Appendix J – Hydrology and Hydraulics

Marsh Lake Dam

Ecosystems Restoration Feasibility Study

Hydraulics & Hydrology Appendix

January 2011

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I. General

The Lac qui Parle Project is located on the Minnesota River in western Minnesota near the South Dakota state line. The project lies along the northeasterly boundary of Lac qui Parle County and the southwesterly boundaries of Chippewa, Swift, and Big Stone Counties. The actual Marsh Lake Dam, which is part of the greater Lac qui Parle Project, is 303.5 River miles above the mouth of the Minnesota River and is located near Appleton, Minnesota just downstream of the Pomme de Terre River.

The purpose of this appendix is to provide feasibility level hydraulic designs for several proposed ecosystem restoration features on Marsh Lake and evaluate impacts of those features in terms of their ability to meet ecosystem objectives, flood impacts, and dam safety.

Much of the design utilized existing hydrologic and hydraulic (H&H) data, which is outlined in Section II. Other H&H data, including unsteady water level models using HEC-RAS software, was developed for the current feasibility study and is detailed in Section III.

II. Hydrologic and Hydraulic Data (previously developed)

1. Pool and Tailwater Elevation Frequency Curve.

Analysis is taken from "Section 22 Study, Minnesota River Main Stem Hydrologic Analyses, October 2001". Graphical frequency plots are shown in Plates 1-2.

	10% Event	2% Event	1% Event	0.5% Event
Pool Elevation	942.5	945.4	947.4	949.2
Tailwater Elevation	941.8	943.5	944.6	945.8

Table 1. Summary of Results from Marsh Lake Frequency Analysis

2. Minnesota River Standard Project Floods & Probable Maximum Floods.

Standard Project Floods and Probable Maximum Floods for several locations near to Marsh Lake were developed in "Report on Probable Maximum Floods (PMF) and Standard Project Floods, (SPF) Minnesota River Basin, St Paul District Corps of Engineers, January 1971". No PMF or SPF was developed specifically for Marsh Lake in the report, but the unit hydrograph shape for the Lac Qui Parle Dam was adapted for the development of the Frequency Inflow Hydrographs (section 5).

3. Probable Maximum Flood.

The Probable Maximum Flood (PMF) specifically for Marsh Lake was developed in "Dam Failure Planning Report, Marsh Lake Dam, Minnesota River, St Paul District Corps of Engineers, August 1987". An inflow hydrograph with a peak of 109,000 cfs was adopted as the PMF for Marsh Lake Dam. Routing of the PMF through the reservoir with an antecedent pool equal to 937.6 resulted in a peak pool elevation of 952.0 (approximately 2' above the top of the embankment). The graphical PMF inflow hydrograph for Marsh Lake is shown in Plate 3.

4. Spillway Design Flood.

The spillway design flood for Marsh Lake was developed in “Dam Failure Planning Report, Marsh Lake Dam, Minnesota River, St Paul District Corps of Engineers, August 1987”. The PMP hyetograph was reduced to obtain a peak stage in the Marsh Lake reservoir of 947.1 (3’ of freeboard). The resultant inflow hydrograph has a peak flow of 21,000 cfs. The SDF inflow hydrograph for Marsh Lake is shown in Plate 6.

5. Flow Frequency Analysis for Pomme de Terre River at Appleton

The peak discharges on the Pomme de Terre River at Appleton are taken from the Flood Insurance Study, City of Appleton, Swift County, Minnesota dated October 1981 and are shown in Table 2 below.

	Peak Discharges, in cfs			
	10-year	50-year	100-year	500-year
Pomme de Terre River at Appleton	2,620	5,300	6,700	11,000

Table 2. Summary of Peak Discharges at Appleton, MN

6. Surveys of Lake Bathymetry

Two lakebed bathymetry surveys are available for Marsh Lake. The Corps of Engineers collected lake bed elevations during the winter of 1991 and the Minnesota Department of Natural Resources collected approximate lake bed elevations referenced to the pool level during a vegetation survey during the summer of 1992.

III. Hydrologic and Hydraulic Data (developed for current study)

7. Historic Inflows and Pool Elevations

Historic inflows into Marsh Lake were obtained for the period from September 1984 to September 2003. The historic inflows consist of outflows from the Highway 75 dam on the Minnesota River, rated flows on the Pomme de Terre at Appleton, and local inflows to Lac Qui Parle Reservoir. Historic pool and tailwater elevations for Marsh Lake were also obtained for use in the calibration of an unsteady model for Marsh Lake.

8. HEC-RAS Unsteady water level model

An unsteady water level model for Marsh Lake was developed for this study using HEC-RAS. The model was calibrated to Marsh Lake Pool Elevations using historic inflows and used primarily for determining the effect of proposed feasibility features to Marsh Lake water levels. The model was also used to estimate the downstream impacts of the proposed project on Lac Qui Parle reservoir and downstream on the Minnesota River at Montevideo. A georeferenced schematic of the HEC-RAS model, which includes Marsh Lake, Marsh Lake Dam, the Minnesota River, Lac Qui Parle Reservoir, Lac Qui Parle Dam, and the Pomme de Terre River, is shown in Plate 23.

The calibrated existing conditions model was altered to determine effects of specific proposed project features on Marsh Lake water levels. Simulations were performed over the 20 year period

(1983-2003) for 1) existing conditions, 2) re-routing of the lower Pomme de Terre River, and 3) re-routing of the Lower Pomme de Terre River combined with a modified primary spillway/fishway.

Separately, unsteady flow simulations were also performed to determine the size of drawdown structure required to achieve desired water level and habitat goals (see section 15). This was done using simplified model geometry (based on calibrated existing conditions geometry) with only the Marsh Lake Reservoir and assuming no tail water submergence at the dam. This model was used to determine the time required to achieve a drawdown (from 938.3 to 935.5) and the duration of water level increases (i.e. "bounce") during a 5 year summer storm during drawdown (935.5).

The model geometry combined data from several sources, outlined in Table 3 below.

Geometry	***Source***
Pomme de Terre River (upstream cross sections)	HEC-2 modeling from FIS study
Pomme de Terre River (downstream cross sections)	Recent field surveys
Marsh Lake Reservoir Elevation-Storage relationship	Water Control Manual (Reference 4)
Minnesota River Downstream of Marsh Lake Dam	Combination of recent field surveys and estimated cross sections
Marsh Lake Dam Primary Spillway	As built: 112' wide, sill elevation of 937.6'
Marsh Lake Dam Overflow Spillway	As built: 90' wide, elevation of 940.0'
Marsh Lake Dam Low Flow Conduit	As built: 2' x 2' square gated conduit, invert of 935.0'. Approximated as 2'x1' conduit to simulate actual operation
Lac Qui Parle Reservoir Elevation-Storage relationship	Water Control Manual (Reference 4)
Lac Qui Parle Dam Outlet Structures	As built drawings
Minnesota River Downstream of Lac Qui Parle	Previous Compilation of FIS study model data

Table 3. Source of HEC-RAS Model Geometry

Calibration of HEC-RAS Water Level Model (existing conditions)

The primary purpose of the unsteady modeling was to evaluate changes to the water level conditions on Marsh Lake between existing conditions and with project conditions, and the initial of the calibration effort focused on matching historic Marsh Lake pool elevations. All HEC-RAS model runs were made using HEC-RAS version 4.1.0 Jan 2010.

Inflows: Historic inflows for the modeling effort were obtained from a variety of sources and described in the table below.

Inflow	**Source**
From HWY 75 Dam to Marsh Lake	USACE Water Control Records (computed flow)
Pomme de Terre River at Appleton	USGS Gage Records (flow)
Combined Lac Qui Parle Reservoir Inflows (Lac Qui Parle River, Chippewa Diversion, and Local)	Combination of Watson Sag, Lac Qui Parle River, and local inflows based on gage records from USGS and USACE

Table 4. Sources of Inflow Data for Modeling

N-Values: Three distinct river reaches were modeled: Pomme de Terre River from Appleton downstream to Marsh Lake, Minnesota River downstream of Marsh Lake to Lac Qui Parle Reservoir, and the Minnesota River downstream of Lac Qui Parle to Montevideo. The Pomme de Terre River used n-values of 0.45 for the main channel and 0.07 for the overbank areas, which are reasonable typically for streams similar to the Pomme de Terre and result in stages in Appleton that match observed data. The Minnesota River downstream of Marsh Lake Dam used n-values of 0.028 for the main channel and 0.053 for the overbank areas, which are typical of streams similar to this reach of the Minnesota River. The Minnesota River downstream of Lac Qui Parle Dam used n-values ranging from 0.02-0.05 for the main channel and values ranging from 0.04-0.08 in the overbank areas, which were taken directly from the previously calibrated model based on the Flood Insurance Study (FIS).

Lac Qui Parle Gates: Marsh Lake Dam is subject to relatively frequent tailwater submergence and is dependent on the operation of the gates on the Lac Qui Parle Dam. The existing conditions model was calibrated to Marsh Lake Pool elevations using an automated gate operating scheme based on pool elevation that maintains the Lac Qui Parle reservoir elevation between 933' and 935' during low inflows and allows for larger outflows during floods (shown in Table 4). This operating scheme is approximately representative of the operation of the gates at Lac Qui Parle according the Water Control Manual (Reference 4).

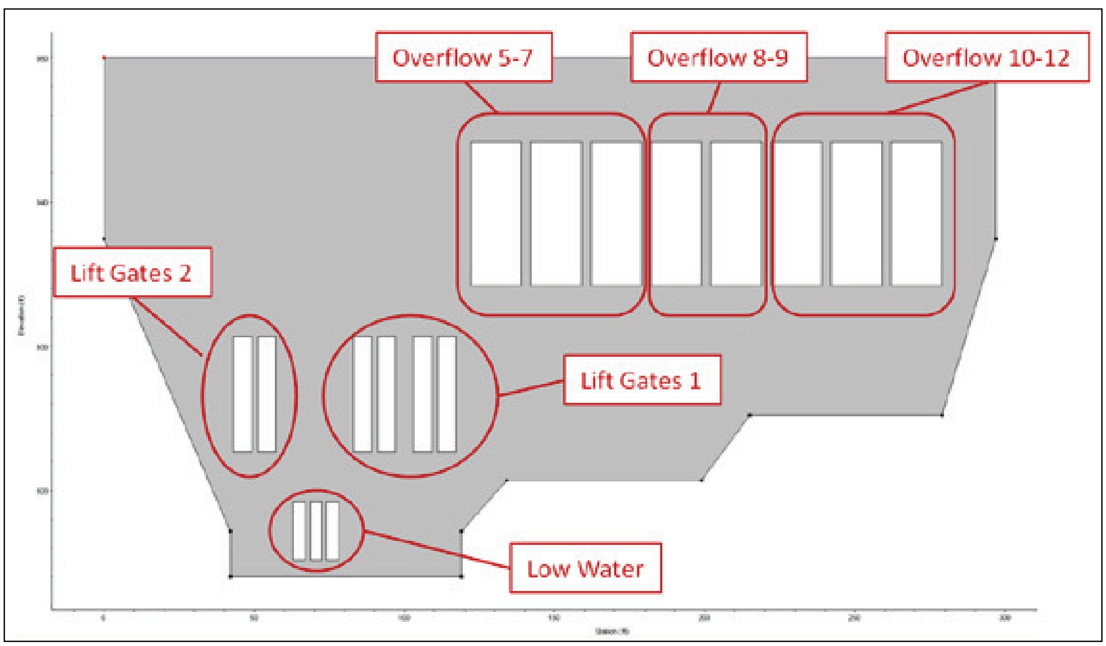

Figure 1. Schematic of Modeled Lac Qui Parle Dam Gates.

	Gate Group Name					
	Lift Gates 1	Low Water	Lift Gates 2	Overflow 5-7	Overflow 8-9	Overflow 10-12
Trigger Elevation to Open	941.1	960	935	941.1	941.1	941.1
Trigger Elevation to Close	940	915	933	940	940	940
Maximum Opening	8	4	8	10	10	10
Minimum Opening	0	0	0	10	3.5	0
Total Width of Gate Group	12	12	24	51	34	51

Table 5. Summary of Simplified Lac Qui Parle Gate Operations used in HEC-RAS modeling

Downstream Boundary Condition: The downstream boundary condition for the model was on the Minnesota River at Montevideo using normal depth with a friction slope of 0.00005. The model was not calibrated for stages at Montevideo, but the downstream boundary is considered to provide reasonable results for the tailwater at Lac Qui Parle Dam and peak flow routing from Lac Qui Parle down to Montevideo.

Marsh Lake Dam Outlets: Marsh Lake dam (existing conditions) consists of 3 distinct outflow features: a 2' gated conduit, a primary spillway, and an auxiliary spillway. The primary spillway is an ogee crested concrete structure which was modeled using a weir coefficient of 3.6. The auxiliary spillway is a grouted rip-rap section cut through the embankment, a weir coefficient of 3.0 was used, which is higher than the default of 2.6 for a broad-crested weir, but chosen to better match the historic pool elevation data. The small, low flow conduit was modeled using HEC-RAS culvert routine and typical values for roughness and loss coefficients. The existing conditions model was calibrated using the available historic inflows and Marsh Lake Pool level data for the 20 year period of October 1984 to September 2003. Results of the calibration are shown on Plates 24-28.

Modeling of With-Project Conditions

In order to estimate Marsh Lake water level changes for existing versus project conditions, the existing conditions model was altered to reflect proposed project conditions.

Primary Spillway: The modification to the primary spillway was modeled as a family of rating curves for various head and tail water conditions, which were determined using a steady flow HEC-RAS model described in section 9 and shown in the figure below.

Auxiliary Spillway: The auxiliary spillway will be modified under proposed conditions to include a stop-log structure will allow for periodic water level drawdowns on Marsh Lake. The structure will have the same width as the existing spillway. For the purposed of feasibility level design, the auxiliary spillway dimensions and weir coefficients was not altered.

Lower Pomme de Terre River: The return of the Pomme de Terre to its historic channel was modeled by altering the lower reach to include and appropriate centerline alignment and utilized surveyed cross sections in the area as well as dimensions of the proposed bridge over the Pomme de Terre at the dam access road.

9. HEC-RAS fish ramp model

   A separate steady flow HEC-RAS model was developed to simulate flow in the proposed fish ramp (primary spillway modification). This model used the detailed cross section geometry that includes a series of rock weirs. Roughness height of 1' was used for the entire fish ramp, and expansion and contraction coefficients were set at 0.3 & 0.1 respectively. Roughness height was chosen over a Manning's N-value roughness definition for the modeling as it better accounts for increased friction losses during low flows. A roughness height of 1' results in an equivalent N-value between 0.032-0.042 for flow depths greater than 1'. Sensitivity analysis was performed on the roughness, contraction, and expansion parameters and it was determined that their effect on the values were relatively minor in terms of their affect on the with-project pool duration curve.

   The fish ramp model was also used to estimate the velocities for the range of flow conditions in order to meet criteria for fish passage and to select a size for the base stone for the ramp. A schematic of the proposed fish ramp spillway as well as the modeled family of rating curves for the modified outlet structure is shown in Plates 14 and 15.

10. Frequency Inflow Hydrographs.

   Marsh Lake summer-time (May – September) inflow hydrographs for more frequent events (2, 5, 10, 25, 50, and 100 year return periods) were estimated for the purposes of this feasibility study. The estimate was obtained by taking the shape of the unit hydrograph for the Lac Qui Parle Reservoir (from Reference 2) and adjusted for drainage area using a simple ratio. The peak inflow frequency at Marsh Lake was determined by adjusting the 2, 5, 10, 25, 50, and 100 year flows at the Lac Qui Parle River and Pomme de Terre River Gages for to the entire Marsh Lake watershed based on a direct drainage area ratio; and then taking an average of the results of the two gages as the adopted Marsh Lake inflow frequency curve. The all-year inflow frequency curve was then adjusted for summer-only (May-September) using a ratio of 0.386 obtained from the ratio of the sum of all-year peaks to the sum the summer peaks at the Pomme de Terre River gage based on the record from 1931 to 1997. The final inflow hydrographs were calculated as a ratio of the Marsh Lake inflow unit hydrograph such that the peak inflow is equal to the peak inflow frequency. The information was used for the preliminary sizing of the stop-log drawdown structure to insure that water level goals can be obtained when the lake is occasionally drained. The graphic plots of the adopted frequency inflow event and their derivation are shown in Plates 8-11.

   The 1% annual chance inflow hydrograph (shown in Plate 11) was also computed in a similar fashion and used to simulate existing and with project peak pool elevations on Marsh Lake, resulting in an existing peak inflow of 16,655 cfs and a peak inflow of 11,372 cfs under with project conditions.

11. Partial Duration Flow Frequency Curve for Pomme de Terre River.

   A partial duration frequency analysis was done for this feasibility study based on the period from 1936 to 2007. The analysis will aid in the estimation of bankfull flow for the Pomme de Terre River in the vicinity of Marsh Lake and in consideration of stream restoration alternatives. Bankfull flow is taken to be approximately equal to a 1.5 year flood, or 850 cfs.

Exceedance Probability (%)	Return Period (years)	Flow (cfs)
0.1	1000	18778
0.2	500	14319
0.5	200	9729
1	100	7072
2	50	5223
5	20	3380
10	10	2420
20	5	1746
30	3.33	1383
40	2.5	1202
50	2	1056
60	1.67	928
70	1.43	809
80	1.25	731
90	1.11	636
95	1.05	587
99	1.01	528

Table 6. Results of Partial Duration Flow Frequency analysis for Pomme De Terre River at Appleton

12. Estimated Sediment Yield from the Pomme De Terre River Watershed.

    Sediment yield for the Pomme De Terre River was estimated by utilizing the existing USGS suspended sediment data from the neighboring Chippewa River gage at Milan, MN. The annual sediment yield at Milan was calculated and adjusted to the Pomme de Terre River based on drainage area. A total average annual suspended sediment load from the Pomme De Terre River was estimated to be 13,200 cubic yards per year. It is noted that estimates of the rate of sediment deposition in Marsh Lake cited in "Water Control Manual, Lac Qui Parle Project, August 1995" are significantly higher than the rate suggested by the Chippewa River gage.

Annual Sediment Yield Chippewa River Near Milan, MN						Adjusted to Pomme De Terre River
Flow-Duration			Water	Sediment	Daily Yield	
Q Exceed.	Mid Ordin.	Increment	Q_w (cfs)	Q_s (tons/day)	Q_s (tons/day)	
0.0%						
	0.05%	0.1%	9,600.0	4,014.4	4.0	
0.1%						Drainage Area of Pomme De Terre River **905 sq. mi.**
	0.30%	0.4%	4,820.0	1,807.8	7.2	
0.5%						
	1.00%	1.0%	2,990.0	1,040.0	10.4	Drainage Area of Chippewa River **1870 sq. mi.**
1.5%						
	3.25%	3.5%	1,771.0	567.1	19.8	
5.0%						
	10.00%	10.0%	1,000.0	292.6	29.3	Average Annual Load from Pomme De Terre --Adjusted for Drainage Area **13221 C.Y. / year** **8.8 Acre-ft / year**
15.0%						
	20.00%	10.0%	581.0	156.0	15.6	
25.0%						
	30.00%	10.0%	360.0	89.6	9.0	
35.0%						
	40.00%	10.0%	232.0	53.9	5.4	
45.0%						
	50.00%	10.0%	159.0	34.8	3.5	
55.0%						
	60.00%	10.0%	101.0	20.6	2.1	
65.0%						
	70.00%	10.0%	65.0	12.4	1.2	
75.0%						
	80.00%	10.0%	38.0	6.6	0.7	
85.0%						
	90.00%	10.0%	19.0	3.0	0.3	
95.0%						
	97.50%	5.0%	5.0	0.6	0.0	
100.0%						
	Sum: Average Daily Sediment Load				108.5 Tons / day	
	Average Annual Sediment Yield				**39,593** Tons / year **27,319** C.Y. / year	

Table 7. Estimate of Average Annual Sediment Load to Marsh Lake from the Pomme De Terre River based in nearby gage site

Source	Result
University of Minnesota Study	105 cm deposited near mouth of Pomme De Terre River in Marsh Lake since construction of Marsh Lake Dam (~30 years). Study done prior to removal of Appleton Mill Dam.
Observed Sediment Rate for Big Stone River	0.05 acre-ft per sq. mi.
Chippewa River at Milan data translated to Appleton	8.8 acre-ft per year

Table 8. Summary of Sediment Load Estimates for Marsh Lake

13. Wind Speed and Direction Frequency and Duration Analysis.

Analysis of the wind speed and direction was performed on data obtained for the nearby Montevideo airport in order to support the utilization of aquatic plant growth modeling for Marsh Lake. Graphical plots of the results of the wind analysis are shown in Plates 12-13.

IV. Project Feature Alternatives: Design

14. Primary Spillway Modification.

The concept for the modification to the primary spillway includes a rectangular notch cut into the existing concrete ogee crest, a sloping rock fill base on the downstream side of the structure, and a series of arched bolder weirs. These features will have the effect of creating greater water level variability, lowering the average water level and allowing for fish passage between the Minnesota River and Marsh Lake.

a. General Layout of Spillway Notch, Rock Ramp, and Boulder Weirs

The specific layout and geometry of the features were optimized to achieve target water levels in Marsh Lake and velocities in the fish way. Optimization was done utilizing a HEC-RAS (steady flow) model of the fish ramp to establish a family of rating curves for the range of head and tail water conditions, and a separate HEC-RAS (unsteady) model to simulate water levels for 20 years of water level data (1983 – 2003).

