Failure Mode and Design Modifications Technical Memorandum for Mt. Carmel Dam

Cavalier County, North Dakota

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SUBMITTED TO

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Table of Contents

List of Tables

List of Figures

List of Appendices

Executive Summary

The purpose of this report is to present the results of our evaluation of the factors that contributed to the erosion beneath the spillway at Mt. Carmel Dam.

The objectives of this evaluation were to: a) identify probable design, site geotechnical, construction, or other elements that may have contributed to the erosion, b) identify a likely failure mode, and c) identify modifications to the design that would have likely prevented the erosion.

Based on the data collected, analyses performed, and our engineering experience with embankment dams, we conclude the following:

- Conditions leading to the large scale erosion began to develop several years prior to the catastrophic event that occurred in March-April 2003.

- The primary site elements contributing to the excessive erosion under the spillway are a) the combination of frost susceptible silt embankment fill soils with the extremely cold climate and b) the combination of highly erodible silt embankment fill soil with likely non-filter-compatible drain and foundation stabilization materials.

- The primary design elements contributing to the excessive erosion under the spillway are, in order of importance:

    - The lack of a filter compatible seepage collection system immediately downstream of the centerline (dam axis) cutoff.
    - The lack of provisions to prevent freezing of the soils directly under the slab upstream of the underdrain system.
    - The shallow depth and limited lateral extent of the sheetpile cutoff at the dam center line.

- The primary construction elements contributing to the excessive erosion under the spillway are a) the use of fine drainfill (as sampled) that does not meet filter criteria for the silt embankment fill, b) the use of foundation stabilization gravel that does not meet filter criteria, and c) the lack of lateral confinement of the granular drain materials resulting in poor compaction at the drain/backfill interface.

- The spillway structure from the inlet downstream to Segment C is undermined and will need to be removed and the embankment restored.

- Stilling basin structure Segments A and B are underlain by geotextile and 1-1/2-inch minus gravel to stabilize the foundation and fine and coarse drain materials. Some of these materials are not filter compatible. Therefore, the stilling basin will need to be removed and filter-compatible foundation conditions restored to provide adequate seepage stability.

- A new service spillway will need to be designed and constructed.

Section 1 - Introduction

1.1 Purpose and Objectives

The purpose of this report is to present the results of our evaluation of the factors that contributed to the erosion beneath the spillway at Mt. Carmel Dam.

The objectives of this evaluation were to:

- Identify probable design, site geotechnical, construction, or other elements that may have contributed to the erosion.
- Identify a likely failure mode.
- Identify modifications to the design that would have likely prevented the erosion.
- Determine if the elements contributing to the erosion are mostly related to site-specific conditions or would likely be common to the design concept.

1.2 Background

Our understanding of historic and operational information and physical conditions is summarized below. Additional information is presented in a GEI memorandum titled "Site Visit and General Condition of Mt. Carmel Dam, Cavalier County, North Dakota," dated August 29, 2003 (GEI, 2003), which is included in Appendix A. The general location of the dam and reservoir are shown on Figure 1.1 and a general plan of the dam and appurtenant facilities are shown on Figure 1.2.

The primary purposes of the Mt. Carmel Dam and Reservoir are a) water supply for the City of Langdon and for Langdon Rural Water and b) recreational uses. Mt. Carmel Dam was initially constructed in 1970-71 as a homogenous earthen embankment with a crest elevation at 1,537.5 feet. The reservoir elevation was controlled with a drop inlet riser that discharged through a 66-inch-diameter concrete pipe (original principal spillway) located at about the center of the dam.

The dam was first filled soon after completion of construction in 1971. In May 1971, shortly after filling, seepage was observed in the right abutment near the downstream toe. A grouting program in the right abutment was completed during the summer of 1972. This program reduced seepage from about 50 to 20 gallons per minute (gpm).

In 1995, the dam crest was raised between 4 and 5 feet to Elevation (El.) 1541.0 and a new reinforced concrete principal spillway, which consisted of a drop inlet, chute, and stilling basin, was constructed over the left part (looking downstream) of the existing embankment. This construction raised the normal water surface 2 feet to El. 1530.0. As part of this construction the original principal spillway was taken out of service by constructing a concrete bulkhead at the upstream end of the 66-inch pipe and partially demolishing the drop inlet and a new low-level outlet was constructed. The outlet discharges into the new reinforced principal spillway and can lower the reservoir to El. 1522.0, which is about 20 feet above the bottom of the reservoir.

In general, the reservoir is operated to maintain the reservoir as high as possible, which is limited by the uncontrolled principal spillway weir at El. 1530.0.

High spillway discharges through the new principal spillway were recorded in 1996, 1997, 2000, and 2002 as a result of large local precipitation events. Flows through the principal spillway last occurred in June 2002.

An erosion and undermining failure of the principal spillway was reported in progress on March 29, 2003, and likely initiated on or about March 28, 2003. North Dakota State Water Commission (SWC) personnel believe that the reservoir was not actively spilling over the crest of the principal spillway when the failure occurred, but was likely several inches below the crest (El. 1530) when the leakage under the spillway started. SWC personnel arrived onsite on March 29, 2003. At that time, the reservoir level had dropped about 2-1/2 to 3 feet to about El. 1527 and the flow through the eroded hole under the spillway had reduced significantly from its apparent high point. The flow likely reduced because the reservoir level had dropped below the top of the soil berm that was present around and upstream of the spillway inlet. SWC estimated that between 700 and 800 acre-feet (ac-ft) of water was lost from the reservoir during the erosion failure event. SWC estimated the flow rate during the failure was on the order of 200 cfs.

Step 1 emergency actions were implemented by SWC between March 30 and April 2, 2003, and included lowering the reservoir by re-opening the 66-inch-diameter spillway. Step 2 emergency actions were implemented by SWC between April 7 and April 17, 2003, and included installing a sheetpile and earthfill cofferdam around the upstream end of the principal spillway inlet thereby taking the principal spillway out of service. The sheetpiles were in 20 to 40 foot lengths and were driven to practical refusal, which resulted in about 8 feet of embedment into the existing dam embankment. The sheetpiles were initially seated using a 5,000-pound hammer and then the driving was finished with a vibratory hammer.

1.3 Scope of Services

The following scope of services have been performed by GEI Consultants, Inc. (GEI) for this phase of the project:

1. Reviewed the design drawings, construction records, and data obtained during a site visit, which occurred on July 31, 2003.

2. Conducted a Failure Modes Workshop to identify elements that may have contributed to the erosion.

3. Performed grain size and Atterberg limits testing on samples of filter and embankment materials collected during the site visit.

4. Performed engineering analyses to evaluate some of the factors identified in the Failure Modes Workshop to support development of the likely failure mechanism.

5. Identified areas where the design could be modified to address the factors contributing to the erosion.

6. Prepared this technical memorandum to present the results of our evaluation.

1.4 Authorization

GEI performed the work described in this report under the terms and conditions of a July 24, 2003 Consulting Agreement between GEI and the North Dakota SWC.

1.5 Project Personnel

GEI personnel responsible for the services described in this technical memorandum include:

Project Manager	Robert J. Huzjak, P.E.
Senior Geotechnical Engineer	Stephen G. Brown, P.E.[1]
Senior Structural Engineer	Brian S. Johnson, P.E.[1]
Staff Geotechnical Engineer	Ed R. Friend, E.I.T.
Staff Structural Engineer	Steve E. Morris, E.I.T.
Technical Review	James R. Talbot, P.E.[1]

Note:
1. Licensed in states other than North Dakota

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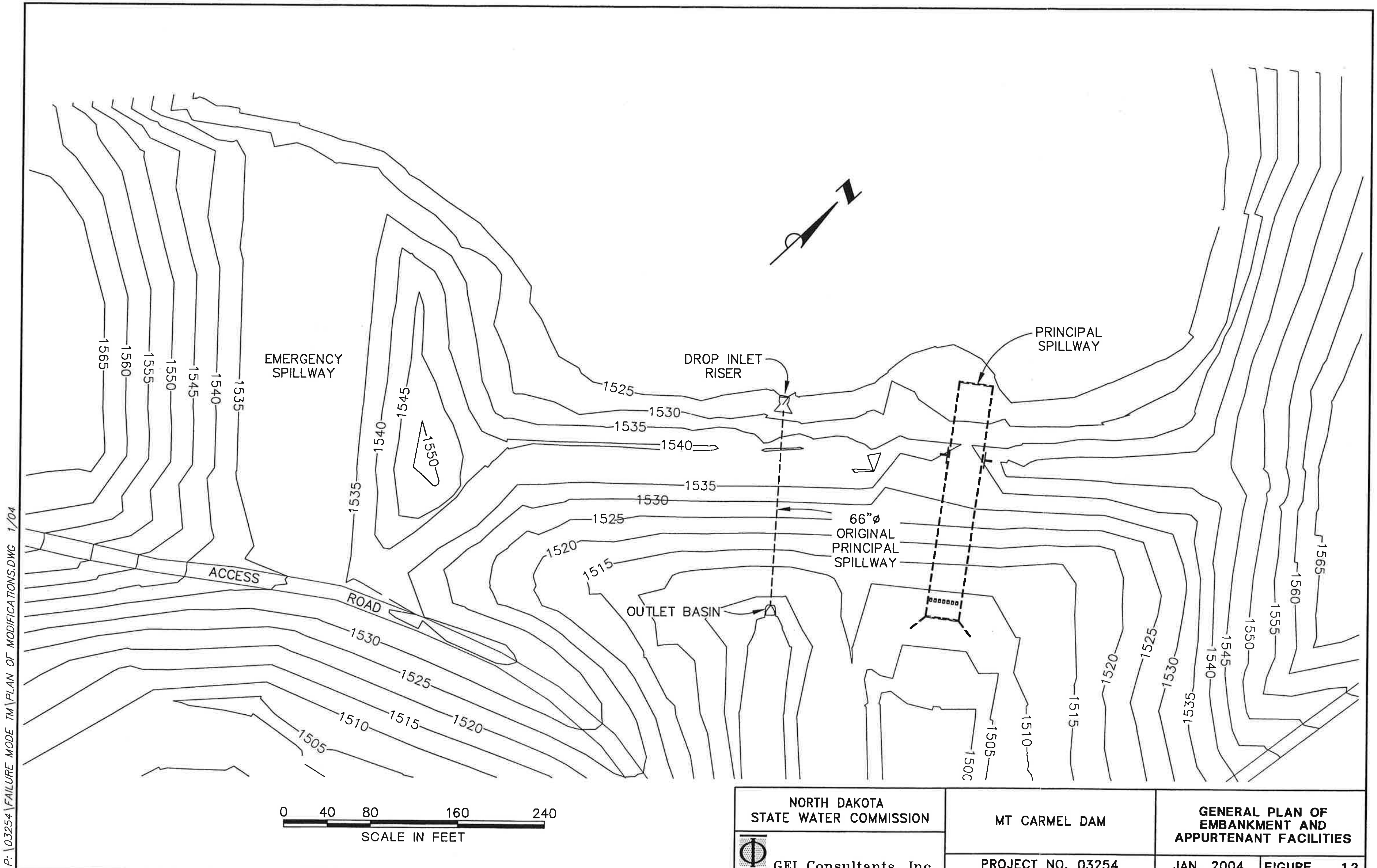
NORTH DAKOTA STATE WATER COMMISSION	MT CARMEL DAM	LOCATION MAP
GEI Consultants, Inc.	PROJECT NO. 03254	JAN. 2004 — FIGURE 1.1



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Section 2 - Possible Failure Modes

2.1 General

GEI used a workshop/brainstorming format to identify possible factors that may have contributed to the erosion under the spillway. The factors were developed based on a) our review of the design drawings, specifications, and construction records, b) observations made and data obtained during our site visit, and c) our experience with embankment dams and spillways. We divided the possible factors into the following four major categories:

- Underdrain System Design
- Structure Design and Seepage Cutoff Provisions
- Climate, Freeze Thaw, and Site Conditions
- Construction Materials and Methods

A brief description of the various factors identified and potential issues associated with each factor are presented in the following sections. A discussion of the analyses performed to evaluate some of the identified factors are presented in Section 3.

2.2 Underdrain System Design

2.2.1 Underdrain System Components

The underdrain system consists of a dual stage granular filter blanket that envelops a perforated drain pipe. The first stage of the granular filter consists of a 12-inch-thick layer of fine drainfill that was specified to have a gradation similar to ASTM C-33 fine aggregate. The fine drainfill layer thickness decreases to 6 inches where the blanket is depressed to form a shallow trench for the perforated drain pipe. The second stage is coarse drainfill used to locally backfill the drain pipe trench and surround the perforated drainpipe. The coarse drain fill was specified to be 4 inches thick on all sides of the perforated pipe. The coarse drainfill is not enveloped by fine drainfill at the top of the pipe trench. The coarse drainfill at the top of the drain pipe trench is directly against the 2-inch-thick layers of rigid insulation. The rigid insulation and underdrain system are located beneath spillway Segments A, B, C, D, and E. Spillway segments are shown on the general spillway plan on Figure 2.1. The perforated drain pipe is a 4-inch-diameter PVC pipe located within the granular filter drain.

2.2.2 Elements

Elements that may have contributed to the erosion are:

- **Location of Underdrain System** – The first underdrain unit is located beneath Segment E at a distance of about 61 feet downstream of the centerline sheetpile cutoff. Therefore, a drain system was not present at the location where the highest seepage gradients, pressures, and flows would be anticipated, which is immediately downstream of the centerline sheetpile cutoff. This configuration requires seepage under and through the sheetpiles and around the concrete cutoff walls to discharge into the fine grained embankment materials. Seepage would tend to find a pathway into the surrounding embankment fill or into the drain system along the paths of least resistance, which would likely be at the interface between concrete and fill materials. Similarly, provisions for managing seepage (seepage collection system or cutoff) adjacent to the spillway walls and footings downstream of the dam centerline was not included in the design.

- **Filter Compatibility of the Drain Materials** - The gradation of the actual materials installed for the fine filter needs to be filter compatible with the embankment and backfill materials to prevent piping of fine grained embankment materials into the coarse filter. Likewise the gradation of the in-place coarse filter needs to be filter compatible with the fine filter to prevent piping of the fine filter into the coarse filter. Failure to meet the above criteria could result in development of a piping failure through the drain system.

  The fine drainfill was specified to be consistent with ASTM C-33 Fine Aggregate for Concrete, which is likely filter compatible with the existing gravelly clay till embankment and the new sandy silt embankment fill placed for the spillway project. The specified coarse drainfill is coarser than an American Association of State Highway Officials (AASHTO) No. 8 Coarse Aggregate for Concrete, which is known to be filter compatible with C-33 sand.

- **Encapsulation and Confinement** – The design of the underdrain system, based on Sheets 12 and 13 of the Design Drawings, did not require complete encapsulation of the coarse drain fill materials with fine drain fill material. The coarse drainfill is not enveloped by fine drainfill at the top of the pipe trench. The coarse drainfill at the top of the drain pipe trench is exposed directly to the rigid insulation. The rigid insulation is installed in two 2-inch-thick layers using 4-foot by 8-foot panels. Based on remnant intrusion of the overlying 1-inch-thick work slab concrete observed during our site visit, it appears that gaps on the order of 1/8-inch thickness existed between the panels. This represents a potential pathway for erosion of fine-grained embankment materials directly into the coarse drainfill and perforated drain pipe system. The relative permeability of the 'fracture' type flow through the panel gaps would be significantly higher than the permeability of the fine drainfill, resulting in a preferred seepage and erosion pathway.

The granular drain material may not have been laterally confined during placement. As indicated on Section B of Sheet 13 and construction photos (see Photo 1 in Appendix B), the granular drain material appears to have not been laterally unconfined because it was not placed either in a trench-type condition or between concrete walls that would have confined the material. Adequate compaction of backfill around the drain materials would have been difficult to achieve. Likewise, the drain materials themselves were likely not adequately compacted. Poor compaction at the important contact between these materials would result in loose materials that have increased porosity and potential for development of preferred erosion pathways along the contact boundary.

- **Capacity of Drain System** – The design hydraulic capacity of the drain system may not have been sufficient to effectively collect the volume of seepage that developed prior to failure. Also, the underdrain could have become clogged prior to failure due to large quantities of suspended sediment in the seepage, which could greatly reduce the underdrain capacity. Once the drain system became overwhelmed, water pressures in the drain system and in the surrounding soils would have increased and alternative seepage paths around the drain system to the sides of the spillway in the chute section may have developed.

