P-10855

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15 December 2003

Mr. Constantine Tjoumas
Director, Division of Dam Safety and Inspections
Federal Energy Regulatory Commission
888 First Street, NE, Room 6N-01
Washington, D.C. 20426

Re: Report No. 2
FERC Independent Consultants Review Panel
Silver Lake Dam

Dear Mr. Tjoumas:

At your request we have agreed to serve as an Independent Review Panel to investigate the breach of Silver Lake Reservoir on May 14, 2003. Enclosed is our Report No. 2 entitled "Technical Reasons for the Release of Silver Lake Reservoir on May 14-15, 2003." This report expresses our best judgment at this time, based on the information furnished to us (Appendix A), the field inspection of the site, and the interviews conducted in the FERC Chicago offices. It is noted that this Panel has also reviewed three reports written on the Silver Lake Reservoir Fuse Plug Release and have taken the contents of these reports into account in the findings presented herein. These reports were:

1) Initial Report of Findings, FERC Investigation of Activation of Fuse Plug Spillway, May 14, 2003, Silver Lake Basin, Dated July 24, 2003.

2) Silver Lake Dam: Root Cause Report on the May 14, 2003 Operation of the Fuse Plug Spillway and Subsequent Channel Erosion Resulting in the Uncontrolled Release of Silver Lake, by Washington Group International Dated October 6, 2003.

3) Silver Lake Reservoir Fuse Plug Release, Facts, Observations and Discussion, by MWH Americas, Inc. Dated October 24, 2003.

Respectfully submitted,

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REPORT NO. 2

FERC INDEPENDENT CONSULTANTS REVIEW PANEL

SILVER LAKE DAM

TECHNICAL REASONS FOR THE RELEASE OF SILVER LAKE RESERVOIR ON MAY 14-15, 2003

December, 2003

TECHNICAL REASONS FOR RELEASE OF SILVER LAKE RESERVOIR ON MAY 14-15, 2003

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1. INTRODUCTION

1.1 Appointment of Independent Consultants Review Panel by the FERC

The FERC has licensees continually reviewing the spillway adequacy of their dams to determine if adequate spillway capacity and routing volume exists to safely accommodate the project inflow design flood. These investigations and analyses are done under the direction and review of the Division of Dam Safety and Inspections. When it is determined that additional discharge capacity is needed, an accepted alternative is to design an auxiliary spillway channel that contains a fuse plug embankment which activates at a predetermined elevation. Several projects under FERC jurisdiction have fuse plugs of various designs incorporated into the project to safely pass the design flood event.

On May 14th the Silver Lake Dam Fuse Plug, Dead River Project, Upper Peninsula Power Co. (Licensee), FERC Project No. 10855, was activated following a storm event lasting several days in the drainage basin. The activation of the fuse plug caused extensive property damage. The fuse plug foundation scoured to a depth of about 25 feet for several hundred yards which was far more extensive than anticipated by the designers and reviewers of this project modification. This headward erosion progressed into and released most of the volume of water stored in the lake and thus was effectively a breach which occurred at the emergency fuse plug foundation rather than at the main dam.

This Panel was convened by the FERC Director of Dam Safety to establish an independent assessment of the technical causes of the release of Silver Lake Reservoir. It is anticipated that the conclusions in this report will be applied in the review of other projects with fuse plugs within the jurisdiction of FERC.

The Director of Dam Safety decided to appoint a Review Panel composed of individual consulting engineers with experience in spillways, dams, and in fuse plug design. The individuals on this Panel were contacted by the Director of

Dam Safety, Mr. Constantine Tjoumas, during the week of May 19-23, 2003. The Review Panel composed of Drs. Duncan, Hendron, and Pinto accepted the assignment of investigating the technical causes of this failure; the contractural arrangements were made by the FERC Dam Safety office in Washington D.C.

1.2 Scope of Investigation

In the contractural scope of work for each Review Panel member it was specified that the Panel should:

1) Evaluate the cause of the activation of the fuse plug at Silver Lake Dam.

2) Review the engineering aspects of the activated fuse plug, such as those shown below.

- Foundation exploration program, design, and implementation
- Hydraulics and hydrology of rainfall event, reservoir operation, and fuse plug performance
- Geotechnical evaluation of fuse plug performance
- Review of design report, plans and specifications, and construction records of fuse plug
- Re-assessment of Silver Lake Inflow Design Flood

3) Based on this review the Panel will assess if the fuse plug performed in accordance with the design intent.

4) Review the design plans and specifications, operation plan, and construction of the replacement structures to safely accommodate the inflow design flood associated with the PMF.

In this report, items 1), 2) and 3) are addressed in detail. It is not known by the Panel what the owner's plans are for a replacement structure to safely handle the Silver Lake Inflow Design Flood. The Panel agrees to participate in a review of that design when it is submitted to the FERC.

Almost immediately after accepting this assignment the Panel began receiving information to review including, most importantly, the design report for the fuse plug. In addition arrangements were made for the entire Panel to inspect the Silver Lake Dam Site, arriving in the afternoon of June 4, 2003 and departing the morning of June 6, 2003. A summary of the Panel activities and comments on initial impressions at the site are given in Panel Report No. 1. Also included in Panel Report No. 1 is an attached list of the documents which had been sent to the Panel at the time of the writing of Report No. 1.

A review of the documents available at the time of Panel Report No. 1 and the observations of the Panel during the site visit generated questions which required clarification. Accordingly a day of interviews was held in the Chicago Regional office of FERC on June 19, 2003. Panel Members Duncan and Hendron conducted these interviews. Representatives of MWH, FERC – Chicago, UPPCO and WPS were interviewed.

The next full meeting of the Panel members was in the Washington offices of FERC on July 31 and August 1, 2003. The purpose of this meeting was threefold:

1) The Panel held internal technical discussions in the morning of July 31.

2) On the afternoon of July 31 the Panel was presented a draft of the "Initial Report of Findings – FERC Investigation of Activation of Silver Lake Fuse Plug Spillway, May 14, 2003." The draft was

dated July 14, 2003. Technical discussions were held between the Panel and the FERC staff from the Washington D.C. offices, as well as authors of various sections of the report from the Atlanta, Chicago, and San Francisco Regional Offices.

3) On Friday, August 1, technical discussions were held between FERC staff and the Panel. The Panel also had internal technical discussions and outlined this report.

A list of all of the documents reviewed at the time of writing this report is contained in Appendix A.

In the remainder of this report, the Panel has described the conditions which existed at Silver Lake Reservoir and fuse plug just prior to the activation of the plug and we have given our opinions on the most probable technical causes of the release of the reservoir at the fuse-plug location.

2, PROJECT EVALUATION FOR PMF CONDITIONS

2.1 General

The Silver Lake Dam is part of the Dead River Hydroelectric System owned by Upper Peninsula Power Company, UPPCO from February 15, 1988 to the present. The dam is located on the Dead River, in the central region of Michigan's Upper Peninsula, in Marquette County, about 32.1 miles (51.6 km) upstream from the mouth of the river at Lake Superior. The drainage basin at the dam site is 23.6 sq.mi. (61.1 km^2). The reservoir has a surface area of 1463 acres (5.9 km^2) at El. 1486.25 and a storage capacity of 33,500 acre-ft (41.3 hm^3). The dam was built to raise the water level of a natural lake and to provide flow regulation for four hydroelectric projects downstream: Hoist, McClure, Forestville and Tourist Park; the last two are owned by the city of Marquette. The main dam, overflow structure, low level outlet structure, and Dikes 1, 2, 3, and 4 as they existed prior to the October 2002 resulted from modifications which were built in 1944.

The main dam consists of a 1,500 ft (457.5 m) long 30 ft (9.1 m) high earth embankment, a 100 ft (30.5 m) long concrete spillway, and a 15 ft (4.6 m) long concrete low-level outlet structure. In 1993, when the safety of the dam against extreme floods was assessed, the main dam had its crest at El. 1490.7 ft MSL. Four isolated earth dikes across low points along the reservoir rim complemented the perimeter of the reservoir; Dikes 1, 2, 3, and 4 had crest elevations of 1488.9, 1488.3, 1488.8, and 1487.7, respectively. After the modification works of 2002, the crest of the main dam and of dikes 1, 3, and 4 were raised to El. 1491.5. Dike No. 2 was replaced by a fuse plug with a crest at El. 1486.5 and two pilot channels with inverts at El. 1485.5. The spillway is divided into 10 bays, about 9 ft (2.7 m) wide, nine of them with a classical ogee shape with crest at El. 1486.25. The fourth bay from the left has its sill cut flush at El. 1480.25, closed by wooden stop logs to El. 1486.25.

An analysis of flood and spillway adequacy carried out by Stone and Webster, Michigan, Inc. in 1993 – 94, found the dam spillway inadequate for passage of the PMF flood with an estimated peak inflow of 31,970 cfs (908 m^3/s) with an initial lake level of 1486.25. The resulting outflow of 18,598 cfs (528.4 m^3/s) compares to the spillway capacity of 3,125 cfs (88.8 m^3/s) for zero freeboard with the lake at El. 1490.7, which is reduced to 545 cfs (15.5 m^3/s) at El. 1487.7, the crest of Dike 4.

The Spillway Adequacy Report, Stone and Webster, Michigan, Inc., 1994, indicates Silver Lake Dam to be a High Hazard Potential dam on the basis of an incremental flood analysis that considered existing and possible future downstream development. In this report it was judged that the spillway capacity and freeboard were inadequate; thus modifications of the project were required. The inflow design flood was to be the PMF flood. Some small structural modifications were also required to improve embankment and spillway stability.

2.2 Evolution of Design

In 1995, Stone and Webster, Michigan, Inc. developed a preliminary design with conceptual drawings, recommending to limit the maximum reservoir stage to El.1488.0, replace the existing spillway with a 112.5 ft (34.3 m) long labyrinth spillway with crest at El.1483.5, and lower Dikes 1, 2 and 3 to El. 1484.0. The labyrinth crest length was about 420 ft (128 m) within the 112.5 ft (34.3 m) spillway span, set at the location of the old spillway. The main embankment dam would have the crest raised to El. 1491.3. The proposed PMF maximum reservoir elevation would be El. 1488.1, with a freeboard of about 3.2 ft (0.98 m).

The maximum operating level would be lowered from 1486.25 to 1483.5 and the operational freeboard to the crest of the auxiliary dikes limited to 0.5 ft (0.15 m).

In May 1999, a Periodic Inspection Report No. 2 – Hoist Hydroelectric Development, Dead River Project FERC No. 10855 for UPPCO, by Stone and Webster, Michigan, Inc. confirms the 1995 recommendations for modifications as adequate to meet FERC dam safety guidelines, and appropriate for upgrading Silver Lake dam to accommodate the PMF flood. At that time the inflow PMF, as approved by FERC, had a peak of 40,700 cfs (1156 m^3/s). Further studies by Harza Engineering Co. in 2001, reviewed by FERC, finally arrived at a peak inflow PMF of 36,500 cfs (1037 m^3/s), and was agreed upon in March 2001. This PMF hydrograph is shown in Figure 2.2-1. The volume of inflow associated with this hydrograph is 16,248 acre-ft (20.0 hm^3).

In March 2001, Harza's report on "Flood Routing of Probable Maximum Floods in Dead River Basin" concludes that only one fuse plug at Dike 2 was required to avoid the overtopping of the raised (crest El. 1491.3) earthen embankment. The 112.5 ft (34.3 m) long labyrinth spillway as proposed in the 1995 report was no longer required. Harza's March 2001 recommendations for the modifications of Silver Lake dam to cope with the PMF can be summarized as follows:

- Raise the main dam, the small dike in the low saddle on the left of the dam, and dikes 1,3 & 4 to El. 1491.3. Harza indicated that a 3 ft (.91m) freeboard is normally recommended.
- Install an approach channel, a fuse plug, and an exit channel at Dike 2.

A basic design along those lines was developed by Harza Engineering Co. in May 2001. The final drawings and Design Report were presented by Montgomery Watson Harza (MWH) in March 2002.

2.3 Fuse Plug Embankment and Spillway

2.3.1 Final Design

The MWH Final Design, dated of March 2002, approved by FERC, consisted of raising the crests of the main dam and Dikes 1, 3, and 4 to elevation 1491.5; constructing a fuse plug at the location of Dike 2, with a foundation level of 1481.0, a crest elevation of 1486.5, and two pilot channels at elevation 1485.5; lowering the stop logs in the fourth bay of the existing spillway from the left to elevation 1482.5; and defining the normal maximum operating level, NMOL, at El. 1481.5.

For this design, the PMF inflow shown in Figure 2.2-1, for a reservoir starting level of 1481.5, and the bottom outlet discharging 280 cfs (8 m^3/s), results in an outflow of about 20,600 cfs (585 m^3/s) for a maximum reservoir elevation of about 1488.45.

The fuse plug embankment was constructed during September 2002 at the location of Dike 2 on the Silver Lake reservoir rim. The purpose of the fuse plug was to breach by overtopping and erosion at water levels just above the pilot channels thereby providing an additional 19,230 cfs (546 m^3/s) spillway capacity for the reservoir during the PMF. Unlined grass covered spillway channels upstream and downstream from the fuse plug embankment were to be provided to conduct flows through the fuse plug section after breaching.

The final design of the fuse plug is described in the MWH report entitled "Silver Lake Dam Fuse Plug Spillway and Dam Modifications," dated March 2002. A plan and profile through the fuse plug embankment and channel are shown in Figure 2.3.1-1, and cross sections through the fuse plug embankment are shown in Figure 2.3.1-2.

The fuse plug embankment was 265 ft (80.8 m) long, with a crest width of 5 ft (1.5 m) and a base width of 27 ft (8.2 m). The base of the embankment was at elevation 1481.0, and the crest at 1486.5. Two pilot channels, with inverts at elevation 1485.5, extended from upstream to downstream across the fuse plug embankment. These channels are shown in Figure 2.3.1-2. Their purpose was to ensure that the erosion of the entire fuse plug embankment would proceed in a controlled manner, beginning from these locations.

The widths of the inlet and outlet channels were the same as the length of the fuse plug embankment – 265 ft (80.8 m). For about 100 ft (30.5 m) upstream and downstream from the fuse plug embankment, the inverts of both channels were level, at elevation 1481.0. From a point 100 ft (30.5 m) upstream from the center of the embankment to a point about 265 ft (80.8 m) upstream, the inlet channel was graded to slope downwards at about 0.7 percent in an upstream direction, and followed the natural grade further upstream, as shown by the profile in Figure 2.3.1-1. From a point about 100 ft (30.5 m) downstream from the center of the fuse plug embankment to a point about 660 ft (201.3 m) downstream, the outlet channel was graded to slope downstream at 1.8 percent, and followed the natural grade further downstream, as shown by the profile in Figure 2.3.1-1.

Erosion protection for the inlet and outlet channels during fuse plug activation was to be provided by erosion-resistant grasses and fescue, planted after final grading of the channels. The natural vegetation was left undisturbed outside the limits of grading, to provide resistance to erosion.

The design included an 8 ft (2.4 m) deep rock trench, with its centerline about 100 ft (30.5 m) downstream from the centerline of the fuse plug embankment, to impede headward erosion of the outlet channel closer to the fuse plug embankment. The cross section through the rock trench is shown in Figure 2.3.1-2.

As shown in Figure 2.3.1-2, the fuse plug embankment was constructed with four zones – Core, Filter, Shell, and Riprap. The gradations and Unified Soil Classification System classifications of these materials are given in Table 2.3.1-1.

Table 2.3.1-1. Grain sizes of fuse plug embankment and foundation soils

Zone	Grain Size	% Finer by weight	USCS Classification
1 – Core	#4 #200	100 30	ML
2 – Filter	3/8 inch #4 #8 #16 #30 #50 #100	100 95 – 100 65 – 95 35 – 75 20 – 55 10 – 30 0 – 10	SP-SW
3 – Shell	1.5 inch 1.0 inch 0.5 inch #8	100 85 – 100 40 – 70 0 – 30	GP-GW
4 – Riprap	6.0 inch 3.0 inch 1.5 inch 0.75 inch	100 40 – 70 20 – 40 0 – 10	Cobbles and gravel
Foundation (design report)	#4 #16 #100 #200	61 – 94 52 – 88 13 – 32 6 – 18	SM or SP-SM
Foundation (STS boring B2, five samples from depths 4 ft to 41 ft)	#4 #16 #100 #200	89 – 92 81 – 83 31 – 36 22 – 27	SM

The filter criteria established by the U. S. Army Corps of Engineers (EM1110-2-2300, July 1994) and the U. S. Bureau of Reclamation (Design Standards: Embankment Dams No. 13, 1994) were evaluated by this Panel for each of the interfaces between embankment zones, foundation, and abutment where flow would occur. The results of this evaluation are shown in Table 2.3.1-2. The areas where the restraint criterion is not satisfied could be subject to erosion of the finer material into the coarser material. These include the downstream filter/riprap contact at the downstream face, the shell/riprap contact at the top of the downstream riprap zone, and the contact between the shell and the abutment at the ends of the fuse plug embankment.

Table 2.3.1-2. Filter Conditions at Interfaces Between Fuse Plug Embankment Zones, Foundation, and Abutment

Interface and location	Filter criteria satisfied?	
	Restraint (Maximum D_{15})	Permeability (Minimum D_{15})
core to filter (Zone 1 to Zone 2) downstream side of core	Satisfied	Satisfied
filter to shell (Zone 2 to Zone 3) upstream side of encapsulated shell zone, and top of encapsulated shell zone	Satisfied	Satisfied
filter to riprap (Zone 2 to Zone 4) beneath downstream riprap zone	Not Satisfied	Satisfied
shell to riprap (Zone 3 to Zone 4) top of downstream riprap	Not Satisfied	Satisfied
foundation or abutment to filter at bottom of embankment and at contact of embankment with abutment	Satisfied	Satisfied
foundation or abutment to shell at abutment where shell is in contact with abutment without intervening filter	Not satisfied for coarsest allowable shell gradation	Satisfied

The gradation of the foundation soil given in the design report presents a much wider range of grain sizes than samples obtained from STS Boring B2, made in June 2003, which showed very little variation for five samples obtained from 4 ft (1.2 m) to 41 ft (12.5 m) depth. The grain sizes of the samples from boring B2 are near the fine limit of the foundation grain size given in the design report. Boring B2 is located on what was the right abutment of the fuse plug embankment, and is the closest boring to the fuse plug alignment.

Standard Penetration Test blow counts in Boring B2 ranged from 34 to 91 as shown in Table 2.3.1-3. The average of the N-values listed in Table 2.3.1-3 is 58.

Table 2.3.1-3. Standard Penetration Test
Blow counts measured in STS boring B2,
Located at STS Station 27+00

Elevation (ft)	SPT blow count, N
1480	91
1476	41
1472	40
1468	34
1465	79
1463	60
1461	82
1459	52
1457	45
1455	58

The bottom of the eroded channel at STS Station 267+00 is approximately elevation 1455 ft.

2.3.2 Comments on the Final Design

By defining the NMOL as elevation 1481.5, which is below the spillway crest at elevation 1486.25 and the proposed stop log bay elevation (1482.5), MWH introduced a substantial change in the operation procedures required to assure the safety of Silver Lake Dam. From 1944 through 2002, the ungated concrete spillway served as an automatic spilling device that did not depend on human intervention. To achieve the new NMOL elevation however, it is necessary to open the low-level outlet valve to pass at least 280 cfs (8 m^3/s) every time the reservoir exceeds elevation 1481.5. This critical necessary change in reservoir operation procedures was not made explicit in any of the design documents or FERC documents. Conditions were made even more critical by setting the elevation of the fuse plug pilot channel inverts at elevation 1485.5, which is below the spillway crest, and only 3 ft (.9 m) above the lowered stop log bay.

The evolution of operating conditions with time during the history of the project helps in the understanding of the nature of this problem. A tabulation of reservoir levels measured at Silver Lake from May 1957 until May 16, 2003 is given in Figure 2.3.2-1, sheets 1 through 5. A plot of the reservoir level versus time is shown in Figure 2.3.2-2.

Two operation patterns are apparent, prior to and after 1988, when the ownership of the project changed from Cliffs Electric Service Company to UPCCO. Before 1988, the reservoir levels prior to snow melt in each year ranged from elevation 1464.0 to 1475.0; this provided an ample reservoir storage capacity to accommodate snow melt and spring rain floods, 22,100 acre-ft (27.3 hm^3) between elevations 1467.5 and 1486.0, Figures 2.3.2-3 and 2.3.2-4.

After 1988, the operational conditions of the reservoir clearly changed. The drawdown of the reservoir each year was limited. The low levels got below elevation 1475 in only three years and from 1994 to 2002 low levels never got below elevation 1477.0. This change in conditions seems to reflect the concerns expressed by representatives of the Michigan Department of Natural Resources and of the U.S. Fish and Wildlife Service during a Special FERC inspection of September 27, 1988. The MDNR and USFWS representatives stated that they would request that any FERC License include requirements on minimum flow releases and reservoir levels. The October 4, 2002 license include the MDEQ regulation requiring the reservoir levels to be operated within a relative small range between a level of 1477.0 in December and 1481.5 in July.

Raising the minimum reservoir level naturally reduces the storage volume to catch snow melt water before the spring rains. By raising the minimum reservoir level from 1467.5 to 1477.0 the storage volume is reduced by about 10,000 acre-ft (12.3 hm^3). The effect of this reduction is probably one of the reasons for the higher frequency of spilling after 1988: once every 2.3 years as compared to once in every 4.3 years prior to 1988.

Until 2002, however, the operation of the reservoir did not require the intervention of the operators for handling the floods. The low setting of the fuse plug at El. 1485.5 for the October 2002 modified project reduced the storage volume from about 13,700 acre-ft (16.9 hm^3) between elevations 1477.0 and 1487.7 in the old project to 10,300 acre-ft (12.7 hm^3) between elevations 1477.0 and 1485.5. More importantly, the new project requires the operator to fully open the bottom outlet to assure the safety of the dam in case of an extreme event, every time the reservoir exceeds elevation 1481.5.

The acceptance of a NMOL elevation below the surface spilling facilities could have inspired a much simpler and safer alternative for the conveyance of the PMF discharges other than the fuse plug concept.

If the main dam and auxiliary dikes are raised to elevation 1491.5 and the NMOL is defined at El. 1481.5, the storage volume available for flood routing above elevation 1481.5 is about 13,000 acre-ft (16.0 hm^3) to a reservoir elevation 1490.65 (0.85 ft freeboard). If the bottom outlet is maintained open for reservoir levels above elevation 1481.5, the PMF hydrograph with a volume of 16,250 acre-ft (20.0 hm^3) and peak of 36,500 cfs (1037 m^3/s), can be safely routed through the reservoir making use of the existing spillway without the need of a fuse plug.

The Panel requested the Chicago FERC office to do a calculation for the PMF hydrograph inflow shown in Figure 2.2-1 routed through the Silver Lake reservoir for an initial reservoir elevation of 1481.5 and considering the low level outlet to operate at 280 cfs (8 m^3/s) starting 20 hours into the inflow hydrograph. It was assumed that all bays in the concrete spillway, including the stop logs in the 4^{th} bay, had an ogee elevation of 1486.25. It was found that the maximum reservoir level raised to 1490.5 ft [a freeboard of about 1.0 ft (.3 m)]. The hydrograph of the reservoir elevation and spillway discharge versus time is shown in Figure 2.3.2-5. It is noted that the reservoir elevation is shown to be above 1490 ft for about 8 hrs.

The maximum discharge for this case (Figure 2.3.2-5) is only 3237 cfs (92 m^3/s) as compared to the 20,000 cfs (568 m^3/s) discharge in the selected fuse plug design. Raising of all embankments to 1491.5 and operating the reservoir to 1481.5 as an initial condition would allow the PMF to be accommodated by use of the original spillway with no fuse plug construction. This concept has the advantage that the key elevations of all structures are equal to or higher than the "old" structures which have accommodated many significant floods since they were constructed in 1944, enhancing the safety for more frequent floods.

2.3.3 As-Built Conditions

The as-built conditions at the fuse plug embankment and spillway channels were documented in the final construction report (2002 Final Construction Report, Silver Lake Basin Project, FERC Project No. 10855, Wisconsin Public Service Corporation, Green Bay, Wisconsin, December 2002). Additional information was obtained through a June 12, 2003 phone conference call with Mr. Ben Trotter, construction inspector for the Upper Peninsula Power Company (UPPCO), and from photographs taken during construction.

Photographs of the fuse plug embankment and a pilot channel taken during the post-construction inspection are shown in Figure 2.3.3-1. It is evident from these and other photos taken during construction, and from interviews of the personnel involved in construction and inspection, that the embankment was built with attention to detail, and was constructed essentially in conformance with the design drawings and specifications.

Ben Trotter indicated that Dike 2 was removed, and the fuse plug embankment was constructed, as required by the design drawings and specifications. He indicated that Dike 2 had been longer than the fuse plug embankment, so the part of Dike 2 that remained after removal served as an abutment for the fuse plug embankment. He indicated that muck that had accumulated in the old Dike 2 borrow pit was removed and replaced with compacted fill.

The most significant differences between the final design and as-built conditions were as follows:

- The rock trench across the outlet channel, with a centerline axis about 100 ft (30.5 m) downstream from the centerline of the fuse plug embankment, was not constructed. The decision to eliminate the rock trench was approved by FERC in response to requests from MWH. The basis for eliminating the rock trench was that the fuse plug spillway channel would be long, with a mild slope for most of its length, and steeper slopes in an area that was forested. It was expected that velocities in the steeply sloping channel would be lower than initially estimated, making headward erosion less likely. In addition it was reasoned that, should headward erosion occur, the additional volume released would have minimal effect on the downstream Hoist project.

- The final construction report shows two survey points in the inverts of the pilot channels across the fuse plug that were lower than the design elevation (1485.5 ft). The elevations of these points were 1485.28 ft and 1485.37 ft. These lower elevations would be of significance if they represented lower elevations along the entire lengths of the pilot channel inverts. However, if they represented local low spots and other parts of the pilot channel inverts were at their design elevation, they would be of little significance. Which of these possibilities is correct is not known.

3. THE MAY 14-15 2003 EVENT

3.1 Initial Reservoir Level

The breaching of the fuse plug occurred on May 14, 2003. The outlet channel underwent intense erosion by the water flow with the consequent release of the lake in a process that extended through May 15. The event is related to the raising of the reservoir level following the intense rainfall in the region on May 10-11, 2003. Prior to the rain, the reservoir level had been last recorded at El. 1483.35, on May 7, 2003.

Due to the remote location of the dam, direct observation of reservoir levels was at about "7-day" intervals. Absence of electric energy at the site precluded automatic and/or long distance readings. Last recorded levels were as follows:

April 03/03 – 1479.06
April 10/03 – 1479.22
April 16/03 – 1480.60
April 23/03 – 1482.34
May 01/03 – 1483.22
May 07/03 – 1483.35

The rising trend of reservoir levels was certainly due to snow melting. Essentially no rain was registered in the basin for several weeks prior to May 10, 2003.

The evolution of Dead River discharges since April 3, 2003 can be evaluated from the available data on reservoir levels. The average rate of reservoir rise is known for each period between reservoir level readings. The surface area of the lake is taken from a table shown in a October 1993 Stone and

Webster report "Flood and Spillway Adequacy Analysis – Dead River Hydroelectric Project" Volume 1, based on a 1992 Falvey, Garske and Strigel survey, Figure 2.3.2-3. The flow estimate is summarized in the table below:

Date	Res. El.	Rate of change	Res. Area	Average	flow
	ft	ft/day	Ac	cfs	m^3/s
4/3/3	1479.06		1204		
4/10/3	1479.22	0.0229	1206	13.85	0.39
4/16/3	1480.60	0.2300	1217	141.8	4.03
4/23/3	1482.34	0.2486	1238	153.4	4.36
5/1/3	1483.22	0.1100	1264	69.20	1.97
5/7/3	1483.35	0.0217	1268	13.77	0.39

The average flows for each 6-8 day periods are net values into the reservoir and do not include the discharge being released through the bottom outlet. At the time of the incident, the bottom outlet gate was set to discharge 20 cfs (0.57 m^3/s), the minimum discharge required in the period by the FERC License.

