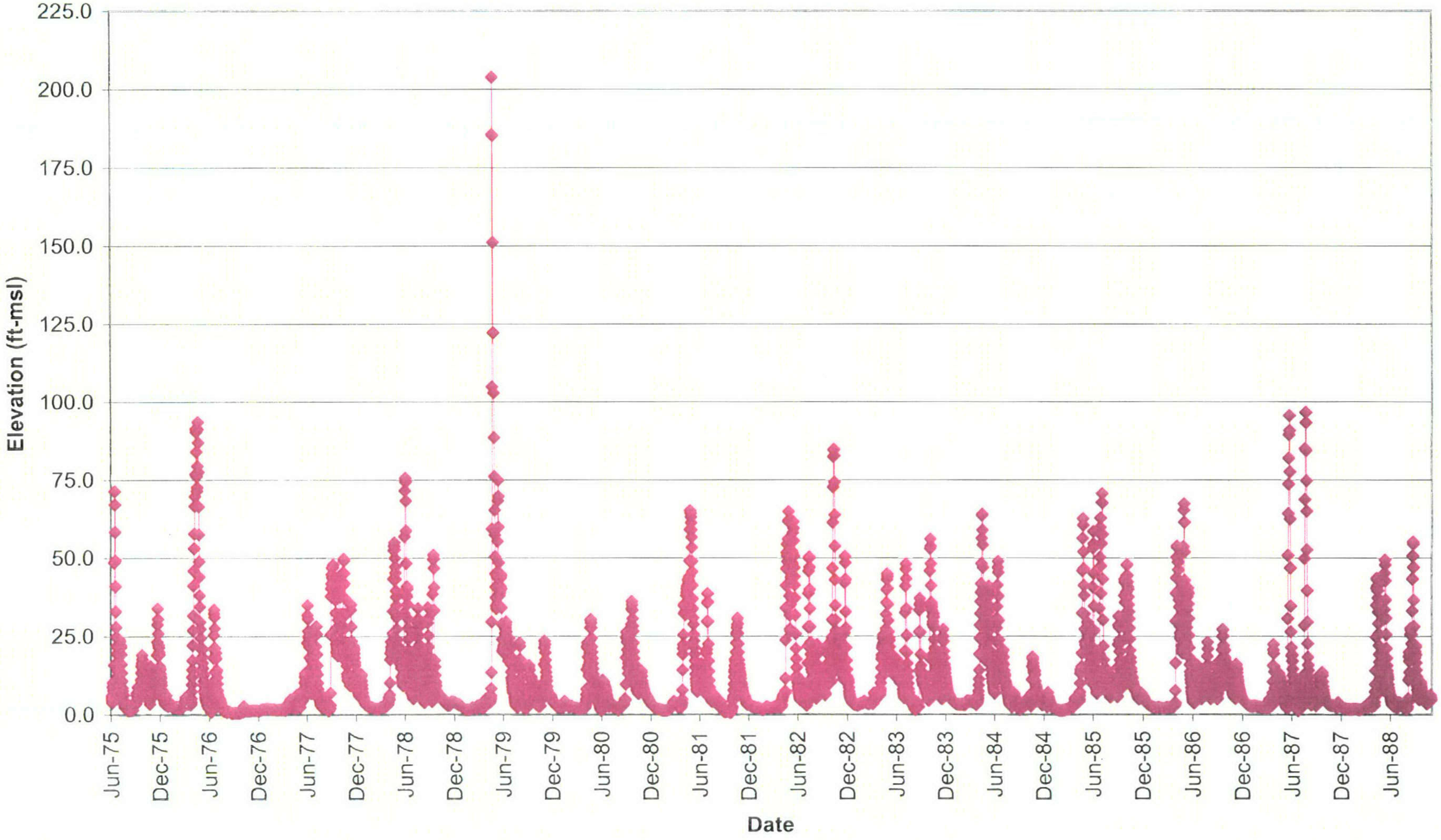
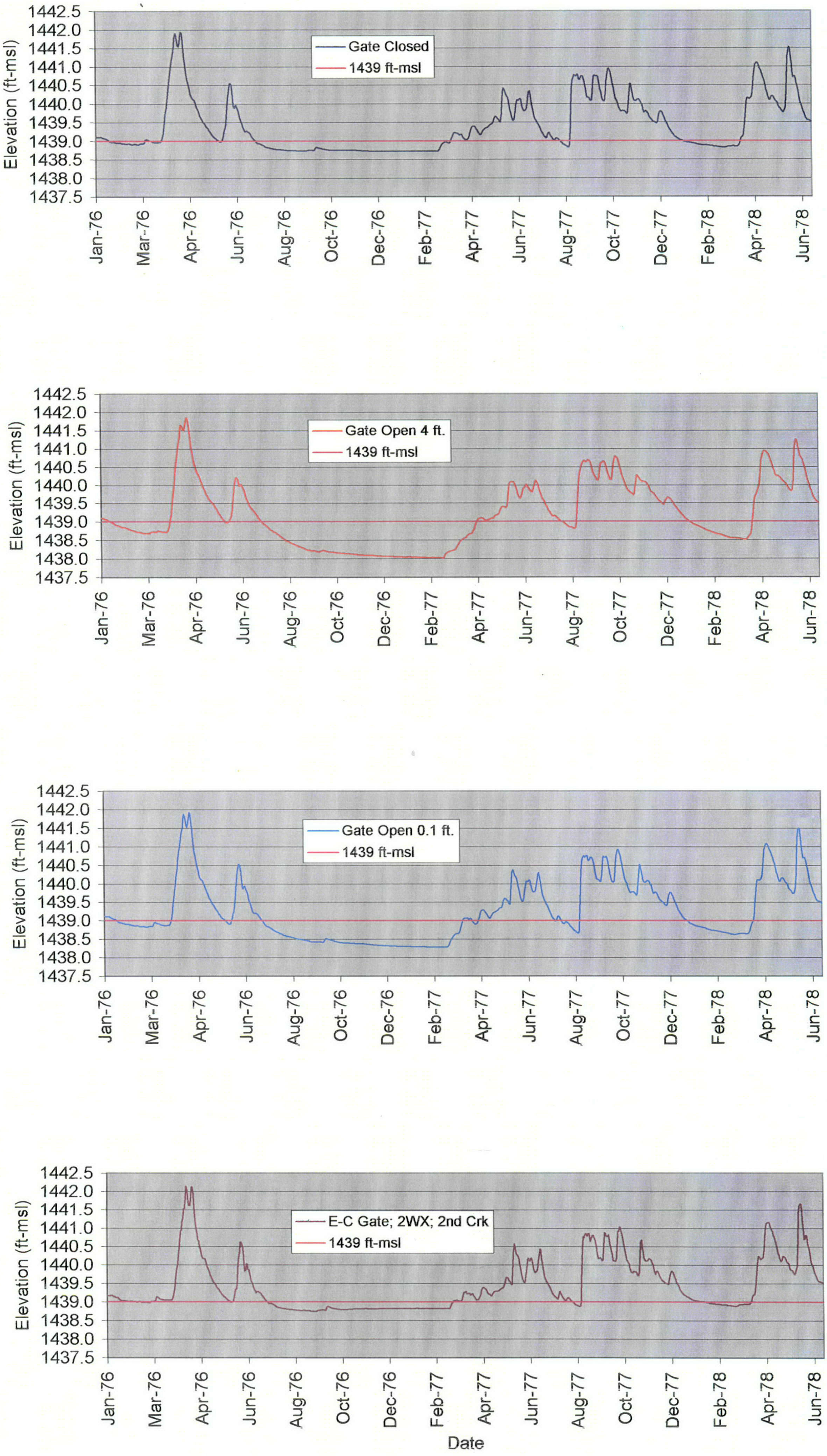


Figure 49. Colby Lake HEC-RAS simulated lake levels.
(1976 - 1978)



Hydrologic Setting

Cliffs-Erie's tailing basin is located immediately north of the main plant (Figure 1). During active mining operations tailing were spigoted into each cell of the basin. Coarse tailing were pushed to the cell's perimeter to form a dike and fine tailing settled in the cell's interior. Clear water was recirculated from the basin to the pellet plant for make-up water.

The tailing basin's three cells vary in height and surface area (Figure 50). Cell 2W is the largest cell, has the highest elevation (200 feet above ground), and makes up the basin's western half. It has a watershed area of 954 acres with no watershed external to the cell's dikes. A small, shallow pool of water existed near the center of the cell immediately following closure. As of summer 2003, the entire cell was dry, making it the only cell with no open water.

Cell 1E is located in the basin's southeast corner. It has a watershed area of 1350 acres. Cell 1E has the largest volume of impounded water, 439 acres at an elevation of 1653 ft-msl. In one area of the cell, water depth exceeds 30 feet. Cell 1E may receive ground water inflow from Cell 2W.

Cell 2E is the smallest cell and is at the lowest elevation. It is located in the basin's northeast corner and has a watershed area of 746 acres. Cell 2E's water surface area is 284 acres at elevation 1559 ft-msl, with a depth not exceeding 8 feet. The cell's water surface is approximately 160 feet below Cell 2W. Cell 2E likely receives ground water flow from one or both of the other cells.

Methodology

Watersheds for each tailing basin cell were delineated by hand digitizing 5-foot contour maps developed by CE. Field investigations were conducted of areas where delineations were questionable.

Bathymetric maps for Cells 1E and 2E were constructed using a depth finder and Trimble GPS. Several transects were run across both cells with depth and location recorded at regular intervals. Data were then analyzed using the software program Tech Base to produce a bathymetric map.

In order to record frequent and accurate water level data for model calibration, INW pressure transducers with Campbell Scientific CR10X data loggers were installed on Cells 1E and 2E in October 2001. The data logger for cell 1E was installed on CE's return-water barge in the deepest area on the cell's west side. This data logger recorded data from 07 November 2001 to 16 September 2003. Cell 2E's data logger was installed in the southwest corner of the cell and recorded data from 23 October 2001 to 20 November 2003. Data loggers were downloaded in the field on a regular basis to an SM4M storage module.

On-site precipitation data was considered essential for accurate model calibration to the basin's cells. Therefore, a precipitation gage with a Campbell Scientific

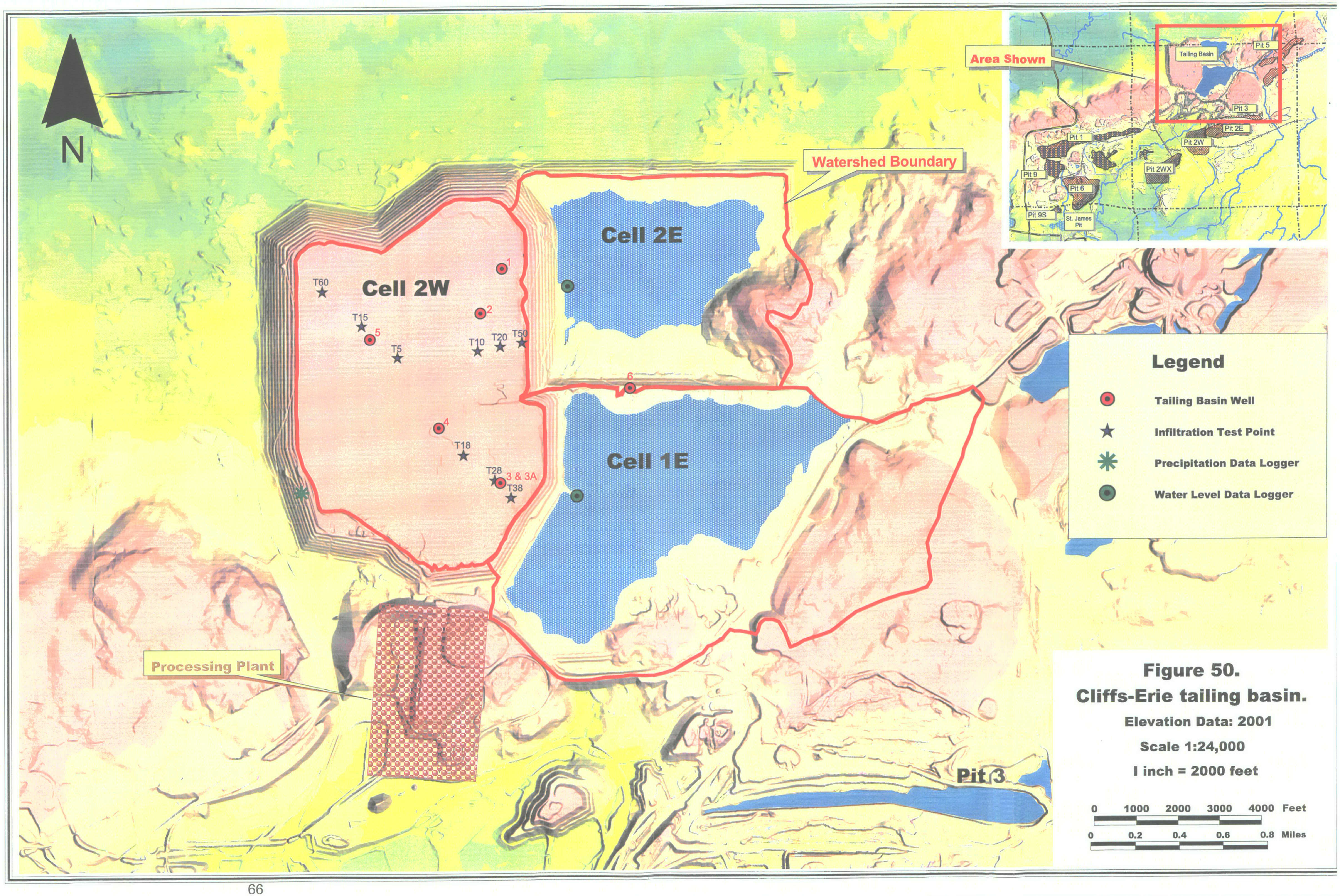


Figure 50.
Cliffs-Erie tailing basin.
Elevation Data: 2001
Scale 1:24,000
I inch = 2000 feet

CR10 data logger was installed on the top of Cell 2W on its west side. The gage operated from April to October in years 2002 and 2003, recording daily and hourly precipitation totals. It was routinely downloaded in the field to an SM192 storage module. Precipitation data from Cell 2W were graphed against data provided by Minnesota Power (Figures 51 and 52), approximately 5.6 miles south of the basin. The importance of having local precipitation data for model calibration of small, isolated water bodies is exemplified on 10 July 2003, when Cell 2W's precipitation gage recorded 0.59 inches of rain while Minnesota Power recorded 1.66 inches. Precipitation data from Cell 2W were used and supplemented where necessary, with precipitation and climate data from the State of Minnesota's Climatology website, under the label "Allen Junction", for model calibration. The 30-year normal climatic record was used for the predictive model.