- **Effectiveness of the Pre-Fabricated Strip Drain around the Inlet Structure** –

    - Strip drains were installed around the inlet drop structure walls upstream of the centerline wing wall to reduce hydrostatic pressure against the concrete inlet walls. Water collected by the strip drains is discharged through a series of weep holes at the bottom of the inlet walls. Strip drains consisted of a commercially produced geosynthetic composite material (Contech Stripdrain 75), which consists of a cuspated high density polyethylene drain board core covered on all sides by a non-woven geotextile fabric. Contech Stripdrain 75 is typically provided in rolls with 22 and 44 inch widths and has a thickness of 3/4 inch. When the pieces of strip drain were cut from the roll to install around the inlet structure walls, the cut ends would need to have been field sealed to prevent migration of particles through the core of the drain. The strip drains were installed against the wall to a height of 44 inches above the footing, or a roll width.

- A fundamental concern with use of geotextiles for filtration and drainage is geotextiles will become clogged by suspended sediment, such as occurs when water moves through a crack in soil. Clogging occurs because the strip drain core does not provide the needed support to the geotextile, which in turn, must support the soil interface and the geotextile where seepage water is discharging. The preferred method to address drainage adjacent to walls in dams is use of a high capacity granular drain with a perforated collection pipe. The strip drains were likely not entirely effective at reducing hydrostatic pressures at the base of the structure. However, if the strip drains failed to provide adequate drainage, the strip drains were probably not the primary cause of failure, but may have been a contributing factor.

2.3 Structure Design and Seepage Cutoff Provisions

- **Size and Type of Centerline Cutoff** – The bottom of the sheetpile cutoff was designed to extend 4 feet below the bottom of the slab. Based on our experience on other projects, penetration of 4 feet could be too short for a condition where full reservoir head develops under the bottom of the inlet basin. For a reservoir at normal pool, which is spillway crest at El. 1530, the pressure head upstream of the cutoff wall could be as much as 10 feet. In addition, the sheetpiles only extended about 6 feet left and right of the spillway structure, which also may not be sufficient for the above condition. If full reservoir head develops upstream of the cutoff, seepage gradients downstream of the cutoff could be sufficiently high to cause internal erosion of the foundation. Also, sheetpiles are not watertight and some uncontrolled seepage through the cutoff would be expected if the saturated zone extends to the sheetpiles.

- **Hydrostatic Uplift of the Inlet Basin** – The intent of the pre-fabricated strip drains and weep holes around the inlet basin is to reduce hydrostatic pressures on the walls and reduce uplift forces on the structure by draining seepage to the interior of the inlet basin. However, if the strip drain becomes clogged or has inadequate hydraulic capacity to pass seepage flows, it is possible that a seepage path could develop adjacent to the strip drain so that full reservoir head is applied to the bottom of the inlet basin. If the net uplift forces were large enough to lift the basin, a preferred seepage path would form and that could apply full reservoir head over a concentrated area of the centerline sheetpiles. Also, uplift pressures could develop if a more permeable zone, independent of the strip drains, is present under the slab. A layer of granular structural fill was evidently placed beneath the inlet basin based on observed granular material embedded into the concrete slab (GEI, 2003). Uplift of the inlet structure could result if sufficient resisting forces are not available to counteract the uplift forces.

- **Frost Protection Upstream of the Drainage System** – Insulation was only provided above the filter drain materials. No insulation was provided under the chute upstream of the underdrains or under the drop inlet structure.

- **Ice loading on Inlet** – Ice forces on the upstream end of the inlet could have caused deflection of the walls and foundation. This was dismissed as a potential contributor because forces from any ice loading would primarily act against the earthen berm and not directly on the concrete structure. Forces on the berm would not be transferred to the structure because the berm would compress under the loads.

2.4 Climate, Freeze Thaw, and Site Conditions

- **Freeze-Thaw Cycles Under Structure** – Frost-susceptible soil, freezing temperatures, and a source of water contribute to the formation of ice lenses and frost-heave that can result in significant uplift forces on structures. Embankment fill used to backfill the spillway excavation and likely placed in some areas beneath the un-insulated part of the spillway inlet and chute slab consist primarily of sandy silt. The presence of silt soil beneath the inlet and chute structures could not be confirmed during the site visit because of the widespread erosion in these areas. Silt soil was identified in samples of backfill adjacent to the spillway walls, in embankment placed for the dam raise, and in the borrow area. Based on samples obtained during the site visit, the embankment fill generally has the following characteristics:

    - Generally classifies as a moderate to high plasticity silt (ML to MH)
    - Liquid limit ranges from about 49 percent to 58 percent
    - Plasticity Index ranges from about 19 to 23 percent
    - Gradation generally consists of about 20 to 30 percent clay, 50 to 60 percent silt and clay fines, 33 to 47 percent sand, and 5 percent gravel

  The above embankment fill soils are considered to be frost susceptible and it is likely that some depth of soils beneath the slab would freeze each year. Where silt soils are present below the slab and if there is a source of water, it is likely that ice lenses would form in the soil. The force exerted on the structure as a result of frost heave could be large enough to result in a slight, but potentially significant, uplift of the structure. Even slight uplift of the structure could contribute to further intrusion of seepage water under the slab. One result of several cycles of freezing and thawing would be the development of either a zone of low density soils or a void below the slab.

- **Colder Winter than Usual with Associated Deeper Frost Penetration** – We obtained weather data from the North Dakota Agricultural Statistics Service (NDASS) for the Town of Langdon. Based this data we calculated the average monthly freezing index, which is based on about 30 years of data, and the monthly freezing index for the winter of 2002-2003 for this area. A higher freezing index number indicates colder conditions and the potential for greater frost penetration. The data presented below indicates that the months of February and March were generally significantly colder during 2002-2003 than the average. Frost depths of up to 10 feet were reported in the general area for the winter of 2002-2003, which is 3 to 4 feet more than normal.

TABLE 2.1
COMPUTED FREEZING INDEX

Month	2002-2003	Average
November	281	297
December	499	831
January	880	1017
February	894	756
March	561	406

We also obtained data on average historical monthly temperatures and average monthly temperatures for the 2002-2003 season. Data collected are presented below. Based on this data, the months of December and January were warmer than usual and the months of February and March were colder than usual. However, on March 8, 2003, Landon had a record low temperature of -25°F. Seven days later, on March 15, Landon had a high temperature of 45°F, which was 4 degrees short of the record, and on March 16, the high was 50°F.

TABLE 2.2
AVERAGE MONTHLY TEMPERATURES

Month	2002-2003	Average
December	16	5
January	7	-4
February	1	5
March	14	18

It was also reported that snow cover was lighter than usual during the winter of 2002-2003.

- **Solar Radiation and Differential Thawing** – The thawing of frozen soils usually proceeds from the top downward. The melt water cannot drain into the frozen subsoil, thus becomes trapped between the concrete slab and the frozen materials below. This process can be even more dramatic when the frozen surface is heated differentially. The orientation of the spillway is such that the left side of the slab and the left wall would be in the sun for most of the day. Therefore it is expected that this area of the spillway would be warmer due to solar radiation, which would result in thawing of the backfill sooner on the left side than on the right side.

2.5 Construction Materials and Methods

2.5.1 Construction Materials

- **Installed Materials versus Specified Materials -** Based on the results of gradation tests on samples of fine and coarse drainfill materials, which were obtained at the time of the site visit from the relatively intact drain system located beneath Segment C of the spillway, the as-placed fine drainfill sample is not consistent with the specifications. The fine drainfill tested is significantly coarser than the specified material, which is similar to the gradation for ASTM C-33 concrete fine aggregate. Using the gradation of the sample tested, filter compatibility criteria between the fine drainfill and embankment fill material is not met. However, it is possible the sample of fine drainfill may not be representative of as-placed materials due to particle migration (erosion) of material from the drainfill during normal operation of the reservoir or otherwise compromised by the limited sampling access in the confined area beneath the slab.

  Based on results of a gradation test on a sample of coarse drainfill, the gravel gradation is consistent with the specifications except that it contains an increased quantity of sand and fine particles: up to 10 percent medium and fine sand and about 5 percent silt/clay size particles. The increased sand and fines could contribute to a slightly reduced drain permeability and flow capacity. However, there is a possibility that the coarse drainfill sample is not representative of as-placed materials because it may have been contaminated by particle migration (erosion) into the filter or otherwise comprised by the limited access for sampling.

2.5.2 Construction Conditions and Methods

Several potentially adverse construction conditions and methods were identified from review of construction photos and the design documents, as follows:

- **Adequate Lateral Containment of the Drain Material** – Containment of the granular drain material does not appear to have been achieved because the material was not extended laterally beyond the structure to the sides of the excavation (see

Photo 1, Appendix B). The drain material placement was terminated at the edge of the structure and the footing/slab poured on top of the drain material in accordance with Section B on Sheet 13 of the Drawings. The footing/slab was poured on top of the drain material before any backfill was placed adjacent to the drain system as can be seen in Photo 2, Appendix B. Adequate compaction of the subsequent backfill placed next to the drain system would have been hindered by the overlying slab and loose granular drain material. As a result, the important contact between the backfill and the drain system was not likely adequately compacted.

- **Compaction Issues** – The narrow spillway excavation required use of small compaction equipment that may not have achieved adequate compaction of backfill along the sides of the structure (see Photo 3, Appendix B). Compaction along the sides of the structure could also have been compromised by the vertical structure walls. Compactive energy, particularly from small compaction equipment, is much more efficiently transferred to the soil when compacting against walls with a slight outward slope.

  As indicated in Photo 3 (Appendix B), there is a potential for damage to the exposed drain discharge pipes during backfilling and compaction operations. The drain discharge pipes were not structurally supported prior to backfilling except at the top of the pipe by the penetration through the structure wall and at the bottom by the granular drain material. However, damage or disturbance to the vertical exposed pipes and pipe joints does not appear to have occurred during construction because if such damage occurred, large quantities of soil would have likely been discharged from the drain outlets prior to the failure.

- **Foundation Stabilization** – Measures were taken during construction to address wet subgrade conditions. In a departure from the design, foundation stabilization gravel (1-½-inch minus) was placed in areas of wet subgrade beneath stilling basin Segments A and B to provide a working surface. This gravel was then covered by non-woven geotextile (see Photo 4 Appendix B), which shows the foundation stabilization materials installed beneath the stilling basin. It is our understanding that foundation stabilization materials were not installed beneath Segments C, D, and E, where most of the erosion occurred. The coarse foundation stabilization gravel would have a very high permeability, generally higher than the underdrain system itself, and would not be filter-compatible with the sandy silt embankment fill. As a result of the higher permeability of the foundation stabilization material, seepage would tend to concentrate in this zone and a gradient would develop from the embankment soils into the foundation stabilization material and into the underdrain system. This condition could cause the sandy silt embankment fill material to pipe into the foundation stabilization material.

Such a drainage condition would not be sustainable long-term because the suspended silt carried by the foundation stabilization material would eventually clog against the overlying geotextile. If the overlying geotextile became clogged, seepage collected by the foundation stabilization material would be discharged either laterally into the surrounding embankment fill or a circuitous pathway around the geotextile and into the underdrain.

2.6 Key Observations

Key observations and information that was obtained and was influential in evaluation of the failure modes are summarized below:

- The reservoir typically has a 3-foot thickness of ice during winter.

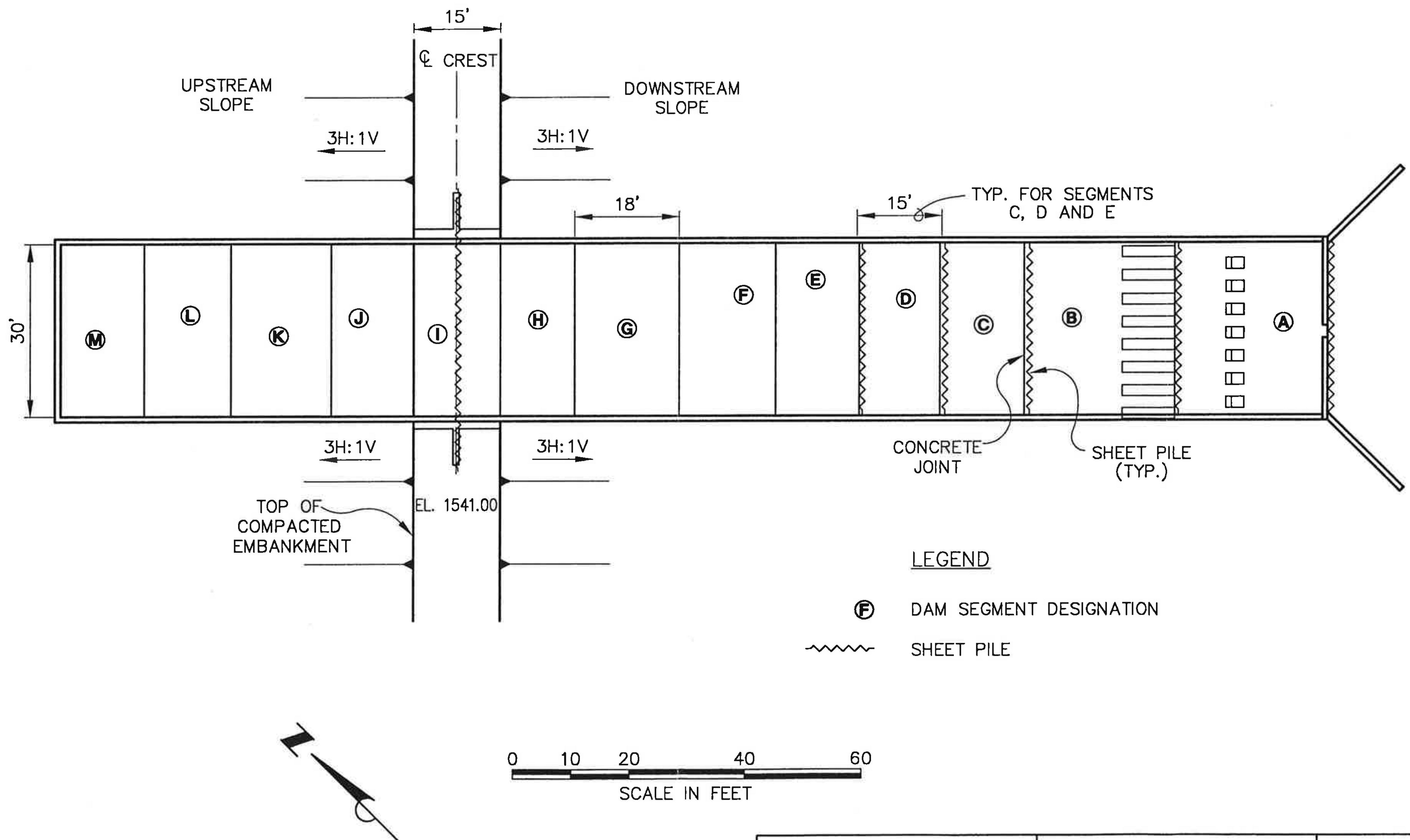
- Deeper than average frost penetration occurred during the winter of 2002/2003 due to colder late winter temperatures and little snow cover.

- Spillway underdrains for Segment C (Drain No. 3 left and right) and E (Drain No. 1 left) were observed discharging during the August 2000 inspection. (Drains are numbered from upstream to downstream and left and right, based on looking in the downstream direction.)

- Stained concrete adjacent to underdrain discharge locations indicates upstream drains flowed more than downstream drains. Underdrains flowed for long periods prior to failure to cause the stains on the chute walls (Photos 5, 6, and 7, Appendix B).

- The sound of water moving near the fifth weep hole on the left side of the principal spillway drop inlet was identified during the August 2000 inspection. This observation likely indicates development of a seepage pathway beneath the inlet slab or adjacent to the footing upstream of the cutoff about 2.5 years before the failure occurred.

- Modifications to the underdrain system during construction, such as structural fill beneath the inlet slab and potential for foundation stabilization gravel beneath the underdrains of Segments C, D, and E (Figure 2.1) can provide high permeability zones that do not meet filter compatibility with the surrounding soil.



NORTH DAKOTA STATE WATER COMMISSION	MT. CARMEL DAM	GENERAL PLAN OF SPILLWAY
GEI Consultants, Inc.	PROJECT NO. 03254	JAN. 2004 **FIGURE 2.1**

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Section 3 - Analyses

3.1 General

We performed seepage, uplift, and filter compatibility analyses to evaluate several of the possible failure mechanisms identified in Section 2. A description of the analyses performed, results, and conclusions are presented in this section.

3.2 Seepage

3.2.1 General

GEI performed two-dimensional, steady state seepage analyses to evaluate relative changes in computed seepage quantities and exit gradients for four general conditions. These conditions were selected to consider changes in seepage conditions that may have resulted from a) placing coarse grained materials below the concrete slabs or b) cycles of freezing and thawing. We used the computer program SEEP/W to perform the seepage analyses. The results are presented in the following sections and computer outputs are presented in Appendix C.

The four cases considered are as follows:

- Case 1 – Design condition. Clayey soils in contact with the bottom of the slab of the inlet basin and chute upstream of the drainage system. Direct connection does not exist between the reservoir and the composite geosynthetic drain material against the inlet walls. Drain system is included in the model as shown in the design drawings.

