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Silver Lake Embankment Seepage Investigation

Sargent County, North Dakota

Investigation Report - SWC Project #391

February 2016

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SWC Project #391
North Dakota State Water Commission
900 East Boulevard
Bismarck, ND 58505-0850

Prepared for:
Sargent County Water Resource District

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1. Introduction

In December of 2006, the North Dakota State Water Commission (SWC) and the Sargent County Water Resource District (SCWRD) entered into an agreement to study rehabilitation alternatives to address the seepage at Silver Lake Dam. A copy of the investigation agreement is located in Appendix A. The agreement outlined the responsibilities of the SWC, which are listed below.

a. Conduct topographic surveys of the upstream and downstream faces of the existing dam in the area where seepage is occurring.
b. Develop and evaluate alternatives to address the uncontrolled seepage through the embankment.
c. Prepare preliminary designs for the proposed rehabilitation.
d. Develop preliminary cost estimates of alternatives.
e. Prepare a preliminary engineering report summarizing the proposed designs and estimated costs.

The purpose of this report is to provide the SCWRD with alternatives that could address the seepage occurring at Silver Lake Dam in accordance with the Agreement.

2. Site Location

Silver Lake Dam is located in Sections 33 and 34, Township 130 North, Range 55 West, near the city of Rutland in Sargent County in southeast North Dakota.

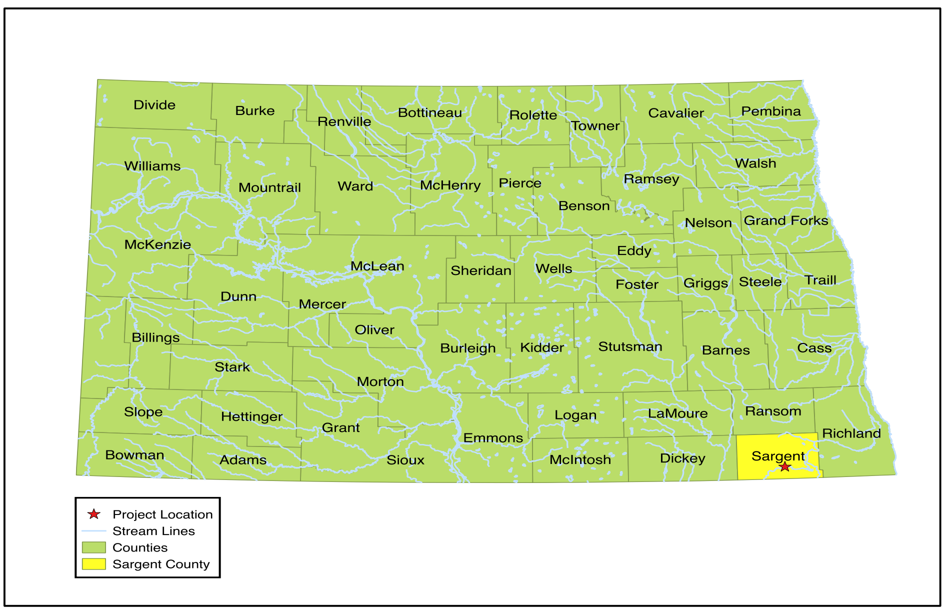


Figure 1. Project Location.

3. Background

Silver Lake Dam is an earthen embankment dam constructed in 1937 by the Works Progress Administration to raise the water level of Silver Lake and provide recreational opportunities. Silver Lake Dam has a watershed contributing area of approximately 344 square miles. The lake level is controlled by a concrete spillway at elevation 1223.8 mean sea level and has a maximum depth of approximately 11 feet with an average depth of 7.3 feet and a volume of 830 acre-feet.

All dams in North Dakota are classified by their hazard level. The “North Dakota Dam Design Handbook” provides that dams can be categorized as low, medium, or high hazard described as follows:

Low Hazard- dams located in rural or agricultural areas where there is little possibility of future development. Failure of low-hazard dams may result in damage to agricultural land, township and county roads, and farm buildings other than residences. No loss of life is expected if the dam fails.

Medium Hazard- dams located in predominantly rural or agricultural areas where failure may damage isolated homes, main highways, railroads, or cause interruption of minor public utilities. The potential for the loss of a few lives may be expected if the dam fails.

High Hazard- dams located upstream of developed and urban areas where failure may cause serious damage to homes, industrial and commercial buildings, and major public utilities. There is a potential for the loss of more than a few lives if the dam fails.

Using these definitions, Silver Lake Dam can be classified as a low hazard dam based on its rural location. If a complete failure of the embankment occurred, the flood wave would at most damage several county roads and agricultural land.

After the hazard classification is made, based on the dam’s location and likelihood of loss of life, the hazard is classified based on its height. This classification is made using the following table provided in the “North Dakota Dam Design Handbook”:

Table 1. Dam Design Classification based on height.

Dam Height (Feet)	Low	Medium	High
Less than 10	I	II	IV
10 to 24	II	III	IV
25 to 39	III	III	IV
40 to 55	III	IV	V
Over 55	III	IV	V

Silver Lake Dam is thus classified as a Class I Low Hazard embankment based on its height being less than 10 feet.