The initial approach anticipated for modeling Cells 1E and 2E included quantifying ground water flow from Cell 2W to Cells 1E and 2E. Data needs included head differential between Cell 2W water table and water level in the other cells. However, water table elevation varied among Cell 2W's six observation wells by over 70 feet, eliminating the possibility of quantifying head difference between the cells.

Figure 50 shows the location of the seven ground water monitoring wells installed on the tailing basin. Six of the seven wells installed (Wells 1-6) utilized a truck-mounted mud-rotary drill rig. Wells could not be logged due to consistency of the tailing. The seventh well (Well 3A) was a sand-point well installed by hand. Well details are shown in Table 2.

Table 2. Tailing Basin Wells

Well #	Depth Of Well (ft)	Screened Interval (ft)	UTM X	NAD 83 Y
1	150	20	565257	5275160
2	160	20	565100	5274834
3	102.5	20	565244	5273593
3A	55	4	565244	5273593
4	101.7	20	564800	5273998
5	160.95	20	564295	5274647
6	102.3	20	566195	5274284

Wells 1, 2, 3, 4, and 5 were installed in January 2002 and Well 3A was installed in April 2002. Well 6 was installed in June 2002 on the dike between Cells 1E and 2E. Depths to water table were measured on a regular basis using a Solinst Model 110 water level meter. Results were recorded and graphed.

It was not possible to apply WATBUD to Cell 2W since it contained no ponded water. However, due to dam safety concerns, the potential for accumulation of

Figure 51. Precipitation totals - 2002.

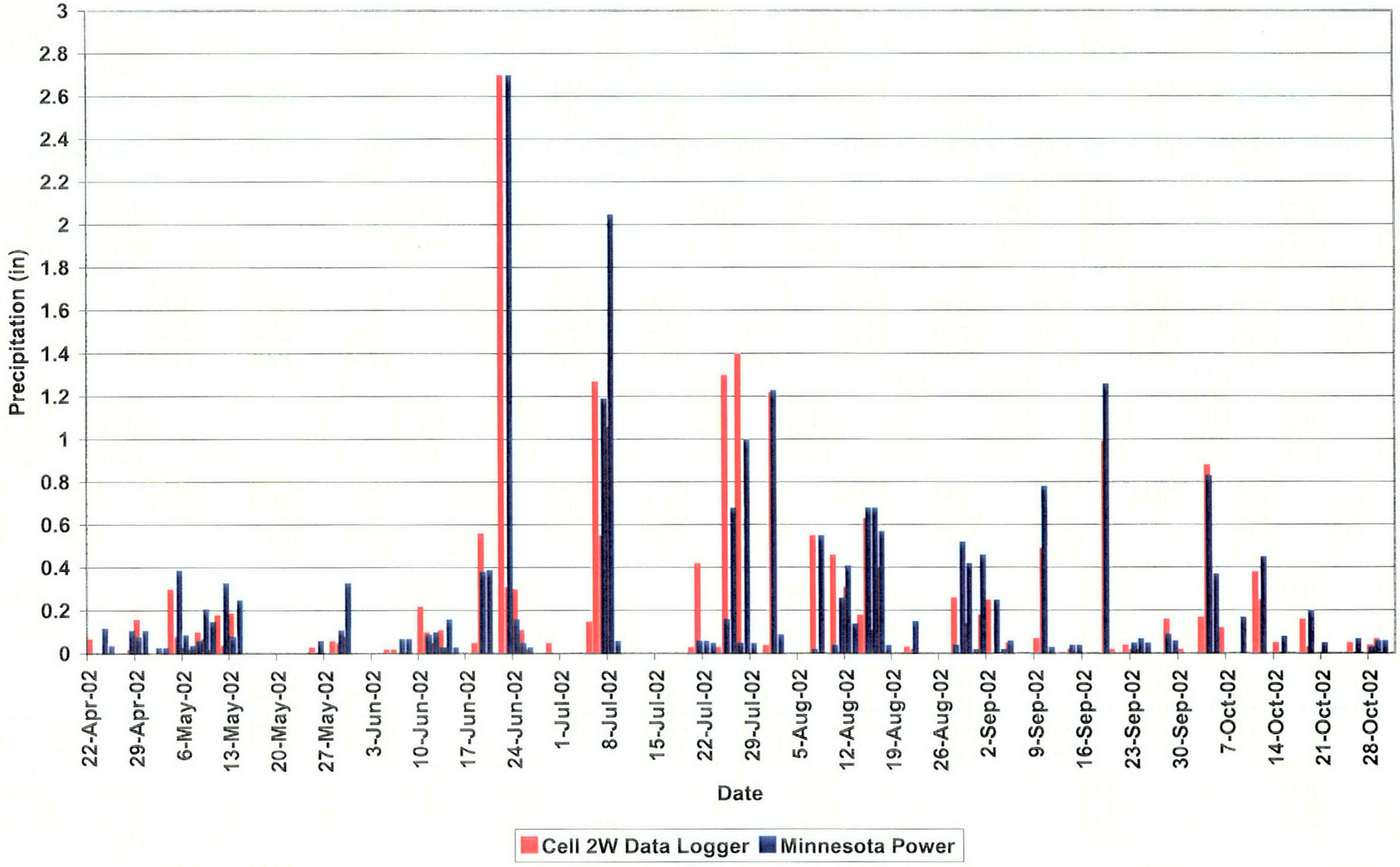
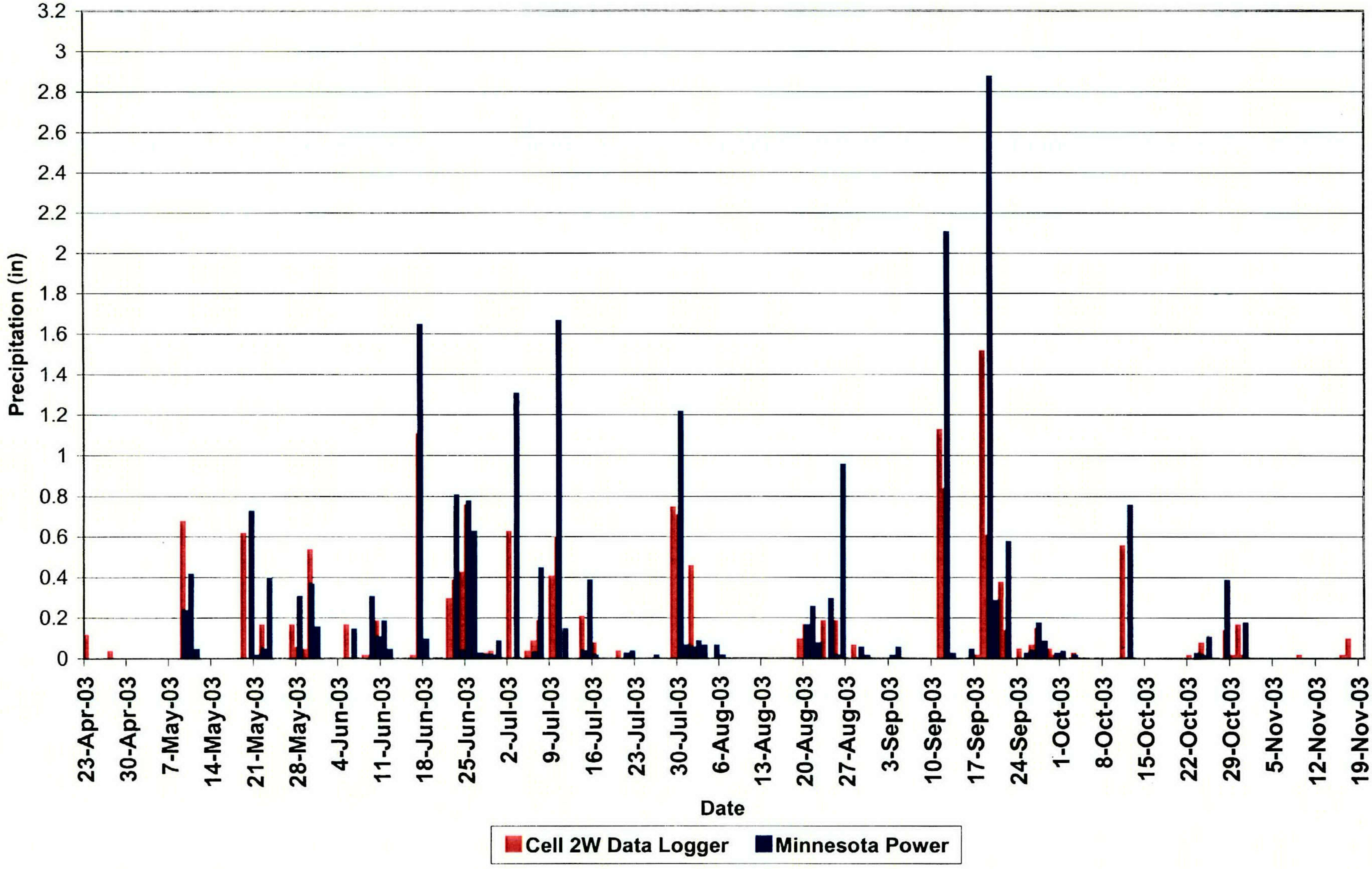


Figure 52. Precipitation totals - 2003.



surface water needed to be assessed. The approach taken to address this need was to measure infiltration rates across the cell and compare them to expected precipitation intensities. Infiltration tests were performed in July 2002. A standard double-ring infiltrometer method was used with water brought to the basin by truck. Testing was done on three transects, each containing three measurement points (Figure 50).

WATBUD was calibrated to selected, recorded water levels for Cells 1E and 2E, then modified to reflect the changing net ground water relationship for each cell for predictive purposes. The approach involved calibrating WATBUD against water levels taken during non-frozen soil conditions to quantify the water level-net seepage relationship for the predictive model. Although based on limited data, the calibrated models produced what is believed to be a reasonably accurate relationship between water level and net ground water for each cell. These relationships were used in the predictive models.

Calibrated Models

Cell 1E

It was not possible to achieve a good WATBUD calibration to the entire record of water level data for Cell 1E (Figure 53). It is suspected that during winter 2002-2003, unusually deep frost inhibited or delayed groundwater movement into cells, preventing a good calibration. However, good calibration was developed for periods of unfrozen soil in 2002 and 2003. The calibrated model and parameter file for *Summer 1* (Figures 54 and 55) used data from 15 April through 15 September 2002. The range of water levels for this period was only 0.67 feet with a median elevation of 1653.01 ft-msl. The calibrated model's net groundwater constant for this period was –2.0 cfs, hence the cell was losing more ground water than it was gaining.

The calibrated model and parameter file for *Summer 2* (Figures 56 and 57) used data from 15 April through 20 July 2003. Water levels during *Summer 2* show a decreasing trend. *Summer 2's* range in water levels was 0.99 feet with a median elevation of 1651.69 ft-msl, about 1.3 feet lower than *Summer 1*. The calibrated model's net groundwater constant for *Summer 2* was –0.82 cfs, demonstrating reduced ground water loss at lower elevations. This trend in ground water loss was used in the predictive model.

Cell 2E

The frozen soil conditions described for Cell 1E also prevented good WATBUD calibration for the entire record of water level data for Cell 2E (Figure 58). Calibrated WATBUD models were developed for the two unfrozen periods in 2002 and 2003. *Summer 1* covered the time period from 22 April through 15 September 2002, while *Summer 2* ran from 15 April through 15 September 2003.

Figure 53. Tailng basin Cell 1E daily water elevation and precipitation.

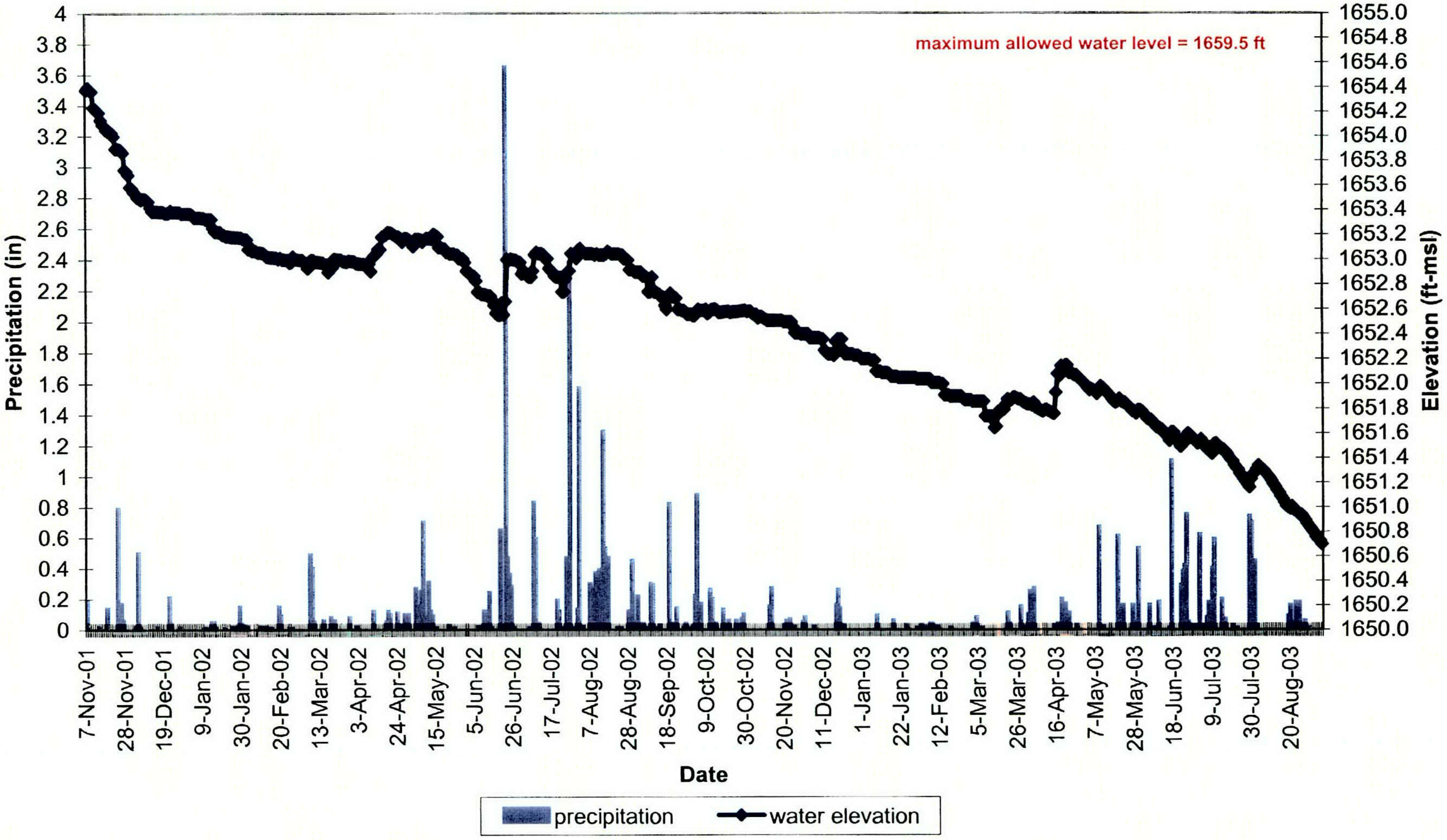


Figure 54. Tailing basin Cell 1E calibrated model and recorded water levels Summer 1 data.