- Case 2 – Void or coarse granular material exists below the inlet slab from the upstream end of the foundation slab to the upstream side of the centerline sheetpile cutoff. Clayey soils in contact with the bottom of the slab of the chute upstream of the drainage system. Direct connection does not exist between the reservoir and the composite geosynthetic drain material against the inlet walls. Drain system is included in the model as shown in the design drawings.

- Case 3 - Void or coarse granular material exists below the inlet slab from the upstream end of the foundation slab to the upstream side of the centerline sheetpile cutoff. Clayey soils in contact with the bottom of the slab of the chute upstream of the drainage system. Coarse gravel or void that is hydraulically connected to the reservoir is present against the inlet walls. Drain system is included in the model as shown in the design drawings.

- Case 4 - Void or coarse granular material exists below the inlet slab from the upstream end of the foundation slab to the upstream side of the centerline sheetpile cutoff. Void or coarse grained gravel exists below the chute slab from the downstream side of the centerline sheetpile cutoff to the upstream edge of the drainage system. Coarse gravel or void that is hydraulically connected to the reservoir is present against the inlet walls. Drain system is included in the model as shown in the design drawings.

3.2.2 Representative Cross Section

We developed a representative section that is parallel to the length of the principal spillway, which is perpendicular to the dam centerline as shown on Figure 2.1. Where a void/gravel layer was considered, this layer was either modeled as a 6-inch-thick zone or as a constant head boundary equal to reservoir head, as appropriate. A 1.5-inch-wide zone of disturbance was included around the sheetpile to account for disturbance and to reduce permeability at the soil/structure interface.

3.2.3 Permeability

Permeability values assigned to various layers considered in the model are presented in Table 3.1. Permeabilities were estimated based on correlations of material properties and soil descriptions to published permeability data and our experience with other similar materials. An equivalent hydraulic conductivity was assigned to the sheetpile in the model. The equivalent hydraulic conductivity was based on the assumption that seepage occurred primarily through the approximately 1-inch-wide joints in between each 18-inch sheet of the wall. For the calculation, the joints were assumed to have a hydraulic conductivity of 1×1^{-3} cm/sec and the sheets were assumed to have a hydraulic conductivity of 1×10^{-7} cm/sec. The primary intent of the modeling was to compare changes in gradient and seepage quantity for various assumptions associated with different seepage paths and not to quantitatively determine the volume of seepage. Therefore the relative difference between the permeability of the various layers is more important than the actual values selected.

TABLE 3.1
PERMEABILITY USED FOR COMPARATIVE ANALYSES

Material/Layer Description	Permeability (cm/sec)	
	Vertical	Horizontal
Embankment/Glacial Till	5×10^{-6}	1×10^{-5}
Void/Gravel	10	10
Centerline Sheetpile	5.3×10^{-5}	5.3×10^{-5}
Disturbance Zone	1×10^{-3}	1×10^{-3}

3.2.4 Results

Results of the seepage analyses are contained in Appendix C and summarized in Table 3.2.

TABLE 3.2
RESULTS OF SEEPAGE ANALYSES

Case Identification	Computed Seepage (1) cubic feet/sec (cfs) x 10^{-7}	Computed Exit Gradient	
		Sheet Pile(2)	Underdrain System(3)
1	0.93	<0.1	1.6
2	1.3	0.2	2.0
3	1.8	0.4	2.2
4	22.0	4.6	1.6

Notes:
1. Seepage is in terms of a unit width perpendicular to the centerline of the dam axis. To estimate total seepage under the spillway, multiply the unit seepage by the width of the spillway.
2. Exit gradient is computed at the downstream side of the centerline sheetpile.
3. Exit gradient is computed at the upstream end of underdrain system.

3.2.5 Conclusions

Based on the results of these analyses we concluded the following:

- For any condition modeled, seepage quantities would be relatively small provided that the embankment soil remains in contact with the upstream and downstream sides of the sheetpiles.

- For any condition modeled, the exit gradients into the underdrain system are sufficient to cause internal erosion of the embankment soils and piping into materials that are not filter compatible.

3.3 Flotation

We performed a relatively simple floatation analysis of the inlet portion of the spillway. Our analysis considered Segment M, as configured on the construction drawings (see Figure 2.1). The original design calculations for the spillway included a floatation analysis of the spillway stilling basin (represented by Segment A), but do not appear to include any analyses for the inlet section. The inlet structure is a rectangular box section about 30 feet wide and 8 feet deep. The floor slab extends about 1 foot beyond the outside face of the walls, acting as a footing for the wall. An earth berm was placed around the outside of the inlet to a height of about 2 feet below the top of the wall.

We evaluated the following three analysis scenarios:

- Structure with no vertical soil load acting to resist floatation. This is a conservative approach, in that the soil berm placed on the outside of the inlet would provide resistance to floatation by placing weight on the footing of the basin.

- Structure with a vertical column of soil acting on the structure footing to resist uplift. This is a less conservative assumption than Scenario 1, but does not account for resistance benefits gained by the shear strength of the soil.

- Structure with a prismatic zone of soil resistance. The resisting soil prism was assumed to extend up from the footing at a 30-degree angle, this angle being roughly equal to the shear strength of the soil.

Our analyses considered the three walls of Segment M, but do not include any resisting loads attributable to the adjoining Segment L. All of the scenarios included the following assumptions:

- Reservoir pool at the top of the inlet wall (maximum normal pool elevation).

- No water inside the inlet basin (no spillway discharge).

- Negligible head loss as water seeps under the structure, resulting in full reservoir pressure under the floor of the inlet.

- Buoyant weight of soil equal to 58 pounds per cubic foot (pcf), based on representative density curves obtained from construction records.

The results of our analyses are summarized in Table 3.3.

TABLE 3.3
FLOATATION ANALYSES RESULTS

Scenario	Computed Factor of Safety
1 - No Soil Uplift Resistance	0.50
2 - Vertical Column Soil Resistance	0.65
3 - Prismatic Column Soil Resistance	0.77

Computed factors of safety less than 1.0 indicate that uplift forces are greater than resisting forces (including the weight of the structure and soil loads, as appropriate), and implies that the structure will float under the respective conditions.

We then performed a simplified analysis of the potential effects of this floatation using the results of Scenario 3. We assumed that the spillway acts as a cantilever beam, with net uplift forces acting on Segments M and L only. We further assumed that these uplift forces varied linearly from full net uplift at the upstream end of Segment M, to zero at the downstream end of Segment L. Based on this analysis, it appears that the net uplift loads could lift the inlet section of the spillway vertically by as much as 0.03 inches. This amount of uplift would not be expected to result in visual evidence of its occurrence, but could be enough to be a contributory factor in the erosion beneath the spillway structure.

3.4 Filter Compatibility

The filter compatibility was checked for critical material contact boundaries as summarized in Table 3.4.

Filter criteria are met at the material contact boundaries listed above except for Case 2 embankment fill against the fine drainfill that was sampled from beneath Segment C, and for Case 7 embankment fill against the 1-1/2-inch minus foundation stabilization gravel. A gradation was not available for the 1-1/2-inch minus foundation stabilization gravel. Therefore, the evaluation is based on qualitative judgment that the foundation stabilization material is significantly coarser than the fine drainfill (as sampled), which did not meet filter criteria.

TABLE 3.4
FILTER COMPATABILITY ANALYSES RESULTS

Case No.	Base Soil	Filter	Comments
1	Embankment Fill (as sampled)	Fine Drainfill (as specified)	Yes - Filter criteria is met.
2	Embankment Fill (as sampled)	Fine Drainfill (as sampled)	No - Filter criteria is not met.
3	Fine Drainfill (as specified)	Coarse Drainfill (as specified)	Qualified Yes - Coarse drainfill is slightly coarse of the D_{15max} criteria, however it is close enough that filter criteria is considered to be met. This could cause a problem under very high gradients.
4	Fine Drainfill (as specified)	Coarse Drainfill (as sampled)	Yes - Filter criteria is met.
5	Fine Drainfill (as sampled)	Coarse Drainfill (as specified)	Yes - Filter criteria is met.
6	Fine Drainfill (as sampled)	Coarse Drainfill (as sampled)	Qualified Yes - Filter criteria is met but increased sand content at D_{15} size indicates the permeability would be restricted.
7	Embankment Fill (as sampled)	Foundation Stabilization Gravel	No – Filter criteria is not expected to be met based on comparison with Case No. 2 above.

Material contact boundary Cases 3 and 6 were given a qualified acceptance for filter criteria. In Case 3, the specified coarse drainfill is slightly coarser than Soil Conservation Service (SCS) filter criteria, but is judged to be close enough to be acceptable. In Case 6, the as-sampled coarse drainfill meets filter criteria but increased sand content in the drainfill sample causes the sample to not meet permeability criteria. To provide a free-draining interface between the materials the filter, which is the coarse drainfill in this case, should have a permeability at least 6 times greater than the base soil (fine drainfill, in this case). The permeability ratio of the coarse drainfill (as sampled) to the fine drainfill (as sampled) is estimated to be about 3, which indicates the coarse drainfill will not provide the desired degree of free-drainage to flows from the fine drainfill. Permeabilities for the materials were based on empirical correlations and our experience with similar materials.

3.5 Underdrain System Capacity

The capacity of the drainage system to collect flows directly under the spillway slab is controlled by flow into the 1-foot-thick by 30-foot-wide upstream face of fine drainfill of the underdrain for Segment E. Assuming the underdrain would function as intended, all seepage that flows along the interface of the slab and the embankment fill downstream of the centerline sheetpile cutoff must enter the underdrain system through this pathway. This pathway has an estimated flow rate capacity in the range of 0.25 gpm to 1.0 gpm for the 30-foot-wide underdrain based on published laboratory permeability test data for sand with a gradation similar to the specified fine drainfill gradation (Sherard et al., 1984) and published empirical correlations between particle size and permeability (NAVFAC DM-7, 1971). The estimated flow rate from the SEEP/W seepage analysis (Section 3.2) is in the range of 0.0013 gpm for design condition (Model 1) to 0.03 gpm for a void gravel zone below the spillway (Model 4) for a 30-foot-wide structure. Based on these estimates, the underdrain system would have sufficient capacity to pass the expected seepage flows unless a piping channel developed under the slab and progressed back to the bottom of the sheetpile, which would substantially increase the volume of flow.

The capacity of the 4-inch-diameter drain pipe located beneath Segments C, D, and E is about 300 gpm, which greatly exceeds the flow rate capacity of the fine drainfill. The capacity of the drain pipe was calculated based on the 3H:1V slope and the assumption that the pipe is flowing at 75 percent full.

Section 4 – Probable Failure Mechanisms

Based on the data collected, analyses performed, and our engineering experience with embankment dams, our opinion of the probable failure mechanisms is as follows:

- Conditions leading to the large scale erosion began to develop several years prior to the catastrophic event that occurred in March-April 2003. This opinion is based on the following:

  - SWC observations that the seepage collection system was conveying water through underdrains for Segment C (No. 3 drains on left and right) and Segment E (No. 1 drain on left) and the sound of flowing water behind the fifth weep hole on the left side of the drop inlet in August 2000, which is about 2.5 years prior to the event (refer to Figure 2.1 for locations of spillway segments). This evidence suggests that a seepage path existed under the spillway prior to the events of March and April 2003.
  - The seepage exiting the underdrain outlets appears to have been associated with seepage flowing under the spillway slab and not general embankment or foundation seepage based on the following reasons:
    - General embankment seepage that is associated with the phreatic surface in the embankment would also have been visible at similar elevations along the toe of the dam. No such seepage was identified.
    - General foundation seepage associated with the documented high foundation pressures would have continued after the erosion failure. Seepage into the eroded area below the spillway or from the underdrain outlets was not observed after the event.
  - The specific reason for no seepage exiting from Drain No. 2 is unknown. It is possible that seepage paths developed either under or around the underdrain system at Segment D.

- Full reservoir head was applied to the upstream side of the sheetpiles at the centerline of the dam. Full reservoir head developed as a result of one or a combination of the following:

  - The presence of coarse grained materials (likely structural fill) that were placed beneath the inlet slab to improve foundation stability during construction.

  - o Cycles of freezing and thawing that resulted in uplift of the structure and associated voids at the slab/soil interface and/or the development of a low density/higher permeability zone directly beneath the slab.
  - o Hydrostatic uplift of the inlet structure that resulted in a void at the slab/soil interface.

- Seepage paths developed under the slab or along the sides of the footings between the centerline sheetpiles and the underdrain system. These seepage paths developed as a result of one or a combination of the following:

  - o Cycles of freezing and thawing that resulted in uplift of the structure, voids at the slab/soil interface and/or the development of a low density/higher permeability zone below the slab.
  - o Inadequate compaction at the contact between drainfill materials and adjacent soil backfill because of lack of lateral confinement of the drain materials.
  - o Possible gaps between the rigid insulation panels.
  - o High seepage gradients in the foundation soils adjacent to the concrete.

- Erosion of the embankment soils under the slab as a result of one or a combination of the following:

  - o Apparent filter incompatibility between the fine grained silt embankment materials and the fine drainfill of the drainage system.
  - o Filter incompatibility between the fine grained silt embankment fill and the coarse drainfill where the coarse drainfill is in direct contact with the rigid insulation panels (panel gaps) and is not protected by fine drainfill.

- The volume of seepage significantly exceeded the capacity of the filter drain system and the seepage exited the left side of the spillway resulting in the large erosion under the spillway that occurred in March and April 2003. The sudden increase in seepage quantity was most likely the result of one or a combination of the following:

  - o A void developing under the left side of the slab as a result of differential thawing and subsequent volume decrease of the foundation soils. The differential thawing was the result of heating of the slab and underlying soils by sunshine on the spillway wall and floor slab.
  - o Progressive piping erosion of silt embankment fill through the coarse drainfill where it is exposed directly to the rigid insulation panels. This flow pathway has no filter protection against suspended sediment. Gaps observed to exist between the insulation panels provided a high permeability pathway for erosion of embankment materials. The permeability of flow through the panel gaps and

coarse drainfill is expected to be several times higher than through the fine drainfill, thereby creating a preferred pathway for erosion of soil.

Section 5 - Recommended Modifications to Design

It is our opinion that the excessive erosion under the spillway likely would not have occurred if all or most of the following elements were incorporated into the initial design and construction:

- Provisions to either a) prevent frost heave in the soils below the spillway slab upstream of the underdrain system or b) anchor the slab to prevent upward movement of the slab from forces associated with freezing soils.

- Deeper and wider centerline (parallel to dam centerline) seepage cutoff. The cutoff should be designed to provide low exit gradients with full reservoir pressure at the upstream side of the cutoff.

- Filter/drain system immediately downstream of the centerline seepage cutoff. The filter/drain system would need to be filter compatible and have adequate hydraulic capacity to convey the expected seepage with an acceptable factor of safety.

- Place only filter compatible materials below structures and along any paths of likely seepage to prevent piping.

Other elements of the design and construction that should be modified to provide a more robust design with multiple levels of redundancy include:

- Using natural aggregate material for filter and drain systems in place of geosynthetics. Filter fabrics will clog if the fabric does not have intimate contact with the soil discharge face that is sufficient to support it so that suspended sediment is carried to the fabric. In addition, fabrics do not provide any margin of defense if they are damaged during installation.

- Sequencing placement of the fine and coarse filters and surrounding backfill so that the materials are laterally confined during placement and compaction.

- Confirming that earth materials used in the construction are filter compatible with each other and the embankment materials.

- Provide filter protection to address not only likely areas of seepage but also at all possible areas of seepage.

- Provide a larger footing or other elements to increase the factor of safety against flotation.

Section 6 - Conclusion

Based on the evaluations described in this report, we conclude the following:

- The primary site elements contributing to the excessive erosion under the spillway are a) the combination of frost susceptible silt embankment fill soils with the extremely cold climate and b) the combination of highly erodible silt embankment fill soil with likely non-filter-compatible drain and foundation stabilization materials.

- The primary design elements contributing to the excessive erosion under the spillway are, in order of importance:

  - The lack of a filter compatible seepage collection system immediately downstream of the centerline (dam axis) cutoff.
  - The lack of provisions to prevent freezing of the soils directly under the slab upstream of the underdrain system.
  - The shallow depth and limited lateral extent of the sheetpile cutoff at the dam center line.

- The primary construction elements contributing to the excessive erosion under the spillway are a) the use of fine drainfill (as sampled) that does not meet filter criteria for the silt embankment fill, b) the use of foundation stabilization gravel that does not meet filter criteria, and c) the lack of lateral confinement of the granular drain materials resulting in poor compaction at the drain/backfill interface.

- The spillway structure from the inlet downstream to Segment C is undermined and will need to be removed and the embankment restored.