A two dimensional hydraulic model was created by Gannett Fleming as part of a hazard classification project. The model estimated the effects of a dam failure due to a Probable Maximum Flood (PMF). A PMF is the largest predicted flood event, created by a combination of the most severe meteorological and hydrologic conditions. The model was produced using a 10-meter digital elevation model. **Figure 2** is the inundation outline of the PMF at Silver Lake Dam produced by the Gannett Flemming model.

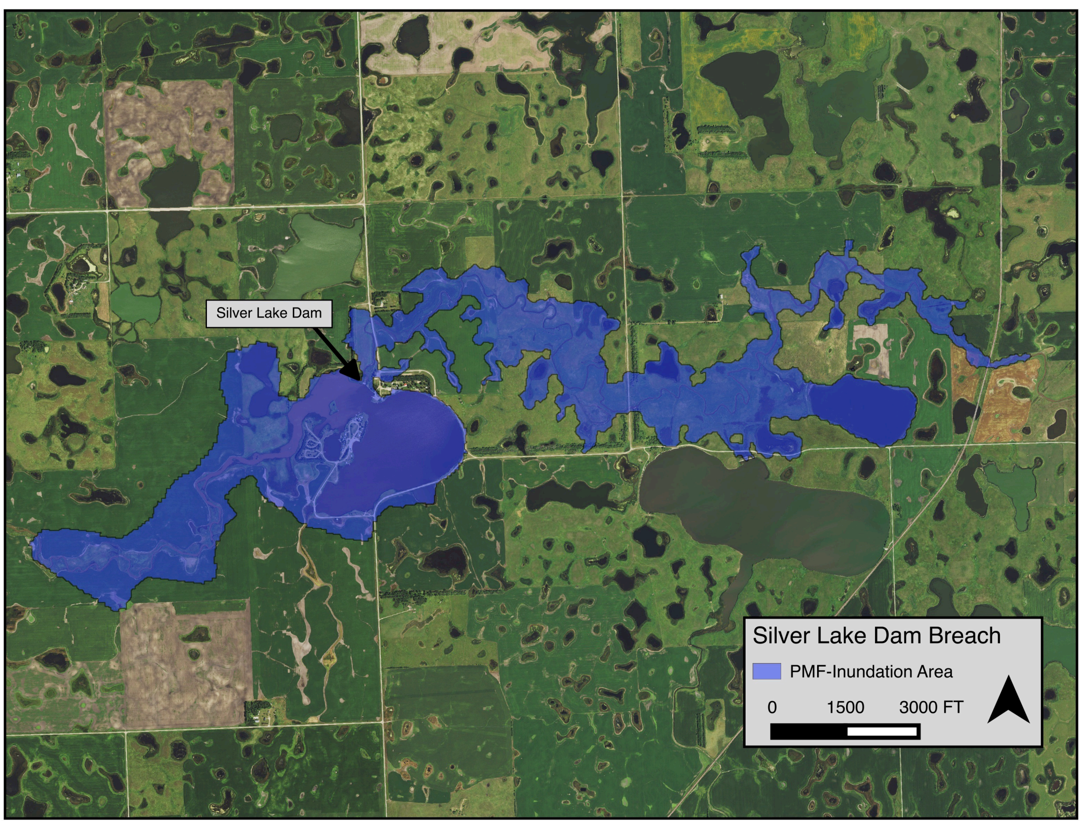


Figure 2. PMF inundation area.

A preliminary engineering report completed by the SWC in 1994 evaluated the water level of Silver Lake and suggested raising the spillway 2 feet to enhance recreational opportunities. Since the dam has a Class I Low Hazard classification the spillway must pass a 25-year frequency event. The preliminary engineering report validated the area's hydrology and the newly designed spillway's ability to pass a 25-year frequency event. The SWC construction crew completed the 2 foot spillway raise in 1998.

After the completion of the spillway raise in 1998 a letter was written documenting seepage through Silver Lake's embankment. A letter (**Appendix A**) dated August 23, 2006, noted that seepage was occurring several years before the dam raise and appeared to have increased shortly afterward.

4. Dam Seepage

Dam seepage is the flow of water through, under, or around a dam. Seepage can be an extremely complex and serious issue for the stability of an embankment. If soil particles are being transported, this flow of water can cause internal erosion (a.k.a. piping), decreasing the stability of the embankment and can lead to dam failure.

Seepage is often monitored to determine if the seep is carrying sediment out of the embankment. Seeps containing clear water, with no sediment load, should be monitored, but do not typically call for immediate action. Seeps containing sediment, however, could have serious implications for the dam stability and public safety.

5. Site Visit

On December 4th of 2015, water resource engineers David Nyhus, Joon Hee Lee, and Chris Korkowski visited the site to examine the conditions of the embankment and evaluate design alternatives to mitigate the embankments seepage. One large tree and many small diameter willows were seen growing out of the embankment (**Figure 3**). Large amounts of cattails were observed on the downstream side of the embankment and they appear to be flourishing.

Figure 3. Silver Lake Dam, right embankment (photograph taken from downstream side).

A culvert was found downstream of the right embankment, discharging into the Wild Rice River. The culvert was in a road providing access to the spillway. This 30-inch culvert had nearly an inch of water flowing through it, towards the river. Due to the seasonal conditions at the time of the visit, existing snowpack and freezing temperatures, this flow indicates considerable seepage through the right embankment. After viewing the flow through the culvert, the toe of the embankment was investigated to determine whether the seepage was coming through or under the embankment.

