Initial Report of Findings

FERC Investigation of Activation of Fuse Plug Spillway
May 14, 2003

Silver Lake Basin
Dead River Project No. 10855
Marquette County, MI
Upper Peninsula Power Company

Draft: July 24, 2003

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Preface

The purpose of this report is to present the findings of a team assembled by the Director, Division of Dam Safety and Inspections to investigate and document events surrounding the failure of the Silver Lake Basin fuse plug emergency spillway on May 14, 2003. The team was charged with gathering all available information on the design and construction of the fuse plug; the events leading to the fuse plug activation; and the subsequent impacts affecting downstream lives, property, infrastructure, and the natural environment. As necessary, additional analyses were conducted to better understand the events and impacts of the incident.

The process included a visit to the project site, interviews with the owner's management and operations staff at the site and in the FERC Chicago Regional Office, an interview of a representative of the design consulting firm in Chicago, and a review of the design analyses in light of actual events and available data. The report is intended to provide information and data to the independent Board of Consultants engaged by FERC to investigate the failure.

Listed below are the members of the team responsible for preparation of this report:

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I. Executive Summary

Late in the afternoon on Wednesday, May 14, 2003, high and turbid flows were observed in the Dead River several miles downstream of the remote Silver Lake Basin in Marquette County, Michigan. An operator was dispatched to the site and found that a fuse plug embankment (a feature designed to fail sacrificially to prevent failure of more critical project works) had failed. The fuse plug embankment was entirely eroded away, and erosion had progressed well into the discharge channel bottom and side slopes. The dam owner activated the emergency action plan, and steps to protect downstream lives and property were initiated. During the subsequent 24-hour period, over 1700 residents were evacuated, several local road bridges and an abandoned railroad bridge were damaged or washed out, a dam near the mouth of the Dead River was overtopped and failed, a large coal-fired power plant was shut down due to flooding, and two mines that rely on electric power from the power plant were shut down. There was extensive erosion of the river banks and significant impacts to the Dead River fishery. No loss of life or personal injuries occurred.

The Silver Lake Basin is a storage reservoir near the headwaters of the Dead River in the Upper Peninsula of Michigan. It is owned and operated by the Upper Peninsula Power Company (UPPCO), and is used to augment flows for power generation at UPPCO's two downstream hydropower projects, Hoist and McClure. Silver Lake, Hoist and McClure are all included in FERC Licensed Project No. 10855. Downstream of McClure Dam, the City of Marquette Board of Light and Power has two dams, Forestville and Tourist Park, which also have hydropower plants associated with them and are licensed by FERC (Project No. 2589). The Dead River flows generally in an easterly direction, emptying into Lake Superior about a mile below the Tourist Park Dam.

The Silver Lake impoundment structures consist of the main earthen embankment, which incorporates a low level outlet structure and a concrete overflow spillway, and three detached embankments (dikes) that fill low points in the reservoir shoreline near the main dam. Dike No. 2 was removed in September of 2002 and was reconstructed as a fuse plug section to increase spillway capacity for extreme flood events.

Conditions in the watershed prior to May 14, 2003, were not untypical for the time of year in the Upper Peninsula. By May 1, essentially all snow pack had melted, with only a few scattered pockets of snow on north-facing slopes. Frost depth during the winter was greater than normal, reportedly up to eight or nine feet, which could have resulted in higher than expected runoff in areas that were still frozen. Between May 9 and 14, significant rainfall was experienced in the area, with most falling on May 10 through 12. In the immediate area of the Silver Lake watershed, it appears that about four to five inches of rain fell during that 48 hour period. While significant, this rain event was not considered extreme by most of the people the team interviewed. By comparison, four to five inches of rain is about equal to a 100-year, 24-hour event, and similar to about 20 percent of the 72-hour warm season probable maximum precipitation (PMP).

Based on the team's review of available design information, National Weather Service records and comments, and interviews with representatives of the licensee, design consultant, emergency management personnel and others, factors contributing to the activation of the fuse plug were uncovered in the areas of: 1) hydrologic and hydraulic design, 2) geotechnical aspects of the fuse plug, and 3) operation of the reservoir.

A. Hydrologic and Hydraulic Design Factors

The fuse plug was designed to allow passage of the probable maximum flood (PMF) without causing the main dam embankment to be overtopped. The main concrete overflow spillway crest is at elevation 1486.25 feet. One of the ten bays of the spillway is fitted with stop logs which could be removed down to about elevation 1480.25 feet. The consultant's initial design was based on a starting water surface elevation of 1481.5 feet, which is shown as the "normal maximum" water level on the design drawings. Later, the design was re-evaluated by the consultant using a normal maximum pool elevation of 1482.5 feet based on the licensee's planned procedures for operating the reservoir. The consultant determined and FERC agreed that starting at elevation 1482.5 feet would not impact the ability of the dam to safely pass the PMF with this design. The design included the provision that the stop logs be removed to elevation 1482.5 feet. The top of the fuse plug embankment was designed to be at elevation 1486.5 feet, with two pilot channels set at 1485.5 feet.

While the design was based on accommodating the full PMF, there is no indication in the design record of the magnitude or frequency of the minimum flood event that would cause overtopping of the fuse plug pilot channels. However, during the interview process, the MWH representative stated that the dam could pass the 500-year event without activating the fuseplug based on the rated capacity of the low-level outlet and the stoplog bay with the stoplogs removed to elevation 1482.5 feet, if the reservoir were at elevation 1481.5 feet prior to the event. The design resulted in the fuse plug being overtopped before any flow would pass over the concrete ogee bays of the main spillway, thereby effectively making the fuse plug channel the primary flood discharge facility at the site.

Another hydraulic design consideration is in the computation of the discharge velocity in the exit channel. Based on the consultant's design, a grass lining was considered sufficient to prevent extreme erosion of the channel. The March 2002 design report only discussed entrance velocities. As a follow-up analysis, the team's computer analysis of the exit channel indicated that the exit velocities would have been close to 14 fps for the PMF, with supercritical flow in the grass-lined portion of the exit channel and a hydraulic jump at the transition to natural ground. The velocity in the exit channel is substantially higher than the entrance velocities the consultant used in the design to support the use of a grass-lined channel for both the entrance and exit channels. Irregardless, the licensee reported that the grass had not become established prior to the May 2003 event.

B. Geotechnical Aspects

The fuse plug was designed according to the United States Bureau of Reclamation REC-ERC-85-6, 1985. The fuse plug design cross section contains small zones that would make construction difficult. However, the construction photos reviewed to date show considerable attention was being paid to lay out and placement of the various zones. The breach removed all of the fuse plug dike, preventing a forensic analysis of the as-built condition.

The fuse plug breach could have been activated by the several inches of flow over the pilot channel, although other mechanisms are possible. The fuse plug was sited over drag-line pits from 1940's construction, which could represent a foundation weakness with regards to seepage and piping.

Regardless of what mechanism initiated the fuse plug dike breach, the downstream consequences would have been minor if the channel floor had remained in place with a sill elevation of 1481.0 feet. Channel erosion allowed the entire reservoir to empty in a relatively short time period. Channel erodability for the sand foundation was considered in the design, and grass was chosen as the defensive feature. The design noted a grass lined channel on these foundation soils could sustain 6-7.5 fps, and compared this to the 4 hour duration that would be exceeded in the entrance channel. A more appropriate design consideration would be the exit channel velocity, with calculated velocities of about 14 fps for the PMF and 10 fps for the reservoir elevation at the top of the pilot channel.

C. Operational Factors

On May 7, 2003, the last time the operators were at the site prior to the event, the reservoir level was at elevation 1483.35 feet, and the outlet facility was set to pass only the required minimum flow of 20 cubic feet per second (cfs). As noted above, the fuse plug design was predicated on the permanent removal of the stop logs to elevation 1482.5 feet. This was not done. New stop logs were placed in the summer of 2002 to a level slightly below the concrete crest of the adjoining ogee bays (1486.25 feet). If the stop logs had been removed and the reservoir level maintained at elevation 1482.5 feet prior to the rain event, the team's analysis indicates the reservoir would not have risen to the level of the fuse plug pilot channels for this rain event.

The licensee's operations personnel state that they were not aware of the operating constraints and stop log removal requirement detailed in the March 2002 design report and discussed in correspondence with the licensee's management from both the consultant and the Regional Engineer.

The fuse plug channel, as designed and constructed, was the principal spillway for flood events, but was not designed with the features of a principal spillway which would have prevented evacuation of the reservoir.

II. Project Descriptions

The Dead River rises in the northwest corner of Marquette County, Michigan, about 20 miles south of Lake Superior in Michigan's Upper Peninsula. The river flows generally in an easterly direction, emptying into Lake Superior in the city of Marquette. There are five reservoirs on the river, all associated with FERC licensed projects. The upper reservoirs are in the Dead River Project No. 10855, followed by the Marquette Project No. 2589. The project features are described below:

A. Dead River Hydroelectric Project No. 10855, Upper Peninsula Power Company

From upstream to downstream, the Dead River Hydroelectric Project consists of the Silver Lake Development (Reservoir No. 10855-01), Hoist Development (10855-02), and McClure Development (10855-03). The Silver Lake Development consists of the following structures: (1) a 1500-foot long earth embankment that has a maximum height of 30 feet; (2) a 100-foot long, 7.7-foot high, overflow concrete gravity spillway containing ten 9-foot long bays; (3) a 14.8-foot long, 34-foot high, non-overflow concrete gravity section containing a low level outlet structure; (4) four remote saddle dikes. Dikes 1, 2, 3 and 4 that are approximately 200 feet, 370 feet, 170 feet, and 290 feet long, respectively, ranging in height from 5 feet to 7 feet. Dike 2 was reconstructed as a fuseplug embankment in the fall of 2002. The storage capacity of the reservoir is 33,513 acre-feet at elevation 1486.25 feet, the crest elevation of the overflow spillway. The dam is classified as having a high hazard potential.