- Stilling basin structure Segments A and B are underlain by geotextile and 1-1/2-inch minus gravel to stabilize the foundation and fine and coarse drain materials. Some of these materials are not filter compatible. Therefore, the stilling basin will need to be removed and filter-compatible foundation conditions restored to provide adequate seepage stability.

- A new service spillway will need to be designed and constructed.

Section 7 - References

GEI Consultants, Inc. (GEI), (2003). "Site Visit and General Condition of Mt. Carmel Dam, Cavalier County, North Dakota," August 29.

Sherard, J.L., Dunnigan, L.P., and Talbot, J.R. (1984). "Basic Properties of Sand and Gravel Filters," Journal of Geotech. Engineering, ASCE, 110(6), June, pp. 684-700.

Appendix A

Site Visit Memorandum

GEI Consultants, Inc.

Memorandum

6950 South Potomac Street
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303 · 662 · 0100
303 · 662 · 8757 Fax

TO: Brad Benson, Head of Construction Section - North Dakota State Water Commission

FROM: Robert J. Huzjak, Project Manager - GEI Consultants, Inc. RJH

DATE: September 2, 2003

RE: Site Visit and General Condition of Mt. Carmel Dam, Cavalier County, North Dakota
GEI Project 03254

1.0 Purpose

The purposes of this memorandum are to present a) a summary of information collected during a start-up meeting and site visit to Mt. Carmel Dam, b) our general assessment of the overall condition of the Mt. Carmel dam and appurtenant facilities, and c) our recommendations for near-term actions needed prior to winter and to evaluate identified dam safety concerns.

2.0 Scope of Services

The following scope of services have been performed by GEI Consultants, Inc. (GEI) for this phase of the project:

1. Participated in a start-up meeting with the North Dakota State Water Commission (SWC) at the SWC offices in Bismarck on July 30, 2003. The purpose of the meeting was to review project requirements and objectives; and to obtain written and verbal information and data regarding the history of the dam, with particular emphasis on the construction and subsequent failure of the principal spillway. The meeting was attended by the following people:

   Todd Sando, NDSWC, Assistant State Engineer*
   Brad Benson, NDSWC, Head of Construction Section *
   Ron Swanson, NDSWC, Construction Section Engineer
   Jason Boyle, NDSWC, Dam Safety Engineer *
   Bob Huzjak, GEI Consultants, Inc. *
   Brian Johnson, GEI Consultants, Inc. *
   Steve Brown, GEI Consultants, Inc. *
   * also attended site visit

2. Participated in a site visit to the dam with SWC staff on July 31, 2003. The purposes of the site visit were to:

   - Observe and document the overall condition of the dam and appurtenant facilities with respect to dam safety issues.
   - Collect data for use in subsequent engineering evaluations and analysis of the failure.
   - Observe the site conditions in the area of the failure from a structural and geotechnical perspective.
   - Identify areas where survey data, which will be obtained by SWC, would be helpful during future phases of evaluation.

3. Participated in a meeting on August 1, 2003 with the Langdon Rural Water Cooperative and Cavalier County Commissioners to discuss the overall schedule of the engineering work and the general condition of the dam and spillway.

4. Identified near-term actions required to maintain the stability of the dam until permanent repairs can be constructed in 2004.

5. Identified additional data needed to evaluate and understand the performance of the dam and to support design of repairs to the principal spillway.

6. Prepared this memorandum that presents the results of our work.

3.0 Background

Our understanding of historic and operational information and physical data obtained during the start-up meeting is summarized below:

- Mt. Carmel Dam was initially constructed in 1970-71 as a homogenous earthen embankment with a crest elevation at 1,537.5 feet. The reservoir elevation was controlled with a drop inlet riser that discharged through a 66-inch-diameter concrete pipe located at about the center of the dam.

- The primary purposes for construction of Mt. Carmel Dam are to provide water supply for the City of Langdon and for Langdon Rural Water and to provide water for lake recreation.

- Water supply intakes for the City of Langdon and for Langdon Rural Water are at El. 1513 and El. 1517 and are located at the upstream end of the reservoir.

- The dam was first filled soon after completion of construction in 1971.

- Seepage was observed in the right abutment near the downstream toe in May 1971. A grouting program in the right abutment was completed during the summer of 1972. This program reduced seepage from about 50 to 21 gallons per minute (gpm).

- In 1995, the dam crest was raised between 4 and 5 feet to Elevation (El.) 1541.0 and a new reinforced concrete principal spillway that consisted of a drop inlet, chute, and stilling basin was constructed over the existing embankment on the left side (looking downstream) of the dam. This construction raised the normal water surface 2 feet to El. 1530.0. As part of this construction, a concrete bulkhead was placed at the upstream end of the 66-inch pipe and the drop inlet was demolished.

- Piezometers installed prior to the 1995 construction showed artesian water pressures in the foundation at the downstream toe. A temporary system of well points was installed during construction of the principal spillway to manage groundwater pressures at the location of the stilling basin.

- High spillway discharge rates were recorded in 1995, 1996, 1997, 2000, and 2002 as a result of large local precipitation events. Principal spillway flows last occurred in June 2002. Emergency spillway flows last occurred in 1995. The 1995 flood event, which occurred during construction of the principal spillway, was large enough to require emergency enlargement of the emergency spillway channel with flow depths of several feet. As a result of this discharge, significant erosion occurred on the downstream part of the emergency spillway channel.

- In general, the reservoir is operated to maintain the reservoir as high as possible, which is limited by the uncontrolled principal spillway weir, at El. 1530.0.

- The reservoir typically has a 3-foot thickness of ice during winter.

- Deeper than average frost penetration occurred during the winter of 2002/2003 due to cold temperatures and little snow cover.

- Principal spillway underdrains, Drains No. 1 and No. 3 left and No. 3 right were observed discharging during the August 2000 inspection. (Drains are numbered from upstream to downstream.)

- The sound of water moving near the fifth weephole on the left side of the principal spillway drop inlet was identified during the August 2000 inspection.

- An erosion and undermining failure of the principal spillway was reported in progress on March 29, 2003, and likely initiated on or about March 28, 2003. Emergency actions were implemented by the SWC that included lowering the reservoir by re-opening the 66-inch-diameter spillway and installing a sheetpile and earthfill cofferdam around the upstream end of the principal spillway inlet, taking the principal spillway out of service.

- A list of pertinent data for the dam is provided in Attachment A.

4.0 Site Visit

4.1 Principal Spillway Geotechnical Conditions

The principal spillway has been taken out of service by installing a sheetpile and earthfill cofferdam at the entrance to the spillway (Photo 1). The reservoir was at El. 1522.6, about 7.5 feet below normal water surface, during our site visit.

A large quantity of soil has eroded from beneath and adjacent to the floor and side walls of the principal spillway. As recorded by photographs taken on March 30. 2003 when the failure was in progress, the reservoir was at about El. 1530 when the failure began and water flowed along the exterior sides of the intake structure and underneath the structure (Photo 2) and exited at the left side of the principal spillway just upstream of the stilling basin. According to SWC, the reservoir surface dropped about 2 feet as a result of the uncontrolled flow of water beneath the principal spillway. The flow slowed by about March 30, 2003. Construction of the emergency cofferdam was performed between April 7 and April 17, 2003.

The embankment soil (foundation of the concrete spillway) has eroded to a depth of up to about 2 feet below a large part of the drop inlet structure (Photo 3). Riprap has been carried beneath the intake structure to near the centerline of the dam, which is a distance of about 75 feet from the upstream end of the intake structure. The erosion extends beneath most of the principal spillway from the inlet structure to about 8 feet upstream of the stilling basin, and possibly around or under the left wingwall. Looking in the upstream direction, the sheetpiles at the dam centerline are hanging from the slab and are exposed full length for about two-thirds of the width of the structure (Photos 4 and 5). The embankment is eroded beneath the centerline sheetpile to a depth of about 1.5 to 3 feet for a length of about 22 feet (Photo 6). A small amount of seepage (about 2 gpm) was flowing beneath the centerline sheetpiles at the time of our site visit (Photo 6). The dam embankment material exposed downstream of the centerline sheetpiles is the Zone I compacted glacial till material and is in a firm condition.

A significantly larger erosion void exists downstream of the centerline sheetpile. A near vertical scarp about 5 feet high is located about 10 feet upstream of the structure Segment E/F joint (Photo 7). This is likely an erosion headcutting scarp. The depth of erosion increases from about 4.5 feet upstream of the scarp to about 9.5 feet downstream of the scarp. The maximum height of the void averages about 8.5 feet beneath segment E and reduces down to about 3 feet at the downstream end of Segment D. Measurements of the height of the underslab void beneath segments D, E, and F are shown on Figure 1. The underslab void ends about 7 feet downstream of the Segment D/C sheetpiles. The volume of soil, consisting of fine drainfill, coarse drainfill, and embankment fill, eroded from beneath spillway Segments D, E, and F is estimated to be on the order of 300 cubic yards.

The underdrain components consisting of fine drainfill and coarse drainfill were completely removed from beneath Segments E and D. The 4-inch ductile iron pipe (DIP) and PVC drain pipe for Segment D was found in a displaced position beneath Segment D (Photo 8). The 4-inch DIP and PVC drain pipe for Segment E was found in the eroded embankment area to the left of Segment C (Photo 8). Most of the 2-inch-thick rigid insulation had been removed during the erosion process, and the remaining pieces of the insulation were found adhered to the underside of the slab for Segment E (Photo 9).

The spillway construction included four rows of sheetpile installed at the locations shown on Figure 1. The sheetpiles extended the width of the spillway as part of the seepage control measures for the spillway. The sheetpiles were specified to be 4 feet long and embedded about 4 inches into the concrete. The exposed sheetpiles at the dam centerline all appear to be 4 feet long. One 3-foot-long sheetpile was observed at the Segment D/E location near the left side of the structure (Photo 10). The sheetpiles at the dam centerline were observed to be generally intact with no visible permanent movement or deflection. The sheetpiles beneath the Section D/E joint were largely displaced and no longer embedded in the joint concrete (Photo 10). The sheetpiles beneath the C/D joint were generally in place, but no longer directly embedded in the joint concrete (Photo 11). The sheet piles beneath the B/C joint were buried and could not be observed.

An apparent erosion hole (Photo 12) was found immediately above the footing along the left chute wall at the erosion scarp, which is located about 4 feet upstream of the Segment E/F joint. The erosion hole had partially collapsed. A small quantity of water appeared to be seeping from or near this hole and the seepage had created a moist area adjacent to the footing.

4.2 Principal Spillway Structural Conditions

Given the extensive amount of erosion beneath and around the principal spillway, the structure was observed to be in remarkably good condition. Based on our visual observations, the concrete appears to be generally sound and in good condition. With few exceptions, the structure shows no obvious signs of distress or failure. Significant observations of the structural conditions of the spillway are summarized below:

- Left Wall, Section K/L Joint: This joint has failed, most likely a result of differential movement of the adjacent structure sections and compressive failure of the concrete. The concrete at the joint is extensively damaged, with failure of the smooth dowels and waterstop, as shown in Photos 13 and 14. Based on earlier photographs and discussions, it appears that this movement and joint failure likely occurred as a result of the erosion of the foundation material in March.
- Floor, Section K/L Joint: There is moderate spalling on the downstream side of the joint near the center of the slab. The spalling has exposed some of the smooth dowels and waterstop in the joint. A portion of the waterstop edge is exposed on the downstream side, creating a water pathway from the foundation into the structure. The damage appears to be relatively "fresh" (Photo 15). It is possible that this damage is a result of the differential movement of the adjacent structure sections resulting from foundation erosion; however, the lack of observed damage extending to the left wall would appear to contradict this.
- Floor, Section B/C Joint: There is delamination along the center third of the joint. The delamination is relatively shallow and appears to extend from the joint a distance of about 3 feet downstream, just above the pooled water in the stilling basin.
- Various Joints: Minor spalling was observed at several of the joints in the structure. In some cases the damage was judged to be relatively "old," and it was not readily

apparent that the damage was a result of the erosion of the foundation material in March.

Openings and offsets at all of the accessible structure joints were measured during the site visit. Joint openings varied from 0 to over 1 inch, with most 1/4 inch or less. Offsets ranged from 0 to over 2 inches, with most less than 1/8 inch. These joint displacement measurements are summarized in Table 1. There is no record of joint openings and offsets prior to the March spillway failure, and so it is not clear how these joint measurements relate to the failure. However, there is reason to believe that some of the more significant joint openings and offsets are a result of the differential movement of the structure sections (Photos 16 and 17).

The principal spillway structure was surveyed by SWC personnel on July 31, 2003 and August 1, 2003. Key elevation data from this survey are summarized in Table 2. In general, the entire spillway structure is lower on the left side than on the right. The differential between the two sides is greatest at the weir (about 0.5 foot), and decreases in the downstream direction to about 0.1 foot at the stilling basin. This is consistent with the extensive foundation erosion on the left side of the structure relative to the right side. The entire structure upstream from the stilling basin is between 0.4 foot and 1 foot lower than the design elevations.

4.3 Dam and Appurtenances

The general condition of the existing facilities is documented on an inspection checklist, which is provided in Attachment B. Key findings include:

4.3.1 Embankment

The embankment is generally considered to be in poor condition because of the damage to the crest and erosion at the principal spillway.

Except at the location of the principal spillway, the upstream slope of the embankment is in generally good condition. The riprap slope protection is sparse at localized areas and minor erosion is present at localized areas.

The dam crest is in poor condition because excavations performed to generate borrow materials for the emergency cofferdam have lowered the crest elevation and because of sinkholes adjacent to the principal spillway caused by erosion.

The downstream slope is considered to be in poor condition because of the major erosion and sinkholes adjacent to the principal spillway. The abutments and toe area are considered to be in good condition.

Seepage, on the order of 2 gpm, was observed flowing under the principal spillway and a moist area is present adjacent to the left wall of the principal spillway at the upstream end of the erosion scarp. The area downstream of the 6-inch right abutment drain was moist, but no flowing water was observed.

4.3.2 Principal Spillway

The principal spillway has been effectively taken out of service through installation of the sheetpile and earth cofferdam at the spillway entrance. The concrete is in generally good condition , except for damage at several joints. The foundation has been severely eroded and most of the underdrain systems have been destroyed. The structure is unfit for service in its current condition.

4.3.3 Emergency Spillway

The emergency spillway is generally in good condition. Minor wave erosion is present on the upstream slope of the approach channel. The left spillway training berm is low where the dam access road crosses it. Flows through the emergency spillway could flow down the right abutment groin and erode the toe of the dam.

4.3.4 Outlet Works

The outlet works is combined with the principal spillway and was severed during the erosion failure and installation of the temporary cofferdam sheetpiles. It is unfit for service in its current condition.

4.3.5 Original Spillway

The concrete plug that was installed as part of the 1995 modifications has been removed and wooden stoplogs have been installed between two steel channels. The top of the stoplogs appears to be at about El. 1524.5, which is about 5 feet above the invert of the 66-inch-diameter pipe. The conduit was not entered for inspection, but appeared to be in good condition.

5.0 Conclusions

Based on the information collected during the start-up meeting and our site visit, we offer the following conclusions:

- The principal spillway has been significantly undermined due to internal erosion (piping) of the foundation material. The structure and foundation will require extensive repair or replacement before the structure can be returned to service.

- The temporary sheetpile/earthfill cofferdam installed around the principal spillway appears to be effectively reducing seepage around and under the principal spillway to a few gpm. The tops of the temporary sheetpiles are above the elevation of the dam crest. However, there is an area between the dam crest and top of the sheetpiles that is lower in elevation than the dam crest. During a significant hydrologic event, water could be channeled through this low spot to the principal spillway before the lake level is to the dam crest and cause more erosion to the vulnerable damaged area of the dam.

- The damaged and undermined principal spillway structure is a potential public safety hazard because the area under the slab can be accessed by the public.

- The earthfill berm portions of the temporary cofferdam are vulnerable to erosion due to wave action.

- The downstream end of the left training berm of the emergency spillway is low and does not protect against spillway flows going down the right abutment contact and eroding the dam toe.

- The existing 66-inch spillway is effectively and appropriately providing a means of temporary reservoir control. However, installation of the stoplogs reduces the size of flood that can be passed without overtopping the dam.

- No piezometer or other instruments are present in the embankment or foundation to measure water pressures.

- The dam crest has been excavated to approximate El. 1539 because material was borrowed to construct the emergency earth cofferdam. This has reduced the size of flood that can be passed without overtopping the dam.

- Slope protection on the upstream slope is sparse.

- The artesian water pressures in the dam foundation are not fully understood and may need to be studied before design of repairs begins.

- The emergency spillway was significantly eroded during the 1996 flood, and the repaired spillway is likely vulnerable to erosion during future large flood events.

- The 66-inch spillway conduit appears to be in relatively good condition and is serviceable. If this spillway is to be retained long-term as part of dam facilities, consideration should be given to a detailed inspection of the conduit and joints and identifying any items needing repair. Rehabilitation of the conduit could include lining the conduit.

