KYTC Dam Assessment Study

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TEAM KENTUCKY®
TRANSPORTATION CABINET

Condition Assessments, Risk Evaluations, and Recommendations for KYTC Dams

February 2026

Prepared for:
Kentucky Transportation Cabinet

Prepared by:
Stantec Consulting Services Inc.

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Prepared by:

Shalyn Landes

Shalyn Landes

Carelynn Hartmann-Spratt

Digitally signed by Carelynn Hartmann-Spratt
Date: 2026.02.20 08:28:23-05'00'

Carelynn Hartmann

Reviewed by:

Digitally signed by Hatton, Robert
DN: CN="Hatton, Robert", OU=Internal, OU=users, OU=stantec, DC=corp, DC=ads
Date: 2026.02.19 16:41:25-05'00'

Robert Hatton

Rauch, Alan

Digitally signed by Rauch, Alan
Date: 2026.02.19 16:51:24 -05'00'

Alan Ruach

Keeling, Jon

Digitally signed by Keeling, Jon
Date: 2026.02.23 14:47:34 -05'00'

Jon Keeling

Approved by:

Len Harper

Len Harper

STATE OF KENTUCKY
LEONARD S. HARPER
27969
LICENSED PROFESSIONAL ENGINEER

Executive Summary

This study assessed the current conditions, failure risks, and potential improvements for nine embankment dams owned and maintained by the Kentucky Transportation Cabinet (KYTC). These dams primarily provide recreation, water supply, and flood risk reduction, with state or interstate highways across their crests. While KYTC owns and maintains 11 embankment dams, as shown in **Figure ES-1**, this study excluded two of those dams undergoing active improvement projects: Panbowl Lake Dam and Lake Sympson Dam.

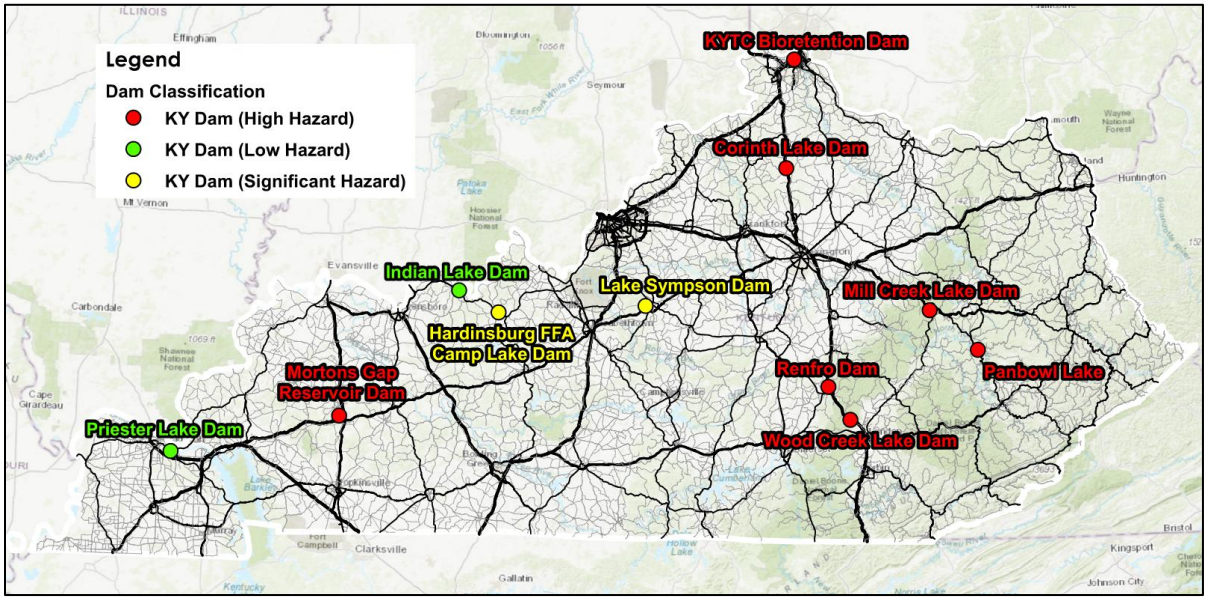


Figure ES-1. Map of Eleven Dams Maintained by KYTC

The assessment process included a detailed review of historical records, site visits, and Potential Failure Mode Analysis (PFMA) workshops. Credible failure modes were identified and associated risks were evaluated. The risk evaluation process followed Federal Energy Regulatory Commission (FERC) guidelines, considering failure likelihood, life safety consequences, and economic impacts. Risk matrices were developed to prioritize dam safety concerns and guide maintenance and capital improvement planning.

Key findings indicate a range of conditions across the portfolio of dams. Seven dams are classified as high hazard due to potential life safety risks and significant economic consequences in the event of failure. Common potential failure modes include slope stability issues, internal soil erosion, seismic vulnerabilities, overtopping, and erosion associated with conduits and spillway structures.

Specific recommendations were developed for each dam to address significant failure modes and maintenance deficiencies. These include recommended Operations and Maintenance (O&M) actions, Capital Improvements, and further Engineering Investigations, as summarized in **Table ES-1**. Along with the recommendations for individual dams, KYTC should consider establishing basic elements of a Dam Safety Program, which could include identifying a KYTC Dam Safety Officer, centralizing dam information,

updating emergency action plans, standardizing inspection protocols, and enhancing dam safety training and monitoring.

Table ES-1. Number and Type of Recommendations for Each Dam

Dam	Recommendations		
	O&M	Investigation	Capital Improvement
Morton's Gap Reservoir Dam	5	1	0
Priester Lake Dam	2	1	0
Indian Lake Dam	3	3	0
Hardinsburg FFA Camp Lake Dam	5	3	0
Wood Creek Lake Dam	4	2	1
Renfro Dam	4	2	1
Corinth Lake Dam	1	2	2
KYTC Bioretention Dam	2	2	2
Mill Creek Lake Dam	2	2	1
TOTAL	**28**	**18**	**7**

This study aims to support KYTC in enhancing dam safety, reducing risks to life and infrastructure, and ensuring continued service of these critical facilities. The findings and recommendations are based on the current (2025) conditions at each of the nine evaluated dams.

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Abbreviation List

APF …….…… Annual Probability of Failure

CMP ……..…… Corrugated Metal Pipe

FEMA …….. Federal Emergency Management Agency

FERC …….. Federal Energy Regulatory Commission

KDOW ……... Kentucky Division of Water

KYTC …….. Kentucky Transportation Cabinet

NID ……..…… National Inventory of Dams

PAR …… Population at Risk

PFM ……..…….. Potential Failure Mode

PFMA ……..…… Potential Failure Mode Analysis

USACE …….. United States Army Corps of Engineers

1.0 Introduction

The Kentucky Transportation Cabinet (KYTC) engaged Stantec to complete a programmatic study of KYTC-owned dams. The objective was to identify the need for and scope of improvements at each dam, based on dam safety considerations.

KYTC owns and maintains 11 embankment dams, as shown in **Figure 1**. At most of these sites, a state or interstate highway is built across the crest of the dam. The reservoirs are generally used for recreation, water supply, and/or flood risk reduction. Nine of these dams (described in the sections below) were evaluated in this study. KYTC has active projects to improve Panbowl Lake Dam and Lake Sympson Dam, which were excluded from this study.

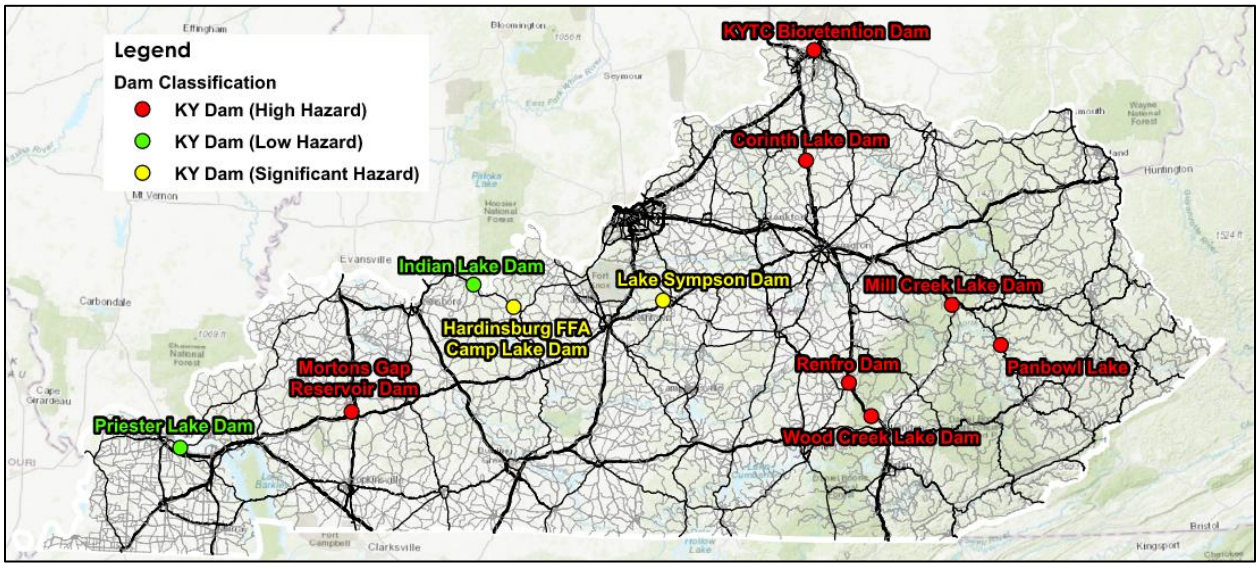


Figure 1. Map of Eleven Dams Maintained by KYTC

This study assessed the nine dams listed below. This list includes the name of the dam as well as the National Inventory of Dams (NID) ID number in parentheses.

- Morton's Gap Reservoir Dam (KY00156)
- Priester Lake Dam (KY00402)
- Indian Lake Dam (KY00014)
- Hardinsburg FFA Camp Lake Dam (KY00107)
- Wood Creek Lake Dam (KY00088)
- Renfro Dam (KY00101)
- Corinth Lake Dam (KY00051)
- KYTC Bioretention Dam (KY01224)
- Mill Creek Lake Dam (KY00259)

The scope of this study included a review of project records and dam site visits to assess current conditions. Potential failure mode analysis (PFMA) workshops were held to characterize dam safety risks at each site. Failure modes were identified and categorized by risk level. Recommendations were then developed to address significant failure modes and dam maintenance issues. KYTC may use the documented results in planning and prioritizing maintenance and capital improvement projects for these facilities.

The evaluation process is described in the body of this report. The findings for each dam are documented in the appendices, which include:

- A description of the dam and appurtenant features
- The available data catalog
- Hydrologic and hydraulic analyses completed for this study
- Identified Potential Failure Modes (PFMs)
- Evaluation of PFM risks
- Results plotted on risk matrices
- Prioritized recommendations for needed improvements
- Cost opinions for recommended capital projects

2.0 Background

According to Kentucky Revised Statutes Chapter 151, a dam is defined as any structure that is 25 feet in height, measured from the downstream toe to the lowest point on the crest of the dam, or has a maximum impounding capacity of 50 acre-feet or more at the top of the structure (Dam Safety Division of Water, 2022).

In the Commonwealth of Kentucky, the Energy and Environment Cabinet has authorization to inspect existing dam structures (Kentucky General Assembly, 2025). A condition assessment of each dam is performed during an inspection. Dams are assigned one of the following four conditions: Satisfactory, Fair, Poor, or Unsatisfactory.

The Energy and Environment Cabinet may establish hazard categories for dams based on downstream floodplain use, size, or type of dam, or other criteria, and may impose different conditions or types of conditions on the approval of dams or reservoirs in the different categories. The hazard categories in all cases are based only on the actual risk imposed by failure of the dam. There are three hazard classifications: High, Significant, and Low.

- A high hazard dam, also known as a class “C” dam, is a structure located such that failure may cause loss of life or serious damage to houses, industrial or commercial buildings, important public utilities, main highways or major railroads.
- A significant hazard dam, also known as a class “B” dam, is a structure located such that failure may cause significant damage to property and project operation, but loss of human life is not envisioned.
- A low hazard dam, also known as a class “A” dam, is a structure located such that failure would cause loss of the structure itself but little or no additional damage to other property.

The National Inventory of Dams (NID) is a public domain database with dam information such as location, type, size, purpose, and structural components. The National Inventory of Dams is maintained by the United States Army Corps of Engineers (USACE) in collaboration with the Federal Emergency Management Agency (FEMA) and the Association of State Dam Safety Officials to obtain current and accurate information (National Inventory of Dams, n.d.).

3.0 Evaluated Dams

A summary of the existing conditions information for the nine dams evaluated in this study is shown in **Table 1**.

Table 1. Summary of Dams Evaluated in this Study

Dam	County	KYTC District	Primary Purpose	Classification	Most Recent Condition Assessment
KYTC Bioretention	Kenton	6	Flood Risk Reduction	High Hazard	Poor (2024, KDOW), Fair (2025, NID)
Corinth Lake	Grant	6	Recreation	High Hazard	Poor (2024)
Indian Lake	Hancock	2	Recreation	Low Hazard	Fair (2013)
Mill Creek	Powell	10	Recreation	High Hazard	Poor (2024, KDOW), Fair (2025, NID)
Hardinsburg FFA	Breckenridge	4	Recreation	Significant Hazard	Poor (2019)
Renfro	Rockcastle	8	Water Supply	High Hazard	Poor (2024)
Morton's Gap	Hopkins	2	Recreation	High Hazard	Fair (2023)
Priester Lake	McCracken	1	Recreation	Low Hazard	Poor (2016)
Wood Creek	Laurel	11	Water Supply	High Hazard	Fair (2024)

4.0 Assessment Process

4.1 Review of Records

Stantec reviewed the available historical documentation provided by KYTC, information from Kentucky Division of Water, and Stantec-sourced records, to develop an understanding of each site and identify key data gaps. A meeting with KYTC personnel to review these records was conducted on April 4th, 2025. These historical documents were compiled and organized within a document master list to simplify review, as summarized in **Table 2**.

Table 2. Summary of the Number of Historical Documents Reviewed for Each Dam

Facility	Geotech / Geology	H&H	Inspections	Drawings	Analysis & Calc Docs	Transportation Docs	Permits
Wood Creek Lake Dam	2	8	81	8	0	2	0
Renfro Dam	1	11	157	15	0	2	0
Mill Creek Lake Dam	1	8	52	2	0	2	0
Panbowl Lake Dam	2	11	44	5	0	6	0
Corinth Lake Dam	4	8	63	4	0	4	0
Morton's Gap Reservoir Dam	0	5	23	3	0	3	0
KYTC Bioretention Dam	2	4	6	2	0	2	0
Lake Sympson Dam	3	5	32	6	0	2	0
Hardinsburg FFA Camp Lake Dam	0	6	35	1	0	2	0
Indian Lake Dam	0	5	22	1	0	2	0
Priester Lake Dam	0	5	7	0	0	2	0

4.2 Site Visits

A team of Stantec and KYTC engineers visited each of the evaluated dams. The upstream slope, crest, downstream slope, and abutment areas at each dam site were walked to observe current conditions as well as downstream vicinity. Spillways, conduits, valves, inlet structures, and outlet structures were also observed. The objective was to note possible deficiencies and develop an understanding of the overall structural components of the dam. All nine site visits were completed in the summer of 2025.



Figure 2. Renfro Dam Site Visit Photo

4.3 Potential Failure Modes

A Potential Failure Mode Analysis (PFMA) was completed for each dam to identify and assess dam safety risks. Relevant Potential Failure Modes (PFMs) were identified, developed, and evaluated in workshop discussions between Stantec and KYTC personnel. Guidelines from the Federal Energy Regulatory Commission (FERC) were followed (Federal Energy Regulatory Commission (FERC), 2021a).

Table 3 identifies the potential failure mode groups used within the analysis. PFMs were developed for each dam under each PFM group, where applicable. Documentation of the PFMs for each dam is provided in the appendices. The failure mode descriptions define loading, flaw, initiation, continuation,

progression, intervention, and breach. The associated tables for each PFM document contributing factors, adverse factors, and supporting figures for the assessment.

Table 3. Potential Failure Mode Groups

	PFM Group
1	Slope Stability
2	Internal Erosion
3	Seismic
4	Overtopping
5	Erosion Associated with Conduits
6	Spillway Structures
7	Operational
8	Other

4.4 Screening Level Risk Assessment

A risk assessment was completed to obtain category estimates for each significant PFM and the overall dam-specific risk profile. FERC guidelines (FERC 2021a; 2021b) for a screening-level assessment were followed. Failure probabilities and consequences were roughly estimated to within an order of magnitude (risks were not quantified). The screening-level results (risk categories) are sufficient as a framework for prioritizing projects and facilities.

4.4.1 Screening

First, each potential failure mode was screened as negligible, credible, or insufficient information. Only the potential failure modes identified as “Credible” were advanced to the next level of the risk assessment. Credible is defined by FERC (2021a) as something physically possible, regardless of likelihood. **Table 4** lists the negligible and credible criteria used to categorize the PFMs.

Table 4. Potential Failure Mode Screening Options (FERC 2021a)

Screen	Categories
Negligible	Ruled out, not physically possible
	Clearly negligible, remote
Credible	Credible
	Urgent credible, failure in progress
Insufficient Information	

4.4.2 Failure Likelihood

Second, failure likelihood categories were estimated for each potential failure mode that was deemed "Credible". Verbal mapping (**Table 5**, FERC 2021b) was used to classify failure likelihood, based on consideration of the PFM's documented influence factors and loading conditions. The categorization for each PFM was discussed, in detail, by the project team. See the appendices for documented verbal mapping of the failure likelihood category for each PFM. Key factors influencing decision making are marked in bold in each table.

Table 5. Potential Failure Mode Failure Likelihood Categories (FERC 2021b)

Failure Likelihood Category	Descriptors/Evidence	Annual Failure Likelihood
FL7	There is direct evidence to suggest it is certain to nearly certain that failure is imminent or extremely likely in the next few years.	more frequent (greater) than 1/10
FL6	There is direct evidence or substantial indirect evidence to suggest that failure has initiated or is very likely to occur during the life of the structure.	1/10 to 1/100
FL5	There is direct evidence or substantial indirect evidence to suggest that failure has initiated or is likely to initiate.	1/100 to 1/1,000
FL4	The fundamental condition or defect is known to exist; indirect evidence suggests it is plausible; and key evidence is weighted more heavily toward "more likely" than "less likely."	1/1,000 to 1/10,000
FL3	The fundamental condition or defect is known to exist; indirect evidence suggests it is plausible; and key evidence is weighted more heavily toward "less likely" than "more likely."	1/10,000 to 1/100,000
FL2	The possibility cannot be ruled out, but there is no compelling evidence to suggest it has occurred or that a condition or flaw exists that could lead to initiation.	1/100,000 to 1/1,000,000
FL1	Several events must occur concurrently or in series to cause failure, and most, if not all, have negligible likelihood such that the failure likelihood is negligible.	more remote (less) than 1/1,000,000

4.4.3 Life Safety Consequences

Next, life safety consequences were considered and categorized using the criteria in **Table 6**, from FERC (2021b). The consequences of dam failure were evaluated for normal and flood loading conditions. Where a breach would be expected to cause a cascading failure of an additional dam downstream, the combined consequences of both dams breaching were considered.

A preliminary hydrologic and hydraulic analysis was performed for each dam to verify capacity and generate consequences. For consequences, models were run for an overtopping flood breach and compared to the sunny-day inundation mapping. This model was also used to estimate population at risk (PAR) and life loss. The workshop group also considered population size, transient population, and confidence in intervention.

Table 6 Potential Failure Mode Life Safety Consequence Categories (FERC, 2021b)

Life Safety Consequence Category	Incremental Life Loss	Description
LS0	None expected	No significant impacts to the downstream population other than temporary minor flooding of roads or land adjacent to the river
LS1	Less than 1	Although life-threatening releases occur, direct loss of life is unlikely due to severity or location of the flooding, or effective detection and evacuation
LS2	1 to 10	Some direct loss of life is likely, related primarily to difficulties in warning and evacuating small population centers
LS3	10 to 100	Large direct loss of life is likely, related primarily to difficulties in warning and evacuating smaller population centers, or difficulties evacuating large population centers with significant warning time
LS4	100 to 1,000	Extensive direct loss of life can be expected due to limited warning for large population centers and/or limited evacuation routes
LS5	1,000 to 10,000	Extremely high direct loss of life can be expected due to limited warning for very large population centers and/or limited evacuation routes
LS6	Greater than 10,000	Catastrophic direct loss of life can be expected due to little to no warning for very large population centers and/or limited evacuation routes

4.4.4 Economic Consequences

Lastly, the economic consequences of each potential failure mode were considered. The consequences of a dam failure would include damage to downstream areas and existing infrastructure. Economic costs were associated with loss of service, repair, and reconstruction. A major economic loss for several KYTC dams would result from a highway closure. These factors were discussed by the workshop personnel. **Table 7** (FERC, 2021b) shows the economic consequence categories used to delineate loss for this assessment.