Although the establishment of the fishway rating curves is complicated by the lack of calibration data, there will be an opportunity during construction to field fit the boulder weirs to achieve the desired hydraulic performance. Modeled hydraulic performance curves, are shown in Plate 14.

Design data for the dam modification is shown below in Table 9 and a figure detailing the design is shown on Plates 15-16.

Primary spillway modification: Design data	
Elevation of Existing Spillway Crest	937.6
Elevation of "notch"	935.5
Width of "notch"	30'
Invert of V-notch at Station 0+20 (d/s of crest)	936.0
Width of V-notch in base rock fill	30'
Slope of rock fill base (starting at Station 0+20)	4%
Number of boulder weirs	9
Spacing of weirs	20'
Vertical drop of each weir	0.8'
Diameter of individual weir boulders	5'
Number of boulders per weir	~34
Spacing between boulders along weir	0' (side by side)
Boulder "stick-up" above rip-rap base: (Min.-Max.)	1' – 3.5'
Upstream Angle Weir Intersection with bank	30°

*Elevations in NGVD 1929 Datum

Table 9. Primary Spillway Modification Design

b. Rip Rap Base Sizing

The rock fill base of the fish ramp will be subject to high velocities and must be constructed of material that resists erosion under the critical condition. The tail water condition at

Marsh Lake is controlled by the Lac Qui Parle Reservoir and does not necessarily submerge the dam at all higher flows. The minimum tail water elevation therefore was estimated based on a 20 year period for the tail water at the dam (1983-2003). Under the minimum tail water condition, average channel velocity for the full range of flows was determined using HEC-RAS (fish ramp model described in Section 9) and D50 riprap size was determined using criteria from HDC 712-1 (high turbulence and gamma of 165 lb/ft^3). Required D50 based on a spherical diameter is 1.6'.

Spillway Flow	Min. TW	Velocity Channel	HDC 712-1 D_{50} (ft)
1000	934	7.9	0.79
2000	936	9.3	1.09
3000	937	10.2	1.32
4000	938.5	10.7	1.47
5000	**941.5**	**11.2**	**1.60**
6000	942.5	8.8	0.98
7000	943.25	8.3	0.89
8000	944	8.1	0.83
10000	945	8.4	0.90
12000	946	8.7	0.96

Table 10. Determination of Critical Condition for Rip Rap Design

c. Fishway Containment Dikes

The rock-ramp fishway must include containment dikes along the left and right banks so as to contain all of the flow leaving the primary spillway within the fishway. For the purposes of the feasibility study, the top of the dikes will tie into to embankment at approximately 946.0' (NGVD 1929) and slope downstream at 4%.

d. Velocity Conditions for Fish Passage

Average velocities in the center (V-notch) of the fish ramp as well as in the sides of the ramp at the restrictive boulder weir cross sections were computed for a range of flow conditions and the results are shown in Table 11. Actual point velocities are expected to be lower than the average velocity especially in the sides where depth varies considerably.

Flow Rate (cfs)	Exceedance Duration	Average Velocity in center, V-notch of channel (ft/s)	Average Velocity in sides of channel (ft/s)
15	90%	3.12	0.26
175	50%	5.23	3.12
1500	10%	8.66	5.19

Table 11. Average velocities in fish ramp at the weir cross sections

15. Overflow Spillway Modification

The concept for modification of the Marsh Lake Dam overflow spillway consists of a series of stop-log bays with a concrete sill at elevation 935.0 (NGVD 1929 datum), with a top of stop log elevation of

940.0 (NGVD 1929 datum). The structure will allow for the periodic removal of the stop logs to achieve a water level drawdown while maintaining full spillway capacity for flood events.

a. Drawdown Structure Width

The desired minimum drawdown lake level is 935.0 (NGVD 1929). The criteria for selection of stop log bay size is based on (1) a maximum duration of bounce in the water surface for a 5-year summer storm (less than 7 days above 936.0), and (2) a maximum time to drawdown from average water surface elevation (938.3) to drawdown elevation (935.5) of about 15 days.

Preliminary routing simulations, as shown in Table 12, suggested that a total effective weir width of approximately 70' will meet the necessary criteria. To insure a conservative feasibility level design; a width of 90' was carried forward for the sizing of the drop structure and outlet channel.

Width of Drawdown Outlet	Equilibrium Flow (cfs)	5-yr Rainfall: duration of bounce (above 936.0')	Maximum Water Surface During Bounce	Time to Drawdown (938.3 to 936.0)
20'	180	19.5 days	937.33	~54 days
40'	350	12 days	936.88	~36 days
60'	520	7.5 days	936.57	9 days
70'	605	6 days	936.45	6.75 days
80'	685	5 days	936.36	5.5 days
90'	770	4 days	936.28	4.5 days
Assumptions used for Feasibility Sizing:		Primary Spillway has 5' wide notch at 935.5' and sloping boulder fill Pomme de Terre has been rerouted and does not flow into the reservoir Sill of drawdown structure is at 934' Weir coefficient for drawdown structure is 3.0 Tailwater in Lac Qui Parle Reservoir is 935.0' Mean Inflow during drawdown is 375 cfs Inflow hydrograph for "bounce" has peak flow of 560 cfs		

Table 12. Feasibility Level Sizing of Drawdown Structure

b. Approach Channel

The sill elevation of the drawdown structure was selected as 935.0' based on the lake bed bathymetry in the lower end of Marsh Lake. The sill will be set very near to the bottom of the lake bed, and the lake bed may limit the discharge through the structure when the stoplogs are removed. At this sill elevation, no approach channel dredging will be required. Some scour of the lake bed would be expected while the stop logs are removed. A map of bathymetry near the outlet is shown in Plate 17.

c. Drawdown Structure Configuration

A typical drop structure as defined in US Army Corps of Engineers Engineering Manual 1110-2-1601, Plate B-48 (Hydraulic Design of Flood Control Channels) was utilized as the basis for the design. The typical design is altered to allow for removable stop logs. A full pool elevation of 950’ and a width of 90’ were used for design, resulting in a design flow of 8500 cfs. Design calculations and structure dimensions are shown in Plate 18 and in Figure 2 below.

A large panel will be included in the design rather than individual stop logs, and will be constructed of aluminum. They will be less apt to seize in place and will eliminate the problem of trying to pull the lower stop-logs out from under water. A secondary/backup stop-log slot and spare panels will be included in the design in order to provide redundancy in case of failure. Although the panels will be removed about once every 10 years, they may need to be exercised every few years

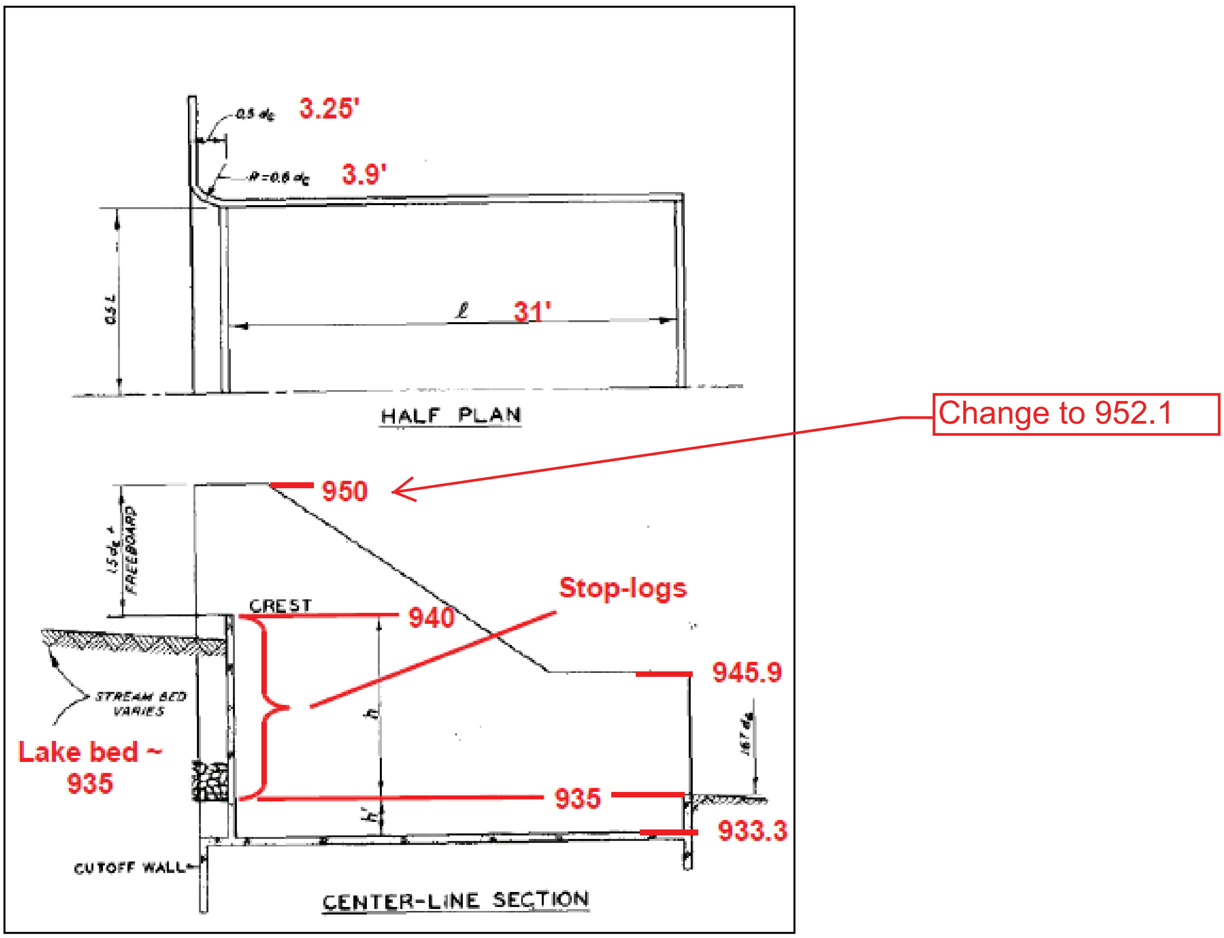

Figure 2. Preliminary design of auxiliary spillway/drawdown structure.

d. Outlet Channel Downstream of Drawdown Structure

The outlet channel will convey water from the drawdown structure to the Minnesota River. The channel will be lined with rip rap to prevent scour. For the design flow of 8500 cfs, a channel width of 90 feet, and Manning's n-value of 0.04, the maximum downstream channel slope to maintain sub-critical flow is approximately 2.75%. The slope must be reduced substantially to minimize the channel velocities and the size of rip-rap required for erosion protection.

The outlet channel will be protected from scour by rip-rap. The detailed design of the channel will be completed in next phase of design.

The minimum ration of radius of curvature to width of 3 is set for outflow channel, using the criteria in EM 1110-2-1601, Section 2-5-c.

e. Frequency of Operation

Duration analysis of the modeled water levels on Marsh Lake for the 20 year period (1983-2003) indicates that pool will reach elevation 940.0' or greater about 12-13% percent of the time during non-drawdown conditions (i.e. stop logs in place). This duration is not significantly altered under with-project conditions.

16. Embankment Sections

Two new sections of embankment are needed to separate the Marsh Lake pool from the rerouted section of the Pomme De Terre River. One of these sections must intersect the current Pomme De Terre River channel. Locations of these embankments are shown in Plate 19.

a. Selection of Design Elevations

The existing Spillway Design Flood (SDF) routed through the existing Marsh Lake dam and resulted in a peak pool elevation of 947.1' *(as determined in Reference 3). The design elevation for the new embankment sections shall include 5' of freeboard above the SDF routing, or an elevation of 952.1'.

Rip-rap protection against wave action is necessary for the lake side of new embankments. Top elevation of the rip-rap layer is assumed be equal to that of the existing embankments, which is 942.0'.

17. Diversion Plug

A diversion plug is needed to divert the Pomme De Terre River into its historic channel in the area upstream of the Marsh Lake Dam. The location of this plug is identified in Plate 19.

a. Selection of Design Elevation

The top elevation of the plug was chosen as 944.0 (NGVD 1929) in order to allow overtopping during floods and allow the river reach to mimic natural geomorphic processes. The plug will be situated in a ~200' reach of the existing Pomme de Terre river channel. The plug has a top-width that fills the much of this area, which will convert the area to terrestrial habitat.

18. Fish Pond Breach

An abandoned fish rearing pond exists downstream of the Marsh Lake Dam embankment. The embankment of the pond (which is separate from the main Marsh Lake Embankment) will be breached with the goal of allowing the area to periodically flood. A bottom elevation of the breach of 936.0 (NGVD 1929), which is expected to flooded by the tail water about 20% of the time, was selected.

19. In-Lake Breakwater Structures

A series of in-lake rock breakwater structures are included in the design features with the intent of reducing wind fetch and wave induced bottom sediment resuspension, in turn promoting water clarity and improving the conditions for aquatic plant growth.

a. Layout

The proposed layout of the rock breakwaters was done primarily by examination of a weighted wind fetch map (shown in Plate 13) which took into account both the shape of Marsh Lake and the frequency of wind directions in the region. The proposed locations of the breakwater structures are shown in Plate 20.

b. Typical Section

The breakwater structure elevation will be 2' above the average water surface elevation of 938.3 (NGVD 1929) or 940.3. A typical section of the breakwater structures is shown in Figure 1. A side slope ratio of 1V to 5H is recommended for structures that are subject to ice loading, which is the case for the proposed breakwater structures. Due to the ice load angular rock (quarry stone) is required for the structure.

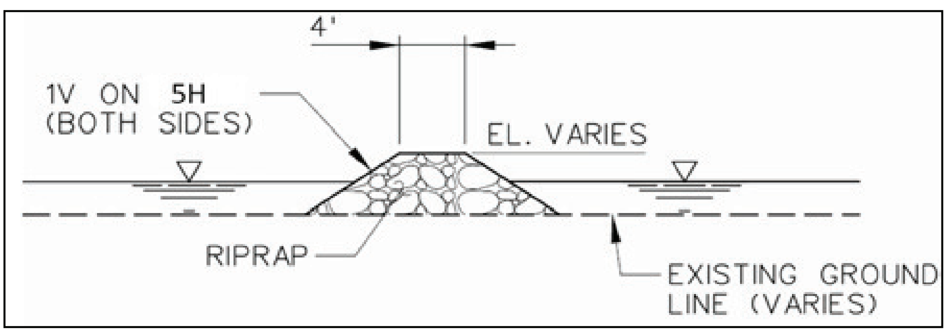

Figure 3. Typical section of in-lake breakwater structure

c. Aquatic Plant Growth Modeling & Optimization

Simulation of the conditions for aquatic plant growth based on reduced wind fetch in Marsh Lake is being conducted. During final design, this modeling will be available for use in the optimization of the breakwater structure layout.

20. Louisburg Grade Road Culvert Modifications

Several culverts connect the upper section of Marsh Lake to the main body of the lake through Louisburg Grade Road. Installation of stop log control structures at these locations in order to maintain higher water levels in the upper part of Marsh Lake during Marsh Lake water level drawdown are included in the design. The structures will provide the ability to maintain Upper Marsh Lake water levels up to the average water surface elevation of 938.3 (NGVD 1929).

21. Rerouting of the Pomme De Terre River

The lower section of the Pomme De Terre River was channelized as part of the original Marsh Lake Dam construction. The current project includes the restoration of this section of river by reconnecting the historic meandering channel. This project feature will include the construction of a bridge over the Pomme De Terre along the current embankment, the construction of two new sections of embankment (see section 16), the construction of a diversion plug (see section 17), some excavation along the historic channel, and erosion control structures.

As the historic channel was originally formed by the geomorphic conditions of the Pomme De Terre River and its watershed, it is expected that the channel plan form dimensions will result in a stable natural channel once the fine sediments are removed.

a. Approach to Construction

The reconnection of the Pomme De Terre to its historic channel will require some excavation of material that now blocks this flow path, particularly through the current embankment and near the mouth where it will meet the Minnesota River. It will also require that fill be placed in two channelized reaches of the current flow path. Some erosion control structures will also be necessary to prevent head cutting. However, the general philosophy will be to connect the river to its original flow path and allow natural processes to form to channel.

b. Stream Classification

The lower reach of the Pomme De Terre was classified according to the Rosgen stream classification system based on field surveys. The lower reach of the river below Appleton falls generally into the “C” class.

c. Bankfull Flow

The Pomme De Terre River below Appleton has a bankfull flow rate of approximately 850 cfs (see section 11).

d. Typical Channel Dimensions

Cross section surveys of the Pomme De Terre below Appleton, MN indicate that the average bankfull width of channel is approximately 90-110 feet. This width was verified with aerial photos. Steady flow modeling of the Pomme de Terre River with a bankfull discharge (850 cfs, see Section 11) shows that hydraulic depth varies from 3-5 feet in the reach between Appleton and the mouth. An average depth of 4’ is therefore considered the typical depth for the Pomme Terre River in the project reach. Based on the stream slope upstream of the project area, a typical slope of 0.0005 ft/ft is considered representative of the reach to be restored. Typical side slopes are approximately 1V:6H.

e. Bridge Dimensions

The bridge over the Pomme De Terre River must have a low flow channel of the appropriate size to mimic natural geomorphologic process, and also have enough flow area such that it does not induce flooding upstream.

Preliminary bridge sizing was done using a low flow channel with a top with of 90', a depth 4.5', side slopes of 1V:3H, as well a overbank area as required to not induce an increase in stages greater than 0.5' upstream of the bridge for the 1% chance flood event. For preliminary sizing, the width of overbank required was calculated based on the results from the HEC-RAS model for a steady flow of 8000 cfs (1% chance flood), and increased until the upstream stage increase was less than 0.5'. Results of the preliminary sizing for the bridge are summarized below.

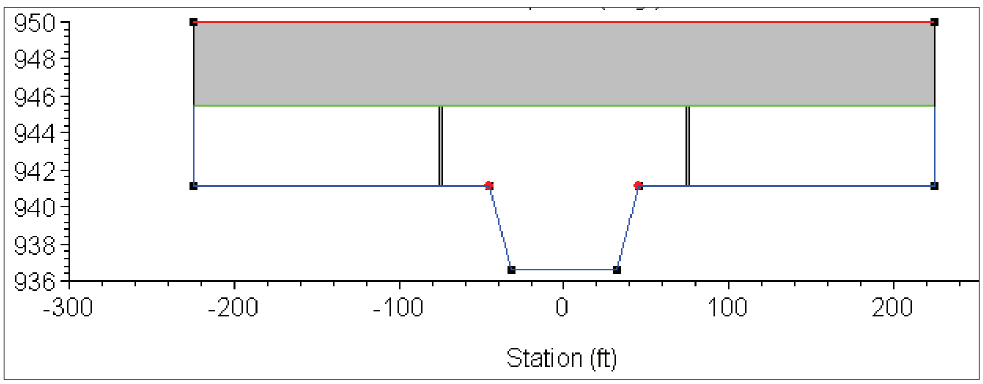

Figure 4. Cross Section View of Preliminary Bridge Design

Station	-225	-225	-45.5	-32	32	45.5	225	225
Elevation	950	941.1	941.1	936.6	936.6	941.1	941.1	950
					* *Bridge Deck Elevation = 950.0'* * *Low Chord of Bridge Elevation = 946.0'*			

Table 13. Station Elevation Data for Preliminary Bridge Design

f. Erosion Control Structures

In-channel erosion control structures will be necessary to insure that excessive head cutting does not take place in the new Pomme De Terre River channel, as it has the potential to threaten infrastructure. The concept for the erosion control structures, shown in Plate 21, consists on a series of small rock cross vane structures the lowest of which is to be placed near the mouth of the re-routed Pomme de Terre River, and the highest of which is located slightly upstream of the re-routed reach. The design of the structures is to be based on guidance from Reference 9 (Rosgen 2001).

V. Project Feature Alternatives: Impacts

22. Overall Impact on Marsh Lake Water Levels

The combined project features will alter the water level regime in Marsh Lake. The overall effect will be increased water level variability, minimal changes during flood events, and occasional managed water level drawdown. An HEC-RAS (unsteady) model was calibrated to simulate 20 years of water level data in Marsh Lake, and then used to simulate the "with-project" condition (dam modification & rerouting of the Pomme De Terre) and evaluate water level changes.

a. Average Water Levels

The water levels on Marsh Lake during non-flood scenarios are controlled by a combination of the inflows to the lake and the primary ogee crest outlet. The "with-project" conditions will alter the Elevation-Discharge relationship at the dam as well as reduce inflow to the lake by draining the Pomme De Terre River directly downstream into the Minnesota River. Existing & with project Elevation-Discharge curves for the primary outlet structure are shown in Plate 22.

	Existing	With Project
Annual 10% Exceedance	940.3	940.3
Annual 25% Exceedance	940.3	939.0
Annual Average	939.0	938.0
Annual 75% Exceedance	938.3	937.3
Annual 90% Exceedance	937.9	936.6
Minimum	937.7	936.0
September Average	938.1	937.7
September 90% Exceedance	937.7	936.8
April Average	939.9	940.0

Table 14. Summary of Existing and With Project Marsh Lake modeled water levels based on 20 years of lake levels (1983-2003)

b. Flood Impacts

Upstream/Marsh Lake Pool

The changes to large flood levels on Marsh Lake from the proposed project were evaluated with two methods:

(1) For water level simulations over 20 years (1983 – 2003), results for the two largest flood events (1997 & 2001) with & without project features were compared

and,

(2) Estimated 100 year flood hydrographs for with and without project conditions were routed through the reservoir.