An assessment of possible causes for the failure and potential repair measures will be included in a separate report.

6.0 Recommendations

Actions

We recommend taking the following actions prior to the end of the current construction season:

- Fill in the holes at the side of the spillway structure to prevent access by the public. Post signs and install temporary construction fence around spillway structure to warn of danger and indicate area off-limits to public.

- Construct an earthfill berm to fill the gap between the sheetpile and the dam crest.

- Perform weekly inspections of the dam, especially at the downstream slope near the principal spillway, to look for changes in seepage flows.

- Extend the downstream end of the left training berm of the emergency spillway to El. 1541.0, or higher, to protect against spillway flows going down the right abutment contact and eroding the dam toe.

- Maintain reservoir levels as low as possible while meeting water supply needs until permanent repairs can be made to the dam and appurtenances. We recommend that the reservoir level be maintained at or below El. 1522, which is the design elevation of the top of the principal spillway slab.

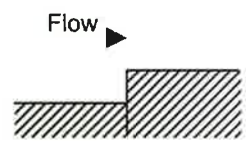
- Data collection: Install piezometers to obtain data on piezometric head in dam embankment, foundation soil, and foundation rock. Piezometers should be installed in the crest and downstream toe along two to three lines perpendicular to the dam centerline. The boring should be logged and sampled to obtain information on soil types and characteristics through performing limited laboratory testing on collected materials.

SGB/RJH/jmm

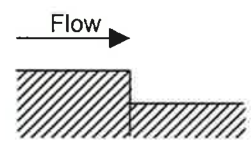
TABLE 1
MT. CARMEL DAM - PRINCIPAL SPILLWAY
RELATIVE JOINT DISPLACEMENTS

Joint	Left Wall		Floor			Right Wall		Comments
	Top	Bottom	Left	Center	Right	Bottom	Top	
Joint Openings								
A-B	1/8	n/a*	n/a*	n/a*	n/a*	n/a*	3/8	* Water in stilling basin to 4-5' depth
B-C	1-1/8	0	h-line	0*	0	0	3/8	* Spall/delam. center 1/3 to ~3' d/s from joint.
C-D	1/8	h-line	0	h-line	0	1/16	1/4	
D-E	h-line	0	0	0	0	< 1/16	h-line	
E-F	h-line	h-line	h-line	0	1/8	1/8	1/16	
F-G	3/16*	1/8	1/16	h-line	1/8	1/16	1/4	* Minor spall on u/s edge of joint.
G-H	1/16	3/16	1/8	0	1/16	1/4	1	
H-I	0	1/16	0	1/16	1/4	1/4	h-line	
I-J	h-line	h-line	h-line	0*	h-line	1/16	h-line	* Minor spall on d/s edge of joint.
J-K	h-line*	1/16	h-line	1/8	1/4	1/4	h-line	* Minor spalling
K-L	*	3/8	1/2	3/4**	1	7/8***	h-line***	* Crushing failure at top of joint ** Moderate spall on d/s edge, dowel & w/s exposed *** Waterstop visible in joint.
L-M	1/8*	h-line	0	0	0	0	1/16	* Minor spall on u/s edge of joint.
Joint Offsets								
A-B	+ 1/16	n/a	n/a	n/a	n/a	n/a	+ 3/8	
B-C	- 1/8	0	+ 1/16	+ 1/2	+ 1/8	+ 1/8	+ 1/8	
C-D	n/a	0	+ 1/4	0	0	+ 1/16	- 1/8	
D-E	<+ 1/16	+ 1/16	0	+ 1/16	0	0	n/a	
E-F	0	+ 1/16	0	+ 1/4	+ 1/4	<+ 1/16	- 1/16	
F-G	+ 1/8	- 1/8	0	+ 1/8	+ 7/8	0	+ 1/16	
G-H	+ 1/4	0	+ 1/16	+ 1/8	- 1/8	+ 1/4	+ 1-3/4	
H-I	0	0	0	0	0	+ 1/8	0	
I-J	0	+ 3/16	0	0	0	0	0	
J-K	+ 1/16	+ 3/8	+ 1/8	0	0	+ 1/16	+ 1/16	
K-L	- 2-1/2	- 3/8	+ 1/4	+ 3/4	+ 1/8	+ 1/16	- 5/16	
L-M	- 1/4	- 1/8	0	0	0	0	0	

Notes:
1. "n/a" indicates joint not accessible during inspection.
2. Measurements made on July 31, 2003.
3. All measurements are approximate.
4. There are no joint displacement data available prior to July 31, 2003.
5. H-line = hairline crack, less than 1/16" opening.



"-" Offset



"+" Offset

TABLE 2

MT. CARMEL DAM - PRINCIPAL SPILLWAY
TOP-OF-WALL ELEVATIONS

Location	Design El.	Left Wall		Right Wall		Survey El. Differential, L/R	
		Survey El.	Design Δ	Survey El.	Design Δ		
Weir, U/S	1530.00	1529.62	-0.38	1529.10	-0.90	0.52	R
Weir, D/S	1530.00	1529.44	-0.56	1528.92	-1.08	0.52	R
Dam Crest, U/S	1541.00	1540.45	-0.55	1540.04	-0.96	0.41	R
Dam Crest, D/S	1541.00	1540.58	-0.42	1540.14	-0.86	0.44	R
Chute, D/S	1509.00	1509.11	0.11	1508.86	-0.14	0.25	R

Notes: 1. Survey El. Differential, "L" or "R" indicates lower of the two sides.

Attachment A

Pertinent Data

PERTINENT DATA

A. GENERAL

1. Name of Dam .... Mount Carmel Dam
2. Federal Inventory Number .... ND 00005
3. State .... North Dakota
4. County .... Cavalier
5. Legal Description .... Section 28, Township 163N, Range 59W
6. River .... Little South Pembina River
7. Basin .... Red River Basin
8. Year Constructed 1970-71
9. Modifications .... Dam raised 4 to 5 feet and new principal spillway in 1995
10. Hazard Classification .... Design Class IV: Medium Hazard, Hydraulic Height 46.5 ft
11. Size .... N/A

B. DAM

1. Type .... Earth embankment
2. Crest Elevation 1541.0 (1)
3. Crest Length 683.28
4. Crest Width 16
5. Height above Streambed 46.0
6. Hydraulic Height 46.5
7. Upstream Slope .... Varies: 5H:1V below El. 1518; 3H:1V above El. 1518
8. Downstream Slope 3H:1V

C. PRINCIPAL SPILLWAY

1. Description .... Concrete chute with uncontrolled overflow weir
2. Location .... Station 13+31.5 to 13+64.5(2)
3. Intake Structure .... Uncontrolled overflow weir drop inlet
   a. Intake Crest Elevation 1530.0
   b. Dimensions .... Weir length 90 feet
   c. Low-Level Gate Size .... Valve on 12" dia. Ductile iron pipe
4. Discharge Chute ....
   a. Length .... Approx. 120 feet
   b. Width .... 30 feet
5. Stilling Basin ....
   a. Basin Invert Elevation 1490.0
   b. Energy Dissipation .... Saint Anthony Falls-type stilling basin
6. Discharge Channel .... Earthcut stream with riprap to 50 feet downstream of basin
7. Discharge Capacity with Water Surface at Top of Dam .... Approx. 10,000 cfs

D. EMERGENCY SPILLWAY

1. Description .... Earth Channel
2. Location .... Centerline Station 19+50
3. Discharge Channel Length .... Approx. 335 feet
   a. Dimensions at Control Section .... 100 ft bottom width and 4H:1V side slopes
   b. Elevation at Control Section 1534.0
4. Energy Dissipation .... None
5. Discharge Capacity .... 5,000 cfs at Elev 1540.0

E. OUTLET WORKS

1. Description: None. 10-in dia. Welded-steel low-level outlet pipe grouted and abandoned in place in 1995

F. RESERVOIR

1. Reservoir Capacity .... See table

Storage Level	Elevation (feet)	Area (acres)	Capacity (acre-feet)
Normal Pool (Principal Spillway Crest)	1530.0	390	4,700
Emergency Spillway Crest	1534.0	470	6,500
Top of Dam	1541.0	600	10,000

G. DRAINAGE BASIN

1. Area of Drainage Basin .... 66.2 square miles contributing
2. Downstream Description: Rural, no occupied structures downstream, crosses several county roads.

H. MANAGEMENT

1. Owner .... Cavalier County Water Resource District

I. NOTES:

1. All elevations are relative to Mean Sea Level.
2. Station 10+83.57 is located at the left abutment contact, looking downstream, and stationing increases left to right.

Attachment B

Inspection Checklist

Dam Name: Mt. Carmel Dam
ID #: ND 00005

Date of Inspection: July 31, 2003

Dam Name: Mt. Carmel Dam ID #: ND 00005	Size: N/A Haz. Class.: Medium Design Class: IV Type: Earth Embankment	Date of Inspection: 7/31/03 Date of Last Insp.: N/A
Inspected By: Bob Huzak, Brian Johnson, and Steve Brown, GEI Consultants, Inc.		
Field Conditions		
Weather: Partly Cloudy; Occ. Rain Air Temp: 78°F Water Temp: Not Measured	Pool Elev.: 1522.6 T.W. Elev.: Approx. 1498	Ground Moisture Condition X Dry Wet Snowcover Other

			ITEM	YES	NO	REMARKS
UPSTREAM SLOPE			1. Animal burrows		X	
			2. Erosion or beaching	X		Major erosion at principal spillway; minor elsewhere.
			3. Depressions or bulges		X	
			4. Too steep		X	
			5. Sinkholes		X	
			6. Slides		X	
			7. Cracks w/displacement		X	
			8. Settlement		X	
			9. Excessive vegetation or trees growing on slope		X	
			10. Concrete facing:			N/A
OBSERVED CONDITION			Holes			N/A
			Cracks			N/A
		X	Displacement			N/A
P	A	G	Undermining			N/A
			11. Slope protection	X		Riprap.
			Missing		X	
			Sparse	X		
			Displacement		X	
			Weathered or deteriorated		X	
			12. Other			

KEY: P = POOR, A = ACCEPTABLE, G = GOOD

Dam Name: Mt. Carmel Dam	Date of Inspection: July 31, 2003
ID #: ND 00005

<table>
<tr><td colspan="3" rowspan="7">CREST</td><td>ITEM</td><td>YES</td><td>NO</td><td>REMARKS</td></tr>
<tr><td>1. Animal burrows</td><td></td><td>X</td><td></td></tr>
<tr><td>2. Erosion</td><td>X</td><td></td><td>Major erosion at principal spillway.</td></tr>
<tr><td>3. Ruts or Depressions</td><td></td><td>X</td><td></td></tr>
<tr><td>4. Inadequate drainage</td><td></td><td>X</td><td></td></tr>
<tr><td>5. Sinkholes</td><td>X</td><td></td><td>Adjacent to principal spillway.</td></tr>
<tr><td>6. Settlement</td><td></td><td>X</td><td></td></tr>
<tr><td colspan="3" rowspan="2">OBSERVED CONDITION</td><td>7. Low area</td><td>X</td><td></td><td>Crest excavated for borrow for emergency berm.</td></tr>
<tr><td>8. Cracks w/displacement</td><td>X</td><td></td><td>Cracks near principal spillway.</td></tr>
<tr><td>X</td><td></td><td></td><td>9. Not wide enough</td><td></td><td>X</td><td></td></tr>
<tr><td rowspan="3">P</td><td rowspan="3">A</td><td rowspan="3">G</td><td>10. Misalignment</td><td></td><td>X</td><td></td></tr>
<tr><td>11. Inadequate freeboard</td><td></td><td>X</td><td></td></tr>
<tr><td>12. Other</td><td></td><td></td><td></td></tr>
</table>

<table>
<tr><td colspan="3" rowspan="11">DOWNSTREAM SLOPE</td><td>ITEM</td><td>YES</td><td>NO</td><td>REMARKS</td></tr>
<tr><td>1. Animal burrows</td><td></td><td>X</td><td></td></tr>
<tr><td>2. Erosion or gullies</td><td>X</td><td></td><td>Major erosion adjacent to principal spillway. *</td></tr>
<tr><td>3. Depressions or bulges</td><td>X</td><td></td><td>See erosion, above.</td></tr>
<tr><td>4. Too steep</td><td></td><td>X</td><td></td></tr>
<tr><td>5. Sinkholes</td><td>X</td><td></td><td>See erosion, above.</td></tr>
<tr><td>6. Slides</td><td></td><td>X</td><td></td></tr>
<tr><td>7. Cracks w/displacement</td><td>X</td><td></td><td>Cracks near principal spillway</td></tr>
<tr><td>8. Livestock damage</td><td></td><td>X</td><td></td></tr>
<tr><td>9. Excessive vegetation or trees growing on slope</td><td></td><td>X</td><td></td></tr>
<tr><td>10. Adequate slope protection</td><td>X</td><td></td><td>Grass covered.</td></tr>
<tr><td colspan="3" rowspan="2">OBSERVED CONDITION</td><td>11. Soft areas</td><td></td><td>X</td><td></td></tr>
<tr><td>12. Settlement</td><td>X</td><td></td><td>See erosion, above.</td></tr>
<tr><td>X</td><td></td><td></td><td>13. Other</td><td></td><td></td><td></td></tr>
<tr><td>P</td><td>A</td><td>G</td><td></td><td></td><td></td><td></td></tr>
</table>

* Backfill has settled by 4 to 5 inches within 7 feet horizontal distance of spillway wall segments D and E on right side of spillway.

<table>
<tr><td colspan="3" rowspan="8">ABUTMENTS AND TOE AREA</td><td>ITEM</td><td>YES</td><td>NO</td><td>REMARKS</td></tr>
<tr><td>1. Seepage or wet areas</td><td>X</td><td></td><td>At discharge for right abutment drain.</td></tr>
<tr><td>2. Sandboils</td><td></td><td>X</td><td></td></tr>
<tr><td>3. Signs of movement</td><td></td><td>X</td><td></td></tr>
<tr><td>4. Slides</td><td></td><td>X</td><td></td></tr>
<tr><td>5. Cracks</td><td></td><td>X</td><td></td></tr>
<tr><td>6. Depressions/Sinkholes</td><td></td><td>X</td><td></td></tr>
<tr><td>7. Erosion</td><td></td><td>X</td><td></td></tr>
<tr><td colspan="3" rowspan="2">OBSERVED CONDITION</td><td>8. Soft Areas</td><td></td><td>X</td><td></td></tr>
<tr><td>9. Vegetation</td><td>X</td><td></td><td>Grass covered.</td></tr>
<tr><td></td><td></td><td>X</td><td>10. Exposed bedrock</td><td>X</td><td></td><td>Shale in access road cut at right abutment.</td></tr>
<tr><td>P</td><td>A</td><td>G</td><td>11. Other</td><td></td><td></td><td></td></tr>
</table>

Dam Name: Mt. Carmel Dam
ID #: ND 00005

Date of Inspection: July 31, 2003

SEEPAGE			ITEM	YES	NO	REMARKS
			1. Flow adjacent to outlet	X		Flow at 2 gpm through erosion hole under principal spillway
			2. Saturated embankment area		X	
			3. Seepage exists at point source	X		Seepage failure under principal spillway; minor seepage at bottom of eroded area to left of Segment C.
			4. Seepage exists on embankment	X		
			5. Seepage increased/muddy	X		Muddy during failure. Current seepage slightly cloudy.
			6. Drain outfalls seen	X		6-inch right abutment drain; not flowing; some seepage around pipe.
			Toe drain dry		X	
			Flow increased/muddy		X	
			Obstructed		X	
			7. Relief wells flowing			N/A
OBSERVED CONDITION			8. Other			
X						
P	A	G				

Dam Name: Mt. Carmel Dam
ID #: ND 00005

Date of Inspection: July 31, 2003

EMERGENCY SPILLWAY

OBSERVED CONDITION		
P	A	G
		X

	ITEM	YES	NO	REMARKS
1.	APPROACH CHANNEL	X		Approach is in reservoir.
	Erosion or backcutting	X		Minor wave erosion.
	Sloughing		X	
	Restricted by vegetation		X	
	Obstructed with debris		X	
	Silted in		X	
	Depressions		X	
	Log boom		X	
2.	CONTROL STRUCTURE	X		Earth channel.
a.	Concrete; apron, crest, walls		X	
	Spalling			N/A
	Cracks			N/A
	Erosion			N/A
	Scaling			N/A
	Exposed reinforcement			N/A
	Displacement or offset			N/A
	Loss or joint material			N/A
	Leakage			N/A
b.	Earth cut	X		
	Slope erosion		X	
	Slope sloughing		X	
	Crest erosion or settlement		X	
	Control at weir/crest		X	Control at earthcut section.
c.	Spillway controls		X	
	Gates bent/broken			N/A
	Gates corroded/rusted			N/A
	Controls/hoists, etc. in good condition			N/A
	Emergency gates/stoplogs			N/A
	Periodically maintained/operated			N/A
	Leak when closed			N/A
3.	CONVEYANCE STRUCTURE	X		Earthcut channel.
	Erosion or backcutting		X	
	Sloughing		X	
	Restricted by vegetation		X	
	Obstructed with debris		X	
a.	Concrete; walls, floor		X	
	Spalling			N/A
	Cracks			N/A
	Erosion			N/A
	Scaling			N/A
	Exposed reinforcement			N/A
	Displacement of offset			N/A
	Loss of joint material			N/A
	Weepholes			N/A
	Drains			N/A

	ITEM	YES	NO	REMARKS
EMERGENCY SPILLWAY (Cont'd)	4. TERMINAL STRUCTURE		X	Discharge down slope into drainage.
	Spalling			N/A
	Cracks			N/A
	Erosion		X	Significant erosion from 1996 event has been repaired.
	Scaling			N/A
	Exposed reinforcement			N/A
	Displacement or offset			N/A
	Loss of joint material			N/A
	Weepholes			N/A
	5. OUTLET CHANNEL	X		Natural drainage gully.
	Erosion or backcutting		X	
	Sloughing		X	
	Restricted by vegetation		X	
	Obstructed with debris		X	
	Silted in		X	
	Other			Left spillway training berm is low where crossed by access road to dam. Flows in emergency spillway could flow down right abutment groin and erode toe of dam. Raise training berm to dam crest elevation at a minimum.