The Hoist Development consists of a 3,674-foot long dam consisting of the following structures: (1) a 1,232-foot long, 48-foot high concrete gravity non-overflow section which includes an 81-foot long, 11-foot high thin wall section near the left abutment; (2) a 32-foot long concrete buttress; (3) a 440-foot long, 63-foot high concrete gravity arch spillway consisting of two non-overflow side sections with 1.9-foot high flashboards and a center ogee spillway section with 2.9-foot high flashboards; (4) a 630-foot long, 20-foot high concrete gravity non-overflow section; and (5) a 1,340-foot long, 45-foot high earth embankment section; (6) a separate intake tower located in the reservoir just upstream of the left buttress which leads to a 342-foot long rock tunnel,10 feet high and 9 feet wide and a 7-foot diameter 193-foot long steel penstock. The dam is 63 feet high and impounds 31,563 acre-feet of water. The dam is classified as having a high hazard potential.

The McClure Development consists of the following structures: (1) 360-foot long, 22-foot high left earth embankment; (2) an 86.6-foot long, 37.5-foot high concrete gravity intake section; (3) a 66.5-foot long, 37-foot high concrete gravity non-overflow section; (4) a 199.7-foot long, 51.4-foot high concrete gravity overflow spillway; (5) a 114-foot long, 46.5-foot high concrete gravity non-overflow section; (6) a 13,302-foot long, 7-foot diameter penstock which leads to the powerhouse; (7) a 30-foot diameter, 40-foot high concrete surge tank; and (8) a powerhouse containing two units, each rated at 4,000 kW. The project is classified as having a high hazard potential, and the dam impounds 1,832 acre-feet of water.

B. Marquette Project No. 2589, Marquette Board of Light and Power

This project comprises two developments. The upper reservoir is impounded by the Forestville Dam, also known as Upper Dam or Dam No. 2. The dam consists of an overflow section flanked by two non-overflow sections (closed dams). The overflow section is about 201.5 feet long and the left and right non-overflow sections are 30 feet and 15.75 feet long, respectively. The dam is a cyclopean masonry structure provided with a concrete cap and is about 62 feet high. A wood stave pipeline conveys the flow from Dam No. 2 to a surge tank and two steel penstocks which feed Powerhouse No. 2. Powerhouse No. 2, the surge tank, and the steel penstocks were built in 1920. Dam No. 2 impounds 2,943 acre-feet of water at normal pool level and is rated as high hazard potential.

A retired hydro site (Dam No. 1 and Powerhouse No. 1) is located in the reach of river between the Dam No. 2 and the powerhouse. Dam No. 1 formerly supplied water to Powerhouse No. 1. Powerhouse No. 1 was built in 1890, decommissioned in 1974, and demolished in 1989. Dam No. 1 also was built in 1890 and abandoned and partially breached in 1912 when the construction on Dam No. 2 was completed. The remaining sections of this structure are to be removed during 2003 per orders from MDNR.

The project structures for Development No. 3 include a short steel penstock, a powerhouse, and a dam (Tourist Park Dam), which includes an intake and adjacent retaining walls, two flanking earth embankments, and a spillway consisting of two sections. The spillway is composed of a gated section equipped with two tainter gates and an overflow section. There are two spillway gates at this development located to the right of the overflow spillway. Tourist Park Dam is classified as having a low hazard potential and impounds 600 acre-feet of water.

III. Construction History

Silver Lake Basin is a natural body of water near the headwaters of the Dead River. A dam was build there in 1896 to increase the storage capability of the basin and augment summer flows in the river. The dam was rebuilt in 1911-12, and again in its present form in 1943-44, when the dam was raised eight feet. The present dam was constructed by Cliffs Power and Light Company, a subsidiary of Cleveland Cliffs Iron Company. It was purchased in 1988, together with the downstream Hoist and McClure projects, by Upper Peninsula Power Company (UPPCO), which is now a subsidiary of Wisconsin Public Service Company. No significant modifications were made to the structures until 2002. In the fall of 2002, detached Dike No. 2 was replaced as a fuse plug embankment, toe drains were installed at the main dam, the slopes of the main dam embankment were regraded to 2H:1V, deteriorated concrete was repaired at the outlet structure, and the other detached dikes were regraded to their original crest elevation of 1491.5 feet.

IV. Standard Operating Procedures

There are no power generation facilities at Silver Lake. The lake is used to store snow melt and spring runoff to augment downstream flows later in the year. The lake is normally drawn down in late fall and winter. Refilling typically begins in March. Average fluctuation is between elevation 1462 and 1480 feet; however, the licensee’s staff stated that during spring runoff the reservoir level occassionally exceeded the level of the concrete crest of the main spillway at elevation 1486.25 feet.

Silver Lake is in a remote location with no electrical power or telephone provisions for remote monitoring of lake elevations or flow regulation. Operators visit the dam site weekly and less frequently during the winter months to record reservoir and piezometer levels and adjust the outlet discharge. During the summer of 2002, the stop logs were replaced. The top of the highest board was slightly below the crest of the concrete ogee bays, elevation 1486.25 feet The fuse plug design scheme was based on removal of the stop logs to elevation 1482.5 feet. Following completion of the fuse plug, the stop logs were not removed and there were no changes in the operating procedures.

Article 402 of the license, issued October 3, 2002, establishes minimum and start of month target reservoir elevation for each month of the year. For May, the minimum elevation is 1478.5 feet, and the start of month target is 1479.0 feet. Article 403 establishes minimum flow requirements which also vary seasonally. In May, the minimum flow is 20 cfs.

V. Event Chronology

The Silver Lake fuse plug activated on May 14, 2003. The exact time of the initiation of the breach is not known. The following chronology is based on a log obtained from the Marquette County Emergency Operations Center (EOC) and interviews with representatives of the Upper Peninsula Power Company (UPPCO), Marquette Board of Light and Power (BLP), and the EOC. All times are EDST.

Silver Lake is located in a remote area of Marquette County, accessible only via gravel and dirt roads. The trip from UPPCO's office in Ishpeming takes 45 minute to an hour each way. The site is routinely visited about once a week – less frequently in the winter months. There are no provisions for remote monitoring of the reservoir level or discharge from the dam. Prior to the incident, the last visit to the Silver Lake dam site by UPPCO personnel was on Wednesday, May 7, 2003. At that time, the reservoir elevation was 1483.35 feet, based on observation of the staff gage affixed to the outlet structure at the main dam. Stop logs were in place in the stop log bay of the uncontrolled spillway. The top of the stop logs was at approximately the elevation of the concrete crest of the remaining overflow bays. The outlet structure gate was open only enough to pass the required minimum flow. The operators who visited the site checked the fuse plug and recalled that water was at the bottom of the fuse plug; however, they also estimated the water surface to be two to three feet below the top of the fuse plug. One of the operators mentioned that the downstream channel appeared moist, but there were no puddles. The next scheduled visit was to have been on May 15th.

Wednesday, May 14, 2003

<u>Time</u>

16:20 Director of Marquette County Road Commission (MCRC) received a call from an employee forwarding a citizen's report of high water at the County Road AAO bridge over the Dead River about 2.5 miles downstream of Silver Lake. Water was beginning to run over the road and was discolored.

16:25 Another MCRC employee called with a similar report. He had observed the high water at about 15:00, but had forgotten to call.

16:33 After calling UPPCO and getting an answering machine, MCRC called Central Dispatch (911), reporting that the Dead River was up 8 to 9 feet.

16:39 Bob Meyers received call from Central Dispatch. (Perhaps a little later according to the EOC log.) UPPCO operators were then called in to work.

17:00 Citizen called 911 to report that the County Road ATT (Mulligan Creek) bridge was not passable. (Mulligan Creek confluence with Dead River is about 2.4 miles downstream of Silver Lake.)

17:13 UPPCO activated EAP. Condition “A” (Imminent Failure).

17:34 UPPCO reported to 911 that an operator was en route to Silver Lake.

17:39 MCRC Director reported that water was even with the deck of the AAO bridge and the bridge was not safe to cross.

18:40 UPPCO operator reported that the fuse plug had washed out. Conditions at the main dam were normal, with the reservoir elevation at 1483.26. The operator drove back to Ishpeming to pick up a camera, then returned to the site, arriving sometime after 20:00. When he returned to the site he found conditions essentially unchanged.

19:33 UPPCO met with the County Sheriff and Emergency Management Coordinator. Estimates of spill over downstream Hoist and McClure dams were to be made in about an hour.

23:10 Situation getting worse. EOC activated.

Thursday, May 15, 2003

01:00 Contractor began construction of temporary fill in low area to the left of Hoist Dam. Work completed at 04:00

01:30 County declared state of emergency

02:20 UPPCO (Bob Meyers) reported 3 feet of spill over Hoist dam.

03:00 NWS issued flash flood warning.

06:30 City of Marquette issued evacuation advisory for area north of Wright Street.

08:45 Evacuation order made mandatory.

09:00 Peak elevation at Hoist. Elevation 1348.94 (Crest of spillway at 1344.50)

13:00 BLP reported to FERC-CRO that water was at the crest of the Tourist Park Dam.

14:00 Peak elevation at McClure. Elevation 1201.53 (Crest of spillway at 1196.40).
Failure of Tourist Park Dam began with water flowing around end of corewall in right embankment. Erosion continued for over an hour causing extensive washout of overburden material to the right of the dam.

15:25 Four feet of water reported in Presque Isle Power Plant.

VI. Emergency Response

The section titled "Event Chronology" provides a detailed summary of the emergency actions taken throughout the flood event. This section summarizes some of the key events and observations made with regards to emergency actions and response.

The reservoir elevation at Silver Lake Dam is typically read weekly by the project operator. The last reading prior to the rainfall event and subsequent activation of the fuseplug was on Wednesday, May 7, 2003. The lake elevation at that time was at 1483.35 feet. On Sunday and Monday, May 11-12, 2003, a significant rainfall event occurred over the area. The licensee did not anticipate any problems from this event and did not have any plans to visually observe the effect of the rainfall event on the lake level. The operator's next observation of the lake level was scheduled for Thursday, May 15, 2003.