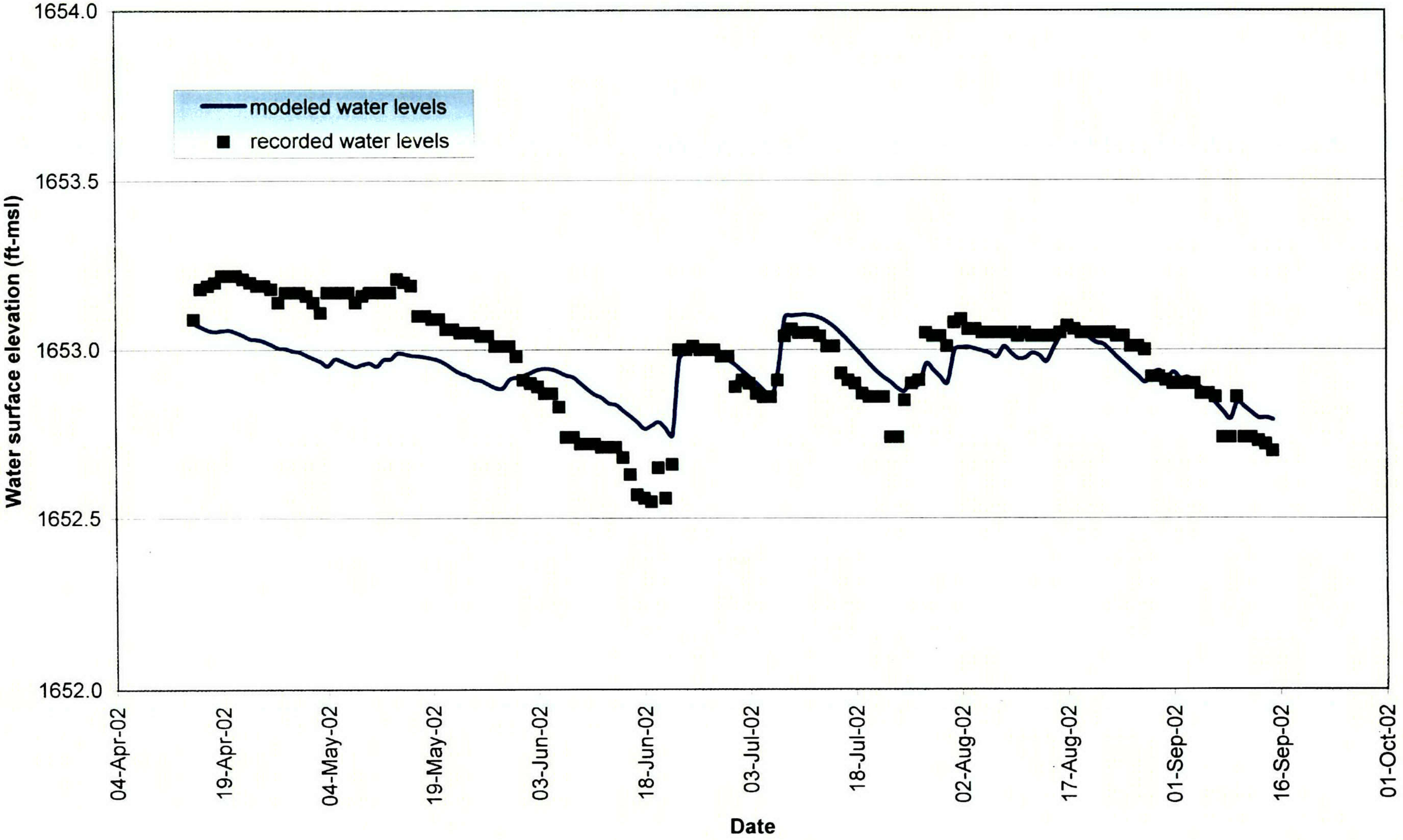


Figure 55. Tailing basin Cell 1E WATBUD parameter file for Summer 1 calibrated model. (see Figure 2 for detailed description of components)

```
1350
17
1639,132,952,0
1640,142,1089,0
1641,155,1238,0
1642,168,1399,0
1643,181,1574,0
1644,194,1761,0
1645,208,1962,0
1646,225,2179,0
1647,244,2413,0
1648,266,2669,0
1649,296,2950,0
1650,332,3263,0
1651,367,3613,0
1652,404,3999,0
1653,439,4420,0
1654,470,4874,0
1655,498,5358,0
B:0:J:\ALL\LTV\WATBUD\CELL 1E\
L:0:1E_ELEV,ELEV,1
P:0,1:2WCLIM,PRECIP
P:3,1: 30.00, 36.00, 0.011040, (,,2WCLIM,TEMPMIN,,1), (,,2WCLIM,TEMPMAX,,1)
P:4,1:
E:2,1,1: 0.8000, (,,2WCLIM,TEMPMIN,,1), (,,2WCLIM,TEMPMAX,,1)
R:2,1: 1.0000
R:4,1,1: (90.78,1), (P:0:2WCLIM,PRECIP), 2.600, 1.8000
R;7,1: 0.2170
R:8,1: (95.81,1)
F:2,1: 1.0000
S:2,1: 1.0000
S:4,1,1: (-3.212,1), 0
```

Figure 56. Tailing basin Cell 1E calibrated model and recorded water levels Summer 2 data.

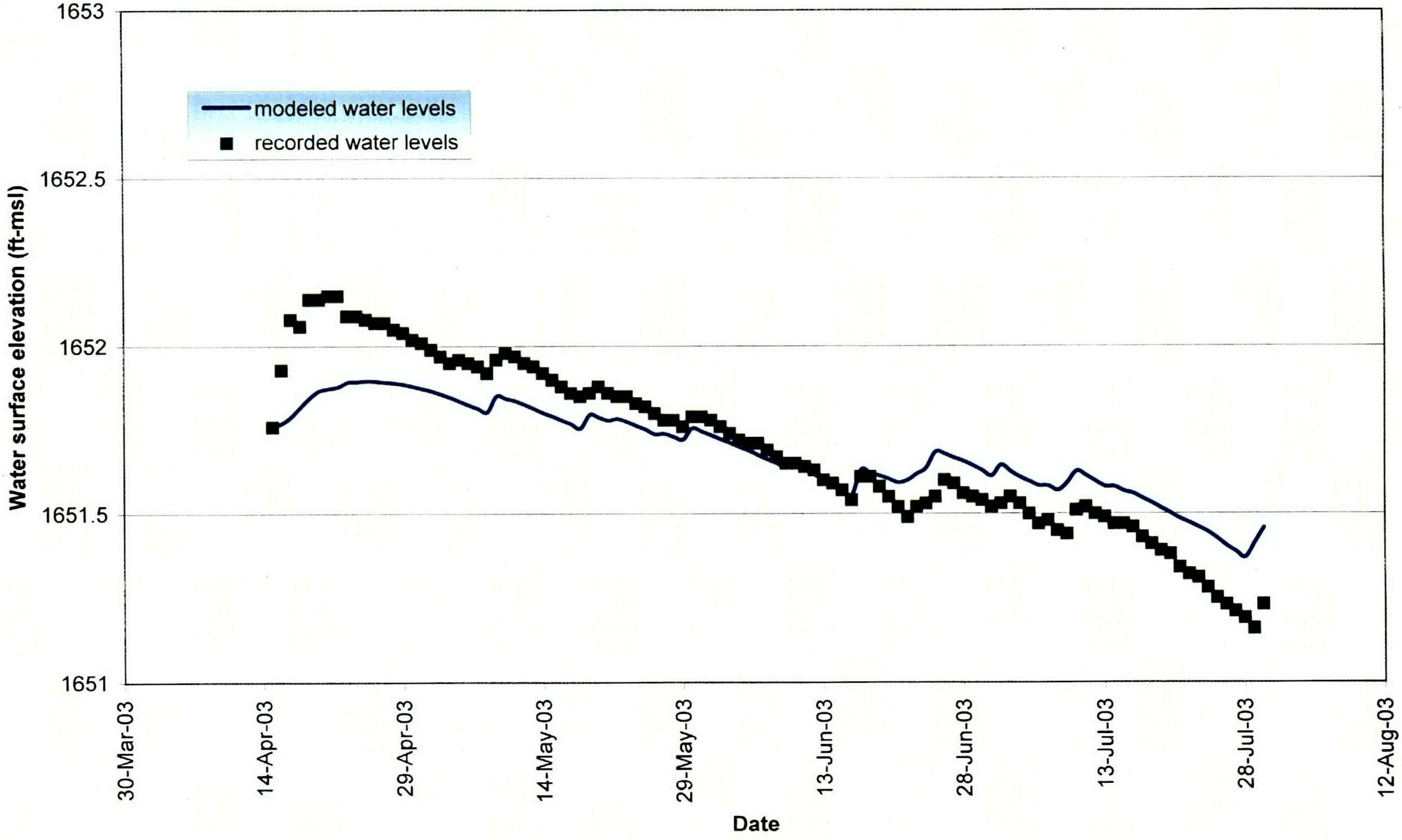
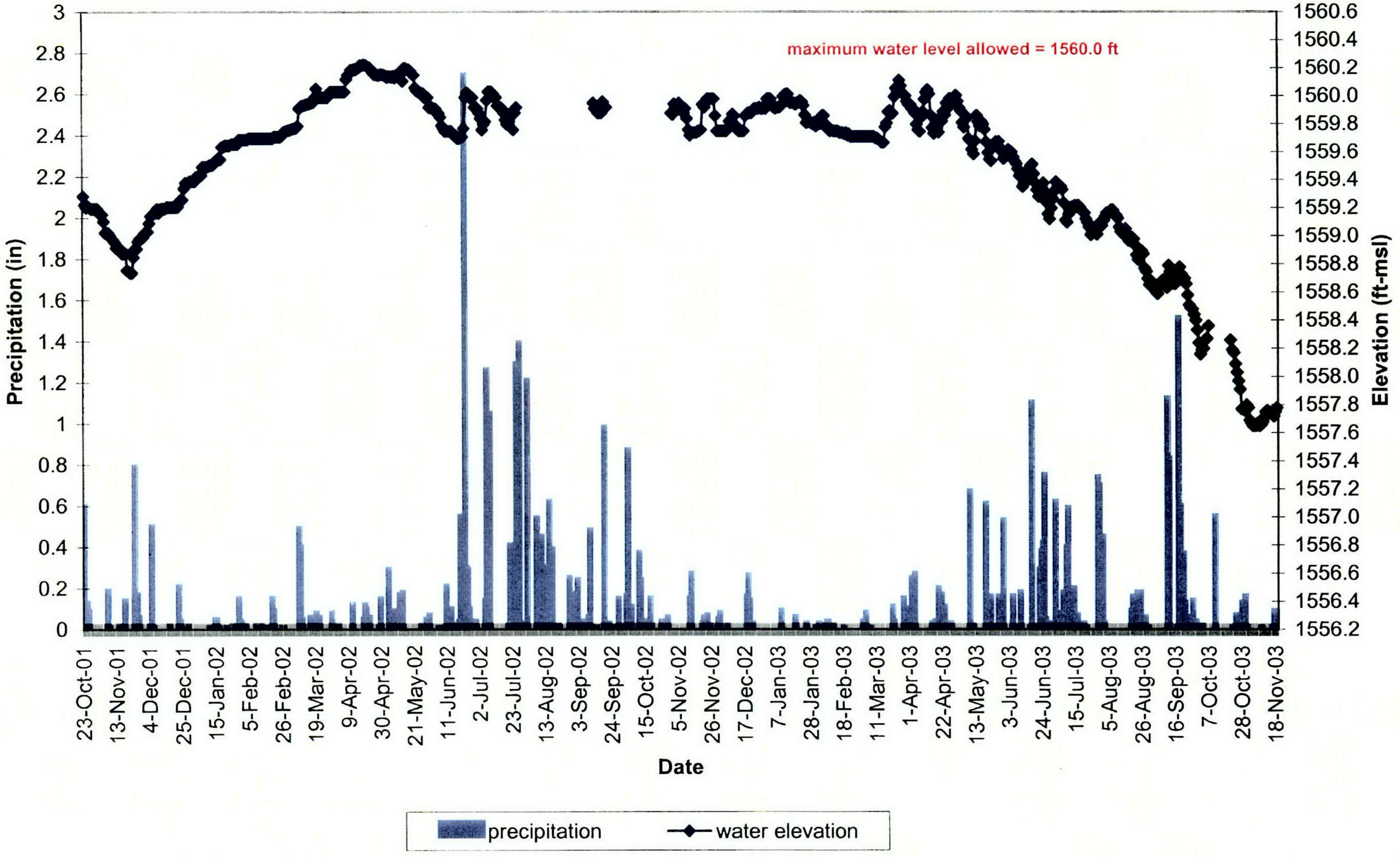


Figure 57. Tailing basin Cell 1E WATBUD parameter file for Summer 2 calibrated model.
(see Figure 2 for detailed description of components)

```
1350
17
1639,132,952,0
1640,142,1089,0
1641,155,1238,0
1642,168,1399,0
1643,181,1574,0
1644,194,1761,0
1645,208,1962,0
1646,225,2179,0
1647,244,2413,0
1648,266,2669,0
1649,296,2950,0
1650,332,3263,0
1651,367,3613,0
1652,404,3999,0
1653,439,4420,0
1654,470,4874,0
1655,498,5358,0
B:0:J:\ALL\LTV\WATBUD\Cell 1E\
L:0:1E_ELEV,ELEV,1
P:0,1:2WCLIM,PRECIP
P:3,1: 30.00, 36.00, 0.011040, (,,2WCLIM,TEMPMIN,,1), (,,2WCLIM,TEMPMAX,,1)
P:4,1:
E:2,1,1: 0.8000, (,,2WCLIM,TEMPMIN,,1), (,,2WCLIM,TEMPMAX,,1)
R:2,1: 1.0000
R:4,1,1: 90.78, (P:0:2WCLIM,PRECIP), 2.600, 1.8000
R:7,1: 0.2170
R:8,1: 95.81
F:2,1: 1.0000
S:2,1: 1.0000
S:4,1,1: (-1.2300,1), 0
```

Figure 58. Tailing basin Cell 2E daily water elevation and precipitation.