Dam Name: Mt. Carmel Dam
ID #: ND 00005

Date of Inspection: July 31, 2003

PRINCIPAL SPILLWAY

(SPILLWAY NOT SERVICEABLE AT TIME OF INSPECTION)

OBSERVED CONDITION		
X		
P	A	G

ITEM		YES	NO	REMARKS
1.	APPROACH CHANNEL	X		Approach is the reservoir.
	Erosion or backcutting	X		Major erosion-undermined structure.
	Sloughing		X	
	Restricted by vegetation		X	
	Obstructed with debris		X	
	Silted in		X	
2.	INTAKE STRUCTURE	X		Concrete intake box with 90-foot weir length.
a.	Concrete	X		30-foot width.
	Spalling	X		At some joints.
	Cracks		X	
	Erosion		X	
	Scaling		X	
	Exposed reinforcement	X		At some joints.
	Displacement or offset	X		At joints, magnitude varies from 0 to 2+ inches.
	Loss of joint material		X	
	Leakage	X		Would leak if in service.
b.	Metal appurtenances	X		Low-level outlet; ladder.
	Corrosion		X	
	Breakage	X		Low-level outlet pipe broken at wall penetration.
	Anchors secure	X		
	Protective coating		X	
c.	Obstructed by debris		X	
3.	CONTROL STRUCTURE		X	
	Are there service gates		X	
	Emergency gates/stoplogs		X	
	Are there control valves		X	
	Controls/hoists, etc. in good condition			N/A
	Periodically maintained/operated			N/A
	Leak when closed			N/A
	Is there a low level outlet	X		12-inch DIP
	Is the low level outlet operational		X	Low-level outlet pipe broken at wall penetration and at temporary sheetpile cofferdam.
4.	CONVEYANCE STRUCTURE	X		30-foot wide concrete chute.
a.	Concrete surfaces;	X		
	Spalling	X		At some joints.
	Cracks		X	At some joints.
	Erosion		X	
	Scaling		X	
	Exposed reinforcement	X		At some joints.
b.	Concrete joints	X		
	Displacement, separation, or offset	X		At some joints, magnitude varies from 0 to 2+ inches.
	Loss of joint material		X	
	Leakage		X	

Dam Name: Mt. Carmel Dam
ID #: ND 00005

Date of Inspection: July 31, 2003

	ITEM	YES	NO	REMARKS
PRINCIPAL SPILLWAY (Cont'd)	c. Metal Conduit		X	
	Protective coating adequate			N/A
	Misalignment			N/A
	Perforation/joint separation			N/A
	Leakage			N/A
	Erosion/cavitation			N/A
	5. TERMINAL STRUCTURE	X		Concrete Stilling Basin. Standing water 4- to 5-feet-deep in basin. Observations are only for portions of structure visible above water surface.
	Spalling		X	
	Cracks		X	
	Erosion		X	
	Exposed reinforcement		X	
	Displacement or offset		X	
	Loss of joint material		X	
	Leakage		X	
	Energy dissipater adequate	X		Riprap is sparse on banks.
	6. OUTLET CHANNEL	X		Earth channel.
	Erosion or backcutting		X	
	Sloughing		X	
	Restricted by vegetation		X	

	ITEM	YES	NO	REMARKS
OUTLET WORKS (NO SEPARATE OUTLET WORKS, SEE PRINCIPAL SPILLWAY)	1. APPROACH CHANNEL			
	Erosion or backcutting			
	Sloughing			
	Restricted by vegetation			
	Obstructed with debris			
	Silted in			
	2. INTAKE STRUCTURE			
	a. Concrete			
	Spalling			
	Cracks			
OBSERVED CONDITION	Erosion			
	Scaling			
	Exposed reinforcement			

Dam Name: Mt. Carmel Dam
ID #: ND 00005

Date of Inspection: July 31, 2003

			ITEM	YES	NO	REMARKS
FOUNDATION			1. BEDROCK FOUNDATION	X		Yes on abutments; alluvium on valley floor.
			Bedrock adversely bedded		X	
			Bedrock contain gypsum		X	
			Weak strength beds		X	
			2. FOUNDED ON OVERBURDEN	X		Alluvium in valley floor.
			Pipable	X		Some sand and gravel zones.
OBSERVED CONDITION			Compressive	X		Some soft organic clay zones.
			3. Potentially liquefiable	X		Potentially saturated sand and gravel zones.
X			Low shear strength	X		Low blowcounts in soft organic clay.
P	A	G	4. Other comments	X		Artesian water pressures observed during drilling.

			ITEM	YES	NO	REMARKS
RESERVOIR AREA			1. Slides in reservoir area		X	
			2. Debris producing areas in watershed		X	
			3. Sediment producing area in watershed	X		Erosion of shale banks.
			4. Slide potential	X		Potential in weak shale zones.
			5. Depressions, sinkholes, or vortices in reservoir area		X	
			6. Low ridges/saddles allowing overflow from reservoir		X	
			7. Structures below elevation of maximum surcharge storage		X	
OBSERVED CONDITION			8. Large impoundments upstream		X	
			9. Change in reservoir operation	X		NWS raised 2 feet in 1995.
		X	10. Recent upstream development		X	
P	A	**G**	11. High water marks	X		

			ITEM	YES	NO	REMARKS
DOWNSTREAM AREA			1. Bridges, culverts that may restrict discharge		X	Minor restriction by culverts at farm crossing directly downstream of dam.
			2. Other obstructions which interfere with discharge		X	
			3. Erosion or headcutting	X		Erosion of stream banks.
			4. Downstream floodwalls, levees, dikes		X	
			5. Downstream impoundments		X	
OBSERVED CONDITION			6. Reservoir-connected springs		X	
			7. Buildings in flood plain		X	
		X	8. Overnight recreational sites		X	
P	A	**G**	9. Public access sites		X	
			10. Changed hazard potential		X	

Dam Name: Mt. Carmel Dam
ID #: ND 00005

Date of Inspection: July 31, 2003

			ITEM	YES	NO	REMARKS
PROJECT AREA			1. SITE ACCESS	X		
			Roads to site adequate	X		
			Reliable under all weather conditions		X	Wet roads will soften and be plastic.
			Reliable at all reservoir and river stages		X	Flows through emergency spillway will cut off access to the dam.
			2. SPILLWAY AND OUTLET CONTROL ACCESS	X		
			Are catwalks, ladders, bridges securely anchored	X		
OBSERVED CONDITION			Are they safe	X		
			Are they above high water elevation	X		
	X		Are there remote controls for outlet works		X	
P	**A**	G				

			ITEM	YES	NO	REMARKS
INSTRUMENTATION			1. Are there?		X	
			Piezometers		X	
			Weirs		X	
			Settlement pins		X	
			Observation wells		X	
			Staff gage		X	
			Other			
			2. In good condition			N/A
			3. Read periodically			N/A
OBSERVED CONDITION			4. Is data available			N/A
			5. Is data monitored, plotted, analyzed			N/A
X						
P	A	G				

Attachment C

Site Visit Photographs

1. Looking right along crest at the temporary berm and sheetpile protection for the drop inlet structure.

2. Photo taken March 30, 2003 during erosion failure. Looking upstream at right wall of drop inlet structure. Note water flowing over riprap berm and down along all sides of the drop inlet. Note location of large erosion hole on right side of structure. Photo provided by NDSWC.

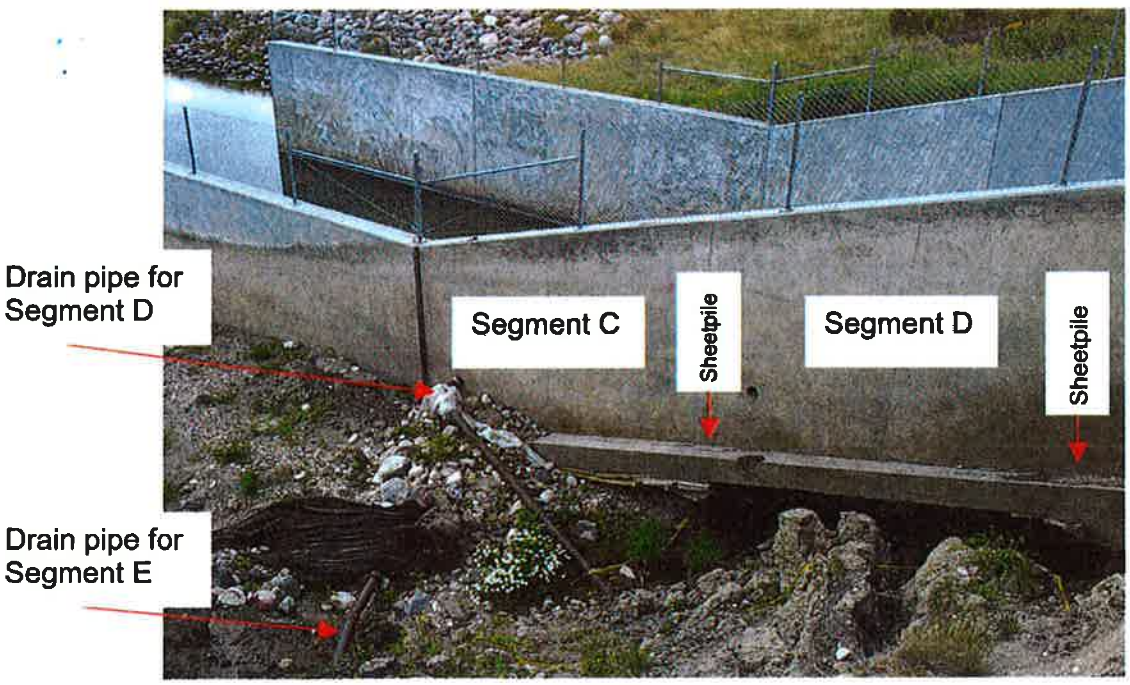
3. Looking right along upstream footing of principal spillway intake structure. Note up to 2-foot-deep void beneath slab. Note riprap that has fallen under slab. All remaining backfill and riprap was removed for installation of emergency sheetpile cofferdam.

4. Looking upstream at right side of centerline sheetpiles.

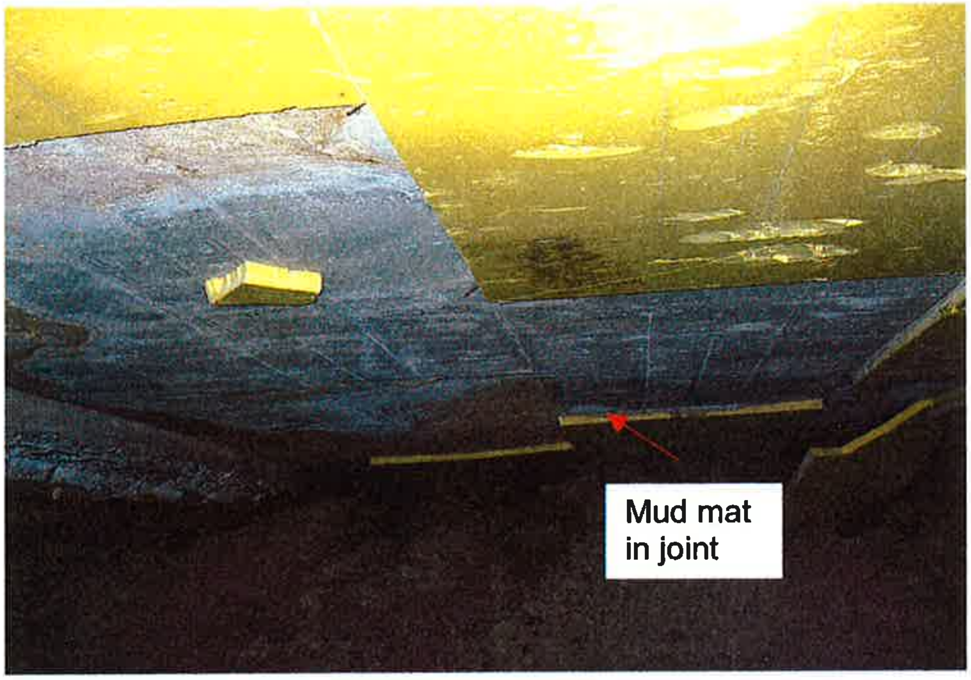
5. Looking upstream and left at centerline sheetpiles. Note moist soil and concrete at upper left area of sheetpiles.

6. Looking upstream at centerline sheetpiles. Note firm condition of exposed embankment fill. Note minor seepage through void beneath sheetpiles. Note riprap in foreground that has passed beneath sheetpiles.

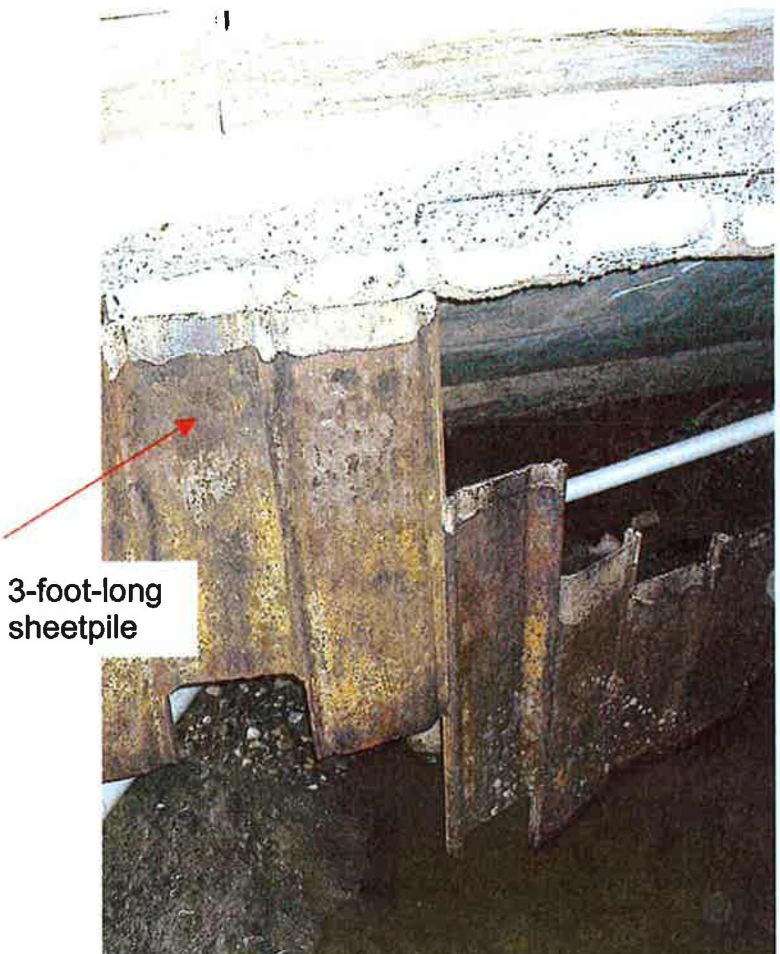
7. Erosion under Segment F. Note 5-foot-high scarp likely resulting from headcutting. Embankment fill is exposed in scarp.



8. Looking downstream and to the right at left wall of chute and void beneath structure. Note the displaced ductile iron pipe drain pipes. Note black geotextile that envelopes a gravel drain installed to control seepage during construction.



9. View of underside of slab Segment E and rigid insulation board. Two layers of 2-inch-thick insulation were installed during construction. Note concrete mud mat in joints between insulation panels.