Table 7. Potential Failure Mode Economic Consequence Categories (FERC, 2021b)

Life Safety Consequence Category	Incremental Life Loss	Description
LS0	None expected	No significant impacts to the downstream population other than temporary minor flooding of roads or land adjacent to the river
LS1	Less than 1	Although life-threatening releases occur, direct loss of life is unlikely due to severity or location of the flooding, or effective detection and evacuation
LS2	1 to 10	Some direct loss of life is likely, related primarily to difficulties in warning and evacuating small population centers
LS3	10 to 100	Large direct loss of life is likely, related primarily to difficulties in warning and evacuating smaller population centers, or difficulties evacuating large population centers with significant warning time
LS4	100 to 1,000	Extensive direct loss of life can be expected due to limited warning for large population centers and/or limited evacuation routes
LS5	1,000 to 10,000	Extremely high direct loss of life can be expected due to limited warning for very large population centers and/or limited evacuation routes
LS6	Greater than 10,000	Catastrophic direct loss of life can be expected due to little to no warning for very large population centers and/or limited evacuation routes

4.4.5 Risk Matrices

After each PFM was evaluated and categorized, the failure likelihood, life safety consequences, and economic consequences were plotted on risk matrices (**Figure 3** and **Figure 4**). The failure likelihood category is plotted on the vertical axis, and the consequence level (life safety or economic) is plotted on the horizontal axis. The diagonal lines on the chart represent lines of equal risk.

The matrix provides a semi-quantitative context for the estimated categories, allowing relative comparison of PFM risk. The results support project prioritization. Failure modes in the upper right of the chart exhibit greater risk and should be prioritized, compared to PFMs that plot in the lower left of the chart.

Figure 3 and **Figure 4** are blank matrices for reference. Completed matrices for each dam are provided in the appendices, under the respective PFM analysis tables.

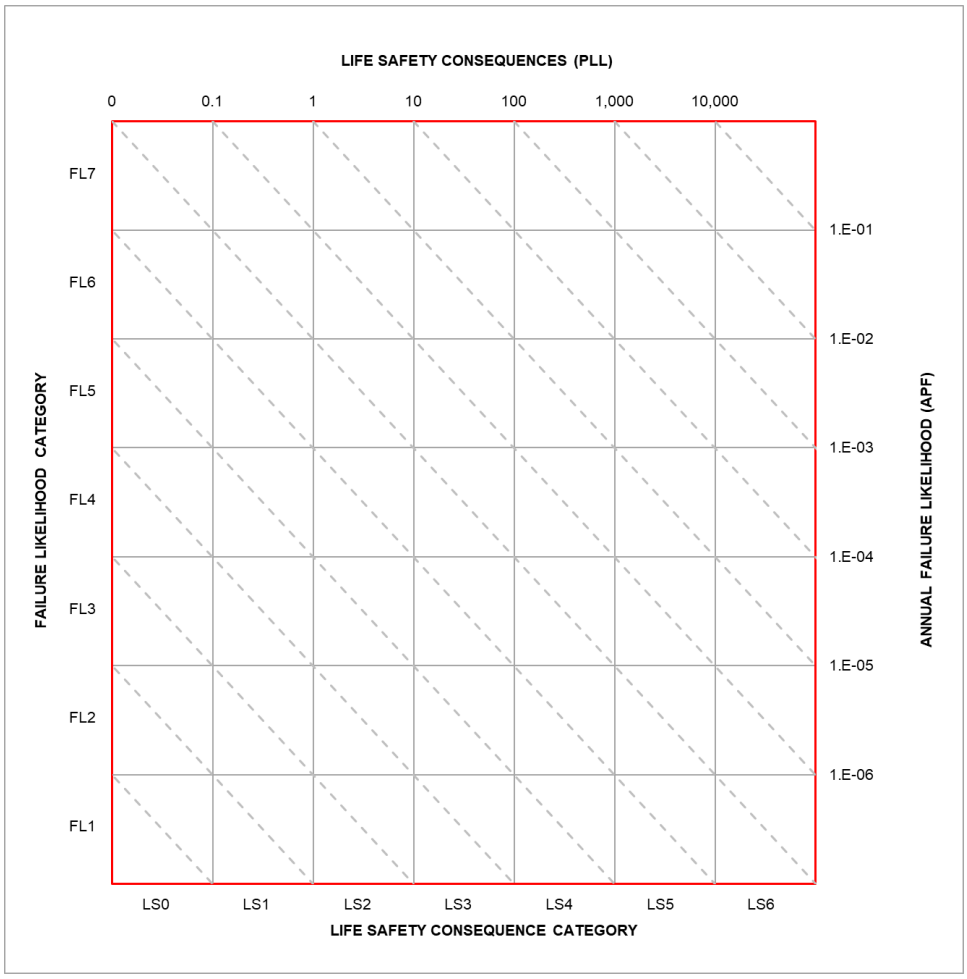


Figure 3. Life Safety Risk Matrix (FERC, 2021b)

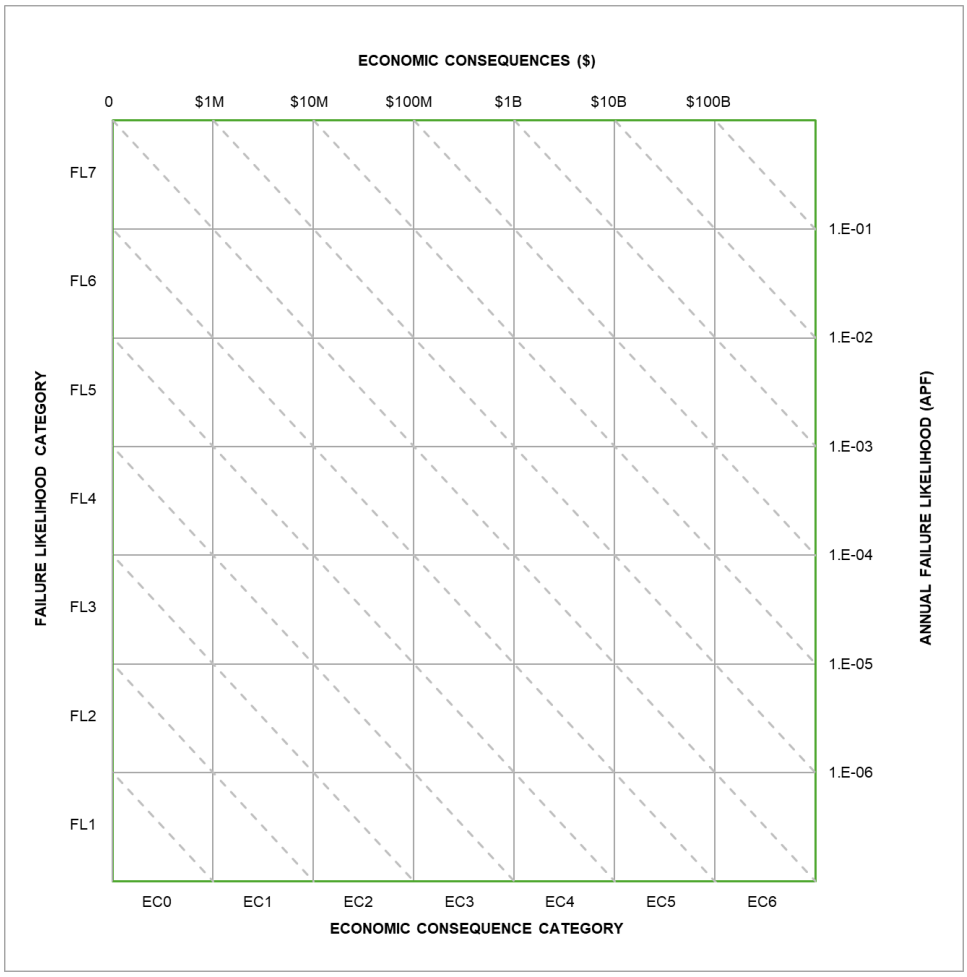


Figure 4. Economic Risk Matrix (FERC, 2021b)

5.0 Recommendations

5.1 Dam Improvements

After completing the risk assessment process, recommendations were developed to address the significant PFMs at each dam. Additional improvements to fix apparent deficiencies, as observed at the site visits and/or reported in past inspections, were identified.

The recommendations for each dam were categorized under Operations and Maintenance (O&M), Capital Improvements, or Engineering Investigations.

- Operations and maintenance include relatively routine or minor improvements that can be accomplished by KYTC staff.
- Investigations are desktop or field studies that would be performed by KYTC engineers or outside consultants.
- Capital improvements are long-term investment projects that would require full design development, construction, and project management.

5.2 Prioritization

The recommendations for all nine dams were compiled into lists and prioritized. The prioritization of projects was discussed with KYTC personnel and generally gave precedence to smaller efforts that can be readily implemented and which address dam safety risks while making progress toward larger projects. The prioritization of improvements for each dam are indicated in the recommendation tables in Section 5.3 and in the appendices.

To aid in the rational prioritization of projects, the following information was noted in the recommendation tables for each dam:

- The “Life Loss Risk” value is the product of the failure likelihood number and the life safety consequence number for the respective PFM. Higher values indicate higher risks, for PFMs that plot in the upper right of the life safety risk matrix.
- The “Economic and Transportations Risk” value is the product of the failure likelihood number and the economic consequence number for the respective PFM. Higher values indicate higher risks, for PFMs that plot in the upper right of the economic risk matrix.
- The “Regulatory Compliance” column indicates whether or not the recommendation would improve state regulatory compliance, typically as noted on KDOW inspection reports.
- The “Cost Range” is an educated estimate of the cost to implement each recommendation. These costs were used for prioritization but are not intended for budgeting.
- The “Planning Horizon” indicates a possible timeline for implementing each recommendation: Short Term (0-2 years), Intermediate (2-6 years), or Long Term (6+ years).

5.3 Recommendation Tables

The recommendation tables provided for each dam are as seen below.

Table 8. Recommendations – Morton's Gap Reservoir Dam							
Recommendation	**Type**	**Life Loss Risk**	**Economic & Transportation Risk**	**Regulatory Compliance**	**Cost Range**	**Planning Horizon**	**Priority**
Repair erosion and place better scour protection in the spillway discharge channel.	O&M	10	10	Yes	10K-100K	Short Term	1
Improve security and install barriers on the walkway to the riser. Install multiple warning signs on riser structure (DANGER - KEEP OFF).	O&M	0	0	No	<10K	Short Term	2
Remove vegetation, cut trees, and grub out stumps on the face of the dam and within 25-feet of the dam abutments.	O&M	0	0	Yes	10K-100K	Short Term	3
Fill any animal burrows that are deeper than about 3-feet.	O&M	0	0	Yes	<10K	Short Term	4
Investigate the alignment, condition, and operability of the 8-inch water line, riser structure, and gate.	Investigation	2	2	No	<10K	Short Term	5
Dewater and abandon the 8-inch water line if it is not being used.	O&M	2	2	No	10K-100K	Intermediate	6

Table 9. Recommendations – Priester Lake Dam

Recommendation	Type	Life Loss Risk	Economic & Transportation Risk	Regulatory Compliance	Cost Range	Planning Horizon	Priority
Remove vegetation, cut trees, and grub out stumps on the face of the dam and within 25-feet of the dam abutments.	O&M	0	0	Yes	10K-100K	Short Term	1
Line the CMP pipes that cross the dam crest. Improve the inlet to mitigate potential clogging. Improve scour protection along the spillway discharge channel.	O&M	0	4	No	10K-100K	Intermediate	2
Perform geotechnical investigation (borings and piezometers) and seismic and liquefaction analyses.	Investigation	0	4	No	10K-100K	Intermediate	3

Table 10. Recommendations – Indian Lake Dam

Recommendation	Type	Life Loss Risk	Economic & Transportation Risk	Regulatory Compliance	Cost Range	Planning Horizon	Priority
Confirm ownership of the dam. Consider transfer of dam and roadway to county or other entity.	Investigation	-	-	No	<10K	Short Term	1
Remove all accessories associated with the orifice plate on the principal spillway entrance.	O&M	0	3	No	<10K	Short Term	2
Remove vegetation, cut trees, and grub out stumps on the face of the dam and within 25-feet of the dam abutments.	O&M	0	0	Yes	10K-100K	Short Term	3
Inspect and evaluate the dam and left abutment for potential seepage exits.	Investigation	0	3	No	10K-100K	Short Term	4
Inspect and evaluate the three pipes (principal spillway, auxiliary spillway, and stormwater) that cross the dam crest.	Investigation	0	4	No	<10K	Short Term	5
If the inspection shows excessive deterioration, then line the CMP pipes that cross the dam crest. Improve scour protection at the spillway and drainpipe outlets.	O&M	0	4	Yes	10K-100K	Intermediate	6

Table 11. Recommendations – Hardinsburg FFA Camp Lake Dam							
Recommendation	**Type**	**Life Loss Risk**	**Economic & Transportation Risk**	**Regulatory Compliance**	**Cost Range**	**Planning Horizon**	**Priority**
Remove vegetation, cut trees, and grub out stumps on the face of the dam and within 25-feet of the dam abutments.	O&M	3	3	Yes	10K-100K	Short Term	1
Re-evaluate hydraulic deficiencies indicated by current H&H study. Consider the lower reservoir in the H&H study.	Investigation	4	4	Yes	10K-100K	Short Term	2
Install multiple warning signs on spillway structure (DANGER - KEEP BACK).	O&M	0	0	No	<10K	Short Term	3
Clear debris out of the spillway and inlet.	O&M	4	4	Yes	<10K	Short Term	4
Modify the trash rack to mitigate potential clogging.	O&M	4	4	No	10K-100K	Intermediate	5
Inspect the spillway riser and conduit. Evaluate operation of the low-level drawdown and perform maintenance.	O&M	2	2	Yes	10K-100K	Intermediate	6
Investigate slope failures on the downstream face, perform geotechnical stability analyses.	Investigation	3	3	Yes	100K-1M	Intermediate	7
Locate and evaluate water lines or other buried utilities that may be on or near the dam.	Investigation	2	2	No	10K-100K	Intermediate	8

Table 12. Recommendations - Wood Creek Lake Dam

Recommendation	Type	Life Loss Risk	Economic & Transportation Risk	Regulatory Compliance	Cost Range	Planning Horizon	Priority
Remove trees in the area surrounding the morning glory spillway entrance.	O&M	6	12	Yes	<10K	Short Term	1
Mark or survey the seepage locations on the downstream face for future monitoring.	O&M	3	12	Yes	<10K	Short Term	2
Install multiple warning signs on spillway structure (DANGER - KEEP BACK).	O&M	0	0	No	<10K	Short Term	3
Survey or otherwise establish the profile elevation of the dam crest and median barrier wall. If there is a hydraulic deficiency, evaluate the median crash barrier for performance as a temporary floodwall.	Investigation	6	12	Yes	10K-100K	Intermediate	4
Modify the weir and/or remove channel obstructions at the dam toe to facilitate accurate measurements of surface flow rates.	O&M	3	12	Yes	10K-100K	Intermediate	5
Perform geotechnical investigation (borings and piezometers) and seepage analyses.	Investigation	3	12	Yes	100K-1M	Intermediate	6
Improve reliability and operability of existing low level drawdown valve and system.	Capital	0	6	Yes	1M-10M	Long Term	7

Table 13. Recommendations – Renfro Dam

Recommendation	Type	Life Loss Risk	Economic & Transportation Risk	Regulatory Compliance	Cost Range	Planning Horizon	Priority
Repair the floating boom on the upstream side of the morning glory spillway entrance.	O&M	9	12	Yes	<10K	Short Term	1
Remove trees in the area surrounding the morning glory spillway entrance.	O&M	9	12	Yes	<10K	Short Term	2
Install multiple warning signs on riser and spillway structures (DANGER - KEEP BACK).	O&M	0	0	No	<10K	Short Term	3
Evaluate the median crash barrier for performance as a temporary floodwall. [To be performed in conjunction with study of the under pass.]	Investigation	9	12	Yes	10K-100K	Short Term	4
Study the performance of the Lake Linville Road underpass as a auxiliary spillway (hydraulics, flow path, erodibility). [To be performed in conjunction with study of the barrier wall.]	Investigation	3	3	Yes	10K-100K	Short Term	5
Implement repairs identified in the 2024 low level inspection, replace the slide gate if necessary.	O&M	0	6	Yes	100K-1M	Intermediate	6
Modify Lake Linville Road underpass to perform as an auxiliary spillway and/or modify the median crash barrier.	Capital	3	3	Yes	1M-10M	Long Term	7

Table 14. Recommendations – Corinth Lake Dam							
Recommendation	**Type**	**Life Loss Risk**	**Economic & Transportation Risk**	**Regulatory Compliance**	**Cost Range**	**Planning Horizon**	**Priority**
Inspect the submerged, low level drawdown gate at the principal spillway. Locate and inspect the inlet to the low-level outlet.	O&M	1	3	Yes	<10K	Short Term	1
Survey or otherwise establish the profile elevation of the dam crest and median barrier wall. If there is a hydraulic deficiency, evaluate the median crash barrier for performance as a temporary floodwall.	Investigation	2	3	Yes	10K-100K	Short Term	2
Install a gate or valve on the upstream side of the low-level outlet (16" Cast Iron pipe).	Capital	3	9	Yes	100K-1M	Long Term	3
Perform geotechnical investigation (borings and instruments) and seepage and stability analyses.	Investigation	3	9	Yes	100K-1M	Intermediate	4
Buttress the downstream face or add a filter berm to address seepage and stability.	Capital	1	3	Yes	1M-10M	Long Term	5

Table 15. Recommendations – KYTC Bioretention Dam

Recommendation	Type	Life Loss Risk	Economic & Transportation Risk	Regulatory Compliance	Cost Range	Planning Horizon	Priority
Remove vegetation, cut trees, and grub out stumps on the face of the dam and within 25-feet of the dam abutments. Remove vegetation within 25-feet of the diversion box spillway inlet and outlet, and small trees on the dam crest.	O&M	8	4	Yes	<10K	Short Term	1
Install multiple warning signs on outlet structure (DANGER - KEEP OFF).	O&M	0	0	No	<10K	Short Term	2
Perform geotechnical analyses for the flood loading conditions.	Investigation	3	3	Yes	10K-100K	Intermediate	3
Verify the spillway capacity, including the discharge channel.	Investigation	3	1	Yes	10K-100K	Intermediate	4
If the hydraulic analysis indicates a deficiency, then construct a small auxiliary spillway near the right abutment or a parapet wall.	Capital	3	1	Yes	100K-1M	Long Term	5
Install a zone of filter sand around the downstream end of the spillway culvert to address potential seepage and erosion.	Capital	3	1	No	100K-1M	Long Term	6

Table 16. Recommendations – Mill Creek Lake Dam

Recommendation	Type	Life Loss Risk	Economic & Transportation Risk	Regulatory Compliance	Cost Range	Planning Horizon	Priority
Mark or survey the seepage locations on the downstream face for future monitoring.	O&M	6	6	Yes	<10K	Short Term	1
Investigate all of the water lines that pass under the dam, repair if leaking, abandon if not being used.	Investigation	4	4	Yes	10K-100K	Short Term	2
Operate and inspect the low-level drawdown and raw water intake valves.	O&M	0	0	Yes	10K-100K	Intermediate	3
Perform geotechnical investigation (borings and piezometers) and seepage and stability analyses.	Investigation	8	8	Yes	100K-1M	Intermediate	4
Construct a filter berm or sub-surface drainage features on the downstream slope to address seepage.	Capital	8	8	Yes	1M-10M	Long Term	5

5.4 Dam Safety Program

Along with the recommendations for individual dams, KYTC should consider establishing basic elements of a dam safety program. The recommendations in **Table 8** will help to establish internal accountability for the maintenance and improvements of the dams owned by KYTC.