Simulated with project water levels were on the order of 1.5' lower than modeled existing conditions for the 1997 & 2001 flood events. This is primarily attributed to reduced inflows to Marsh Lake due to the altered Pomme De Terre flow path. Note that the calibration of the HEC-RAS unsteady model focused on average water levels and that the calibration of the peak flows to the observed data was complicated by tailwater conditions controlled by the Lac Qui Parle dam. Despite this complication, the model gives a general estimate of the effect of the proposed project on Marsh Lake flood water levels.

Inflow hydrographs for the 100 year flood were estimated (as described in Section 5). The 100 year runoff was determined to be 1.06 inches, which resulted in a peak inflow of 16,655 cfs for existing conditions and 11,372 for with project conditions. Antecedent water level was 938.3 and tailwater was held at 935 (artificially low for a flood event) in order to make a direct comparison. The with-project routing resulted in a peak stage approximately 1.2' lower than existing conditions.

	1997 Peak	**2001 Peak**	**1% inflow**
Existing Observed	948.54	946.04	n/a
Existing Modeled	947.43	946.63	944.72
With Project Modeled	945.85	945.1	943.52
Difference	-1.58'	-1.53'	-1.2'

Table 15. Summary of Modeled Peak Pool Elevations for historic peaks, Existing vs. Project Conditions

In summary, this analysis shows that Marsh Lake is expected to experience lower peak flood elevations due to the project as designed in this feasibility study. Note that the current 100-year Pool Elevation on Marsh Lake of 947.4' is above the maximum pool elevation and is not relied upon for flood control downstream.

Downstream/Lac Qui Parle & Montevideo

The flood damage reduction benefits from the Lac Qui Parle Project are largely focused on the city of Montevideo and downstream to the City of Granite Falls. The project features consist of the Lac Qui Parle Dam (gated), the Chippewa Sag Diversion dam and weir (gated), downstream channel modifications, and Marsh Lake dam (un-gated). The Marsh Lake Dam, with its relatively low spillway crest and lack of operating gates, contributes relatively little actual flood control storage compared to the Lac Qui Parle Reservoir.

The HEC-RAS water level model, which routes inflows for the period of 1983-2003, shows only minor changes to the outflow from Lac Qui Parle Dam and stages at Montevideo. Depending on the timing and sources of inflows, the modeling indicates that the proposed project conditions may slightly decrease the water level at Montevideo for some flood events, and may slightly increase it for some flood events. The modeling shows changes on the order of +/- 0.1' at Montevideo.

The proposed project at Marsh Lake includes an overflow spillway with removable gates with the purpose of allowing occasional water level draw-downs of Marsh Lake for environmental purposes. Following a drawdown, Marsh Lake has the potential to provide a large amount of additional storage if the gates were to close during the flood event. This flood control benefit outweighs any perceived flood control dis-benefit resulting from the dam modification

23. Dam Safety

a. Selection of Appropriate of Hazard Potential Classification and Dam Safety Standard

Marsh Lake Dam has been classified in the National Inventory of Dams data base as a Low Hazard dam. Although no official classification of the Corps of Engineers Dam Safety Standard according to ER 1110-8-2 (FR) has been determined for Marsh Lake, it is likely a Standard 2. Dam Safety Standard 2 applies to structures with relatively small head differentials during floods and states that the dam must be able to safely pass major floods typical of the region.

b. Consequences of Marsh Lake Dam Failure

The consequences of failure at Marsh Lake Dam are relatively minor as it lies above the Lac Qui Parle Reservoir, which contains more storage than Marsh Lake. A flowage easement up to elevation 945 exists for the Lac Qui Parle Reservoir, and there is no population below that elevation.

Failure at Marsh Lake Dam during a flood event could cause an increase in the water level on Lac Qui Parle. The two largest recent flood events (1997 and 2001), the 1% Annual Exceedance Probability Event, and the 0.5% Annual Exceedance Probability Event were analyzed to determine the worst case condition on the Lac Qui Parle Reservoir (maximum pool level and maximum increase in stage) that would result from a failure of Marsh Lake Dam. The results, show in Table 16 below, show that the non-overflow section of the Lac Qui Parle Dam would not be overtopped for any of the scenarios.

Event	**1997**	**2001**	**Pool Frequency Curve**	
Annual Exceedance Probability	0.69%	1.54%	1%	0.50%
Marsh Pool Return Period	145 year	65 year	100 year	200 year
Marsh Pool	948.5	946	947.4	949.2
Marsh Storage (x 1,000 acre-ft)	123	88	106.9	134.2
LQP Pool	944.4	938	943.6	944.7
LQP Storage (x 1,000 acre-ft)	168.2	86	156.6	172.85
Combined Storage (x 1,000 acre-ft)	291.2	174	263.5	307.05
Marsh Lake Dam Failure: Worst Case Condition on Lac Qui Parle Reservoir				
Combined LQP & Marsh Lake Pool	946.3	941.8	945.4	946.9
Increase on LQP vs. Non-Failure	1.9	3.8	1.8	2.2
Remaining Freeboard at Lac Qui Parle (non-overflow embankment section)	2.2	6.7	3.1	1.6
Depth Above Flowage Easement (EL 945)	1.3	below	0.4	1.9
Estimated Loss of Life	0	0	0	0

Table 16. Potential for Increase in Lac Qui Parle Stages in the case of Marsh Lake Dam Failure

The Lac Qui Parle Reservoir can pass the Probably Maximum Flood (PMF) with 2' of freeboard. At larger events up to the PMF, Marsh Lake is already overtopped and poses no additional risk downstream if it were to breach.

c. Adequacy of Spillway and Freeboard at Marsh Lake Dam

Existing Conditions

The Probable Maximum Flood was determined in "Dam Failure Planning Report, Marsh Lake Dam, August 1987" using an all season storm with a peaking factor of 1.0. The PMF inflow hydrograph has a peak inflow of 109,000 cfs and the routing of the PMF through Marsh Lake, using an antecedent water level of 937.6' (NGVD 1929) resulted in a maximum pool elevation of 952.0' (NGVD 1929).

The Spillway Design Flood (SDF) as determined in "Dam Failure Planning Report, Marsh Lake Dam, August 1987" using a ratio of the Probable Maximum Storm (PMS) hyetograph to obtain a routing through Marsh Lake that produced a maximum stage of 947.1 (NGVD 1929) which allowed for the minimum of 3' of freeboard using an antecedent water level of 937.6 (NGVD 1929). The SDF inflow hydrograph has a peak flow of 21,000 cfs. Therefore, in terms of peak inflow to Marsh Lake, the SDF is less than 20% of the PMF for Marsh Lake.

Dam Safety Standard 2 requires that the dam be able to safely pass majors floods typical of the region. According to the pool frequency curve, the 100 year (1% annual exceedance probability) and 200 year (0.5% annual exceedance probability) pool elevations are 947.4 and 949.2 respectively. Using the minimum embankment elevation of 948.6, less than 2' of freeboard is available for the 100 year event, and the dam is overtopped for the 200 year event. It is unlikely that the dam meets current dam safety criteria under existing conditions.

With Project Conditions

Under "with-project" conditions, the drainage area into Marsh Lake will be reduced by approximately 30% from 2853 mi^2 to 1948 mi^2, which will have the effect of reducing the volume of flood inflows. The discharge capacity of the primary outlet will be subtly altered as the primary spillway will include more flow area for a given pool elevation, but have a lower discharge coefficient due to the effect of the fishway and boulder weirs. The capacity of the overflow spillway will also be subtly altered as discharge coefficient over the stoplogs will increase compared to the existing broad crested weir, but the introduction of stop log bay piers will reduce flow area. As shown in the analysis Section 22, the combined effect of project features will have the overall effect of decreasing the Marsh Lake pool elevation for large flood events.

In summary, the ability for the Marsh Lake Dam to safely pass the design flood event will be somewhat improved as a result of the proposed project.

VI. References

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3. Dam Failure Planning Report, Marsh Lake Dam, Minnesota River, St Paul District Corps of Engineers, August 1987

4. Water Control Manual, Lac Qui Parle Project, August 1995

5. US Army Corps of Engineers Engineering Manual 1110-2-1601, Hydraulic Design of Flood Control Channels, July 1991

6. US Army Corps of Engineers, Upper Mississippi River System Environmental Management Program, Design Handbook, July 2005

7. Federal Emergency Management Agency, Flood Insurance Study, City of Appleton Minnesota, Swift County , October 1981

8. US Army Corps of Engineers Engineering Regulation 1110-8-2 (FR), Inflow Design Floods for Dams and Reservoirs, March 1991

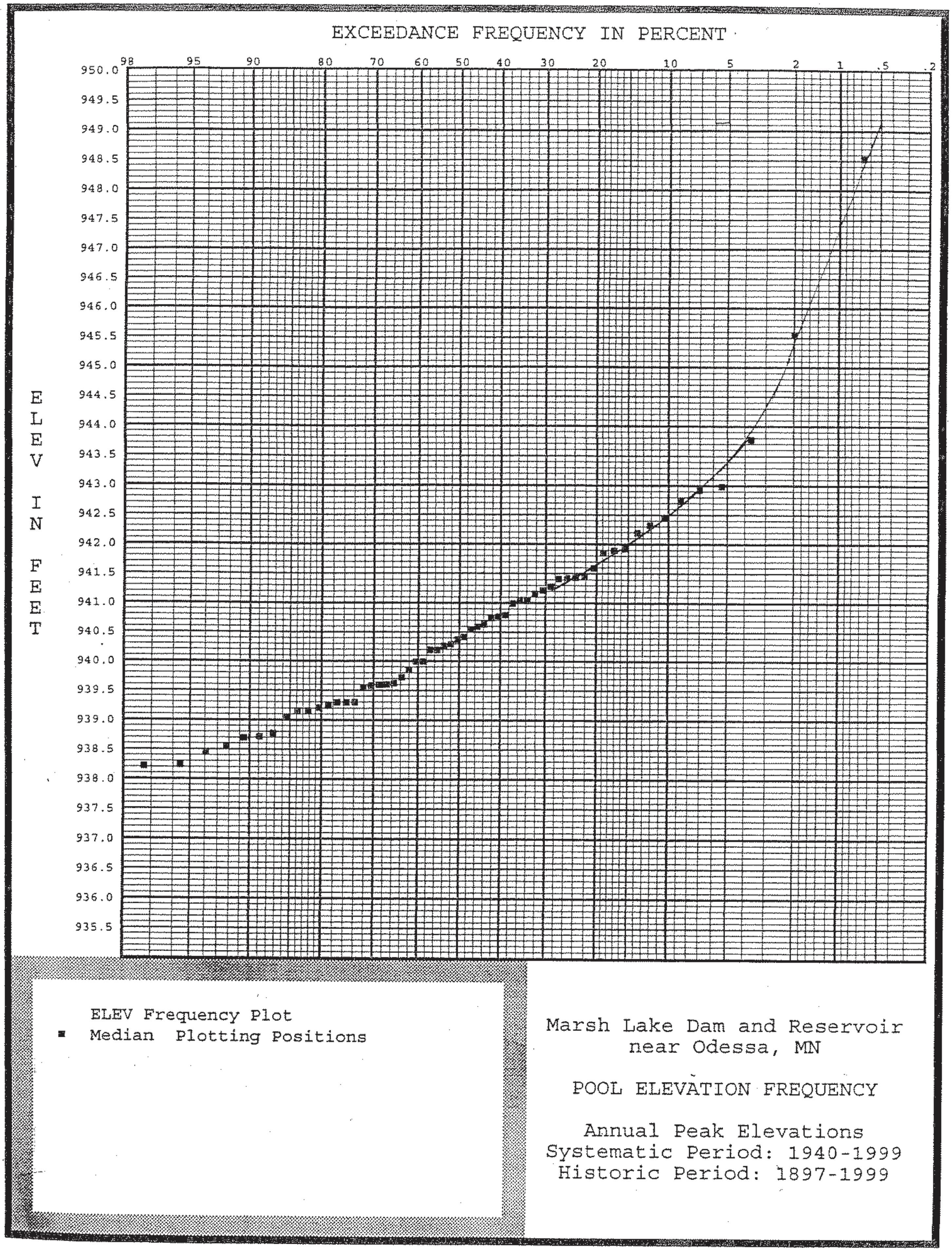
9. Rosgen, David, “The Cross-Vane, W-Weir and J-Hook Vane Structures…Their Description, Design and Application for Stream Stabilization and River Restoration”, 2001

Marsh Lake Dam

Ecosystems Restoration Feasability Study

H&H Appendix

PLATES


EXCEEDANCE FREQUENCY IN PERCENT
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940.5
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938.5
938.0
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936.5
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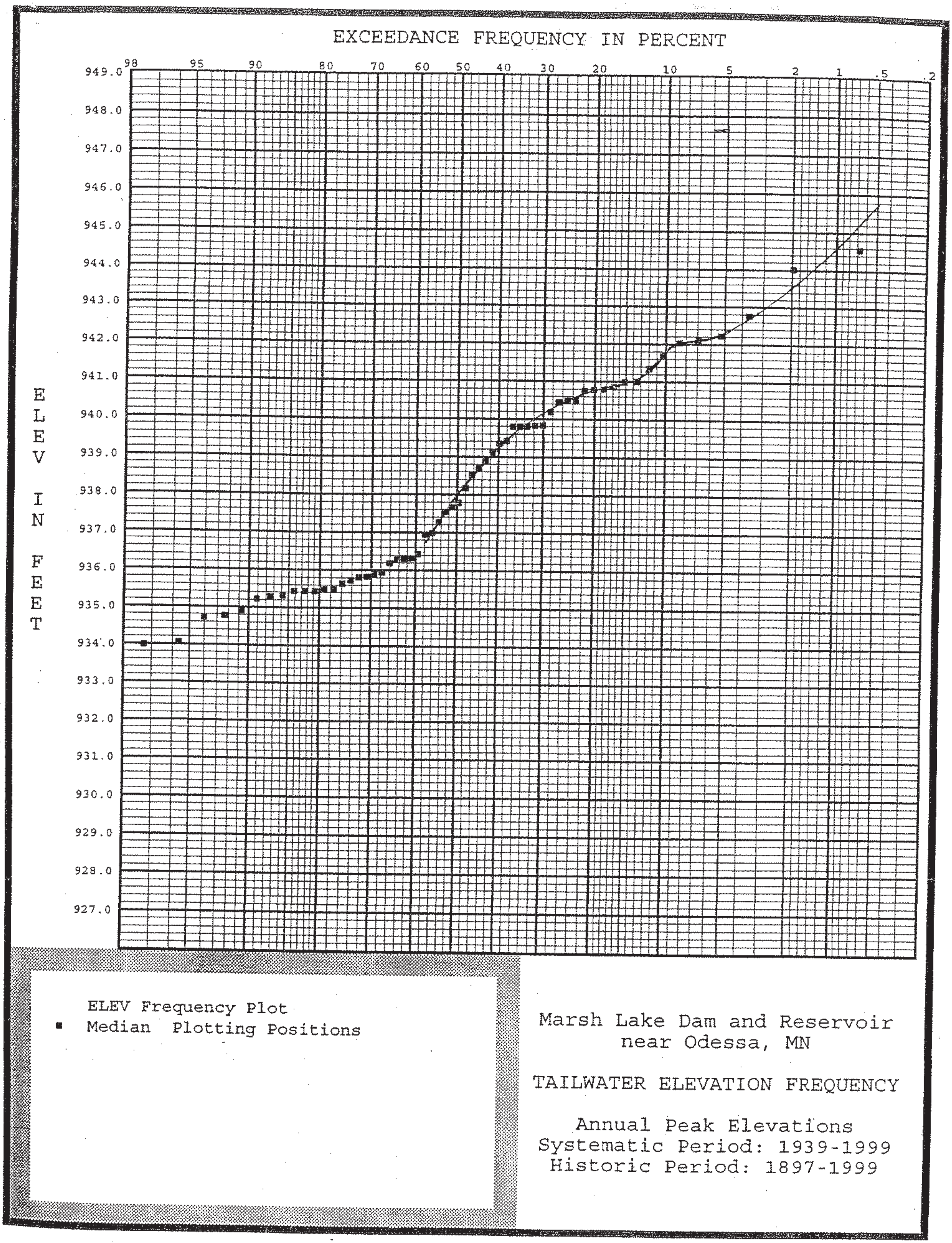
935.5
ELEV IN FEET
ELEV Frequency Plot
Median Plotting Positions
Marsh Lake Dam and Reservoir
near Odessa, MN
POOL ELEVATION FREQUENCY
Annual Peak Elevations
Systematic Period: 1940-1999
Historic Period: 1897-1999



EXCEEDANCE FREQUENCY IN PERCENT
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930.0
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928.0
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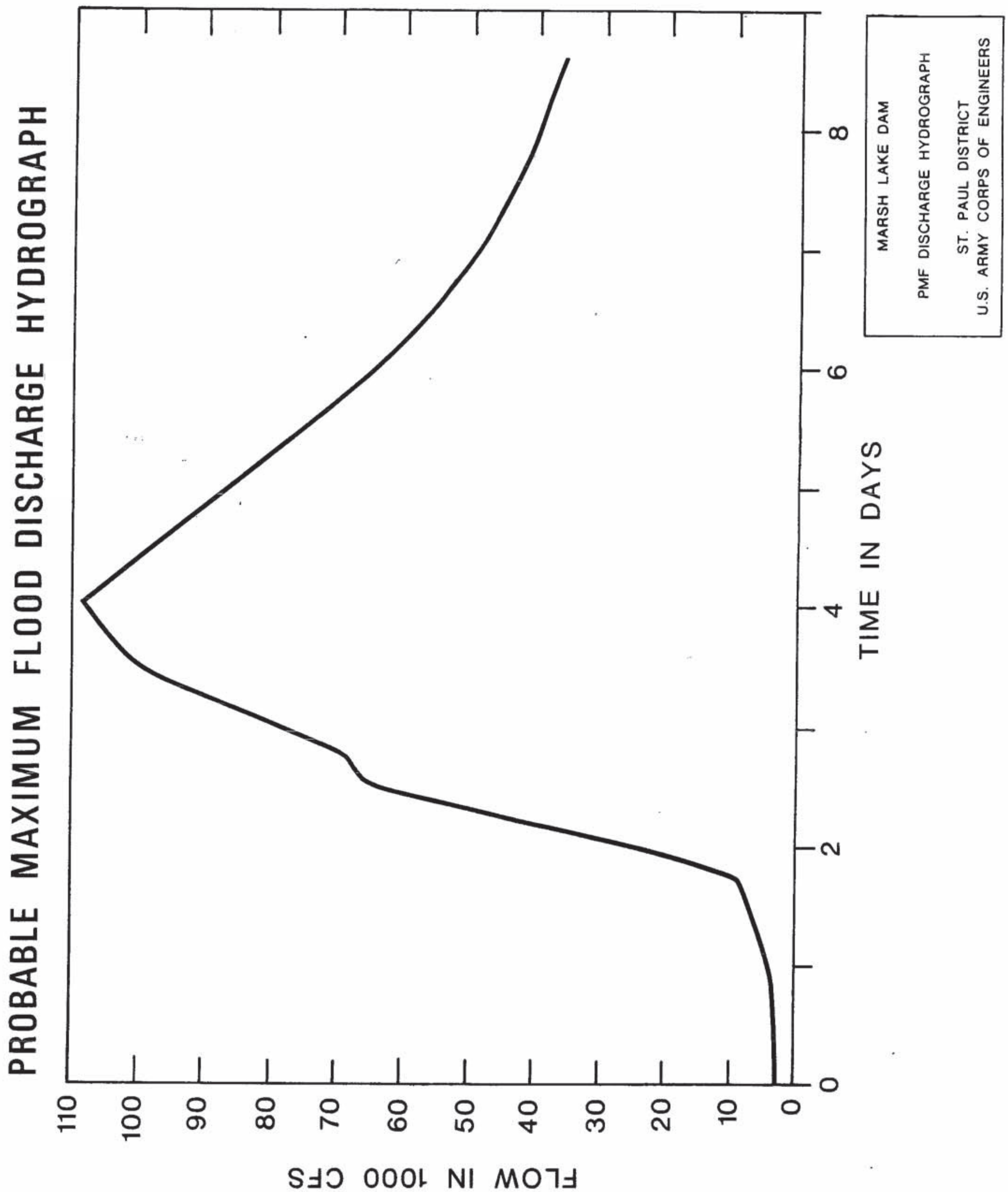
ELEV IN FEET
ELEV Frequency Plot
Median Plotting Positions
Marsh Lake Dam and Reservoir
near Odessa, MN
TAILWATER ELEVATION FREQUENCY
Annual Peak Elevations
Systematic Period: 1939-1999
Historic Period: 1897-1999