10. Looking downstream and right at sheetpiles for Segment D/E joint. Note undermined sheetpiles have fallen down from broken slab embedment. Note short sheetpile (only 3-feet long) versus 4-foot length specified. Note displaced PVC drain pipe beneath Segment D.

11. Looking downstream and to the right at sheetpiles for Segment C/D. Note 4-inch-diameter underdrain lying in foreground.

Erosion hole, partially collapsed

12. Looking upstream at left side of spillway chute at erosion scarp.

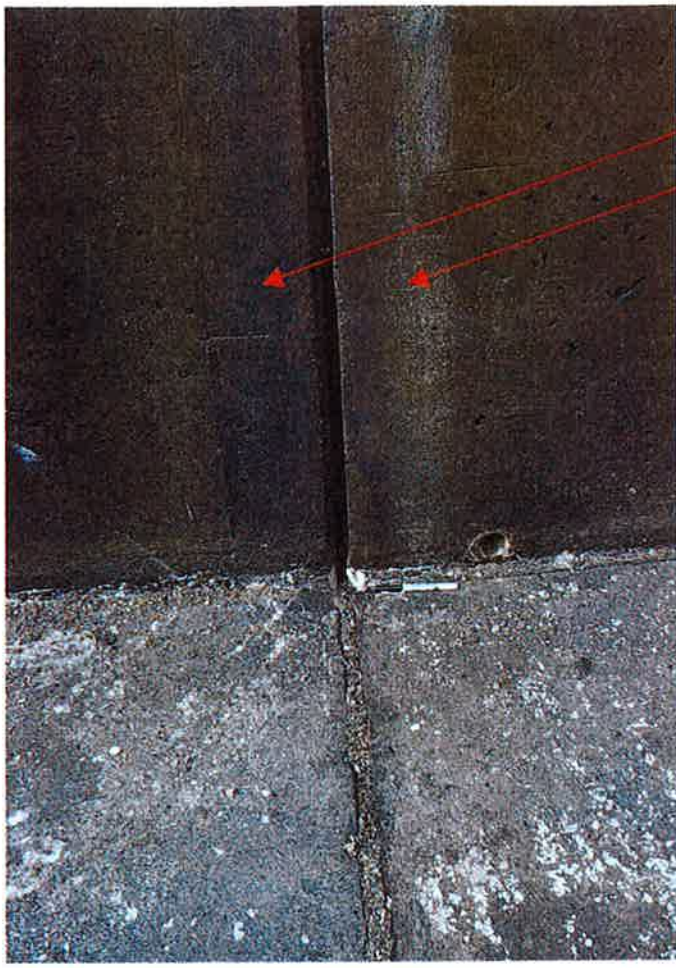
Moist soil

Void beneath structure

13. Looking left at joint between principal spillway structure Segments K and L. Looking at interior of left wall.

14. Looking right at joint between principal spillway structure Segments K and L. Looking at exterior of left wall.

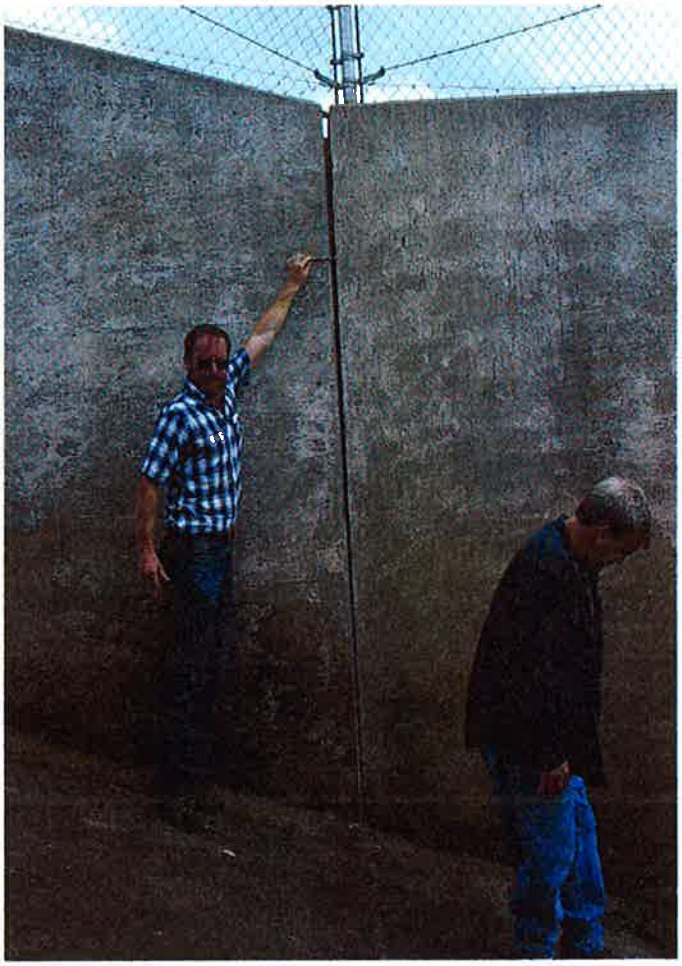
15. Close-up view of slab joint K/L. The waterstop visible to left of dowel is no longer embedded on upstream edge.



Segment K

Segment L

16. Waterstop visible in joint. Looking right at right wall of spillway intake structure.



17. Joint displacement between Segments B and C on left wall of principal spillway.

Φ

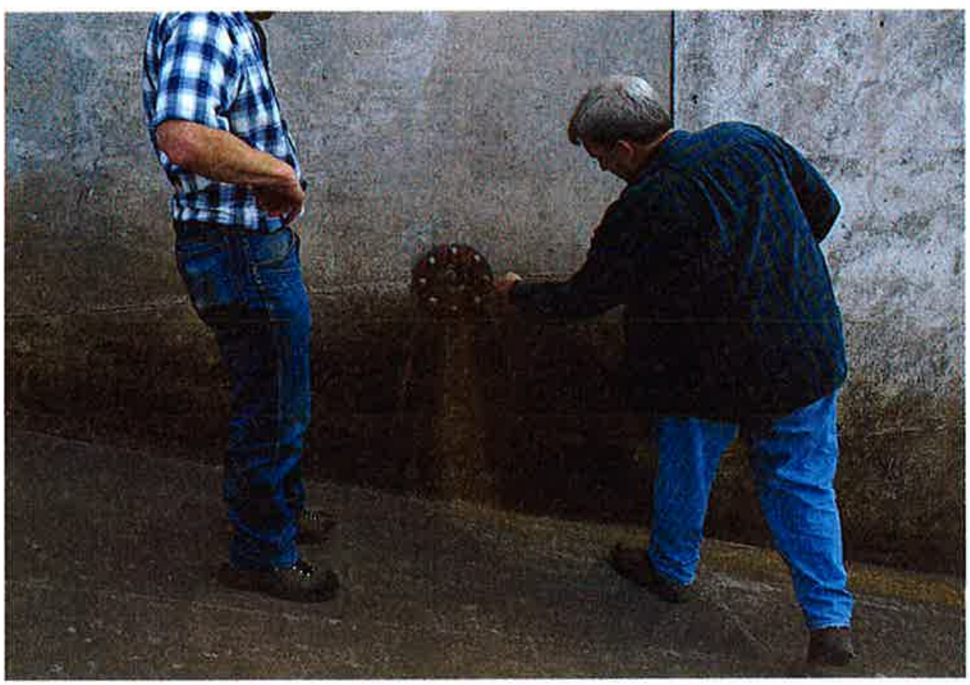
1. Looking downstream at construction of underdrain for Segment B. Note lack of lateral confinement of fine drainfill material. Note 1-1/2-inch-minus gravel used for subgrade stabilization beneath fine drainfill.

2. Looking downstream and to the left at formwork for the Segment D slab. Note the concrete forms that temporarily enclose the drain system will be subsequently removed and lack of backfill to provide lateral confinement of the drain system.

3. Backfill compaction using lightweight equipment adjacent to stilling basin Segment A. Photo looking upstream and to the left. Note exposed underdrain discharge pipes and insulating wrap.

4. Placement of fine drainfill for Segment A stilling basin. Note the perforated drain pipe supported at grade before coarse drainfill is placed around the pipe using the guide forms. Note the fine drainfill is placed over 1-1/2-minus gravel foundation stabilization material and a non-woven geotextile that was installed to address wet subgrade conditions. Photo taken looking upstream and to the left.

5. Looking downstream and to the right at spillway chute and right wall. Spillway underdrain outlets for Segment E and D are visible, whereas the outlet for Segment C is beneath the tailwater in the stilling basin.

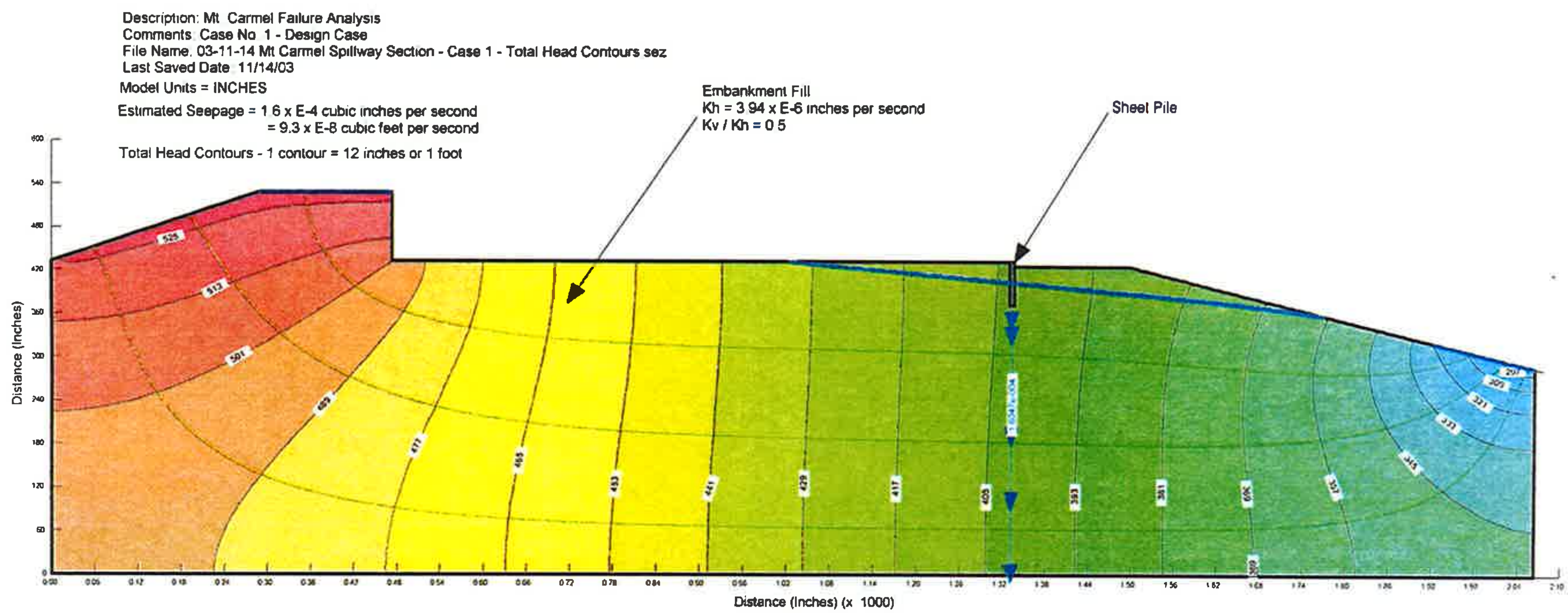


6. Looking to the left in the spillway chute at the outlet for spillway underdrain Segment E. Note the increased concrete staining that has occurred at this location compared to the outlets in Photos 5 and 7.

7. Looking downstream and to the left at spillway chute and left wall. Spillway underdrain outlets for Segments E and D are visible, whereas the outlet for Segment C is beneath the tailwater in the stilling basin. Note increased concrete staining at the outlet for Segment E. See close-up Photo 6.