A small seep was located several yards east of the large tree in **Figure 3**. **Figure 4** shows the small seep in location to the culvert, and **Figure 5** is a photograph of the seep. The seep does not appear to produce the amount of flow observed at the culvert.

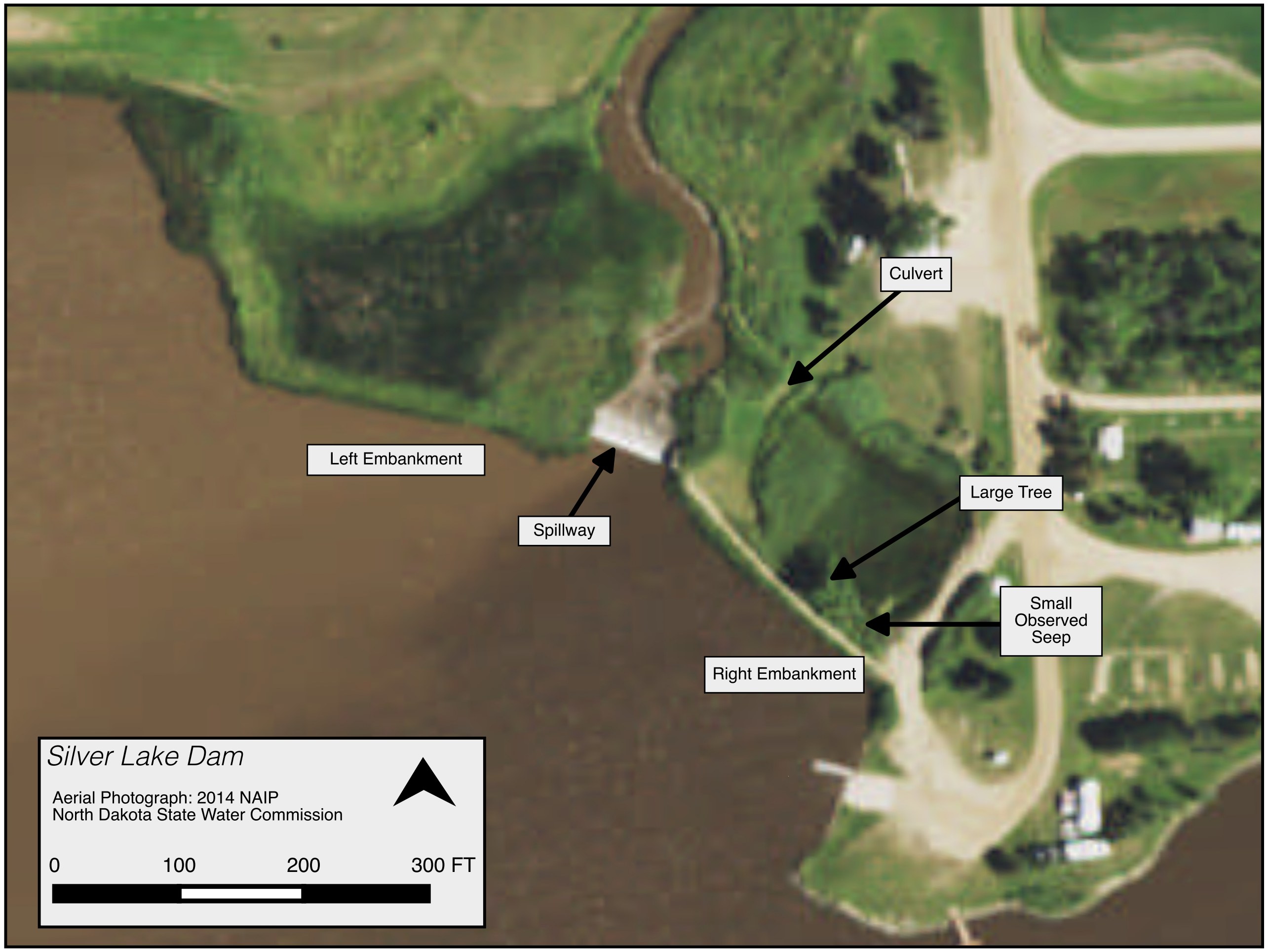


Figure 4. Shows the small observed seep in location to the culvert and the embankments.

Figure 5. Seep on the right embankment east of the large tree.

After observing a discrepancy in flows between these points, it is apparent that another flow source is contributing to the flow at the culvert. This source could be from flow moving from the east edge of the embankment below the stagnant surface water or from flow under the embankment though a permeable seam flowing into the cattails to the north of the right embankment.

6. Seepage Control Alternatives

Several primary objectives must be met when designing seepage control.

- Prevent piping and internal erosion.
- Limit pore pressure, uplift, and seepage forces.
- Prevent slope instability and surface sloughing.
- Prevent “wet spots” and surface erosion.

A secondary objective of seepage rehabilitation is to limit the loss of water in the reservoir. This option, however, does not directly relate to the dam’s safety.

After the objectives of the project are defined, alternatives can be selected to fulfill the project needs. In general there are two broad categories of seepage rehabilitation alternatives. The first category is collection and control and the second category is seepage reduction.