There are no provisions in the emergency action plan (EAP) for high water warning devices or alarms for headwater and/or tailwater readings at the dam. The EAP does not include a means for advance warning that the water level in the lake is rising and approaching the elevation of the pilot channel in the fuseplug, with the likelihood that the fuseplug will activate. The only way advance warning of activation of the fuseplug could have been issued would have been by visual observation of the fuseplug if someone "just happened" to be at the fuseplug site at the time of activation. Because of the remoteness of the site, that is highly unlikely. As a result, the next best warning that the fuseplug had activated would be by observations in areas downstream of the fuseplug of changes in the river flow. A third indication would be the increase in lake level at the downstream Hoist reservoir.

Initial indications that something had happened at Silver Lake Dam occurred on Wednesday afternoon, May 14, 2003 as a result of visual observations made by a citizen in Marquette County. The citizen stopped at the Marquette County Road Commission (MCRC) to report that water was beginning to run over the road at the Dead River Bridge, County Road AAO and the water was discolored. Mr. Brian Lille of the MCRC at 4:20pm then reported this problem to Mr. Mike Morissette of the MCRC. At 4:25pm, Mr. Larry Durquette of MCRC called Mr. Morissette to report that he had observed abnormally high and discolored water at the AAO bridge at about 3:00pm. By 4:46pm, the MCRC was able to contact Mr. Bob Meyers of UPPCo and advise him of the situation. Ten minutes later UPPCo officials were enroute to Silver Lake Dam. By 5:13pm a decision was made to initiate the call-out procedure of the EAP. At 11:10pm, emergency management (EMA) activated their emergency operations center (EOC).

Throughout the emergency event, there was close coordination between the dam owner (UPPCo) and its projects on the Dead River (Silver Lake, Hoist, McClure), the EMAs, and the City of Marquette and its projects (Upper Dam and Tourist Park Dam). The UPPCo EAPs were used extensively throughout the event. Since the rain had ceased several days before the activation of the fuseplug, the sunny day dambreak inundation maps were used to estimate incremental rises and arrival times of the flood at downstream areas. UPPCo and the EMAs used both the Silver Lake Dam EAP and the Hoist Dam EAP inundation maps to identify areas for that could be flooded and require evacuation. Fortunately, flooding to habited areas was limited and no lives were lost. However, about 1700 people below Hoist Dam were evacuated. Some of the lakefront property around Hoist Reservoir was affected by the floodwaters. The EAP provided a fairly accurate indication of the incremental rises and flooding that could be expected. However, the timing was off. This was probably based on the assumed time of 5:00 P.M. for the start of the dambreak event. When the time was adjusted a few hours, then time also closely matched that shown on the inundation maps.

The Tourist Park Dam, the last dam in the series of dams on the Dead River, is classified as a low hazard potential structure. As a low hazard potential structure, at the City's request, it was issued an exemption from the requirement for an EAP. The breach width during this event was much more extensive than what would normally be expected. In fact, the breached area was not confined to the dam. The breach included the cutting and erosion of a significant length of the natural abutment which consisted primarily of sand. Several areas downstream of the dam were affected as a result of the flow passing through the extremely wide breach. The abutments and the part of the roadway of a bridge located over the Dead River just upstream of the confluence with Lake Superior were washed out. This bridge is regularly in use and is the only means of access to several residences. Also, the Presque Isle Powerplant was shut down as a result of the materials carried by the flood release. The inundation maps of the Hoist EAP used by the EMAs during this event covered the areas downstream of Tourist Park Dam including the area in the vicinity of the bridge and powerplant. These areas were included in the evacuation and recovery actions of the EMAs.

A citizen who had observed our investigation team at the Tourist Park Dam approached some of the team members and stated that she was extremely pleased with the response of emergency management personnel throughout this entire event.

Emergency management reported that in 1998 they participated with UPPCo in a functional exercise of the Hoist Dam EAP. They stated they believe it was that exercise that prepared them for this event. The coordination and the lessons learned during the exercise helped make everything run smoothly between UPPCo, City of Marquette, and the EMAs through-out this actual event. Since there was little if any turn-over in personnel among the EMAs involved since the 1998 exercise, everyone understood their role and responsibility. Evacuation took place both above and below Hoist Reservoir, and search and rescue went to isolated areas up near Silver Lake where the AAO Bridge had been destroyed.

The event is currently being evaluated by UPPCo and the EMAs to identify lessons learned and where improvements in the EAP-EOC process can be further improved.

VII. Meteorology, Hydrology and Hydraulic Issues

The purpose of this section of the report is to present the pertinent information on the meteorology, hydrology, and hydraulics of the Silver Lake basin and of the events involving the breach of the fuseplug spillway on May 14, 2003. This information was compiled from pre-failure studies (probable maximum flood (PMF) studies, consultant's safety inspection reports (CSIR), and other documents submitted to the FERC), the May 2003 storm event (information obtained during our inspection and interview sessions subsequent to the breach), and follow-up review and analyses.

A. Meteorology

a) Pre-failure Information

The Silver Lake basin, which has an area of 23.6 square miles, has no precipitation gages in or near the basin.

The 1993 EPRI Wisconsin/Michigan Probable Maximum Precipitation (PMP) Study was used to determine the Probable Maximum Storm (PMS) in (1) the Stone & Webster Michigan, Inc., December 1994 Addendum to the 1993 Consultant's Safety Inspection Report (CSIR), (2) the Montgomery Watson Harza (MWH) January 2001 Warm Season PMF study, and (3) the MWH February 2001 Cool Season PMF Study. Based on these studies, the 72-hour warm season PMP is equal to 21.6 inches, with 14.38 inches occurring in the peak 6-hour period. The 72-hour cool season PMP was determined in the February 2001 Cool Season PMF Study to be equal to 9.73 inches. The total snowmelt used in the cool season analysis was equal to 7.56 inches, based on the Degree-Day method using temperature data for the month of April with an unlimited snow pack.

b) May 2003 Storm Event

Prior to the breach of the fuseplug spillway at Silver Lake, a significant rainfall event occurred in the Silver Lake Basin during the period from May 9 to May 13, 2003. We contacted Mr. Edward Fenelon, Chief Meteorologist, National Weather Service (NWS), Marquette, Michigan, to obtain information on this rainfall event. He provided us with a map showing the estimated rainfall in the Upper Peninsula of Michigan based on gage readings and radar estimates. The precipitation gages are located across the Upper Peninsula and are cooperatively maintained and read by local residents who report the 24-hour total rainfall as of 8 a.m. each day. Figure 1 and Table 1, attached, show the map and the 24-hour totals at all of the precipitation sites in the Upper Peninsula. The map and table were edited to show the location of the Silver Lake basin, and to correlate the gage locations on the map to the 24-hour totals listed in the table.

We also obtained digital video radar images of the rainfall density from the NWS web site – these are available if needed.

We visited the NWS office in Marquette on June 4, 2003 and met with Mr. Fenelon's staff. They confirmed that no hourly precipitation data was available since the gage site managers only take readings at 8:00 a.m., each day. In addition, the NWS staff told us that there had been no measurable rainfall for several weeks prior to this event.

The NWS staff provided us with temperature data for the month of May, 2003 while we were at their office (Figure 2). The temperature data, which were taken at elevation 1415 feet at their office near the Hoist Dam, show that the last temperature reading below freezing was on May 3, 2003. No snow depth was recorded at the site for the entire month of May.

c) Follow-up review and analyses

A review of the NWS rainfall map indicates there are no rain gages located in or near the Silver Lake basin. However, based on the rainfall patterns shown on the map, it appears that 4 to 5 inches of rain occurred within the basin during this rainfall event. A review of the Herman, Champion 4E, Champion/Clarksburg, Humbolt, Huron Mtn Club, Marquette NWS, and Marquette WWTP precipitation gages listed on Table 1 indicates most of the rain fell during the 48-hour period from 8 a.m. May 10^{th} to 8 a.m. May 12^{th}, 2003.

The 4 to 5 inches of rain equates to about 20% of the 72-hour warm season PMP (21.6 inches). It is also approximately equal to the 100-year 24-hour rainfall as shown in Figure 9-57 of the "Handbook of Applied Hydrology", by Ven Te Chow.

B. Hydrology

a) Pre-failure Information

The Silver Lake basin is located in a forested area near the headwaters of the Dead River. There are no dams upstream of Silver Lake Dam. No stream gages exist in the basin.

Because there are no precipitation or stream gages in the Silver Lake basin, the unitgraph for the basin was developed using the Soil Conservation Service (SCS) dimensionless unit hydrograph method.

In 1993, Stone & Webster Michigan, Inc., computed the lag to be 1.92 hours, and Mead & Heat, Inc., in their determination of the PMF for the downstream Forestville Dam, independently computed the lag to be 2.7 hours for the Silver Lake basin. Harza Engineering Company, now Montgomery Watson Harza (MWH), adopted a lag of 1.92 hours for their 2001 analysis of the Silver Lake PMF. The same personnel from Stone & Webster Michigan, Inc., who developed the PMF analysis in 1993, also worked on the 2001 analysis for MWH.

The characteristics of the soils in the basin are based on the STATSGO database in the 1993 Mead & Hunt report and the 2001 MWH reports. According to the 1993 Mead & Hunt report, the STATSGO database indicates that rock outcroppings cover as much as 14% of the area in the Mulligan Creek sub basin (just north of the Silver Lake basin) and a significant portion of the other basins upstream of Forestville dam. The consultant also states that low depth to bedrock in this region could also increase runoff as the thin soil becomes quickly saturated and effectively impervious; although no depth to bedrock maps were available.