Table 17. Dam Safety Program Recommendations

Recommendation	Type	Planning Horizon
Identify a Dam Safety Officer with responsibilities for dam safety and coordination with KDOW.	O&M	Short Term
Establish a central file for information on each dam.	O&M	Short Term
Establish or finalize or update an Emergency Action Plan for all high hazard and significant hazard dams.	O&M	Short Term
Establish inspection checklist and frequency.	O&M	Short Term
Initiate a dam safety training for appropriate personnel.	O&M	Short Term
Monitor identified seepage, slumps, and slide areas.	O&M	Short Term
Monitor instruments and assess data.	O&M	Short Term
Coordinate identified needs of potential capital expenditures for KYTC owned dams.	O&M	Short Term

6.0 References

Dam Safety Division of Water. (2022). Retrieved from https://eec.ky.gov/Environmental-Protection/Water/FloodDrought/Pages/DamSafety.aspx

Department for Natural Resources and Environmental Protection. (n.d.). *Division of Water Engineering Memorandum No. 5.*

Federal Energy Regulatory Commission (FERC). (2021a). *Engineering Guidelines for the Evaluation of Hydropower Projects - Chapter 17 Potential Failure Mode Analysis.*

Federal Energy Regulatory Commission (FERC). (2021b). *Engineering Guidelines for the Evaluation of Hydropower Projects - Chapter 18 Level 2 Risk Analysis.*

FERC Potential Failure Modes. (2025, June 26). Retrieved from ferc.gov: https://www.ferc.gov/dam-safety-and-inspections/potential-failure-modes-pfms

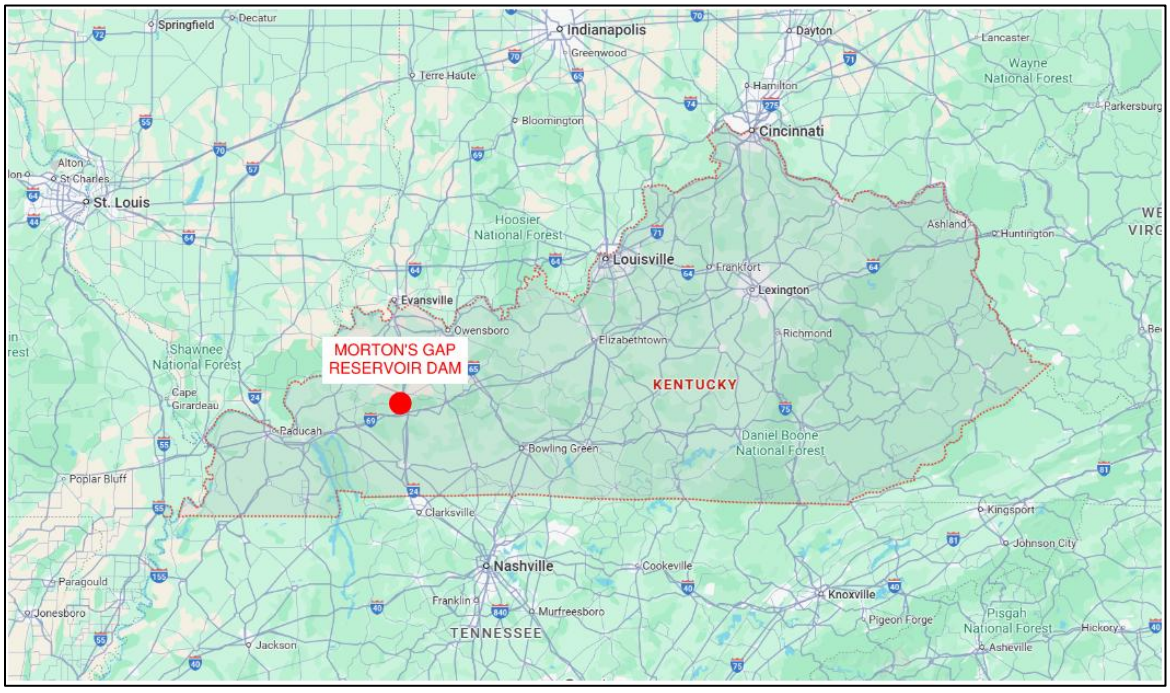
Kentucky General Assembly. (2025, 11 13). Retrieved from https://apps.legislature.ky.gov/law/statutes/chapter.aspx?id=37731

National Inventory of Dams. (n.d.). Retrieved from https://nid.sec.usace.army.mil/nid/#/

Appendix A
Morton's Gap Reservoir Dam

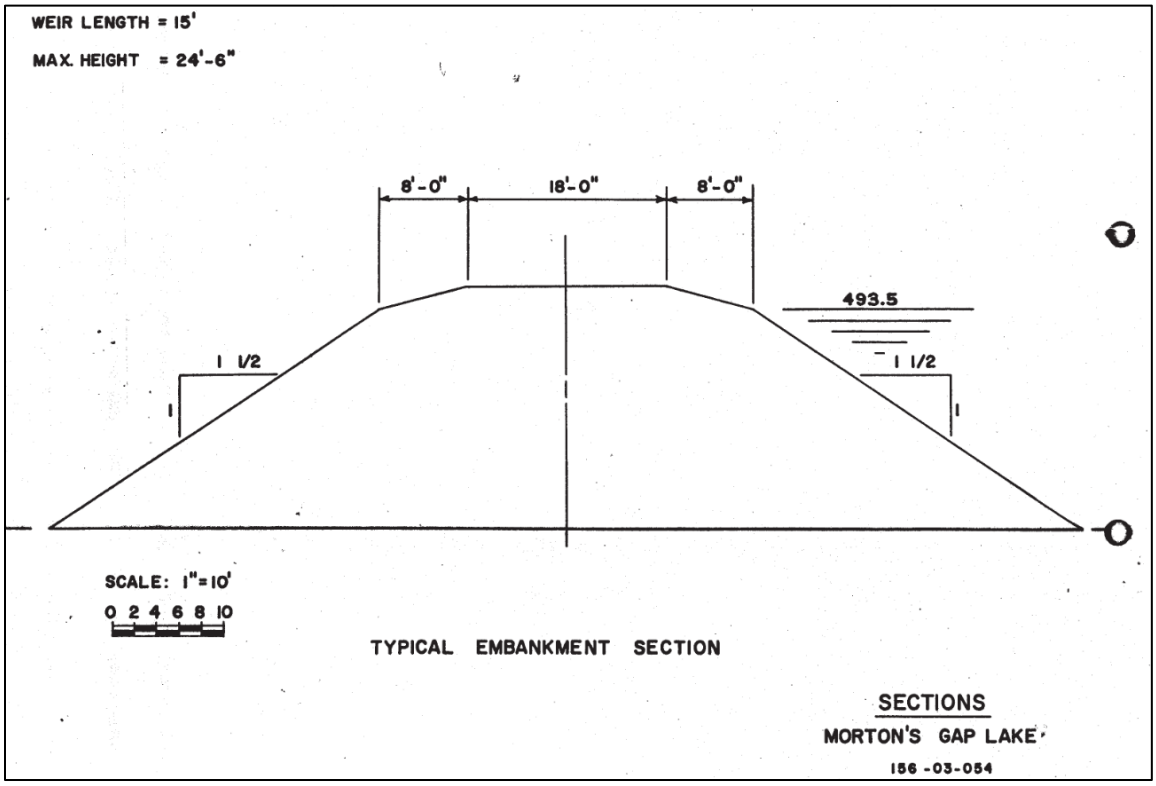
A.1 Dam and Appurtenant Features

Morton's Gap Reservoir Dam is located in western Kentucky in Hopkins County (location map below). The National Inventory of Dams lists the purpose of the dam as recreation. This dam was constructed in 1945 and is classified as high hazard. The dam crest elevation is 494 ft, and KY-41 runs along the entire crest. The normal pool elevation is 943.5 ft. The height of the dam is 25 ft, and the crest width is 18 ft.

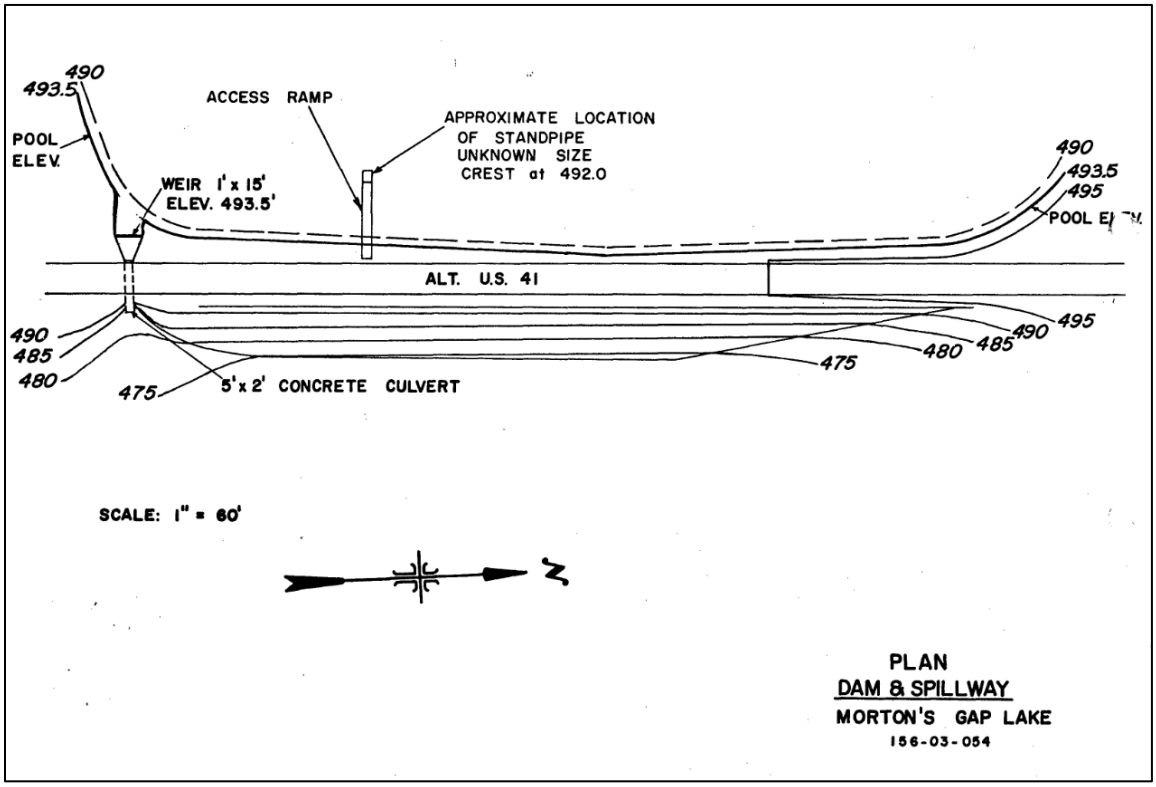


Morton's Gap Reservoir Dam - Vicinity Map

The principal spillway of this dam is a concrete culvert located at the right abutment. The intake has a weir that transitions into a 9 ft x 5 ft concrete box culvert that runs under the dam and discharges into Flat Creek downstream. There is a riser tower located in the lake with a concrete walkway extending from the upstream slope. There is a low-level drawdown valve in the riser structure along with valves that used to serve as a water supply intake for the city of Morton's Gap. Based on available information, the intake structures are no longer being used. Instead, Mortons Gap Water Department purchases their water supply from South Hopkins Water District. The figures below show the typical cross section and plan view of the dam components.



Morton's Gap Reservoir Dam - Typical Cross Section



Morton's Gap Reservoir Dam - Plan View

A.2 Data Catalog

FILE #	DATA TYPE	TITLE	FILE DESCRIPTION
06.02.001	H & H	H & H Report	1996 Hydrology Review
06.02.002	H & H	Emergency Action Plan	***
06.02.003	H & H	Evacuation Map	***
06.02.004	H & H	Inundation Map	***
06.03.001	Inspections	Phase I Inspection	1980 Booker
06.03.002	Inspections	Inspection Report	2010 Division of Water
06.03.003	Inspections	Inspection Report	2012 *** KDOW
06.03.004	Inspections	Inspection Report	2022 Division of Water
06.03.005	Inspections	Inspection Report	2023 Division of Water
06.04.001	Drawings	Cross Section	
06.04.002	Drawings	Plan View	
06.06.001	Transportation Docs	Traffic Counts	
06.06.002	Transportation Docs	Road Plans	
06.06.003	Transportation Docs	Road Plans	
06.03.101	Inspections	Phase 1 Inspection Report	1981 Booker & '72-80 Insp.
06.03.102	Inspections	Inspection Report	1985 Division of Water
06.03.103	Inspections	Inspection Report	1995-1996 Division of Water
06.03.104	Inspections	Inspection Report	1996 Division of Water
06.03.105	Inspections	Inspection Report	1994 Division of Water
06.03.106	Inspections	Inspection Report	1992 Division of Water
06.03.107	Inspections	Inspection Report	1990-1992 Division of Water
06.03.108	Inspections	Inspection Report	1989 Division of Water
06.03.109	Inspections	Inspection Report	1992-1999 Division of Water
06.03.110	Inspections	Inspection Report	1981-1989 Division of Water
06.03.111	Inspections	Inspection Report	1998 Division of Water
06.03.112	Inspections	Inspection Report	2000 Division of Water
06.03.113	Inspections	Inspection Report	2002 Division of Water
06.03.114	Inspections	Inspection Report	2004 Division of Water
06.03.115	Inspections	Inspection Report	2014 Division of Water

06.03.116	Inspections	Inspection Report	2012 Division of Water
06.03.117	Inspections	Inspection Report	2022 Division of Water
06.03.118	Inspections	Inspection Report	2023 Division of Water
06.02.201	H & H	H & H Report	2019
06.04.201	Drawings	Plan and Section Exhibit	

A.3 Hydrologic and Hydraulic Analyses

Elevation-Frequency Analysis

Previous hydrologic and hydraulic analyses were performed by the Kentucky Division of Water using the Soil Conservation Service (SCS) DAMS2 model in 1996. The input data from the DAMS2 model was used to generate a new U. S. Army Corps of Engineers (USACE) Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) model (version 4.12) to estimate water surface elevations associated with various precipitation depths. The following information was taken from the DAMS2 model:

- Curve Number
- Drainage Area
- Time of Concentration
- Stage-Storage-Discharge Information

NOAA Atlas 14 was used to generate precipitation depths for frequencies ranging from the 10-year (10-percent-annual-chance) up to the 500-year (0.2-percent-annual-chance) storm. For the Probable Maximum Precipitation (PMP), Kentucky Engineering Memorandum No. 2 was used to determine the PMP rainfall depth. A 24-hour SCS Type II rainfall distribution was applied to the precipitation depths from NOAA Atlas 14, and a 6-hour SCS Type II rainfall distribution was applied to the PMP rainfall depth within the HEC-HMS model. The probability associated with the PMP was estimated using two methods:

- The FEMA Spillway Capacity and Extreme Flood Discharge Estimator (which uses flow-frequency data input by the user along with extrapolation using a power function to estimate the return period of the PMP)
- The Australian Rainfall Runoff method (which uses drainage area to estimate a return period of the PMP).

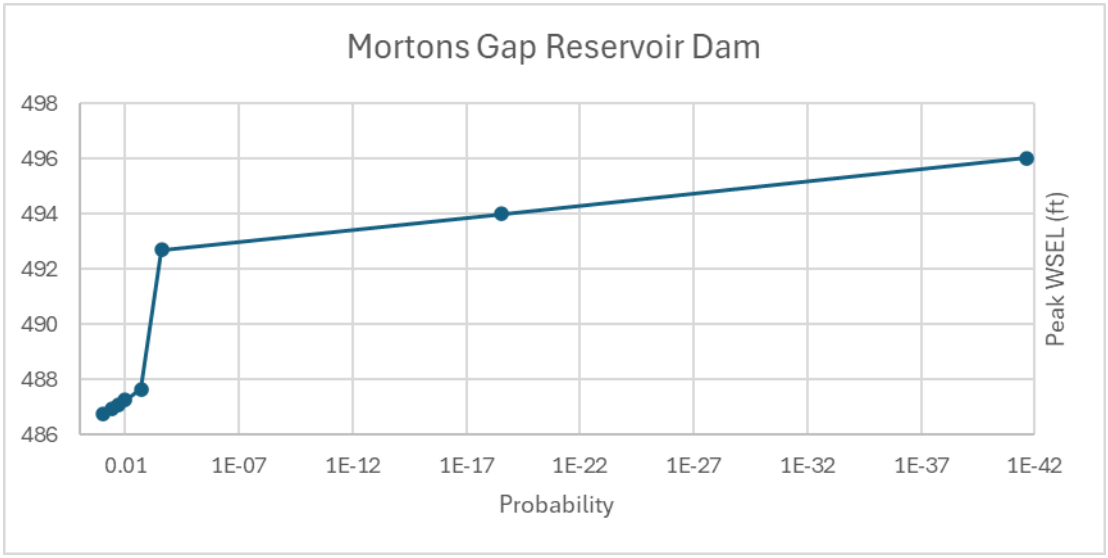
The results of the two methods were averaged to estimate the PMP probability.

Using trial and error, additional storms were run with higher rainfall depths until a rainfall depth that produced a water surface elevation that would just overtop the dam and a water surface elevation that overtopped the dam by two feet was obtained. A log-log curve was fit to the flow frequency data (including the PMP) and extrapolated to approximate a return period associated with these higher rainfall depths.

The resulting water surface elevations from the model runs are tabulated and plotted below.

Morton's Gap Reservoir Dam Model Results

Morton's Gap (Dam Crest = 494.0 feet)				
Precipitation (inches)	**Peak Inflow (cfs)**	**Peak WSEL (feet)**	**Return Interval**	**Notes**
3.4	130	486.8	0.1	10yr
4.1	176	486.9	0.04	25yr
4.6	215	487.1	0.02	50yr
5.2	258	487.3	0.01	100yr
6.7	369	487.7	0.002	500yr
28.6	2005	492.7	0.0002	PMP
33.9	2391	494.0	2.8E-19	**Overtopping**
76.0	5444	496.0	2.4E-42	**~2' overtopping**



Morton's Gap Reservoir Dam Elevation-Frequency Curve

Consequences Analysis

Previous inundation mapping (Stantec, 2013) that modeled a sunny-day breach of the dam was reviewed along with inundation mapping publicly available on Kentucky's Dam Inundation Viewer (watermaps.ky.gov). The inundation extents were reviewed along with aerial imagery to evaluate consequences. Structures identified in the inundation area included approximately 85 residences, 5 non-residential structures (industrial buildings) and six road crossings. A population at risk of approximately 250 was estimated based on the following assumptions:

- 2.5 people per home inundated
- 2 people per road crossing
- 5 people per industrial building

The consequences are summarized in the table below.

Consequences Associated with a Failure of Morton's Gap Reservoir Dam

MORTON'S GAP	
NID_ID	KY00156
Number of Residences	85 (approximate)
Number of Non-Residential Structures	5
Description of Non-Residential Structures	Industrial buildings
Number of Critical Infrastructure Structures	0
Description of Critical Infrastructure Structures	N/A
Number of Road Crossings	6
List of Roads Affected	US-41 (South Hopkinsville Road), I-69, KY-813 (White City Road), Morton Street, Frank Stafford Blvd., Sycamore Street
Estimated PAR	250
PAR Assumptions	Assumes 2.5 people per home, 5 people per industrial building and 2 people per road crossing.
Inundation Mapping Source	KY Dam Inundation Viewer + Aerial Imagery
Life Loss Notes	Travel time to majority of the population estimated to be ~10 minutes (based on prior Stantec simplified breach analysis)

A.4 Potential Failure Modes

PFM NUMBER	PFM GROUP	PFM DESCRIPTION	RISK ASSESSMENT
MG-1	SLOPE STABILITY	Normal Pool Condition - Under normal pool conditions, a slope failure triggers a mass movement of soil on the downstream face of the dam. Successive slope failures retrogress back to the crest, then to the upstream side of the crest. Material is pushed into failure from the crest, but the intervention fails. The crest drops below the pool elevation (493.5'), which overtops the dam breach. The resulting flows scour downward through the dam embankment, releasing the reservoir.	NEGLIGIBLE
MG-2	INTERNAL EROSION	Under normal pool conditions, seepage develops along a defect through the dam embankment. The downstream exit is not filtered. The flow scours the soil to either side of the defect. The embankment over the seepage path does not collapse. The flow path expands and the flow accelerates. The seepage is not detected and there is no intervention. The flow scours a larger void in the embankment, leading to a collapse of the dam crest. The dam is breached and there is an uncontrolled release of the reservoir.	CREDIBLE
MG-3	SEISMIC	A strong earthquake occurs near the dam site. The dynamic loads on the dam embankment cause slope displacements and possible slope failures. The deformations are larger on the downstream face, which is steeper than the upstream slope. Successive slope movements during and after the earthquake progress across the width of the dam crest. There is no time for intervention. The crest drops below normal pool and the reservoir overtops. The resulting flows scour downward through the dam embankment, releasing the reservoir.	CREDIBLE

MG-4	OVERTOPPING	A heavy precipitation event occurs in the watershed, causing the reservoir level to rise. Water is released through the spillway, but the spillway capacity is insufficient to pass the stormwater inflow. The water levels continue to rise and overtop the dam crest. Efforts to raise the dam crest are unsuccessful. The overtopping flows begin to erode the downstream slope of the dam embankment. The flow causes head cutting, which progresses backward across the width of the dam crest. The dam is breached when the crest erosion reaches the upstream pool. The resulting flows scour downward through the dam embankment, releasing the reservoir.	NEGLIGIBLE
MG-5	EROSION ASSSOCIATED WITH CONDUITS	The slide gates on the riser structure are open or leaking, and the wet well is full. The 8" metal pipe is pressurized by the headwater. Due to a leak in the pipe, the porewater pressures are elevated at the downstream toe of the dam embankment. This condition triggers a slope failure on the downstream face. The mass movement may break the 8-inch pipe, resulting in an uncontrolled discharge that further erodes the dam toe. The slope failure is not observed, allowing it to progress without intervention. Successive slope failures retrogress back to the crest, then to the upstream side of the crest. The crest drops below the pool elevation, which overtops the dam breach. The resulting flows scour downward through the dam embankment, releasing the reservoir.	CREDIBLE
MG-6	SPILLWAY STRUCTURES	Reservoir levels rise during a flood event and the spillway is activated. The downstream channel, near the right groin, is scoured by flows from the spillway discharge. Erosion progresses up to the end of the spillway chute. The erosion is not detected and there is insufficient time to intervene. Head cutting of the foundation soils undermines the slab and the pre-cast concrete culvert (spillway structure) is displaced. The dam is breached and there is an uncontrolled release of the reservoir.	CREDIBLE
MG-7	OPERATIONAL	Considered this under the "Erosion Associated with Conduits" Miss operations would not lead to economic or life safety consequences.	NEGLIGIBLE

A.5 Evaluation of PFMs

Potential Failure Mode Analysis Table:

PFM No.:	MG-1	**Dam:**	Morton's Gap (MG)
PFM Group:	Slope Stability		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*

Normal Pool Condition

Under normal pool conditions, a slope failure triggers a mass movement of soil on the downstream face of the dam. Successive slope failures retrogress back to the crest, then to the upstream side of the crest. Material is pushed into the failure from the crest, but the intervention fails. The crest drops below the pool elevation (493.5'), which overtops the dam breach. The resulting scour flows downward through the dam embankment, releasing the reservoir.