6.1 Collection & Control

Collection and control alternatives meet the primary objectives but fail to prevent or reduce the flow of water through the embankment. The goal of collection and control measures is to move the water through the embankment without causing erosion or producing destabilizing forces. Filters are the most common collection and control alternatives and can be designed to service most embankments. Filters consist of sand and gravel layers allowing water to flow without removing fine particles from the embankment. A geotechnical investigation is needed to determine the depth, extent, and material size of the filter.

6.2 Seepage Reduction

Unlike collection and control alternatives, seepage reduction alternatives can meet both the primary and secondary objectives of an embankment rehabilitation project. The goal of seepage reduction alternatives is to create an impervious layer preventing the flow of water through the embankment and its foundation. Geotechnical analysis of the embankment and foundation are crucial to designing seepage reduction measures. The geotechnical analysis can help estimate seepage flow paths and help determine whether the embankment core or foundation is impervious. Grouting, impermeable blankets, and barrier walls are the most common methods to reduce seepage.

Grouting consists of boring holes and filling them with concrete while following the seepage path through the embankment. Although grouting fills the boring holes with impermeable concrete, it is extremely expensive and is more likely to fail than other methods.

Impermeable blankets are typically impermeable clay or geotextile placed on the upstream face of the embankment and possibly out on to the floor of the reservoir, but require draining the reservoir for placement. Impermeable blankets are also expensive and require extensive knowledge of the existing seep in order to properly place the blanket.

Barrier walls are the most common of the three methods for earthen embankments. Barrier walls consist of placing impermeable clay in a trench down to the impermeable foundation. Barrier walls have a high success rate if the wall is placed down to and keyed into the impermeable foundation.

Seepage reduction alternatives can be viewed as either complete or partial cutoff alternatives. Understanding the design of the existing right embankment is crucial to determine cutoff alternatives that could improve the dam's safety and reduce seepage. The "North Dakota Dam Design Handbook" states, "Generally, design class I and II dams have homogenous embankments, are constructed without extensive moisture control, and do not have foundation and embankment drains." (ND Dam Design Handbook). Silver Lake Dam being categorized as a class I dam and the age of the embankment may point to the embankment being constructed with only homogenous materials on a pervious foundation. The USACE "General Design and Construction Considerations for Earth and Rock-Fill Dams" states that "when the dam foundation consists of a relatively thin deposit of pervious alluvium, the designer must decide whether to make a complete cutoff or allow a certain amount of under seepage to occur under controlled conditions. It is necessary for a cutoff to penetrate a homogenous isotropic foundation at least 95 percent of the full depth before there is any appreciable reduction in seepage beneath the dam. The effectiveness of a partial cutoff in reducing the quantity of seepage decrease as the ratio of the width of the dam to the depth of the penetration of the cutoff increases. Partial cutoffs are effective only when they extend down into an intermediate stratum of lower permeability. This stratum does not negate the effectiveness of a partial cutoff." (USACE). Based on this, more information in the form of a geotechnical investigation is needed to determine the makeup of the soils and the location of an impervious layer, if any, before a seepage reduction alternative can be considered for Silver Lake's right embankment. Excessive amounts of material would likely need to be removed in order to place an impervious layer deep enough to reduce the seepage. Seepage reduction alternatives would likely be infeasible when compared to collection and control alternatives due to cost. For this reason, seepage reduction alternatives were not examined in this report.

Two things must be accomplished for each alternative. The first is a complete geotechnical analysis of the site, and the second is removal of the large tree and brush on the right embankment.