Figures 59 & 60 show the calibrated model and parameter file for *Summer 1*. The range of water levels for this period was 0.58 feet, with a median elevation of 1560.02 ft-msl. Net groundwater for was –1.53 cfs.

Figures 61 & 62 show the calibrated model and parameter file for *Summer 2*. The range of water levels was 1.42 feet, with a median elevation of 1559.31 ft-msl, about 0.7 feet lower than *Summer 1*. Net groundwater was –1.12 cfs, indicating a decrease in ground water loss as water levels dropped. As with Cell 1E, the relationship between net groundwater and water level was used in the predictive model.

Predictive Models

Cell 2W Hydrologic Analysis

An examination of water table elevations from the monitoring wells shows no obvious response to precipitation (Figure 63). It was surmised that although infiltration rates are high, ground water rapidly moves horizontally as it finds flow paths not connected to the water table. This scenario makes sense when construction of the basin is considered. Active spigot lines were moved every three to four days to allow coarse tailing to settle and be pushed to the outside for dike formation. Moving the spigots created fingers of fine tailing with gradated particle size as tailing slurry flowed to the basin's lowest point. As these fingers formed and were subsequently covered, a series of overlapping layers of tailing with varying degree of hydraulic conductivity were formed. Infiltrating water appears to follow a circuitous route to the outside of the dike, contributing to the many seeps around the cell's base. It is likely that infiltrating water also flows to Cells 1E and 2E without reaching Cell 2W's water table. Seepage loss from the tailing basin is tributary to the Embarrass River and Second Creek, but does not affect any of the pits or Colby Lake.

Results of the infiltration tests (Table 3) show water infiltrates tailing at different rates, with slowest infiltration occurring near the basin's center where tailing is finest. Even the lowest infiltration rates indicate water moves readily into the tailing. Measured infiltration rates varied from 0.08 in/hr to 13 in/hr, or 1.9 in/day to 312 in/day. The lowest measured infiltration rate approaches precipitation intensity from the *NRCS Hydrology Guide to Minnesota* for the area's one-year, 24-hour rainfall event of 2.1 in/day. Therefore, some water may temporarily accumulate on the basin every year after major storms, but it will rapidly infiltrate. Infiltration rates should increase with time as the basin becomes more vegetated and an organic layer develops.

Figure 59. Tailing basin Cell 2E calibrated model and recorded water levels
Summer 1 data.

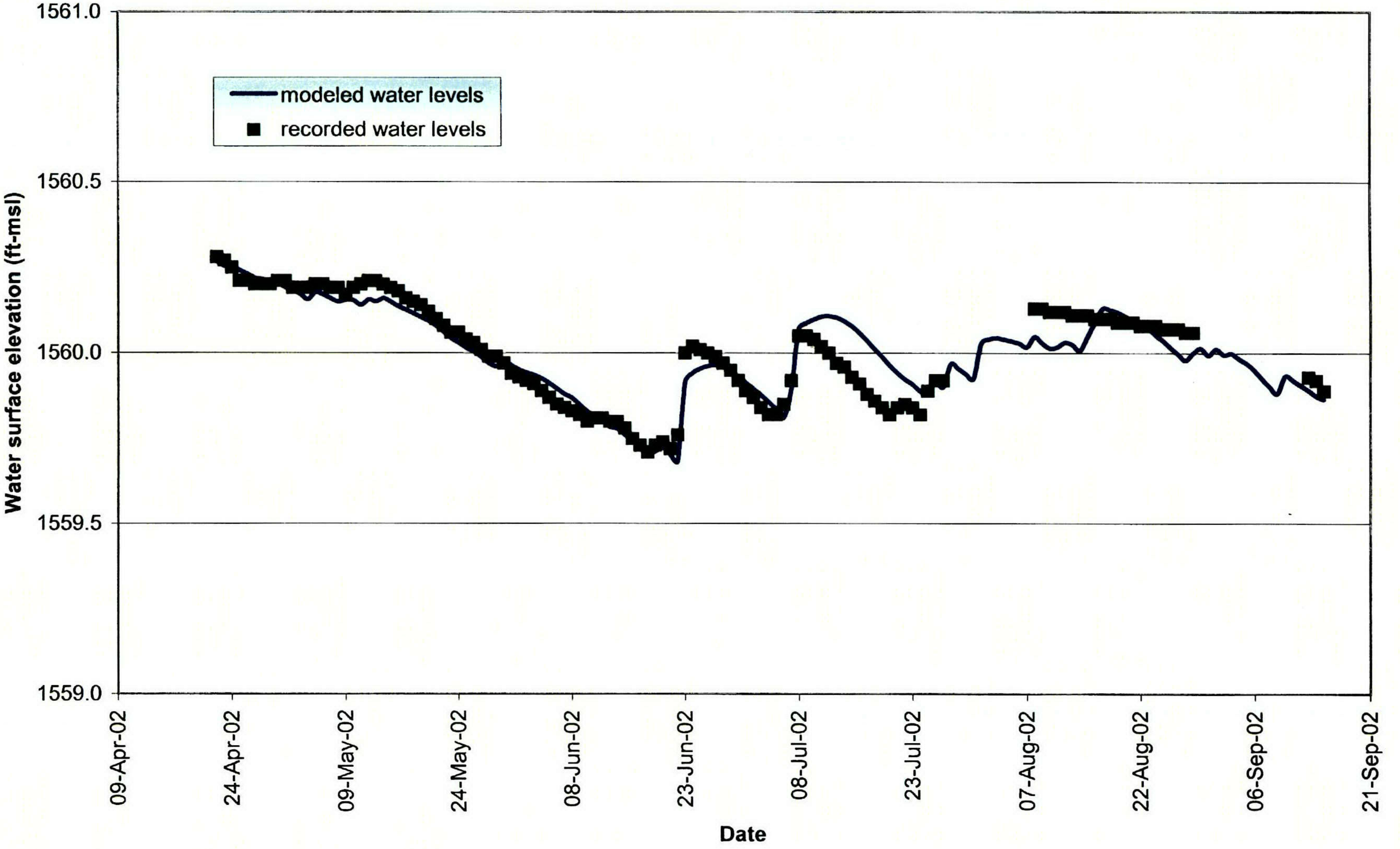


Figure 60. Tailing basin Cell 2E WATBUD parameter file for Summer 1 calibrated model. (see Figure 2 for detailed description of components)

```
746
16
1545,1,1,0
1546,2,2,0
1547,3,5,0
1548,4,9,0
1549,5,13,0
1550,8,20,0
1551,14,31,0
1552,27,51,0
1553,49,89,0
1554,82,155,0
1555,128,260,0
1556,224,436,0
1557,243,670,0
1558,270,927,0
1559,284,1204,0
1560,295,1493,0
B:0:J:\ALL\LTV\WATBUD\Cell 2E\
L:0:2ENEW LEVEL,ELEV,1
P:0,1:2WCLIM,PRECIP
P:3,1: 30.00, 36.00, 0.011040, (,,2WCLIM,TEMPMIN,,1), (,,2WCLIM,TEMPMAX,,1)
P:4,1:
E:2,1,1: 0.8000, (,,2WCLIM,TEMPMIN,,1), (,,2WCLIM,TEMPMAX,,1)
R:2,1: 1.0000
R:4,1,1: (96.34,1), (P:0:2WCLIM,PRECIP), (2.800,1), (1.6000,1)
R:7,1: 0.2170
R:8,1: (95.51,1)
F:2,1: 1.0000
S:2,1: 1.0000
S:4,1,1: (-3.0603,1),0
```

Figure 61. Tailing basin Cell 2E calibrated model and recorded water levels
Summer 2 data.

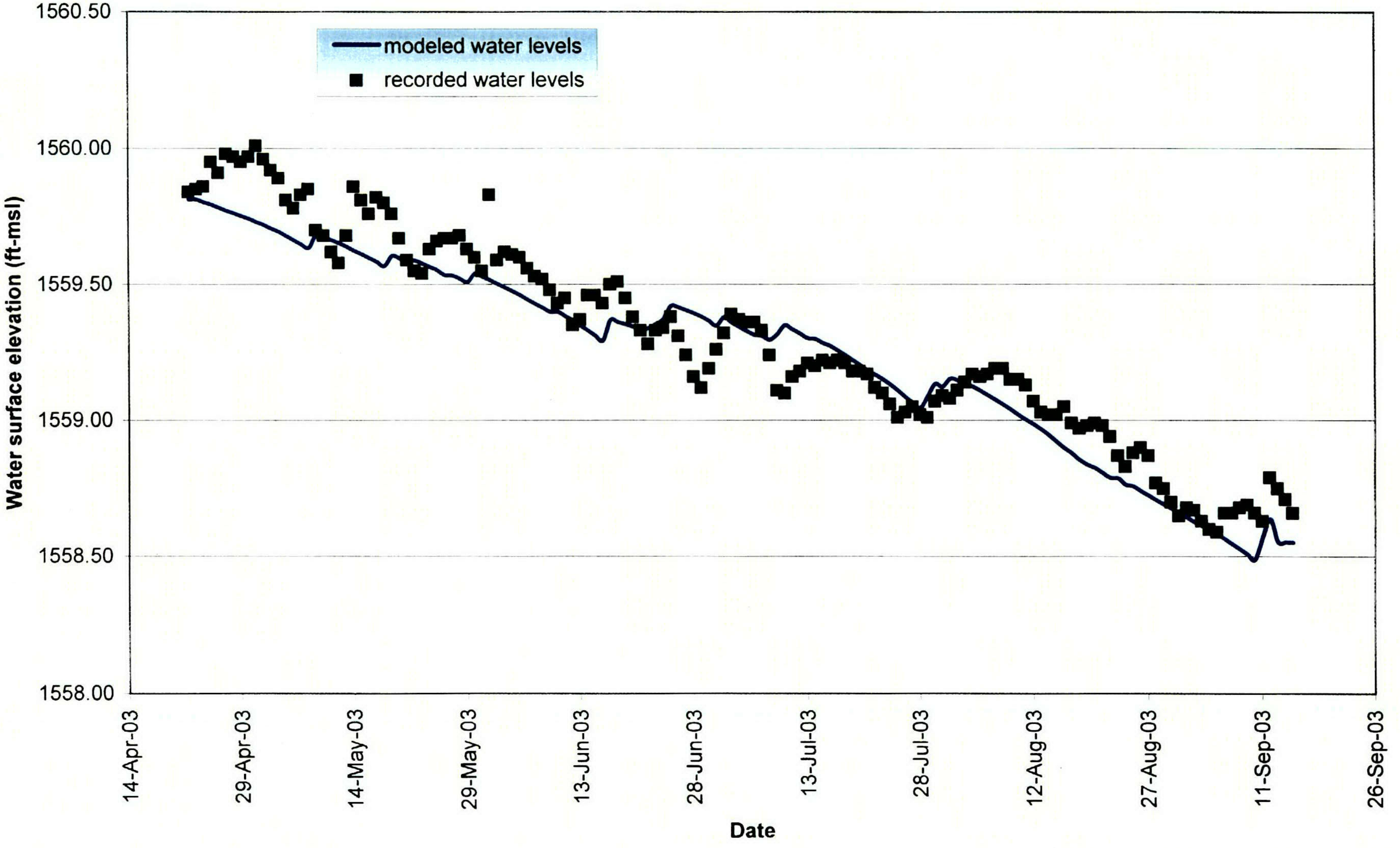


Figure 62. Tailing basin Cell 2E WATBUD parameter file for Summer 2 calibrated model.
(see Figure 2 for detailed description of components)

```
746
16
1545,1,1,0
1546,2,2,0
1547,3,5,0
1548,4,9,0
1549,5,13,0
1550,8,20,0
1551,14,31,0
1552,27,51,0
1553,49,89,0
1554,82,155,0
1555,128,260,0
1556,224,436,0
1557,243,670,0
1558,270,927,0
1559,284,1204,0
1560,295,1493,0
B:0:J:\ALL\LTV\WATBUD\CELL 2E\
L:0:2ENEW LEVEL2,ELEV,1
P:0,1:TBCLIMATE,PRECIP
P:3,1: 30.00, 36.00, 0.011040, (,,TBCLIMATE,TEMPMIN,,1), (,,
TBCLIMATE,TEMPMAX,,1)
P:4,1:
E:2,1,1: 0.8000, (,,TBCLIMATE,TEMPMIN,,1),  (,,TBCLIMATE,TEMPMAX,,1)
R:2,1: 1.0000
R:4,1,1: (96.34,1), (P:0:TBCLIMATE,PRECIP), 2.800, 1.6000
R:7,1: 0.2170
R:8,1: (95.51,1)
F:2,1: 1.0000
S:2,1: 1.0000
S:4,1,1: (-2.203,1), 0
```

Figure 63. Tailing basin water table elevations.