The reduction of flow after April 23 coincides with the last snow packs on the ground. The rate of reservoir rising was very slow in the first week of May. At that rate, the reservoir level would have reached about El. 1483.5 on May 14, except for the later rainfall effects. Taking into account a gradual recession of the base flow, the initial reservoir level, defined as the level that would be attained on May 14 if not influenced by rain, is estimated at about El. 1483.4.

3.2 Low Level Outlet Operation

The discharge through the low level outlet remained constant at 20 cfs (0.57 m^3/s) during the entire episode, and was not increased to lower the lake level when the reservoir rose above 1481.5.

3.3 Stop Log Setting

The wooden stop logs in the 4th bay from the left were installed up to about El. 1486.25, the same level of the crest of the spillway (1486.25). This has been confirmed by UPPCO representatives during the Panel's visit of June 2003. In recent years the stop logs have been installed to that elevation. They had last been replaced with new boards during the Summer of 2002. Photos taken by UPCCO and FERC in the evening of May 15 and May 16 respectively confirm the setting of the stop logs.

The Design Report by MWH of March 2002, in Chapter 9.0 – Additional Site Improvements, states: "Stop logs in the fourth bay of existing concrete spillway from the left will be removed to elevation 1482.5."

UPPCO claims it was not aware of the requirement for lowering the stop logs to El. 1482.5. However, in a letter dated May 16, 2002 from the FERC Chicago Regional Engineer to the Assistant Vice President – Energy Supply of Wisconsin Public Service Corporation it was stated that part of the work would include "... the stop logs in the fourth bay of the spillway will be removed to elevation 1482.5 feet."

The requirement that the stop logs should be removed to elevation 1482.5 is not explicit on the construction drawings. The MWH Report of October 24, 2003 indicates that construction drawings and specifications initially submitted by MWH for UPPCO review included statements requiring removal of the stop logs. Why those statements were deleted, and do not appear in the final drawings and specifications is not clear.

The final Construction Report by FERC of November 29, 2002 refers to the October 8, 2002 inspection after all the concrete work and the fuse plug had been completed. Item 1 of the Construction Report, Scope of Work Description, under Part A – GENERAL CONSTRUCTION INFORMATION specifies: "the stop logs in the fourth bay of the spillway were removed to elevation 1482.5." Under Part B – WORK PROGRESS AND INSPECTION OBSERVATIONS, the question of stop log setting is not mentioned, although the stop logs were set at El. 1486.25 at the time of the inspection.

The existing operating plan for the dam does not refer to reservoir operation proper but to procedures and care during operation of gates and stop logs. It does not include instructions to handle flood conditions and/or to enhance dam safety. The need for such a requirement after the modifications of 2002 to prevent overtopping of the fuse plug is not explicit in any document previous to the May 2003 event. The new operating plan, after the construction works of 2002, had not been drafted at the time of the incident and was not due before October 30, 2003.

The fact remains that the stop logs were installed up to El. 1486.25 at the time of the May 14-15, 2003 event.

3.4 Rainfall Event – May 10-11

After a dry period of several weeks, intense rainfall was registered in the region, mostly concentrated in two days, May 10 and 11, 2003.

There are no rain gages installed in the drainage basin of Dead River upstream from Silver Lake. The rainfall in the basin had to be evaluated from rain gages installed in the area surrounding the basin and from an isopluvial map obtained by FERC from E. Fenelon, Chief Meteorologist, National Weather Service (NWS), Marquette, Mi. "Multi Sensor Precipitation Estimates from May 9-13, 2003", based on rainfall derived from gage readings and radar estimates.

The amount of rainfall and distribution with time are illustrated by the recorded values of selected rain gage stations around the drainage basin shown in the table below. Rainfall water is collected at 8 AM of the day shown, and referred to the previous 24 h period.

Gage St.	No.	Rainfall (in – mm)					
		May 9	May 10	May 11	May 12	May 13	Total
Baraga	2	0.00	0.22-5.6	0.34-8.6	2.91-73.9	0.0-0.0	3.47-88.1
Herman	7	0.15-3.8	0.03-0.8	2.10-53.3	2.78-70.6	0.0-0.0	5.06-129
Pelkie 5 SW	16	0.00	0.27-6.9	0.20-5.1	2.94-74.7	0.02-0.5	3.43-87.1
Watton	21	0.00	0.29-7.4	0.23-5.8	3.15-80.0	0.11-2.8	3.78-96.0
Champion/Clarksb.	23	0.00	0.15-3.8	0.11-2.8	1.92-48.8	0.0-0.0	2.18-55.4
Huron Mtn Club	32	0.00	0.30-7.6	1.2-30.5	1.2-30.5	0.0-0.0	2.70-68.6
Marquette NWS	35	0.00	0.32-8.1	0.2-5.1	3.07-78.0	0.35-8.9	3.94-100
Average-in-mm		0.02-.5	0.23-5.7	0.63-15.9	2.57-65.2	0.07-1.74	3.51-89.1
%		0	6.6	17.9	73.2	2.0	100.0

About 91% of the rain was concentrated on May 10-11 (based on 8 AM readings on May 11 and 12). The isopluvial map indicates the Dead River basin upstream from Silver Lake as falling between isolines 4 in (102 mm) and 5 in (127 mm). Total rainfall in the basin is therefore estimated as 4.5 in (114 mm) in the 5 day period May 8-12, 2003, with about 4.1 in (104 mm) concentrated on May 10-11.

The studies carried out for Silver Lake fuse plug and dam modifications do not include frequency analyses of rainfall values. A rough indication of the frequency of the precipitation is given by comparison to an isopluvial map of 100-yr 24-h precipitation in the U.S.A., prepared by Hershfield 1961 and published as Figure 2.13 in the ASCE Hydrology Handbook, 1996. For the Silver Lake region, the 100 yr 24h point precipitation is estimated at about 110 mm or 4.3 in. It can be compared to the maximum value recorded in rain gage 21 of 3.14 in (80 mm). Huff and Angel, 1992 Atlas, according to WGI, Oct. 6, 2003 Study, indicates 5.32 in (135 mm) as the 100-yr 24-hr point rainfall.

The May 10-11 rainfall, although significant, had a return period of less than 100 yr for essentially all rain gage stations in the area. Rain gage No. 7, at Herman, with a total of 4.88 in (124 mm) in two days would indicate a rarer event if most of the water caught at 8 am of May 11 refers to the first 8h of that day and the precipitation recorded at 8 AM of May 12 is measuring essentially rainfall of the previous day.

The total precipitation estimated for the Silver Lake basin of 4.5 in (114 mm) in five days, about 4.1 in (104 mm) in two days is a significant event with annual frequency evaluated as less than 1:100. It is considerably lower than the PMP value defined as 16.6 in (422 mm) in 24 h or 19.6 in (498 mm) in 3 days, in Stone Webster's report of October, 1993.

3.5 Maximum Reservoir Level

3.5.1 Field Evidence

The first direct observation of the reservoir level after the collapse of the fuse plug was at about 6:30 pm on May 14, 2003, during the first UPPCO inspection following the news on abnormal river flows downstream. The reservoir level was recorded at El. 1483.26. The erosion process was in evolution and the reservoir level receding. At 7:00 pm, the level was recorded at El. 1482.82, indicating a rate of drop in water level of about 0.88 ft/h (0.27 m/h).

A photograph of the concrete spillway upstream face at about 7:00 – 8:00 pm of the same day, Figure 3.6.2-2, distinctly shows a horizontal water mark of wet surface about 12-15 in (0.3 – 0.4 m) above the reservoir level. It indicates that the reservoir had been at least up to about El. 1484.3 – 1484.5. This photo is not conclusive with respect to higher levels. The wet band of concrete surface would be following the reservoir level and being dried out at its upper boundary at an unknown rate. A more conclusive evidence on the maximum reservoir level reached prior to activation of the fuse plug are high water marks left on the dam face and reservoir rim.

During the first FERC inspection on May 16, 2003, a high water mark was detected on the felt paper on the upstream side of the stop logs. The level was measured to be about El. 1485.6. Some leaves and grass were seen also in the left stop log slot up to that same level. The latter could have been carried into the slots by leaking water but could also have been placed by the operators during the last stop log erection. The existing operating procedures for stop log installation at the out-flow structure specify: "... If leaks are encountered and they are not heavy, you can seal them by using whole kernel corn and sod." That could have inspired a similar operation at the spillway stop logs.

An independent confirmation of reservoir level above El. 1485.0 is given by high water marks found during the survey works in the area of the fuse plug channel by STS Consultants, LTD. The drawing 10452/1 of 07/21/2003 identifies several points just upstream of the fuse plug location with high water levels at Els. 1485.34, 1485.38, 1485.30, 1485.28. The accuracy of those marks is recognizably poor. However, the water levels along the channel would be about 0.5 – 1.0 ft (.15 - .30 m) below reservoir level at the initial phase of the breaching because of the velocity head and head losses along the channel. The surveyed high water marks roughly confirm El. 1485.6, or even a somewhat higher level, at the onset of the fuse plug breaching.

3.5.2 Runoff Estimates from May 10-11 Rainfall

The estimated rainfall of 4.5 in (114 mm) in the period May 8-12 produced a total rainfall volume over the drainage basin above Silver Lake dam of 5708 acre-ft (7.04 hm^3). The corresponding runoff volume can be evaluated approximately either by assuming a runoff coefficient or by estimating the infiltration losses.

The depth to frost in the ground is reported at an average depth of about 28 in (0.7 m). A relatively high runoff coefficient of about 0.60, assumed to take in consideration this shallow frozen ground, results in a total runoff volume of 3425.0 acre-ft (4.22 hm^3).

The reservoir volume between El. 1483.4 and El. 1485.6 is about 2913 acre-ft (3.59 hm^3). If the reservoir takes about 2.5 days to reach El. 1485.6, a volume of about 100 acre-ft (0.123 hm^3) is lost through the bottom outlet. The required inflow volume to fill the reservoir to El. 1485.6 is 3013 acre-ft. This minimum volume needed to attain El. 1485.6 corresponds to a runoff coefficient of 0.53 instead of 0.60, a reasonable figure also. The actual runoff coefficient was certainly equal to or greater than 0.53. These results, although unavoidably crude indicate that the reservoir rise to about El. 1485.6 has been produced by and is consistent with the rainfall event of May 10-11, 2003.

A similar exercise could be carried out assuming an hourly distribution for the rainfall, applying hourly infiltration losses to partial surface areas according to corresponding soil characteristics, and computing the runoff volume from the output of a rainfall - runoff model such as HEC – 1. The more sophisticated approach would not improve the quality of the conclusion because of the many subjective parameter choices needed in the process.

The basic conclusion is that the rise of reservoir level to about El. 1485.6 is consistent with the runoff volume to be expected from the May 10-11 precipitation. Because most of the precipitation fell on May 11, most of the runoff likely occurred on May 12 and 13.

3.6 Fuse Plug Breaching

3.6.1 First Observations

At about 3:00 PM on May 14, 2003, high and muddy water was observed at the bridge over County Road AAO, about 2.5 miles downstream from Silver Lake. Although this was the first observation of the ensuing flood resulting from breach of the fuse plug, it was not reported to authorities until about 4:25 PM.

The first call to UPPCO reporting high water was made at 4:39 PM, whereupon an operator was sent to Silver Lake to investigate. The operator found that the fuse plug embankment had "washed out," but did not have a camera to record what he saw. He returned to Marquette to get a camera, and arrived back at Silver Lake about 7:30 or 8:00 PM.

3.6.2 Conditions Prior to and During Breaching

The last observation of the Silver Lake Water level prior to the breach was made on May 7, 2003. At that time the water level was recorded as elevation 1483.35. The operator personnel who visited the reservoir on that day observed the water level about 2 to 3 ft (.6 to .9 m) below the crest of the fuse plug embankment, which is consistent with the recorded lake level at that time (1483.35 ft). They also observed that the ground surface downstream from the fuse plug embankment was "moist," but did not see active seepage or standing water.

On May 9, 10, and 11, and 12, 2003, about 4.5 in. (114 mm) of rain fell in the Silver Lake area within a period of 48 hours. This rainfall, called the "Mother's Day Storm" caused the Silver Lake water level to rise, but there is no record of the level reached.

It is possible to infer the highest water level reached between May 7 and May 14 from grass and debris adhered to the felt paper and wedged into the gap at the side of the stop log opening by water seeping through small openings at the ends of the stop logs. This is shown in photographs like the one in Figure 3.6.2-1, which was taken after the breach. The top of the debris is about 8.5 in (216 mm) below the top of the stop logs. This corresponds to a maximum water level at about elevation 1485.6 ft.

At about 8:30 PM on May 14, the operator who had returned to the site with a camera took the photograph shown in Figure 3.6.2-2, which shows the upstream side of the concrete spillway. Scaling on this photograph indicates that the water level at 8:30 PM was about 5 ft (1.5 m) below the top of the stop logs, or elevation 1481.0 ft. Thus with some degree of confidence, it can be concluded that the Silver Lake level rose from 1483.35 ft on May 7 to a maximum of about 1485.6 ft, and then fell to about 1481 ft by 8:30 PM on May 14.

Although the maximum water level, and the time at which it was reached, cannot be determined with precision, the facts available have been used to develop the graph of estimated Silver Lake water levels from May 7 to May 15 shown in Figure 3.6.2-3. The estimated water levels between May 7 and May 14 are based on the assumptions that the lake level would be about constant until the Mother's Day storm event, and that the resulting inflow was the principal cause of the rise in lake level, and that the maximum lake level corresponds to the high water mark indicated by the debris trapped at the ends of the stop logs. While there is some uncertainty about the variation of water level with time shown in Figure 3.6.2-3, the variation shown is consistent with the available information.

3.6.3 Triggering Mechanism

The top of the debris trapped at the ends of the stop logs, at about elevation 1485.6 ft, indicates that the highest lake level likely exceeded the pilot channel invert elevations by a small margin. The estimate of water depth reached in the pilot channels depends on the estimated maximum lake level and whether the pilot channel invert elevation is considered to be 1485.5 or the lower elevations measured in the post-construction survey (1485.28 ft and 1485.37 ft). As mentioned previously, these lower elevations do not necessarily indicate that the entire lengths of the pilot channel inverts were below the design elevation.

Using these elevations, it can be concluded that the depth of water flowing through the pilot channels could vary from 0.1 ft (.03 m) to as much as 0.3 ft (.09 m).

Other possible triggering mechanisms include erosion and piping of the embankment, the foundation, or the abutment, and slope instability.

Because the slopes of the embankment were constructed of sound, free-draining material, and were stable at the end of construction, triggering due to slope failure does not appear to be a possibility.

Internal erosion of the core into the filter is highly unlikely because the gradations of the core and the filter satisfy filter criteria. Erosion of the foundation into the filter downstream from the core is also highly unlikely for the same reason.

If filter material was not placed on the abutment beneath the downstream zone of shell material, it is possible that abutment material could pipe into the shell zone, because the coarsest acceptable gradation for the shell material does not satisfy filter criteria with respect to the abutment material. The hydraulic gradient along this seepage path is not high, however. Even if erosion and piping was occurring at the abutment, it is unlikely that it would have proceeded quickly enough to cause the breach.

Another possible location for erosion would be at the downstream end of the pilot channel, due to seepage through the 6 in (152 mm) layer of shell material that tops the embankment at elevation 1485.0 in the pilot channel sections, as shown in Figure 3.6.3-1, and forms the bottoms of the pilot channels. With the water level in the lake at elevation 1485.6, the average hydraulic gradient through this layer would be approximately 0.1. While unlikely to cause erosion in the absence of the overtopping flow, this seepage could have resulted in more rapid erosion due to the overtopping flow than would have occurred without the seepage.

Because the entire fuse plug dike was removed by the erosion that followed the breach, there can be no direct evidence of the cause of the breach. Although internal erosion and piping, foundation erosion and piping, or abutment erosion and piping cannot be completely eliminated as possible triggering mechanisms, they appear to be improbable causes. In addition, the fact that the breach occurred at a time when the best available evidence indicates that the lake level was very close to the elevation at which the fuse plug was designed to fail by overtopping erosion makes this mode of triggering the most likely.

3.6.4 Extent of Erosion

Figure 3.6.4-1 shows photographs taken of approximately the same areas upstream and downstream from the fuse plug during the post-construction inspection, and on May 14, May 15, and May 16, 2003. The progressively deepening erosion from May 14 through May 16 is clearly evident. By May 16 the bottom of the eroded channel had reached approximately elevation 1455, or perhaps a slightly lower elevation, 26 ft (7.9 m) or more below the original invert of the spillway channel (1481.0).

Figure 3.6.4-2 shows a cross section at STS station 27+00, approximately at the axis of the fuse plug embankment. The eroded channel is about 300 ft (91.5 m) wide, extending 130 ft (39.6 m) to the right of the STS stationing axis, and 170 ft (51.8 m) to the left. An un-eroded "island" about 120 ft (36.6 m) to the left of the station axis indicates that the course of erosion was governed to some extent by non-uniform resistance to backcutting as the eroded channel became progressively wider and deeper.

3.6.5 Downstream Damage

In addition to the extensive erosion of the river banks shown in Figure 3.6.4-1, the large volume of flow through the Dead River into the Hoist reservoir resulted in large releases from the dams downstream (Hoist and McClure).

Farther downstream, the Tourist Park Dam was overtopped and failed at about 2:00 PM on May 15, 2003. The debris carried downstream from the Tourist Park Dam failure entered the cooling water intake of Wisconsin Electric Power Company's Presque Isle coal-fired thermal power station, causing considerable damage, and shutting it down.

Several railroad and highway bridges suffered damage to foundations or abutments that rendered them unusable, One of the damaged highway bridges is shown in Figure 3.6.5-1. More than 1,700 people were evacuated from an area of about 485 acres (195 ha) in the city of Marquette from 8:45 AM on May 15 through 1:00 PM on May 16.

A report of damage and injury submitted by Marquette County to the Michigan State Police Emergency Management Division on May 29, 2003 estimated that the monetary loss resulting from release of the Silver Lake Reservoir totaled $102 million, including damage to public facilities, individuals, businesses, and the environment.

4. TECHNICAL CAUSES OF FUSE PLUG ACTIVATION AND RELEASE OF RESERVOIR

4.1 Bottom Outlet Operation

If the bottom outlet valve were opened on April 23, when it was first noticed that the NMOL elevation had been surpassed, to discharge 280 cfs (8 m^3/s) , the reservoir level could have been brought to elevation 1481.5 in about 3 days. This maneuver, which is consistent with the concept of the NMOL elevation, would have prevented the May 14 breaching accident. The storage volume in the reservoir between elevations 1481.5 and 1485.5 is about 5700 acre-ft (7.0 hm^3), which would be sufficient to store any conceivable runoff from the May 10-11, 2003 rainfall.

4.2 Low Setting of Fuse Plug

4.2.1 General

Without changes in operation of the bottom outlet to prevent raising the reservoir level above 1481.5, the project modifications designed to provide spilling capacity for the PMF flood increased the chances of overtopping incidents. The probability of fuse plug breaching was higher than the probability of overtopping Dike 4 prior to modification of the project.

Prior to the 2003 modifications, Silver Lake dam had the lowest earthen dike crest at El. 1487.7 and the spillway at El. 1486.25. The capacity of the 100 ft (30.5 m) long spillway was 545 cfs (15.5 m^3/s) with the reservoir at 1487.7 ft. The reservoir volume available for flood routing, from El. 1486.25 to El. 1487.7, was 2110 acre-ft (2.60 hm^3).

The modified project set the crest of the fuse plug at El.1486.5 with the pilot channel inverts at El. 1485.5. For the sake of comparison, the intermediate level between the fuse plug crest and pilot channel invert, El. 1486.0, will be taken as the critical level for fuse plug activation. Actual experience suggests it could be even lower, as the May 14 breaching event is related to a maximum reservoir level at El. 1485.6. With respect to prior conditions, the elevation at which overtopping would begin is therefore lowered from El. 1487.7 to El. 1486.0. Storage capacity is reduced by about 3 000 acre-ft (3.7 hm^3).

Silver Lake reservoir has attained El. 1486.0 many times in the recent past. Data recorded by the previous owner of the dam, from May 1957 to December 1987, indicates El. 1486.0 was reached or surpassed in seven different years; an average of once in 4.3 years. In the period 1988-2002, under UPCCO, El. 1486.0 was surpassed in six different years, or once every 2.3 years. On the average, El. 1486.0 was reached or surpassed once every 3.5 years over the entire history of the reservoir.

The spilling capacity of the modified project for the reservoir at El. 1486.0 is 195 cfs (5.5 m^3/s) over the single 9 ft (2.7 m) long bay controlled by stop logs at El. 1482.5. The reduction in capacity from 545 to 195 cfs (15.5 to 5.5 m^3/s) is partially compensated by the larger reservoir volume available for flood routing between El.1482.5 and El. 1486.0, about 4635 acre-ft (5.7 hm^3) as against 2110 acre-ft (2.60 hm^3) in the unmodified project between 1486.25 and 1487.7. When a replacement spillway is designed it should be checked for the hydrological conditions at the site, not just the calculated value of the PMF.

The old project performed well under historical flood conditions. Maximum reservoir level was recorded at El. 1486.9 in 2002. Remaining freeboard was 0.8 ft (0.24 m). The hypothetical performance of the modified project can be assessed only on the basis of the scarce and incomplete data available on reservoir levels, and snow and rainfall precipitations.

4.2.2 May 14-15, 2003 Event

In the May 14-15 event , the crest of the stop logs was set at El. 1486.25, above the critical level, El. 1486.0. Given the water level in the reservoir on May 7, 2003 and the low level outlet setting of 20 cfs (.57 m^3/s), the breaching of the fuse plug was unavoidable for the estimated volume of run off from May 10-11 rainfall, equal to or larger than 3013 acre-ft (3.7 hm^3). The water would and did spill first over the fuse plug.

If the stop logs had been placed to El. 1482.5, the conditions to store and route the inflow and prevent the washing out of the fuse plug would be more favorable from the start. The reservoir level on May 7, 2003 would be at about El. 1483.15, 0.2 ft (0.06 m) below the recorded elevation 1483.35, by the effect of the water spilled since the reservoir level surpassed El.1482.5. Accordingly, the initial level, unaffected by the rainfall, could be estimated at about El. 1483.1 instead of El. 1483.4. The base flow in the period May 7-14 was less than about 13 cfs (0.37 m^3/s) as against the spilling capacity of about 15.5 cfs (0.44 m^3/s) for the reservoir at El. 1483.15, which accounts for this lower level.

The evolution of reservoir level with time after the rainfall, or the shape of the inflow hydrograph, is not known. It is estimated that it took about 2.5 days for the level to reach El. 1485.6 at about noon of May 14th. Some exercises on routing the flood for different time distributions of the inflow, assuming a starting reservoir El. of 1483.15, show that the maximum level attained by the reservoir would be limited to about El. 1485.0 for a total runoff volume equal to 3013 acre-ft (3.7 hm^3), as described below.

The lower starting reservoir level of 1483.15 increases by 380 acre-ft (0.47 hm^3) the reservoir volume available for routing. The volume spilled during the reservoir filling is of the order of 320 acre-ft (0.41 hm^3). The extra volume of about 700 acre-ft (0.86 hm3) explains the maximum reservoir level at El. 1485.0, about 0.6 ft (.18 m) below the required level to activate the fuse plug on May 14, 2003. For that runoff volume, the fuse plug breaching would not have occurred.

The runoff from the May 10-11, 2003 rainfall could have been larger. The volume of 3013 acre-ft was the minimum needed to reach El. 1485.6 with initial reservoir level at El. 1483.4 and zero spilling. The excess of a larger volume would be lost as the fuse plug breached. The runoff volume needed to raise the reservoir level to about El. 1485.6 is of the order of 4300 acre-ft (5.3 hm^3), about 75% of the rainfall of May 10-11.

The risk of breaching the fuse plug for the newly revised project, in any case, was higher than for overtopping Dike 4 in the old unmodified project; a remaining freeboard of 1 ft (.3 m) or less for the fuse plug as compared to 2.1 ft (.64 m) for Dike 4.

4.2.3 April 4-20, 2002 Flood Conditions

Spring flood conditions in 2002 were more severe than in 2003. The reservoir reached El. 1486.9 on April 20 and spilled for at least 17 days up to May 7, when the reservoir level was recorded at El. 1486.5. Reservoir levels recorded at the time are as follows:

March	19/02	El. 1480.0 (42 in snow on ground)
April	04/02	El.1480.01 (35 in snow on ground)
April	20/02	El 1486.90
May	03/02	El.1486.50
May	07/02	El. 1486.50
June	01/02	El. 1485.90

From April 4 to April 20, the reservoir raised from El. 1480.01 to El. 1486.9, 0.65 ft (0.2 m) above the crest of the spillway for the 16 day period, the average rate of rise is 0.43 ft/d (0.13 m/d). There are no direct measurements of reservoir levels between those two dates. However, weather conditions recorded in the meteorological station of Marquette indicate that the reservoir rise took place in less than 16 days. Some of the collected data on temperature, rainfall, and snow on the ground for the month of April 2002 in Marquette, MI. are indicated below.

Day April	Temp of Max – Av – Min °F			RAINFALL Inches	SNOWFALL Inches	SNOW ON GROUND Inches
4	29	24	18	0	0.5	33
5	30	19	8	0.02	1.1	33
6	38	20	1	0	T	32
7	36	32	27	0.07	0.3	32
8	37	34	31	0	0	30
9	39	32	25	0.01	T	30
10	36	31	26	1.08	1.0	29
11	43	39	35	1.14	0	28
12	55	42	29	0.12	0	25
13	61	44	26	0	0	22
14	58	49	39	0.08	0	20
15	76	59	41	0	0	15
16	83	72	61	0	0	8
17	73	59	44	0	0	T
18	67	52	36	0.59	0	0
19	46	37	28	0.02	0.2	0
20	35	31	26	0	0	0

The rise of the reservoir level from El. 1480.0 to El. 1486.9 occurred essentially after April 9, due to snow melting and the effect of rainfalls recorded on April 10-11 and 18. Climatological data for the station of Herman, to the west of Silver Lake basin, confirm the weather conditions and precipitation time distribution in the region.

4.2.4 Evaluation of April 4-20, 2002 Weather Conditions on the Modified Project

Total volume stored in the reservoir between El. 1480.0 and El. 1486.9 is 9381 acre-ft (11.6 hm^3). The volume spilled while the lake was above El. 1486.25, prior to April 20, is estimated at about 250 acre-ft (.31 hm^3). The total volume of 9631 acre-ft (11.9 hm^3) corresponds to an average discharge of 438 cfs (12.4 m^3/s) in 11 days. Routing of this constant inflow shows the reservoir level attaining El. 1485.9 at the end of the period. The exercise is crude but indicates that the breaching of the fuse dike would have been all but unavoidable even if the low setting of the stop logs at El. 1482.5 had been used. To prevent triggering of the fuse plug the low level outlet would have had to have been fully open after April 4.

4.2.5 Prior Flood Events

Particularly high water levels in Silver Lake were recorded in 1966, 1996, 1998, and 1999. The wettest year was 1966. The available data do not specify the day of the month but high reservoir levels are recorded from May through September of 1966, as follows:

May ———— El. 1486.10
June———— El. 1486.00
July———— El. 1486.65
August——— El. 1486.65
September—El. 1486.65

In 1966, the reservoir level apparently remained above El. 1486.0 for about 4 months or 120 days. The period of time above elevation 1486.0 was 71 days in 1996, 15 days in 1998, and 50 days in 1999. They compare with the April 2002 episode in which the reservoir level was above El. 1486.0 for 20 days. Hydrological conditions in the past have been similar if not more severe than in 2002. Evidence strongly suggest that the risk of attaining El. 1486.0 would have been high for the modified project in those years, given that the operating procedures did not change [i.e. stop log setting of 1482.5 and low level outlet set at about 20 cfs (.57 m^3/s)].