7. Project Alternatives

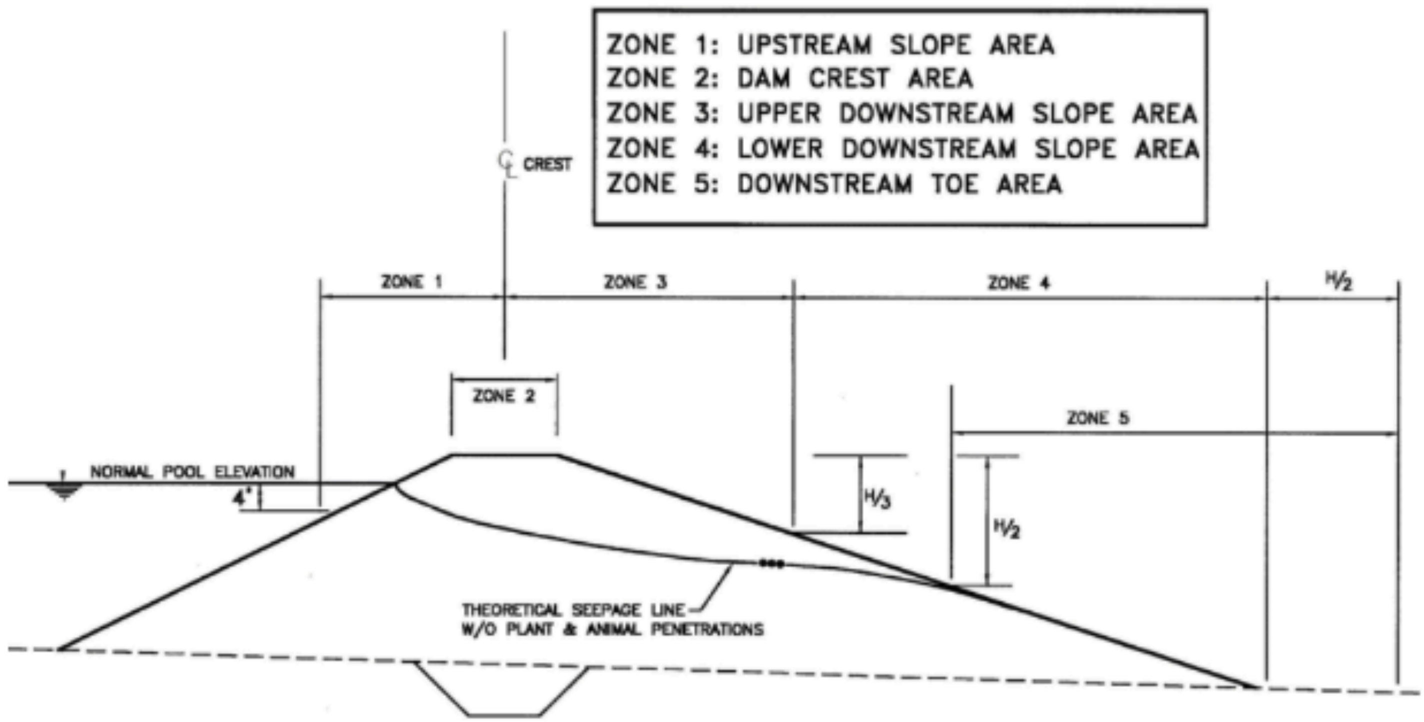
7.1 Geotechnical Analysis

A geotechnical analysis of the site is needed to improve the understanding of how the embankment is seeping and determining which embankment rehabilitation alternatives would have the best chance of success. Soil borings of the embankment and downstream cattail slough would provide information on the composition of the embankment and foundation, leading to an understanding of the flow path the seep is following. The recommended geotechnical analysis would include at least five soil borings, four would be at a depth of 50-feet and one at 100-ft along with a geotechnical report to provide sufficient information to create rehabilitation designs. A preliminary cost estimate, provided by a geotechnical consulting firm in the region, was $20,000. Adding contingency of 20 percent to this estimate to account for review and overages brings estimated cost of the geotechnical analysis of the site to about $24,000. This initial geotechnical investigation may result in a recommendation for more borings and testing.

7.2 Embankment Maintenance

Clearing the embankment of woody vegetation is necessary to maintain embankment integrity. Woody vegetation, such as shrubs or trees, grow extensive root systems that can grow through the embankment leaving flow paths along each root. This can cause erosion of the embankment, which can lead to the failure of the embankment. Each year, dam operators should examine the embankment making sure there are no new trees or shrubs growing on the embankment.

The large tree growing in the right embankment presents a hazard to the dam and should be removed regardless of which alternative is chosen. Removal of this tree will require excavation to remove its root system which could lead to the failure of the embankment if proper construction methods aren't used. FEMA details several inspection and evaluation zones in an earthen embankment and the significance of having woody vegetation in each zone. **Figure 6,** from FEMA's "Technical Manual for Dam Owners", details the inspection and evaluation zones. The large tree located on Silver Lake's embankment is located in Zone 4. "Zone 4 is one of the two most critical zones relative to dam safety issues associated with tree and woody vegetation growth as well as other potential dam safety issues. This zone typically contains the interceptions of both the zone of saturation and the seepage line with the downstream slope. The close proximity of the zone of saturation and seepage line to the surface of the downstream embankment slope in this zone is a critical factor relative to dam safety issues associated with tree and woody vegetation growth" (FEMA Dam Owners). For these reasons, FEMA guidelines suggest complete removal of trees having a diameter greater than about six inches. The repairs of the tree removal process on page 6-9 of FEMA's "Technical Manual for Dam Owners", recommends a subdrain or filter be installed in the root ball cavity. The filter system installed would need to connect to a major subdrain such as a toe drain.



REMEDIAL DAM REPAIR ZONES

Figure 8

Figure 6. Inspection and evaluation zones for wooded vegetation (FEMA Dam Owners, 4-14).

Many small diameter willows are also located in Zone 4 of Silver Lake's right embankment. FEMA guidelines for removing trees of this diameter in Zone 4 call for removing the tree flush with the ground and treating the stumps with wood preservative.

Based on FEMA's guidelines for tree removal in Zone 4, consideration should be placed on stabilizing the embankment during tree removal. A temporary cofferdam on the upstream side of the right embankment near the large tree, would reduce the surface pressure the water would place on the embankment and reduce the risk of dam failure while removing the tree. The void left by removing the tree's root ball would be filled with drain material and capped with an impervious clay material. After repairs are made, the temporary cofferdam could be removed. The cofferdam required to maintain the stability of the embankment during the root ball removal along with drain placement makes removing a tree in Zone 4 expensive.

7.3 Alternative 1- No-Change Alternative

Alternative 1 is a no-change alternative. A no-change alternative would leave the embankment in its existing condition, but would not comply with standard dam maintenance practices. Removal of the large tree and the willows is necessary maintenance.