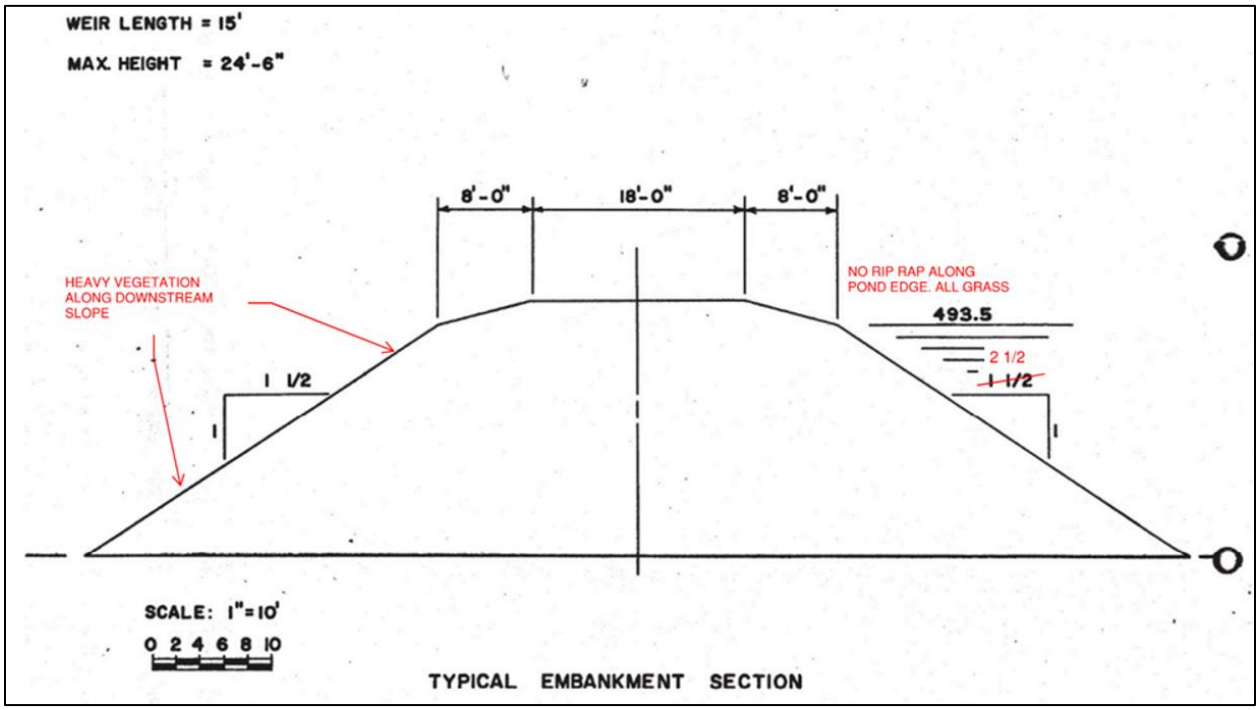
More Likely (Adverse) Factors	Less Likely (Favorable) Factors
• **The downstream slope is 1.5:1** • Possible tension cracks observed in the inspections • Irregularities in surface on downstream slope • **The geotechnical properties are unknown** • **No stability analysis available** • May not be able to draw down the lake	• **The crest is 34' wide and the dam is 24.5' tall** • **It would take a long time to retrogress across the crest** • May be able to draw down the lake • **KYTC could readily repair a slide** • The guardrail appeared to be in a straight alignment • The pavement is in good condition - no longitudinal cracking.

Risk Assessment	Category	Notes
Negligible? Credible?	Negligible	It would take a long time to breach and it is almost certain we would be able to intervene successfully.
Failure Likelihood		
Life Safety Consequences		
Economic Consequences		

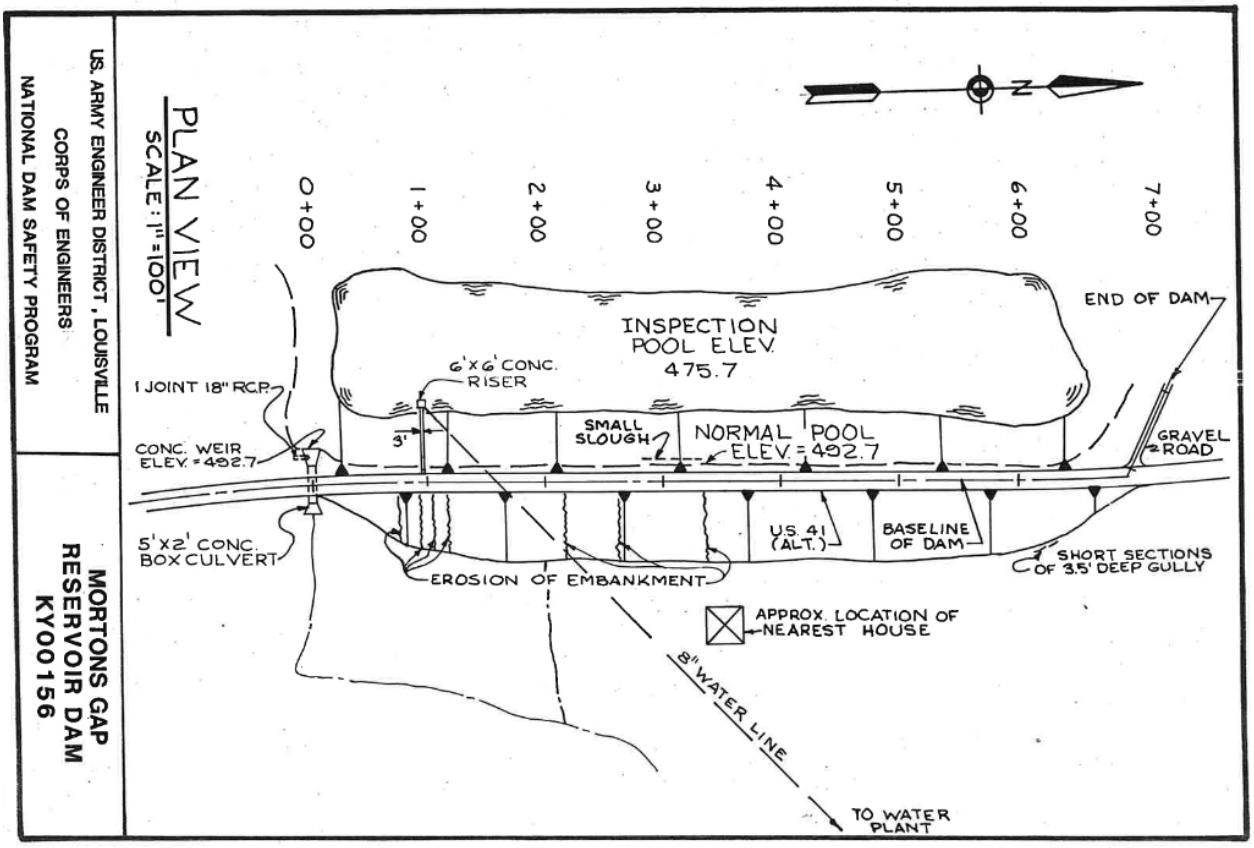
Risk Reduction Measures	
Studies and Investigations	Geotechnical information and stability analysis needed.

Maintenance and Monitoring	Mowing prior to inspections
Design and Modifications	Downstream berm

Supporting Figures:



Cross Section (Booker, 1981)



Plan View (Booker, 1981)

Drinking Water Branch

Water System Details

Water System No. :	KY0540269	**Federal Type :**	C
Water System Name :	MORTONS GAP WATER DEPARTMENT	**State Type :**	C
Principal County Served :	HOPKINS	**Primary Source :**	SWP
Status :	A	**Activity Date :**	03-01-1973

Points of Contact

Name	Job Title	Type	Phone	Address	Email
MORTONS GAP WATER DEPARTMENT	null	OW	270-258-5362	102 S MAIN ST MORTONS GAP, KY 42440	
VANDIVER, JAMES		EC			
ADAMSON, CHASITY		AC	270-258-5362	131 CROSS STREET MORTONS GAP, KY 42440	mgww@mortonsgapky.com

Annual Operating Periods & Population Served

Start Month	Start Day	End Month	End Day	Population Type	Population Served
1	1	12	31	R	1485

Service Connections

Type	Count	Meter Type	Meter Size Measure
CM	7	MU	0
IN	0	MU	0
RS	493	MU	0

Sources of Water

Name	Type Code	Status
PURCHASE-KY0540406 SOUTH HOPKINS WATER	CC	A

Service Areas

Code	Name
R	RESIDENTIAL AREA

Water Purchases

Seller Water System No.	Water System Name	Seller Facility Type	Seller State Asgn ID No.	Buyer Facility Type	Buyer State Asgn ID No.
KY0540406	SOUTH HOPKINS WATER DISTRICT	DS	0540406DS001	CC	0540269CC001

Morton's Gap Reservoir Water System Details (Drinking Water Branch, n.d.)

The water intake at this site is one of the sources of raw water for the City of Mortons Gap's water treatment plant. The intake structure is a concrete riser which is accessible from a four (4) span concrete access bridge located at station 0+96 on the upstream face of the dam. The intake structure (see Photographs 11 and 12) is approximately 6 feet square with its top at elevation 494.6 m.s.l. The intake structure feeds the water treatment plant at Mortons Gap through an 8-inch metal pipe which stubs into the base of the concrete wetwell. The concrete riser (wetwell) has two 8-inch circular intake gates: the upper one at elevation 482.1 m.s.l. and the lower one at about 474.6 m.s.l. The manual gate controls at the reservoir have been chained and padlocked so that all control is by means of a valve at the water plant. The platform includes a steel cover plate which provides access to the inside of the structure. There are approximately 2-inch wide lines painted on the side of the riser to form a type of gage. The top of the uppermost line is at about elevation 492.8 (approximately normal pool) and is the zero point for the gage.

Phase 1 Report Information (Booker, 1981)

E. Drawdown Capabilities

The drawdown system for this lake is the water supply system which consists of an 8-inch diameter pipe that connects to the bottom of a 6-foot square concrete riser (wet well). The riser has both a low and high intake. It was learned from Mr. James Browning, operator of the water treatment plant, that the lower intake would allow lowering of the lake level to about four feet deep. There are valves controlling the intake on the riser and valves at filter plant to control outflow. Drawdown of the lake would take approximately 15 days to get to a level of 4 feet deep. This drawdown rate would be less than one foot per day. Lesser drawdown rates could be obtained through use of the plant's valves.

Phase 1 Report Information (Booker, 1981)

Watershed

Area: 0.06 mi^2 Curve Number: 75

Length: 1500 ft. Elev. Change: 170 ft.

Time of Concentration: _____ min. 0.08 hr.

Method to compute Time of Concentration: FORMULA

Storms

Duration: 6 hr.

Design storms for this hazard class (Memo. No. 5, Sec. C, Part V, Pages C-2 & C-3)

Emergency Spillway Hydrograph: 11.0 in. Freeboard Hydrograph: 28.6 in.

Analysis results

Model used for analysis: **DAMS2** HEC-1 Other _____

Rain to overtop: 52.0 in. Maximum Spillway Discharge: 846.1 cfs

Principal spillway capacity: 52.0 in. Principal Spillway Discharge: 846.1 cfs

Spillway Material

Principal: 9 X 5 FEET BOX CONCRETE CULVERT

Emergency: SAME AS ABOVE

Drawdown

Material: WATER LINE TO WATER PLANT

Valved on: UPSTREAM **DOWNSTREAM**

ADD COMMENTS ON ADDITIONAL PAGES
ATTACH ANALYSIS PRINTOUT AND DRAINAGE AREA MAP

Rev. 03/17/93
File: 156.HYDREVME

Structure Data (Dam Safety and Floodplain Compliance, 1996)

Potential Failure Mode Analysis Table:

PFM No.:	MG-2	**Dam:**	Morton's Gap (MG)
PFM Group:	Internal Erosion		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*

Under normal pool conditions, seepage develops along a defect through the dam embankment. The downstream exit is not filtered. The flow scours the soil to either side of the defect. The embankment over the seepage path does not collapse. The flow path expands, and the flow accelerates. The seepage is not detected and there is no intervention. The flow scours a larger void in the embankment, leading to a collapse of the dam crest. The dam is breached and there is an uncontrolled release of the reservoir.

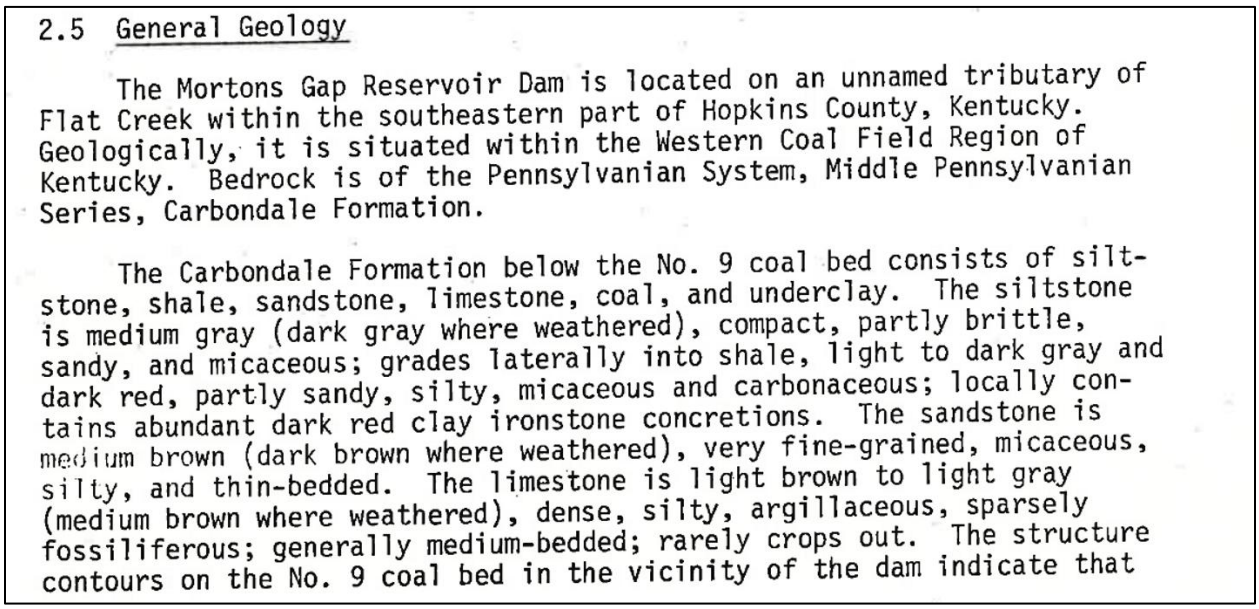
More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
• **One of the most common ways a dam fails** • **There is a wet area at the toe** • Unlikely to have been constructed as a dam embankment • We do not have an internal drain system • We do not have a downstream filter • May not see the seepage develop • We lack geotechnical information	• This was likely a compacted embankment • If detected, there will be time for intervention

Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Credible	This is one of the most common ways a dam fails and we do not have filtered drainage systems in the dam.
Failure Likelihood	FL3	The gradient is relatively low, so less likely factor.
Life Safety Consequences	LS2	PAR - 248 (flood condition) but the volume of water is less than the flood condition
Economic Consequences	EC2	Road closures, railroad, detour costs, damage to 100 homes, repair/rebuild dam

Risk Reduction Measures	
Studies and Investigations	Geotechnical explorations

Maintenance and Monitoring	Install piezometers, periodic inspections of the wet areas.
Design and Modifications	Build a toe drain along downstream toe

Supporting Figures:



2.5 General Geology

The Mortons Gap Reservoir Dam is located on an unnamed tributary of Flat Creek within the southeastern part of Hopkins County, Kentucky. Geologically, it is situated within the Western Coal Field Region of Kentucky. Bedrock is of the Pennsylvanian System, Middle Pennsylvanian Series, Carbondale Formation.

The Carbondale Formation below the No. 9 coal bed consists of siltstone, shale, sandstone, limestone, coal, and underclay. The siltstone is medium gray (dark gray where weathered), compact, partly brittle, sandy, and micaceous; grades laterally into shale, light to dark gray and dark red, partly sandy, silty, micaceous and carbonaceous; locally contains abundant dark red clay ironstone concretions. The sandstone is medium brown (dark brown where weathered), very fine-grained, micaceous, silty, and thin-bedded. The limestone is light brown to light gray (medium brown where weathered), dense, silty, argillaceous, sparsely fossiliferous; generally medium-bedded; rarely crops out. The structure contours on the No. 9 coal bed in the vicinity of the dam indicate that

Phase 1 Report Information (Booker, 1981)

Potential Failure Mode Analysis Table:

PFM No.:	MG-3	**Dam:**	Morton's Gap (MG)
PFM Group:	Seismic		

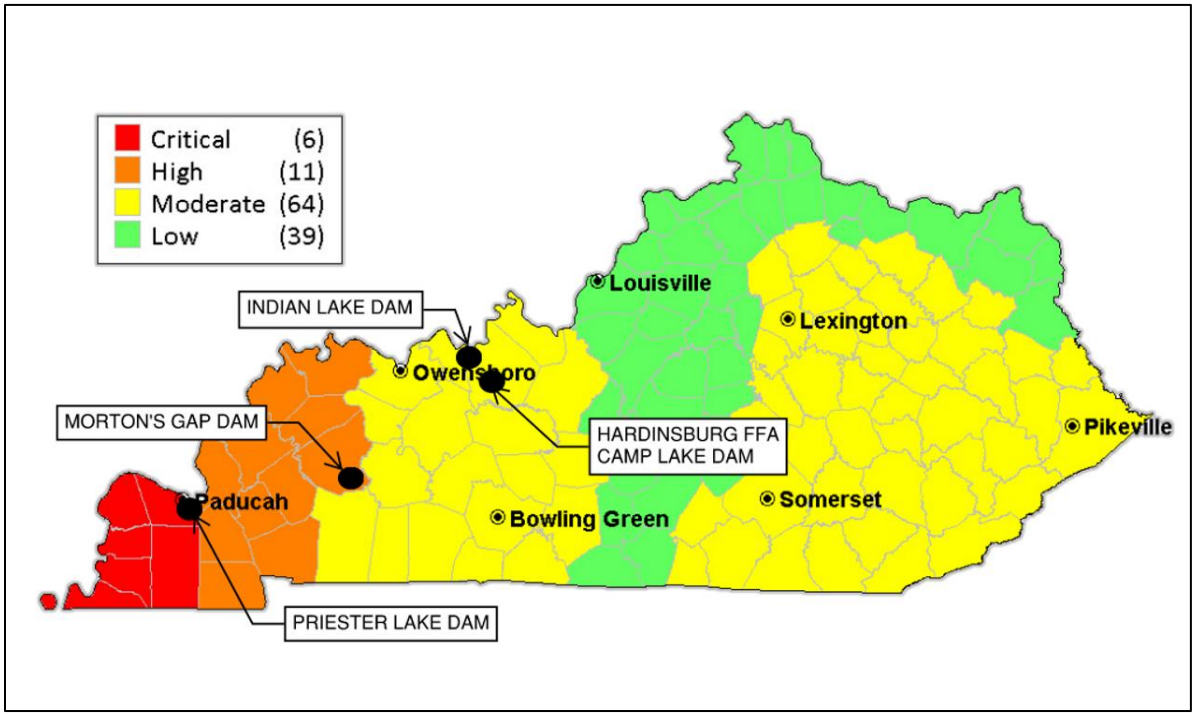
PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*
A strong earthquake occurs near the dam site. The dynamic loads on the dam embankment cause slope displacements and possible slope failures. The deformations are larger on the downstream face, which is steeper than the upstream slope. Successive slope movements during and after the earthquake progress across the width of the dam crest. There is no time for intervention. The crest drops below normal pool and the reservoir overtops. The resulting flows scour downward through the dam embankment, releasing the reservoir.