This practical aspect of the project concerning the probable frequency of fuse plug breaching, without significantly increasing flows from the low level outlet, was not treated in the October 2002 design. The high frequency could be classified as a nuisance with tolerable economic impact if the breaching were confined to the fuse plug proper and the discharge limited to the upper 5 ft (1.5 m) of the reservoir. The total release of the reservoir in May 2003 was the result of the deep erosion of the outlet channel following the activation process.

4.3 High Velocities in the Fuse Plug Channel

The MWH Design Report of March 2002 includes, under chapter 5.0 HYDRAULIC DESIGN AND ANALYSIS, a sub heading 5.5 – Velocities at Entrance of Emergency Spillway Channel. The maximum entrance velocity of approximately 9.1 ft/sec (2.8 m/s) is referred to in that report in Figure 7, and occurs at hour 43, during the outflow of the PMF through the fuse plug at Dike 2.

This maximum velocity is compared to guidelines established by the Natural Resources Conservation Services, which set the permissible velocity for a grassed channel on easily erodible bed materials as 6.0 ft/sec (1.8 m/s). This velocity can be increased by 25% for events with return periods greater than 100 years, that is to 7.5 ft/sec (2.3 m/s).

In Figure 7 of the MWH Report it is indicated that the velocity at the channel entrance exceeds 6 ft/sec (1.8 m/s) for approximately 8.5 hours and 7.5 ft/sec (2.3 m/s), for approximately 4.4 hours.

The report ignores the velocities along the outlet channel which, after a horizontal reach about 100 ft (30.5 m) long, slopes downstream at 1.8% slope for about 540 ft (165 m). The higher velocities in that portion of the channel can be inferred from Figure 8 of the Design Report "Profile Along the Emergency Spillway Channel". The flow depth at PMF conditions, which is about 8.0 ft (2.44 m) at the channel entrance, is reduced to 5 ft (1.5 m) along the 1.8% slope channel. The corresponding flow velocity is about 14.5 fps (4.4 m/s), far above the permissible velocities for grassed channels.

Even for smaller flows at the beginning of the process, the velocities on the outlet channel were bound to be higher than 6.0 or 7.5 fps (1.8 - 2.3 m/s). For the May 14, 2003 event, the breaching of the fuse plug is assumed to have occurred for water level at El. 1485.6. After the breaching, critical depth occurs at the onset of the steeper channel downstream from the fuse plug. At the initial stages, after washing out of the fuse plug, head losses in the horizontal channel add to the control and restrict the discharge over the wide channel to about 5000 cfs (142 m^3/s). Critical velocity reaches about 8.5 fps (2.6 m/s).

Along the inclined channel, the flow tends to uniform flow. For a Manning rougness coefficient n= 0.04, as adopted in the Design Report, the flow remains near critical at about that same velocity. On May 14, 2003, the grass cover had barely grown and n= 0.04 is certainly too optimistic a value for the regular fine sand bed. A more realistic n value (0.033 – 0.03) results in velocities of 9.5 – 10.1 fps (2.9 – 3.1 m/s).

The maximum velocities in the fuse plug channel were underestimated. Grass cover would not provide adequate protection against erosion.

4.4 High Erodibility of Fuse Plug Foundation

4.4.1 Characterization of Foundation Materials

The natural foundation materials at the Silver Lake Dam-Fuse Plug are a complex series of glacial tills and glacial outwash materials. Although there were no known exploratory borings at the site of the fuse-plug during the design phase, Figure 9 of the MWH Design Report gives the designers' impression of the grain size distribution curve of the foundation materials. This curve is shown on Figure 4.4.1-1 in this report. It is noted that 61-74% passes the #4 sieve and that from 41-71% passes the #40 size. About 6-18% passes the #200 sieve. Thus the foundation materials would be classified as a sand in the Unified Soil Classification System. The classification could be SP, SW, SW-SM, SP-SM, or SM, assuming that the fines were non-plastic.

During construction of the fuse plug, one grain size analysis was performed on material identified as "foundation soil". The sample was identified as Sample 10 in the MWH final construction report. The grain size distribution of this sample is given in Figure 1 of the FERC Investigation Report and is shown as Figure 4.4.1-2 of this report. This sample has 92% passing the #4 sieve, 80% passing the #40 sieve, and 7% passing the #200 sieve. With non-plastic fines this material would classify as an SP-SM material in the Unified Soil Classification system.

Since the breach, STS has sampled materials of the foundation adjacent to the breach and has made borings and taken samples from these borings. As mentioned previously in Section 2.3.1 of this report, the grain size distributions from boring B-2, (Table 2.3.1-1) on the right side of the fuse plug indicate that the materials in the foundation are silty sands, which are classified as SM. The grain size distribution curves for five samples from Boring B2 from depths of 4 to 41 ft (1.2 to 12.5 m) are shown in Figures 4.4.1-3 through 4.4.1-7.

STS also sampled foundation materials from the "island" which remained on the left side just downstream of the fuse plug. The grain size distribution of samples SC22, SC14, SC13 and SC17 which were taken from this area are shown in Figures 4.4.1-8, through 4.4.1-11. All of these materials are classified as SP, SM, and SP-SM materials in the Unified Soil Classification System.

The information on the grain sizes of the foundation materials given from the sources mentioned above are consistent with the observations of the Panel during our field inspection. The materials observed appeared and felt to be void of plastic fines and they were predominantly sands in the upper 25 ft (7.6 m) of the foundation. It is also noted from the grain size distribution curves that a high percentage of the sand materials are fine sands and silts.

Thus these foundation materials are sands which range from uniform clean sands (SP) to silty sands which contain enough silt (non-plastic fines > 12%) to be classified as (SM). There are silty sands which would be classified as SP-SM. Cohesionless fine sands and silty sands are generally well known to be highly erodible and pipeable materials in the practice of geotechnical engineering.

4.4.2 Erodibility of Foundation Soils

The maximum permissible flow velocities that will not cause erosion in open channels with various soils in the channel bottom have been summarized by Ven Te Chow (1988) in "Open-Channel Hydraulics", McGraw-Hill Classic Textbook Reissue. Table 7.3 of that publication is given in Figure 4.4.2-1 herein. Note that the allowable velocities for fine sand with clear channel water, which would be the case at Silver Lake Fuse plug, is 1.5 fps (0.46 m/s). The permissible velocity for fine gravel, in the case of clear channel water, is 2.5 fps (0.76 m/s). Thus for the range of fine to coarse cohesionless sands in the foundation soils at the Silver Lake fuse plug, the permissible velocities could range from 1.5 to 2.5 fps (0.46 to 0.76 m/s). It is noted that Table 2 of the March 1947 "Handbook of Channel Design for Soil and Water Conservation" of the U. S. Dept. of Agriculture Soil Conservation Service is virtually the same table as the table referenced by Chow and is included in this report as Figure 4.4.2-2.

In 1936, Russian data was presented regarding permissible velocities for various sizes of cohesionless soils. This data is presented in Figure 7-3 of Chow and in Figure 4.4.2-3 of this report. As shown in Figure 4.4.2-3, the permissible velocity for fine sand is 0.75 fps (0.23 m/s) and for the material retained on the #4 sieve is 2.5 fps (0.76 m/s). Thus for coarse sand or fine gravel the limit of 2.5 fps (0.76 m/s) is the same as given in Figures 4.4.2-1 and 4.4.2-2.

From the grain size distribution of the foundation soils it is clear that the foundation soils are composed of silty fine sands (SM) and uniform fine to coarse sands (SP). For no channel treatment, the permissible velocity could probably not exceed 2.5 fps (0.76 m/s). Since it was not possible for grass to grow between the late fall of 2002 and May 14, 2003, the possible effect of grass in increasing the permissible velocity is a moot point. The pictures taken at the end of construction show a bare untreated foundation surface upstream and downstream of the fuse plug.

In section 4.3 of this report it is shown that the channel velocities could have ranged between 8.5 fps (2.6 m/s) and 10 fps (3.0 m/s) for the May 14, 2003 event. It is clear that these velocities exceeded the 2.5 fps (0.76 m/s) permissible velocities for no grass cover for a channel composed of cohesionless sands. This is the root technical cause for the most significant aspect of the behavior of the fuse plug which was the fact that erosion did not stop at the base of the fuse plug at El. 1481 ft. The erosion proceeded downward through the erodible foundation materials down to El. 1455. This resulted in eventual release of nearly the entire reservoir.

In the Design Report, MWH references the Harza Engineering Co. 1983 paper on "Fuse Plug Structures Designed to Fail" by Jones, Marold, and Borg. Although most of this paper concerned the zoning of the fuse plug to make sure that it fails, in item 11 of that paper it is said that "Typical spillway sections for fuse plug structures consist of a horizontal concrete sill on a rock foundation. The concrete sill is designed to be directly beneath the impervious sloping clay core to permit a continuous controlled cut-off. The concrete sill acts as a broad crested weir controlling the discharge of the breached fuse plug structure." The Panel agrees with the general practice stated by Jones, Marold, and Borg. Fuse plugs are normally built on materials which are considered to be clearly nonerodible, such as rock. The Panel knows of no precedent for the construction of a fuse plug on materials characterized as sands.

In the original MWH design, a Rock Trench was included as shown in Figure 2.3.1-2. The Rock Trench was 8 ft (2.4 m) deep and 3 ft (0.9 m) wide at the bottom with side slopes of 1V to 2H. Although this structure may have slowed the erosion, it is most likely that it would have been undermined from the downstream side. Because the trench was founded on erodible materials, due to its shallow depth of penetration (8 ft) (2.4 m) it most likely would have sunken down slowly as it was undermined from the downstream side. It is our understanding, from documents reviewed, that FERC agreed with the removal of this feature from the original design at the request of MWH.

4.5 Optimistic Evaluation of Resistance of Grass Cover

In section 5.5 of the Design Report it is clear that MWH used the guidelines of the Natural Resources Conservation Services to determine permissible velocities for the fuse plug channel. It is also clear that MWH had correctly identified the foundation materials as "easily erodible bed materials". In these guidelines the "easily eroded soils" are those that do not meet the requirements for "erosion-resistant soils". The "erosion-resistant soils" are cohesive (clayey) fine-grained and coarse grained soils that have cohesive fines with a plasticity index of 10 to 40. Unified Soil Classifications include CL, CH, SC, and GC. Although in Chapter 7 on Grassed Waterways, the Table reproduced in Figure 4.5-1 of this report indicates that the permissible velocities of "Easily erodible soils" can range from 2.5 fps (0.76 m/s) to 6 fps (1.8 m/s) depending on the type of grass cover, there are some warnings given on page 7-7 of Chapter 7. For example it is warned that: "Some soils such as dispersed clays and non plastic fine silty sands may be so erosive that successful grassed waterways cannot be constructed." The restrictions to Figure 4.5-1 were also stated in the following five points.

"1. A velocity of 0.9 m/s (3.0 ft/s) should be the maximum if, because of shade, soils, or climate, only a sparse cover can be established or maintained.

2. A velocity of 0.9 to 1.2 m/s (3.0 to 4.0 ft/s) should be used under normal conditions if the vegetation is to be established by seeding.

3. A velocity of 1.2 to 1.5 m/s (4.0 to 5.0 ft/s) should be used only in areas if a dense, vigorous sod is obtained quickly or if water can be diverted out of the waterway while the vegetation is being established.

4. A velocity of 1.5 to 1.8 m/s (5.0 to 6.0 ft/s) may be used on well-established, good-quality sod. Special maintenance may be required.

5. A velocity of 1.8 to 2.4 m/s (6.0 to 8.0 ft/s) may be used only on established, excellent quality sod, and only under special circumstances in which the flow cannot be handled at a lower velocity. Under these conditions, special maintenance and appurtenant structures will be required."

Considering the qualifications given above it is the Panel's judgment that the permissible velocity in the MWH design report of 7.5 ft/sec (2.3 m/s) for a grassed channel in the foundation materials present at the Silver Lake Fuse Plug site was an overly optimistic evaluation.

In any case, the channel velocities of 14.5 fps (4.4 m/s) just downstream of the fuse plug for the PMF case would have resulted in deep erosion even if the permissible velocity of 7.5 fps (2.3 m/s) had been achieved for the grassed channel.

5. CONCLUSIONS

5.1 General

The behavior of the newly constructed fuse plug spillway at Silver Lake Reservoir, which resulted in release of the reservoir, required (1) lake levels sufficient to activate the fuse plug, (2) breaching of the fuse plug, and (3) erosion of the fuse plug foundations after breaching. In the following sections our conclusions are presented regarding these three significant aspects of the behavior which resulted in release of the reservoir.

5.2 Maximum Reservoir Level

5.2.1 Field Evidence

Independent observations of high water marks in the area of the fuse dike channel were carried out by STS Consultants, LTD. STS identified several points just upstream of the fuse plug with apparent high water levels ranging from 1485.28 to 1485.38. A high water mark of about 1485.6 was identified during the FERC inspection of May 16, 2003 at the spillway structure. This high water mark was identified by debris adhered to the felt paper on the upstream side of the stop logs and by the observation of some leaves and grass which were left in the stop log slots at the same elevation on the upstream side of the stop logs.

The last recorded lake level before the breach was 1483.35 on May 7, 2003. Calculations taking into account the rainfall event of May 10-11, the low level outlet flows of 20 cfs (.57 m^3/s), the stop log elevation of 1486.25, and the May 7 elevation of the lake indicate reasonable agreement with the maximum lake elevation of about 1485.6 prior to the breach.

5.2.2 The Influence of Bottom Outlet Opening and Stop Log Setting

Reservoir level readings of 1482.34 and 1483.22 on dates of April 23 and May 1, respectively, indicate that the maximum operating level of the lake of 1481.5 was exceeded sometime before April 23. The discharge from the low level outlet remained constant at the minimum value of 20 cfs (.57 m^3/s) after late April. The stop logs were not set at elevation 1482.5 as specified in the March 2002 design report and required by the FERC letter of May 16, 2002. These two facts made it possible for the May 10-11 rainfall event to raise the lake to levels above the fuse plug pilot channel elevation of 1485.5.

By opening the low level outlet valve in late April, the reservoir could have been controlled at about elevation 1481.5 and the breaching of the fuse plug avoided.

If the bottom outlet discharge had been maintained at about 20 cfs (.57 m^3/s) and the stop logs were at elevation 1482.5, it is probable that the breaching of the fuse plug could have been avoided.

5.3 Fuse Plug Breaching

5.3.1 Performance of Fuse Plug

The zoning of the fuse plug embankment was consistent with conventional practice based on Bureau of Reclamation studies, except for the zone of shell encapsulated within filter material downstream from the core. There is no reason to believe that this zone represented a deficiency in the design.

It appears that the fuse plug embankment was constructed with care and attention to detail.

Although the interfaces between the filter and the riprap, the shell and the riprap, and the abutment and the shell do not satisfy filter criteria for restraint, and erosion of the finer materials into the coarse materials would be possible at these locations, it does not appear likely that internal erosion played any significant role in triggering the breach of the fuse plug embankment.

There is no reason to conclude that the mechanism of failure of the fuse plug embankment was other than erosion by overtopping flow, beginning at the pilot channels. From the as-built drawings the fuse dike pilot channels could have been at an elevation slightly lower than the design elevation (1485.28 – 1485.37, instead of 1485.5).

As indicated in section 5.2, the field evidence substantiated that the reservoir level reached about El. 1485.6 just before dike breaching. Thus it is concluded that the fuse plug embankment, with pilot channels at 1485.5, behaved "as designed" since it was designed to breach when the reservoir level exceeded 1485.5.

5.3.2 Low Setting of the Fuse Plug

The reasons that the rainfall event of May 10-11, 2003 could cause this breach on May 14, 2003 were the low setting of the fuse plug pilot channels (1485.5) relative to the spillway crest (1486.25), the low discharge settings [20 cfs (.57 m^3/s)] of the low level outlet, and the high setting of the stop logs (1486.25) in Bay 4 of the spillway.

The October 2002 project modifications, intended to provide spilling capacity for the PMF flood, increased the probability of overtopping incidents in smaller floods. After the modification, for equivalent operating rules, the annual probability of fuse plug breaching was higher than the annual probability of overtopping Dike 4 prior to the modifications.

5.4 Reservoir Release

The principal difference between the design intention and the failure that occurred is that the resulting erosion continued about 25 ft (7.6 m) below the base of the fuse plug embankment, and resulted in the loss of nearly the entire reservoir.

Thus the release of the Silver Lake Reservoir was a consequence of the flow velocities produced by the fuse plug breaching and by the gradient of the channel downstream of the fuse plug embankment. The actual flow velocities in the channel after the May 14 breach exceeded the velocities which would cause erosion of the foundation materials.

It has been documented that the channel materials at the fuse plug are cohesionless silty sands. It is estimated that these materials could erode at velocities between about 1 fps (0.3 m/s) to 2.5 fps (0.76 m/s) with no grass cover. It is not likely that any significant grass cover could have grown between the end of construction in the Fall of 2002 and May of 2003.

In section 4.3 of this report it is shown that the channel velocities could have ranged between 8.5 fps (2.6 m/s) and 10 fps (3.0 m/s) for the May 14, 2003 event. It is clear that these velocities exceeded the 2.5 fps (0.76 m/s) permissible velocities for no grass cover for a channel composed of cohesionless sands. This is the root technical cause for the most significant aspect of the behavior of the fuse plug, which was the fact that erosion did not stop at the base of the fuse plug at El. 1481 ft. The erosion proceeded downward through the erodible foundation materials down to El. 1455. This resulted in eventual release of nearly the entire reservoir.

Typically fuse plug embankments are built on rock foundations; this Panel knows of no precedent for construction of a fuse plug structure on cohesionless sand foundations.

It is our conclusion that the fuse plug design was adopted in part because the maximum flow velocities in the channel after breaching were underestimated in the March 2002 Design Report [9 fps (2.7 m/s) versus 14.5 fps (4.4 m/s) estimated in this report]. In addition, a grassed channel was estimated to have a permissible velocity of about 7.5 fps (2.3 m/s). It is the Panel's judgment that the permissible velocity in the MWH design report of 7.5 ft/sec (2.3 m/s) for a grassed channel in the foundation materials present at the Silver Lake Fuse Plug site was an overly optimistic evaluation. A more conservative evaluation of this point may have resulted in the selection of a different alternative than the fuse plug for safely passing the PMF.

In any case, the channel velocities of 14.5 fps (4.4 m/s) just downstream of the fuse plug for the PMF case would have resulted in deep erosion even if the permissible velocity of 7.5 fps (2.3 m/s) had been achieved for the grassed channel.

The erodibility of the fuse plug foundation and emergency spillway channel is the root cause of the Silver Lake Reservoir releases. Although the low elevation setting of the fuse plug crest, the low releases from the bottom outlet, and the high setting of the stop logs are factors which affect the frequency of fuse plug breaching, the reservoir would not have been released, except for the upper 5 ft (1.5 m), for any breaching of the fuse plug if the fuse plug were founded on a non-erodible foundation in a non-erodible channel.

One difference between the initial MWH design and the as-built conditions was the elimination of the rock trench erodible inhibitor. This feature was obviously in the design as a concern for the erodible nature of the foundation materials. It is our understanding that FERC agreed to this change at the request of MWH. It was a change which made the constructed fuse plug more susceptible to foundation erosion than the March 2002 Design. However, the probability that such a structure would be effective to mitigate the release of the reservoir was at best, very remote.

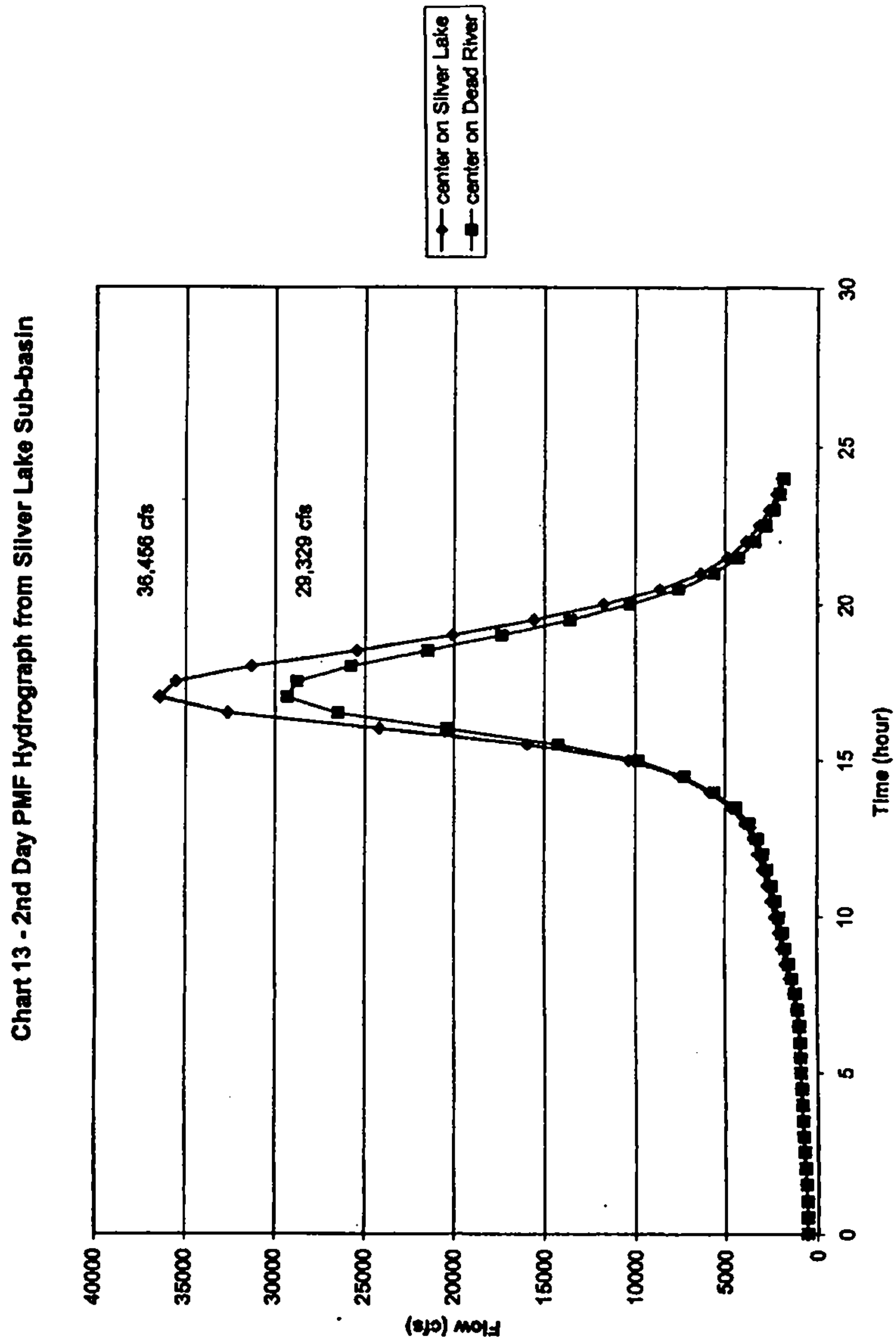


Figure 2.2 -1
("Warm Season Probable Maximum Flood For Dead River Projects", Harza Engineering Company, Denver, CO, January 2001)