PROBABLE MAXIMUM FLOOD DISCHARGE HYDROGRAPH
FLOW IN 1000 CFS
110
100
90
80
70
60
50
40
30
20
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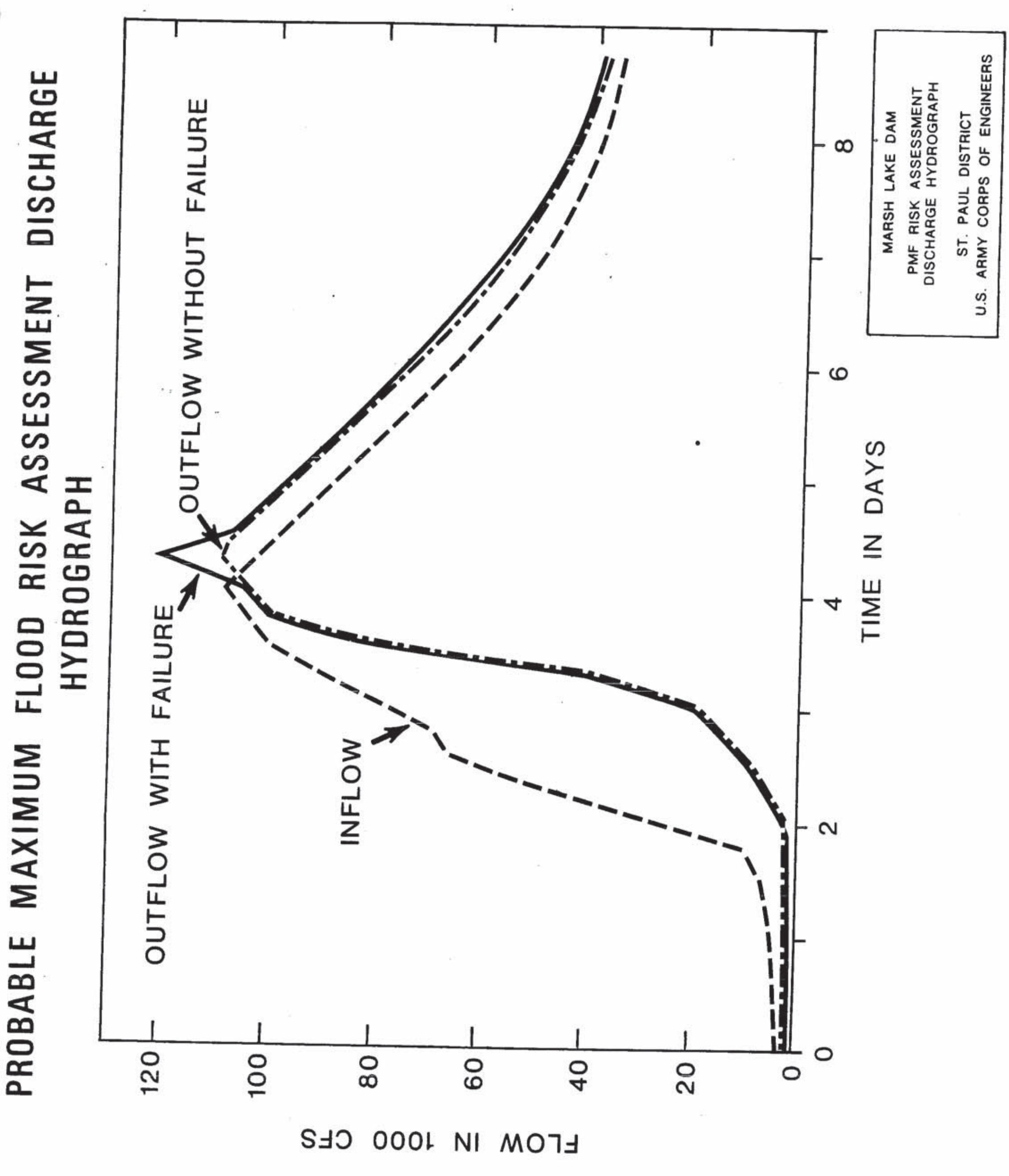
4
6
8
TIME IN DAYS
MARSH LAKE DAM
PMF DISCHARGE HYDROGRAPH
ST. PAUL DISTRICT
U.S. ARMY CORPS OF ENGINEERS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OUTFLOW WITH FAILURE
INFLOW
FLOW IN 1000 CFS
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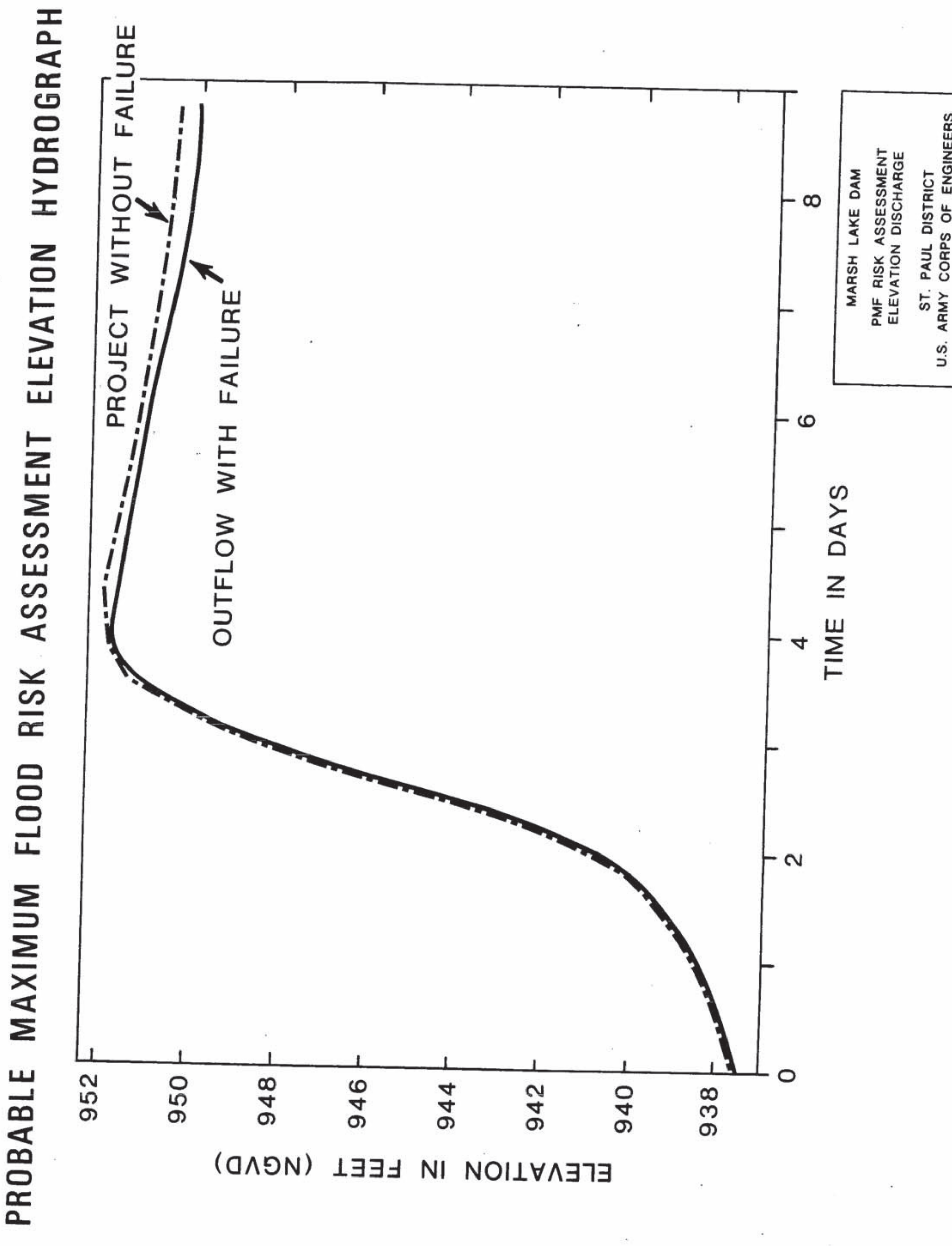
60
40
20
0
0
2
4
6
8
TIME IN DAYS
MARSH LAKE DAM
PMF RISK ASSESSMENT
DISCHARGE HYDROGRAPH
ST. PAUL DISTRICT
U.S. ARMY CORPS OF ENGINEERS


PROBABLE MAXIMUM FLOOD RISK ASSESSMENT ELEVATION HYDROGRAPH
PROJECT WITHOUT FAILURE
OUTFLOW WITH FAILURE
ELEVATION IN FEET (NGVD)
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950
948
946
944
942
940
938
TIME IN DAYS
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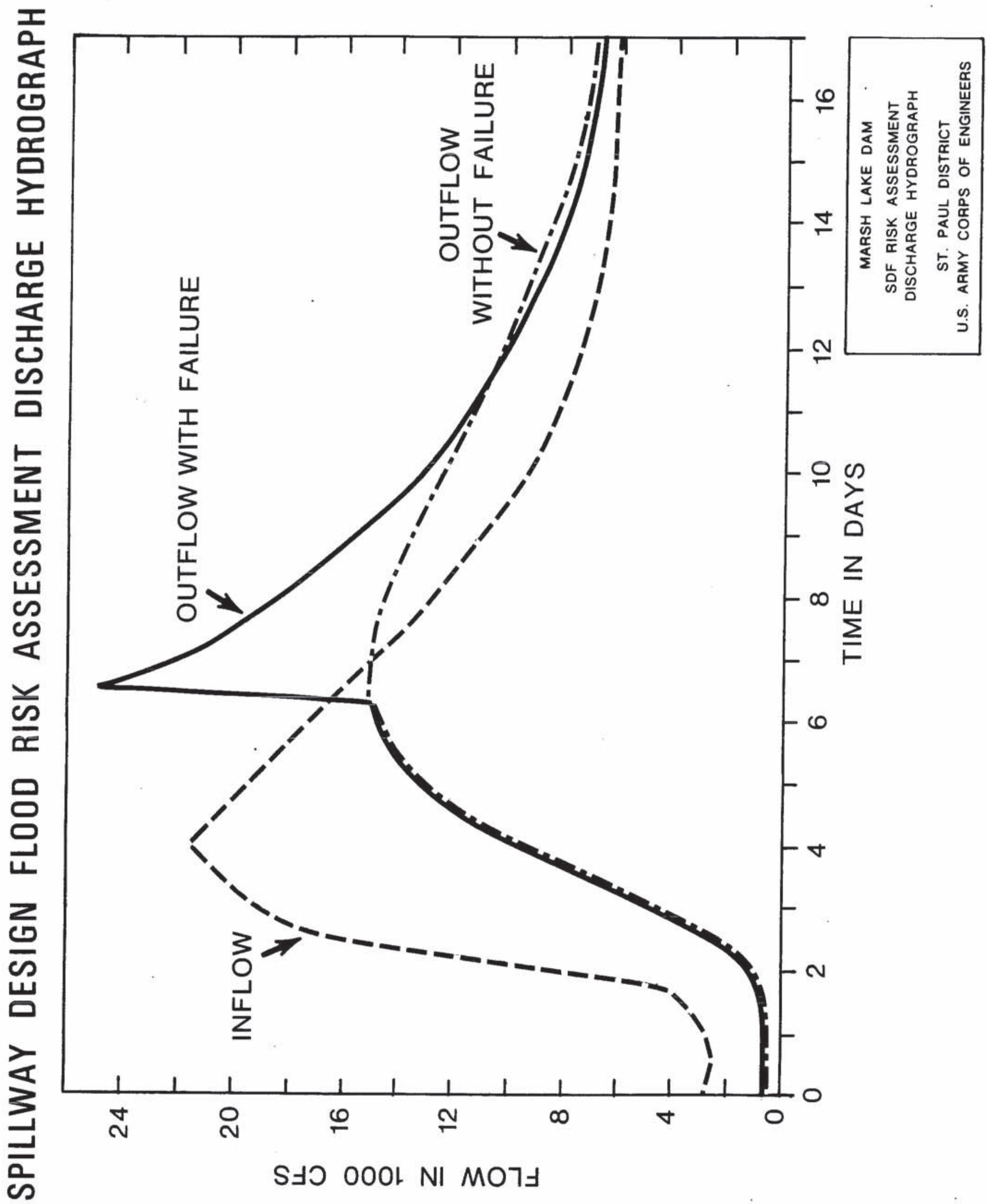
MARSH LAKE DAM
PMF RISK ASSESSMENT
ELEVATION DISCHARGE
ST. PAUL DISTRICT
U.S. ARMY CORPS OF ENGINEERS


SPILLWAY DESIGN FLOOD RISK ASSESSMENT DISCHARGE HYDROGRAPH
FLOW IN 1000 CFS
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12
16
20
24
TIME IN DAYS
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2
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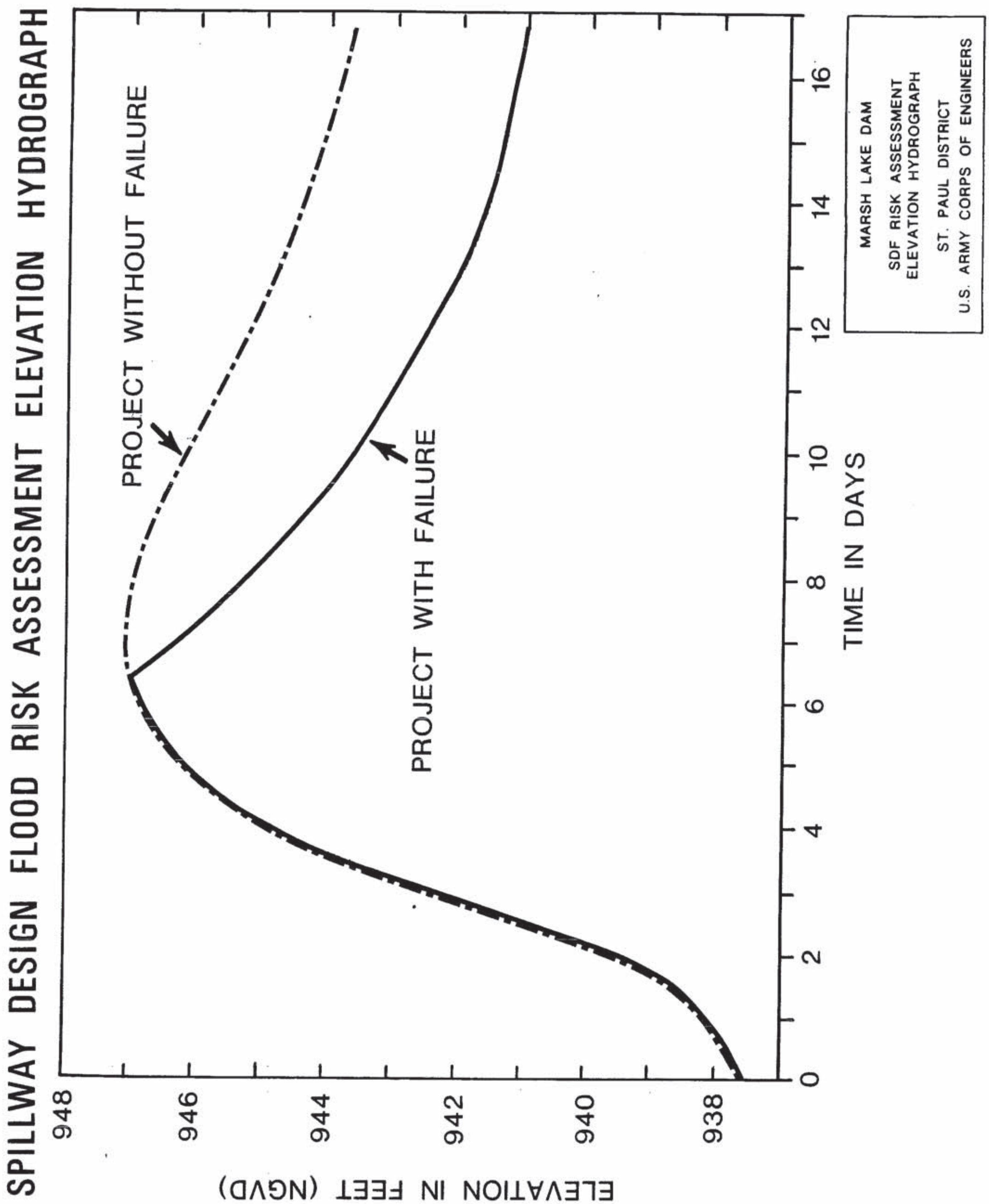
10
12
14
16
INFLOW
OUTFLOW WITH FAILURE
OUTFLOW WITHOUT FAILURE
MARSH LAKE DAM
SDF RISK ASSESSMENT
DISCHARGE HYDROGRAPH
ST. PAUL DISTRICT
U.S. ARMY CORPS OF ENGINEERS


SPILLWAY DESIGN FLOOD RISK ASSESSMENT ELEVATION HYDROGRAPH
ELEVATION IN FEET (NGVD)
948
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TIME IN DAYS
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12
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16
PROJECT WITHOUT FAILURE
PROJECT WITH FAILURE
MARSH LAKE DAM
SDF RISK ASSESSMENT
ELEVATION HYDROGRAPH
ST. PAUL DISTRICT
U.S. ARMY CORPS OF ENGINEERS

Determination of Unit Hydrographs For Marsh Lake Inflow
With and Without Project

12-hr Unit Hydrograph Lac Qui Parle Excluding Area above Big Stone Dam *from 1971 PMF Study of Minnesota River		Adopted 12-hr Unit Hydrograph Marsh Lake Reservoir (MN River U/S) based on Drainage Area Translation Existing Conditions		**Adopted 12-hr Unit Hydrograph Marsh Lake Reservoir (MN River U/S) based on Drainage Area Translation with Rerouted PDT**	
D.A. =	2890	D.A. =	2853	**D.A. =**	**1948**
		Drainage Area Factor = 0.987		**Drainage Area Factor = 0.674**	
Hour	Flow	Hour	Flow	**Hour**	**Flow**
12	630	12	622	**12**	**425**
24	1350	24	1333	**24**	**910**
36	2340	36	2310	**36**	**1577**
48	3700	48	3653	**48**	**2494**
60	5650	60	5578	**60**	**3808**
72	8100	72	7996	**72**	**5460**
84	11700	84	11550	**84**	**7886**
96	**15960**	96	**15756**	**96**	**10758**
108	15200	108	15005	**108**	**10246**
120	12650	120	12488	**120**	**8527**
132	10200	132	10069	**132**	**6875**
144	8400	144	8292	**144**	**5662**
156	7250	156	7157	**156**	**4887**
168	6300	168	6219	**168**	**4247**
180	5640	180	5568	**180**	**3802**
192	5100	192	5035	**192**	**3438**
204	4620	204	4561	**204**	**3114**
216	4200	216	4146	**216**	**2831**
228	3750	228	3702	**228**	**2528**
240	3380	240	3337	**240**	**2278**
252	3000	252	2962	**252**	**2022**
264	2620	264	2586	**264**	**1766**
276	2320	276	2290	**276**	**1564**
288	1980	288	1955	**288**	**1335**
300	1700	300	1678	**300**	**1146**
312	1480	312	1461	**312**	**998**
324	1280	324	1264	**324**	**863**
336	1100	336	1086	**336**	**741**
348	950	348	938	**348**	**640**
360	800	360	790	**360**	**539**
372	710	372	701	**372**	**479**
384	560	384	553	**384**	**377**
396	400	396	395	**396**	**270**
408	280	408	276	**408**	**189**
420	200	420	197	**420**	**135**
432	100	432	99	**432**	**67**

Determination of Peak Inflow Frequency for Marsh Lake

Flow Frequency at Pomme de Terre Gage
Drainage Area = 905 mi ^{2}

Event	Flow	Flow Adjusted for Marsh existing DA = 2853 Ratio (2853/905) = 3.15	Flow Adjusted for Marsh w/o PDT DA = 1948 Ratio (1948/905) = 2.15
2-yr	704	2219	1515
5-yr	1470	4634	3164
10- yr	2130	6715	4585
25-yr	3140	9899	6759
50-yr	4010	12641	8631
100-yr	4980	15699	10719