Based on the STATSGO database, the following loss rates were assigned to each of the soil loss rate classes in the MWH January 2001 PMF study:

Loss rate, inches/hr	% of total area	Area, square miles
0	31.6	7.45
0.01	15.68	3.70
0.2	12.23	2.89
0.6	6.72	1.58
6.0	33.80	7.98

The loss rates are equal to the minimum permeability (or hydraulic conductivity) of the least permeable layer for each soil type. To compute the runoff using the distributed loss rate method discussed in Chapter 8 of the FERC Engineering Guidelines, the rainfall hyetograph is applied to each loss rate class and its corresponding area, and the results are summed to compute the total runoff hyetograph. This is then used in the HEC-1 program with the loss rate set to zero inches per hour to compute the inflow hydrograph into the reservoir. For the cool season analysis, the consultant assumed that all loss rates less than 6.0 inches per hour would be impervious. This is consistent with the FERC Engineering Guidelines.

In the Stone & Webster 1993 CSIR and the December 1994 Addendum to the 1993 CSIR, Stone & Webster used the runoff curve number (RCN) method to determine the losses. A RCN equal to 65 with 11.1% impervious was used in the 1993 analysis. The 1993 analysis was not accepted by FERC because the Probable Maximum Storm (PMS) was not centered over the Silver Lake basin. In the 1994 addendum, with the PMS centered over the Silver Lake basin, the consultant lowered the RCN to 53, and computed an inflow PMF equal to 40,700 cfs. In the 2001 study using the distributed loss rate method, MWH determined the inflow PMF to be equal to 36,500 cfs. The January 2001 MWH study was used in the design of the fuseplug spillway.

b) May 2003 Storm Event

UPPCo operators reported that they visually check the reservoir level on a weekly basis at Silver Lake Dam. They reported that the lake level on May 7, 2003 (the last reading prior to the storm event), was at elevation 1483.35 feet. This was the highest level the lake had reached following completion of construction of the fuseplug on September 17, 2002 and prior to the May 2003 storm event. The next reading taken by the operators was elevation 1483.26 feet recorded at 6:30 p.m. on May 14, 2003, which is subsequent to the failure.

The UPPCo operators reported that there had been no significant rainfall for at least the month prior to the May 2003 storm event.

The UPPCo operators reported that there were some small patches of snow in some areas of the basin in the early part of May. They also reported that the frost depth reached 8 to 9 feet during the winter, which is unusual. The impact this would have had on the runoff is unknown.

There is no data available indicating the timing of the runoff into the reservoir and the rate of rise and fall of the reservoir.

During the initial FERC inspection by Messrs. John Hawk and James Evans on May 16, 2003, they reported that they were able to detect a high water mark on the felt paper on the upstream side of the stoplogs (Photographs 1 and 2). This line was initially noticed by Mr. Craig Harris of MWH. Note that some leaves and grass could be seen in the left stoplog slot up to the high water mark. The high water mark elevation is 1485.6 feet according to Messrs. Hawk and Evans. During the June 3, 2003 site visit, the high water mark could not be clearly detected, but the vegetation in the slots on both sides up to the high water mark was still present. The felt paper and stoplogs were installed during the reservoir drawdown last summer, and the licensee's operation records indicate that the reservoir remained drawn down below elevation 1481 until late April 2003. Therefore, it appears that the high watermark could have only resulted from the peak headwater elevation that occurred sometime between May 7th (when the operators were last on the site before the event and reported the headwater elevation to be at 1483.35 feet) and 6:30 pm May 14th (when the operators went to the site after the breach had occurred and the reservoir had already dropped to elevation 1483.26 feet).

c) Follow-up Review and Analyses

Since the May 2003 storm event was not preceded by antecedent rainfall, any saturation of the ground would be from snowmelt. Also, the increase in reservoir levels over the month prior to May 7, 2003, would again be mostly from snowmelt. By the start of the event, it appears that any remaining snow on the ground was an insignificant contributor to the runoff event.

A review of the previous consultant's studies indicates that the Silver Lake Dam, as operated, is a volume control, rather than a peak control project. That is, the volume rather than the peak of the runoff from a storm event controls the peak reservoir elevation attained during the event. Since precipitation and stream gages do not exist in or near the basin, it is not possible to develop a model that accurately reproduces this storm event. However, given that the reservoir is volume control, a comparison of the May 2003 to the PMF event can be made and used as an indicator of the reasonableness of the assumptions made in the PMF analysis.

According to the HEC-1 model used to determine the PMF, the volume of the PMF is equal to 16,257 acre-feet. We performed a comparison analysis using the HEC-1 model that was developed to compute the PMF at the dam. We reduced the total precipitation from the PMP using the same distribution to determine what volume would have raised the reservoir from elevation 1483.50 feet to the high water mark elevation of 1485.60, assuming the only outflow was equal to 20 cfs from the low level outlet. The HEC-1 model computed the inflow volume for this case to be equal to 3,241 acre-feet. A comparison of the volumes indicates the inflow from the storm event was equal to about 20% of the inflow PMF volume.

C. Hydraulics

a) Pre-failure Information

a. Concrete Spillway

The crest elevation of the Main Dam and Dikes Nos. 1, 3 and 4 is at 1491.5 feet, as per the construction work in 2002. Dike No. 2 is the location of the fuseplug, which had a crest elevation of 1486.5 feet.

The project has ten overflow concrete spillway bays. Each bay is 9 feet wide. The crest elevation of nine bays is at elevation 1486.25 feet. Bay No. 4 has a crest elevation of about 1480.25 feet and has stoplogs up to just below the crest of the ogee sections.

The low level outlet at the project has a maximum capacity of about 280 cfs and is used to pass minimum flows (10 to 25 cfs) and regulate the reservoir.

The reservoir can store 33,510 acre-feet at the spillway crest elevation of 1486.25 feet. It is used to store snowmelt and spring runoff to augment downstream flows later in the year. The consultant's safety inspection reports (CSIR) state that the reservoir fluctuates from an average low of 1462 feet to an average high of about 1480 feet, although the reservoir has crested the overflow spillway on occasion prior to the construction of the fuseplug spillway.

b. Fuseplug

The conceptual design for the fuseplug spillway was presented to the FERC during a meeting in the Washington Office on March 23, 2001. The original conceptual design called for three fuseplugs, one each at Dikes Nos. 1, 2 and 3, with a crest elevation at 1486.5 feet and with a pilot channel invert elevation of 1486.0 feet. The consultant later changed the design to use just one fuseplug spillway at Dike No. 2. The September 24, 2001 MWH letter that was enclosed with the licensee's September 27, 2001 letter included the final BOSS DAMBRK input file that was used to model the operation of the fuseplug. The operation of the fuseplug was modeled as a breach with the following parameters:

Initial Elevation of Water Surface (ft)	1482.50
Top of Fuseplug Crest Elevation (ft)	1486.50
Uncontrolled Spillway Crest Elevation (ft)	1486.25
Overtopping Discharge Coefficient x Length of Fuseplug (ft)	1552.50
Low Level Outflow Discharge (cfs)	283.00
Breach Side Slope (Z)	1:2.5
Breach Bottom Elevation (YBMIN, ft MSL)	1481.00
Breach Base Width (BB, ft)	260.00
Time of Breach Formation (TFH, hr)	1.00
Water Surface Elevation at Time of Start of Breach (HF, ft MSL)	1487.00

The Overtopping Discharge Coefficient x Length of Fuseplug used in the analysis is equal to 3.0 x 517.50 feet, which was the original length of the three fuseplugs that were going to be built at Dikes 1, 2 and 3. The consultant did not reduce the overtopping crest length for the redesign. FERC corrected this in their review of the PMF in 2001 and found that the peak PMF elevation would actually be 0.15 feet higher (1488.90 feet), but they accepted this on the basis of this error being within the accuracy of the determination of the PMF. Also note that the actual channel was designed with a base width of 265 feet, not 260 feet.

The spillway rating curve used in the BOSS DAMBRK model was as follows:

Elevation (ft)	Flow (cfs)
1486.25	0.0
1487.00	193.0
1488.00	724.0
1489.00	1476.0
1490.67	3126.0
1493.00	6181.0
1494.00	7730.0
1495.00	9442.0

This rating curve does not include the additional flow that would have been available had the licensee removed the stoplogs to elevation 1482.5 feet in Bay No. 4 of the overflow spillway.

No tailwater submergence effects resulted from the routing of the outflow hydrograph in the river downstream of Silver Lake. The consultant computed the peak headwater elevation for the PMF to be at elevation 1488.75 feet with a peak outflow of 22,050 cfs, of which 20,760 cfs passed through the fuseplug channel and 1,290 passed over the overflow spillway (DAMBRK automatically cuts off the low level outlet flow during a breach). This provides for a minimum freeboard of 2.75 feet at the Main Dam. The March 2002 Design Report, which was not updated to incorporate the consultant's September 24, 2001 letter report, used a flow of 19,230 cfs that was computed assuming a reservoir starting elevation of 1481.5 feet.

The fuse plug was designed to allow passage of the probable maximum flood (PMF) without causing the main dam embankment to be overtopped. The consultant's initial design was based on a starting water surface elevation of 1481.5 feet, which is shown as the "normal maximum" water level on the design drawings. However, according to the September 24, 2001 letter from MWH to Mr. David Harpole, which was enclosed with Mr. Harpole's September 27, 2001 letter to the FERC, the design was re-evaluated by the consultant using a normal maximum pool elevation of 1482.5 feet based on the licensee's planned procedures for operating the reservoir. The consultant determined that starting at elevation 1482.5 feet would not impact the ability of the dam to safely pass the PMF with this design. During the review of the headwater level change, FERC performed a sensitivity analysis using BOSS DAMBRK and determined that this one foot increase in reservoir level would only raise the peak headwater elevation of the PMF event by about 0.2 feet. This change was accepted per FERC letter dated December 13, 2001. However, the final Design Report, dated March 2002, still listed 1481.5 feet as the design headwater elevation.

The design included the provision that the stop logs be removed to elevation 1482.5 feet. The top of the fuse plug embankment was designed to be at elevation 1486.5 feet, with two pilot channels set at 1485.5 feet.

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Based on the design lake elevation of 1482.5 feet, the stoplogs in spillway Bay 4 were to be removed to elevation 1482.5 feet as part of the work done in 2002 in conjunction with the construction of the fuseplug. This, however, was not done.