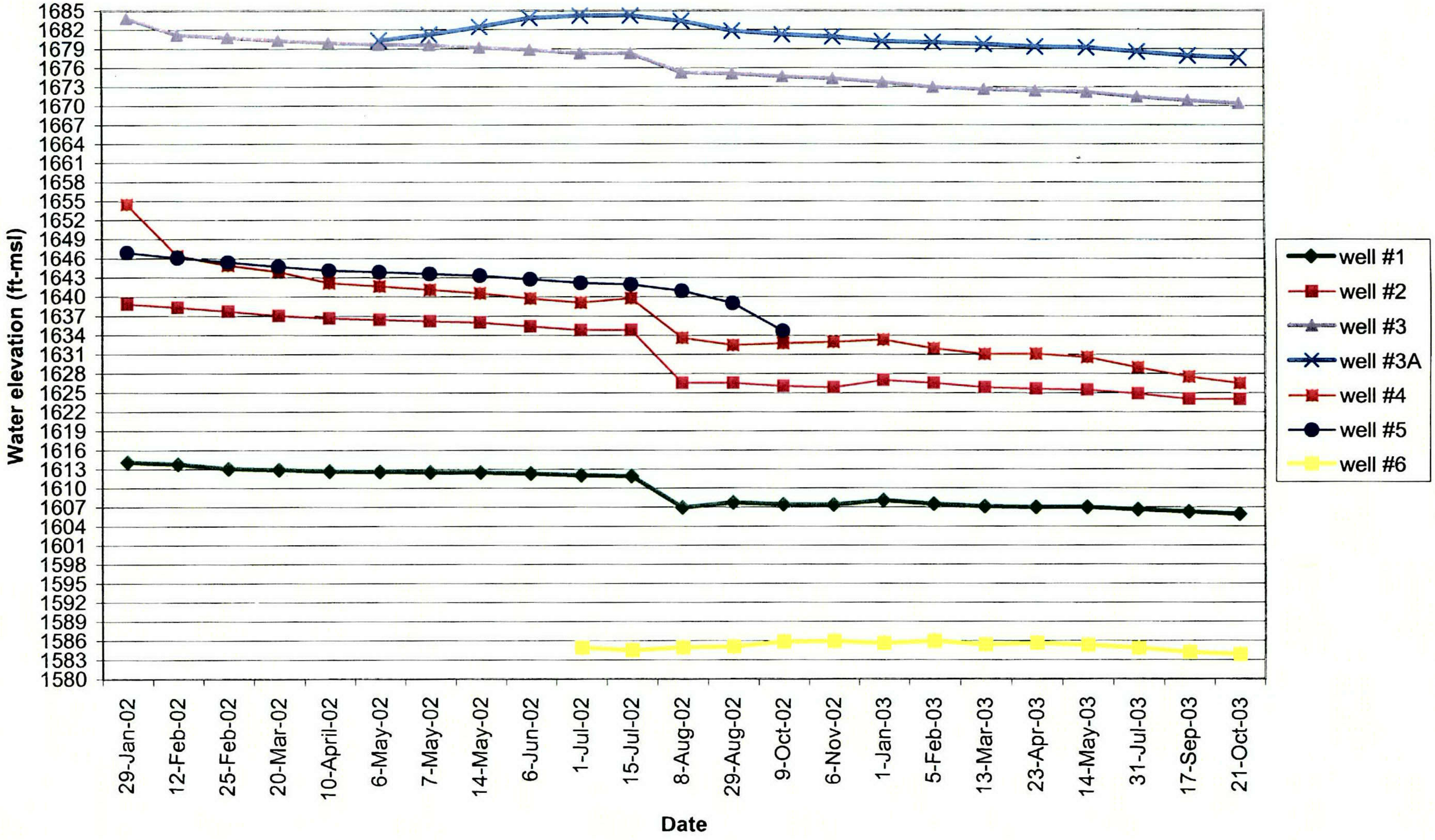


Table 3. Cell 2W Infiltration Rates

Sample ID	Infiltration Rate (in/hr)
T60	13.15
T15	1.15
T5	0.12
T50	4.60
T20	1.77
T10	0.08
T38	4.32
T28	0.29
T18	1.15

Cell 1E

Before a predictive WATBUD model could be developed for Cell 1E, the relationship between net ground water and water level needed to be established. Net groundwater (cfs) was plotted against average water elevation for *Summer 1* and *Summer 2* periods (Figure 64). An equation representing the line drawn between the two points was developed for the predictive model. The 30-year normal climatic record was then used to predict the probable range of future water levels (Figure 65). Predicted water levels vary with precipitation, generally ranging between 1651 ft-msl to 1653 ft-msl, but always stay at least six feet below the dam safety threshold of 1659.5 ft-msl.

Cell 2E

Net groundwater values for both *Summer 1* and *Summer 2* were plotted against average water elevations, with the resulting relationship incorporated into the parameter file for the predictive model (Figure 66). The 30-year normal climate file was then used to predict the range of future water levels. Predicted water levels range from 1557.8 ft-msl to 1560.0 ft-msl, the maximum allowed by dam safety freeboard regulation (Figure 67).

D. St. James Pit

Objective

The objective for the St. James Pit was to model future, static water levels without water level control pumping. This information will help Aurora determine if it is appropriate to move their pump house.

Hydrologic Setting

St. James Pit is an exhausted natural ore pit located on the north edge of Aurora (Figure 68). The pit has a water surface area of approximately 125 acres, and a

Figure 64. Tailing basin Cell 1E Summer 1 & Summer 2 average net ground water vs. average elevation.

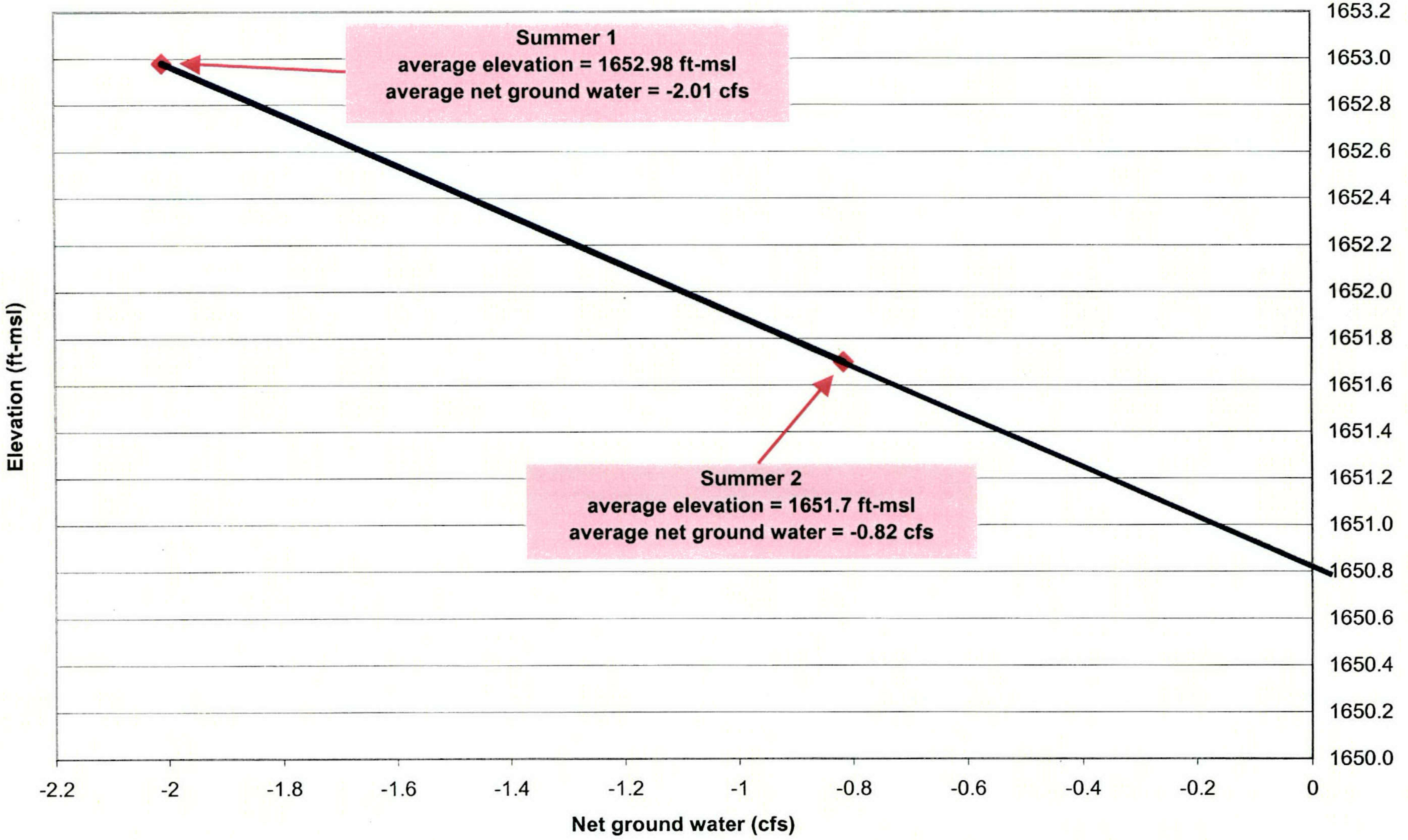


Figure 65. Tailing basin Cell 1E predicted water levels using the 30-year normal climate file.

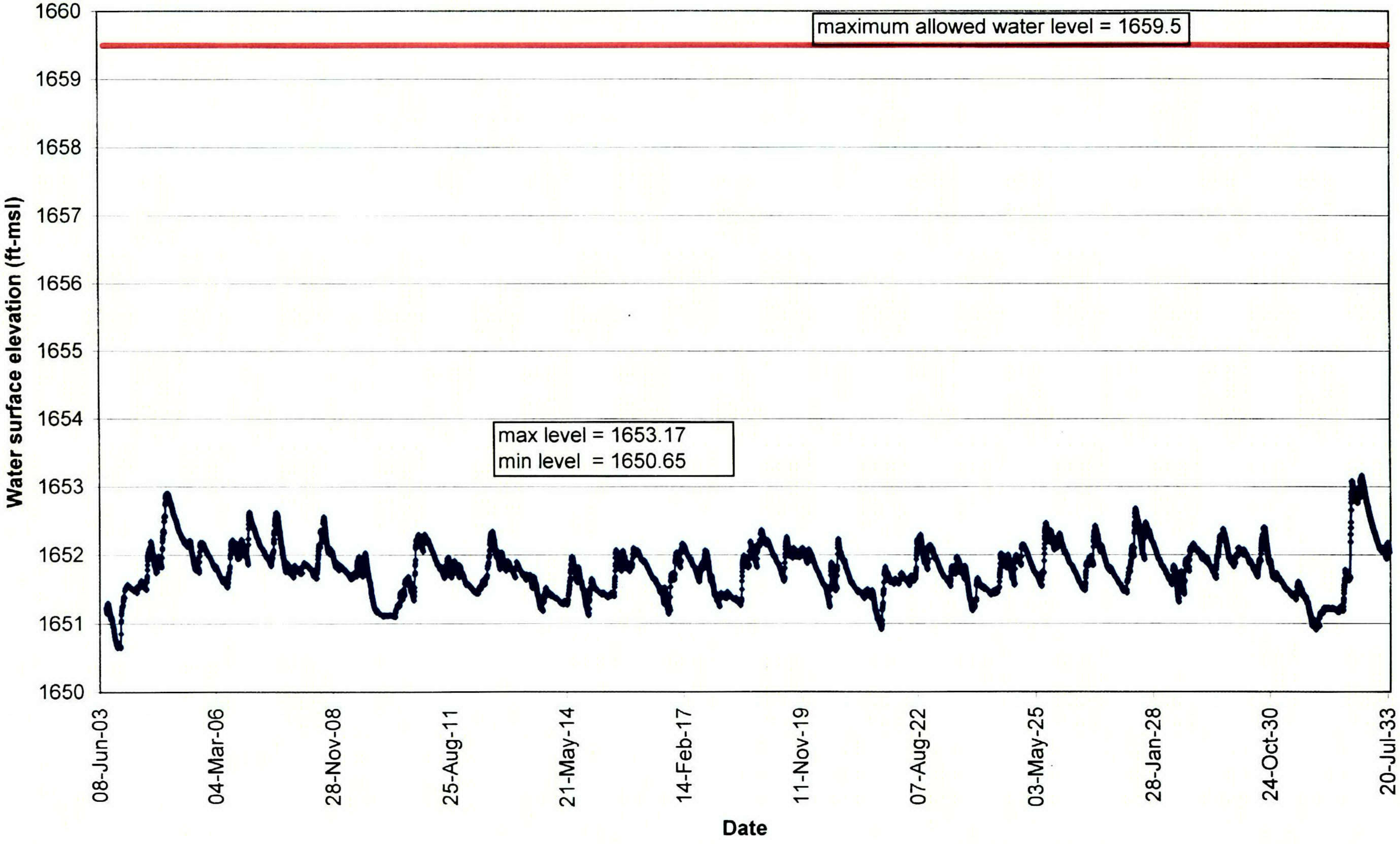
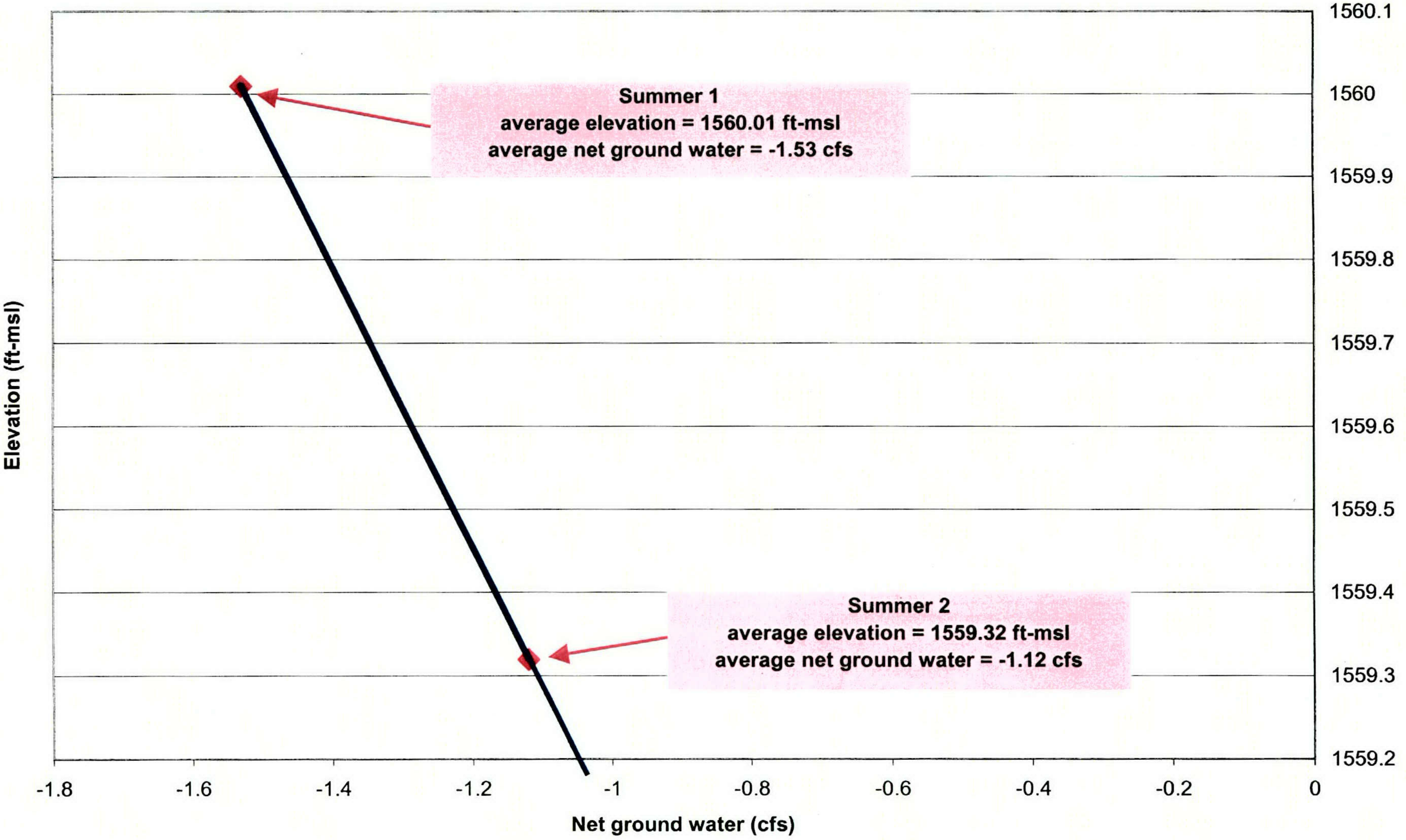