Flow Frequency at Lac Qui Parle Gage
Drainage Area = 4050 mi ^{2}

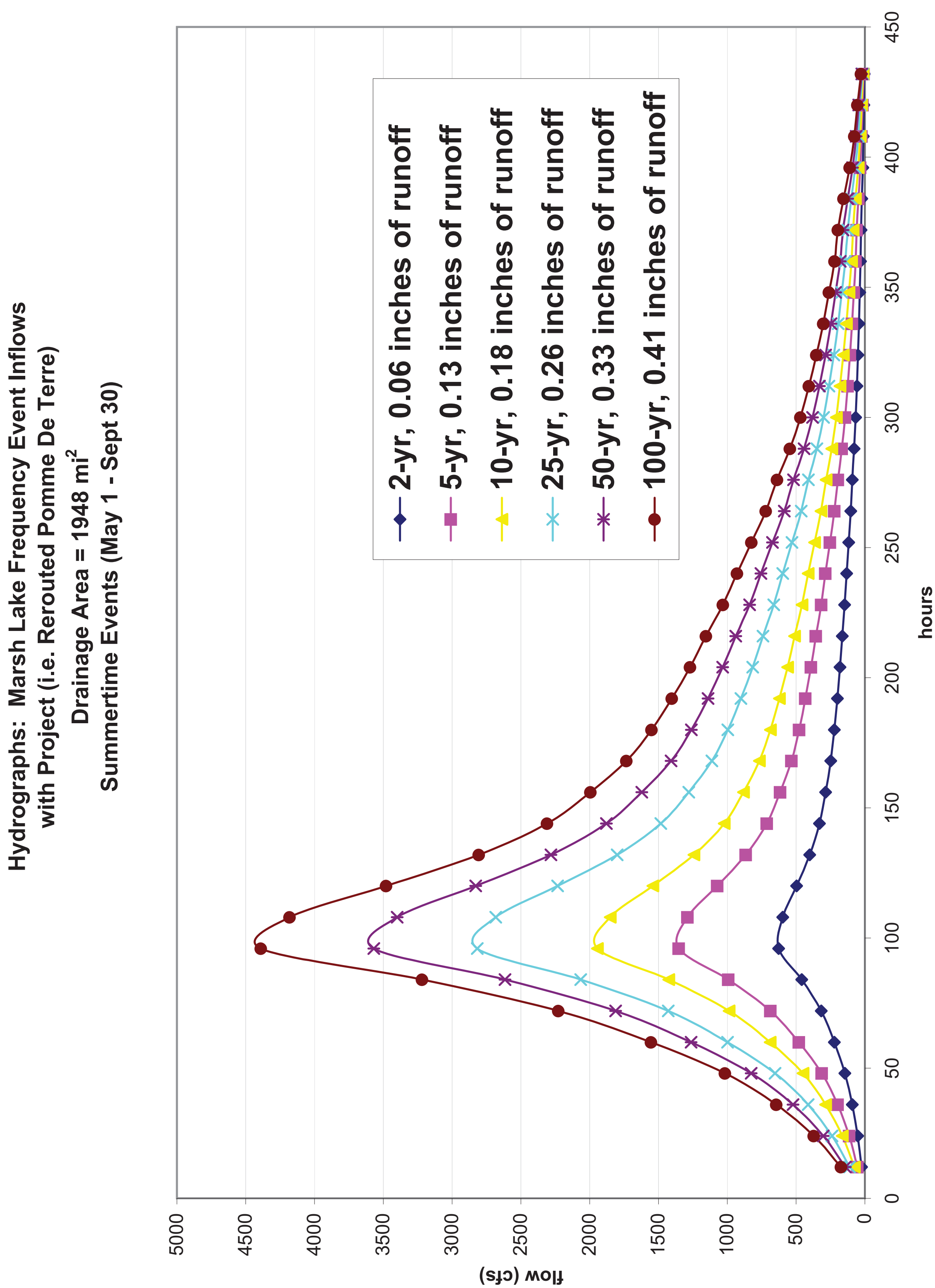
Event	Flow	Flow Adjusted for Marsh existing DA = 2853 Ratio (2853/4050) = 0.70	Flow Adjusted for Marsh w/o PDT DA = 1948 Ratio (1948/4050) = 0.48
2-yr	3600	2536	1732
5-yr	8000	5636	3848
10- yr	11400	8031	5483
25-yr	16300	11482	7840
50-yr	20500	14441	9860
100-yr	25000	17611	12025

Adopted Inflow Frequency Estimate For Marsh Lake
Average of Estimates from Translations from Two Nearby Frequency Curves

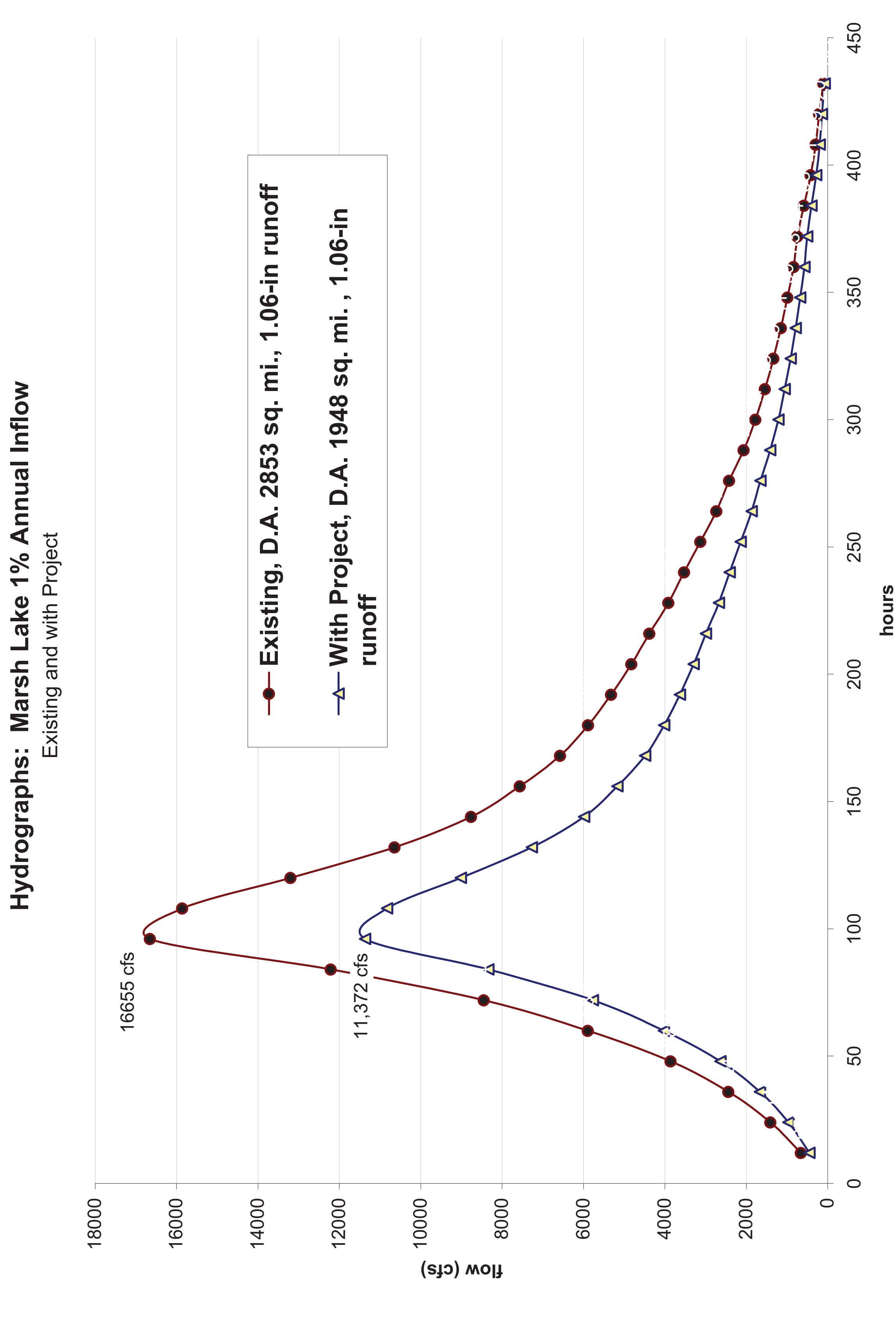
Event	Marsh Lke Inflow w/o PDT DA = 1948	Marsh Lake Inflow existing DA = 2853	Inches of Runoff
2-yr	1623	2378	0.15
5-yr	3506	5135	0.33
10- yr	5034	7373	0.47
25-yr	7299	10691	0.68
50-yr	9246	13541	0.86
100-yr	11372	16655	1.06

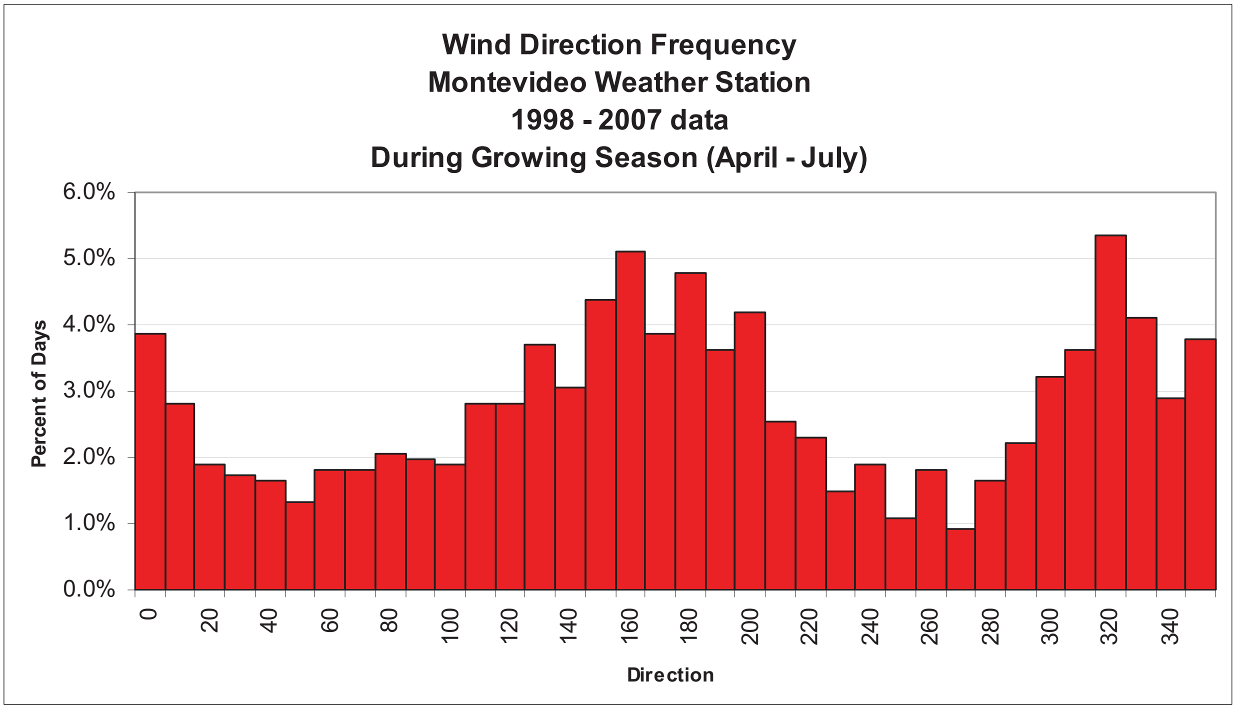
Adopted Summer (May-Sept) Frequency Estimate for Marsh Lake
Based on ratio of Annual to Summer Peak flow from (1931-1997)
Ratio = 0.386

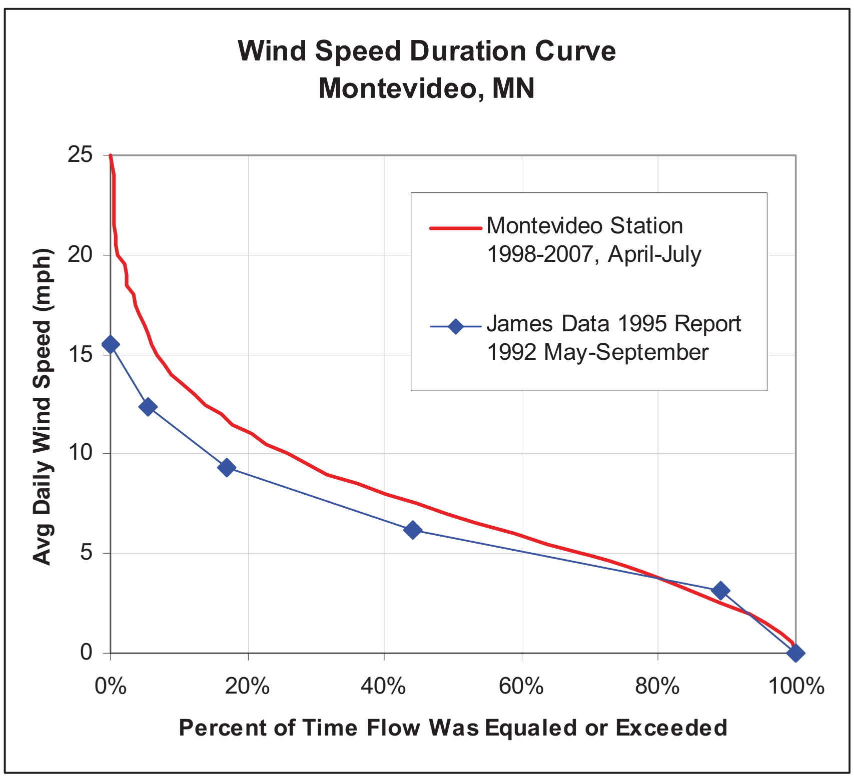
Event	Marsh Lke Summertime Inflow w/o PDT DA = 1948	Marsh Lke Summertime Inflow existing DA = 2853	Inches of Runoff
2-yr	627	918	0.06
5-yr	1353	1982	0.13
10- yr	1943	2846	0.18
25-yr	2818	4127	0.26
50-yr	3569	5227	0.33
100-yr	4390	6429	0.41

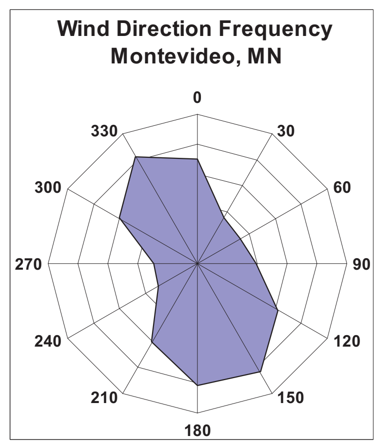


Hydrographs: Marsh Lake Frequency Event Inflows
with Project (i.e. Rerouted Pomme De Terre)
Drainage Area = 1948 mi2
Summertime Events (May 1 - Sept 30)
2-yr, 0.06 inches of runoff
5-yr, 0.13 inches of runoff
10-yr, 0.18 inches of runoff
25-yr, 0.26 inches of runoff
50-yr, 0.33 inches of runoff
100-yr, 0.41 inches of runoff
flow (cfs)
hours
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
50
100
150
200
250
300
350
400
450


Hydrographs: Marsh Lake 1% Annual Inflow
Existing and with Project
Existing, D.A. 2853 sq. mi., 1.06-in runoff
With Project, D.A. 1948 sq. mi. , 1.06-in runoff
16655 cfs
11,372 cfs
flow (cfs)
hours
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
50
100
150
200
250
300
350
400
450


Wind Direction Frequency
Montevideo Weather Station
1998 - 2007 data
During Growing Season (April - July)
6.0%
5.0%
4.0%
3.0%
2.0%
1.0%
0.0%
Percent of Days
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
Direction

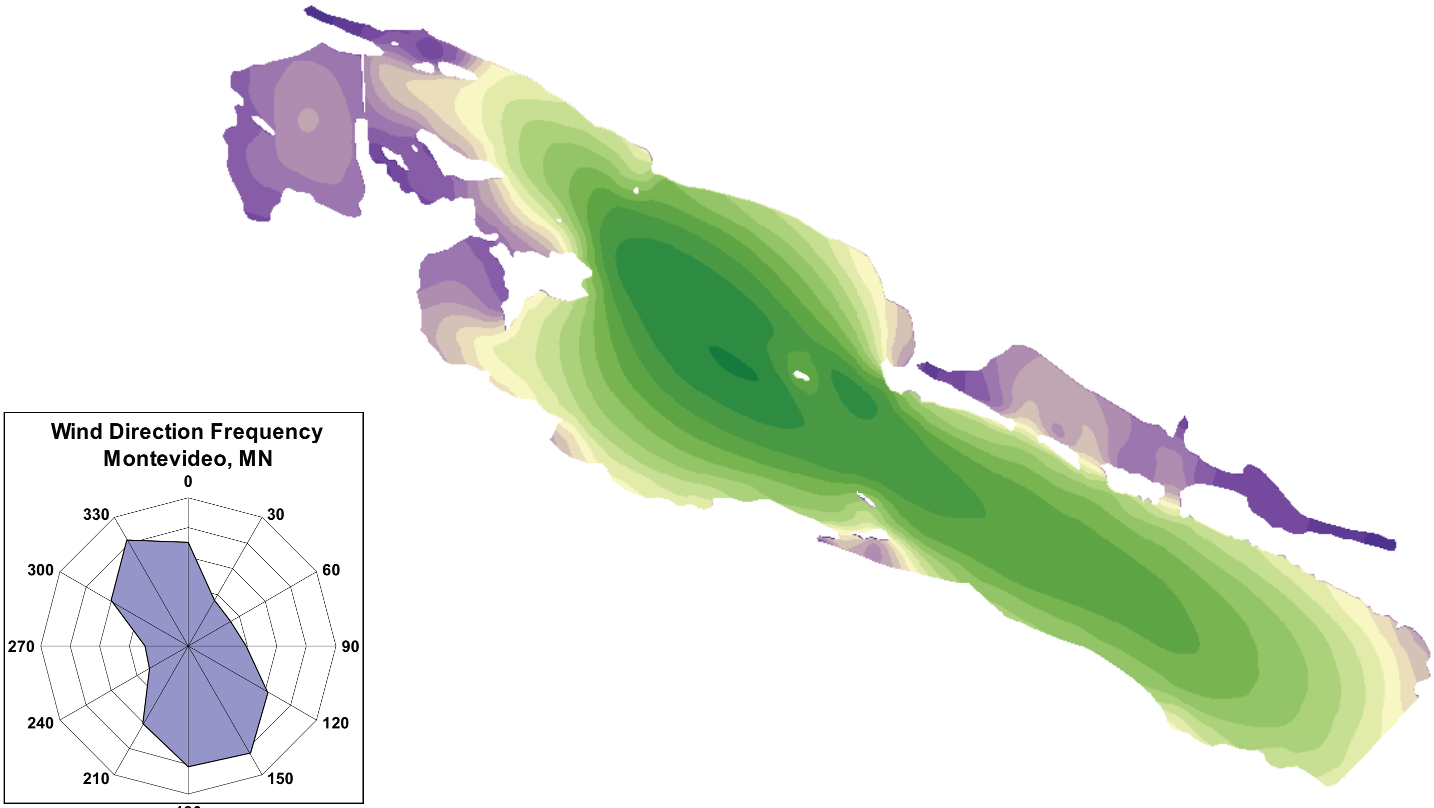

Wind Speed Duration Curve
Montevideo, MN
25
20
15
10
5
0
Avg Daily Wind Speed (mph)
Montevideo Station
1998-2007, April-July
James Data 1995 Report
1992 May-September
0%
20%
40%
60%
80%
100%
Percent of Time Flow Was Equaled or Exceeded


Wind Direction Frequency
Montevideo, MN
0
30
60
90
120
150
180
210
240
270
300
330