The seep through the right embankment would likely continue as it has for the last 17 years. The site visit on December 4th of 2015 indicates that the seep is not currently carrying sediment.

The first priority of a seepage rehabilitation project is to insure dam safety. Silver Lake Dam is classified as a low hazard dam that would provide no imminent danger if it failed. Figure 2 shows the flood wave dissipating within a few miles downstream, likely causing minor erosion to agricultural land and county roads. The seep as viewed on December 4th appears to be causing no erosion. The cattail slough downstream of the embankment may be acting as a natural filter, capturing eroding particles and preventing them from moving downstream.

Besides dam safety concerns, maintaining the pool in Silver Lake would also be a concern with Alternative 1. The seep could continue and create issues with loss of recreational use, however, this does not currently seem to be an issue due to the ongoing wet cycle.

A cost estimate was prepared using "RSMeans Heavy Construction Cost Data 2014" and estimates based on previously constructed projects. **Table 3** is a cost estimate for alternative 1, the removal of the wooded vegetation from the right embankment. The cost estimate includes a cofferdam, which is necessary to maintain the stability of the dam during tree removal. A spreadsheet detailing the costs of individual lines of work is located in Appendix C.

Table 2. Alternative 1 cost estimate.

Alternative 1	
Geotechnical Analysis	$24,000
Cost of Materials and Construction	$34,500
15% Mobilization	$5,000
10% Design Contingency	$3,500
20% Contingency	$7,000
Total Cost	**$74,000**

7.4 Alternative 2- Filter System

Alternative 2 would involve the installation of a collection and control structure known as a filter. Filters can be designed to meet a variety of different seepage issues. FEMA describes the types of filters in four separate classes. Using the classification system, “Table 2-1” of FEMA’s “Filters for Embankment Dams Best Practices for Design and Construction October 2011”, and assuming the foundation and embankment at Silver Lake are pervious, a toe drain would be an appropriate filter system for the right embankment.

Toe drains are composed of sand and gravel layers allowing the passage of water to a perforated drain while blocking particles eroding due to the seep. The drain then conveys the seepage downstream of the embankment. **Figure 7** is the general cross section view of a toe drain edited from “Figure 2-12” from FEMA’s “Filters for Embankment Dams Best Practices for Design and Construction October 2011”. The designed toe drain would run parallel to the embankment along the downstream toe.

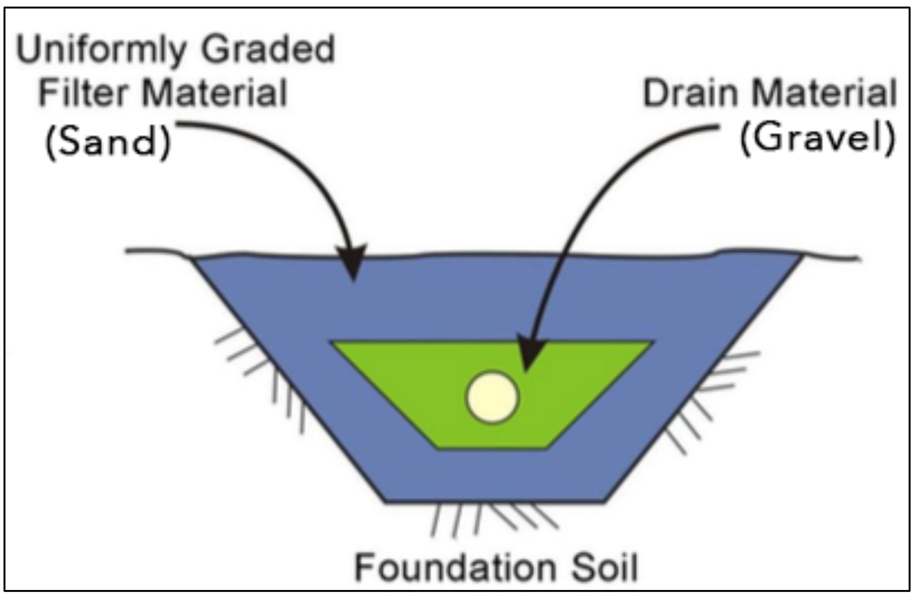


Figure 7. Cross section view of a standard toe drain.

Correctly sizing the sand and gravel layers is crucial in preventing soil particles of the embankment from eroding and to maintain the dam’s stability. Due to lack of soil samples, general design criteria are used to determine the size of filter materials. “In lieu of complete design, experience has shown that a modification to fine concrete aggregated designated in ASTM C33 meets the design requirements for many foundation materials.” (FEMA Filter, 129). **Table 3** is the gradation for ASTM C33 concrete sand.

Table 3. ASTM C33 Concrete Sand (FEMA Filter, 129).

Sieve Size	Percent Passing by Weight
3/8-in	100
No. 4	95-100
No. 8	80-100
No. 16	50-85
No. 30	25-60
No. 50	5-30
No. 100	0-10
No. 200	0-2

"In a similar manner, when modified C33 concrete sand is used as a filter, standard materials can be used as the gravel drain that surrounds the pipe. Several materials in ASTM D448 have been checked against modified C33 concrete sand and are included in Table 6-4. When using modified C33 concrete sand, the D448 materials do not have to be checked since the filters size is fixed." (FEMA Filter). **Table 4** is ASTM D448 gradation from Table 6-4 of FEMA's "Filters for Embankment Dams – Best Practices for Design and Construction.". Using these standard materials tested by FEMA, a preliminary toe drain design can be developed for Silver Lake's right embankment.