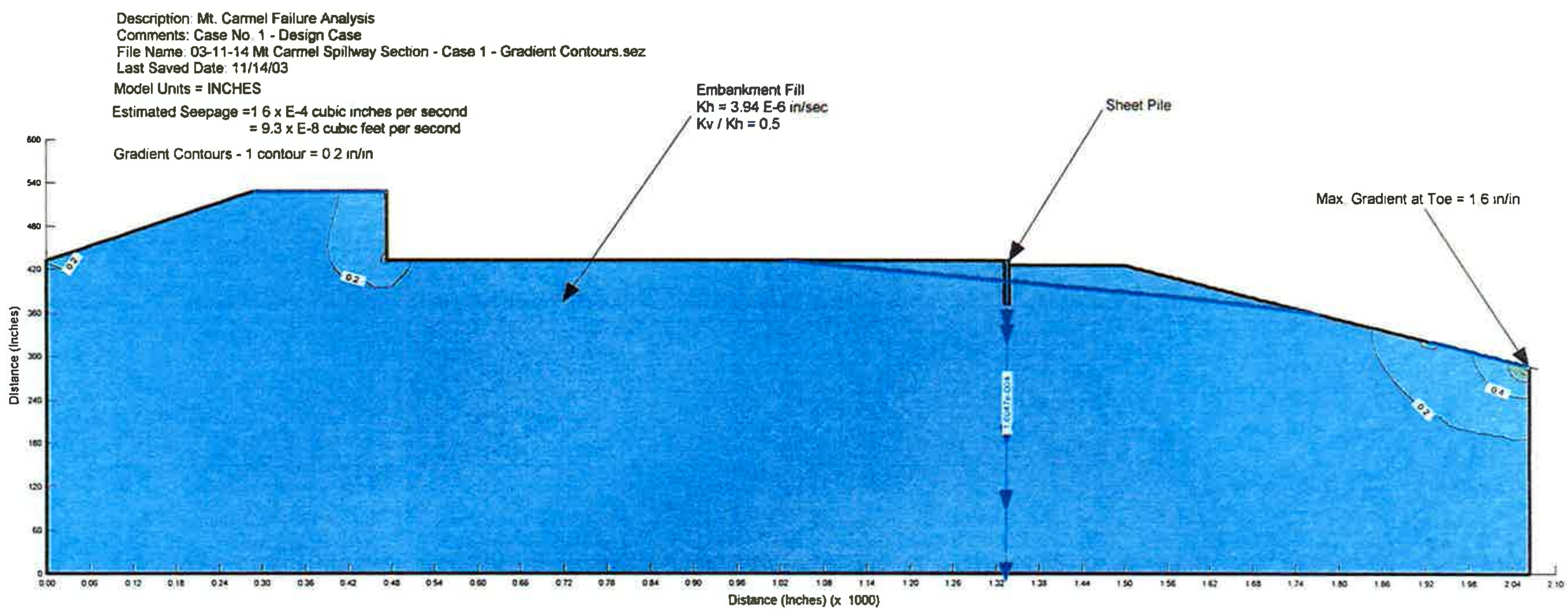
Appendix C

Seepage Analysis



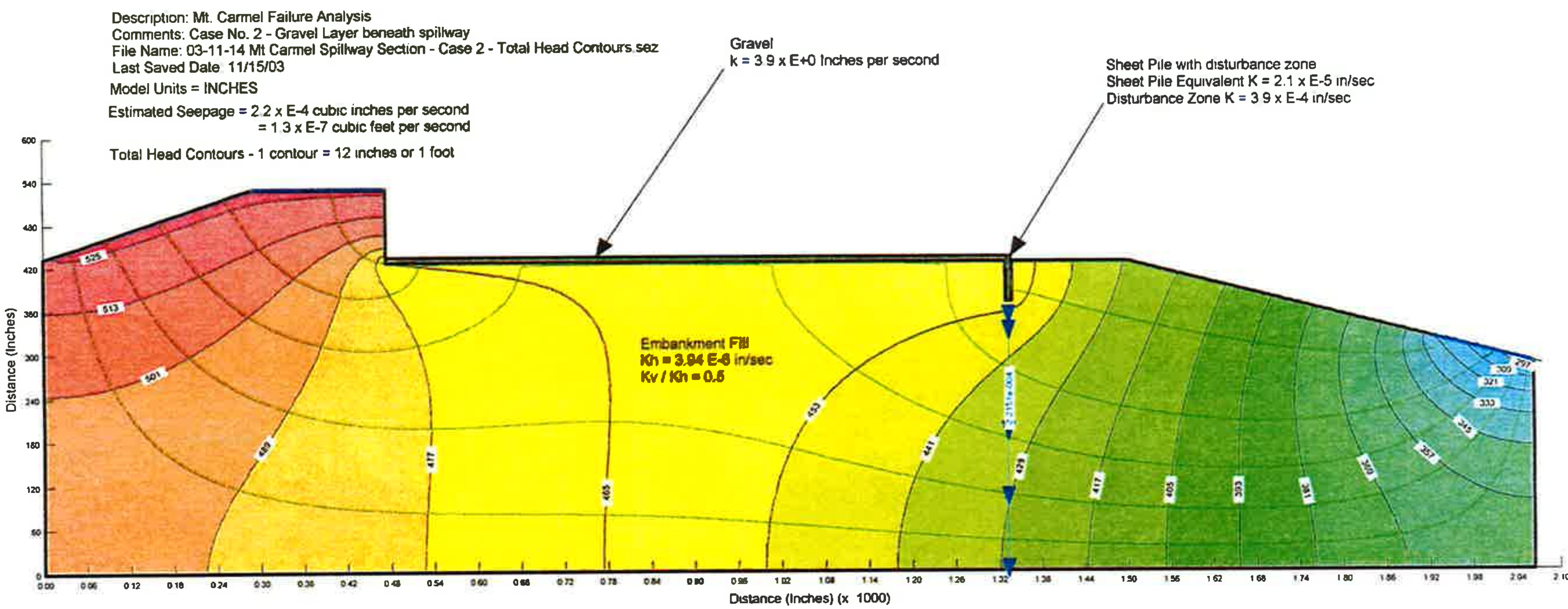
SCALE 1 INCH = 20 FEET

FIGURE C-1



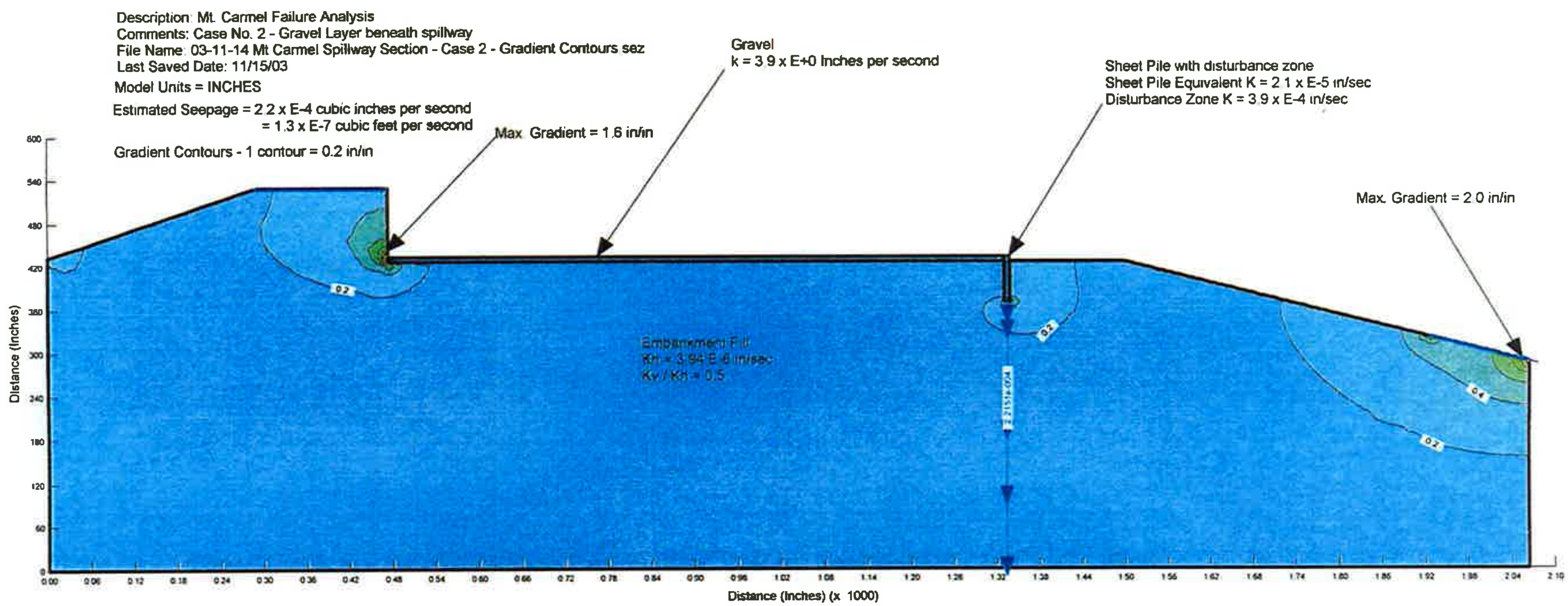
SCALE 1 INCH = 20 FEET

FIGURE C-2



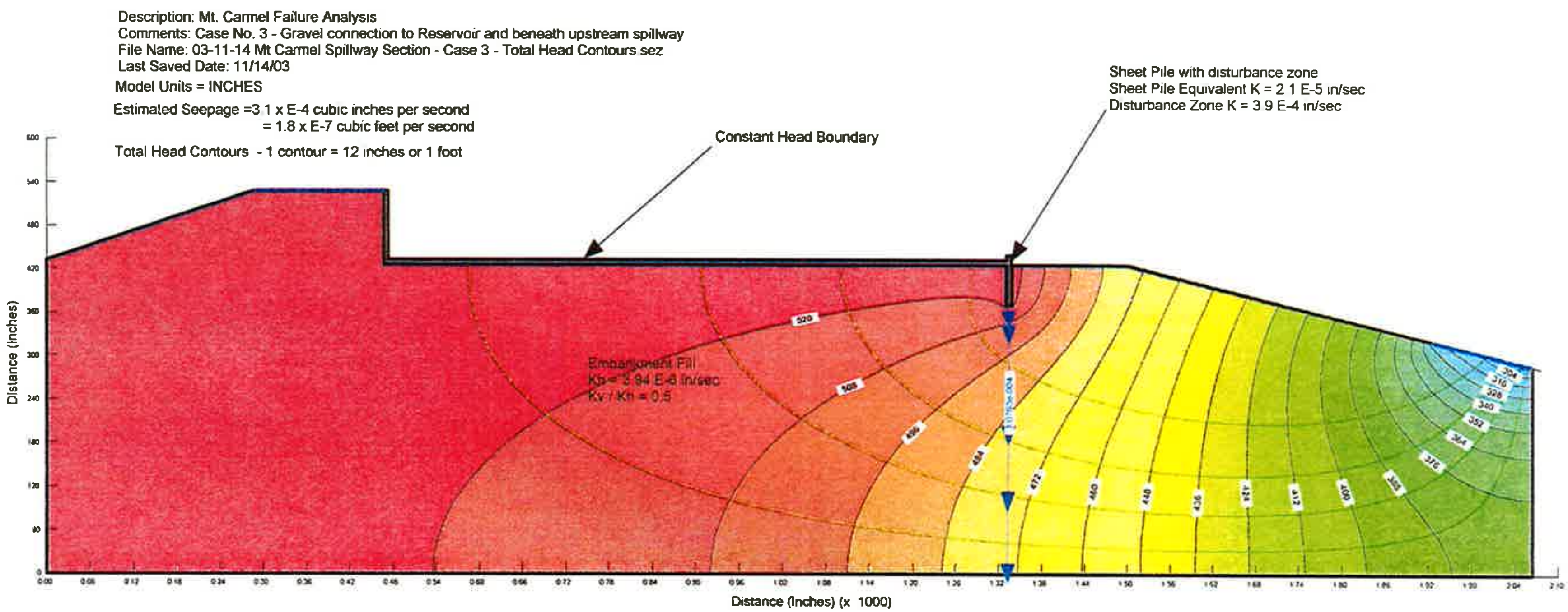
SCALE 1 INCH = 20 FEET

FIGURE C-3



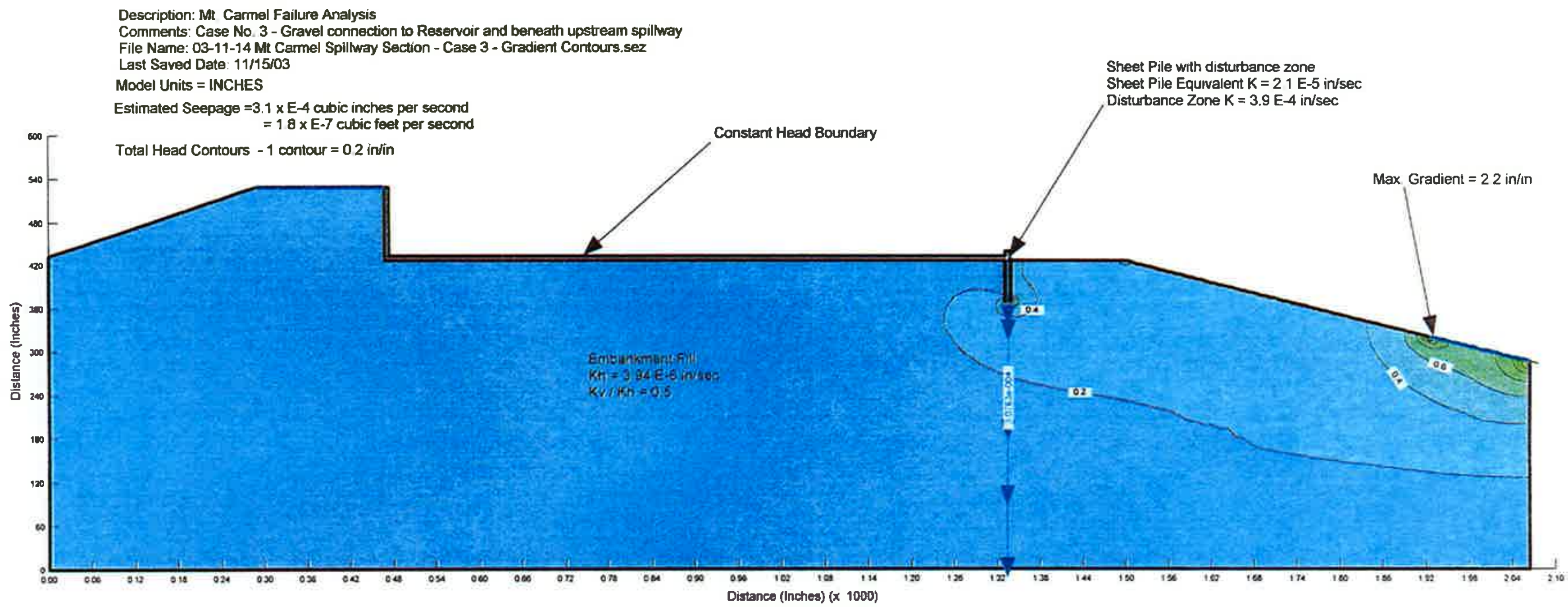
SCALE 1 INCH = 20 FEET

FIGURE C-4



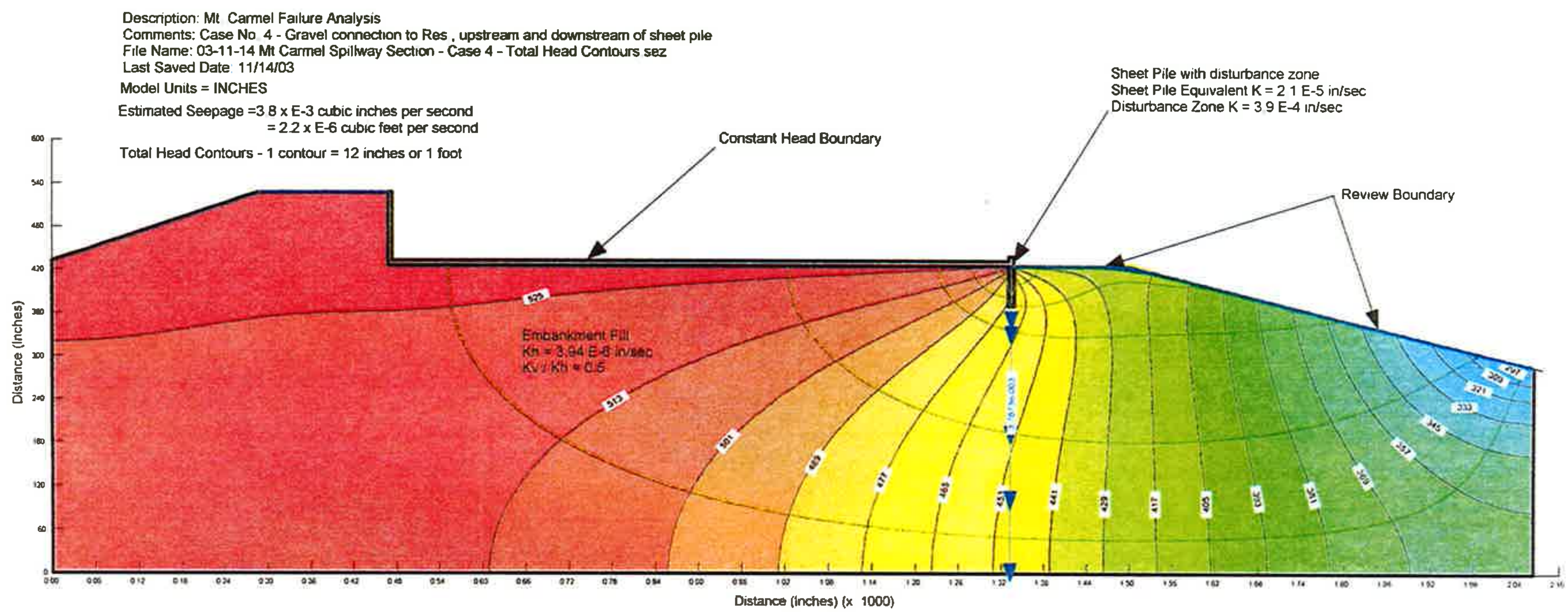
SCALE 1 INCH = 20 FEET

FIGURE C-5



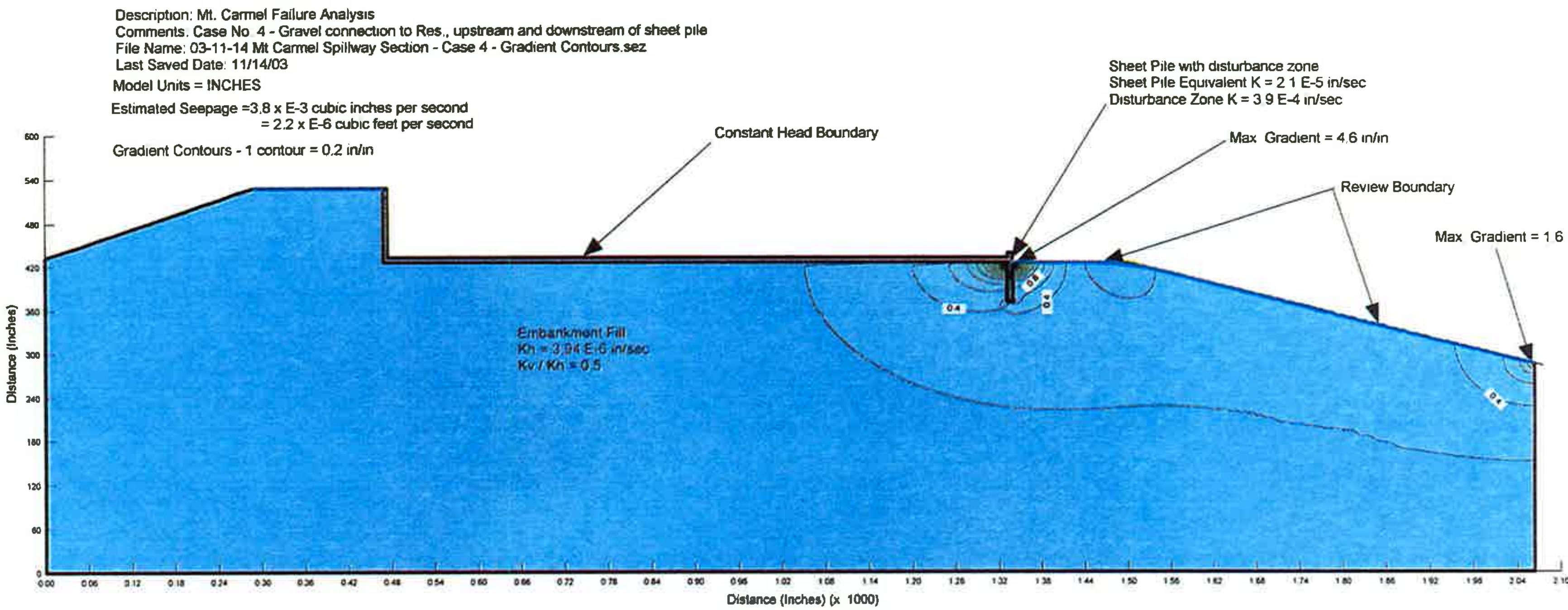
SCALE 1 INCH = 20 FEET

FIGURE C-6



SCALE 1 INCH = 20 FEET

FIGURE C-7



SCALE 1 INCH = 20 FEET

FIGURE C-8