Marsh Lake Reservoir

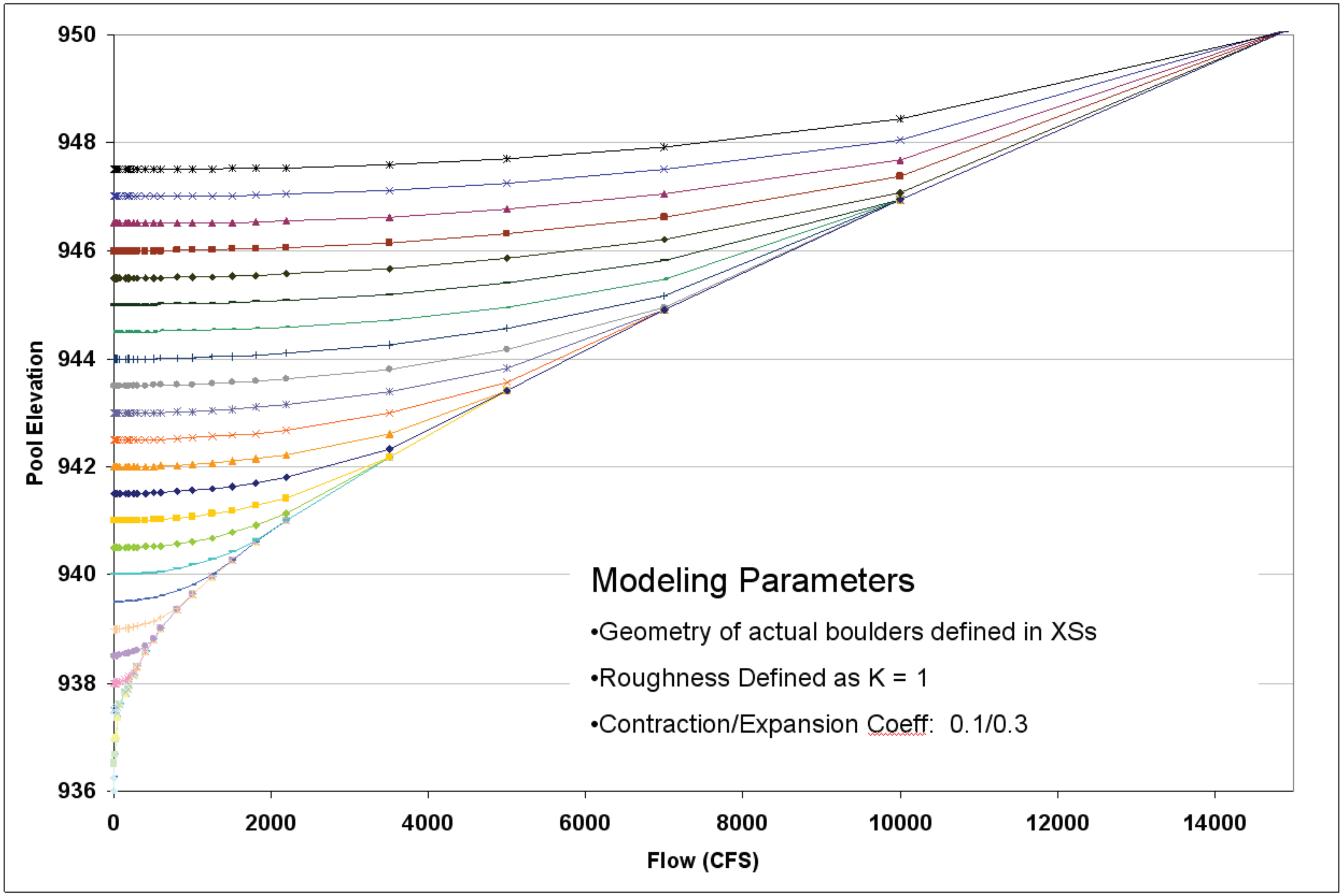
Weighted Wind Fetch

Existing Conditions

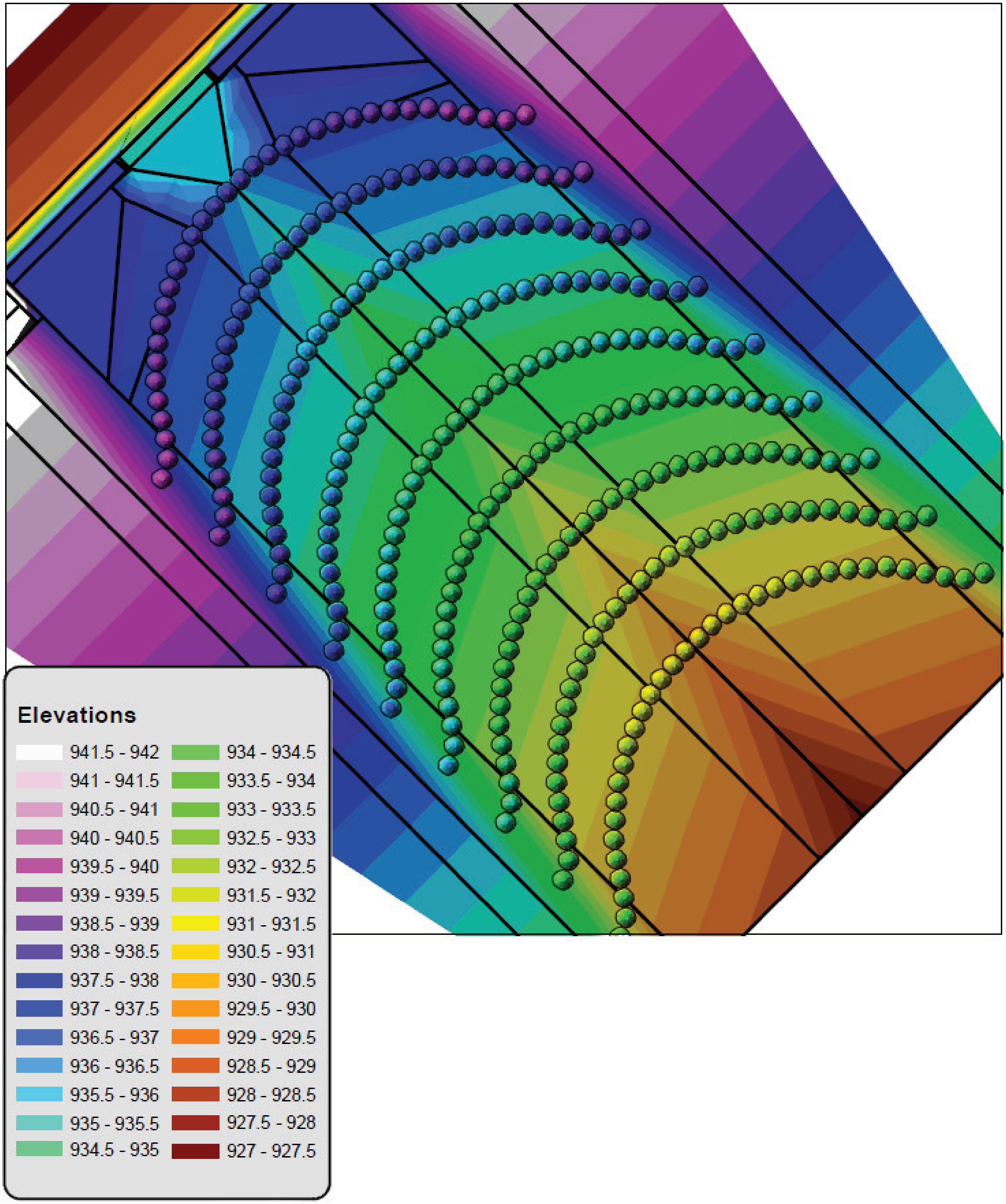


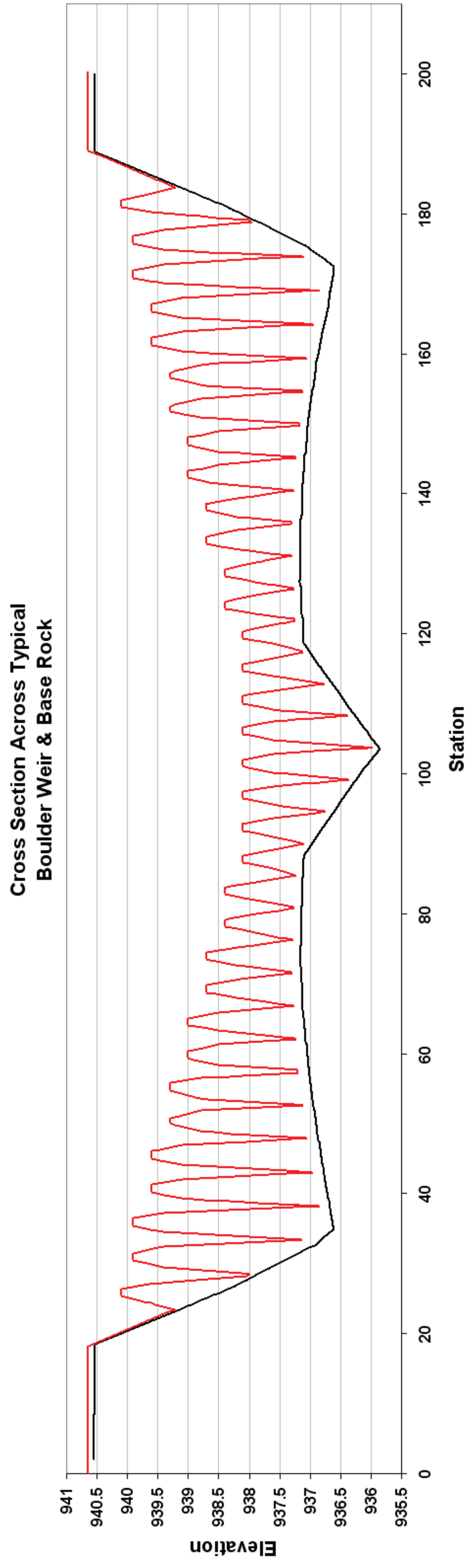
Marsh Lake Proposed Primary Spillway Modifications

Estimated Discharge Rating Curve for Various Tailwater Conditions



Marsh Lake Dam
Proposed Modification to Primary Spillway

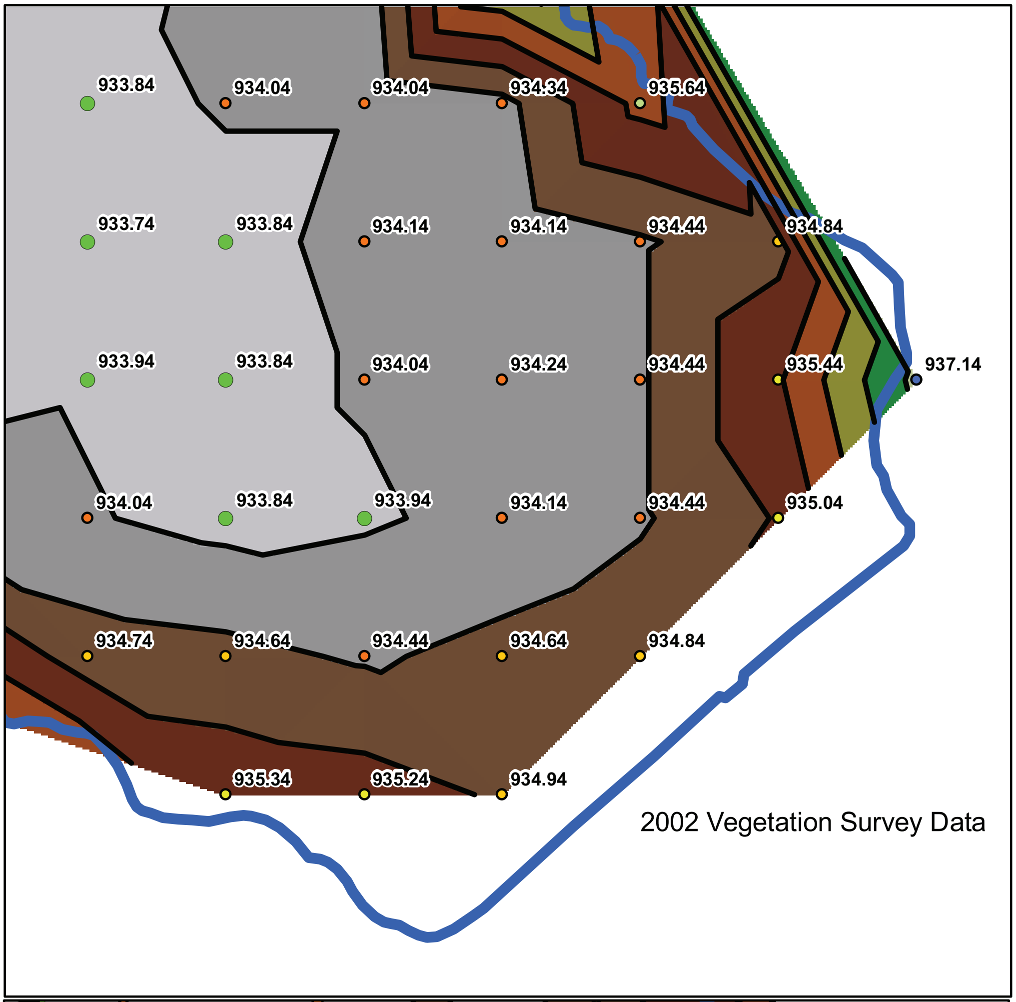


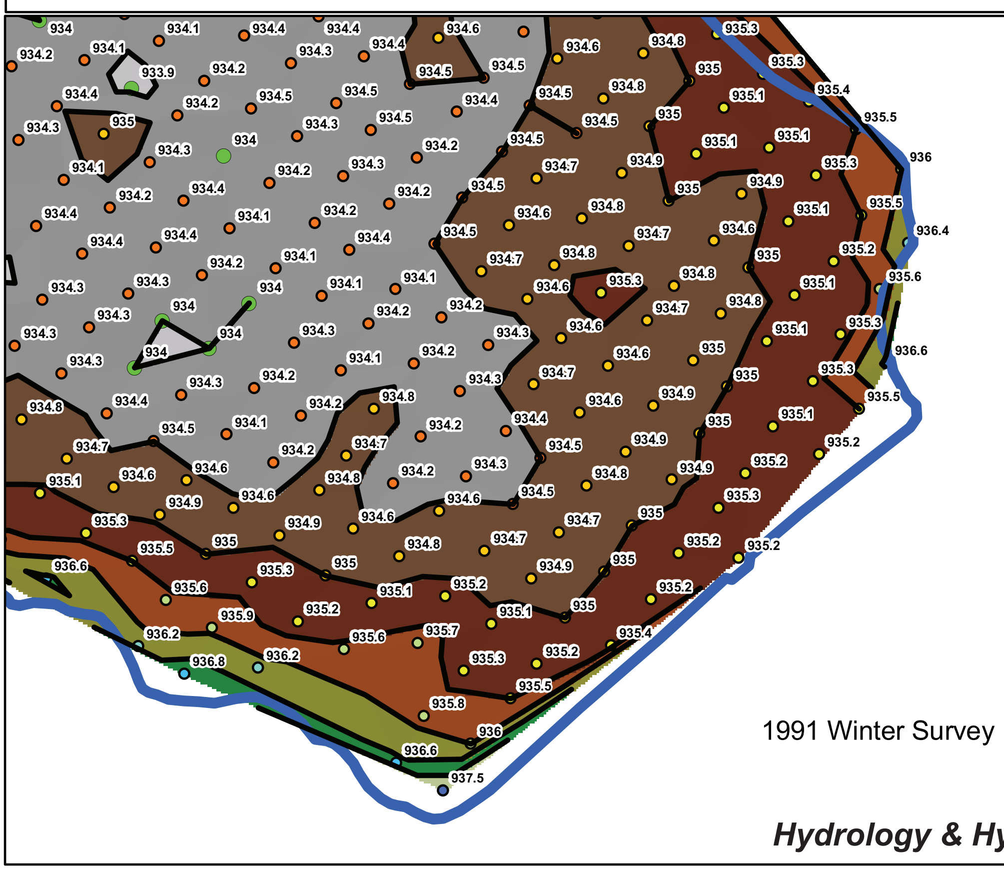


Cross Section Across Typical
Boulder Weir & Base Rock
Elevation
941
940.5
940
939.5
939
938.5
938
937.5
937
936.5
936
935.5
Station
0
20
40
60
80
100
120
140
160
180
200

Marsh Lake Bathymetry Near Outlet

Simple interpolation of raw survey points

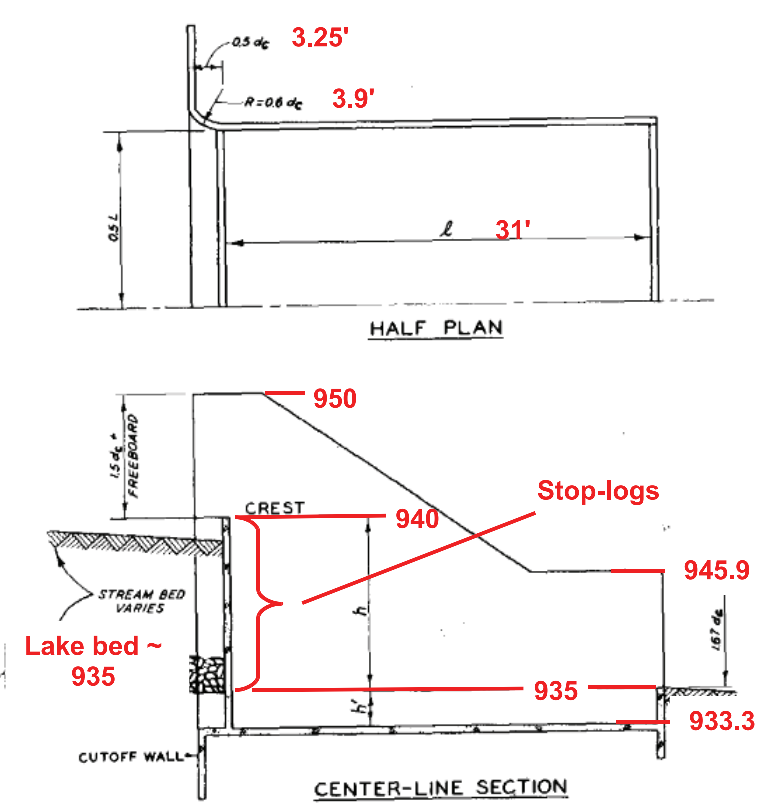




Elevations

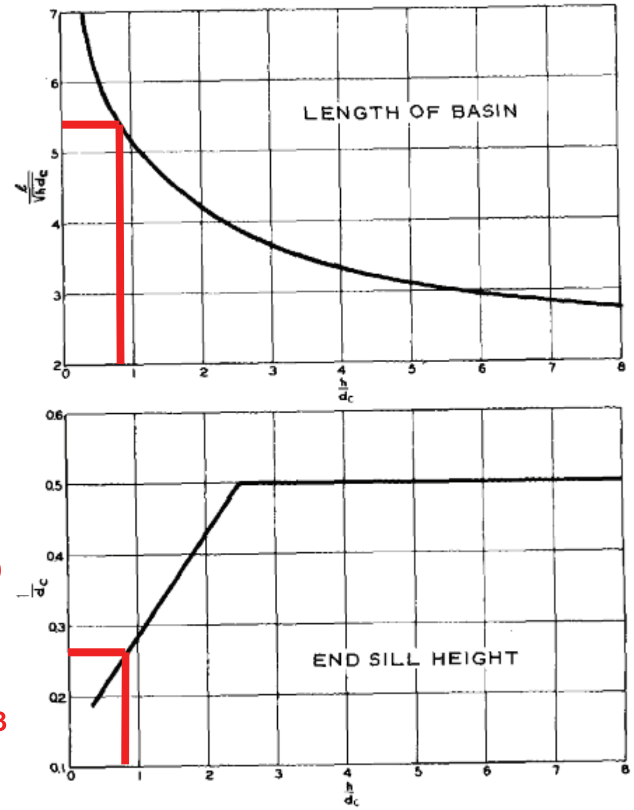
- 937.5 - 938
- 937 - 937.5
- 936.5 - 937
- 936 - 936.5
- 935.5 - 936
- 935 - 935.5
- 934.5 - 935
- 934 - 934.5
- 933.5 - 934

Datum: NGVD 1929



C = WEIR DISCHARGE = 3.0
d_c = CRITICAL DEPTH OVER CREST
h = HEIGHT OF DROP
h' = HEIGHT OF END SILL
H = HEAD ON WEIR = 3/2(d_c)

ℓ = LENGTH OF BASIN
L = LENGTH OF WEIR CREST
Q = DISCHARGE, $CLH^{3/2}$



DETAILS AND DESIGN CHART
FOR TYPICAL DROP STRUCTURE

Marsh Lake Drawdown Structure

Hydraulic Design Parameters

Design Pool	950'
Q (cfs)	8500
q (cfs/ft)	94
d_c (ft)	6.5
h (ft)	5
h/d_c	0.77

$$\frac{l}{\sqrt{hd_c}}=5.4$$

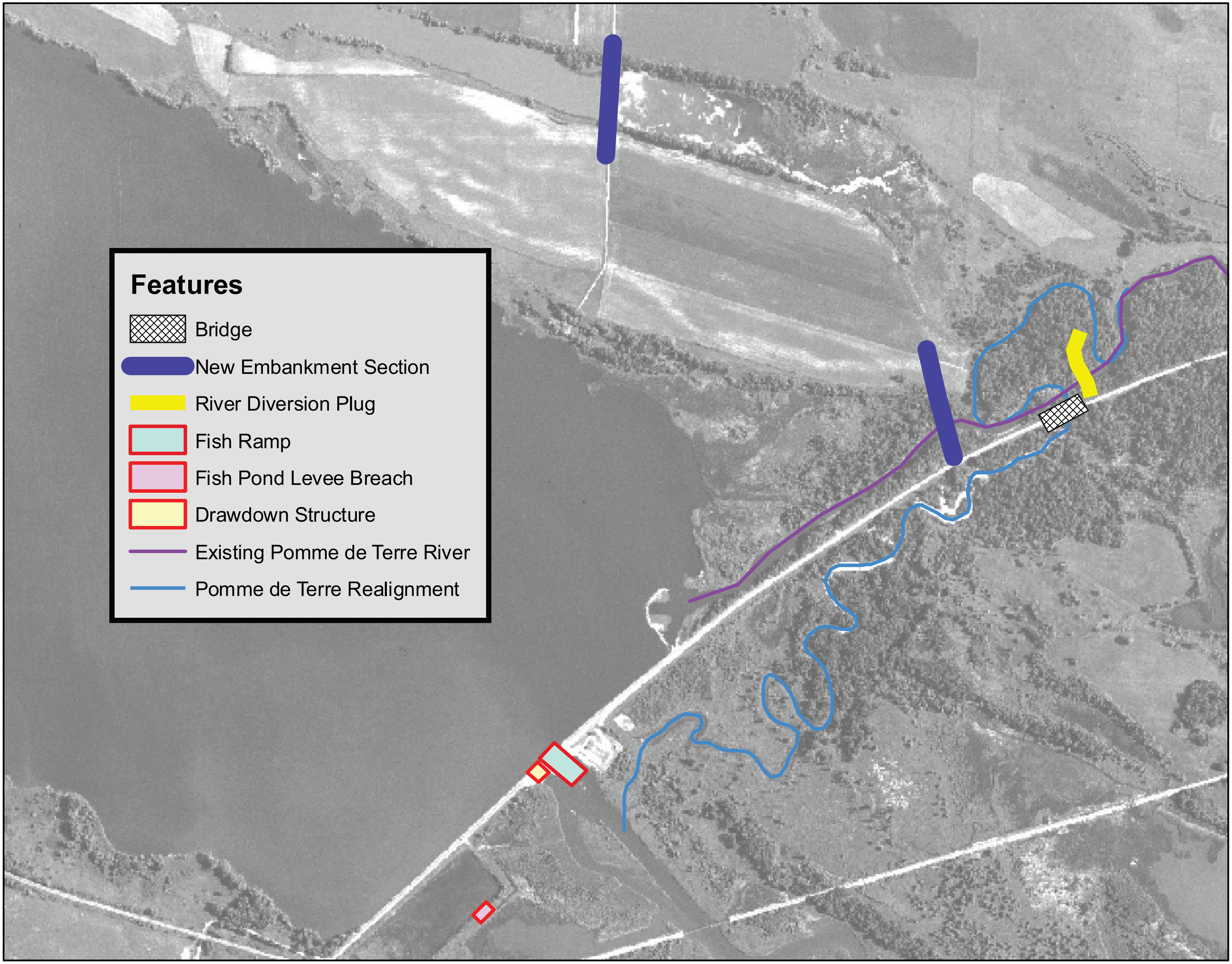
$$\frac{h'}{d_c}=0.25$$

Sizing & Dimensions

Length of Basin	31'
Elevation of Crest (top of stop logs)	940.0
Elevation of Crest (bottom of stop logs)	935.0
Elevation of Basin	933.3
Elevation of Top of End Sill	935.0
Elevation of Top of Wingwall (upstream)	950.0
Elevation of Top of Wingwall (downstream)	945.9
Abutment Radius	3.9'
Abutment upstream offset	3.25'