Table 4. ASTM D448 gradation, percent passing by weight (FEMA Filter, 130).

Sieve Size	Blend 5791	No.8	No. 89
2-in	-	-	-
1-1/2-in	100	-	-
1-in.	90-100	-	-
3/4-in.	75-85	-	-
1/2-in.	-	100	100
3/8-in	45-60	85-100	90-100
No. 4	20-35	10-30	20-55
No. 8	5-15	0-10	5-30
No. 16	0-5	0-5	0-10
No. 50	-	-	0-5

The minimum requirements for designing toe drains from the Bureau of Reclamation were used to develop the drains cross sectional layout and determine volumes of materials needed to construct the drain. The preliminary drain design, however, is based on standard specifications for a toe drain design since no geotechnical analysis has been completed. After a geotechnical analysis is complete, the depth of the filter can be designed to meet the projects objectives. **Figure 8** is a preliminary cross section view of the toe drain designed for Silver Lake's right embankment and **Figure 9** is the approximate footprint of the toe drain. Approximate quantities for construction materials to complete the toe drain are in **Table 5** below. Volumes were calculated using the geometry in Figure 6 and given a 15 percent buffer to account for compaction.

Table 5. Toe drain material quantities.

Material	Volume (C.Y.)	Length (ft)	Fitting (unit)
ASTM C33 sand or comparable	304	-	-
ASTM D448 or comparable	45	-	-
Clay (gradation to be determined)	445	-	-
8-in perforated double wall HDPE	-	260	-
8-in HDPE Tee Adaptor	-	-	1
8-in HDPE 22.5 Degree Bend Adaptor	-	-	3
8-in HDPE 45 Degree Bend Adaptor	-	-	1

A cost estimate for the construction of the drain designed above was created using several methods. The costs of materials were estimated by contacting local construction firms and material providers, while construction costs were estimated using "RSMeans Heavy Construction Cost Data 2014". The cost estimate includes the removal of the wooded vegetation and creation of a toe drain to control the embankment seepage. A spreadsheet detailing the costs of individual lines of work is located in Appendix C.

Table 6. Alternative 2 cost estimate.

Alternative 2	
Geotechnical Analysis	$24,000
Cost of Materials and Construction	$93,00
15% Mobilization	$14,000
10% Design Contingency	$9,000
20% Contingency	$18,000
Total Cost	**$158,000**

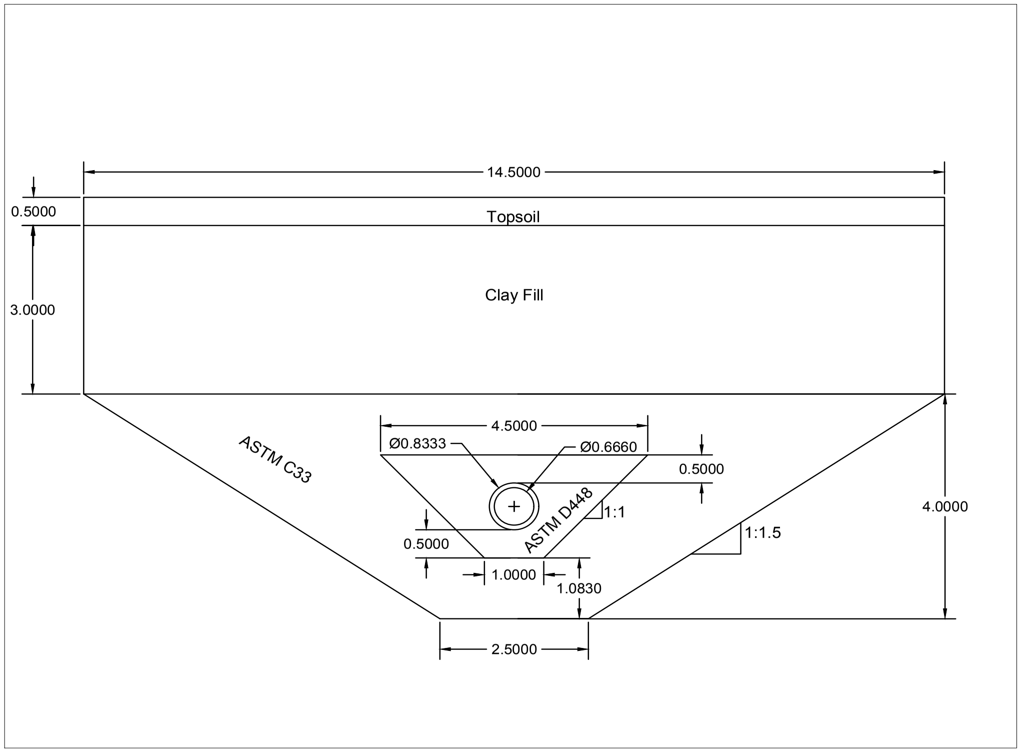


Figure 8. Silver Lake proposed toe drain design (dimensions in feet).