The fuseplug was constructed at the location of and replaced Dike No. 2. It was 265 feet long and had a crest elevation of 1486.5 feet, with two pilot channels with a design invert elevation of 1485.5 feet. The fuseplug was 5.5 feet high with a channel invert elevation of 1481.0 feet. According to the Final Construction Report, filed on January 13, 2003, the as-built drawings show two survey points within the invert of each of the two pilot channels to be at elevations 1485.28 feet and 1485.37 feet.

c. Emergency Spillway Channel Design

The final channel design is documented in the March 2002 Design Report. With the fuseplug at Station 0+35, the channel was designed as a grass-lined trapezoidal channel with a Manning’s n of 0.04 from Station -3+00 to Station 6+26. A Manning’s n of 0.08 was assumed for the rest of the exit channel based on leaving the natural vegetation, trees, and brush in place. A base width of 265 feet with side slopes of 2.5H to 1V was used in the design.

The invert of the channel varies from 1480.0 feet at the entrance channel (Station -3+00), to 1481.0 feet from Station -1+35 to Station 0+66.5, to 1471 feet at about Station 6+26. Downstream of Station 6+26, the natural grade has a downward slope varying from 2.3% to 3.0% before it converges with the Dead River. The consultant reported in the design report that the maximum velocity at the entrance channel was computed to be 9.1 fps, with the duration exceeding 7.5 fps equal to 4.4 hours, and the duration exceeding 6.0 fps equal to 8.5 hours. The consultant reported that the area of supercritical flow was determined to generally be downstream of Station 0+52, which is in the vicinity of the invert slope change from flat to 1.8% grade down. The consultant did not report on velocities in the exit channel.

b) May 2003 Storm Event

The UPPCo operators reported that by the time they arrived at the project at 6:30 p.m. on May 14, 2003, the fuseplug had already activated. They reported hearing a thunderous noise as the water passed through the channel, and continued its widening and deepening of the breach.

A great amount of material was deposited downstream of the eroded channel, effectively blocking the flow from the Dead River downstream of the low level outlet structure at the dam.

Our field inspection on May 16, 2003 indicated that the high water mark was at elevation 1485.6 feet. If the high water mark and as-built survey of the pilot channels are accurate, then it appears that there would have been 0.3 to 0.4 feet depth of flow through the two pilot channels at the peak reservoir elevation.

c) Follow-up Review and Analyses

a. Fuseplug Design Flood

The fuseplug was designed to pass the PMF. The March 2002 Design Report did not discuss what flood would initially trigger the fuseplug. However, the MWH representative stated during our interview that if the reservoir was maintain at elevation 1481.5 feet and the full capacity of the low-level outlet was utilized, the dam would be able to pass a 1 in 500 event without triggering the fuseplug. Since the pilot channel invert elevation was designed at 0.75 feet below the crest of the overflow spillway, the design did not consider the overflow spillway for lesser flows.

As part of our analyses of the event, to determine the size of the flood event that would just raise the reservoir to the invert elevation of the pilot channels, we performed an analysis using the HEC-1 model that was developed for the PMF. We reduced the total precipitation from the PMP using the same distribution to determine what percentage of the PMP would raise the reservoir from the initial design elevation of 1481.5 feet to the design elevation of the two pilot channels (1485.5 feet). We found through trial and error that using 44% of the total PMP would raise the reservoir from 1481.5 feet to 1485.5 feet. For this case, the model computed the peak inflow to be equal to 14,400 cfs, which is equal to about 40% of the peak PMF inflow. Likewise, the model determined the inflow volume to be equal to about 40% of the inflow PMF volume. This demonstrates that had the reservoir been maintained at the initial design headwater elevation, the fuseplug would not have activated until an event close to 40% of the PMF occurred.

As discussed earlier, the May 19-13 storm event was equal to about a 20% PMF event by volume. Even if the reservoir had been held to elevation 1482.5 feet, which was the maximum normal pool elevation specified in the licensee's September 27, 2001 letter, it still would have taken a 30% PMF event by volume to raise the reservoir to the pilot channel invert elevation of 1485.5 feet.

b. Effect of Stoplog Crest Elevation and Starting Reservoir Elevation Prior to the Event

The reservoir was below elevation 1479 feet from August 2002 through March 2003. During April and early May 2003, the reservoir refilled due primarily to snowmelt. The licensee's operators recorded the following reservoir elevations during the months of April and May 2003:

Date	Headwater Elev., feet
April 3	1479.06
April 10	1479.22
April 16	1480.60
April 23	1482.34
May 1	1483.22
May 7	1483.35

As a simple check of the sensitivity of the peak reservoir elevation to the crest elevation of the stoplogs in Bay No. 4 and the starting reservoir elevation just prior to the rainfall event, we used the HEC-1 program from the PMF model to vary the crest elevation of the stoplogs and starting reservoir elevation. For the rainfall, we assumed the 24-hour readings for the peak two days from the Herman precipitation gage were divided into equal hourly rainfall increments. The total rainfall from the peak two days at this gage was equal to 4.88 inches. A minimum flow of 20 cfs was used in the low level outlet consistent with the operator's records. To model the stoplog bay, a 9-foot long sharp-crest weir was assumed with a coefficient of discharge equal to 3.3.

Case 1 was done to try to match the actual elevations before and after the May 9-13, 2003 storm event. A starting reservoir elevation equal to 1483.5 feet was assumed; this is slightly higher than the last known reading of 1483.35 feet that was taken on May 7, 2003. The actual reservoir elevation just prior to the event is unknown, but the weekly readings indicate that the reservoir was continuing to slowly rise. In order to match the high water mark at elevation 1485.60 feet, the loss rates in the PMF model were slightly adjusted. This adjusted model was then used for Cases 2 and 3 with different starting reservoir elevations and stoplog crest elevations. The following table illustrates the results of the sensitivity analysis of the rainfall /runoff from the May 2003 event:

Case 1	Starting Reservoir Elev., Feet	Stoplog Crest Elev., Feet	Peak Reservoir Elev., Feet	Peak Spillway Outflow, cfs
1	1483.50	1486.25	1485.60	-
2	1482.50	1486.25	1484.65	-
3	1482.50	1482.50	1484.55	87

Comparing Case 1 to Case 2 shows that if the reservoir had been at an elevation of 1482.50 feet rather than 1483.5 feet, the May 9-13 rainfall event would have raised the reservoir to only 1484.65 feet, which is about 0.95 feet lower than the high water mark. This is assuming the low level outlet was still only passing the required minimum flow.

Case 3 is the same as Case 2 except that it was assumed the stoplogs were removed to elevation 1482.5 feet just prior to the event. Comparing Case 2 to Case 3 demonstrates that the capacity of the stoplog bay to pass flood flows during the event was insignificant. The additional capacity available through the stoplog bay during the event would have been a maximum of about 87 cfs, resulting in only a 0.10-foot headwater difference from Case 2.

If the stoplogs were removed to elevation 1482.5 feet at the time of construction, it would not have passed any flow until sometime between April 23, 2003 and May 1, 2003, based on the operator's readings. We determined using BOSSDBK that the reservoir elevation would have been at elevation 1483.15 feet on May 7, 2003, instead of 1483.35 feet, if the stoplogs were removed to elevation 1482.5 feet at the time of the construction work or any time prior to April 23, 2003. This was calculated based on a comparison of the volume changes in the reservoir between April 23 and May 7, 2003. This demonstrates that even if the stoplogs were removed to elevation 1482.5 feet during construction as designed by the consultant, the reservoir still would have been within 0.20 feet of the actual reading on May 7, 2003, just a few days prior to the event.

c. Exit Channel Velocities

The Design Report did not discuss exit channel velocities, although it did mention that supercritical flow would be expected to occur in the exit channel near where the invert slope changed from flat to a 1.8% down slope. We performed an open channel analysis to determine the water surface profile and the maximum flow velocities that would be expected to occur in the exit channel for the design flood after the fuseplug has activated. Using the BOSS DAMBRK program with the channel dimensions and invert elevations from Station -3+00 to Station 10+45 as shown in the design report, a constant flow of 19,230 cfs, and channel control at the downstream end of the model, we determined that a maximum velocity of 13.8 feet per second would occur in the reach of river from about Station 1+38 to Station 5+71 in the exit channel. See Figure 2.

This reach is in the portion of the exit channel that has a 1.8% slope, although the model computed a 1.69% slope based on the elevations shown at the Stations on the design. For this slope, normal depth is 5.02 feet, and critical depth is 5.37 feet; therefore, this slope meets the definition of a steep slope. The DAMBRK model computed a depth of 5.00 feet, with a

Froude number of 1.1 for this slope. This flow is supercritical in this section of the channel.

We assumed Manning's n values of 0.04 for the grass lined portion of the channel and 0.08 for the rest of the exit channel, as stated in the design report. The DAMBRK model predicts that a hydraulic jump will occur at the transition from the grass-lined channel to the natural channel, even though the slope is slightly greater in the natural channel. However, the Froude numbers are still close to unity is this reach (0.7 to 0.8), which indicates that a lower Manning's n value may result in supercritical flow in this reach also, depending on the correctness of the channel control assumption at the downstream end of the model.

The program computed a water surface elevation at 1489.7 feet at Station –3+00, which is about one foot higher than the PMF design headwater elevation for the reservoir. The profile in the entrance canal in Figure 8 of the Design Report is shown as being flat, but our model predicts a head loss of almost 2 feet. Therefore, it appears that the consultant did not take into account the hydraulic losses in the channel entrance. The model does not include the portion of the entrance channel upstream of Station –3+00, which may also have an effect on the reservoir level needed to pass the design flow.

We also performed an open channel analysis using the same model to approximately match the water surface elevation at the entrance channel entrance to the high water mark of 1485.60 feet observed on the upstream side of the overflow spillway. Through trial and error, we determined that a flow of about 8,000 cfs was needed to match the water surface elevation at Station –3+00 to the high watermark. For this scenario, the velocity in the sloped section of the exit channel was computed to be equal to about 10 fps.

d. Breach characteristics.