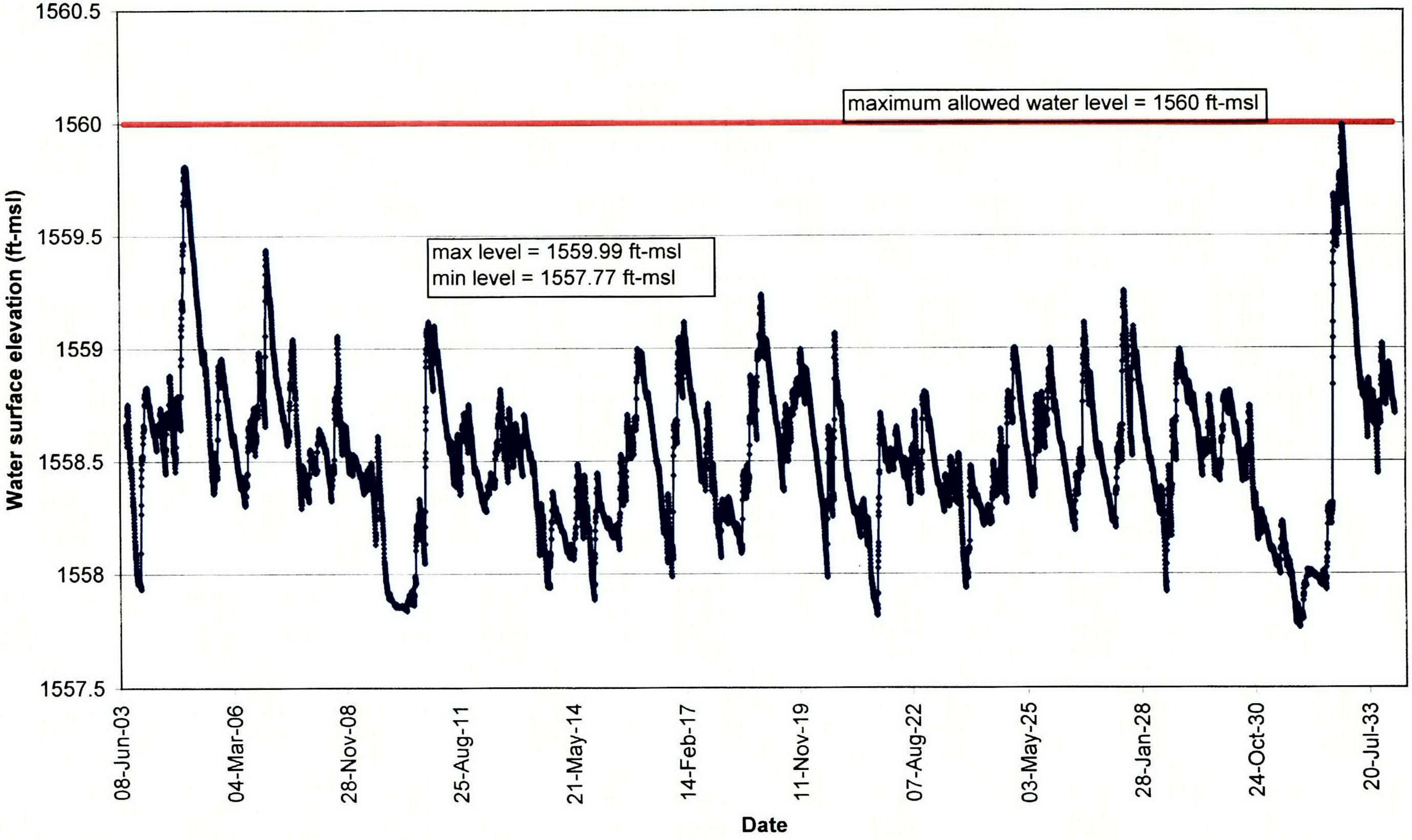
Figure 66. Tailing basin Cell 2E Summer 1 & Summer 2 average net ground water vs. average elevation.



Summer 1
average elevation = 1560.01 ft-msl
average net ground water = -1.53 cfs

Summer 2
average elevation = 1559.32 ft-msl
average net ground water = -1.12 cfs

Figure 67. Tailing basin Cell 2E predicted water levels using the 30-year normal climate file.



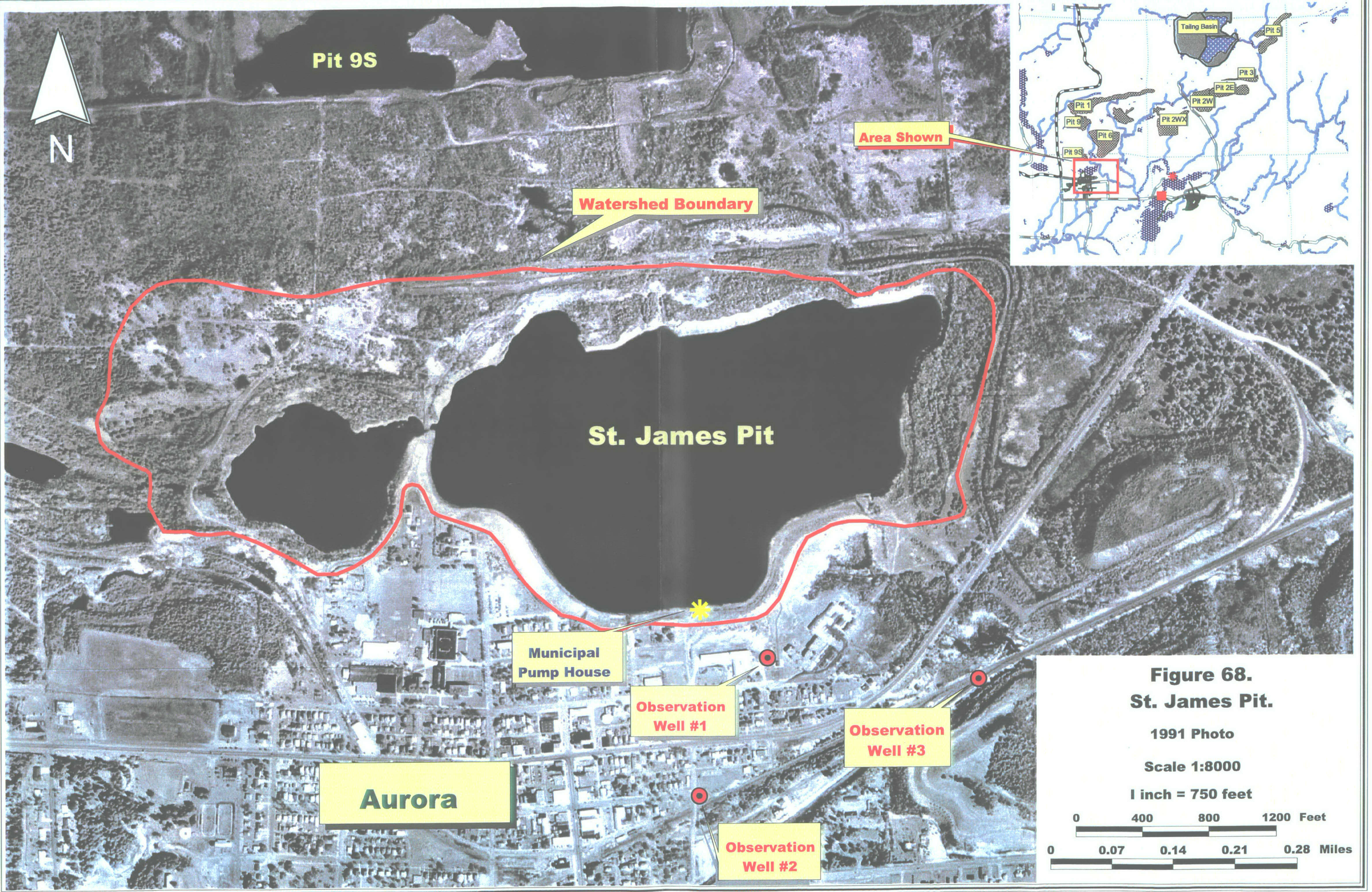


Figure 68.
St. James Pit.

1991 Photo

Scale 1:8000

I inch = 750 feet

watershed area of approximately 360 acres. The pit is an important resource for the city; it has a public boat landing and is stocked with trout annually. It is also the city's municipal water supply, with annual appropriation averaging about 6.3 million gallons. The city's pump house is located along the pit's south shore, with a floor elevation of 1442.8 ft-msl. Water levels recorded during the project ranged from approximately 1439 ft-msl to 1441 ft-msl. The pit is presently gaining more water than it is losing, prompting the city to periodically discharge water at 400 gpm in order to protect their pump house from flooding.

Methods

Water levels collected by the city of Aurora were used for model calibration. They also supplied data on the volume and timing of water pumped for municipal use and discharged for water level control. Unlike the CE pits, the St. James Pit is surrounded by deep glacial drift (approaching 100 feet) that allows increasing ground water outflow as water level rises. The calibrated model seepage residual for St. James Pit is net ground water, the difference between ground water inflow and outflow. In order to predict future water levels the most accurate way possible, net ground water had to be adjusted for increasing ground water outflow at higher water levels. Ground water outflow could be quantified by collecting data needed for Darcy's Equation (Driscoll 1986):

$$Q = KIA$$

Where: Q = ground water outflow
K = average aquifer hydraulic conductivity
I = aquifer gradient, and
A = cross-sectional area of aquifer.

Three observation wells were installed in the down-gradient aquifer, near the pit (Figure 68), for the purpose of quantifying hydraulic conductivity (K). Observation wells were constructed of 4-inch Schedule 40 PVC with 10-slot, 10-foot screens installed within the most permeable zones logged. Table 4 summarizes pertinent information about the observation wells. Additional aquifer water table elevations were obtained from the county well index in order to determine aquifer gradient. Aquifer area was estimated using depth to bedrock information from borehole data.

Table 4. Aurora Observation Wells

Well #	Depth of Well (Ft)	Screened Interval (Ft)	UTM X	NAD 83 Y
1	91	10	557825	5264526
2	39.4	10	558134	5264545
3	76	10	557688	5264254

In order to estimate average aquifer K, slug tests were conducted on each observation well utilizing a 10-foot long, 3-inch diameter Schedule 40 PVC pipe filled with sand and capped at both ends. Test results were analyzed and estimates of K for each well were made using the Hvorslev method (Fetter 1994). The range of calculated K values were too large to produce a realistic estimate of average aquifer K. It was concluded that accurately quantifying ground water outflow was not feasible due to the limited number of observation well K values compared to the complexity of the aquifer. An alternative approach was to attempt to quantify the relationship between pit water level and net ground water using multiple calibrations of WATBUD. This method can facilitate accurate prediction of the expected range of future water levels if the range in recorded water levels for calibration is large enough to allow accurately defining the ground water-water level relationship. Given the limited range in water level data (approximately 2 feet), successive, over-lapping segments of three measured water levels were used in WATBUD to generate corresponding net ground water values. Over-lapping data segments allowed a finer look at the relationship between water level and net ground water; however, this procedure does not increase the inherent accuracy of the data. A regression analysis of the over-lapping data did not produce a significant correlation coefficient ($r^2 = 0.06$), probably a consequence of the limited range of water level data. However, as a whole, the data shows an expected trend of decreasing net ground water with increasing water level (Figure 69). Given the nominal amount of pumping necessary to control water levels, it was concluded that the slope of the best-fit line was reasonable and the relationship could be used in WATBUD for roughly estimating future water levels. In order to increase confidence in the range of predicted water levels, a second trend line was drawn near the upper limits of the data, parallel to the best-fit line (Figure 69). Use of the upper line is believed to result in predictions of maximum probable future water levels.