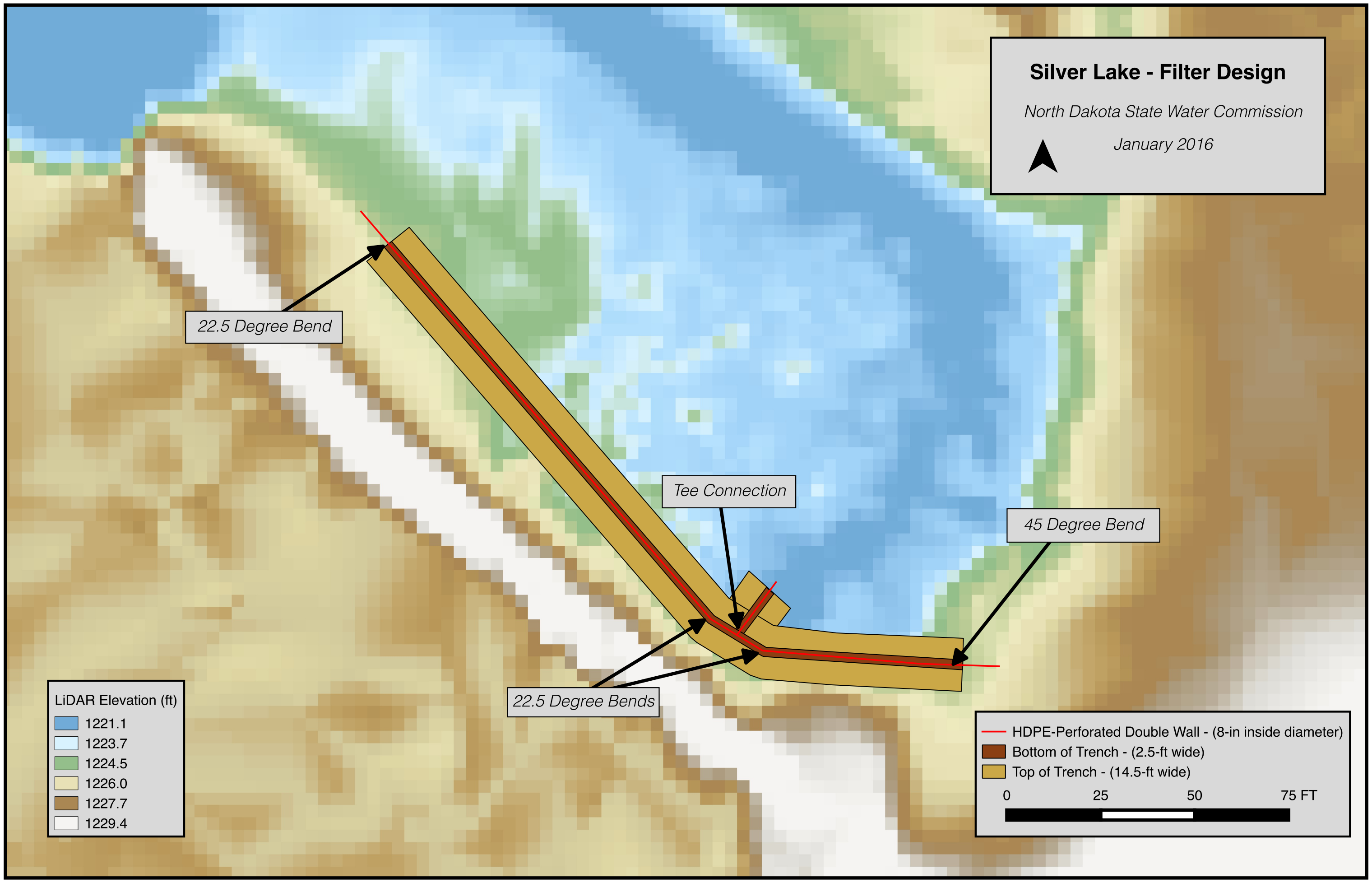


Figure 9. Silver Lake proposed toe drain footprint.

8. Summary & Recommendation

Two alternatives are detailed in this report, the no-change alternative and the toe drain alternative. Each alternative has advantages and disadvantages that should be carefully considered.

The no-change alternative would require the removal of woody vegetation from the embankment and the creation of a small drain in the void left by the large tree being removed. This alternative would allow uncontrolled seepage to continue through the embankment. The advantage of this alternative is the low cost, **$74,000** compared to toe drain alternative, if the embankment survives. The disadvantages of this alternative are possible loss of recreational use due to low water during dry cycles, and the possibility of soil erosion from the embankment leading to failure of the embankment.

The toe drain alternative would require the removal of wooded vegetation along with the creation of a toe drain. The toe drain would reduce the risk of dam failure due to particle erosion from the seep. The advantages of this alternative is the reduction of dam failure potential. The disadvantage of this alternative is the cost, $158,000 in addition to 50,000 dollars for tree removal in Alternative 1 for a total of **$208,000**.

We recommend the SCWRD proceed with Alternative 2.

9. Citations

(FEMA Filter) Filters for Embankment Dams - Best Practices for Design and Construction. Washington, D.C.: U.S. Dept. of Homeland Security, FEMA, 2011. Print.

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