More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
• There are no stability analyses • Located in Western Kentucky with higher seismic hazard • AEP=2E-3 when g=0.1 so 2/1000 likelihood • Intervention is not possible	• The failure must go all the way across the crest • Must have a lot of deformation (freeboard=?)to get to normal pool

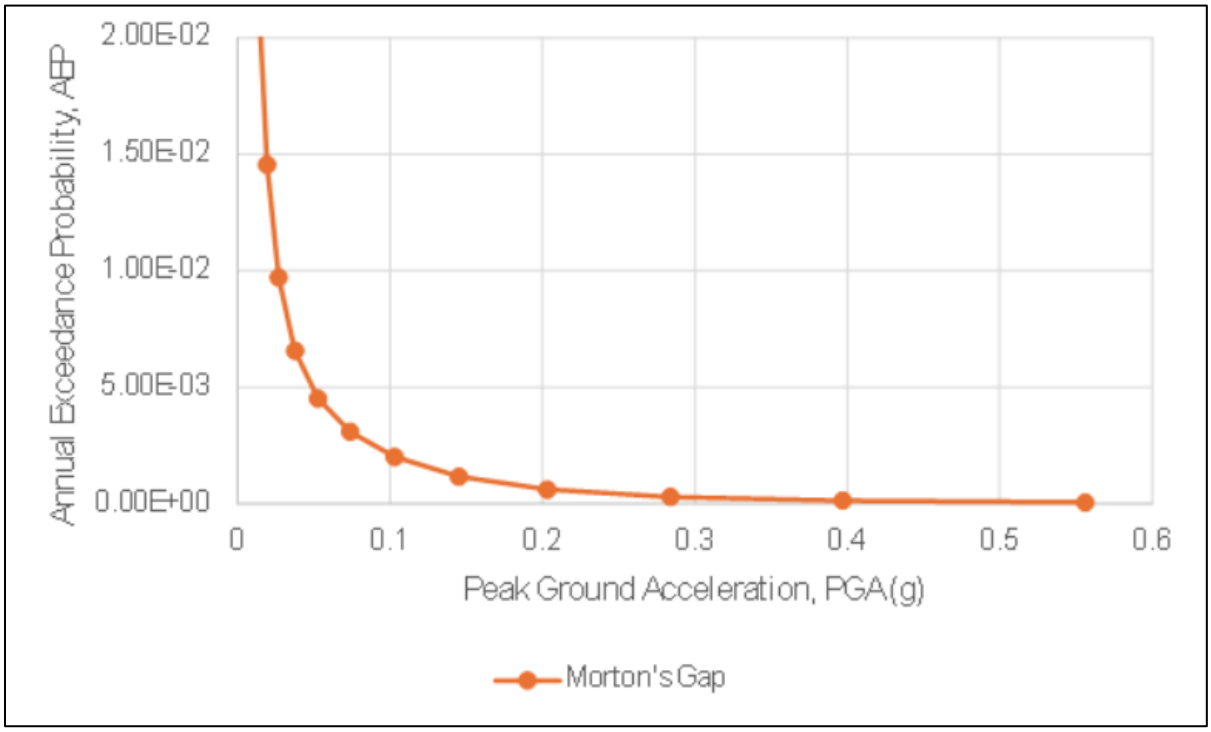
Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Credible	
Failure Likelihood	FL1	Possible due to location but lower likelihood due to size and geometry of structure
Life Safety Consequences	LS2	See MG-2
Economic Consequences	EC2	See MG-2

Risk Reduction Measures	
Studies and Investigations	Geotechnical explorations and analysis
Maintenance and Monitoring	
Design and Modifications	Downstream berm

Supporting Figures:



Seismic Map



Peak Ground Acceleration versus Annual Exceedance Probability Graph

Potential Failure Mode Analysis Table:

PFM No.:	MG-4	**Dam:**	Morton's Gap (MG)
PFM Group:	Overtopping		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*

A heavy precipitation event occurs in the watershed, causing the reservoir level to rise. Water is released through the spillway, but the spillway capacity is insufficient to pass the stormwater inflow. The water levels continue to rise and overtop the dam crest. Efforts to raise the dam crest are unsuccessful. The overtopping flows begin to erode the downstream slope of the dam embankment. The flow causes head cutting, which progresses backward across the width of the dam crest. The dam is breached when the crest erosion reaches the upstream pool. The resulting flows scour downward through the dam embankment, releasing the reservoir.

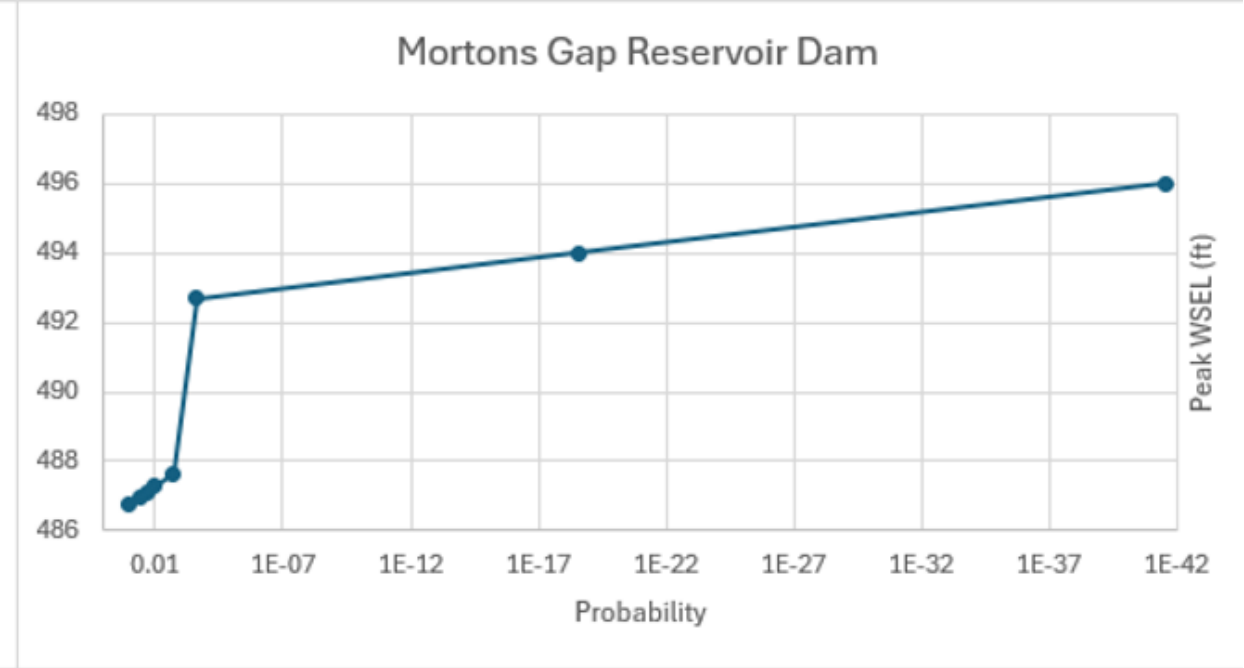
More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
• No auxiliary spillway • Has a potential for clogging, and inspections have noted debris	• The dam has very large spillway • Currently hydraulicly adequate to pass the 6 hour PMP • The probability of an overtopping event is 2.8E-19

Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Negligible	The annual probability of an overtopping event is 2.8E-19
Failure Likelihood		
Life Safety Consequences		
Economic Consequences		

Risk Reduction Measures	
Studies and Investigations	Detailed H&H analysis
Maintenance and Monitoring	Routine maintenance management
Design and Modifications	

Supporting Figures:

Mortons Gap (Dam Crest = 494.0 ft)				
Precip (in)	**Peak Inflow (cfs)**	**Peak WSEL (ft)**	**Return Interval**	**Notes**
3.41	129.67	486.7648	0.1	10yr
4.07	175.93	486.9427	0.04	25yr
4.61	215	487.0954	0.02	50yr
5.19	257.76	487.2651	0.01	100yr
6.67	368.91	487.6579	0.002	500yr
28.6	2004.81	492.6941	0.00024505	PMP
33.88	2390.96	493.9995	2.802E-19	**Overtopping**
76	5443.61	496.021	2.35E-42	**~2' overtopping**



H&H Results

Potential Failure Mode Analysis Table:

PFM No.:	MG-5	**Dam:**	Morton's Gap (MG)
PFM Group:	Erosion Associated with Conduits		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*

The slide gates on the riser structure are open or leaking, and the wet well is full. The 8" metal pipe is pressurized by the headwater. Due to a leak in the pipe, the porewater pressures are elevated at the downstream toe of the dam embankment. This condition triggers a slope failure on the downstream face. The mass movement may break the 8-inch pipe, resulting in an uncontrolled discharge that further erodes the dam toe. The slope failure is not observed, allowing it to progress without intervention. Successive slope failures retrogress back to the crest, then to the upstream side of the crest. The crest drops below the pool elevation, which overtops the dam breach. The resulting flows scour downward through the dam embankment, releasing the reservoir.

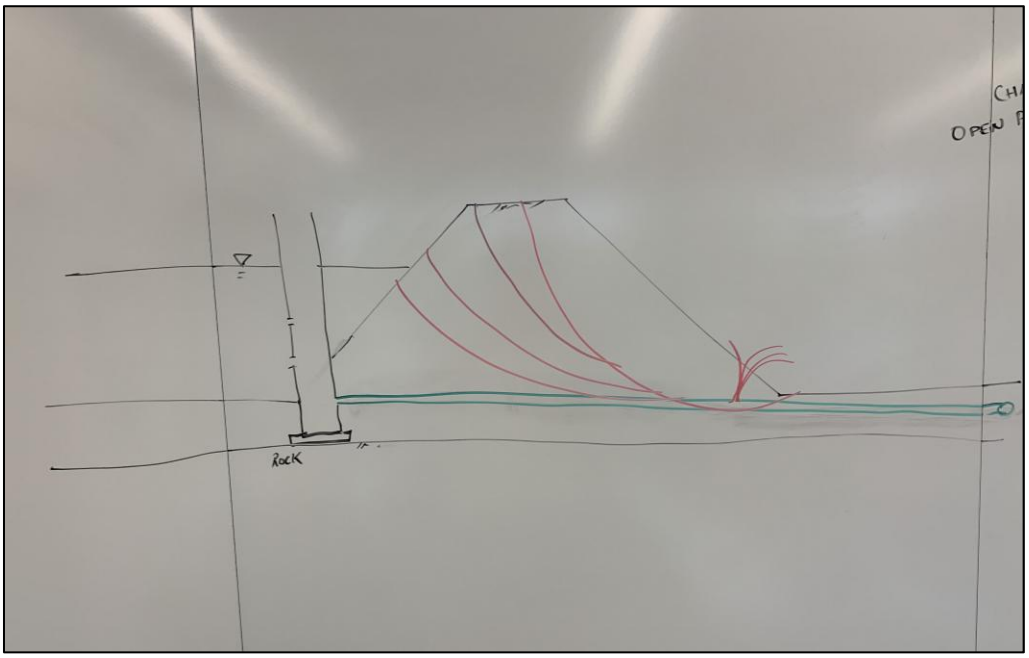
More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
• Metal pipe is subject to corrosion over time. • **Observed wet condition at toe of the dam** • **Wet condition is along the apparent length of pipe** • 1981 report cited the slide gate is chained in the open position • Condition of the wet well is unknown • **Valve operators are publicly accessible**	• Gates today are not chained and appear to have a lug to prohibit opening • **8" pipe limits the potential flow** • **It would take a long time (weeks to months) to progress slope failures across the crest of the dam** • Chances of intervention for slope failure are strong • The water treatment plant is not present

Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Credible	
Failure Likelihood	FL1	The likelihood of initiating this with leakage is moderate but the likelihood of progressing to breach is low.
Life Safety Consequences	LS2	See MG-2
Economic Consequences	EC2	See MG-2

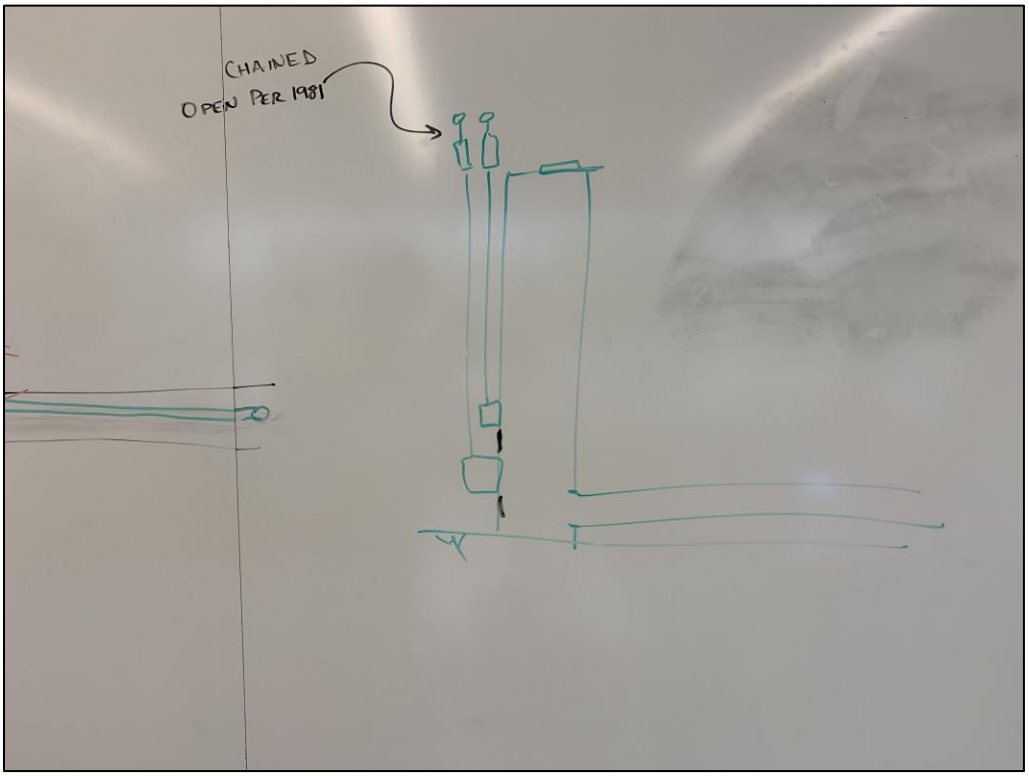
Risk Reduction Measures

Studies and Investigations	Locate the pipe, exit point, and determine the condition inside the riser, video inspection of pipe under the dam, dive inspection of the wet well
Maintenance and Monitoring	Determine condition inside the riser, then operate and test gates on the intake tower
Design and Modifications	Pending results of studies

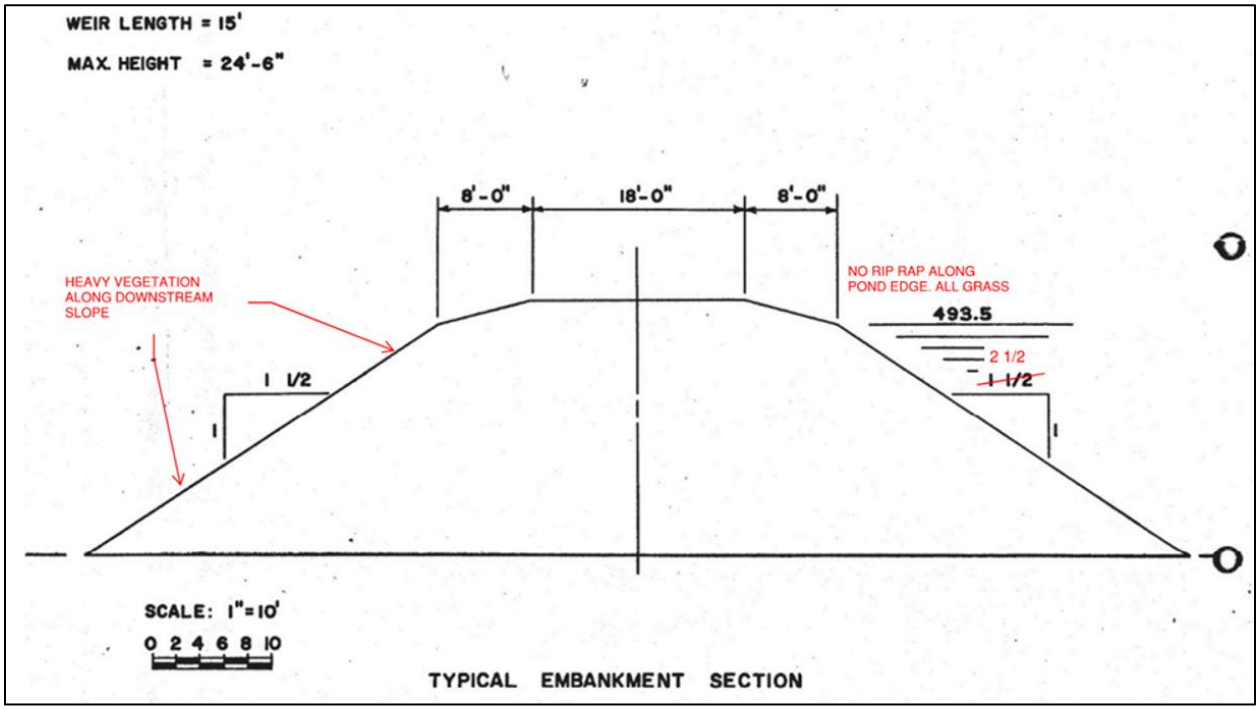
Supporting Figures:



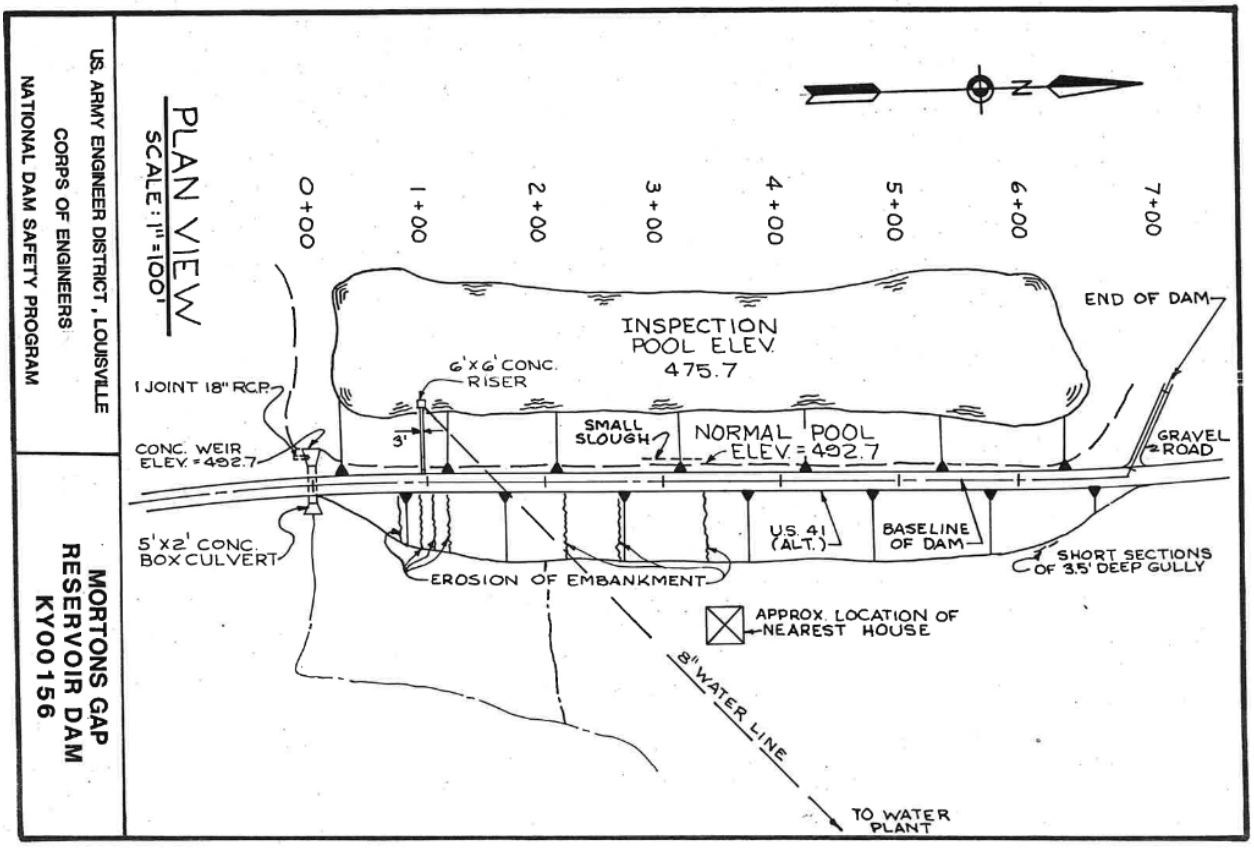
Sketch From Workshop Discussion



Sketch From Workshop Discussion



Cross Section (Booker, 1981)



Plan View (Booker, 1981)

Potential Failure Mode Analysis Table:

PFM No.:	MG-6	**Dam:**	Morton's Gap (MG)
PFM Group:	Spillway Structures		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*

Reservoir levels rise during a flood event and the spillway is activated. The downstream channel, near the right groin, is scoured by flows from the spillway discharge. Erosion progresses up to the end of the spillway chute. The erosion is not detected and there is insufficient time to intervene. Head cutting of the foundation soils undermines the slab and the pre-cast concrete culvert (spillway structure) is displaced. The dam is breached and there is an uncontrolled release of the reservoir.