The licensee hired STS Consultants to survey the breached channel. Their results were included with the licensee's June 12, 2003 letter. Photographs 3-7 show the channel as observed during our June 3, 2003 site visit. The breach scoured the entire entrance and exit channels and further downstream, where it deposited a large amount of material on the right bank, effectively blocking the Dead River from the Main Dam.

According to the STS survey, the channel scoured the foundation of the fuseplug to elevation 1453 feet at its lowest point, which is 28 feet below the constructed channel invert at 1481.0 feet. Most of the breach channel invert is between elevation 1458 and 1468 feet. A 20-foot wide remnant of the channel remains near the left abutment which still has its top elevation at 1481.0 feet. The breach scoured the sides of the channel to a width of about 335 feet at the location of the fuseplug.

During our meeting with the licensee and the consultant on June 19, 2003 in the Chicago Regional Office, Mr. Gerald Laurila, the operator who was at Silver Lake dam on the day of the breach, provided the following reservoir elevations and their corresponding times as shown in the first two columns below:

	Time	Reservoir Elevation, feet	Surface Area, Acres
May 14, 2003	18:30	1483.26	1265.6
	19:00	1482.82	1252.3
	20:45	1480.92	1219.1
	21:06	1480.40	1215.0
	22:05	1479.00	1204.1
	22:30	1478.20	1197.8
May 15, 2003	01:00	1474.0	1023.1
	02:00	1472.70	986.1
	02:30	1471.90	962.7
	03:00	1471.32	942.7
	03:30	1470.70	921.3
	04:00	1470.0	897.1
	04:30	1469.30	869.4
	05:00	1468.70	845.6
	05:15	1468.66	844.0

The reservoir surface area shown in the third column in the above table was computed for each elevation using the basin area measurements that were developed from a Stone & Webster topographic drawing of the basin developed from a

1992 Feley, Garske, and Strigel survey, which is contained in the 1993 CSIR. Using this information, we computed the following average reservoir outflows:

	Time	Average Reservoir Outflow, cfs	Headwater Elev. Range, feet
May 14, 2003	18:30-19:00	13,400	1483.26 - 1482.82
	19:00-20:45	16,200	1482.82 - 1480.92
	20:45-21:06	21,900	1480.92 - 1480.40
	21:06-22:05	20,800	1480.40 - 1479.00
	22:05-22:30	27,900	1479.00 - 1478.20
	22:30-01:00	22,600	1478.20 - 1474.0
May 15, 2003	01:00-02:00	15,800	1474.0 - 1472.70
	02:00-02:30	18,900	1472.70 - 1471.90
	02:30-03:00	13,400	1471.90 - 1471.32
	03:00-03:30	14,000	1471.32 - 1470.70
	03:30-04:00	15,400	1470.70 - 1470.0
	04:00-04:30	15,000	1470.0 - 1469.30
	04:30-05:00	12,500	1469.30 - 1468.70
	05:00-05:15	1,600	1468.70 - 1468.66

It appears that the peak breach outflow occurred when the reservoir elevation was already below the channel invert elevation at the fuseplug. The above table shows with a drop in reservoir level over time, the discharge actually increased for a period of time before it started to drop off. This indicates that erosion of the channel (widening and deepening) may have been in progress during a portion of the time that the readings in reservoir level were recorded.

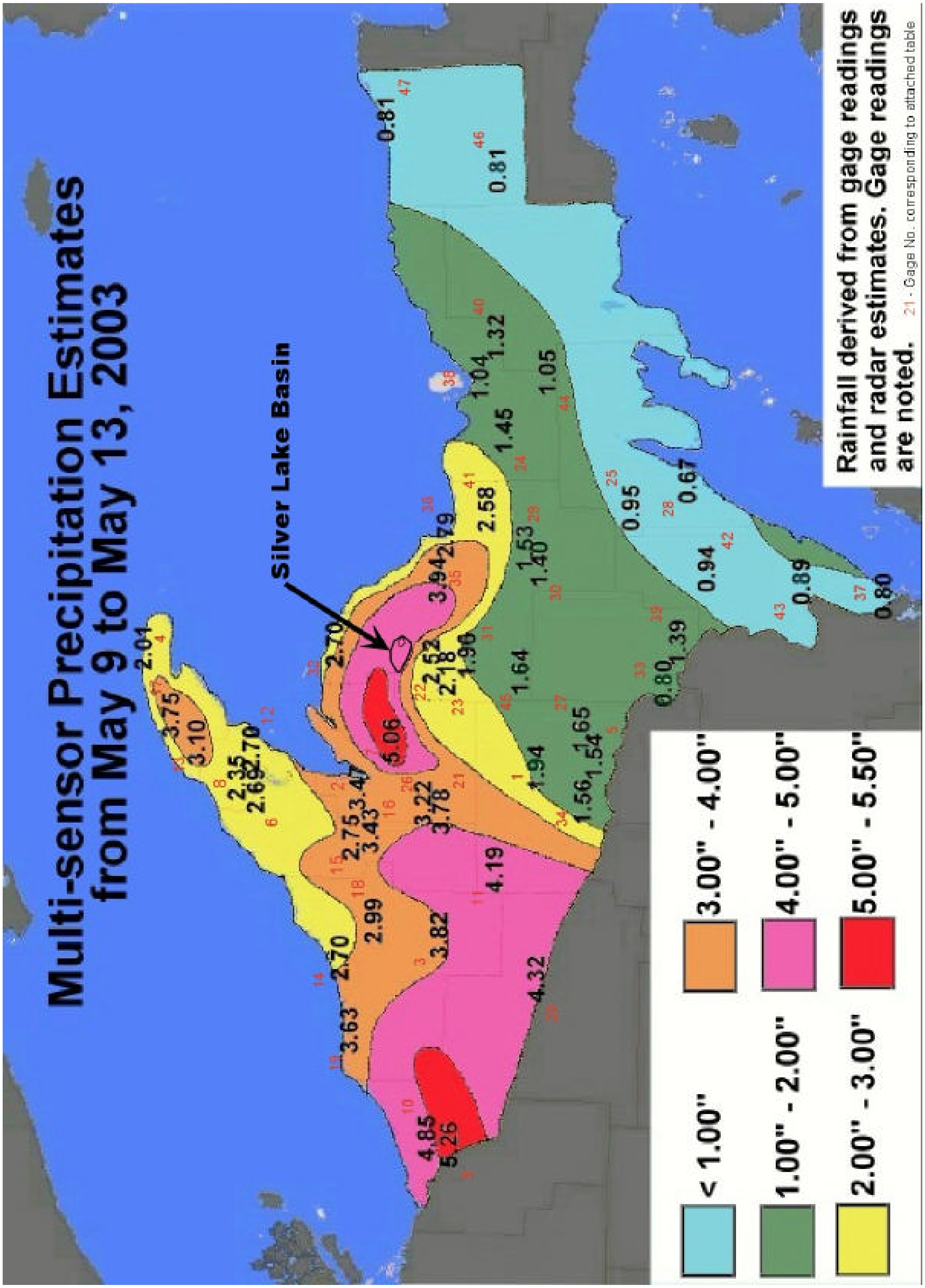


Figure 1. May 9-13, 2003 Rainfall Estimates and Precipitation Gage Totals

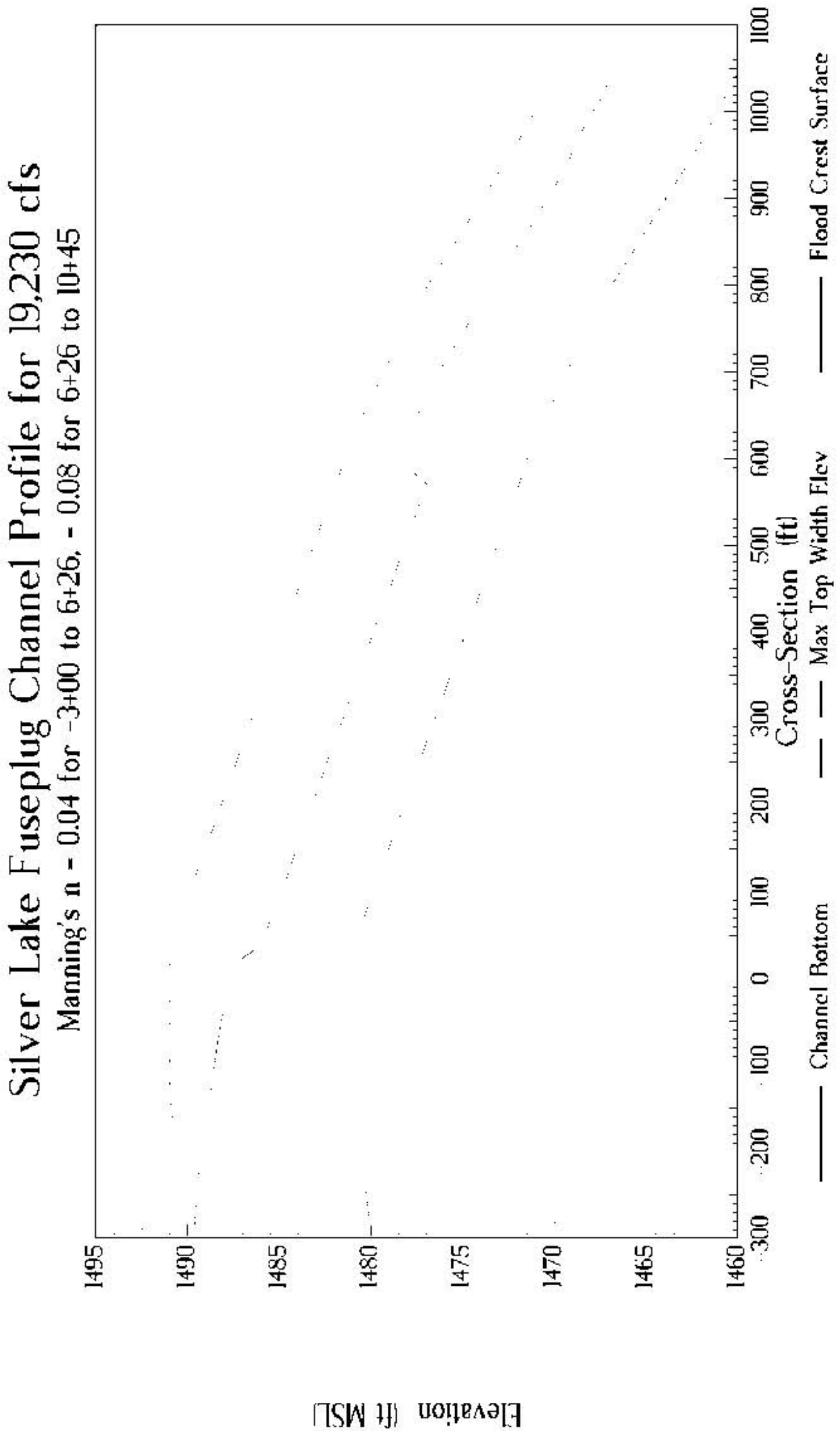


Figure 2. Slope Profile of the Fuseplug Channel during the PMF.