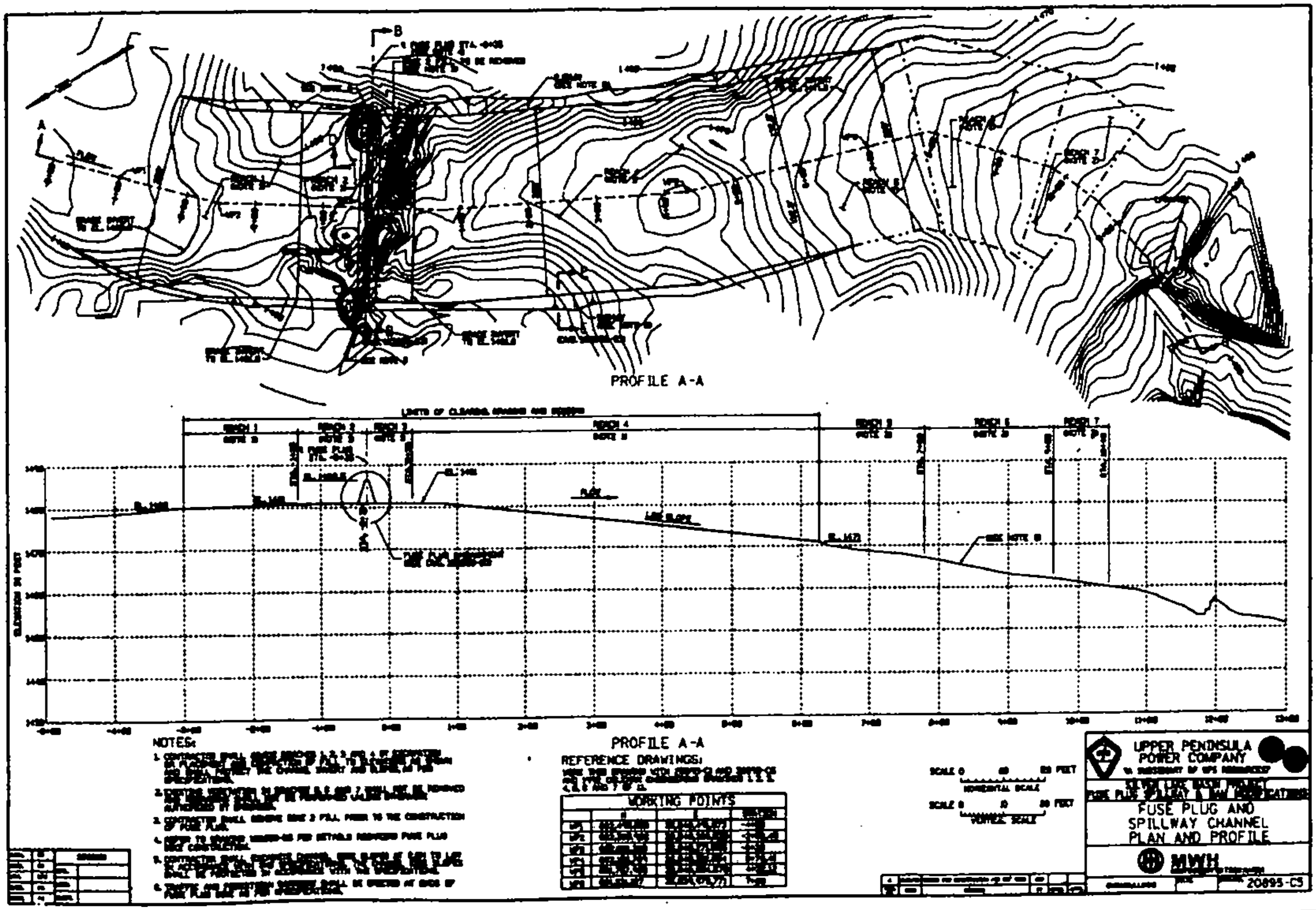


Figure 2.3.1-1 Fuse plug and channel plan and profile

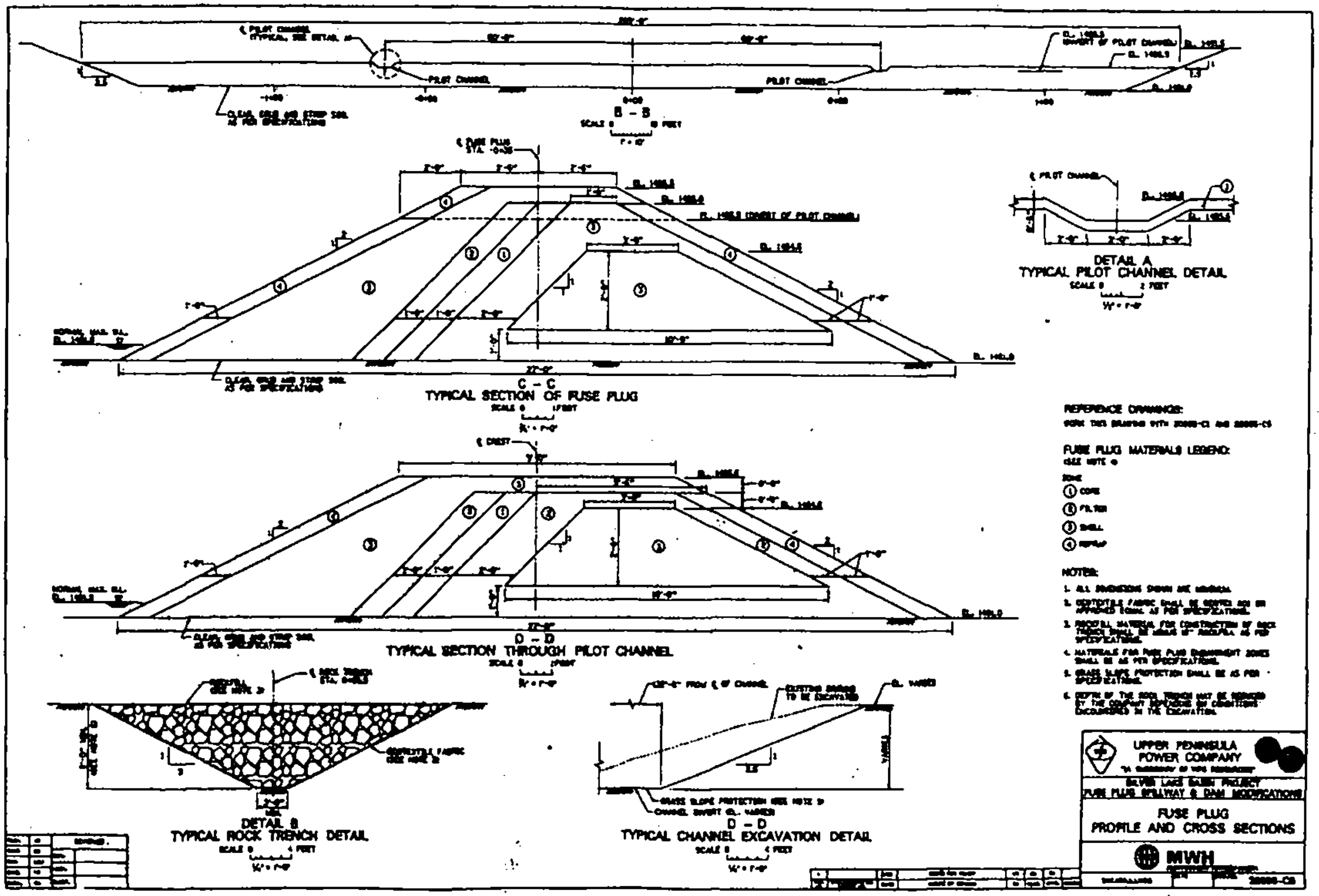


Figure 2.3.1-2 Fuse plug cross sections

Document # GB-0474

Silver Lake Elevations
April, 1993

Maximum	1485.80	1485.00	1483.00	1486.00	1486.10	1486.30	1486.65	1486.65	1486.65	1486.50	1485.40	1485.80
Average	1471.07	1471.14	1469.94	1475.95	1479.30	1480.63	1480.52	1480.29	1479.37	1478.51	1476.86	1474.68
Minimum	1461.80	1462.70	1462.60	1468.00	1472.00	1472.50	1473.85	1472.25	1465.10	1461.50	1460.00	1463.50
Year	January	February	March	April	May	June	July	August	September	October	November	December
1995												
1994												
1993	1483.80	1478.80	1474.10	1478.00								
1992	1481.60	1480.30		1478.30	1485.20	1485.60	1485.80	1484.00	1483.20	1483.70	1483.70	1484.10
1991	1478.00	1472.70		1472.70	1478.30	1478.00	1478.80	1478.70	1478.80	1480.10	1481.40	1482.00
1990	1482.00	1474.80	1476.90	1479.30	1482.70	1484.20	1482.00	1481.50	1481.50	1482.00	1484.70	1484.40
1989	1485.80	1483.20	1477.00	1475.50	1481.80	1485.60	1485.50	1485.20	1484.40	1484.40	1485.40	1483.30
1988	1483.90	1471.90	1468.60	1478.70	1479.80	1475.50	1475.20	1476.50	1476.85	1480.30	1485.40	1485.80
1987	1464.50	1463.20	1467.10	1470.10	1472.00	1472.50	1474.50	1476.90	1478.30	1481.50	1482.90	1483.90
1986	1468.00	1464.90	1465.30	1477.60	1478.40	1478.50	1478.50	1478.80	1479.20	1480.70	1477.00	1466.00
1985				1477.90	1480.10	1481.70	1481.90	1482.30	1483.00	1485.60	1485.40	1477.00
1984	1471.80		1471.00	1478.30	1480.90	1481.10	1481.00	1481.50	1482.50	1483.10	1472.40	1466.40
1983				1482.40	1485.10	1485.10	1485.00	1485.00	1486.10	1485.80	1482.40	1481.00
1982			1462.60	1472.80	1479.50	1479.70	1481.40	1482.30	1483.70	1486.50	1483.90	1472.60
1981	1463.80			1476.90	1478.70	1480.90	1480.80	1481.30	1481.50	1484.10	1483.70	1480.50
1980	1463.20	1462.70		1473.60	1474.80	1477.00	1477.40	1477.60	1480.10	1477.70	1472.20	1466.80
1979	1464.50	1464.00	1464.60	1477.10	1481.70	1484.40	1484.90	1481.60	1481.70	1479.50	1479.50	1468.80
1978	1462.60				1477.50	1478.30	1478.90	1480.25	1480.35	1482.60	1478.60	1468.00
1977	1463.00			1477.30	1478.10	1478.20	1478.60	1478.80	1479.50	1482.10	1470.00	1466.40
1976	1467.90	1465.00	1464.50	1478.70	1480.20	1480.40	1480.30	1479.90	1479.80	1479.70	1472.00	1465.50
1975	1464.75		1463.75	1470.14	1479.30	1481.60	1481.50	1477.50	1475.80	1473.60	1473.00	1473.00
1974	1461.80			1473.10	1475.50	1478.70	1479.40	1481.40	1481.80	1478.30	1476.40	1470.60
1973	1469.40	1464.90	1464.50	1478.40	1483.90	1484.40	1484.70	1483.90	1476.90	1469.90	1465.20	1463.50
1972				1468.00	1474.30	1481.10	1481.00	1475.40	1478.70	1479.55	1480.65	1477.09
1971	1471.75	1465.55	1478.40	1480.80	1482.80	1483.50	1480.20	1479.90	1475.00	1466.35	1460.00	
1970	1469.00	1468.10	1463.10			1480.00	1481.00	1481.10	1481.10	1480.00	1479.50	1478.90
1969	1465.50			1472.00	1484.00	1484.90	1482.50	1483.70	1481.15	1474.65	1479.65	
1968	1464.50				1476.25	1479.80	1486.00	1484.00	1486.00	1483.00	1479.00	1477.00
1967	1472.75	1465.00	1470.00	1481.50	1480.90	1486.25	1481.80	1486.00	1483.60	1479.00	1475.50	1475.50
1966		1476.00	1476.00	1476.00	1486.10	1486.00	1486.65	1486.65	1486.65	1485.00	1466.50	1475.00
1965	1474.40	1474.42	1475.00	1475.00	1486.00	1486.00	1477.50	1472.25	1470.00	1468.00	1466.50	1466.50
1964				1473.25	1477.90	1479.20	1478.90	1482.35	1483.50	1485.00	1479.65	1474.42
1963			1463.45	1472.55	1475.75	1479.70	1479.13	1479.42	1479.50	1471.90	1464.75	
1962					1474.90	1476.65	1475.75	1475.65	1474.84	1470.50	1469.75	
1961	1465.00			1472.50	1477.00	1477.42	1477.75	1477.50	1465.75			
1960	1484.50	1485.00	1483.00	1486.00	1484.60	1486.30	1485.95	1483.60	1481.80	1478.80	1476.25	1467.65
1959					1472.65	1473.40	1473.85	1475.10	1476.85	1479.35	1483.50	1484.00
1958				1469.90	1472.00	1473.50	1477.00	1477.10	1472.80	1463.90		
1957					1476.85	1477.50	1477.65	1475.65	1465.10	1461.50		

Figure 2.3.2-1 Sheet 1 of 5

TABLE 5-1
SUMMARY OF PIEZOMETRIC DATA – SILVER LAKE DAM, GROUP 1

10-Aug-92	1484.4	1476.2	1480.3	1484.6	1483.6	1483.3	1468.4	1474.9	1477.7
15-Sep-92	1483.0	1475.2	1479.4	1483.0	1480.9	1481.0	1468.0	1473.3	1475.6
6-Oct-92	1483.2	1475.3	1479.4	1483.1	1481.0	1481.2	1467.9	1473.0	1475.3
28-Oct-92	1483.6	1475.2	1479.8	1483.6	1481.3	1481.6	1467.9	1473.0	1475.3
13-Nov-92	1482.9	1475.2	1477.0	1482.2	1480.6	1480.7	1467.4	1472.3	1473.6
27-Apr-93	1478.0	1475.2	1476.7	1480.6	1477.3	1472.6	1467.4	1470.0	1469.3
8-Jun-93	1482.8	1475.2	1479.3	1483.0	1480.8	1480.9	1467.4	1473.4	1476.3
13-Jul-93	1478.2	1475.2	1476.2	1482.0	1476.9	1472.8	1466.9	1470.4	1472.7
6-Aug-93	1477.9	1475.2	1475.7	1481.3	1476.5	1472.7	1466.4	1470.2	1473.1
14-Sep-93	1477.7	1475.2	1475.6	1480.6	1476.3	1475.7	1466.2	1470.0	1472.5
12-Oct-93	1478.0	1475.2	1476.9	1480.6	1476.6	1472.8	1466.6	1470.0	1472.5
4-Nov-93	1478.4	1475.2	1476.2	1480.6	1477.0	1472.8	1466.6	1470.0	1472.7
13-Dec-93	1479.4	1475.2	1476.9	1481.7	1477.8	1472.8	1466.7	1470.0	1473.3
26-Apr-94	1482.4	1475.2	1476.9	1480.6	1480.7	1472.7	1467.8	1472.1	1473.5
14-Jun-94	1485.0	1477.0	1480.6	1484.6	1482.8	1483.3	1468.2	1474.5	1473.4
27-Jul-94	1484.7	1476.5	1476.9	1484.5	1482.4	1482.6	1468.7	1474.7	1473.7
30-Aug-94	1482.0	1475.2	1476.9	1482.3	1480.2	1472.7	1467.7	1472.5	1473.7
6-Oct-94	1481.3	1475.2	1476.8	1481.8	1479.5	1472.6	1467.2	1471.9	1473.7
25-Oct-94	1480.5	1475.2	1476.9	1481.6	1478.9	1472.8	1467.0	1471.4	1473.8
7-Nov-94	1480.0	1475.2	1476.9	1481.6	1478.5	1472.7	1466.7	1470.8	1473.7
1-Dec-94	1479.3	1475.2	1476.9	1481.4	1477.7	1472.8	1466.6	1470.8	1473.4
3-Apr-95	1477.9	1475.2	1475.9	1481.4	1477.5	1472.7	1466.8	1470.6	1469.2
19-Apr-95	1479.0	1475.2	1476.9	1480.7	1477.6	1472.7	1467.1	1470.6	1473.2
3-May-95	1481.3	1475.2	1475.8	1481.9	1479.6	1472.7	1467.4	1471.2	1473.7
13-Jun-95	1484.8	1476.7	1477.0	1484.4	1482.2	1472.7	1468.0	1472.5	1472.7
28-Jul-95	1484.6	1476.6	1477.2	1484.2	1482.2	1482.4	1468.2	1474.3	1473.3
28-Aug-95	1484.4	1476.3	1477.1	1484.1	1482.0	1482.1	1468.0	1473.8	1473.5
14-Sep-95	1483.7	1475.2	1476.8	1483.4	1481.4	1472.7	1467.7	1472.9	1473.3
30-Oct-95	1483.6	1475.2	1476.9	1483.6	1481.4	1472.7	1467.4	1472.4	1473.5
29-Nov-95	1484.9	1475.2	1476.8	1484.4	1482.0	1472.5	1467.3	1472.8	1472.8
10-Jun-96	1486.7	1478.5	1476.8	1484.8	1483.6	1472.7	1467.3	1474.4	1473.1
10-Jul-96	1486.2	1478.0	1476.9	1484.7	1483.3	1472.7	1467.3	1473.1	1473.1
20-Aug-96	1486.1	1477.2	1476.9	1484.8	1483.2	1472.7	1467.4	1473.0	1473.2
1-Oct-96	1483.6	1475.2	1476.8	1483.4	1481.1	1472.6	1467.7	1472.7	1473.6
21-Oct-96	1482.5	1475.2	1476.8	1482.7	1480.3	1472.7	1467.3	1471.8	1473.4
18-Nov-96	1482.9	1475.2	1476.9	1482.9	1480.6	1472.7	1467.4	1471.4	1473.4
2-Dec-96	1483.0	1475.2	1476.7	1482.9	1480.4	1472.7	1467.2	1471.2	1473.4
13-May-97	1484.7	1475.2	1476.7	1483.9	1481.7	1472.7	1467.3	1472.3	1472.8
3-Jun-97	1486.3	1477.1	1477.0	1484.3	1483.0	1472.6	1467.3	1473.5	1472.5
1-Aug-97	1486.8	1477.7	1477.0	1484.8	1482.9	1472.7	1467.4	1474.4	1473.3
14-Aug-97	1486.5	1477.0	1476.8	1484.7	1482.6	1472.6	1467.6	1472.8	1473.2
26-Sep-97	1480.1	1475.2	1476.9	1481.8	1478.3	1472.7	1467.1	1471.2	1473.5
24-Oct-97	1479.9	1475.2	1476.9	1481.1	1478.1	1472.7	1466.5	1470.0	1473.4
10-Nov-97	1480.2	1475.2	1476.9	1481.0	1478.3	1472.7	1466.6	1470.0	1473.3
9-Dec-97	1480.4	1475.2	1476.7	1481.6	1478.4	1472.6	1466.6	1470.0	1473.3
7-Jan-98	1480.5	1475.2	1476.8	1481.5	1478.4	1472.6	1466.6	1470.0	1472.9
29-Jan-98	1480.6	1475.2	1476.8	1481.3	1478.0	1472.6	1466.6	1470.0	1472.8
24-Mar-98	1481.2	1475.2	1476.8	1481.4	1479.0	1472.6	1466.8	1470.0	1472.1
3-Apr-98	1484.6	1475.2	1476.9	1482.5	1481.7	1472.6	1467.1	1472.8	1473.5
20-Apr-98	1486.4	1477.0	1476.9	1484.3	1483.1	1472.6	1467.4	1471.9	1471.4
5-May-98	1486.2	1477.3	1476.9	1484.4	1483.1	1472.5	1467.3	1471.1	1471.0
14-Jul-98	1484.8	1476.7	1476.9	1484.3	1482.2	1472.3	1467.3	1473.8	1477.8
4-Aug-98	1484.1	1475.6	1476.9	1483.7	1481.6	1472.8	1467.3	1474.4	1473.7
Maximum	1487	1479	1481	1486	[illegible]	[illegible]	[illegible]	1475	1479
Minimum	1478	1475	1476	1481	[illegible]	1472	[illegible]	1470	1469
Average	1482	1476	1477	1483	1480	1474	1467	1472	1473

Figure 2.3.2-1 Sheet 2 of 5
(" Periodic Safety Inspection Report No. 2 Hoist Hydroelectric Development ", Stone & Webster, MI, Inc. May 1999)

Document # GB-0474

Silver Lake Reservoir Levels

DATE	BASIN LEVEL		DATE	BASIN LEVEL	
3-Apr-95	1477.90		24-Nov-98	1481.00	
19-Apr-95	1479.00		17-Dec-98	1481.50	
3-May-95	1481.30		22-Apr-99	1482.30	
13-Jun-95	1484.80		18-May-99	1484.60	
28-Jun-95	1484.60		15-Jun-99	1486.50	
28-Aug-95	1484.40		13-Jul-99	1486.50	
15-Sep-95	1483.70		4-Aug-99	1486.00	
30-Oct-95	1483.80		17-Sep-99	1481.50	
29-Nov-95	1484.90		13-Oct-99	1478.40	
10-Jun-96	1486.70		15-Nov-99	1479.00	
10-Jul-96	1486.20		9-Dec-99	1479.30	
20-Aug-96	1486.10		3-Mar-00	1480.10	
1-Oct-96	1483.60		5-Apr-00	1483.70	
21-Oct-96	1482.50		11-May-00	1485.20	
18-Nov-96	1482.90		29-Jun-00	1482.80	
2-Dec-96	1483.00		27-Jul-00	1482.10	
13-May-97	1484.70		8-Aug-00	1481.70	
3-Jun-97	1486.30		16-Aug-01	1479.55	
1-Aug-97	1485.80		24-Sep-01	1477.40	
14-Aug-97	1485.50		2-Oct-01	1477.30	
25-Sep-97	1480.10		25-Oct-01	1477.05	
24-Oct-97	1479.90		8-Nov-01	1477.60	
10-Nov-97	1480.20		11-Dec-01	1478.60	
9-Dec-97	1480.40		20-Apr-02	1486.90	
29-Jan-98	1480.60		7-May-02	1486.50	
24-Mar-98	1481.20		18-Jun-02	1485.90	
3-Apr-98	1484.60		16-Jul-02	1480.70	
20-Apr-98	1486.40		18-Aug-02	1472.25	
5-May-98	1486.20		24-Sep-02	1471.53	
14-Jul-98	1484.80		24-Oct-02	1475.58	
4-Aug-98	1484.10		5-Nov-02	1476.04	
2-Sep-98	1482.10		3-Dec-02	1477.18	
8-Oct-98	1480.40				

Figure 2.3.2-1 Sheet 3 of 5

Silver Lake Elevations

Date	Elevation	Remarks/Notes
05/30/01	1486.00	
06/26/01	1486.45	
07/03/01	1485.70	
07/16/01	1483.60	
08/02/01	1481.50	
08/16/01	1479.55	
08/17/01	1479.80	
08/22/01	1479.30	
09/04/01	1477.90	
09/05/01	1477.90	
09/13/01	1477.50	
09/24/01	1477.40	
10/01/01	1477.30	
10/25/01	1477.05	
11/08/01	1477.60	
11/26/01	1477.60	
12/11/01	1478.60	
01/04/02	1479.10	12" Snow on ground
01/29/02	1479.20	17" Snow on Ground
03/19/02	1480.00	42" snow on ground
04/04/02	1480.01	35" Snow on Ground
04/20/02	1486.90	
05/03/02	1486.50	
05/07/02	1486.50	
06/01/02	1485.90	
06/18/02	1485.90	
06/20/02	1485.90	
06/28/02	1485.85	
06/29/02	1485.80	
07/03/02	1485.75	valve to 36"
07/04/02	1485.20	
07/05/02	1484.90	
07/07/02	1484.20	
07/08/02	1483.85	
07/10/02	1483.00	
07/11/02	1482.50	
07/15/02	1481.00	
07/16/02	1480.60	
07/17/02	1480.20	
07/23/02	1478.10	
07/24/02	1477.70	valve to 42"
07/26/02	1476.90	valve to 48"
07/29/02	1475.80	
07/31/02	1475.00	
08/02/02	1474.60	
08/03/02	1475.50	valve closed by Moyle
08/06/02	1474.30	valve to 40"
08/11/02	1472.60	
08/13/02	1472.60	

Figure 2.3.2-1 Sheet 4 of 5

08/14/02	1472.75	
08/15/02	1472.00	
08/18/02	1472.30	
08/20/02	1472.00	
08/26/02	1471.25	
08/28/02	1471.05	
08/30/02	1470.95	
09/04/02	1471.10	valve to 4"
09/14/02	1471.20	
09/24/02	1471.53	
10/17/02	1475.05	valve to 4.5"
10/22/02	1475.50	
10/24/02	1475.58	
10/30/02	1475.90	
11/04/02	1476.04	
11/05/02	1476.04	
11/11/02	1476.40	
11/14/02	1476.62	
11/21/02	1476.80	
12/03/02	1477.18	
12/19/02	1477.38	
01/08/03	1477.63	
01/14/03	1477.70	
02/18/03	1477.94	valve to 5 & 1/8"
02/25/03	1477.94	valve to 6 & 1/8"
03/04/03	1477.89	valve to 8"
03/11/03	1477.70	
03/18/03	1477.54	
03/27/03	1478.48	
04/03/03	1479.06	
04/10/03	1479.22	
04/16/03	1480.60	
04/23/03	1482.34	
05/01/03	1483.22	
05/07/03	1483.35	Visual OP's water just up to toe of Fuse Plug
05/14/03	1483.26	
05/15/03	1468.70	
05/16/03	1460.00	estimated

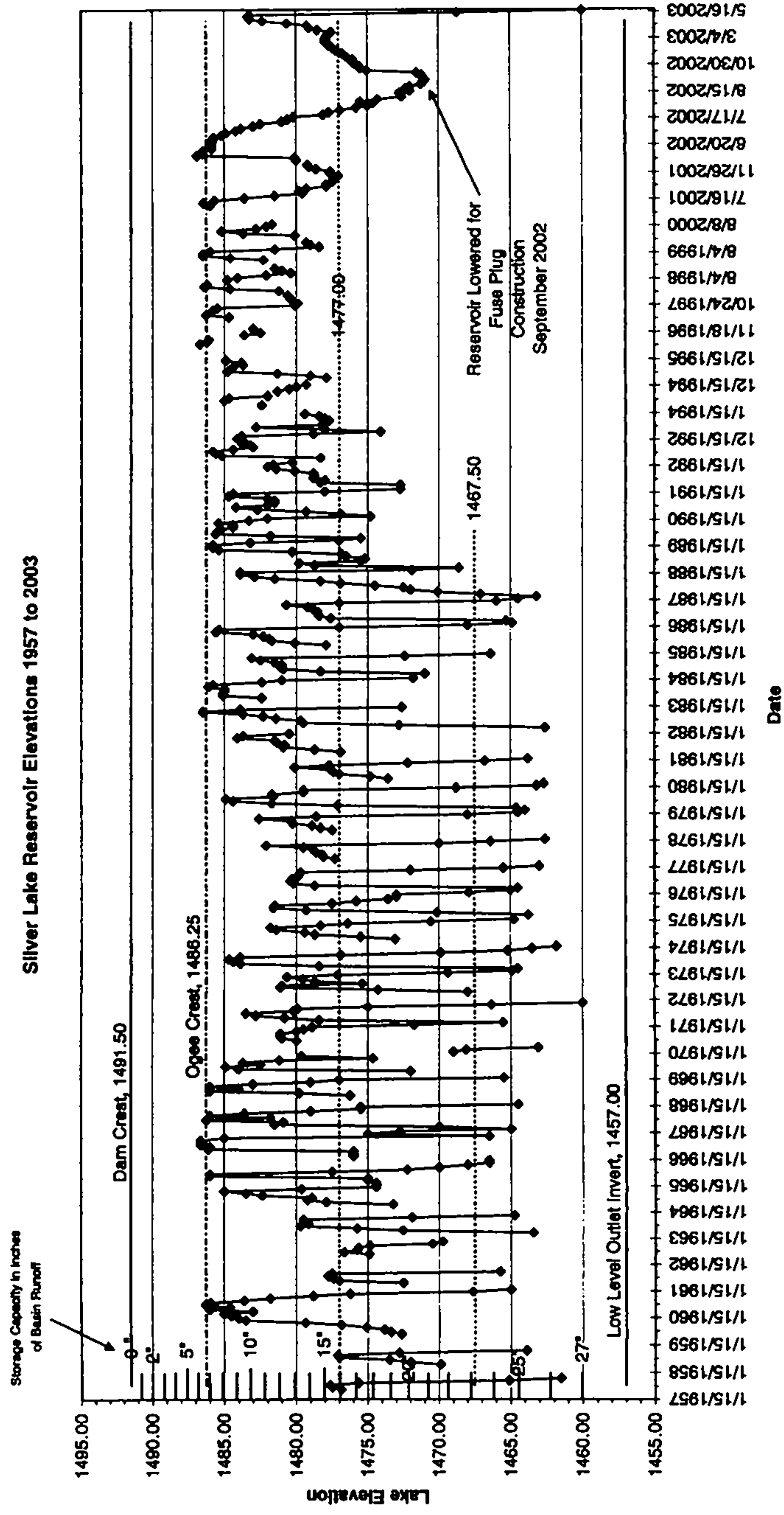

Silver Lake Reservoir Elevations 1957 to 2003
Lake Elevation
Date
Dam Crest, 1491.50
Ogee Crest, 1486.25
1477.00
1467.50
Low Level Outlet Invert, 1457.00
Storage Capacity in Inches of Basin Runoff
Reservoir Lowered for Fuse Plug Construction September 2002

Figure 2.3.2-2

1334 12-4-20 0

SILVER LAKE AREA / CAPACITY INFO

...: SILELCAP.WKT, SILAREA.PIC, SILVOL.PIC, VOLINTRP.PIC

...s file is for the development of the Area vs. Elevation and ...servoir Volume vs. Elevation curves for the Dead River ...ydroelectric Project. The basic area measurements are from a Stone & Webster topographic drawing of the Silver Lake Basin developed from the 1992 Foley, Garske and Strigel survey. Incremental volumes are obtained from the areas using the conic method. All elevations reference the National Geodetic Vertical Datum of 1929.

Elevation (feet)	Area (ft^2)	Area (acres)	Incremental Volume (acre-ft)	Total Volume (acre-ft)
1403	0	0.00		0.00
			0.03	
1405	2143.54 ✓	0.05		0.03 ✓
			2.21	
1410	45736.44 ✓	1.05		2.24 ✓
			15.35	
1415	248815.12 ✓	5.71		17.60 ✓
			63.35	
1420	926672.60 ✓	21.27		80.96 ✓
			165.23	
1425	2022764.08 ✓	46.44		246.18 ✓
			318.24	
1430	3597263.38 ✓	82.58		564.42 ✓
			527.50	
1435	5672342.04 ✓	130.22		1091.92 ✓
			786.52	
1440	8104056.98 ✓	186.04		1878.44 ✓
			1058.38	
1445	10384119.3 ✓	238.39		2936.81 ✓
			1334.98	
1450	12922724.24 ✓	296.66		4271.79 ✓
			1639.05	
1455	15680530.64 ✓	359.98		5910.84 ✓
			2056.83	
1460	20255158.07 ✓	464.99		7967.67 ✓
			2889.75	
1465	30440395.37 ✓	698.82		10857.42 ✓
			3979.59	
1470	39079620.05 ✓	897.14		14837.01 ✓
			1862.86	
1472	42085325.61 ✓	966.15		16699.87 ✓
			1988.94	
1474	44564682.2 ✓	1023.06		18688.81 ✓
			2094.92	
1476	46698302.04 ✓	1072.05		20783.73 ✓
			2267.15	
1478	52108277.53 ✓	1196.24		23050.89 ✓
			2408.11	
1480	52789647.91	1211.88		25458.99 ✓
			2439.39	
1482	53471018.29 ✓	1227.53		27898.39 ✓
			2515.20	
1484	56101627.77 ✓	1287.92		30413.59 ✓
			2735.45	
1486	63123482.91 ✓	1449.12		33149.03 ✓
			364.08	
1486.25	*	1463.52		33513.11
			6989.73	
1490.65	*	1717.00		40502.84
			1040.56	
1491.25	*	1751.57		41543.40
			5033.09	
1494	OLD CURVE	1910.00		46576.49

NEW CURVE

29500
29500
5000
4000
33000
37000
8500
41600

* The last 4 area entries (1486.25 thru 1491.25) are based on interpolation between the new curve and the old curve between elevations 1486 and 1494.