More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
• Erosion observed • The culverts are founded on erodible soils • Pre cast culverts would fail in segments • Rapid progression impedes ability to intervene	• Requires rare flood event • The flow event is limited in time • The culvert is approximately 40' long

Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Credible	
Failure Likelihood	FL5	Experiencing the flaw at something other than the flood event, so increases the failure likelihood.
Life Safety Consequences	LS2	See MG-2 Consequences may be less since the culvert is on the abutment and might not release the entire reservoir.
Economic Consequences	EC2	See MG-2

Risk Reduction Measures	
Studies and Investigations	hydraulic analysis to design erosion protection of outlet channel (estimated to reduce failure likelihood to FL1)
Maintenance and Monitoring	Observe condition of outlet channel as part of the periodic inspections
Design and Modifications	Riprap discharge channel with class 3 channel lining (we estimated it would reduce the failure likelihood to FL2)

Supporting Figures:



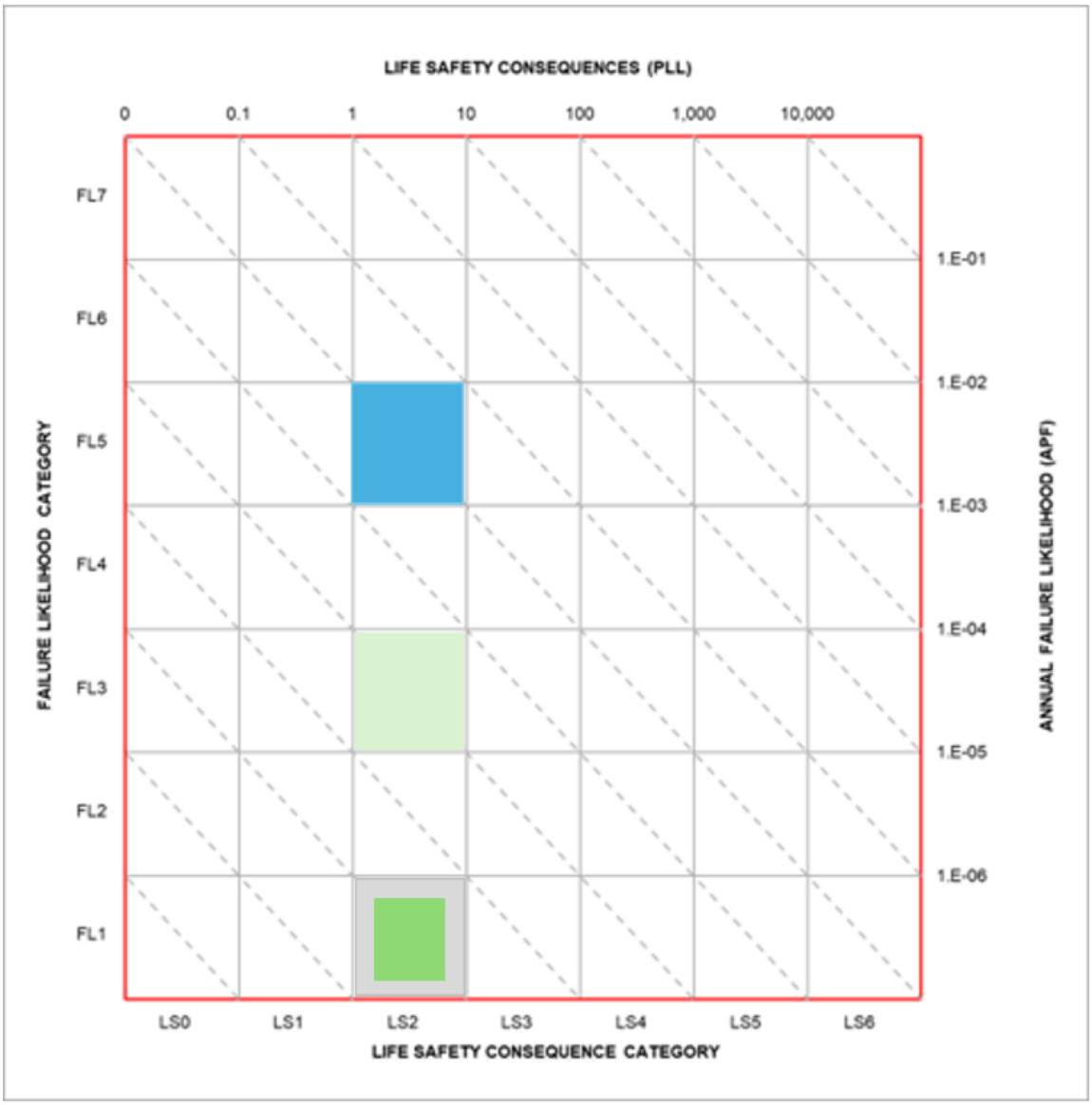
Photo From Site Visit

Potential Failure Mode Analysis Table:

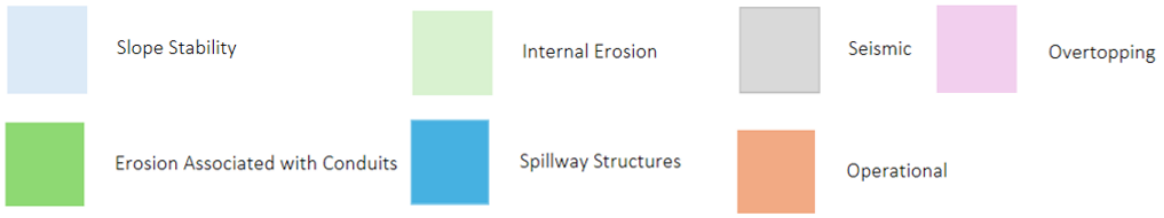
PFM No.:	**MG-7**	**Dam:**	**Morton's Gap (MG)**
PFM Group:	**Operational**		
PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*			
Considered this under the "Erosion Associated with Conduits" Miss operations would not lead to economic or life safety consequences.			
More Likely (Adverse) Factors		**Less Likely (Favorable) Factors**	
•		•	
Risk Assessment	**Category**	**Notes**	
Negligible? Credible?	**Negligible**		
Failure Likelihood			
Life Safety Consequences			
Economic Consequences			
Risk Reduction Measures			
Studies and Investigations			
Maintenance and Monitoring			
Design and Modifications			

A.6 Risk Matrices

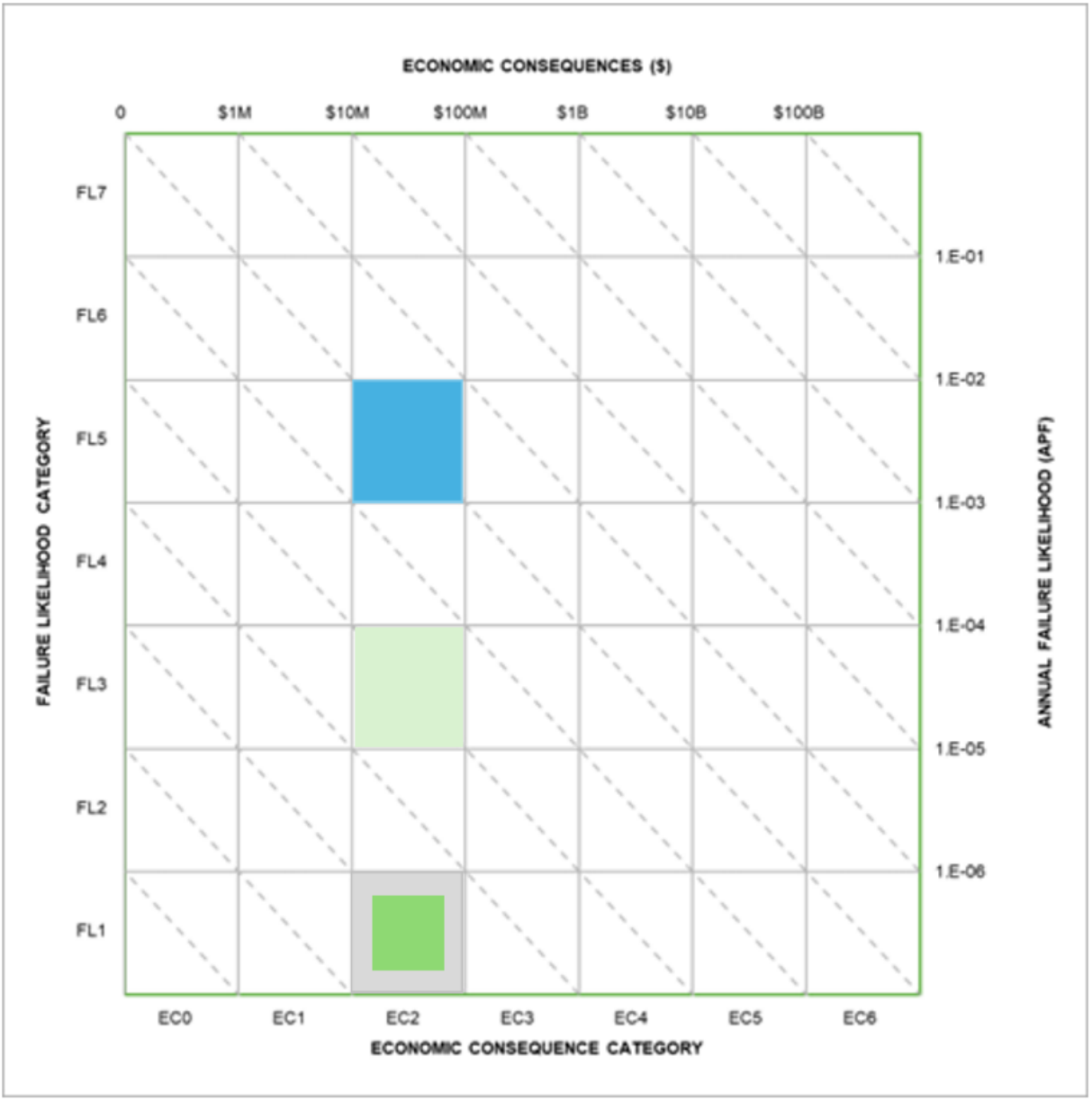
Life Safety Risk Matrix:



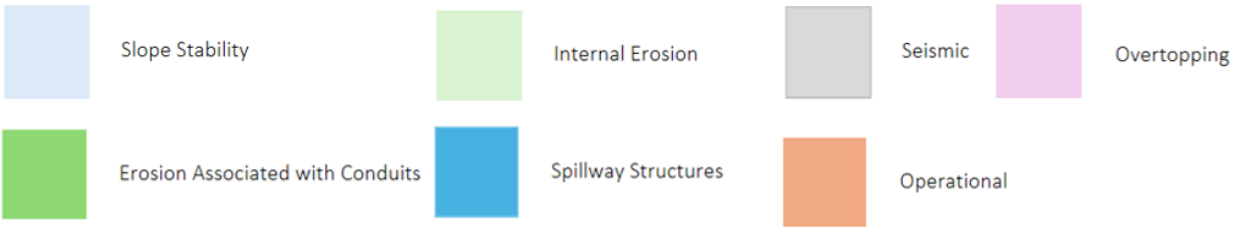
Legend:



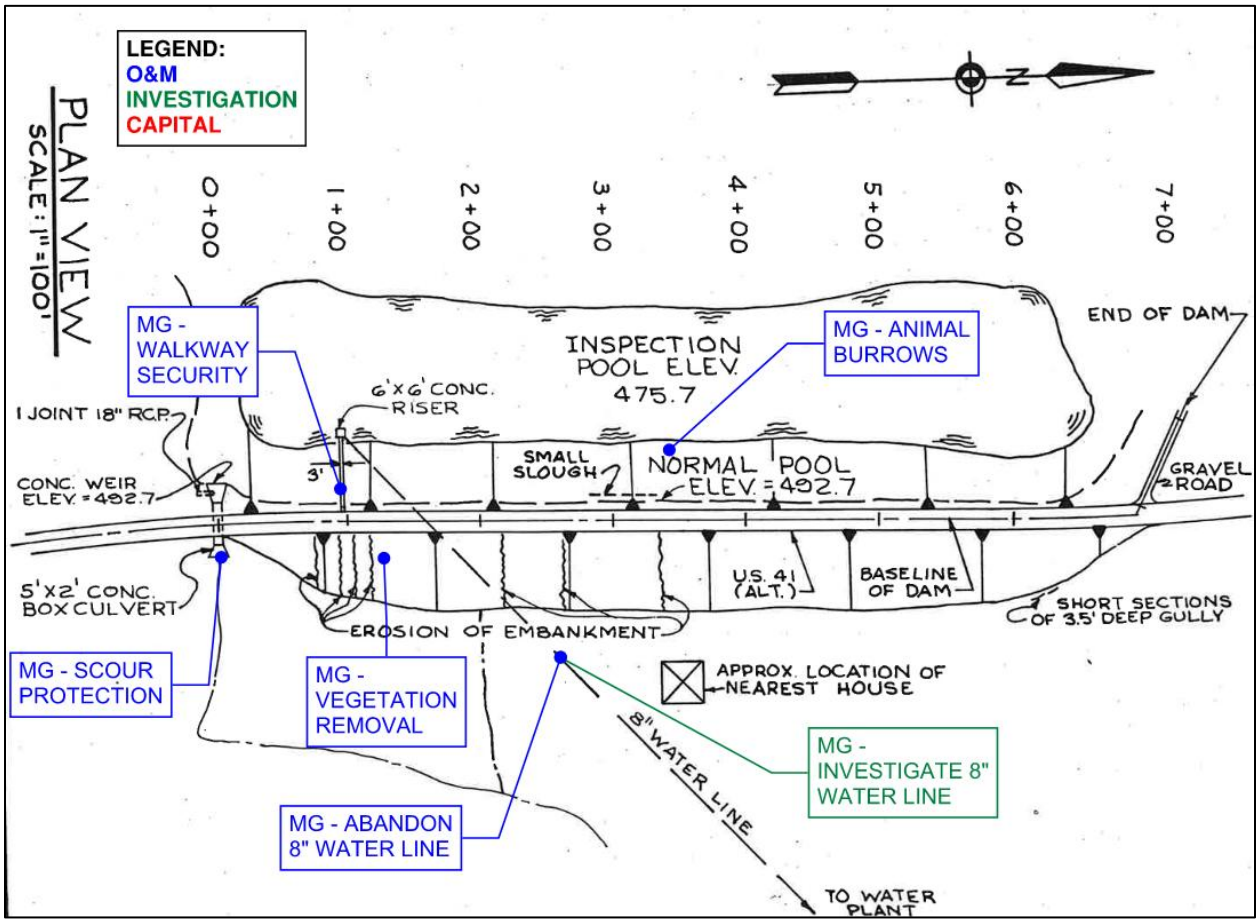
Economic Consequences Risk Matrix:



Legend:



A.7 Recommendations



Recommendations – Morton's Gap Reservoir Dam								
CODE	**Recommendation**	**Type**	**Life Loss Risk**	**Economic & Transportation Risk**	**Regulatory Compliance**	**Cost Range**	**Planning Horizon**	**Priority**
MG - SCOUR PROTECTION	Repair erosion and place better scour protection in the spillway discharge channel.	O&M	10	10	Yes	10K-100K	Short Term	1
MG - WALKWAY SECURITY	Improve security and install barriers on the walkway to the riser. Install multiple warning signs on riser structure (DANGER - KEEP OFF).	O&M	0	0	No	<10K	Short Term	2
MG - VEGETATION REMOVAL	Remove vegetation, cut trees, and grub out stumps on the face of the dam and within 25-feet of the dam abutments.	O&M	0	0	Yes	10K-100K	Short Term	3
MG - ANIMAL BURROWS	Fill any animal burrows that are deeper than about 3-feet.	O&M	0	0	Yes	<10K	Short Term	4
MG - INVESTIGATE 8" WATER LINE	Investigate the alignment, condition, and operability of the 8-inch water line, riser structure, and gate.	Investigation	2	2	No	<10K	Short Term	5
MG - ABANDON 8" WATER LINE	Dewater and abandon the 8-inch water line if it is not being used.	O&M	2	2	No	10K-100K	Intermediate	6

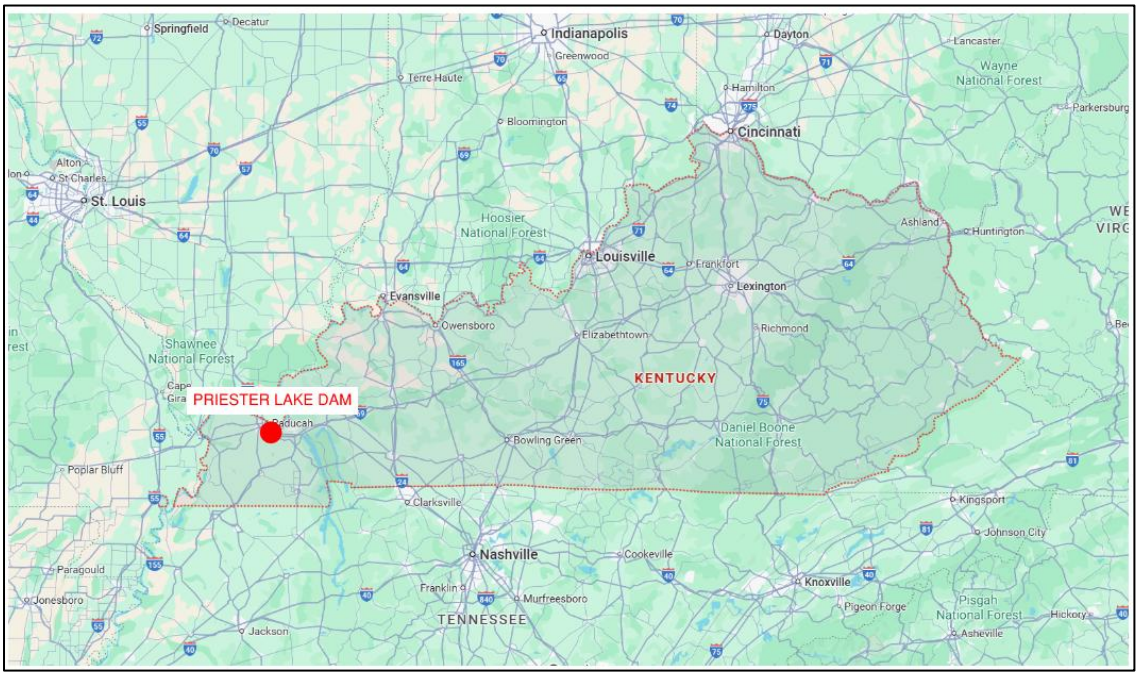
A.8 Cost Opinions for Capital Projects

No capital projects recommended for this dam.

Appendix B
Priester Lake Dam

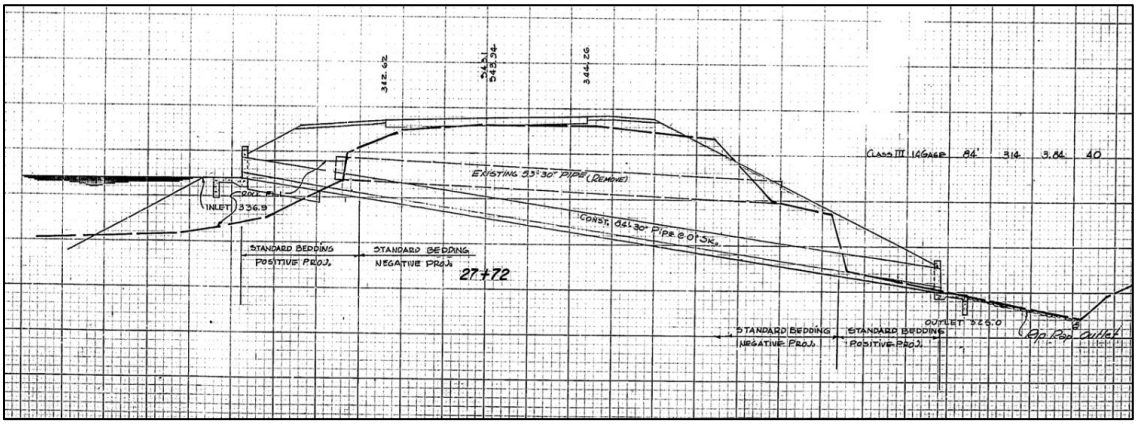
B.1 Dam and Appurtenant Features

Priester Lake Dam is located in western Kentucky in McCracken County (location map below). The National Inventory of Dams lists the purpose of the dam as recreation. This dam was constructed in 1940 and is classified as low hazard. The dam crest elevation is 344 ft, and KY-284 runs along the entire crest. The normal pool elevation is 337 ft. The height of the dam is 29 ft, and the crest width is 42 ft.