Calibrated Model

WATBUD was calibrated to water levels collected during the project, using local precipitation data. The calibrated model and parameter file are shown in Figures 70 and 71.

Predictive Model

The relationships between water level and net ground water shown in Figure 69 were used in the predictive model. Along with these relationships, the 30-year normal climatic record (1970 to 2000) was used to predict the probable range of future water levels (Figure 72). The predictions suggest that maximum future water level of the St. James Pit, without water level control pumping, should be about elevation 1445 ft-msl.

Figure 69. Ground water (net) for St. James Pit using WATBUD on successive 3 day intervals 16 November - 23 October 2002.

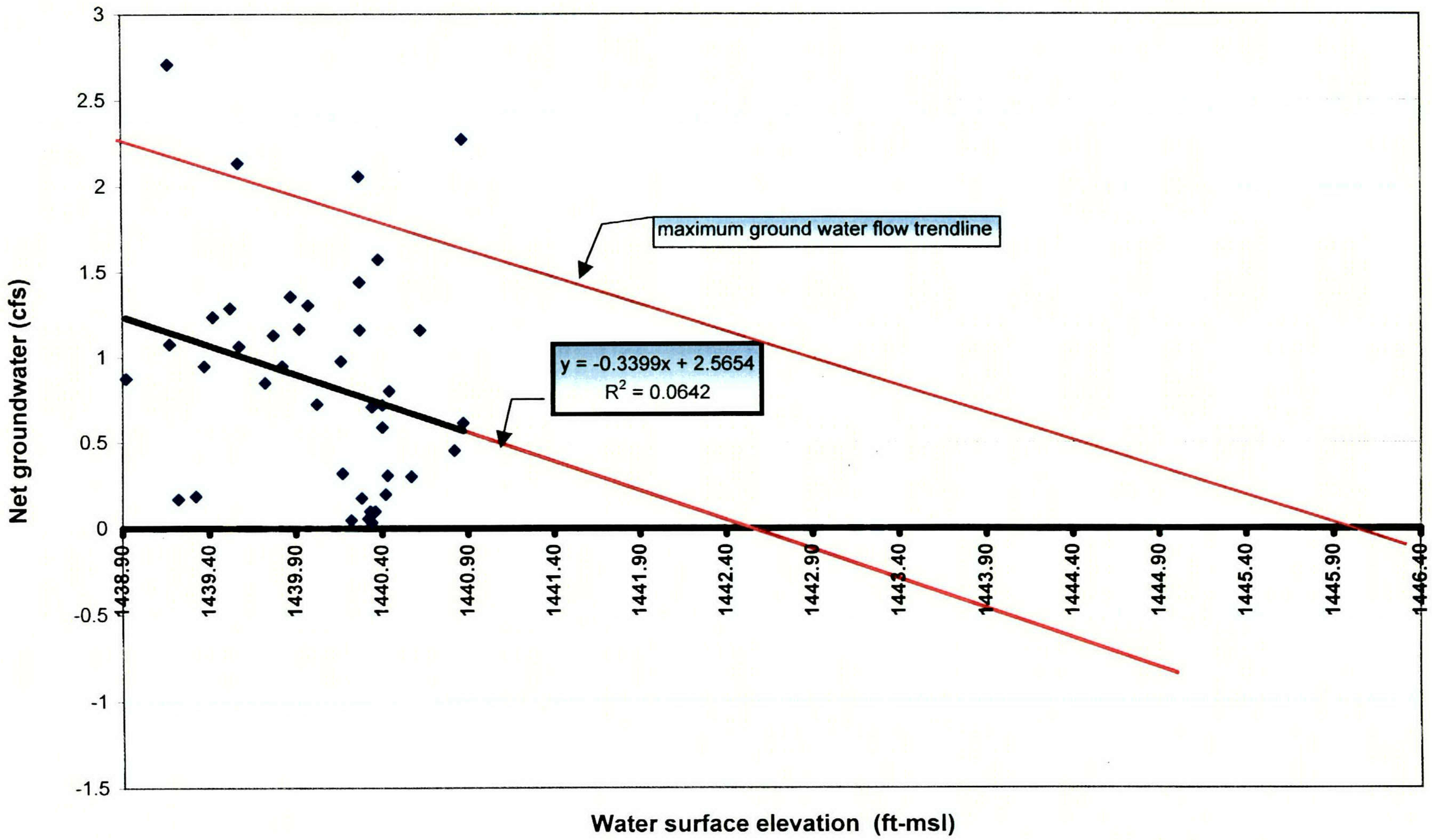


Figure 70. St. James Pit calibrated model and recorded water levels.

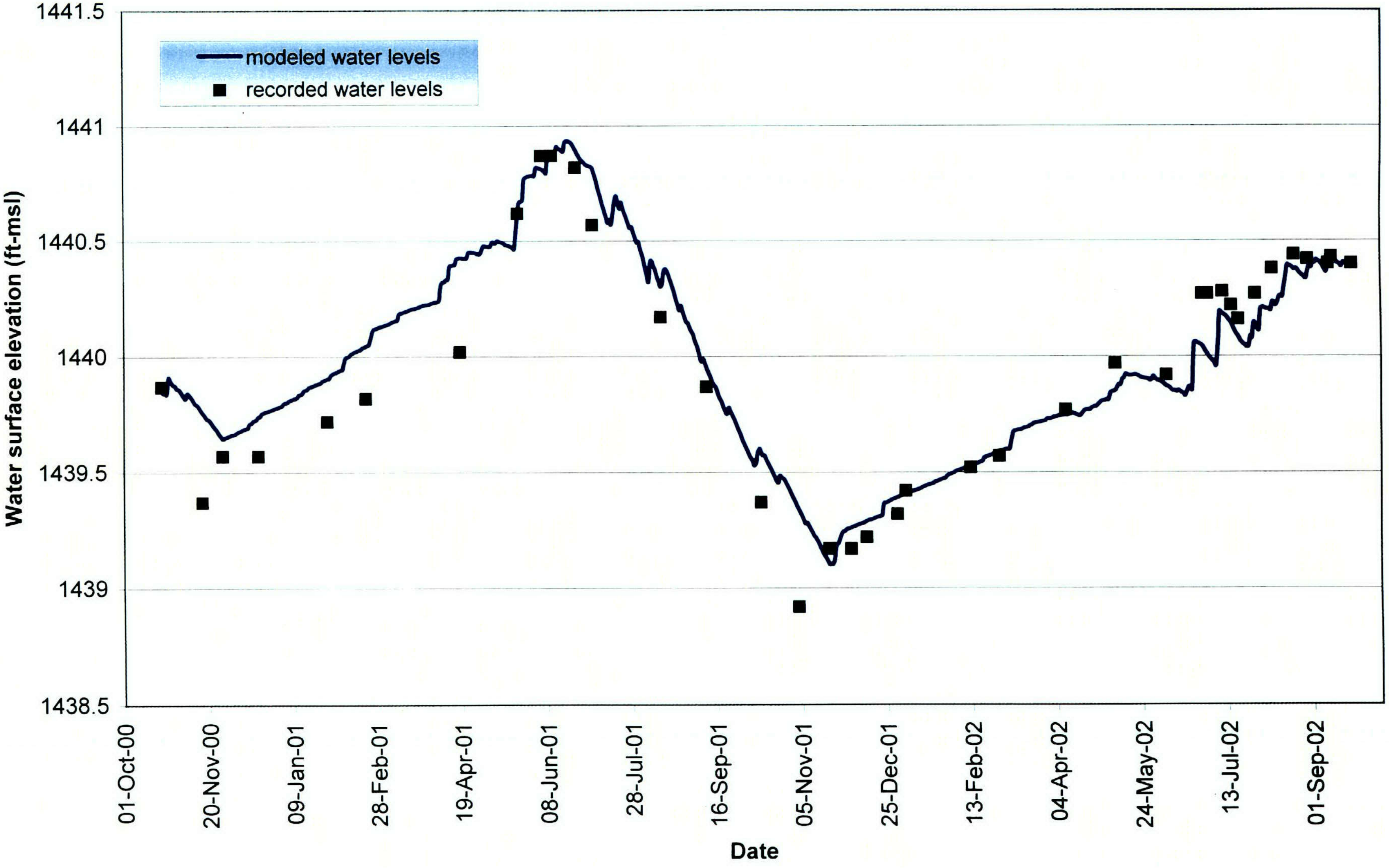
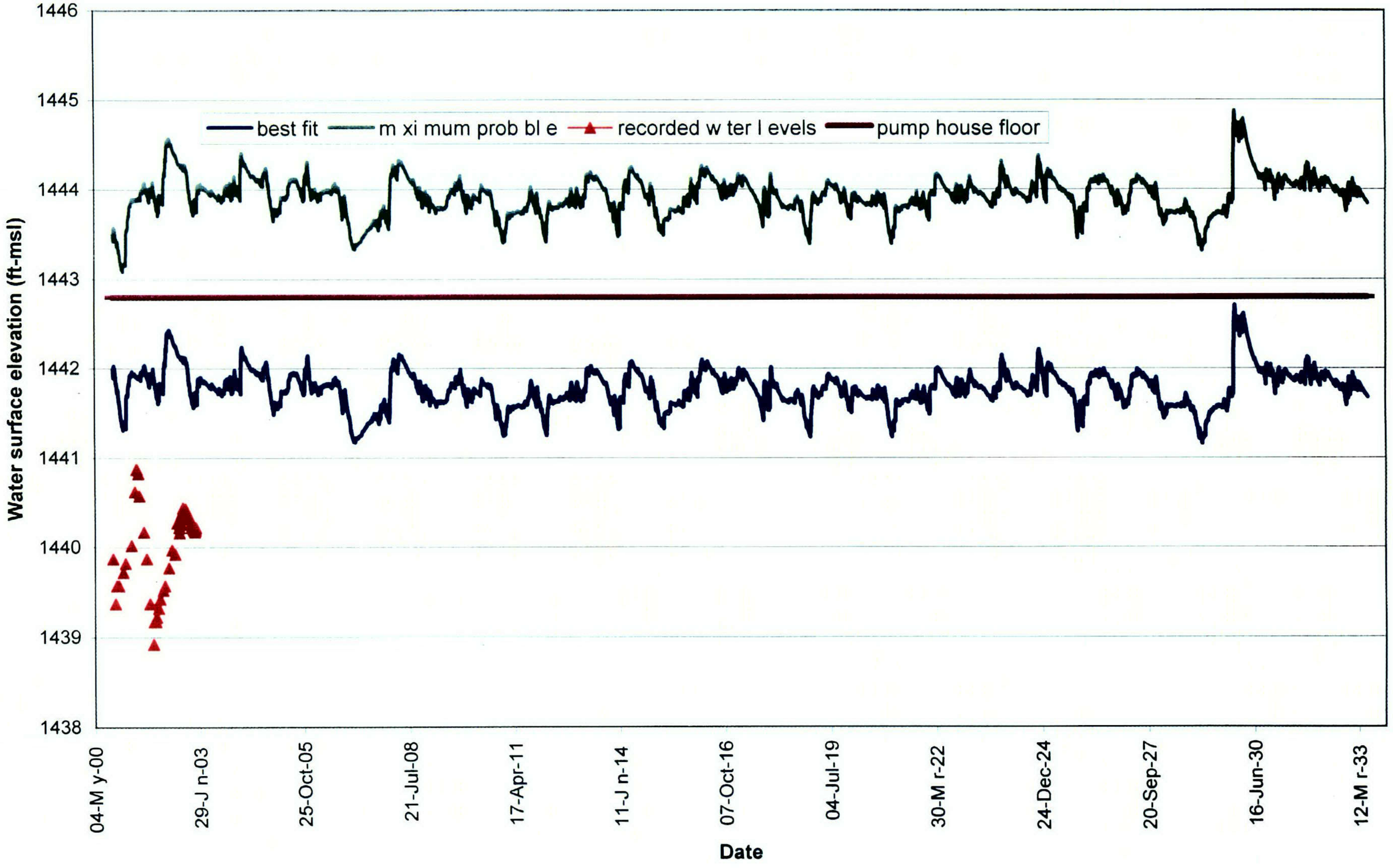


Figure 71. St. James Pit WATBUD parameter file for calibrated model.
(see Figure 2 for detailed description of components)

```
360
6
1435,119,29840,.82
1440,122,30500,.95
1445,125,31118,1.09
1450,129,31753,1.24
1455,132,32405,1.39
1460,135,33073,1.54
B:0:J:\ALL\LTV\WATBUD\STJAMES\
L:0:STJ6,ELEV,1
P:0,1:WWRCLIMAT,PRECIP
P:3,1: 31.00, 40.00, 0.011040, (,,WWRCLIMAT,TEMPMIN,,1),
(,,WWRCLIMAT,TEMPMAX,,1)
P:4,1:
E:2,1,1: 0.8000, (,,WWRCLIMAT,TEMPMIN,,1), (,,WWRCLIMAT,TEMPMAX,,1)
R:2,1: 1.0000
R:4,1, 1:80.00, (P:0:WWRCLIMAT,PRECIP), 2.350, 2.196
R:7,1: 0.2170
R:8,1: 82.03
F:0:STJ;UMP4,CFS
F:2,1: 1.0000
S:2,1: 1.0000
S:4,1,1: 0,0
```

Figure 72. Predicted St. James Pit water level assuming two different relationships for net ground water.