Figure 2.3.2-3
(" Flood and Spillway Adequacy Analysis "
Stone & Webster, MI, Inc. October 1993)

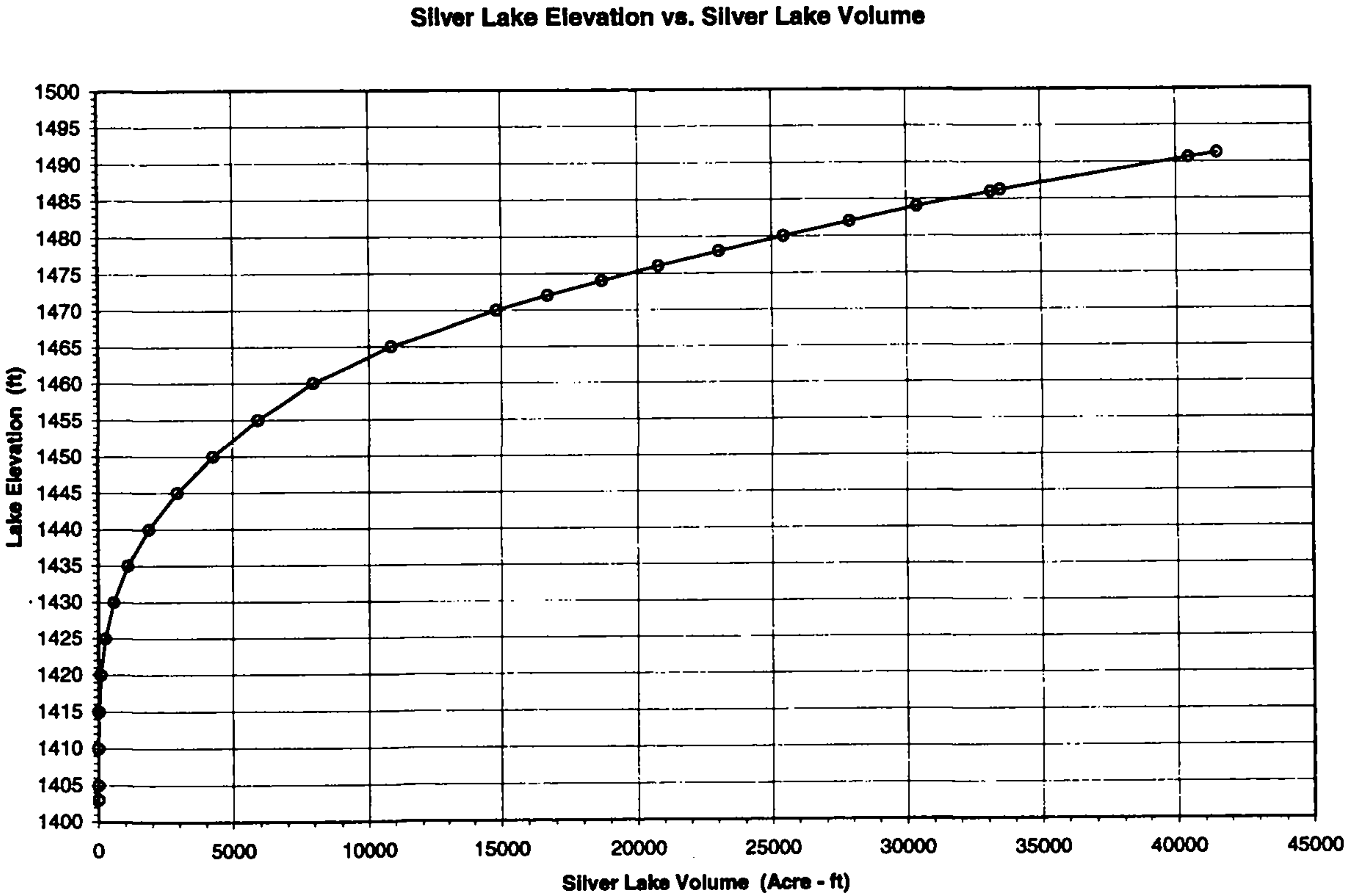
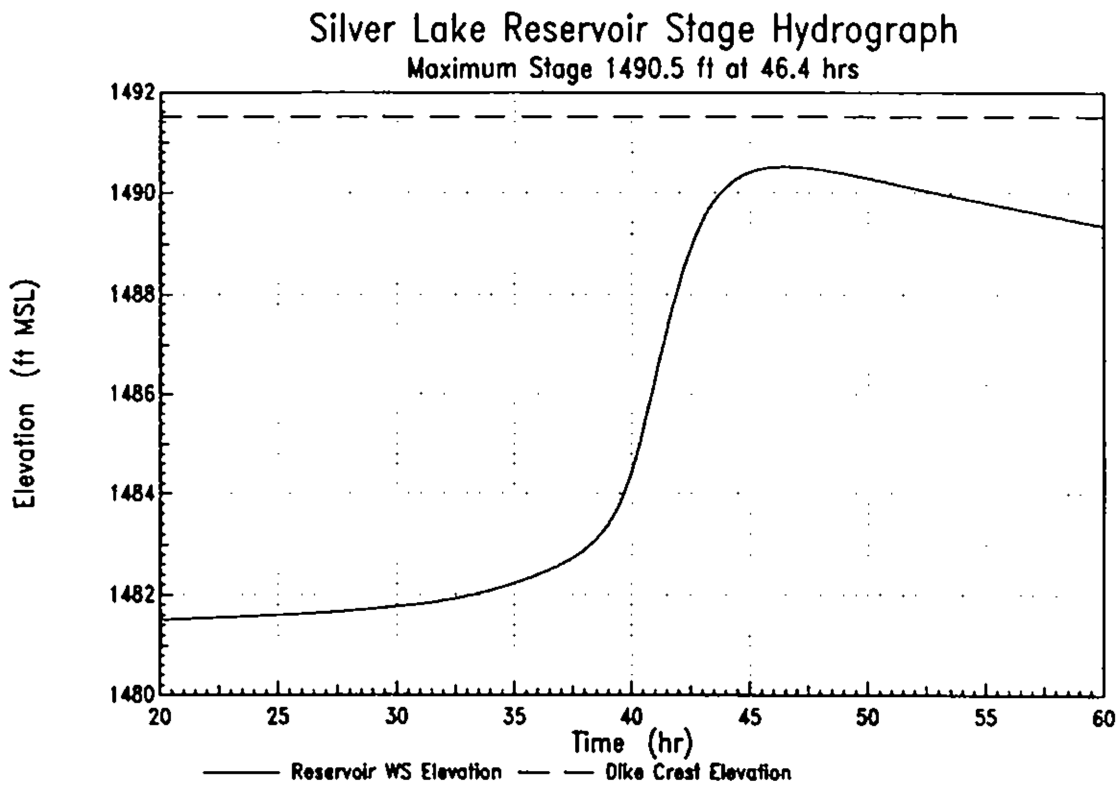

Silver Lake Elevation vs. Silver Lake Volume
Lake Elevation (ft)
1500
1495
1490
1485
1480
1475
1470
1465
1460
1455
1450
1445
1440
1435
1430
1425
1420
1415
1410
1405
1400
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
Silver Lake Volume (Acre - ft)

Figure 2.3.2-4


Silver Lake Reservoir Stage Hydrograph
Maximum Stage 1490.5 ft at 46.4 hrs
Elevation (ft MSL)
1480
1482
1484
1486
1488
1490
1492
20
25
30
35
40
45
50
55
60
Time (hr)
Reservoir WS Elevation
Dike Crest Elevation

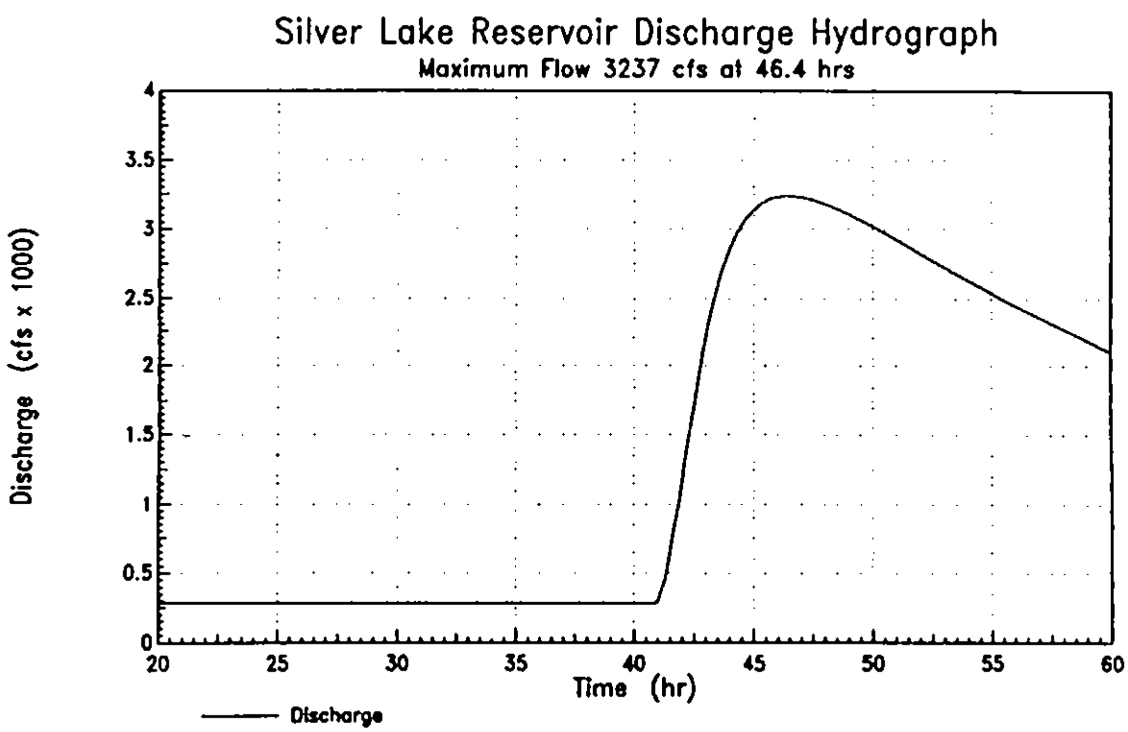

Silver Lake Reservoir Discharge Hydrograph
Maximum Flow 3237 cfs at 46.4 hrs
Discharge (cfs x 1000)
0
0.5
1
1.5
2
2.5
3
3.5
4
20
25
30
35
40
45
50
55
60
Time (hr)
Discharge

Figure 2.3.2-5

Fuse plug embankment at end of construction, October 8, 2002

Pilot channel across fuse plug embankment, October 8, 2002

Figure 2.3.3-1 Fuse plug embankment during post-construction inspection

Figure 3.6.2-1 Debris and grass trapped at left side of stop-logged spillway notch

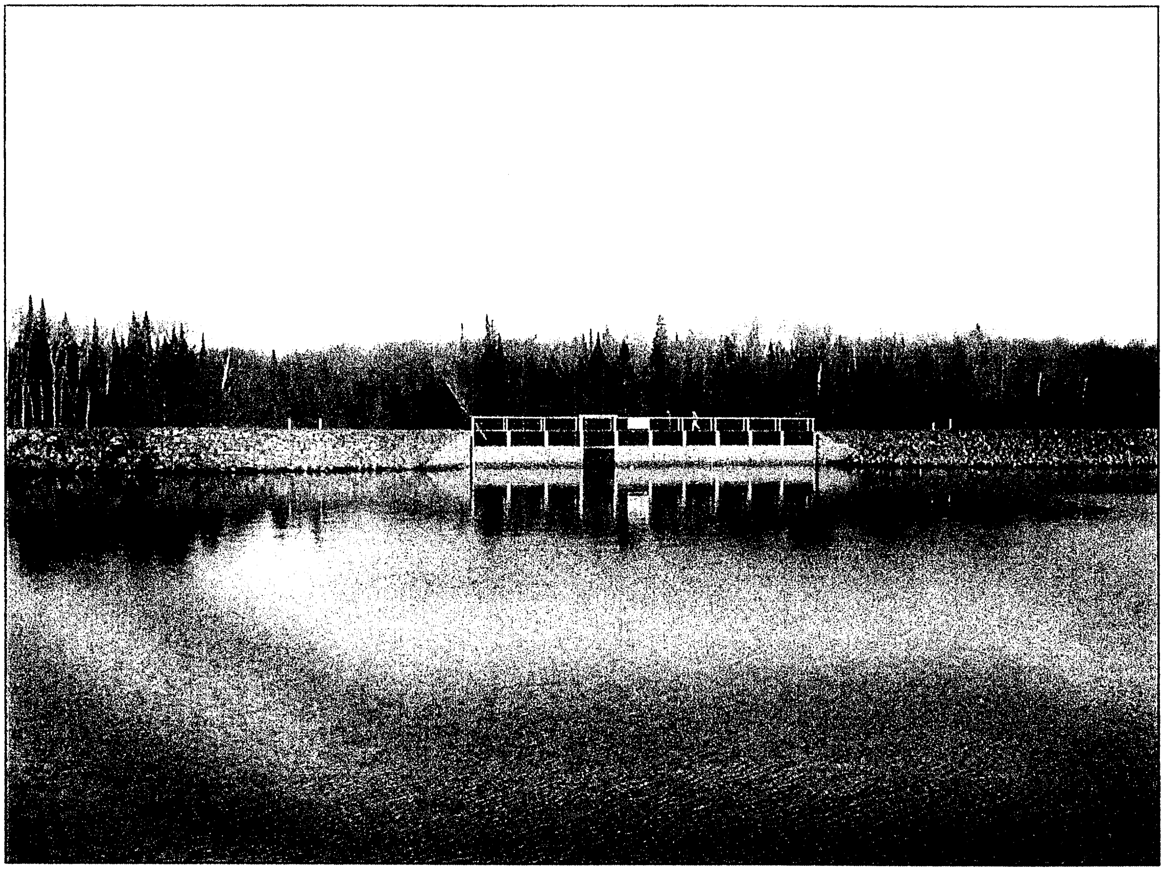


Figure 3.6.2-2 Upstream side of concrete spillway at about 8:30 PM, May 14, 2003

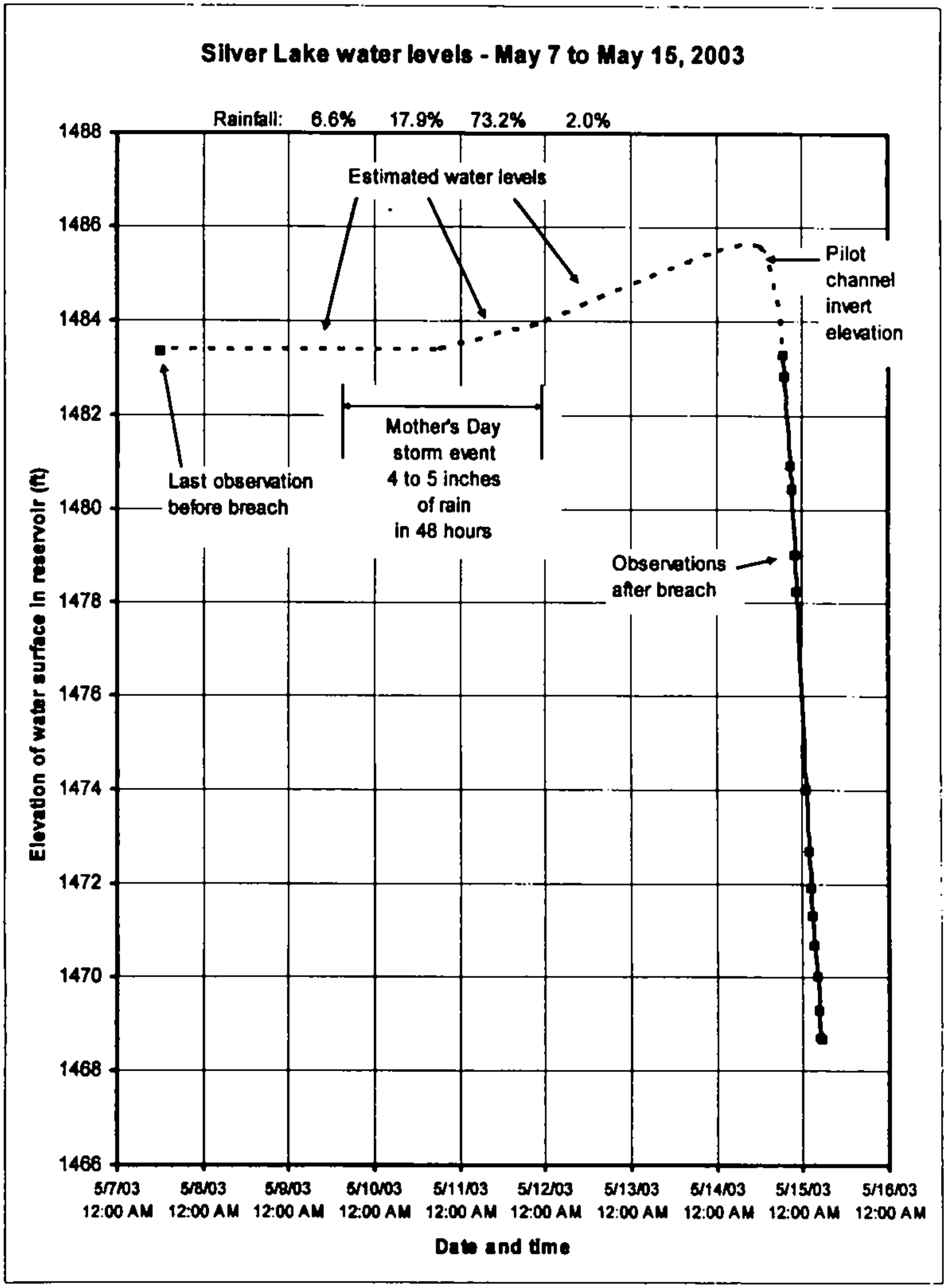


Figure 3.6.2-3 Water levels in Silver Lake before and after fuse plug breach

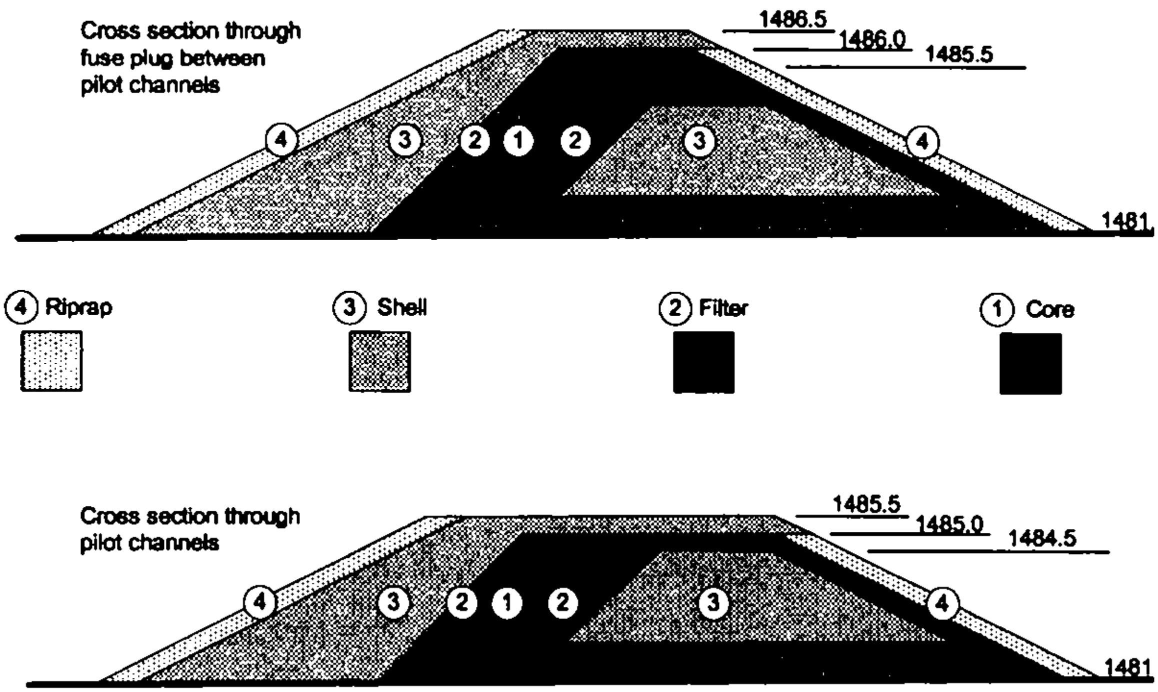


Figure 3.6.3-1 Cross sections through fuse plug embankment

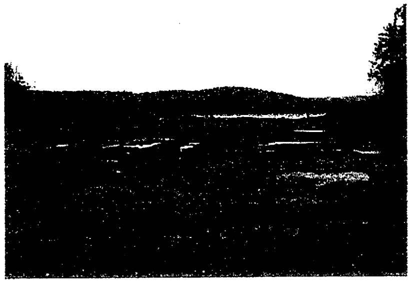
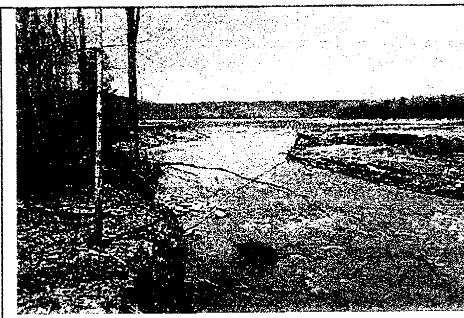
 Upstream, October 8, 2002 (during post-construction inspection)	 Upstream, May 14, 2003, about 8:30 PM (operator photo)	 Upstream, May 15, 2003 (Spicer photo)	 Upstream, May 16, 2003 (Evans photo)
 Downstream, October 8, 2002 (during post-construction inspection)	 Downstream, May 14, 2003, about 8:30 PM (operator photo)	 Downstream, May 15, 2003 (Spicer photo)	 Downstream, May 16, 2003 (Evans photo)

Figure 3.6.4-1 Photographs upstream and downstream from fuse plug embankment on October 8, 2002 at the end of construction, and on May 14; May 15; and May 16; 2003, showing progressively deepening erosion

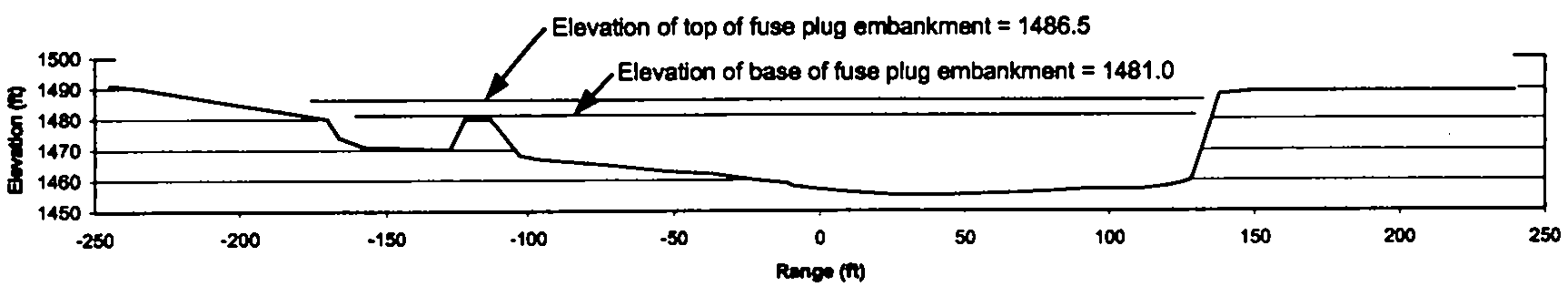


Figure 3.6.4-2 Cross section through eroded channel at STS Station 27+00, near fuse plug axis