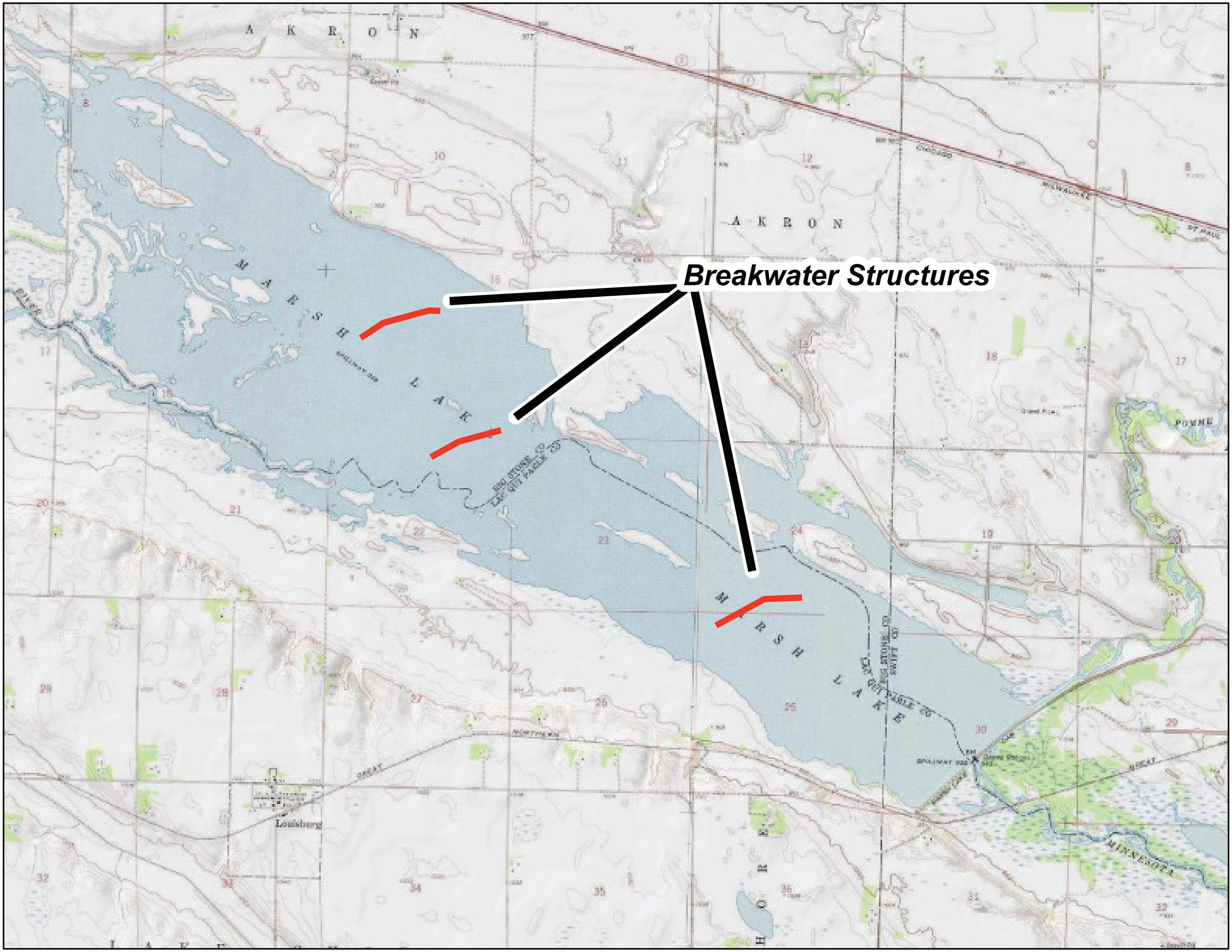
Marsh Lake Reservoir

Dam Modification / Pomme de Terre Realignment / Fish Pond Breach



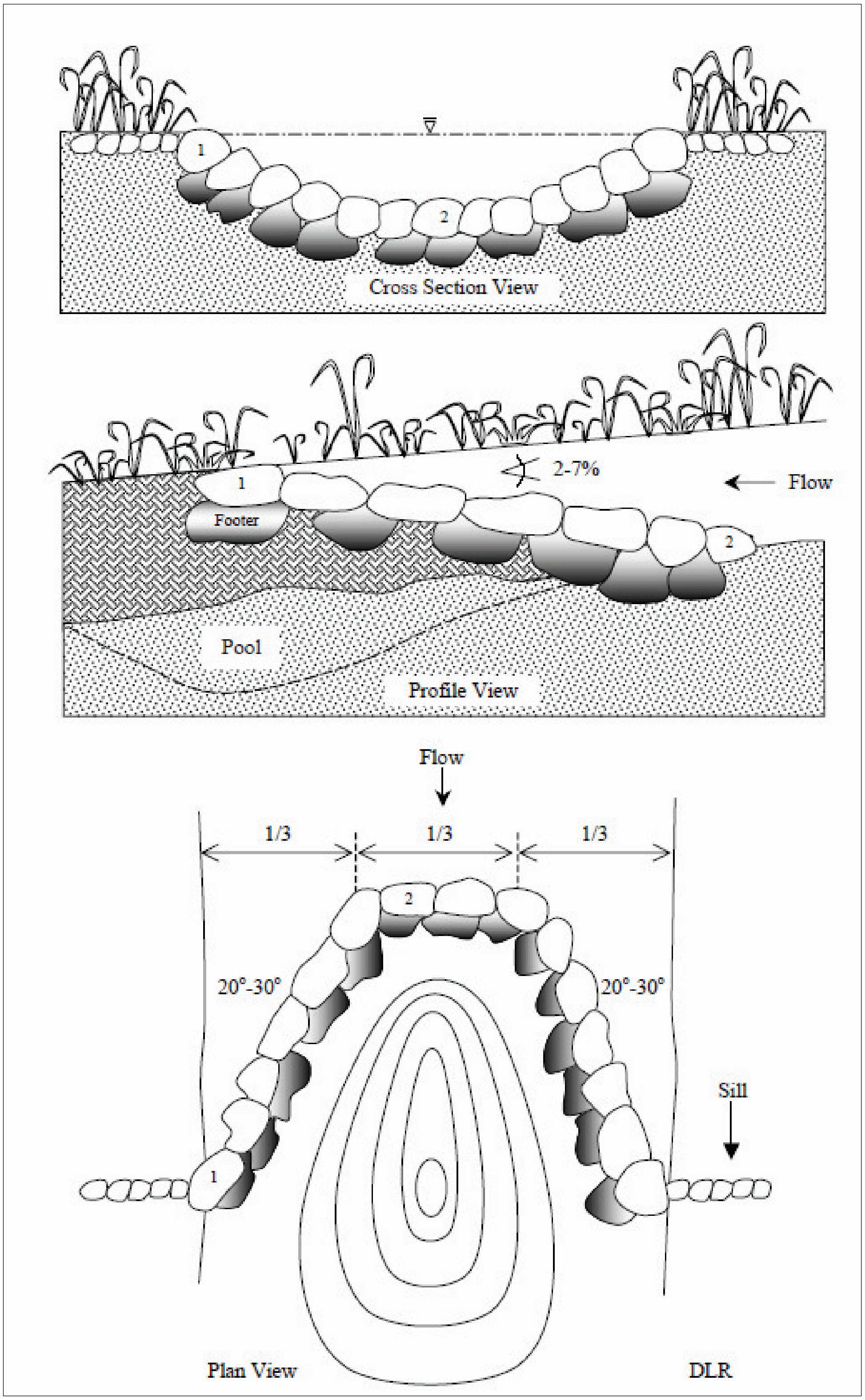
Marsh Lake Reservoir

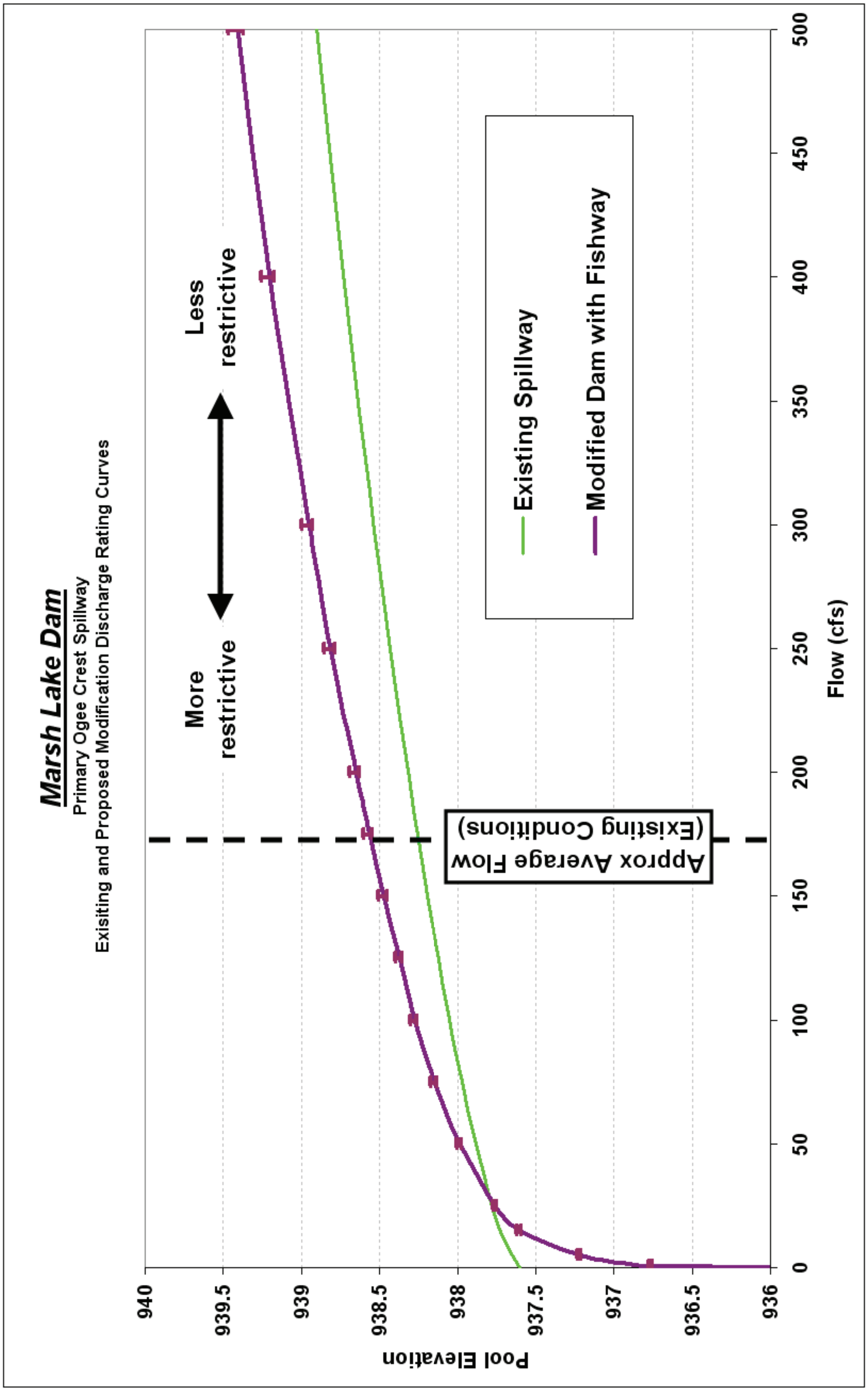
Proposed Breakwater Structure Layout



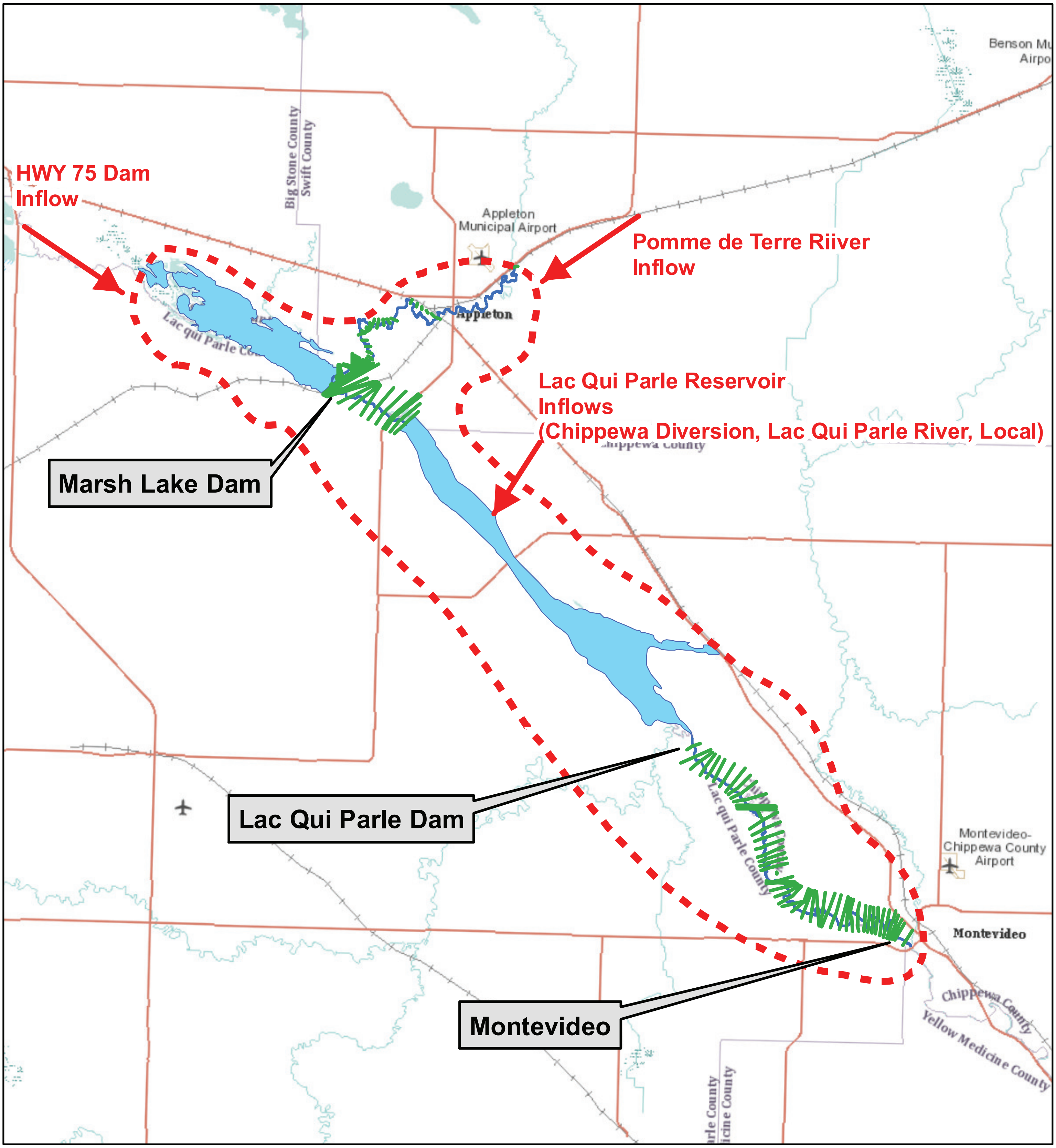
Conceptual Design of Re-routed Pomme de Terre Grade Control Structures

*per Reference 9: Wildland Hydrology/Dave Rosgen



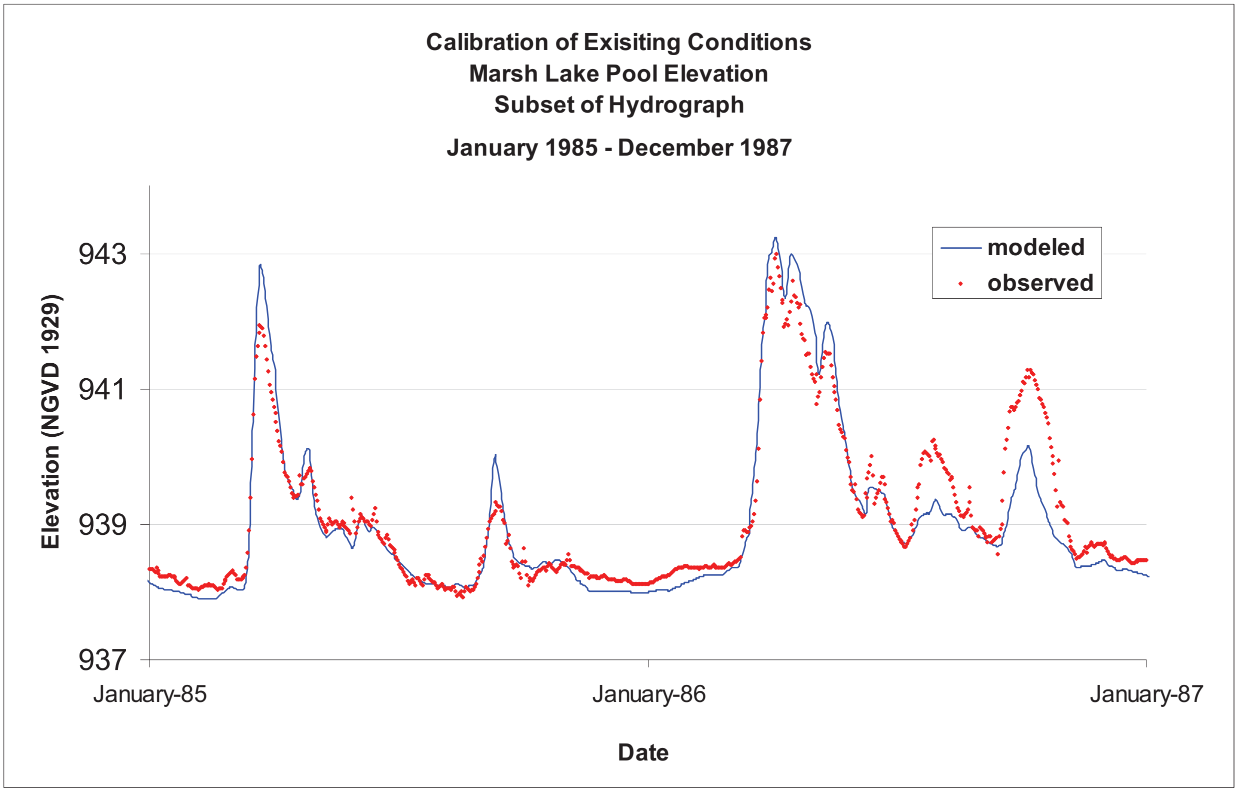

Marsh Lake Dam
Primary Ogee Crest Spillway
Exisiting and Proposed Modification Discharge Rating Curves
More restrictive
Less restrictive
Existing Spillway
Modified Dam with Fishway
Approx Average Flow (Existing Conditions)
Pool Elevation
940
939.5
939
938.5
938
937.5
937
936.5
936
Flow (cfs)
0
50
100
150
200
250
300
350
400
450
500

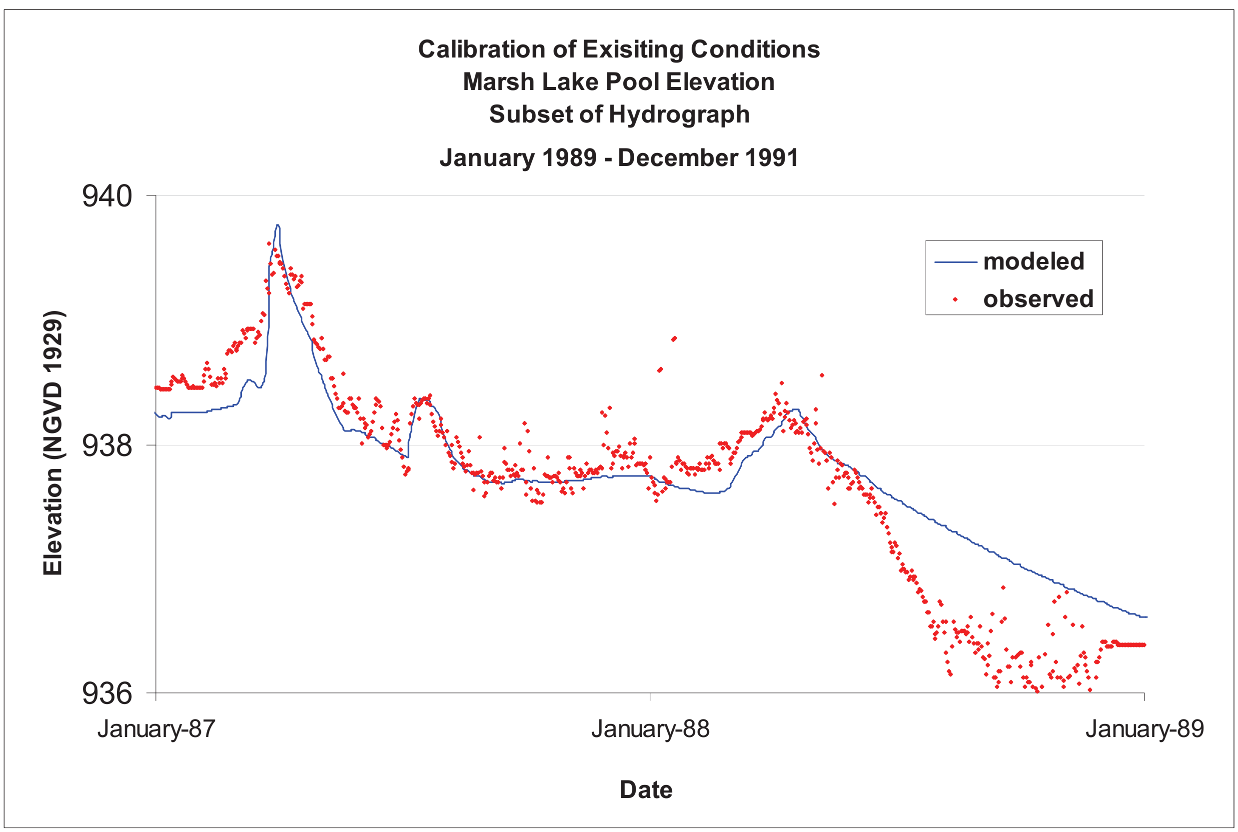
Marsh Lake
Unsteady HEC-RAS Model Schematic