Rainfall reports from the Mother's Day Weekend rain event.

Amounts shown (in inches) are for a 24-hour period ending at 8 AM each day as indicated. TOTAL represents total rainfall observed between 8 AM May 9 through 8 AM May 13, 2003.

Data courtesy of National Weather Service Volunteer Cooperative Weather Observers, U.S. Geological Survey gauge sites, and National Weather Service Automated Observing Platforms.

24-hour Precipitation Reports prior to the Dead River Flood Event (inches)

SITE	5/09/03	5/10/03	5/11/03	5/12/03	5/13/03	**TOTAL**
Western UP						
(1) Amasa	0.00	0.21	0.71	1.02	0.00	1.94
(2) Baraga	0.00	0.22	0.34	2.91	0.00	3.47
(3) Bruce Crossing	0.03	0.28	0.70	2.81	0.00	3.82
(4) Copper Harbor (KP59)	0.00	0.21	0.21	1.59	0.00	2.01
(5) Fortune Lake	0.01	0.22	0.30	1.00	0.01	1.54
(6) Hancock	-	-	-	-	-	2.69
(7) Herman	0.15	0.03	2.10	2.78	0.00	5.06
(8) Houghton Co. Airport	0.00	0.34	0.08	1.93	T	2.35
(9) Ironwood	0.28	0.27	0.62	4.09	0.00	5.26
(10) Ironwood (KIWD)	0.10	0.27	0.43	4.05	0.00	4.85
(11) Kenton/Paint Lake	0.04	0.36	0.44	3.35	0.00	4.19
(12) Lake Linden	-	-	-	-	-	2.70
(13) Mohawk	0.00	0.54	0.13	2.43	T	3.10
(14) Ontonagon 1S	-	-	-	-	-	2.70
(15) Pelkie 7W	0.00	0.32	0.73	1.70	0.00	2.75
(16) Pelkie 5SW	0.00	0.27	0.20	2.94	0.02	3.43
(17) Phoenix	0.00	0.45	0.20	3.10	0.00	3.75
(18) Rockland	-	-	-	-	-	2.99
(19) Silver City	0.00	0.84	0.53	2.26	0.00	3.63
(20) Thousand Island Lake	0.00	0.62	0.57	3.10	0.03	4.32

(21) Watton	T	0.29	0.23	3.15	0.11	3.78
Central UP						
(22) Champion 4E	-	-	-	-	-	2.52
(23) Champion/Clarksburg	0.00	0.15	0.11	1.92	0.00	2.18
(24) Chatham	-	-	-	-	-	1.45
(25) Cornell 1NW	-	-	-	-	-	0.95
(26) Covington 3NW	-	-	-	-	-	3.22
(27) Crystal Falls	-	-	-	-	-	1.65
(28) Escanaba (KESC)	0.00	0.16	0.37	0.14	0.00	0.67
(29) Gwinn	0.00	0.30	0.46	0.77	0.00	1.53
(30) Gwinn/Shag Lake	-	-	-	-	-	1.40
(31) Humboldt	-	-	-	-	-	1.96
(32) Huron Mtn Club	0.00	0.30	1.20	1.20	T	2.70
(33) Iron Mt/Ford Airport	T	0.25	0.38	0.17	0.00	0.80
(34) Iron River 2E	-	-	-	-	-	1.56
(35) Marquette NWS	0.00	0.32	0.20	3.07	0.35	3.94
(36) Marquette WWTP	0.00	0.32	0.13	2.11	0.23	2.79
(37) Menominee (KMNM)	0.00	0.12	0.68	0.00	0.00	0.80
(38) Munising	0.00	0.10	0.19	0.55	0.20	1.04
(39) Norway	0.01	0.29	0.87	0.22	0.00	1.39
(40) Shingleton	0.00	0.10	0.13	0.64	0.45	1.32
(41) Skandia	0.53	0.55	1.21	0.29	0.00	2.58
(42) Spaulding	T	0.00	0.79	0.15	0.00	0.94
(43) Stephenson	0.00	0.19	0.11	0.59	0.00	0.89
(44) Wetmore 16S	0.00	0.23	0.15	0.52	0.15	1.05
(45) Witch Lake 3S	-	-	-	-	-	1.64
Eastern UP						
(46) McMillan	0.00	0.17	0.03	0.61	0.00	0.81
(47) Two Heart	0.00	0.03	0.05	0.73	0.00	0.81

TABLE 1. Note: The number preceding the station name corresponds to the number on the preceding map.

Preliminary Local Climatological Data
(WS Form: F-6)

Station: MARQUETTE, MI
Month: May
YEAR: 2003

Latitude 46.53° N Longitude 87.55° W Gnd Elev. 1415 ft Std Time: Eastern

Temperature in Fahrenheit							:Precip :	Snow		:Wind	:Fastest 2-Min:		Sunshine :		Sky		:Peak Wind	
-1-	-2-	-3-	-4-	-5-	-6a-	-6b-	-7-	-8-	-9-	-10-	-11-	-12-	-13-	-14-	-15-	-16-	-17-	-18-
Day	Max	Min	Avg	Dep.	HDD	CDD	Water	Snow	Depth	Avg.	Speed	Dir	Mins.	%PSBL	SR-SS	Weather	Speed	Dir
1	55	29	42	-2	23	0	0.00	0.0	0	M	M	M	814	94%	M	N	25	360
2	46	27	37	-7	28	0	0.00	0.0	0	M	M	M	818	95%	M	N	20	135
3	62	22	42	-3	23	0	0.00	0.0	0	M	M	M	817	94%	M	N	17	180
4	66	35	52	6	14	0	0.00	0.0	0	M	M	M	800	92%	M	N	26	180
5	49	42	46	0	19	0	0.14	0.0	0	M	M	M	0	0%	M	N	34	135
6	59	39	49	3	16	0	0.00	0.0	0	M	M	M	785	90%	M	N	20	135
7	63	36	50	3	15	0	T	0.0	0	M	M	M	803	91%	M	N	16	90
8	56	41	49	2	16	0	T	0.0	0	M	M	M	796	90%	M	N	20	90
9	50	41	46	-2	19	0	0.32	0.0	0	M	M	M	0	0%	M	3	31	90
10	64	42	53	5	12	0	0.03	0.0	0	M	M	M	642	72%	M	2	18	90
11	46	37	42	-7	23	0	2.32	0.0	0	M	M	M	0	0%	M	2,3	44	360
12	51	34	43	-6	22	0	1.27	0.0	0	M	M	M	450	50%	M	N	50	360
13	68	35	52	3	13	0	0.00	0.0	0	M	M	M	896	100%	M	N	23	45
14	69	37	53	3	12	0	0.00	0.0	0	M	M	M	837	93%	M	N	18	90
15	64	39	52	2	13	0	0.00	0.0	0	M	M	M	802	89%	M	N	20	135
16	65	39	52	1	13	0	0.00	0.0	0	M	M	M	787	87%	M	N	25	135
17	62	49	56	5	9	0	0.00	0.0	0	M	M	M	580	64%	M	N	16	90
18	71	46	59	8	6	0	0.00	0.0	0	M	M	M	843	93%	M	N	19	180
19	70	52	61	9	4	0	0.12	0.0	0	M	M	M	522	57%	M	N	25	180
20	59	34	47	-5	18	0	0.18	0.0	0	M	M	M	710	78%	M	1	34	315
21	62	29	46	-6	19	0	0.00	0.0	0	M	M	M	863	94%	M	N	22	180
22	64	35	50	-3	15	0	0.00	0.0	0	M	M	M	736	80%	M	N	20	135
23	61	40	51	-2	14	0	0.00	0.0	0	M	M	M	859	94%	M	N	20	45
24	68	39	54	0	11	0	0.00	0.0	0	M	M	M	920	100%	M	N	18	90
25	66	42	54	0	11	0	0.00	0.0	0	M	M	M	922	100%	M	N	22	360
26	67	43	55	1	10	0	0.00	0.0	0	M	M	M	924	100%	M	N	21	45
27	77	41	59	5	6	0	0.00	0.0	0	M	M	M	861	93%	M	N	20	90
28	66	48	57	2	8	0	0.61	0.0	0	M	M	M	256	28%	M	N	29	360
29	71	38	55	0	10	0	0.12	0.0	0	M	M	M	929	100%	M	N	32	360
30	59	39	49	-6	16	0	0.98	0.0	0	M	M	M	0	0%	M	2	20	90
31	52	34	43	-13	22	0	0.08	0.0	0	M	M	M	872	94%	M	N	26	360
Sum	1908	1184			460	0	6.17	0.0					20374					
Avg	61.6	38.2												74.6%			Max	Dir.
																	50	360

[Temperature Data]
Average Monthly: 49.9
Departure from Normal: -0.4
Highest: 77 on 27
Lowest: 22 on 3

[Precipitation data]
Total for Month: 6.17
Departure from Normal: +3.10
Greatest in 24 hrs: 3.07 on 11-12