Figure 3.6.5-1 Bridge at mouth of Dead River after fuse plug breach

FIGURE 9

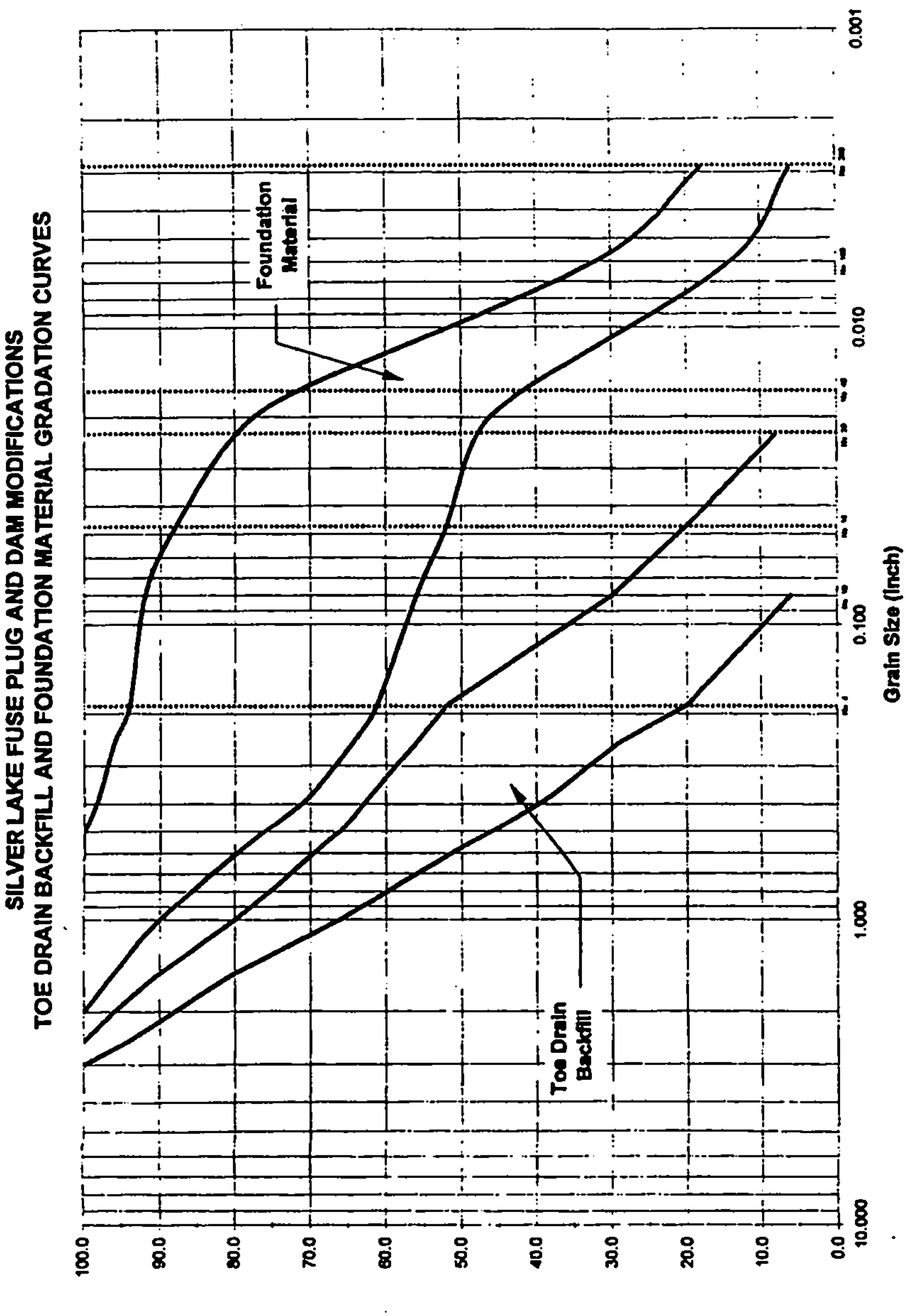


Figure 4.4.1-1

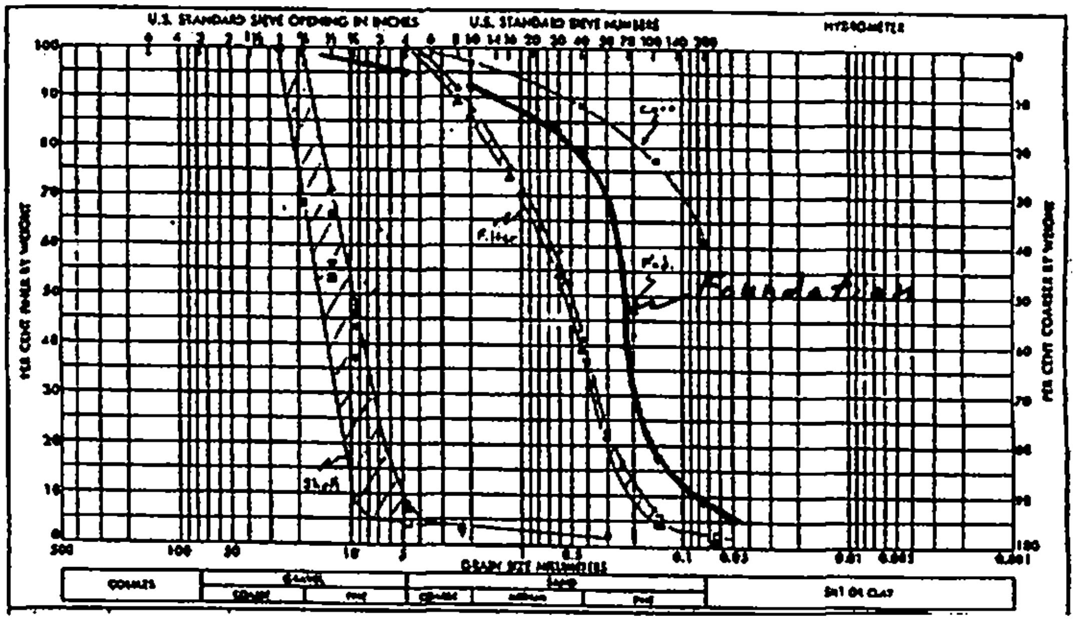
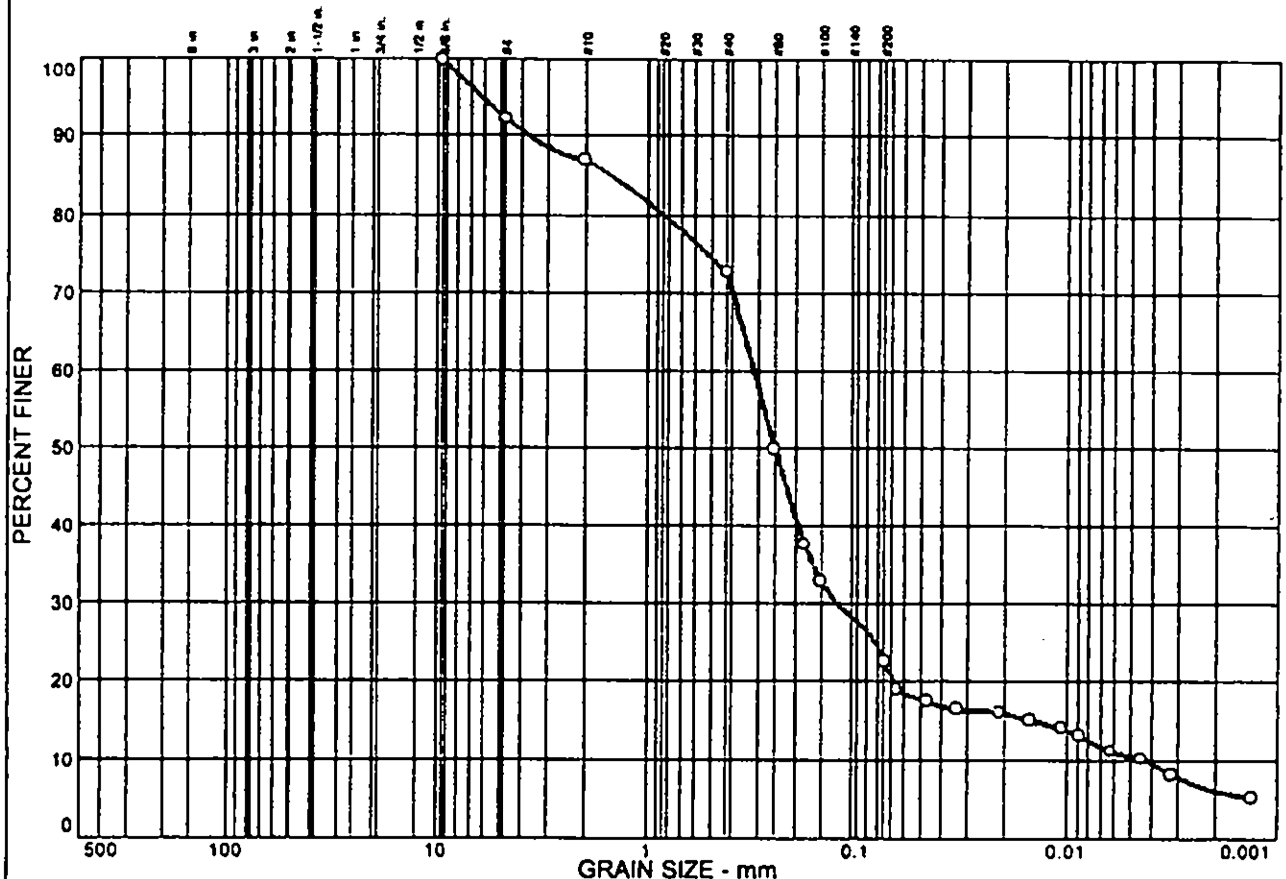


Figure 1, Gradation Curves

Figure 4.4.1-2

PARTICLE SIZE ANALYSIS OF SOILS (ASTM D 422)



% COBBLES	% GRAVEL	% SAND	% SILT	% CLAY
0.0	7.7	69.6	12.2	10.5

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.375 in.	100.0		
#4	92.3		
#10	87.1		
#40	72.7		
#60	49.8		
#80	37.6		
#100	32.8		
#200	22.7		

* (no specification provided)

Soil Description

F-C SAND LITTLE SILT LITTLE CLAY TRACE F GRAVEL

Atterberg Limits

PL= LL= PI=

Coefficients

D_{85}= 1.52 D_{60}= 0.318 D_{50}= 0.251
D_{30}= 0.125 D_{15}= 0.0145 D_{10}= 0.0044
C_u= 72.61 C_c= 11.21

Classification

USCS= SM AASHTO=

Remarks

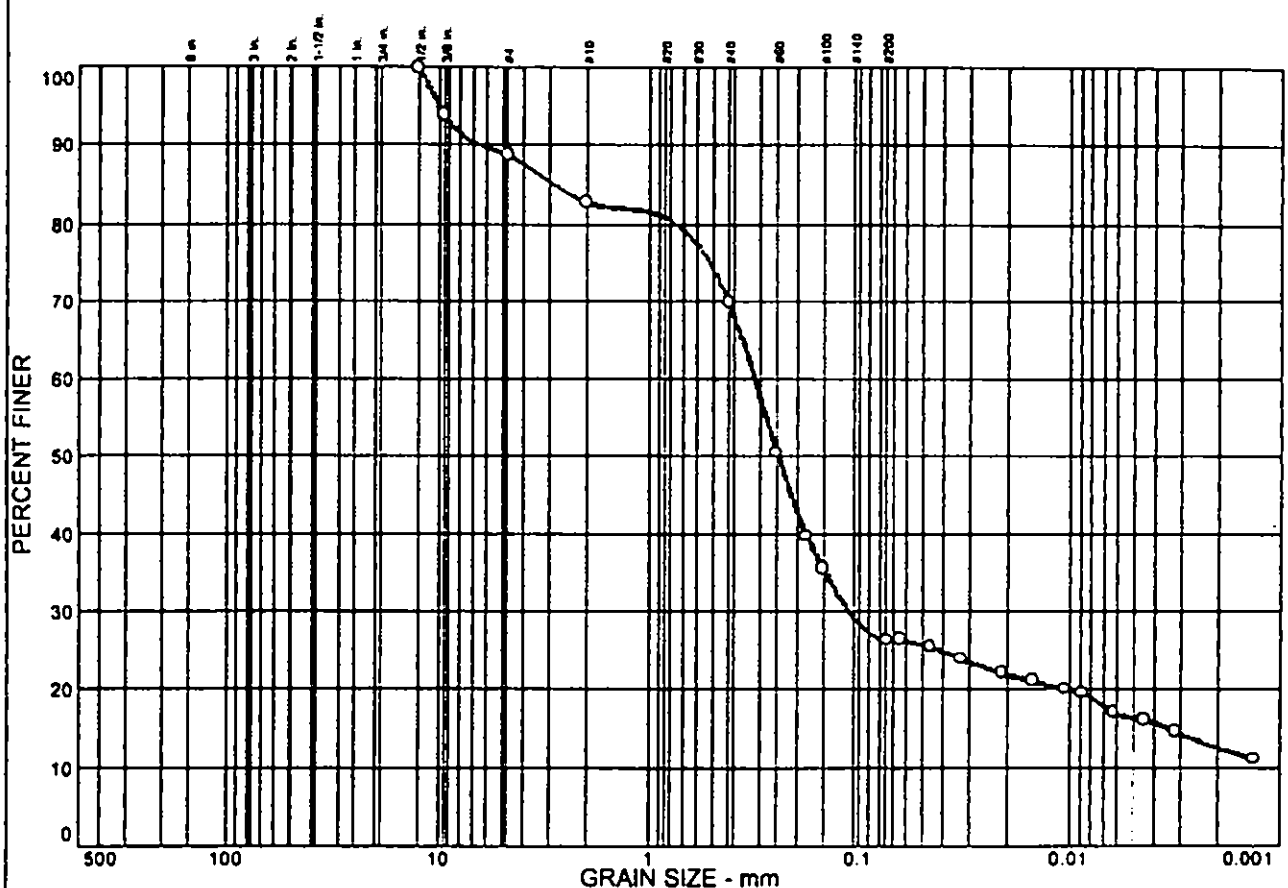
Sample No.: 3 **Source of Sample:** BORING 2 **Date:** 6-19-03
Location: **Elev./Depth:** 4.0-6.0

STS Consultants Ltd.
750 Corporate Woods Parkway
Vernon Hills, IL 60061

Client: GARAN LUCOW MILLER
Project: WPS-EVALUATION OF FAILURE AT SILVER LAKE
Project No: 10452 **Plate**

Figure 4.4.1-3

PARTICLE SIZE ANALYSIS OF SOILS (ASTM D 422)



% COBBLES	% GRAVEL	% SAND	% SILT	% CLAY
0.0	11.3	62.3	10.1	16.3

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.5 in.	100.0		
.375 in.	93.8		
#4	88.7		
#10	82.7		
#40	69.8		
#60	50.5		
#80	39.8		
#100	35.5		
#200	26.4		

* (no specification provided)

Soil Description

F-C SAND LITTLE CLAY LITTLE F GRAVEL TRACE SILT

Atterberg Limits

PL= LL= PI=

Coefficients

D_{85}= 2.86 D_{60}= 0.320 D_{50}= 0.247
D_{30}= 0.112 D_{15}= 0.0035 D_{10}=
C_u= C_c=

Classification

USCS= SM AASHTO=

Remarks

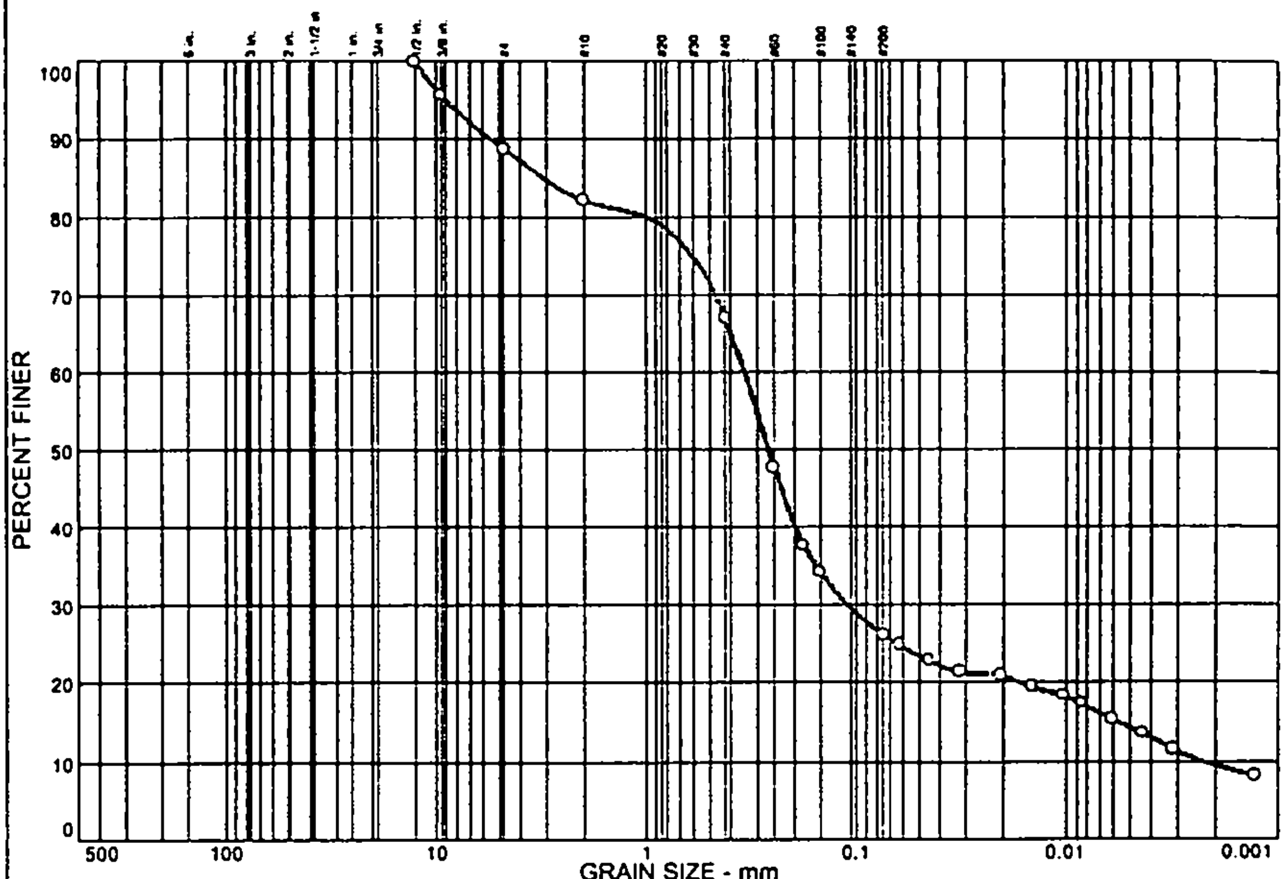
Sample No.: 7 **Source of Sample:** BORING 2 **Date:** 6-19-03
Location: **Elev./Depth:** 16.0-18.0

STS Consultants Ltd.
750 Corporate Woods Parkway
Vernon Hills, IL 60061

Client: GARAN LUCOW MILLER
Project: WPS-EVALUATION OF FAILURE AT SILVER LAKE
Project No: 10452 **Plate**

Figure 4.4.1-4

PARTICLE SIZE ANALYSIS OF SOILS (ASTM D 422)



% COBBLES	% GRAVEL	% SAND	% SILT	% CLAY
0.0	11.2	62.7	11.8	14.3

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.50 in.	100.0		
.375 in.	95.7		
#4	88.8		
#10	82.2		
#40	66.8		
#60	47.6		
#80	37.6		
#100	34.2		
#200	26.1		

* (no specification provided)

Soil Description

F-C SAND LITTLE CLAY LITTLE SILT LITTLE F GRAVEL

Atterberg Limits

PL= LL= PI=

Coefficients

D_{85}= 3.06 D_{60}= 0.348 D_{50}= 0.267
D_{30}= 0.111 D_{15}= 0.0057 D_{10}= 0.0023
C_u= 151.77 C_c= 15.47

Classification

USCS= SM AASHTO=

Remarks

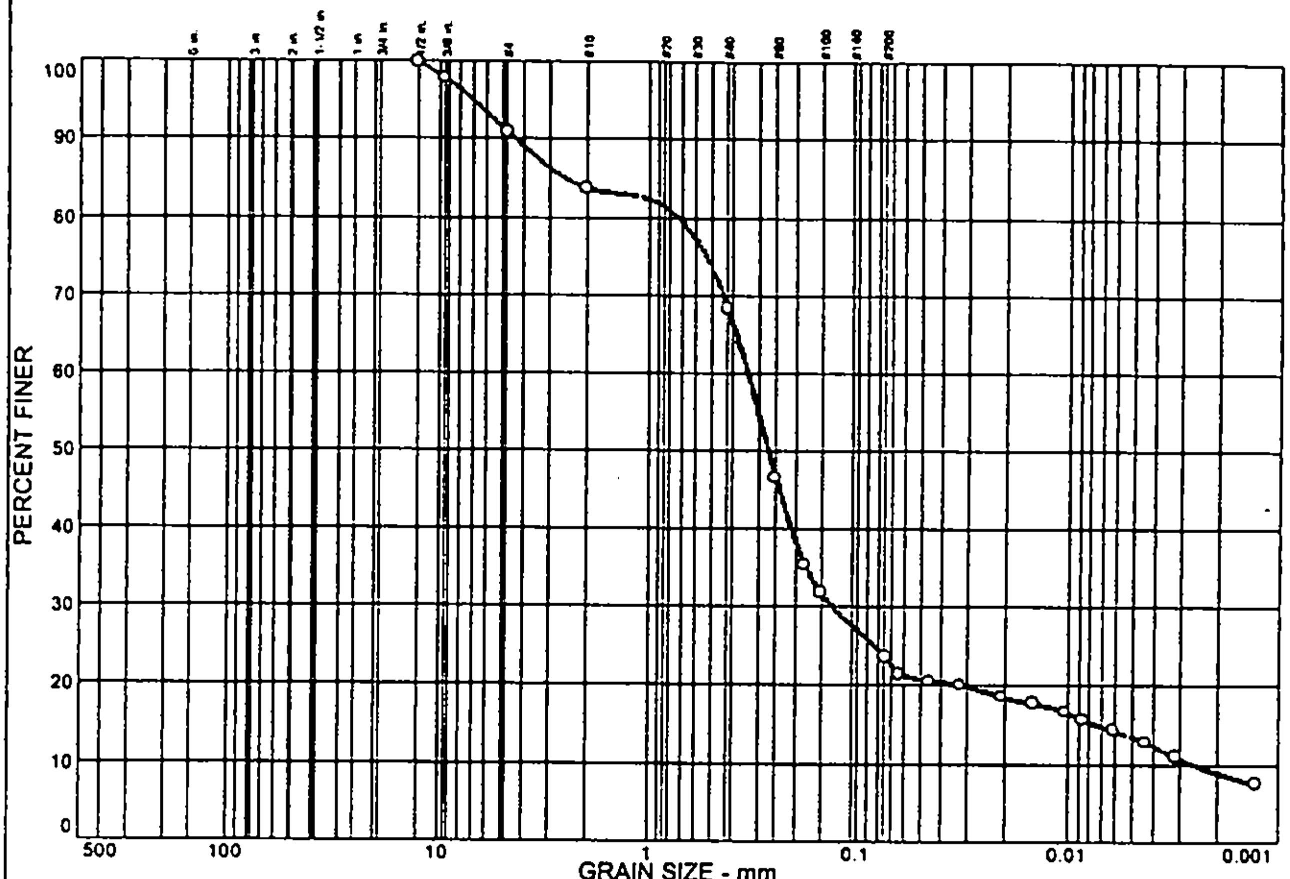
Sample No.: 13 **Source of Sample:** BORING 2 **Date:** 6-21-03
Location: **Elev./Depth:** 23.0-25.0

STS Consultants Ltd.
750 Corporate Woods Parkway
Vernon Hills, IL 60061

Client: GARAN LUCOW MILLER
Project: WPS-EVALUATION OF FAILURE AT SILVER LAKE
Project No: 10452 **Plate**

Figure 4.4.1-5

PARTICLE SIZE ANALYSIS OF SOILS (ASTM D 422)



% COBBLES	% GRAVEL	% SAND	% SILT	% CLAY
0.0	9.0	67.4	10.2	13.4

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.50 in.	100.0		
.375 in.	97.9		
#4	91.0		
#10	83.7		
#40	68.4		
#60	46.6		
#80	35.4		
#100	31.8		
#200	23.6		

* (no specification provided)

Soil Description

F-C SAND LITTLE CLAY LITTLE SILT TRACE F GRAVEL

Atterberg Limits

PL= LL= PI=

Coefficients

D_{85}= 2.53 D_{60}= 0.342 D_{50}= 0.271
D_{30}= 0.132 D_{15}= 0.0074 D_{10}= 0.0026
C_u= 129.97 C_c= 19.39

Classification

USCS= SM AASHTO=

Remarks

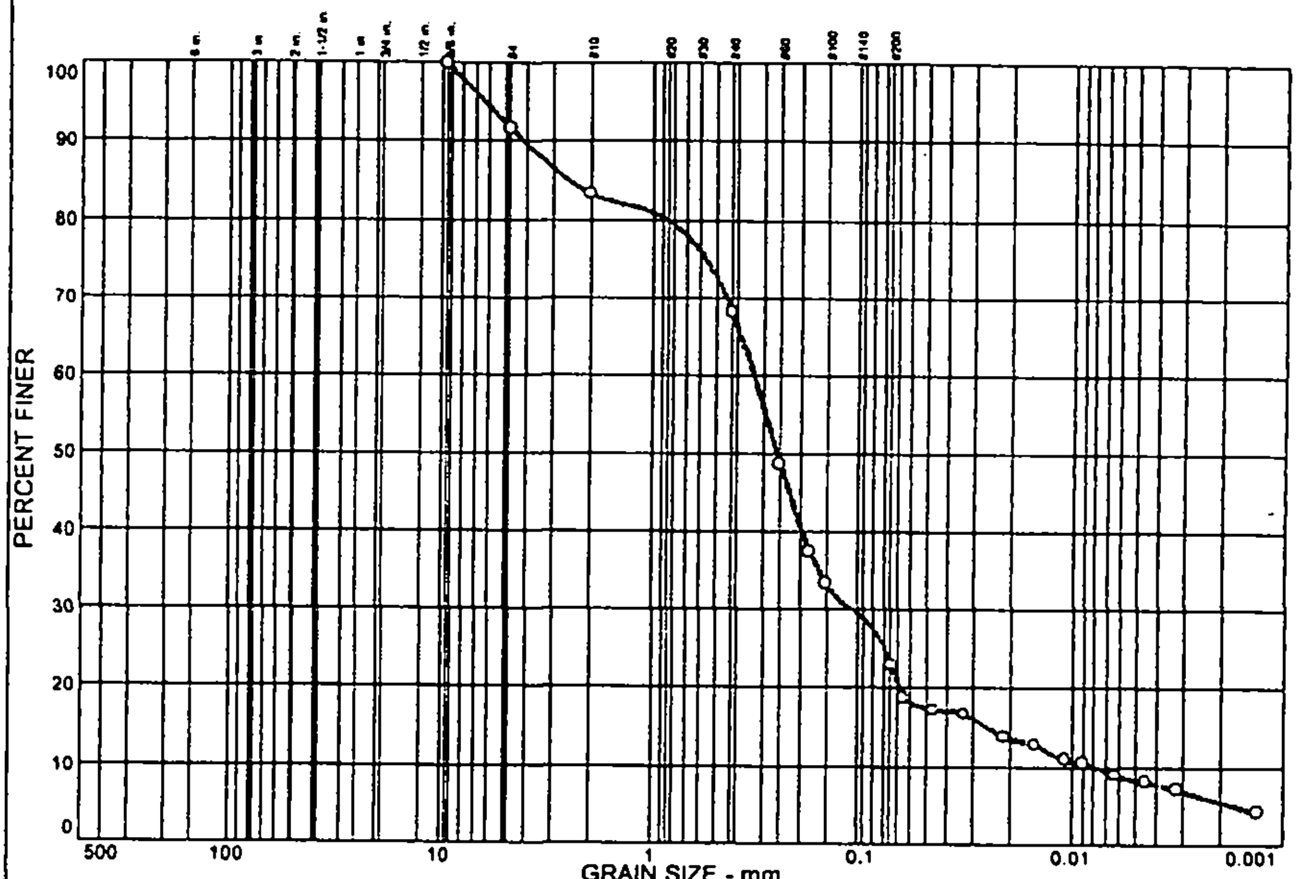
Sample No.: 15 **Source of Sample:** BORING 2 **Date:** 6-19-03
Location: **Elev./Depth:** 29.0-31.0

STS Consultants Ltd.
750 Corporate Woods Parkway
Vernon Hills, IL 60061

Client: GARAN LUCOW MILLER
Project: WPS-EVALUATION OF FAILURE AT SILVER LAKE
Project No: 10452 **Plate**

Figure 4.4.1-6

PARTICLE SIZE ANALYSIS OF SOILS (ASTM D 422)



% COBBLES	% GRAVEL	% SAND	% SILT	% CLAY
0.0	8.3	68.7	14.8	8.2

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.375 in.	100.0		
#4	91.7		
#10	83.3		
#40	68.1		
#60	48.7		
#80	37.5		
#100	33.3		
#200	23.0		

* (no specification provided)

Soil Description

F-C SAND LITTLE SILT TRACE CLAY TRACE F GRAVEL

Atterberg Limits

PL= LL= PI=

Coefficients

D_{85}= 2.54 D_{60}= 0.335 D_{50}= 0.259
D_{30}= 0.113 D_{15}= 0.0258 D_{10}= 0.0080
C_u= 41.65 C_c= 4.76

Classification

USCS= SM AASHTO=

Remarks

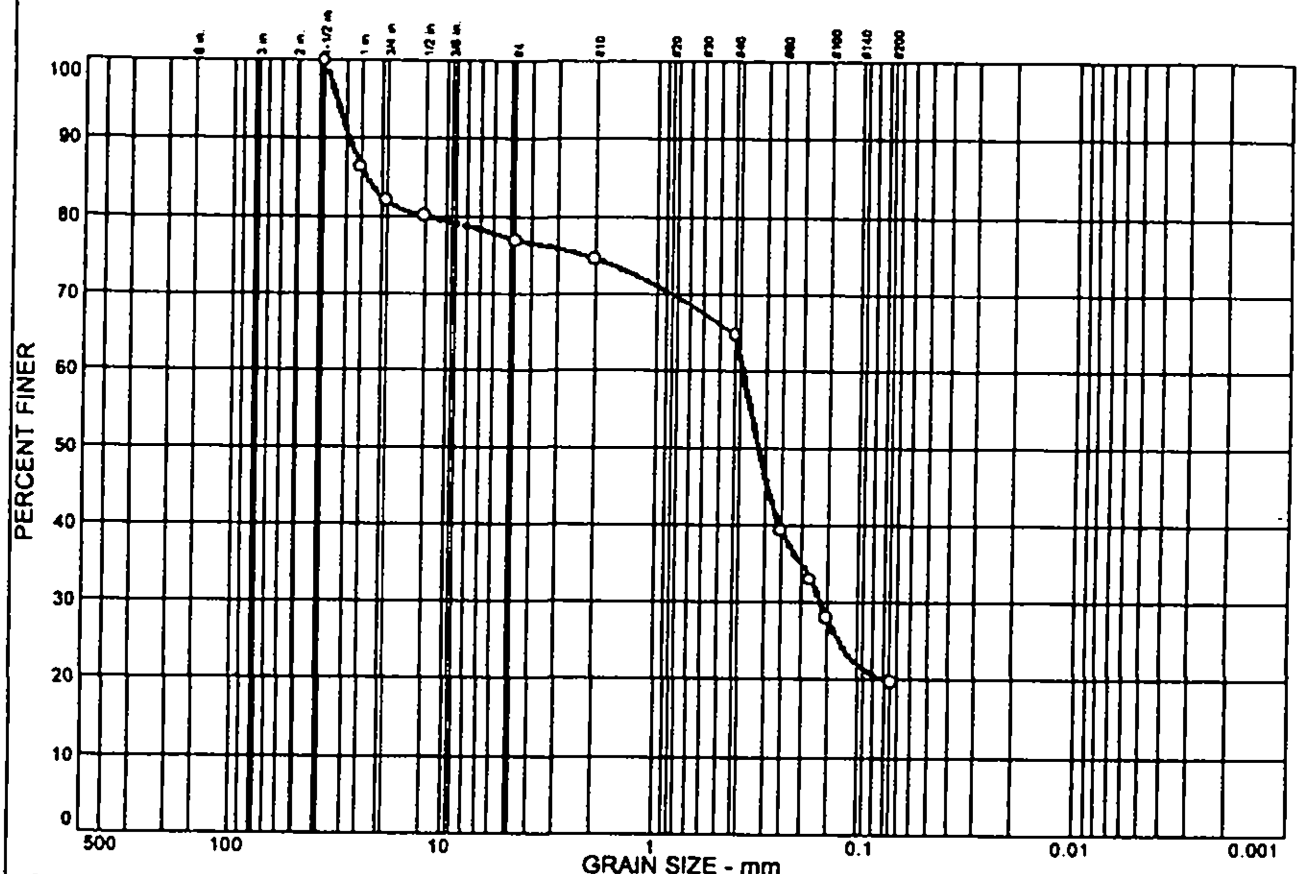
Sample No.: 21 **Source of Sample:** BORING 2 **Date:** 6-19-03
Location: **Elev./Depth:** 39.0-41.0