Water Level Hydraulic Model Calibration and Validation

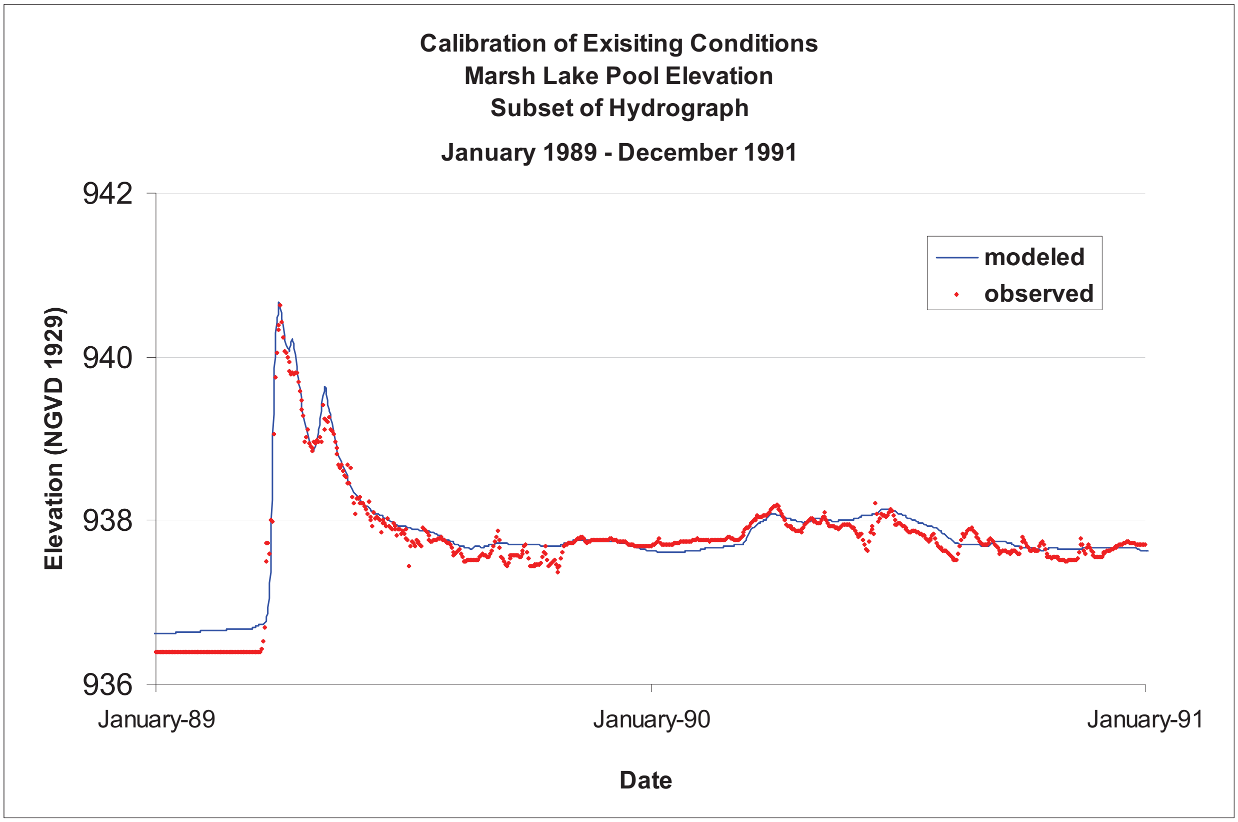
Marsh Lake Water Surface Elevation
Modeled and Observed Data

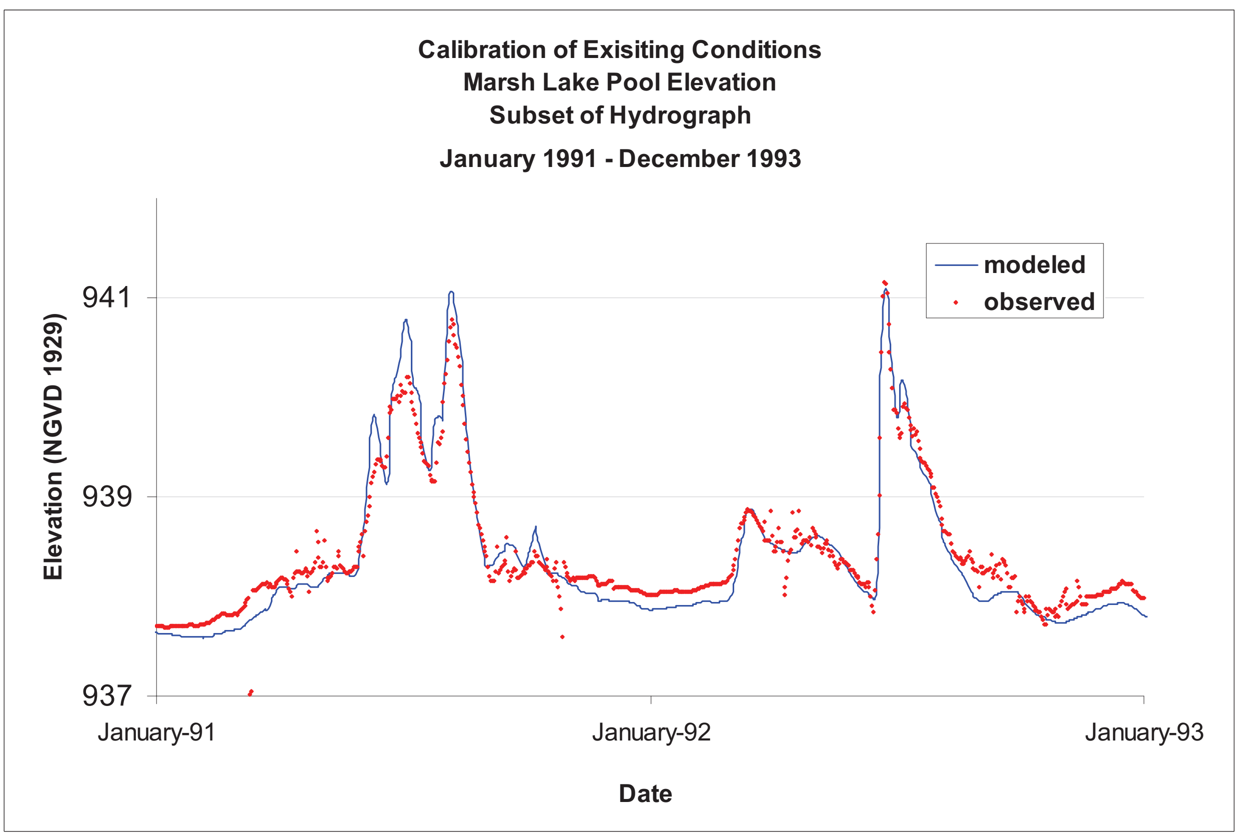




Water Level Hydraulic Model Calibration and Validation

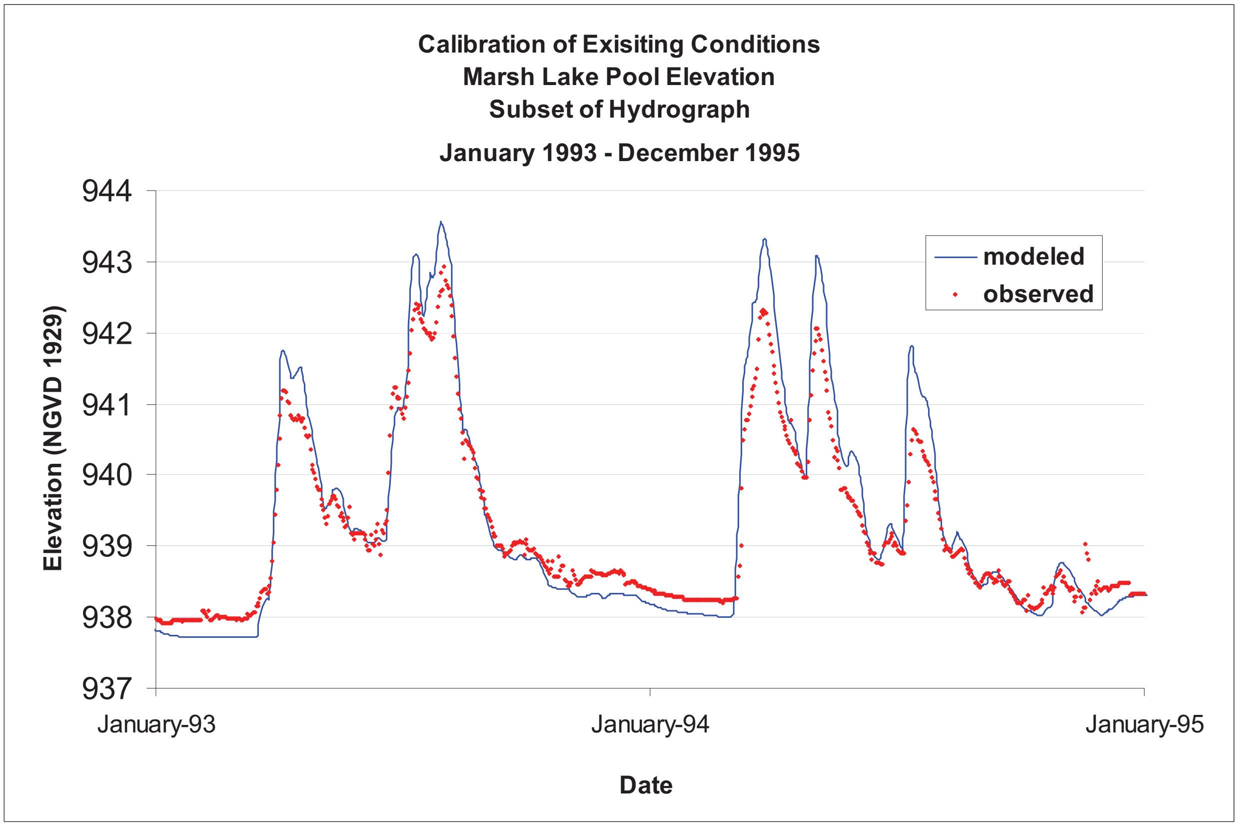
Marsh Lake Water Surface Elevation
Modeled and Observed Data

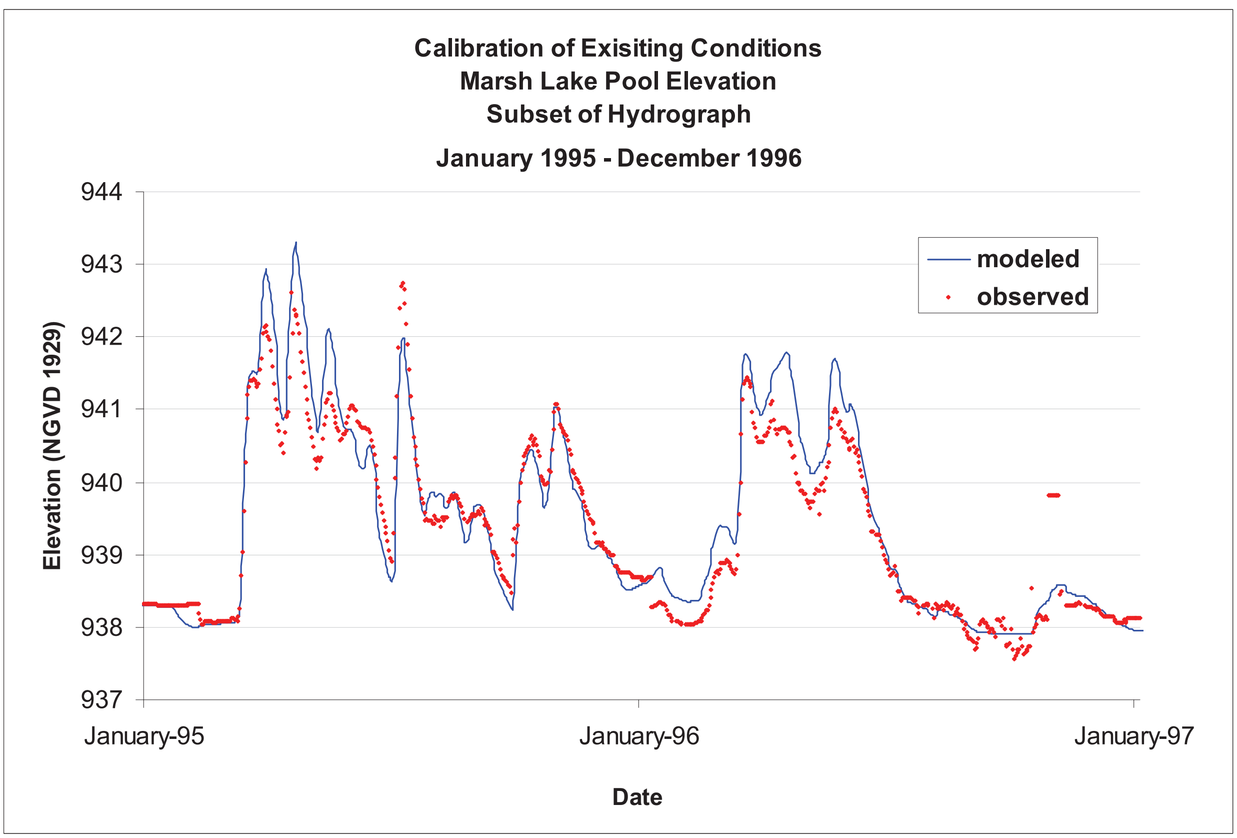




Water Level Hydraulic Model Calibration and Validation

Marsh Lake Water Surface Elevation
Modeled and Observed Data





Water Level Hydraulic Model Calibration and Validation

Marsh Lake Water Surface Elevation
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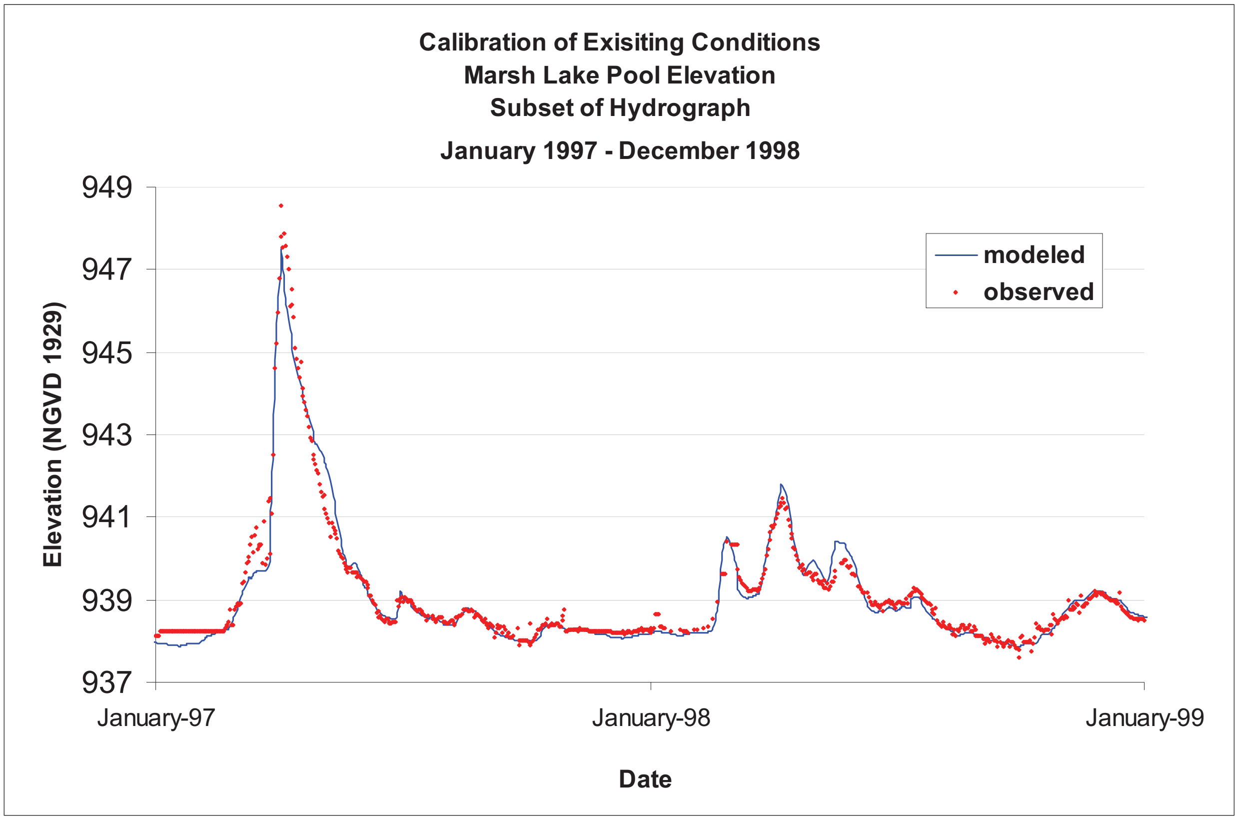

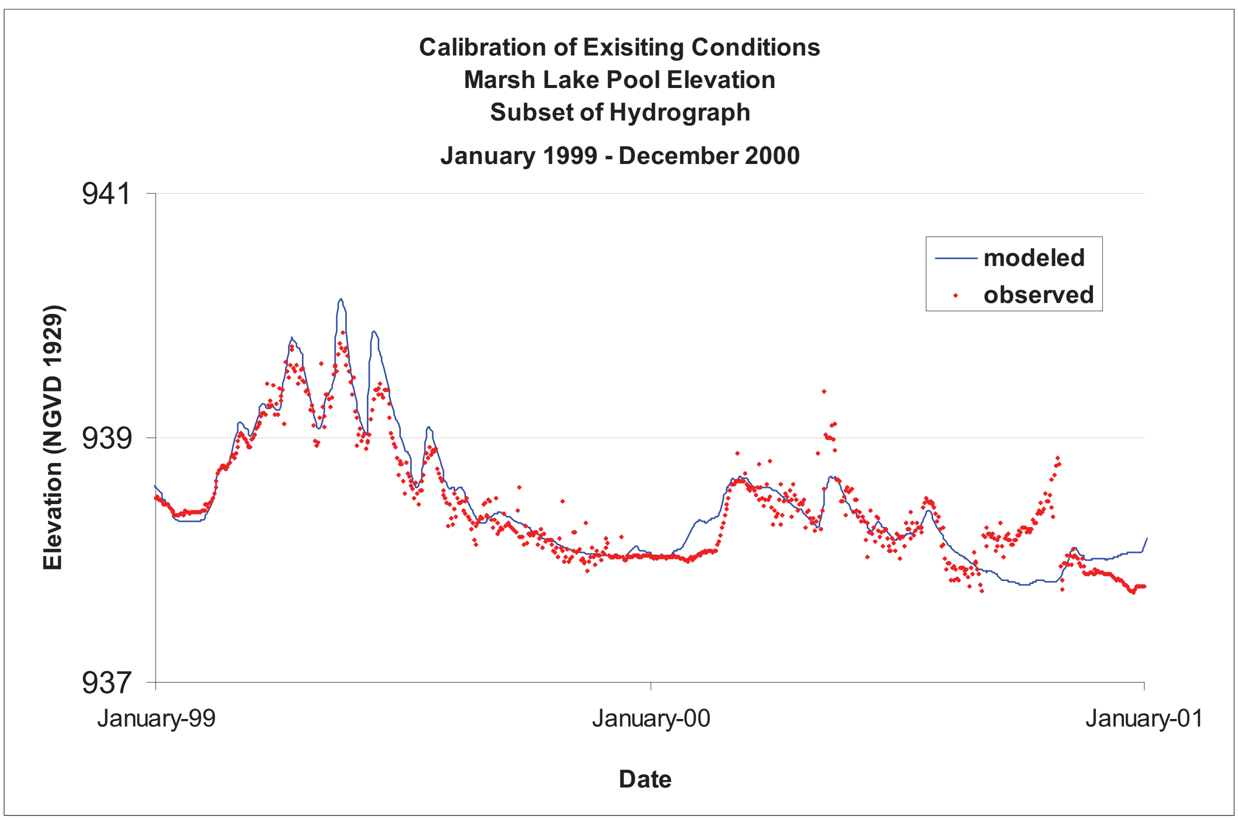

Water Level Hydraulic Model Calibration and Validation

Marsh Lake Water Surface Elevation
Modeled and Observed Data