SNOWFALL, ICE PELLETS, HAIL
Total for month: 0.0 inches
Greatest snowfall in 24 hrs: 0.0
Greatest snow depth: 0

Symbols used in colmun 16

1 = Fog
2 = Fog reducing visibility to 1/4 mile or less
3 = Thunder
4 = Ice Pellets
5 = Hail
6 = Glaze or Rime
7 = Blowing dust or sand reducing visibility to 1/2 mile or less
8 = Smoke or haze
9 = Blowing snow
X = Tornado
N = None

[No. days with]
Max 32 or below: 0
Max 90 or above: 0
Min 32 or below: 5
Min 0 or below: 0

[WEATHER -No. days with]
0.01 inch or more precip: 11
0.10 inch or more precip: 9
0.50 inch or more precip: 4
1.00 inch or more precip: 2

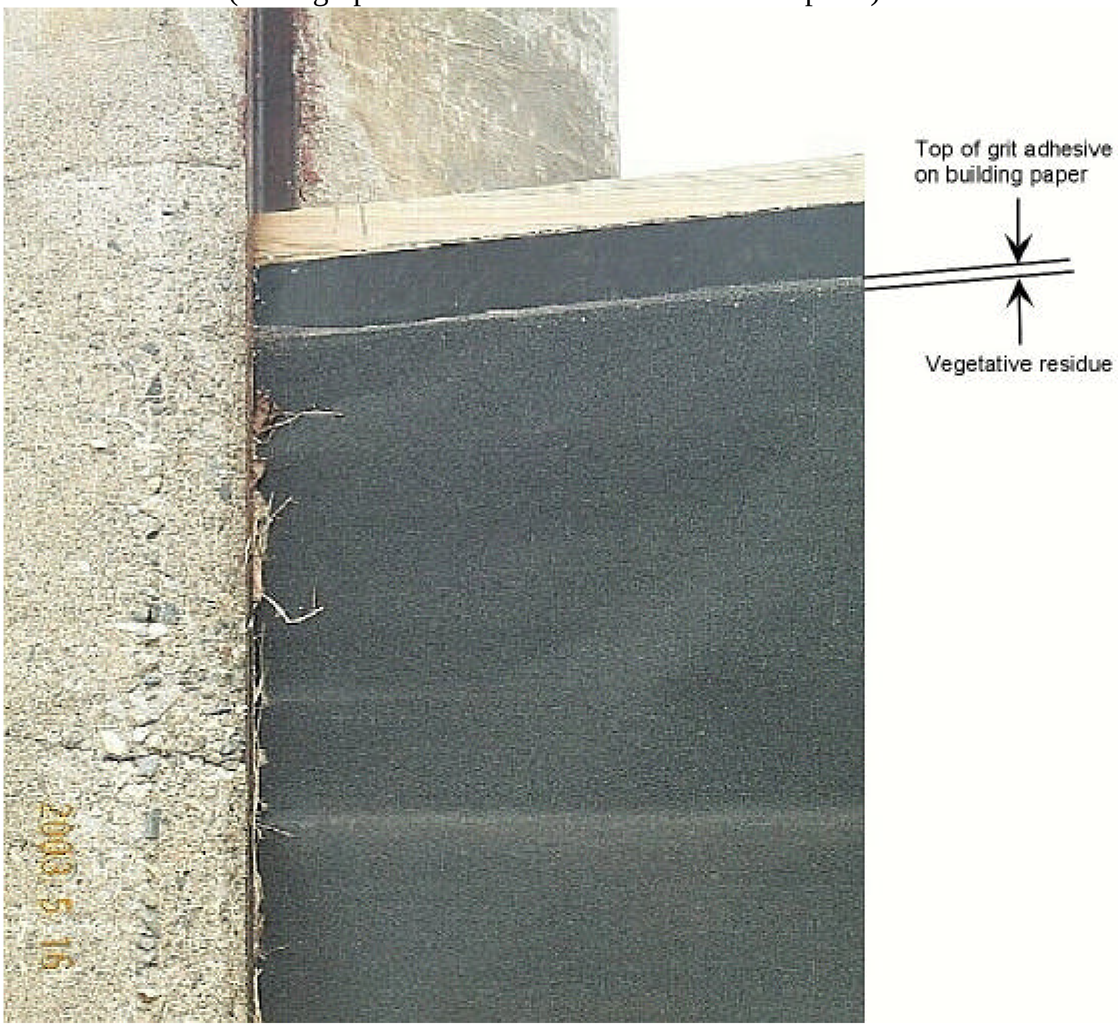
[Heating Degree Days (Base 65)]
Total this month: 460
Departure from Normal: -8
Seasonal Total: 9575
Departure from Normal: +60

[Cooling Degree Days (Base 65)]
Total this Month: 0
Departure from Normal: -12
Seasonal Total: 0
Departure from Normal: -12

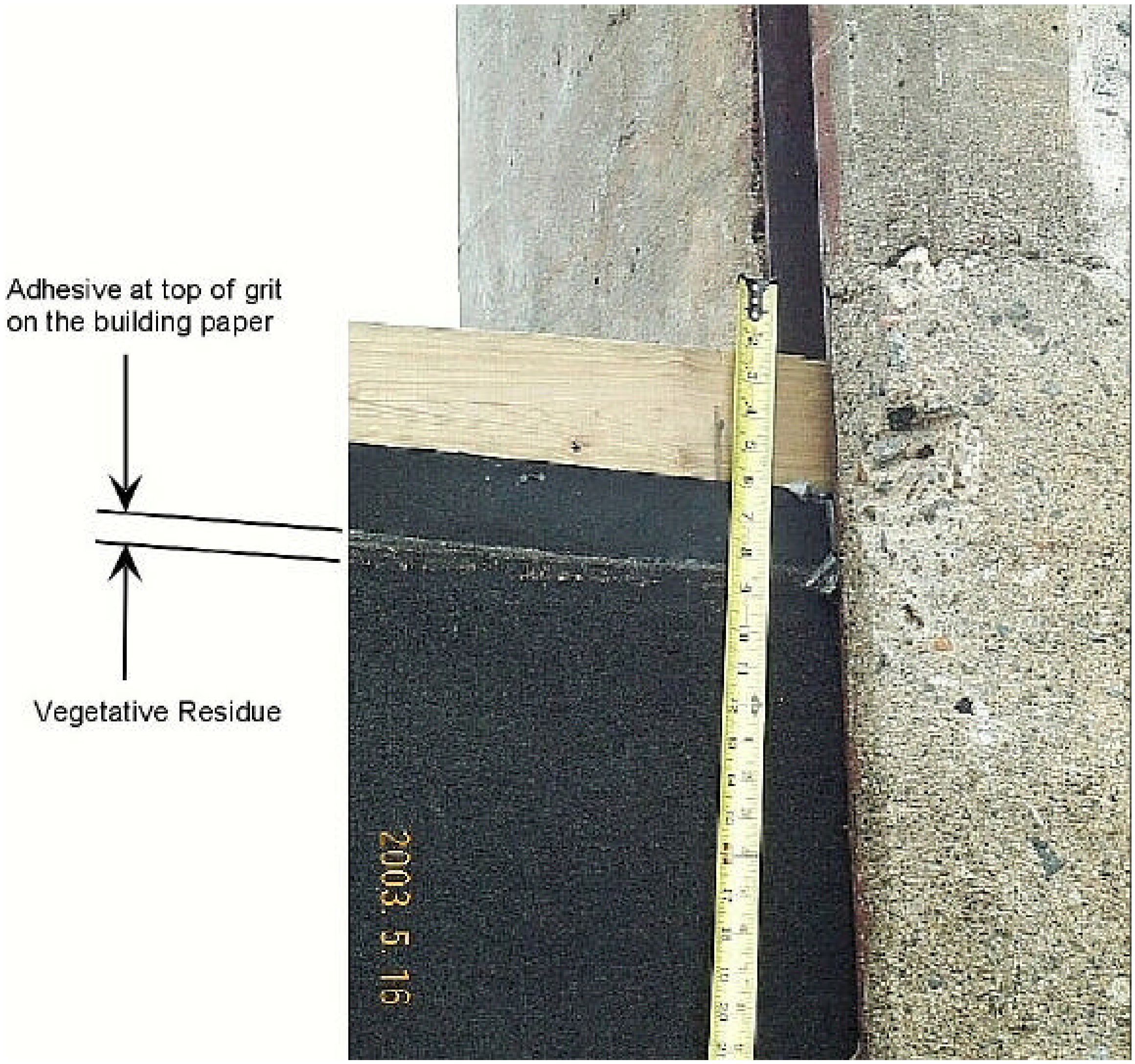
[Remarks]
Rainfall and snowfall amounts in columns 7, 8, and 9 are the offical precipitation for MARQUETTE, MI.
Snow depth in column 9 is recorded at 7 AM.

Table 2.

(Photograph taken on date indicated in the caption)



Photograph 1. Downstream right side of the stoplog bay of the overflow spillway at Silver Lake. Photograph taken on May 16, 2003. Note the vegetative debris in the slot and small debris on the felt paper indicative of a watermark near the top of the felt paper.



Photograph 2. Downstream left side of the stoplog bay of the overflow spillway at Silver Lake. Photograph taken on May 16, 2003. Note the small debris on the felt paper indicative of a watermark near the top of the felt paper.

Photograph 3. Silver Lake channel entrance as viewed from the right abutment near Station 0+35. Photograph taken on June 3, 2003.

Photograph 4. View of the upstream portion of the channel as viewed from the right abutment near Station 0+35. Photograph taken on June 3, 2003.

Photograph 5. The left abutment at Station 0+35 where the fuseplug dike was located. According to the STS survey, the top of the remnant section is at elevation 1481 feet. Photograph taken on June 3, 2003.

Photograph 6. Downstream portion of the channel as viewed from the right abutment near Station -0+60. Photograph taken on June 3, 2003.

Photograph 7. Downstream channel as viewed from the right abutment near Station -0+60. Photograph taken on June 3, 2003.