STS Consultants Ltd.
750 Corporate Woods Parkway
Vernon Hills, IL 60061

Client: GARAN LUCOW MILLER
Project: WPS-EVALUATION OF FAILURE AT SILVER LAKE
Project No: 10452 **Plate**

Figure 4.4.1-7

PARTICLE SIZE ANALYSIS OF SOILS (ASTM D 422)



% COBBLES	% GRAVEL	% SAND	% SILT	% CLAY
0.0	23.1	57.2	19.7	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
1.5 in.	100.0		
1 in.	86.2		
.75 in.	81.9		
.5 in.	80.0		
#4	76.9		
#10	74.5		
#40	64.7		
#60	39.3		
#80	33.0		
#100	28.0		
#200	19.7		

* (no specification provided)

Soil Description

GRAVELLY FINE TO COARSE SAND LITTLE SILT

Atterberg Limits

PL= LL= PI=

Coefficients

D_{85}= 24.0 D_{60}= 0.392 D_{50}= 0.326
D_{30}= 0.161 D_{15}= D_{10}=
C_u= C_c=

Classification

USCS= SM AASHTO=

Remarks

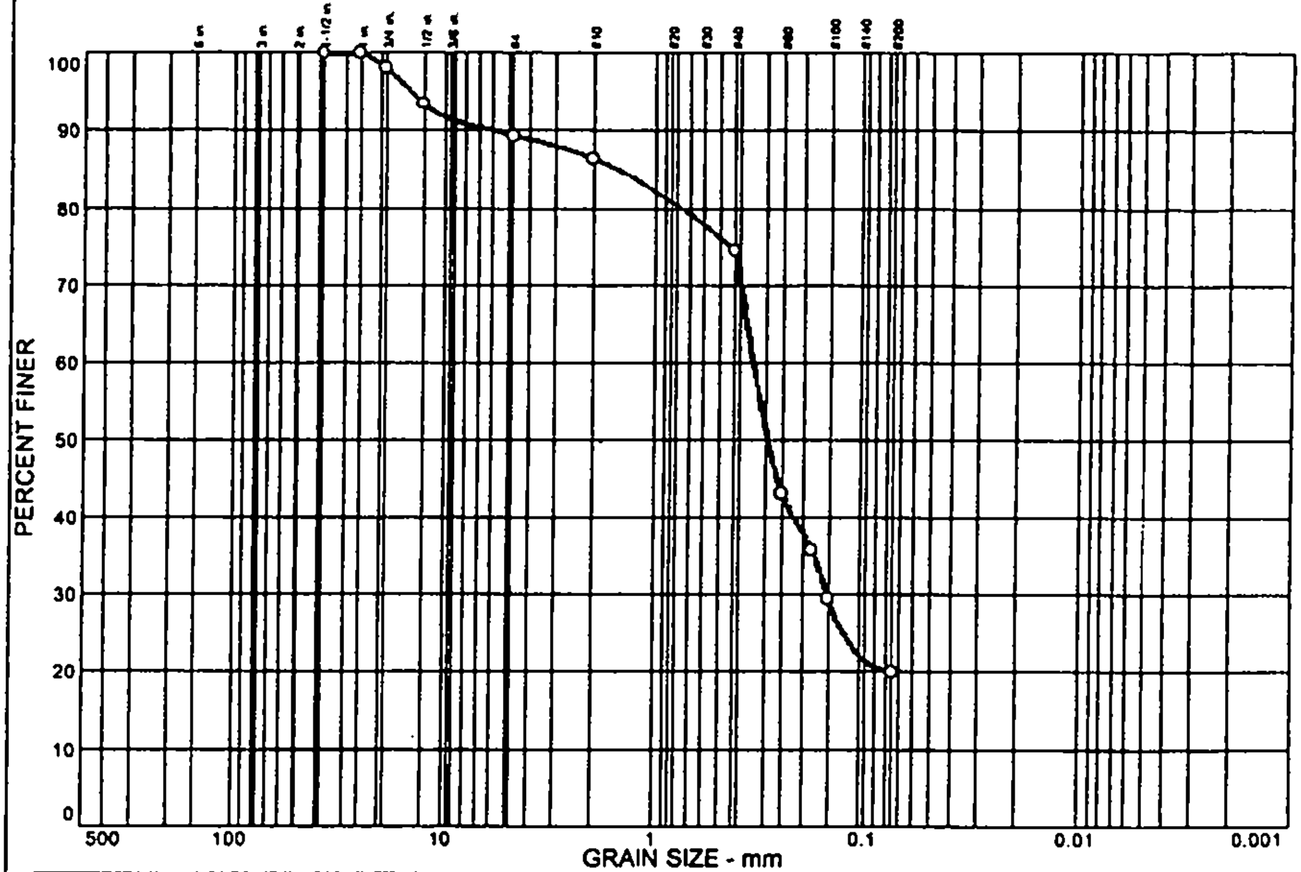
Sample No.: SC-13 **Source of Sample:** SAND CONE DENSITY TEST LOCATIONS **Date:** 06/06/03
Location: **Elev./Depth:**

STS Consultants Ltd.
750 Corporate Woods Parkway
Vernon Hills, IL 60061

Client: GARAN LUCOW MILLER
Project: WPS-EVALUATION OF FAILURE AT SILVER LAKE
Project No: 10452 **Plate**

Figure 4.4.1-8

PARTICLE SIZE ANALYSIS OF SOILS (ASTM D 422)



% COBBLES	% GRAVEL	% SAND	% SILT	% CLAY
0.0	10.7	69.4	19.9	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
1.5 in.	100.0		
1 in.	100.0		
.75 in.	98.0		
.5 in.	93.5		
#4	89.3		
#10	86.4		
#40	74.4		
#60	43.0		
#80	35.7		
#100	29.4		
#200	19.9		

* (no specification provided)

Soil Description

SILTY FINE TO COARSE SAND LITTLE FINE GRAVEL

Atterberg Limits

PL= LL= PI=

Coefficients

D_{85}= 1.54 D_{60}= 0.347 D_{50}= 0.294
D_{30}= 0.153 D_{15}= D_{10}=
C_u= C_c=

Classification

USCS= SM AASHTO=

Remarks

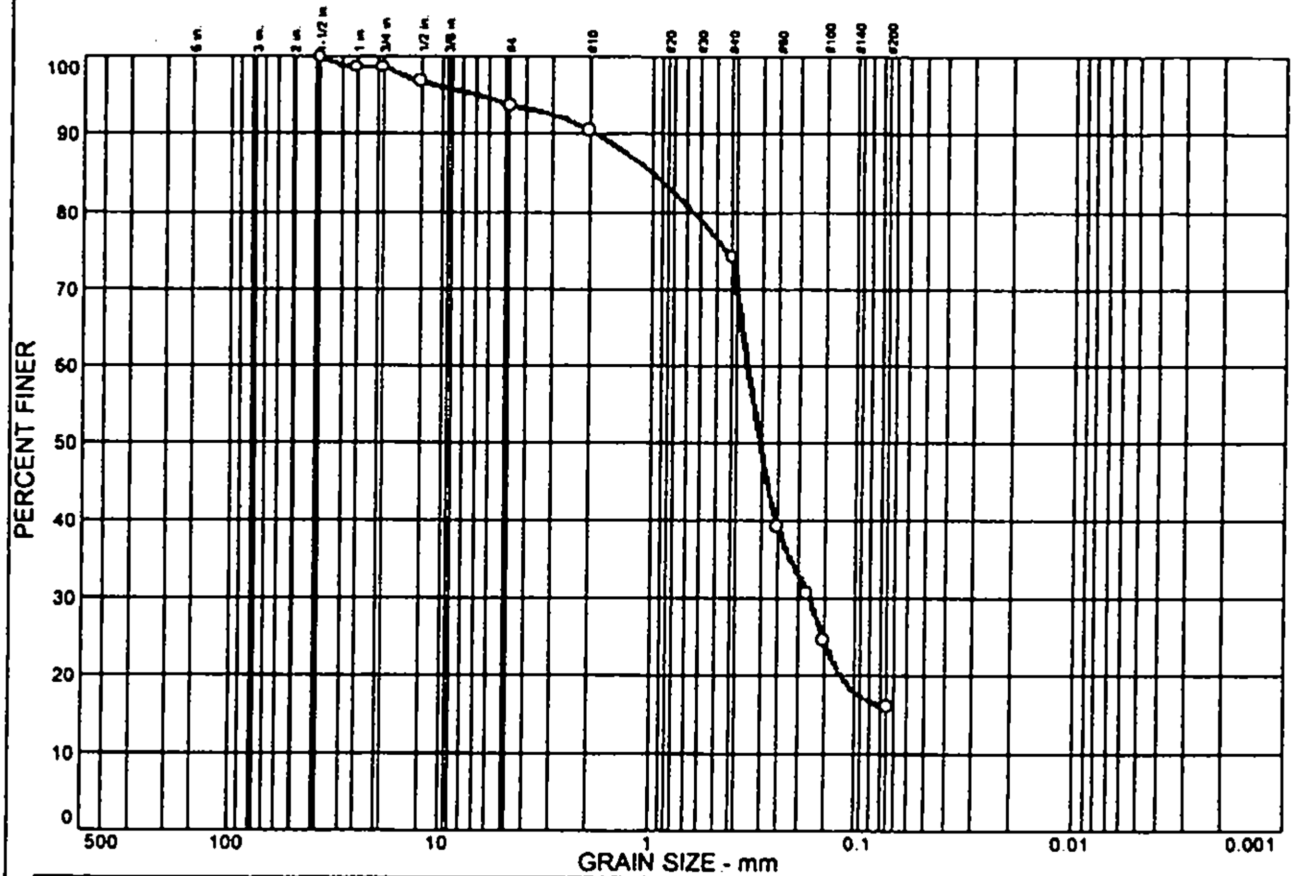
Sample No.: SC-14 **Source of Sample:** SAND CONE DENSITY TEST LOCATIONS **Date:** 06/06/03
Location: **Elev./Depth:**

STS Consultants Ltd.
750 Corporate Woods Parkway
Vernon Hills, IL 60061

Client: GARAN LUCOW MILLER
Project: WPS-EVALUATION OF FAILURE AT SILVER LAKE
Project No: 10452 **Plate**

Figure 4.4.1-9

PARTICLE SIZE ANALYSIS OF SOILS (ASTM D 422)



% COBBLES	% GRAVEL	% SAND	% SILT	% CLAY
0.0	6.4	77.5	16.1	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
1.5 in.	100.0		
1 in.	98.6		
.75 in.	98.6		
.5 in.	96.8		
#4	93.6		
#10	90.5		
#40	74.1		
#60	39.1		
#80	30.6		
#100	24.6		
#200	16.1		

* (no specification provided)

Soil Description

SILTY FINE TO COARSE SAND TRACE FINE GRAVEL

Atterberg Limits

PL= LL= PI=

Coefficients

D_{85}= 1.01 D_{60}= 0.355 D_{50}= 0.308
D_{30}= 0.176 D_{15}= D_{10}=
C_u= C_c=

Classification

USCS= SM AASHTO=

Remarks

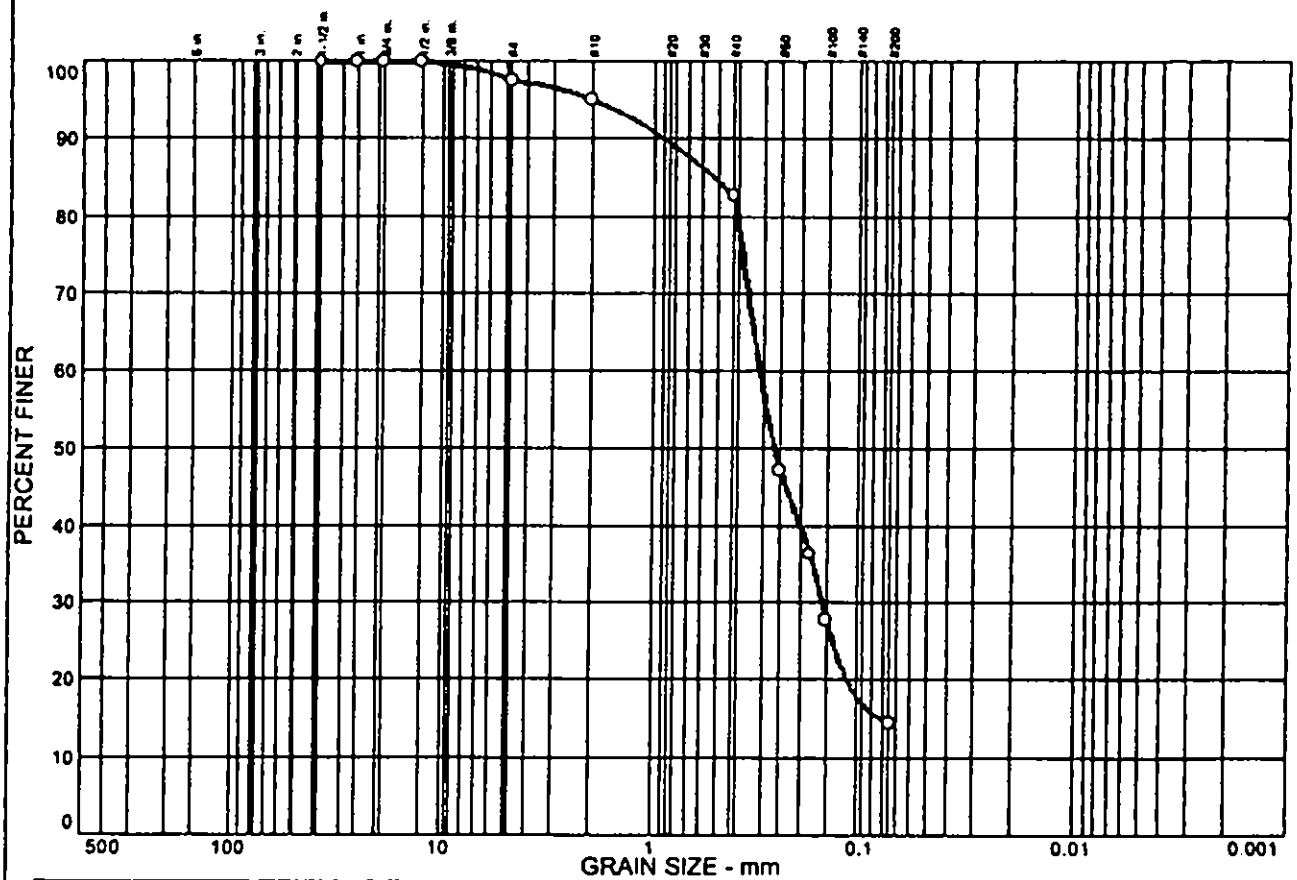
Sample No.: SC-17 **Source of Sample:** SAND CONE DENSITY TEST LOCATIONS **Date:** 06/06/03
Location: **Elev./Depth:**

STS Consultants Ltd.
750 Corporate Woods Parkway
Vernon Hills, IL 60061

Client: GARAN LUCOW MILLER
Project: WPS-EVALUATION OF FAILURE AT SILVER LAKE
Project No: 10452 **Plate**

Figure 4.4.1-10

PARTICLE SIZE ANALYSIS OF SOILS (ASTM D 422)



% COBBLES	% GRAVEL	% SAND	% SILT	% CLAY
0.0	2.5	83.2	14.3	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
1.5 in.	100.0		
1 in.	100.0		
.75 in.	100.0		
.5 in.	100.0		
#4	97.5		
#10	95.1		
#40	82.7		
#60	47.2		
#80	36.4		
#100	27.8		
#200	14.3		

* (no specification provided)

Soil Description

SILTY FINE TO COARSE SAND TRACE FINE GRAVEL

Atterberg Limits

PL= LL= PI=

Coefficients

D_{85}= 0.525 D_{60}= 0.315 D_{50}= 0.266
D_{30}= 0.157 D_{15}= 0.0829 D_{10}=
C_u= C_c=

Classification

USCS= SM AASHTO=

Remarks

Sample No.: SC-22 **Source of Sample:** SAND CONE DENSITY TEST LOCATIONS **Date:** 06/07/03
Location: **Elev./Depth:**

STS Consultants Ltd.
750 Corporate Woods Parkway
Vernon Hills, IL 60061

Client: GARAN LUCOW MILLER
Project: WPS-EVALUATION OF FAILURE AT SILVER LAKE
Project No: 10452 **Plate**

Figure 4.4.1-11

TABLE 7-3. MAXIMUM PERMISSIBLE VELOCITIES RECOMMENDED BY FORTIER AND SCOBEY AND THE CORRESPONDING UNIT-TRACTIVE-FORCE VALUES CONVERTED BY THE U.S. BUREAU OF RECLAMATION*
(For straight channels of small slope, after aging)

Material	n	Clear water		Water transporting colloidal silts	
		V, fps	τ_0, lb/ft²	V, fps	τ_0, lb/ft²
Fine sand, colloidal	0.020	1.50	0.027	2.50	0.075
Sandy loam, noncolloidal	0.020	1.75	0.037	2.50	0.075
Silt loam, noncolloidal	0.020	2.00	0.048	3.00	0.11
Alluvial silts, noncolloidal	0.020	2.00	0.048	3.50	0.15
Ordinary firm loam	0.020	2.50	0.075	3.50	0.15
Volcanic ash	0.020	2.50	0.075	3.50	0.15
Stiff clay, very colloidal	0.025	3.75	0.26	5.00	0.46
Alluvial silts, colloidal	0.025	3.75	0.26	5.00	0.46
Shales and hardpans	0.025	6.00	0.67	6.00	0.67
Fine gravel	0.020	2.50	0.075	5.00	0.32
Graded loam to cobbles when noncolloidal	0.030	3.75	0.38	5.00	0.66
Graded silts to cobbles when colloidal	0.030	4.00	0.43	5.50	0.80
Coarse gravel, noncolloidal	0.025	4.00	0.30	6.00	0.67
Cobbles and shingles	0.035	5.00	0.91	5.50	1.10

* The Fortier and Scobey values were recommended for use in 1926 by the Special Committee on Irrigation Research of the American Society of Civil Engineers.

Figure 4.4.2-1

TABLE 2.--Permissible canal velocities after aging; for channels with linings other than vegetation[1]

Original material excavated	Clear water, no detritus	Water transporting colloidal silts	Water transporting noncolloidal silts, sands, gravels, or rock fragments
	Ft. per sec.	*Ft. per sec.*	*Ft. per sec.*
Fine sand, noncolloidal	1.50	2.50	1.50
Sandy loam, noncolloidal	1.75	2.50	2.00
Silt loam, noncolloidal	2.00	3.00	2.00
Alluvial silts, noncolloidal	2.00	3.50	2.00
Ordinary firm loam	2.50	3.50	2.25
Volcanic ash	2.50	3.50	2.00
Fine gravel	2.50	5.00	3.75
Stiff clay, very colloidal	3.75	5.00	3.00
Graded, loam to cobbles, noncolloidal	3.75	5.00	5.00
Alluvial silts, colloidal	3.75	5.00	3.00
Graded, silt to cobbles, colloidal	4.00	5.50	5.00
Coarse gravel, noncolloidal	4.00	6.00	6.50
Cobbles and shingles	5.00	5.50	6.50
Shales and hardpans	6.00	6.00	5.00

[1] Recommended in 1926 by Special Committee on Irrigation Research, American Society of Civil Engineers.

Although not specifically stated in the original recommendations, these values apply only to channels with mild bed slopes.

Figure 4.4.2-2

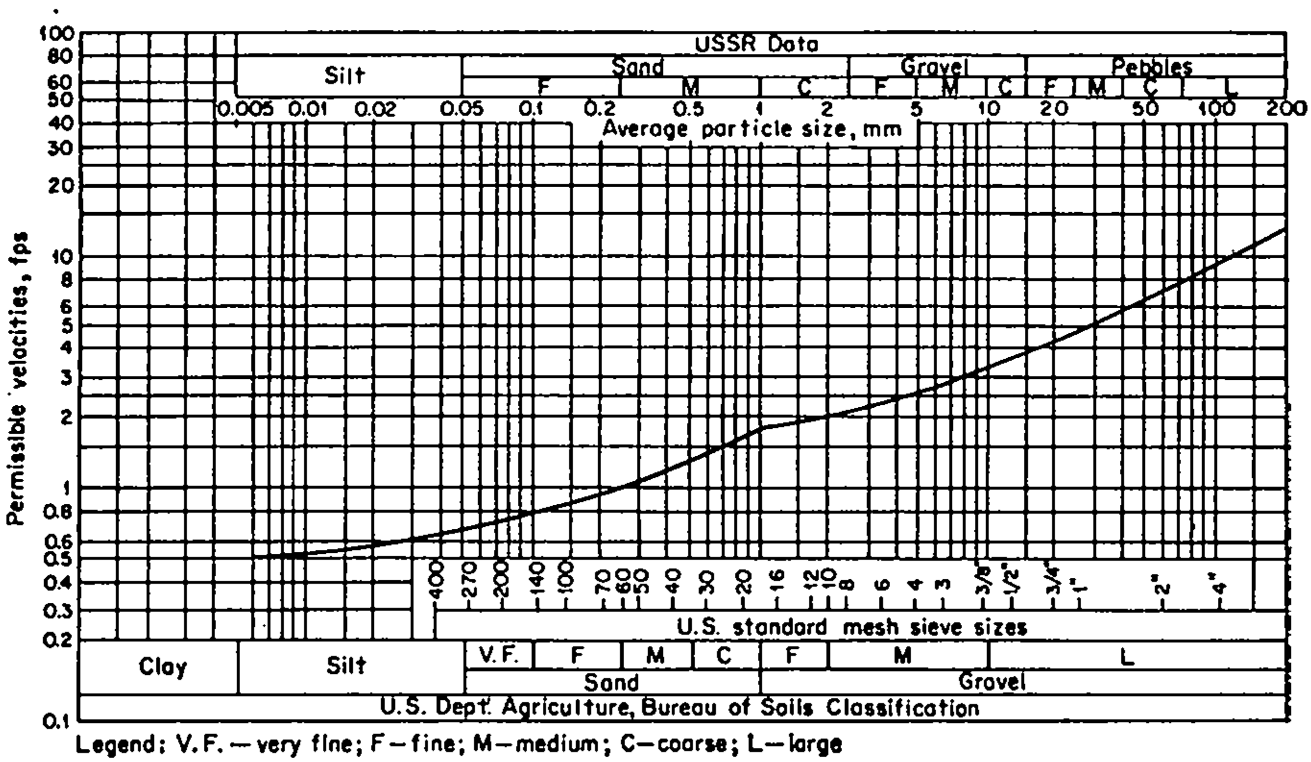


FIG. 7-3. U.S. and U.S.S.R. data on permissible velocities for noncohesive soils.

Figure 4.4.2-3

Cover	Slope range[2]	Permissible velocity[1] Erosion resistant soils[3]	Easily eroded soils[4]
	percent	*m/s (ft/s)*	*m/s (ft/s)*
Bermudagrass	<5	2.43 (8)	1.82 (6)
	5-10	2.13 (7)	1.22 (4)
	over 10	1.82 (6)	0.91 (3)
Bahiagrass Buffalograss Kentucky bluegrass Smooth brome Blue grama Tall fescue	<5 5-10 over 10	2.13 (7) 1.82 (6) 1.52 (5)	1.52 (5) 1.22 (4) 0.91 (3)
Grass mixture Reed canarygrass	[2]< 5-10	1.52 (5) 1.22 (4)	1.22 (4) 0.91 (3)
Sericea lespedeza Weeping lovegrass Yellow bluestem Redtop Alfalfa Red fescue	[5]<5	1.06 (3.5)	0.76 (2.5)
Common lespedeza[6] Sudangrass[6]	[7]<5	1.06 (3.5)	0.76 (2.5)

[1]Use velocities exceeding 1.52 m/s(5ft/s) only where good covers and proper maintenance can be obtained.
[2]Do not use on slopes steeper than 10 percent except for vegetated side slopes in combination with a stone, concrete, or highly resistant vegetative center section.
[3]Cohesive (clayey) fine-grain soils and coarse-grain soils with cohesive fines with a plasticity index of 10 to 40 (CL, CH, SC, and CG).
[4]Soils that do not meet requirements for erosion-resistant soils.
[5]Do not use on slopes steeper than 5 percent except for vegetated side slopes in combination with a stone, concrete, or highly resistant vegetative center section.
[6]Annuals—use on mild slope or as temporary protection until permanent covers are established.
[7]Use on slopes steeper than 5 percent is not recommended.

Exhibit 7-3.—Permissible velocities for channels lined with vegetation.

Figure 4.5-1

APPENDIX A

List of Documents Received from FERC Up To December 8, 2003

1. **Friday, May 30, 2003.**

Date	Author	Title
Nov. 29, 2002	Strat, T. G.	"FERC Final Construction Report For the Period June 19, 2002 to October 8, 2002. Fuse Plug Spillway for Silver Lake, Marquette Co., Michigan,"
August 30, 2003	Strat, T. G.	"FERC Operation Report for the Period Sept. 13, 2001 to June 19, 2002 for Silver Lake Development, Marquette Co., Michigan."
August 29, 2002	Strat, T. G.	"FERC Operation Report for the Period Sept. 13, 2001 to June 19, 2002 for the Hoist Development", Marquette Co., Michigan.
August 29, 2002	Strat, T. G.	"FERC Operation Report, Fourth period Sept. 12, 2001 to June 18, 2002 for the McClure Development, Marquette Co., Michigan."
September 12, 2002	Strat, T. G.	"FERC Operation Report for the Period Sept. 12, 2001 to June 18, 2002 for the Marquette Development - Upper Dam and Plant 2, Marquette Co. Michigan."
September 12, 2002	Strat, T. G.	"FERC Operation Report for the Period Sept. 12, 2001 to June 18, 2002 for the Marquette Development - Lower Dam, Marquette Co. Michigan."
April 6, 2001	Harpole, D. W.	Letter to P. Harding, Re: Dead River Hydros Silver Lake grass lined channel velocity.