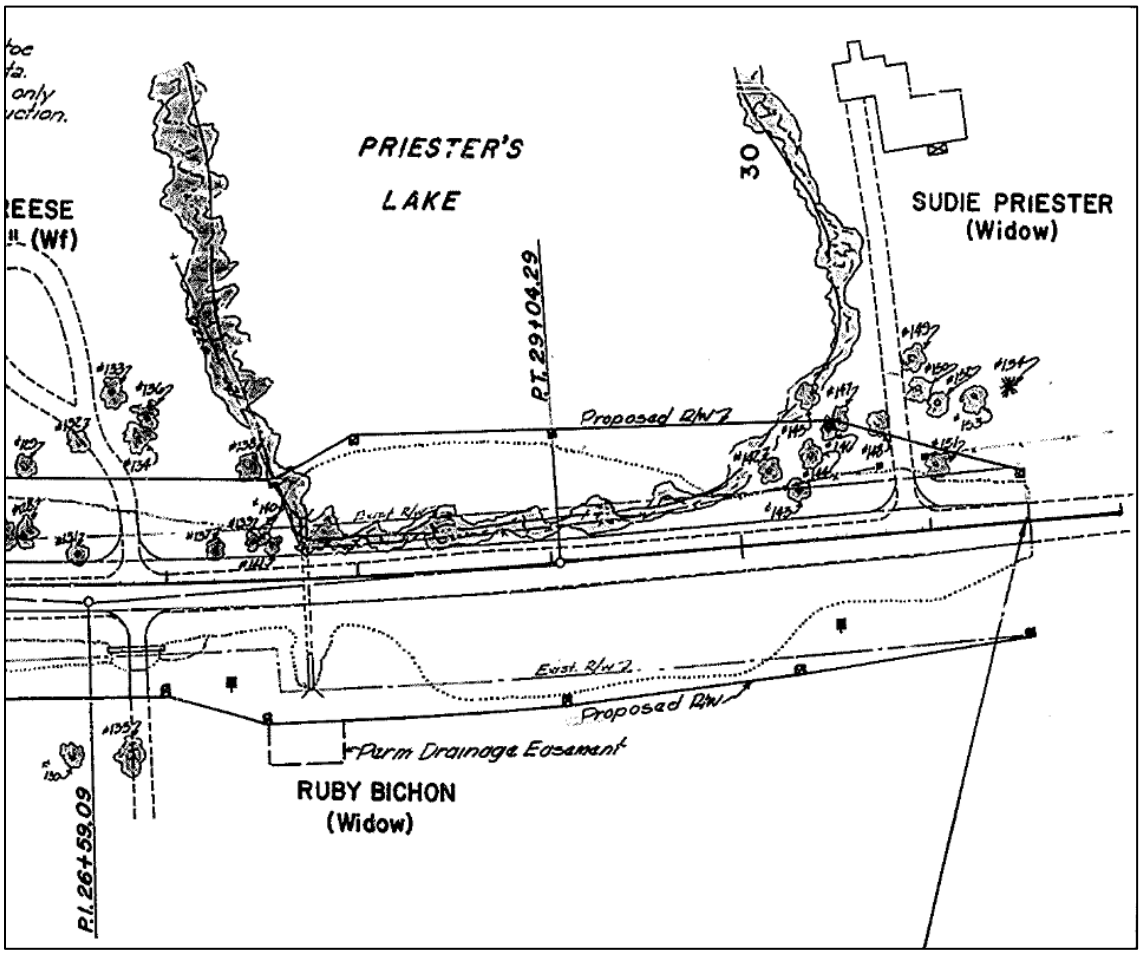


Priester Lake Dam - Vicinity Map

The principal spillway of this dam is a 30-inch diameter corrugated metal pipe (CMP) culvert along the right abutment with a trash rack affixed to the inlet. The outlet of this culvert discharges downstream towards Clarks River. The figures below show the cross section and plan view of the dam components.



Priester Lake Dam – Typical Cross Section



Priester Lake Dam – Plan View

B.2 Data Catalog

FILE #	DATA TYPE	TITLE	FILE DESCRIPTION
11.02.001	H & H	Emergency Action Plan	***
11.02.002	H & H	Evacuation Map	***
11.02.003	H & H	Inundation Map	***
11.03.001	Inspections	Inspection Report	2016
11.06.001	Transportation Docs	Traffic Counts	
11.06.002	Transportation Docs	Road Plans	
11.03.101	Inspections	Inspection Report	1996 Division of Water
11.03.102	Inspections	Inspection Report	1995 Division of Water
11.03.103	Inspections	Inspection Report	1993 Division of Water
11.03.104	Inspections	Inspection Report	2014 Division of Water
11.03.105	Inspections	Inspection Report	2016 Division of Water
11.03.106	Inspections	Inspection Report	2016 Division of Water
11.02.201	H & H	H & H Report	1996 Dam Safety Section
11.02.202	H & H	H & H Report	2014

B.3 Hydrologic and Hydraulic Analyses

Elevation-Frequency Analysis

Previous hydrologic and hydraulic analyses were performed by the Kentucky Division of Water using the Soil Conservation Service (SCS) DAMS2 model in 1996. The input data from the DAMS2 model was used to generate a new U. S. Army Corps of Engineers (USACE) Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) model (version 4.12) to estimate water surface elevations associated with various precipitation depths. The following information was taken from the DAMS2 model:

- Curve Number
- Drainage Area
- Time of Concentration
- Stage-Storage-Discharge Information

NOAA Atlas 14 was used to generate precipitation depths for frequencies ranging from the 10-year (10-percent-annual-chance) up to the 500-year (0.2-percent-annual-chance) storm. For the Probable Maximum Precipitation (PMP), Kentucky Engineering Memorandum No. 2 was used to determine the PMP rainfall depth. A 24-hour SCS Type II rainfall distribution was applied to the precipitation depths from NOAA Atlas 14, and a 6-hour SCS Type II rainfall distribution was applied to the PMP rainfall depth within the HEC-HMS model. The probability associated with the PMP was estimated using two methods:

- The FEMA Spillway Capacity and Extreme Flood Discharge Estimator (which uses flow-frequency data input by the user along with extrapolation using a power function to estimate the return period of the PMP)
- The Australian Rainfall Runoff method (which uses drainage area to estimate a return period of the PMP).

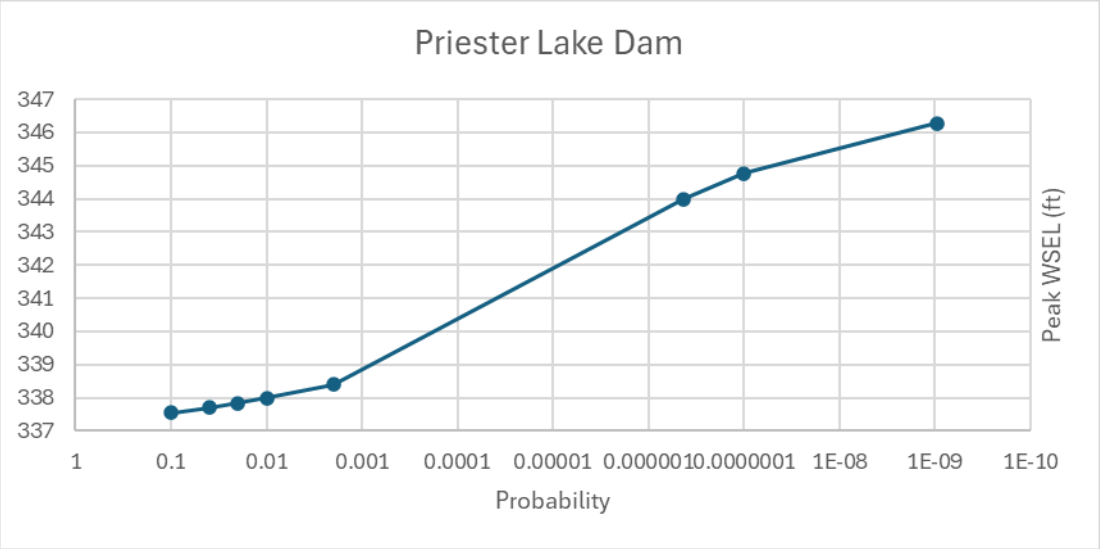
The results of the FEMA tool were used to estimate the PMP probability.

Using trial and error, additional storms were run with varying rainfall depths until a rainfall depth that produced a water surface elevation that would just overtop the dam and a water surface elevation that overtopped the dam by two feet was obtained. A log-log curve was fit to the flow frequency data (including the PMP) and interpolated/extrapolated to approximate a return period associated with these rainfall depths.

The resulting water surface elevations from the model runs are tabulated and plotted below.

Priester Lake Dam Model Results

Priester (Dam Crest = 344.0 feet)				
Precip (inches)	**Peak Inflow (cfs)**	**Peak WSEL (feet)**	**Return Interval**	**Notes**
3.5	276	337.5	0.1	10yr
4.2	363	337.7	0.04	25yr
4.7	435	337.8	0.02	50yr
5.2	512	338.0	0.01	100yr
6.6	713	338.4	0.002	500yr
24.4	3338	344.0	4.2E-07	**Overtopping**
28.7	3972	344.8	1.0E-07	**PMP**
35.0	4881	346.3	9.6E-10	**~2' overtopping**



Priester Lake Dam Elevation-Frequency Curve

Consequences Analysis

Previous inundation mapping (Stantec, 2013) that modeled a sunny-day breach of the dam was reviewed. Inundation extents were reviewed along with aerial imagery to evaluate consequences. Structures identified in the inundation area included two road crossings. A population at risk of less than 5 was estimated, assuming 2 people per road crossing. The consequences are summarized in the table below.

Consequences Associated with a Failure of Priester Lake Dam

PRIESTER	
NID_ID	KY00402
Number of Residences	0
Number of Non-Residential Structures	0
Description of Non-Residential Structures	N/A
Number of Critical Infrastructure Structures	0
Description of Critical Infrastructure Structures	N/A
Number of Road Crossings	2
List of Roads Affected	KY-284, US-60
Estimated PAR	Less than 5
PAR Assumptions	Only PAR would be associated with road crossings, limited areas of the road are inundated.
Inundation Mapping Source	Prior Stantec Analysis (Simplified Dam Breach Run)
Life Loss Notes	Life Loss would be associated with roads/transient population only

B.4 Potential Failure Modes

PFM NUMBER	PFM GROUP	PFM DESCRIPTION	RISK ASSESSMENT
P-1	SLOPE STABILITY	Normal Pool Condition - Under normal pool conditions, a slope failure triggers a mass movement of soil on the downstream face of the dam. Successive slope failures retrogress back to the crest, then to the upstream side of the crest. Material is pushed into the failure from the dam crest, but the intervention fails. The crest (344') drops below the pool elevation (337'), which overtops the dam breach. The resulting flows scour downward through the dam embankment, releasing the reservoir.	NEGLIGIBLE
P-2	INTERNAL EROSION	Under normal pool conditions, seepage develops along a defect through the dam embankment. The downstream exit is not filtered. The flow scours the soil to either side of the defect. The embankment over the seepage path does not collapse. The flow path expands and the flow accelerates. The seepage is not detected and there is no intervention. The flow scours a larger void in the embankment, leading to a collapse of the dam crest. The dam is breached and there is an uncontrolled release of the reservoir.	CREDIBLE

P-3	SEISMIC	A strong earthquake occurs near the dam site. The seismic shaking triggers liquefaction in the foundation sands under the dam embankment. The strength of the foundation soil drops significantly, resulting in upstream and/or downstream slope failures. During and after the earthquake, the failure progresses across the width of the dam crest. There is no time for intervention. The crest drops below normal pool and the reservoir overtops. The resulting flows scour downward through the dam embankment, releasing the reservoir.	CREDIBLE
P-4	OVERTOPPING	A heavy precipitation event occurs in the watershed, causing the reservoir level to rise. Water is released through the spillway pipe, but the entrance becomes clogged with vegetation and debris. The reduced spillway capacity is insufficient to pass the stormwater inflow. There is no auxiliary spillway. The water levels continue to rise and overtop the dam crest. Efforts to raise the dam crest are unsuccessful. The overtopping flows begin to erode the downstream slope of the dam embankment. The flow causes head cutting, which progresses backward across the width of the dam crest. The dam is breached when the crest erosion reaches the upstream pool. The resulting flows scour downward through the dam embankment, releasing the reservoir.	CREDIBLE

P-5A	EROSION ASSOCIATED WITH CONDUITS	The 30-inch corrugated metal pipe (CMP) in the dam embankment is corroded and deteriorated. At normal pool conditions, eroded soil enters the CMP and is carried away with the discharge flow. The erosion and loss of soil is accelerated during flood events. A void develops along the pipe and enlarges and lengthens over time. The erosion and void are not detected and there is no intervention. Water flows through the void along the pipe, scouring downward through the dam embankment. The dam is breached and there is an uncontrolled release of the reservoir.	CREDIBLE
P-5B	EROSION ASSOCIATED WITH CONDUITS	When reservoir levels are above normal pool, seepage develops within the backfill along the outside of the CMP spillway pipe. Over multiple events, the seepage erodes the soil and an open flow path develops along the pipe. The erosion and void are not detected and there is no intervention. During a flood, water flows through the void along the pipe, scouring downward through the dam embankment. The dam is breached and there is an uncontrolled release of the reservoir.	CREDIBLE
P-6	SPILLWAY STRUCTURES	Reservoir levels rise during a flood event and the spillway is activated. The downstream channel, along the embankment toe, is scoured by flows from the spillway discharge. Erosion of the dam toe triggers a slope failure on the downstream face of the dam. Successive slope failures retrogress back to the crest, then to the upstream side of the crest. Material is pushed into the failure from the crest, but the intervention fails. The crest drops below the pool elevation, which overtops the dam breach. The resulting flows scour downward through the dam embankment, releasing the reservoir.	NEGLIGIBLE
P-7	OPERATIONAL	Clogging of the trash rack at the inlet of the spillway is covered in P-4 (Overtopping). No mechanical equipment to operate or maintain at the site.	NEGLIGIBLE

B.5 Evaluation of PFMs

Potential Failure Mode Analysis Table:

PFM No.:	P-1	**Dam:**	Priester (P)
PFM Group:	Slope Stability		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*

Normal Pool Condition

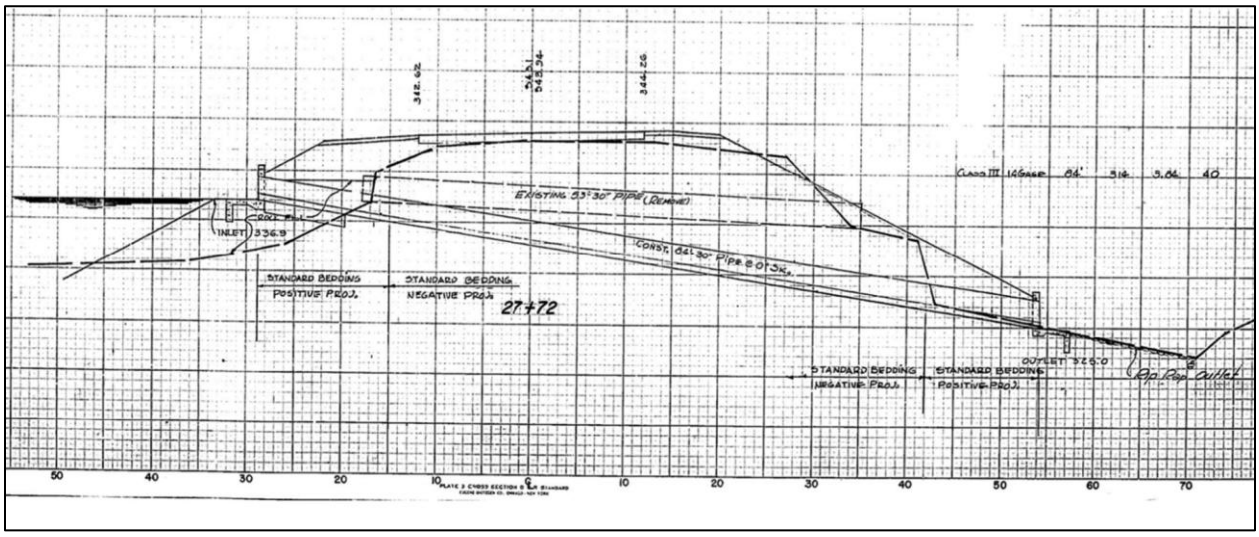
Under normal pool conditions, a slope failure triggers a mass movement of soil on the downstream face of the dam. Successive slope failures retrogress back to the crest, then to the upstream side of the crest. Material is pushed into the failure from the dam crest, but the intervention fails. The crest (344') drops below the pool elevation (337'), which overtops the dam breach. The resulting flows scour downward through the dam embankment, releasing the reservoir.

More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
• **The downstream slope is 2:1** • **The geotechnical properties are unknown** • **No stability analysis available** • Cannot drawdown the lake • Due to vegetation, cannot see the downstream slope	• **The crest is 42' wide and the dam is 29' tall** • **It would take a long time to retrogress across the crest** • **KYTC could readily repair a slide** • The guardrail appeared to be in a straight alignment • The pavement is in good condition - no longitudinal cracking.

Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Negligible	It would take a long time to breach, and it is almost certain we would be able to intervene successfully.
Failure Likelihood		
Life Safety Consequences		
Economic Consequences		

Risk Reduction Measures	
Studies and Investigations	Geotechnical information and stability analysis needed.
Maintenance and Monitoring	Remove vegetation on the downstream face
Design and Modifications	Downstream berm

Supporting Figures:



Cross Section



Photo From Site Visit



Photo From Site Visit

Potential Failure Mode Analysis Table:

PFM No.:	P-2	**Dam:**	Priester (P)
PFM Group:	Internal Erosion		
PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure*)			
Under normal pool conditions, seepage develops along a defect through the dam embankment. The downstream exit is not filtered. The flow scours the soil to either side of the defect. The embankment over the seepage path does not collapse. The flow path expands and the flow accelerates. The seepage is not detected and there is no intervention. The flow scours a larger void in the embankment, leading to a collapse of the dam crest. The dam is breached and there is an uncontrolled release of the reservoir.			
More Likely (Adverse) Factors		**Less Likely (Favorable) Factors**	
• **One of the most common ways a dam fails**		• This was likely a compacted embankment	

• Unlikely to have been constructed as a dam embankment • We do not have an internal drain system • We do not have a downstream filter • May not see the seepage develop • We lack geotechnical information • **Downstream face covered in heavy vegetation so could not observe** • **Given site geology, likely a permeable layer in the foundation**	• If detected, there will be time for intervention • **Low gradient condition (low head, wide embankment)**

Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Credible	This is one of the most common ways a dam fails and we do not have filtered drainage systems in the dam.
Failure Likelihood	FL2	The gradient is relatively low, so less likely factor. No evidence of a defect.
Life Safety Consequences	LS0	PAR - <5 based on consequence studies. One road crossing is impacted.
Economic Consequences	EC1	Road closure
Risk Reduction Measures		
Studies and Investigations	Geotechnical explorations	
Maintenance and Monitoring	Install piezometers, clear vegetation on downstream face of dam, perform additional inspection	
Design and Modifications		

Supporting Figures:

PRIESTER	
NID_ID	KY00402
Number of Residences	0
Number of Non-Residential Structures	0
Description of Non-Residential Structures	N/A
Number of Critical Infrastructure Structures	0
Description of Critical Infrastructure Structures	N/A
Number of Road Crossings	2
List of Roads Affected	KY-284, US-60
Estimated PAR	Less than 5
PAR Assumptions	Only PAR would be associated with road crossings, limited areas of the road are inundated.
Inundation Mapping Source	Prior Stantec Analysis (Simplified Dam Breach Run)
Life Loss Notes	Life Loss would be associated with roads/transient population only

Overtopping Consequences Table

Potential Failure Mode Analysis Table:

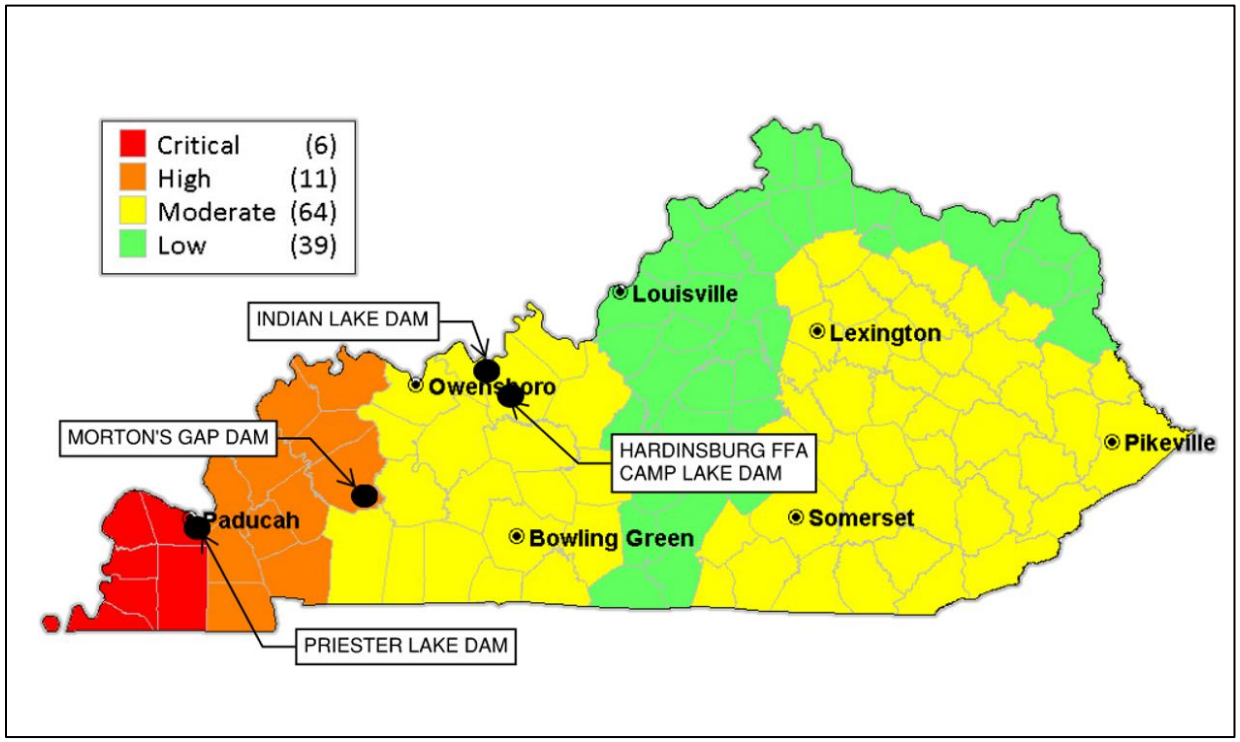
PFM No.:	P-3	**Dam:**	Priester (P)
PFM Group:	Seismic		
PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*			
A strong earthquake occurs near the dam site. The seismic shaking triggers liquefaction in the foundation sands under the dam embankment. The strength of the foundation soil drops significantly, resulting in upstream and/or downstream slope failures. During and after the earthquake, the failure progresses across the width of the dam crest. There is no time for intervention. The crest drops below normal pool and the reservoir overtops. The resulting flows scour downward through the dam embankment, releasing the reservoir.			
More Likely (Adverse) Factors		**Less Likely (Favorable) Factors**	
• **There are no stability or liquefaction analyses**		• **The failure must go all the way across the crest**	