V. CONCLUSIONS AND RECLAMATION RECOMMENDATIONS

Modeling Methods and Input Data

WATBUD has proven to be a useful model for predicting future static water levels, time to fill, and outflow hydrographs for both mine pits and tailing basins. The accuracy of WATBUD predictions is dependant on availability of accurate input data including 1) water levels, 2) climatic, 3) hydrogeologic, 4) bathymetric, 5) topographic, and 6) ground water inflow/outflow. Ground water relationships are developed by interpreting hydrogeologic data, such as depth to bedrock, drift thickness, aquifer hydraulic conductivity, down-gradient water table elevation, and/or an intensive examination of calibrated model seepage residual values over the range of collected water levels. A lack or shortage of data, or wrong interpretations or assumptions may result in significant errors. For this reason, it is recommended that pit and tailing basin water levels continue to be monitored at least twice each year, about 01 May and 01 November, until static water levels are achieved. This data will allow a check on the model predictions and refinement of modeling procedures where appropriate.

The Corp of Engineer's HEC-RAS model proved valuable for accurately modeling the effects on Colby Lake and Whitewater Reservoir water levels from alternative management options for the Diversion Works. Model calibration and prediction requires known or accurately estimated inflow and outflow data. The model could be used to predict water levels under additional Diversion Works management options, including effects of pumping water from Whitewater Reservoir to Colby Lake, if pumping volumes and trigger thresholds are known.

Cliffs-Erie Mining Company Pits

Restoring Watersheds

Restoring watersheds affected by mining to their original drainage patterns is seldom practical or warranted. For example, CE's Pit 1 is nearly four miles long and crosses the headwaters of First and Second Creek watersheds. It is presently outflowing at its east end to Second Creek. In order to proportion Pit 1 runoff to both drainages, massive amounts of earth would have to be removed for channel construction and stockpile movement. A similar, but less dramatic condition exists for Pits 6, 2WX, 2W, and 2E, which all intercept water from two watersheds. Although a single outlet for each pit will result in some water being diverted from one watershed to another, constructing two outlets for any CE pit in the project area is neither practical nor warranted from a hydrologic perspective. However, with accurate predictions of future hydrologic conditions, much can be done to accommodate and control future runoff in a manner that is environmentally acceptable.

Pit 2E

Pit 2E is not expected to need an outlet channel, as outflow should freely pass through existing road and railroad rock fill to Pit 2W. If it does not, and the road/railroad is threatened, an appropriately-sized culvert should be installed.

Pits 2W, 2WX, and 6

Pits 2W, 2WX, and 6 will each need a constructed outlet channel. Outlet channels for all of these pits can be constructed to the following configuration:

Channel slope = 0.003 ft/ft
Channel bottom width = 5.0 ft.
Channel side slope = 3:1 (H:V)

Channels with these configurations will have maximum storm runoff velocities of about 2 feet/second, minimizing potential erosion problems. Steeper channel gradients can be used provided it is demonstrated channel erosion will not be a problem. Outlet channels can be surveyed, designed, and constructed as soon as practical, however, they must be promptly vegetated with grasses to control sideslope erosion and discourage establishment of woody vegetation in channel bottoms.

Time for the pits to fill is predicted to range from a minimum of 5½ years for Pit 6 to a maximum of 18 years for Pit 2E. Peak daily outflow is expected to range from about 8 cfs for Pit 2E to near 20 cfs for Pit 6. Table 5 summarizes predictive model results.

Table 5. Predictive model results summary for Pits 2E, 2W, 2WX and 6.

Pit	Time to Fill (years)	Runout Elevation (ft.-msl)	Water Surface Area at Runout (acres)	Average Outflow (cfs)*	Maximum Outflow (cfs)*
2E	16 to 18	1535	192	0.25	8.2
2W	11½ to 16½	1488	287	2.0	9.0
2WX	10½ to 14½	1455	507	1.5	12
6	5½ to 6	1455	268	4.0	19

* with recommended outlet channel design

Pit 2W's outlet channel should be constructed at an elevation no higher than 1488 ft.-msl to prevent uncontrolled outflow through or over the haul road along the north rim of the pit. The outlet channel will daylight a few hundred feet down-gradient in an existing railroad ditch. Spot improvements to the railroad ditch will be necessary to remove constrictions.

Outflow from Pit 2WX will follow an existing, remnant channel that flows to Colby Lake. Coarse road rock and culverts associated with two crossings of this channel must be removed to at least the original channel dimensions to provide for unimpeded outflow.

Pit 6 will need an outlet channel located at the east-central side of the pit, along the north side of an existing road that runs approximately 600 feet due east, through a wetland to Second Creek. There are no alternative outlet channel locations that avoid wetland impacts. It is recommended the pit runout elevation be no more than 2½ feet higher than the elevation of the bed of Second Creek where the channel enters the creek. This should result in a channel about 800 feet long with a low enough gradient to prevent erosion of the wetland's sandy soil substrate.

Pit 1

Pit 1 water level has stabilized at approximate elevation 1546.5 ft-msl, and outflows at its east end through coarse road and railroad rock fill. A controlled outlet system must be constructed for this location. Water daylights along the south toe of the south road across a broad area, perhaps 200 feet wide, between elevations 1545 ft.-msl and 1550 ft.-msl. Given the broad, flat outflow, construction of an outlet channel through the roads/railroad fill would not likely capture the entire outflow. It is therefore recommended the roads/railroad be excavated down to approximately elevation 1548 ft-msl, for a minimum width of 25 feet. This excavation would provide an overflow channel in the event the rock fill plugs with debris. The channel could be designed to accommodate or discourage motorized traffic. Below the roads/railroad, most of the water concentrates and flows down an abandoned, gravel road enroute to Second Creek. It is recommended that a 10-foot wide channel be constructed diagonally through the gravel road from WNW to ESE. This channel should start near the top of the gravel road and be designed to collect the majority of the outflow and carry it to the east side of the road. Large rock should be placed along both sides of the channel to prevent motorized traffic from crossing. Below this channel flow would follow existing, rocky flow paths to the wetland leading to Second Creek.

Pit 3

Pit 3 presently outlets through a culvert under Dunka Road and enters Wyman Creek. Wyman Creek then flows through an existing culvert under a large rock stockpile. These two crossings can remain in place; however, the owner of Dunka Road will be responsible for structure maintenance. If the Dunka Road is to be abandoned as part of CE's Mineland Closure Plan, a structure removal plan must be developed.

Pits 5N, 5S, 9 and 9S

Each of these pits has reached its static water level. It is not anticipated that any of them will need outlet channel construction. Pit 5S has developed a stable surface water outlet that forms the headwaters of Wyman Creek. Based on field observations, it appears that Pit 5N outflows through a rock stockpile to the north and forms the headwaters of Spring Mine Creek.

Pit 9 water has stabilized approximately 40 feet below the lowest rim elevation, about one foot above the water level of Pit 1. A narrow strip of glacial material about 250 feet wide separates the pits. This material apparently has sufficient conductivity to allow Pit 9 to stabilize with only the 1-foot head differential.

Pit 9S water stabilized at about elevation 1476 ft-msl, then dropped about three feet during 2002. Prior to the water level drop, a large seep formed along the southwest wall of Pit 6, about ½ mile to the east. Isotope analysis of water samples suggests the source of water for the seep includes water from Pit 9S. Future Pit 6 water levels will not affect the seepage flow rate, which in turn should keep Pit 9S water level from rising any higher than it is today, about elevation 1473 ft-msl.

Colby Lake and Whitewater Reservoir

DNR Waters Permit 49-135 requires Minnesota Power to keep Colby Lake at or above 1439.0 ft-msl. The original purpose for the 1439.0 ft-msl threshold was to assure a minimum outflow of 13 cfs to Partridge River while still providing adequate make-up water for taconite processing. A new Colby Lake rating table (Table 1) developed during this project showed 13 cfs discharge at 1439.0 ft-msl. Colby Lake runout elevation is 1438.5 ft-msl.

Whitewater Reservoir seepage loss has apparently not changed since Barr Engineering quantified losses (up to 15 cfs at high water levels) in 1964. In addition, natural inflow to Colby Lake during dry periods typically drops to extremely low rates. The combination of these two factors has a controlling influence on low water levels for all gate management options evaluated for this project. Consequently, none of the management options evaluated, including keeping the gate permanently closed, maintain Colby Lake above the minimum permitted elevation of 1439.0 ft-msl during normal dry periods. In addition, two management options (*gate open* and *gate open 0.1 foot)* resulted in Colby Lake dropping below its runout elevation during dry periods, resulting in zero discharge to Partridge River.

Whitewater Reservoir fluctuated between a minimum of 1432 ft-msl for the *gate-closed* option, and a maximum of 1442 ft-msl for the *gate-open* option. Desirability of any range of Whitewater Reservoir water levels depends on MP's reservoir management objectives, and Hoyt Lake's wastewater disposal, campground, and public access management needs.

No Diversion Works pumping options were evaluated. However, it is apparent if Colby Lake is to be maintained above the minimum-permitted 1439.0 ft-msl elevation, additional water must be brought into the lake during dry periods. Pit 2WX is filling with water but will not outflow to Colby Lake for 10½ to 14½ years. Pit outflow is predicted to frequently drop to zero and have no influence on Colby Lake low water levels during dry periods. Likewise, diverting 75% of Second

Creek flow through Knox Pit and Pit 2WX to Colby Lake, including all future outflow from Pits 2E and 2W, would have little effect on Colby Lake low water levels. Watershed characteristics in Second Creek headwaters and for Pits 2E, 2W, and 2WX are similar to those of Partridge River, e.g., shallow glacial drift, leading to rapid storm runoff and little base flow during dry periods.

Options for keeping Colby Lake above 1439.0 ft-msl include pumping water from Whitewater Reservoir during dry periods or possibly diverting flow from Second Creek through a water control structure at the outlet of Pit 2WX. This project did not evaluate the effectiveness of either of these options. A means of diverting water from Second Creek to Knox Pit, and from Knox Pit to Pit 2WX, would have to be designed and constructed. Any Second Creek diversion would trigger mandatory environmental review and permitting.

Since MP does not consume water from Colby Lake, as the mining companies did, the need for the 1439.0 ft-msl elevation requirement could be re-evaluated in light of an agreed-upon, new management plan for the Diversion Works.

Tailing Basin

Cell 2W does not presently hold ponded water. Its infiltration capacity is high enough so only small amounts of water will temporarily accumulate near the center of the cell after major rainstorms or snowmelt. Continued establishment of vegetation will increase infiltration and evapotransporation rates, further reducing the probability of water accumulating. For these reasons, no outlet control structure is deemed necessary, and no dam safety permit is required for this cell. However, as a safety precaution it is required that a plan be submitted to address the concrete standpipe structure extending from Cell 2W to Cell 1E. It is recommended consideration be given to filling both ends of the structure with porous material such as coarse tailing or crushed rock.

Cells 1E and 2E each contain impounded water and are predicted to permanently retain water. The DNR will treat these two cells as one unit for dam safety requirements. Cell 1E's water level is predicted to fluctuate between elevation 1651 ft-msl and 1653 ft-msl, at least six feet below the maximum permitted for dam safety. Cell 2E's water level is predicted to fluctuate from elevation 1558 ft-msl to 1560 ft-msl, the maximum allowed for dam safety. Several reclamation options exist, depending on long-term DNR Dam Safety permit requirements and CE's management objectives. Cliffs-Erie, or any subsequent owner of the basin, must retain a Dam Safety permit if the dam is greater than 6 feet high at maximum storage capacity, or contains more than 15 acre-feet of water. One reclamation option would be to construct outlet channels at elevations that reduce the volume of water in each cell to less than 15 acre-feet, thus eliminating the need for the Dam Safety permit. For Cell 1E, this would mean constructing a ±2800 foot channel, at approximately elevation 1625 ft-msl, from the west-central part of the cell through the north dike to Cell 2E. The cut through the dike would be about 45 feet deep. Substantial riprap would be required to control erosion below where the channel would exit the dike. Cell 2E would also need an outlet channel, at approximately elevation 1551 ft-msl, from the west-central part of the cell through the north or east dike. The cut through the dike would be about 24 feet deep. Channel length would vary considerably with location, ranging from about 1200 feet at the northwest end of the north dike to about 5000 feet for the east dike. Regardless of location, riprap would be required for erosion control below where the channel would exit the dike.

There are also two reclamation options whereby the owner of the dam would retain the Dam Safety permit. One option is to leave the cells as they are and retain the Dam Safety permit. This would require continued monitoring, safety inspections, and associated costs and fees, paid by the owner of the structure. A second option exists as a consequence of predicted water levels stabilizing at or below the maximum permitted water elevations. This option involves retaining the Dam Safety permit, but constructing emergency spillways so the permit can be re-written as a Class III, Low Hazard, No Outflow permit. The DNR does not require monitoring or an inspection fee for this class of dam, although provisions of the permit are subject to change if future hydrologic conditions warrant. An emergency spillway would need to be constructed in the dike between Cell 1E and 2E at the dam safety threshold elevation. Location of the spillway is not critical, however, the elevation of the dike is lowest (approximately 1670 ft-msl) near its center. Recommended design criteria include:

Invert elevation = 1659.5 ft-msl (dam safety threshold)
Minimum bottom width = 5 ft
Side slopes = 4:1 (H:V)
Channel length = 200 ft (approximate, depending on location)

Given the large margin of safety facilitated by the predicted maximum water level 6 feet below the threshold elevation, no riprap would be needed below the spillway. Normal mineland reclamation standards for vegetation establishment would apply.

The emergency spillway for Cell 2E could be located in either the north or east dike, at the dam safety threshold elevation. Recommended design criteria include:

Invert elevation = 1560 ft-msl (dam safety threshold)
Minimum bottom width = 5 ft
Side slopes = 4:1 (H:V)
Channel length = 400 ft to 600 ft (depending on location)

Given the predicted maximum water level equal to the recommended spillway invert, a riprapped channel would be needed from the spillway outfall to natural ground. Normal mineland reclamation standards for vegetation establishment would apply elsewhere.

St. James Pit

Predicted maximum water elevation for the St. James Pit, without water level control pumping, is 1445 ft-msl, about two feet above the floor of Aurora's pump house. However, given the uncertainty associated with the ground water component of the pit's water balance analysis, it is recommended the city use the 1445 ft-msl estimate conservatively.

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