Date	Author	Title
May 2001	Harza Engineering Company	"Silver Lake Basin Project Design Report Emergency Fuse Plug Spillway and Channel Design" with some of Appendix A. Complete document?
June 6, 2001	Harpole, D. W.	Silver Lake Fuse Plug, Revised Schedule.
June 28, 2001	P. Harding	FERC Letter to D. W. Harpole, WPSC, Review comments on Design Report, Emergency Fuse Plug Spillway and Channel Design for Silver Lake Development, includes Attachment 1 and 2.
August 30, 2001	P. Harding	FERC to D. W. Harpole, WPSC, Review Comments to WPSC submittal for Quality Control and Inspection Program. P-10855 NATDAM No. MI00197
January 15, 2002	P. Harding	FERC letter to D. W. Harpole, Comments to proposed revised schedule for the design and construction of remedial measures needed at the Dead River Project (Silver Lake, Hoist and McClure developments) and Au Train Project.
February 14, 2002	D. W. Harpole	WPSC letter to P. Harding, FERC, Re: Monthly Status Report Due 15th of the Month on Obtaining Needed Permits.
March 14, 2002	D. W. Harpole	WPSC letter to P. Harding, FERC, Re: Monthly Status Report Due 15th of the Month on Obtaining Needed Permits.
March 2002	MWH	Silver Lake Damn Fuse Plug Spillway and Dam Modifications, Design Report, Appendix A, NA, Appendix B, complete?

Date	Author	Title
March 20, 2002	MWH	Silver Lake Dam Fuse Plug and Dam Modifications Project, Quality Control and Inspection Program, Appendix J-4, QCIP Personnel Resumes, J-5, example reports, J-6, Material Testing Schedule and reference documents, JH-7, Construction Schedule, J-8, Record Keeping Procedures.
April 12, 2002	D. W. Harpole	WPSC letter to P. Harding, FERC, Re: Monthly Status Report Due 15th of the Month on Obtaining Needed Permits
May 14, 2002	D. W. Harpole	WSPC letter to P. Harding, FERC, Re: Monthly Status Report Due 15th of the Month on Obtaining Needed Permits.
June 14, 2002	D. W. Harpole	WSPC letter to P. Harding, FERC, Re: Monthly Status Report Due 15th of the Month on Obtaining Needed Permits.
July 15, 2002	D. W. Harpole	WSPC letter to P. Harding, FERC, Re: Monthly Status Report Due 15th of the Month on Obtaining Needed Permits.
September 18, 2002	Craig Harris, MWH	Fax to M. Davis (CRO) and B. Trotter (UPPCO) Re: Recommend that the "rock trench" be eliminated and request FERC concurrence.
September 18, 2002	Craig Harris, MWH	E-mail to M. Davis (CRO) and B. Trotter (UPPCO) Re: 5 Photos of upstream area of the Fuse Plug channel, and Fuse Plug Foundation.
September 26, 2002	P. Harding	Letter response to D. W. Harpole about e-mail from Craig Harris dated September 18, 2002 requesting FERC concurrence that "rock trench" be eliminated.

Date	Author	Title
November 5, 2002	P. Harding	Letter to D. W. Harpole, WPSC, Fuse Plug Spillway at Silver Lake and Au Train Projects. (Missing page 2 of 3)
December 2002	WPSC	2002 Final Construction Report, Silver Lake Basin Project, FERC Project No. 10855.
May 2003	FERC	CD ROM with the following information 2002 CRO Inspection Reports 11/29/02; Strat, Final Construction Report, Period June 19, 2002 to October 8, 2002 Silver Lake Fuse Plug 08/30/02; Strat, Operation Report, Period Sept. 13, 2001 to June 19, 2002, Silver Lake 8/29/02; Strat, Operation Report, Period Sept. 13, 2001 to June 19, 2002, Hoist Development 8/29/02; Strat, Operation Report, Period Sept. 12, 2001 to June 18, 2002, McClure Development 09/12/02; Strat, Operation Report, Period Sept. 12, 2001 to June 18, 2002, Marquette Development - Upper Dam and Plant 2. 09/12/02; Strat, Operation Report, Period Sept. 12, 2001 to June 18, 2002, Marquette Development - Lower Dam. "Additional Air Photos" Folder containing 24 JPEG Images "Construction Inspection Photos, 10/08/02" Folder; 46 JPEG Images "Construction Inspection Photos, 09/05/02" Folder; 85 JPEG Images "J. H. Evans 5-16-03 Photos" Folder; 36 JPEG Images "Spicer 5-15-03 Photos" Folder; 62 JPEG Images

Date	Author	Title
		"UPPCO 5-15-03 Photos" Folder; 71 JPEG Images

Information on 5/30/05 CD ROM cont'd

Date	Author	Title
June 28, 2001	Harding to Harpole	Letter review comments to Design Report, Emergency Fuse Plug Spillway and Channel Design for Silver Lake Development by Harza Engineering Company
May 22, 2003	Brent Nault ?	Dead River Flood May 14- May 16, 2003 Microsoft Powerpoint Presentation
May 1999	Stone & Webster Michigan, Inc.	"Periodic Safety Inspection Report No. 2, Hoist Hydroelectric Development, Dead River Project FERC Project No. 10855 for Upper Peninsula Power Company, Houghton, Michigan

2. <u>Monday, June 16, 2003 Chicago Regional Office, Mike Davis</u>

Date	Author	Title
December 16, 2002	MWH	Dwg. No. 20895-C1 Area Map, Site Location Map and Site Plan
		Dwg. No. 20895-C2 Main Dam Plan
		Dwg. No. 20895-C3 Main Dam and Spillway Sections and Details
		Dwg. No. 20895-C4 SH.1 Concrete Outlet Structure Sections and Details
December 31, 2002	MWH	Dwg. No. 20895-C4 SH.2 Concrete Outlet Structure, Repaired Sections

Date	Author	Title
December 16, 2002	MWH	Dwg. No. 20895-C5 Fuse Plug and Spillway Channel Plan and Profile
		Dwg. No. 20895-C6 Fuse Plug, Profile and Cross Sections
November 5, 2002	Coleman Eng. Co.	Dwg. No. WSK745 S1 As Built Drawing
?	?	29 Photos with captions. Illustrates Silver Lake Dam and Fuse Plug Spillway as construction progressed.

3. **Wednesday, June 18, 2003, Washington Office, Bill Allerton**

"Silver Lake P-10855, Supporting Reference Materials for PMP/PMF" - Compiled June 16, 2003

Two White Notebooks with 22 Documents, separated by tabs numbering from 1 to 22 as follows.

September 8, 1999	1 - Supplement to 2nd Part 12 Report
January 18, 2000	2 - D2SI-CRO letter - PMF issues
June 6, 2000	3 - D2SI-CRO review of 12/2/1988 letter report
August 1, 2000	4 - D2SI-CRO 7/28/00 summary letter of conference call
August 28, 2000	5 - Public Service (PS) letter PMP&PMF and schedules
October 11, 2000	6 - PS letter Hoist & McClure PMP&PMF study
December 12, 2000	7 - D2SI-CRO e-mail to Harza
December 14, 2000	8 - D2SI-CRO e-mail to Harza

Date	Author	Title
December 15, 2000		9 - D2SI-CRO review of July 1999 Supplement to 2nd Part 12
January 8, 2001		10 - D2SI-CRO e-mail to Harza
January 8, 2001		11 - Harza e-mail to D2SI-CRO
January 12, 2001		12 - D2SI-CRO phone conversation record w/Mr. Bob Edwards
January 30, 2001		13 - PS submits Harza Warm Season PMP study
February 19, 2001		14 - PS submits draft copy of Harza Cool Season PMP
March 12, 2001		15 - D2SI-CRO review of PMP to D2SI-Washington
March 19, 2001		16 - D2SI-CRO review comments of PMP to PS
April 4, 2001		17 - PS submits flood routing of the PMF
June 21, 2001		18 - D2SI-CRO review letter to PS discusses flood routing
August 6, 2001		19 - D2SI-CRO e-mail to Yung Shen
September 27, 2001		20 - PS letter to D2SI-CRO reanalysis of PMF
December 3, 2001		21 - Internal D2SI-CRO memoranda
December 13, 2001		22 - D2SI-CRO letter to PS reviewing PMF headwater el.

Date	Author	Title
4. **Thursday, June 19, 2003,**	**Washington Office, Lula James**	
June 12, 2003	D. Harpole	UPPC to FERC P. Harding Response to Request of Information of June 10, 2003.
June 2, 2003	D. Harpole	UPPC to FERC P. Harding Incident report for Silver Lake Fuse Plug Spillway and Earthen Dike Breach, FERC Project No. 10855
June 13, 2003	?	Dead River Project FERC # P-10855 Status Update: Friday, June 13, 2003
November 5, 2002	P. Harding	FERC to UPPC D. Harpole Re: Fuse plug Spillways at Silver Lake and Au Train projects.
May 16, 2002	P. Harding	FERC to UPPC D. Harpole Re: Dam Safety Modification Design and Quality Control Inspection Program
October 4, 2002	FERC	101 FERC 62, 013 Order Issuing Original License for the Project 10855-002, Upper Peninsula Power Company
August-October 2002?	?	46-8 ½" x 11" photos of Silver Lake Dam and Fuse Plug Spillway
June 10, 2002	? UPPCO	McClure, Reservoir elevation and generation data
May 9, 2003	Marquette Co. Road Comm. ?	Frost Test Data Sheets
May 15, 2003	Marquette Co. Road Comm. ?	Frost Test Data Sheets
March 19 to April 28, 2003	Marquette Co. Road Comm.	Frost tube readings from #7 and #10 Frost Tubes, with location map

Date	Author	Title
?	National Weather Service Cooperative Observers And Snow Spotters	9-8 ½" x 11" color print outs - 2002-2003 Season Snowfall totals - Feb. 11, 2003 Snow Water Equivalent Values - Feb. 18, 2003 Snow Water Equivalent Values - Feb. 25, 2003 Snow Water Equivalent Values - Mar. 3, 2003 Snow Water Equivalent Values - Mar. 13, 2003 Snow Water Equivalent Values - Mar. 20, 2003 Snow Water Equivalent Values - April 1, 2003 Snow Water Equivalent Values - April 9, 2003 Snow Water Equivalent Values
?	STS Consultants, Ltd. & Midwest Regional Climate Center	May 2003 Precipitation for Marquette, MI Station ID # 205178
June 11, 2003	?	Rainfall reports from Mother's Day Weekend rain event; Also 8½" x 11" color printout "Multi-sensor Precipitation Estimates from May 9 to May 13, 2003 derived from gage readings and radar estimates"
?	UPPCO	Hydro Plant Operating Procedure Subject: · Silver Lake project description · Installation of Stop Logs at the out-flow structure · Silver Lake Main Valve · Instrumentation Data Collection and Evaluation Procedure
July 1, 2002	B. Trotter (UPPCO)	Pre-Construction Meeting Minutes, Silver Lake Fuse Plug and Dam Modification (Date ?)

Date	Author	Title
August 13, 2002	B. Trotter	Construction Meeting No. 1, Meeting Minutes (Date ?)
August 30, 2002	B. Trotter	Construction Meeting No. 2, Meeting Minutes (Aug. 27, 2002)
September 10, 2002	B. Trotter	Construction Meeting No. 3, Meeting Minutes (Sept. 10, 2002)
September 24, 2002	B. Trotter	Construction Meeting No. 4, Meeting Minutes (Sep. 24, 2002)
October 9, 2002	B. Trotter	Construction Meeting No. 5, Meeting Minutes (Oct. 9, 2002)
October 25, 2002	B. Trotter	Construction Meeting No. 6, Meeting Minutes (Oct. 22, 2002)
?	UPPCO	Silver Lake Elevation from 5/30/01 to 5/16/03 with Excel plot of Lake Elevation vs Data.
?	UPPCO	McClure Head Water Elevation, Dates with Generator output and flow discharge from 10/15/02 to 5/31/03.

5. **Tuesday, July 1, 2003, CRO, Mike Davis**

December 1995	Stone & Webster Michigan, Inc. Denver, CO	"Recommended Modifications Dead River Hydroelectric Project Silver Lake Development, Hoist Development, McClure Development"
December 1985	US Bureau of Reclamation	Hydraulic Model Studies of Fuse Plug Embankments

	Date	Author	Title
6.	**Tuesday, July 1, 2003, Washington Office, Bill Allerton (e-mail)**		
	1986	Soil Conservation Service	Engineering Field Handbook, Chapter 7, Grassed Waterways
	?	Soil Conservation Service	AH 667, Chapter 4, Grass-Lined Channel Design
7.	**Thursday, July 10, 2003, Washington Office, Bill Allerton (e-mail)**		
	?	Frank Calcagno	Geology Description of Foundation Materials-Fuse Plug at Dike #2
8.	**Thursday, July 24, 2003, FERC, CRO, M. Davis (e-mail)**		
	July 24, 2003	FERC Team	Initial Report of Findings, FERC Investigation of Activation of Fuse Plug Spillway, May 14, 2003, 1st Draft

James H. Evans – Senior Geotechnical Engineer, FERC-HQ – Team Lead
Steve A. Collins, Ph.D. – Lead Engineer, FERC, Atlanta
Michael S. Davis – Lead Engineer, FERC, Chicago
Jerrold W. Gotzmer – Regional Engineer, FERC, Atlanta
John K. Hawk – Deputy Regional Engineer, FERC, Chicago
Thomas J. Lovullo – Fisheries Biologist, FERC-HQ
Jessica Mistak – Fisheries Biologist, Michigan DNR
Jinm Pawlowski – Michigan DNR, Dam Safety
Teresa Schwalbach – Marquette County EOC Manager
Takeshi Yamashita – Regional Engineer, FERC, San Francisco

9. **Friday, July 25, 2003, FERC, CRO, P. Harding (by FedEx)**

July 24, 2003 Hard Copy of Item listed in 8 above.

	Date	Author	Title
10.	**Monday, July 28, 2003, FERC, Washington Office, Bill Allerton by regular mail**		
	July 16, 2003	STS Consultants Ltd. for WPSRC	Drawing - GB-0325 Silver Lake Air Photos with superposed 1 foot contour intervals.
	July 16, 2003	STS Consultants Ltd. for WPSRC	Compact Disc - GB-0323 Silver Lake air photos with superposed 1 foot contour intervals.
11.	**Monday, July 28, 2003, FERC, Washington Office, James Evans (e-mail)**		
	July 28, 2003	FERC, Washington	Silver Lake Meeting Agenda for July 31 and August 1, 2003.
12.	**Thursday and Friday, July 31 and Aug. 1, 2003, Meeting at FERC Washington**		
	1975	Soil Conservation Service	Engineering Field Manual; Preface and Table of Contents
	Sept. 1987	Temple, Robinson, Ahring, and Davis	Stability of Grass-Lined Open Channels, USDA, Agriculture Handbook 667. Chapter 4, "Grass-lined Channel Design," by D. M. Temple, pp. 51-70.
	?	?	Chapter 7, Grassed Waterways
	March 1947	Stillwater Outdoor Hydraulic Laboratory, Stillwater, Oklahoma	USDA, Handbook of Channel Design for Soil and Water Conservation
13.	**Monday, August 4, 2003, FERC, CRO, Mike Davis (e-mail)**		
	Aug. 4, 2003	M. Davis	Silver Lake headwater elevations, 1957 through 1993; (pdf file) Originally from Bob Meyers (WPSR) to Mike Davis (FERC-CRO)

Date	Author	Title
May 6, 1999	?	2 pages, Table 5-1, Summary of Piezometric Data – Silver Lake Dam, Group 1 (data from 10 Aug. 92 to 4 Aug. 98)
?	?	2 pages, Table of Silver Lake Piezometer Readings (data from 3 Mar. 00 to 7 Dec. 02)
July 23, 2003	D. Harpole (UPPC)	To P. Harding (FERC) Cover letter with Attachments containing - Soil parameter test results - Location Diagram - In particular • Document #GB-0352 - Particle Size Analysis of Soils(STS Consultants, Ltd.) • Document #GB-0353 - Particle Size Analysis of Soils (STS Consultants, Ltd.) • Document #GB-0354 - Particle Size Analysis of Soils and Sand Cone Field Density Tests (STS Consultants, Ltd.) • Document #GB-0355 - Specific Gravity of Soils, Particle Size Analysis of Soils, Liquid and Plastic Limits Test of Soils, Direct Shear Tests of Soils, Moisture Density Relationship of Soils (STS) • Document #GB-0356 - Boring Logs 1, 2, 2A, 3, 3A, 3B, 3C, 4, 4A, 4B, 4C, 5, 6 • Document #GB-0357 - Plan view Location map for STS Borings (1 - 8 ½ x 11 sheet) • Document #GB-0358 - Moisture Content Data Sheet, STS • Compact Disk of Silver Lake Soil Parameters dated 7/23/2003

14. Wed., Aug. 13, 2003, FERC, e-mails

Aug. 13, 2003	M. Davis (CRO)	e-mail of photos taken by UPPCo operators on 5-14-2003

Date	Author	Title
Aug. 13, 2003	Bill Allerton	e-mail stating CD of UPPCo 5-14-2003 photos along with additional Board requested information would be put in the mail for delivery to each board member.
Aug. 13, 2003	Jim Evans	Comments on UPPCo 5-14-03 Operator's photo P5140051.JPG

15. Monday, Aug. 18, 2003, FERC, Washington, mail

Date	Author	Title
Aug. 5, 2003	J. Myers (WPSC)	Transmittal letter to Mr. C. G. Tjoumas (FERC) with large plan drawing illustrating Soil Testing Locations (drawing by STS)

16. Thursday, Aug. 21, 2003, FERC, Washington Office by regular mail

Date	Author	Title
Aug. 11, 2003	Paula Coates (WPSC)	Silver Lake Document Transmittal Letter
Aug. 11, 2003	D. W. Harpole	2 page letter to Mr. Tjoumas Re: Additional Information on Fuse Plug Spillway, 7 items addressed.
May 14, 2003	Silver Lake Operator (WPSC)	GB-0415 Compact Disc of photographs of Silver Lake taken by the operator on May 14, 2003. Hard copy of photos Fig. 1 through Fig. 18
1988	National Climatic Data Center	Document No. GB-0468 "Climatological Data Annual Summary, Michigan," 1988, Volume 103, No. 13
1996	?	Document No. GB-0469 "Total Precipitation and Departures from Normal," Michigan, 1996.

Date	Author	Title
2002	National Climatic Data Center	Document No. GB-0470 2002 Michigan, Monthly Station and Division Summary, Volume 117
?	WPSC	Document No. GB-0474, Silver Lake Basin Elevation (Lake level) Plot and data from 3 April 95 through 3 Dec. 2002.
	WPSC	Lake elevation table from 1957 to 1993.
1985	Jones, Marold And Borg	Document No. GB-0475 "Fuse Plug Structures Designed to Fail"
16 Dec. 2002	MWH	Document Nol GB-0017; As built drawings of Silver Lake Basin Project, Drawings: 20895-C1 20895-C2 20895-C3 20895-C4 Sh.1 20895-C4 Sh.2 20895-C5 20895-C6 WSK745 S1 WSK745 S4

17. Friday, Sept. 5, 2003, FERC, Washington Office by Fed. Ex. from Mr. Jim Evans

Group of Drawings prepared by STS as bid documents for UPPCO to install a temporary control structure upstream of the previous fuse plug location.

STS Drawings 1 through 9 of Job No. 10452A

Date	Author	Title

18. Thursday, Sept. 25, 2003, FERC, Washington Office, Mr. Bill Allerton (e-mail)

- e-mail from Bill Allerton, informing Independent Review Team members they will receive MWH written response to Questions from 9/11/03. (These questions took the place of a phone interview with MWH)
- e-mail from Bill Allerton; Re: Question to Mr. Harpole (WPSCo) with respect to material observed, on reservoir side, between concrete spillway and fourth bay stop logs; could material have been placed there by UPPCO personnel?

19. Friday, Sept. 26, 2003, FERC, Washington Office by Fed Ex, from Lula James

Date	Author	Title
19 Sept. 2003	MWH American, Inc.	Response to Questions from the Independent Consultants Review Team for Silver Lake, dated 11 Sept. 2003. Included are color copies of 42 photos taken at the Silver Lake Fuse Plug during construction.

20. Monday, Sept. 29, 2003, FERC, Washington Office by Fed Ex, Mr. Bill Allerton

Date	Author	Title
July 1984	Soil Conservation Service	Engineering Field Manual, Chapters 1, 2, 3, 4, 5, 6, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19.

21. Friday, Oct. 3, 2003, FERC, CRO, e-mail from M. Davis

Date	Author	Title
Aug. 8, 2001	WPSR	UPPCo Silver Lake Basin Project Fuse Plug Spillway Spec. No. UPC-SL-251671 Project No. 010001.202; Sections: Division 1, 4 pages of 4 pages Division 2, 4 pages of 4 pages Division 3, 22 pages of 22 pages Section 1, 2 only 1 page of 15 pages

	Date	Author	Title
22.	**Friday, Oct. 10, 2003, FERC, CRO, Fed Ex from M. Davis**		
	Oct. 6, 2003	Washington Group International for UPPCo	Silver Lake Dam: Root Cause Report on the May 14, 2003 Operation of the Fuse Plug Spillway and Subsequent Channel Erosion Resulting in the Uncontrolled Release of Silver Lake
23.	**Friday, Oct. 31, 2003, FERC Washington, D.C. Office, Fed Ex. Package**		
	Oct. 24, 2003	MWH Americas, Inc.	Silver Lake Reservoir Fuse Plug Release, Marquette County, Michigan, May 2003, FACTS, OBSERVATIONS AND DISCUSSION
24.	**Thursday, Nov. 6, 2003, FERC, CRO, M. Davis, 17 page FAX**		
	Dec. 3, 2001	M. Davis	Memorandum to P. Harding, "Dead River Project No. 10855-MI Probable Maximum Flood Study, Upper Peninsula Power Company"
	Attachments to Dec. 3, 2001 Memo are listed below as items a-e		
a)	Sept. 27, 2001	D. Harpole, WPSCo	Letter to P. Harding, "Dead River Project PMF water levels (FERC Project No. 10855)"
b)	Sept. 24, 2001	C. Harris, MWH	Letter to R. Edwards (WPSCo) "Effect of Starting Water Levels on PMF Routing for Dead River Project"
c)	Nov. 5, 2001	Yung Shen, MWH	e-mail to M. Davis "Response to your Nov. 2, 2001 Questions"
d)	June 21, 2001	John Hawk for P. Harding (FERC, CRO)	Letter to D. Harpole (WPSCo)

	Date	Author	Title
e)	?	P. Harding (FERC.CRO)	Draft letter to D. Harpole (WPSCo) "Attachment 4"
	Dec. 13, 2001	J. Hawk for P. Harding (FERC, CRO)	Letter to D. Harpole, response to Harpole letter Sept. 27, 2001 transmitting C. Harris letter dated Sept. 24, 2001.

25. Friday, Nov. 7, 2003, FERC, CRO, M. Davis e-mail

PMF Reservoir Routing Analyses, cases requested by FERC Independent Consultants Review Panel

B - Prior to construction with Dikes 1, 2, 3 & 4 at 1489, stop logs at 1486.25, low level outlet set @ 283 cfs and reservoir start at el. 1481.5

A - Dam and All Dikes 1, 2, 3 & 4 raised to 1491.5, stop logs at 1486.25, low level outlet set @ 283 cfs, reservoir start at el. 1481.5

– Dam and All Dikes 1, 2, 3 & 4 raised to 1491.5, stop logs at 1486.25, low level outlet set @ 20 cfs, reservoir start at 1481.5

26. Monday, Nov. 10, 2003, FERC, CRO, M. Davis e-mail

Document A - Inflow, reservoir stage and discharge hydrographs for case A of item #24 of this list.

27. Wednesday, Nov. 12, 2003, FERC, CRO, M. Davis e-mail

Document A
Document B - Inflow, reservoir stage and discharge hydrographs for cases A and B of item #24 of this list.

Date	Author	Title
28.	**Wednesday, Nov. 12, 2003, FERC, CRO, M. Davis e-mail**	
	Washington Group - International (13 Oct. 2003 report)	Monthly Reservoir Elevations document
	Document D -	PMF Reservoir Routing Analysis requested by FERC Independent Consultants Review Board, case D, Dam and all Dikes 1, 2, 3 & 4 raised to el. 1491.5, stop logs removed (el. 1480.25) low level outlet set @ 20 cfs, reservoir start at el. 1480.25. Also inflow, reservoir stage and discharge hydrographs for this case D
29.	**Wednesday, Nov. 12, 2003, FERC, CRO, M. Davis e-mail**	
	Document E -	PMF Reservoir Routing Analysis requested by FERC Independent Consultants Review Board, Case E, Dam and All dikes 1, 2, 3 & 4 raised to el. 1491.5, stop logs at el. 1482.5, low level outlet set @ 283 cfs, reservoir start at el. 1481.5. Also inflow, reservoir stage and discharge hydrographs for this case E.
30.	**Tuesday, Nov. 18, 2003, FERC, CRO, M. Davis e-mail**	
	-	Reservoir Routing Analysis to determine the event that would cause reservoir rise to the pilot channel invert el. 1485.5, given Dam and all dikes 1, 3 & 4 raised to el. 1491.5, stop logs at el. 1482.5, low level outlet set at 20 cfs, reservoir start at el. 1481.5

Date	Author	Title

31. Wednesday, Nov. 19, 2003, FERC, CRO, John K. Hawk, Fed Exp. package

Seven FERC, CRO, Prelicense Operaton Reports on Silver Lake Dev. for periods of:

1. Sept. 22, 1992 to Sept. 13, 1994 by M. Davis
2. Sept. 13, 1994 to Sept. 25, 1996 by M. Davis
3. Sept. 25, 1996 to Sept. 23. 1997 by M. Davis
4. Sept. 24, 1997 to Aug. 25, 1998 by T. Verges
5. Aug. 26, 1998 to Aug. 10, 1999 by T. Verges
6. Aug. 11, 1999 to Aug. 22, 2000 by T. Verges
7. Aug. 22, 2000 to Sept. 12, 2001 by T. Strat

32. Wednesday, Nov. 26, 2003, FERC, CRO, Mike Davis, Fed Ex Envelope

January 30, 1987	L. Coffill, FERC, CRO	"Special Inspection Unlicensed Project No. 31-49 - Hoist Projects Dead River Marquette County, Michigan" Inspection by T. Smith
November 18,1988	R. Lesniak, FERC, CRO	"Special Inspection of Unlicensed Hoist Project, No. 31-49 on the Dead River, owned by Upper Peninsula Power Company Houghton, Michigan" Inspection by S. Spicer

Date	Author	Title
November 15,1990	R. Lesniak, FERC, CRO	"Special Inspection of Unlicensed Hoist Project No. 10855 on the Dead River, Owned by Upper Peninsula Power Company, Houghton, Michigan" Inspection by R. Rysdam and A. Pawelek
March 10, 1993	R. Lesniak, FERC, CRO	"Special Inspection of Unlicensed Hoist Project No. 10855 on the Dead River, owned by Upper Peninsula Power Company, Houghton, Michigan" Inspection by R. Rysdam

33. Friday, Dec. 5, 2003, FERC, CRO, Mike Davis, e-mail

PMF Reservoir Routing Analyses, cases requested by FERC Independent Consultants Review Board.

Document G - Reservoir routing analysis case G, Dam and All dikes 1, 2, 3 & 4 raised to 1491.5, Stop logs at 1482.5, low level outlet set @ 20 cfs, reservoir start at el. 2481.5. Also inflow, reservoir stage and discharge hydrographs for this case G.

Document F - HEC-1 output file for item 29 of this list.

34. Monday, Dec. 8, 2003, FERC, CRO, Mike Davis, e-mail

Inflow, Reservoir Stage and Discharged Hydrographs for Case C, originally received on 7 Nov. 2003

Document C - PMF Reservoir Routing Analysis requested by FERC Independent Consultant Review Board, Case C, Dam and All Dikes 1, 2, 3 & 4 raised to 1491.5, stop logs at el. 1486.25, low level outlet set @ 20 cfs, reservoir start at el. 1491.5