• **Located in Western Kentucky with higher seismic hazard** • **Liquifiable soils are present based on geologic setting** • AEP=5E-3 when g=0.1 • **Intervention is not possible** • **With liquification in the foundation, large slope movements are more likely** • Could have internal planes of weakness in the embankment due to construction history • Some of the embankment may have been placed by pushing soil into reservoir without compaction	• The liquified deposits may be deep (with respect to the height) beneath the dam

Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Credible	
Failure Likelihood	FL4	Liquifiable soils known to be in the region, although not specifically known at the dam.
Life Safety Consequences	LS0	See P-2
Economic Consequences	EC1	See P-2
Risk Reduction Measures		
Studies and Investigations	Geotechnical explorations and analysis	
Maintenance and Monitoring		
Design and Modifications	Downstream berm	

Supporting Figures:

Peak Ground Acceleration versus Annual Exceedance Probability Graph



Seismic Map

Potential Failure Mode Analysis Table:

PFM No.:	P-4	**Dam:**	Priester (P)
PFM Group:	Overtopping		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*

A heavy precipitation event occurs in the watershed, causing the reservoir level to rise. Water is released through the spillway pipe, but the entrance becomes clogged with vegetation and debris. The reduced spillway capacity is insufficient to pass the stormwater inflow. There is no auxiliary spillway. The water levels continue to rise and overtop the dam crest. Efforts to raise the dam crest are unsuccessful. The overtopping flows begin to erode the downstream slope of the dam embankment. The flow causes head cutting, which progresses backward across the width of the dam crest. The dam is breached when the crest erosion reaches the upstream pool. The resulting flows scour downward through the dam embankment, releasing the reservoir.

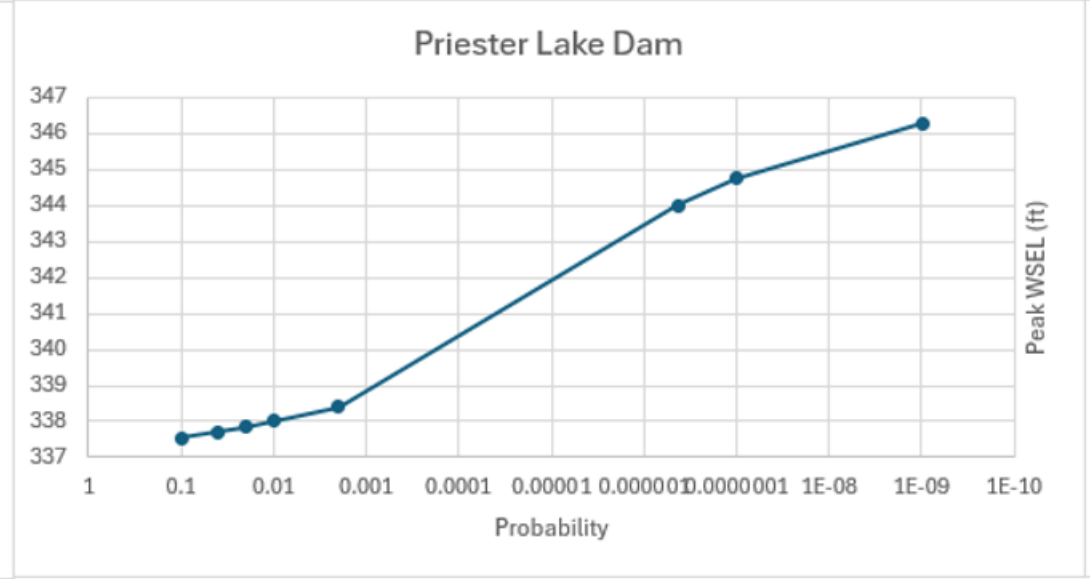
More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
• No auxiliary spillway • Has a potential for clogging due to small diameter (24"). From regulatory perspective, this is not an "non-clogged spillway pipe". • High potential for widespread flooding in area, leading to difficulty intervening • Debris can be caught in chain-link fence	• Currently meets regulatory requirement for design flood for a low hazard dam. • The probability of an overtopping event is 4.25E-7

Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Credible	The probability of an overtopping event is 4.25E-7
Failure Likelihood	FL1	Based on probability of overtopping
Life Safety Consequences	LS0	See P-2
Economic Consequences	EC1	See P-2
Risk Reduction Measures		
Studies and Investigations	Detailed H&H analysis	

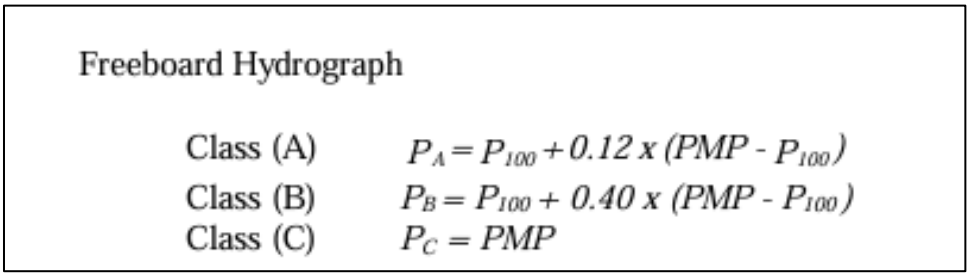
Maintenance and Monitoring	Routine debris management
Design and Modifications	Replace the culvert

Supporting Figures:

Priester (Dam Crest = 344.0 ft)				
Precip (in)	**Peak Inflow (cfs)**	**Peak WSEL (ft)**	**Return Interval**	**Notes**
3.54	276.25	337.5408	0.1	10yr
4.17	362.65	337.7076	0.04	25yr
4.68	434.49	337.8479	0.02	50yr
5.22	511.97	338.0003	0.01	100yr
6.59	713.37	338.3996	0.002	500yr
24.35	3338.05	343.9979	4.252E-07	**Overtopping**
28.7	3971.85	344.765	1.00E-07	**PMP**
34.97	4881.1	346.2802	9.59E-10	**~2' overtopping**



H&H Results



Freeboard Hydrograph Formula from KDOW Memo #5 (Department for Natural Resources and Environmental Protection)

Potential Failure Mode Analysis Table:

PFM No.:	P-5A	**Dam:**	Priester (P)
PFM Group:	Erosion Associated with Conduits		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*

The 30-inch corrugated metal pipe (CMP) in the dam embankment is corroded and deteriorated. At normal pool conditions, eroded soil enters the CMP and is carried away with the discharge flow. The erosion and loss of soil is accelerated during flood events. A void develops along the pipe and enlarges and lengthens over time. The erosion and void are not detected and there is no intervention. Water flows through the void along the pipe, scouring downward through the dam embankment. The dam is breached and there is an uncontrolled release of the reservoir.

More Likely (Adverse) Factors	Less Likely (Favorable) Factors
• **The pipe is demonstrating corrosion and deterioration** • **Failure mode is more common with CMP** • Exceeded the service life of CMP • Failure mode can accelerate under flood pool conditions • **Poor compaction around corrugated pipe**	• **The gradients are low under normal pool** • **Likely have time to intervene under normal pool**

Risk Assessment	Category	Notes
Negligible? Credible?	Credible	
Failure Likelihood	FL4	No evidence of erosion in the pipe

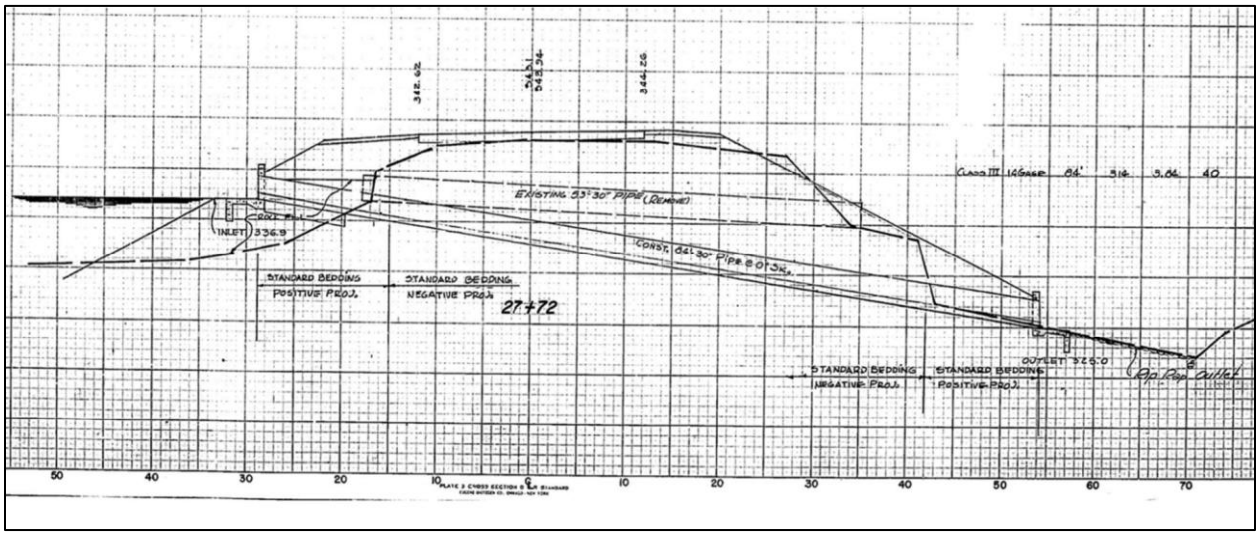
Life Safety Consequences	LS0	See P-2
Economic Consequences	EC1	See P-2
Risk Reduction Measures		
Studies and Investigations		
Maintenance and Monitoring	Monitor for depression in the road	
Design and Modifications	Lining or replacing the CMP pipe	

PFM No.:	P-5.2	**Dam:**	Priester (P)
PFM Group:	Erosion Associated with Conduits		
PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*			
When reservoir levels are above normal pool, seepage develops within the backfill along the outside of the CMP spillway pipe. Over multiple events, the seepage erodes the soil and an open flow path develops along the pipe. The erosion and void are not detected and there is no intervention. During a flood, water flows through the void along the pipe, scouring downward through the dam embankment. The dam is breached and there is an uncontrolled release of the reservoir.			
More Likely (Adverse) Factors		**Less Likely (Favorable) Factors**	
• **Poor compaction around corrugated pipe**		• **The gradients are generally low** • **Likely have time to intervene under normal pool**	

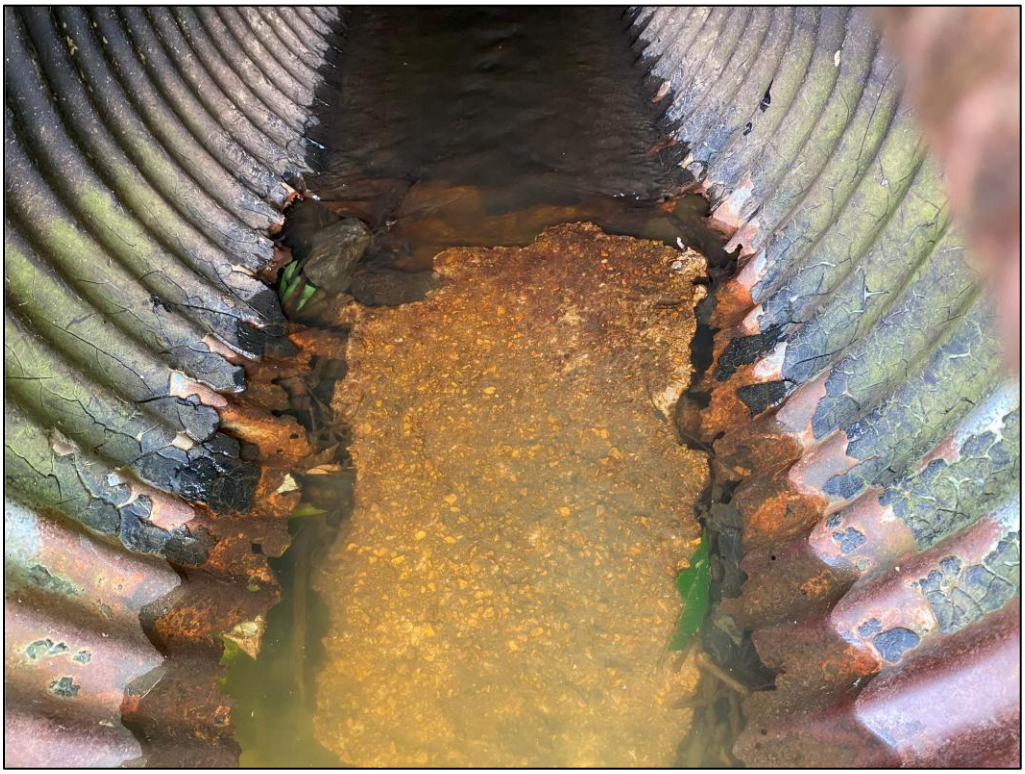
Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Credible	
Failure Likelihood	FL1	Only occurs during flood events
Life Safety Consequences	LS0	See P-2
Economic Consequences	EC1	See P-2
Risk Reduction Measures		

Studies and Investigations	
Maintenance and Monitoring	Monitor for depression in the road
Design and Modifications	Lining or replacing the concrete pipe

Supporting Figures:



Cross Section



Site Visit Photo



Site Visit Photo

Potential Failure Mode Analysis Table:

PFM No.:	P-6	**Dam:**	Priester (P)
PFM Group:	Spillway Structures		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*
Reservoir levels rise during a flood event and the spillway is activated. The downstream channel, along the embankment toe, is scoured by flows from the spillway discharge. Erosion of the dam toe triggers a slope failure on the downstream face of the dam. Successive slope failures retrogress back to the crest, then to the upstream side of the crest. Material is pushed into the failure from the crest, but the intervention fails. The crest drops below the pool elevation, which overtops the dam breach. The resulting flows scour downward through the dam embankment, releasing the reservoir.

More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
• Discharge channel has erodible materials near the toe of the dam • The discharge channel is on the dam	• Tailwater flooding from Clark's river submerge toe during flood events • Our inspection did not reveal erosion of the stream channel

Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Negligible	
Failure Likelihood		
Life Safety Consequences		
Economic Consequences		

Risk Reduction Measures	
Studies and Investigations	
Maintenance and Monitoring	
Design and Modifications	

Supporting Figures:



Site Visit Photo

Potential Failure Mode Analysis Table:

PFM No.:	P-7	**Dam:**	Priester (P)
PFM Group:	Operational		
PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*			
Clogging of the trash rack at the inlet of the spillway is covered in P-4 (Overtopping). No mechanical equipment to operate or maintain at the site.			
More Likely (Adverse) Factors		**Less Likely (Favorable) Factors**	
•		•	

Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Negligible	
Failure Likelihood	N/A	
Life Safety Consequences	N/A	
Economic Consequences	N/A	

Risk Reduction Measures	
Studies and Investigations	N/A
Maintenance and Monitoring	N/A
Design and Modifications	N/A

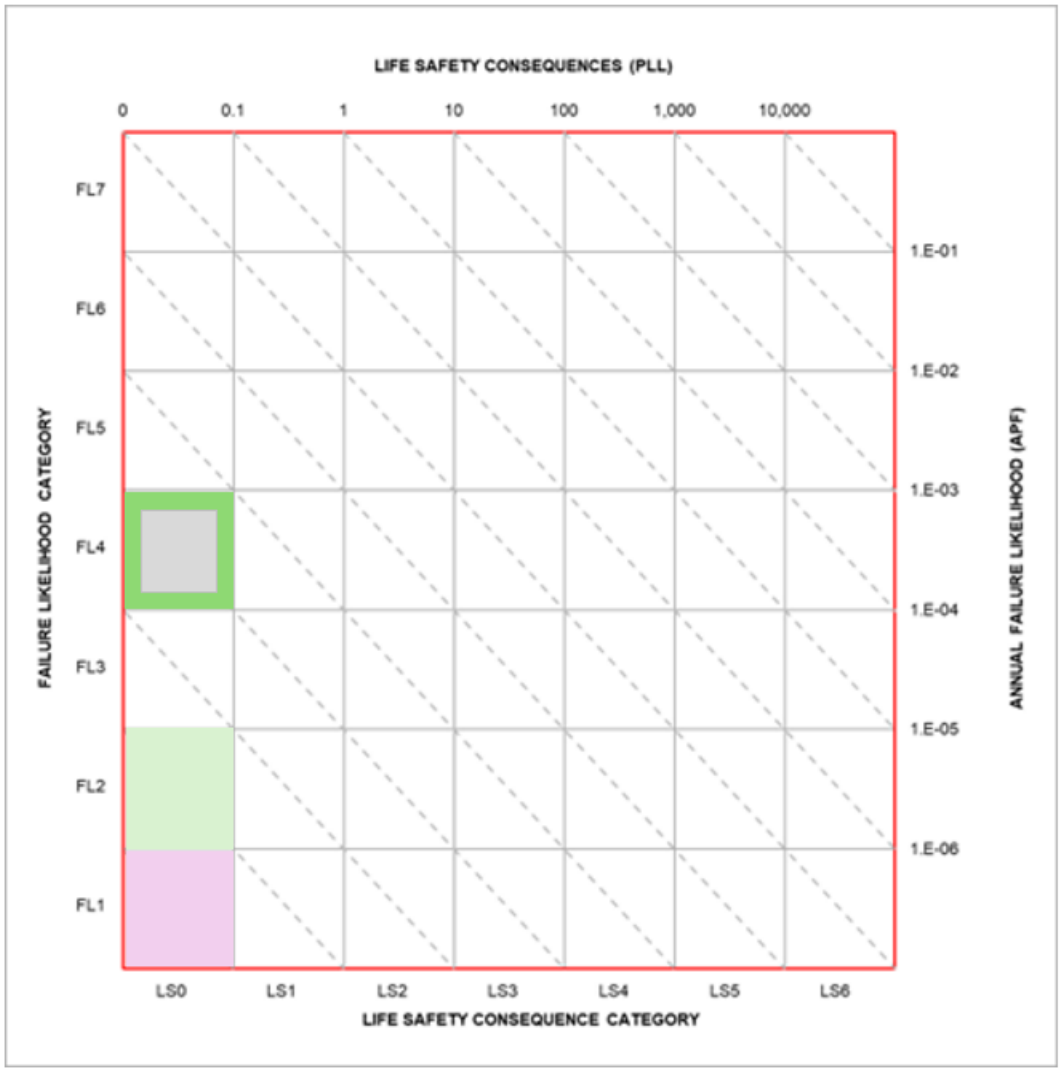
Supporting Figures:



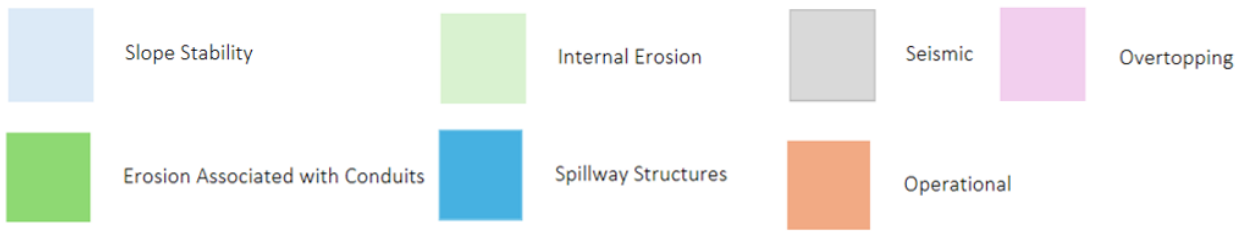
Site Visit Photo

B.6 Risk Matrices

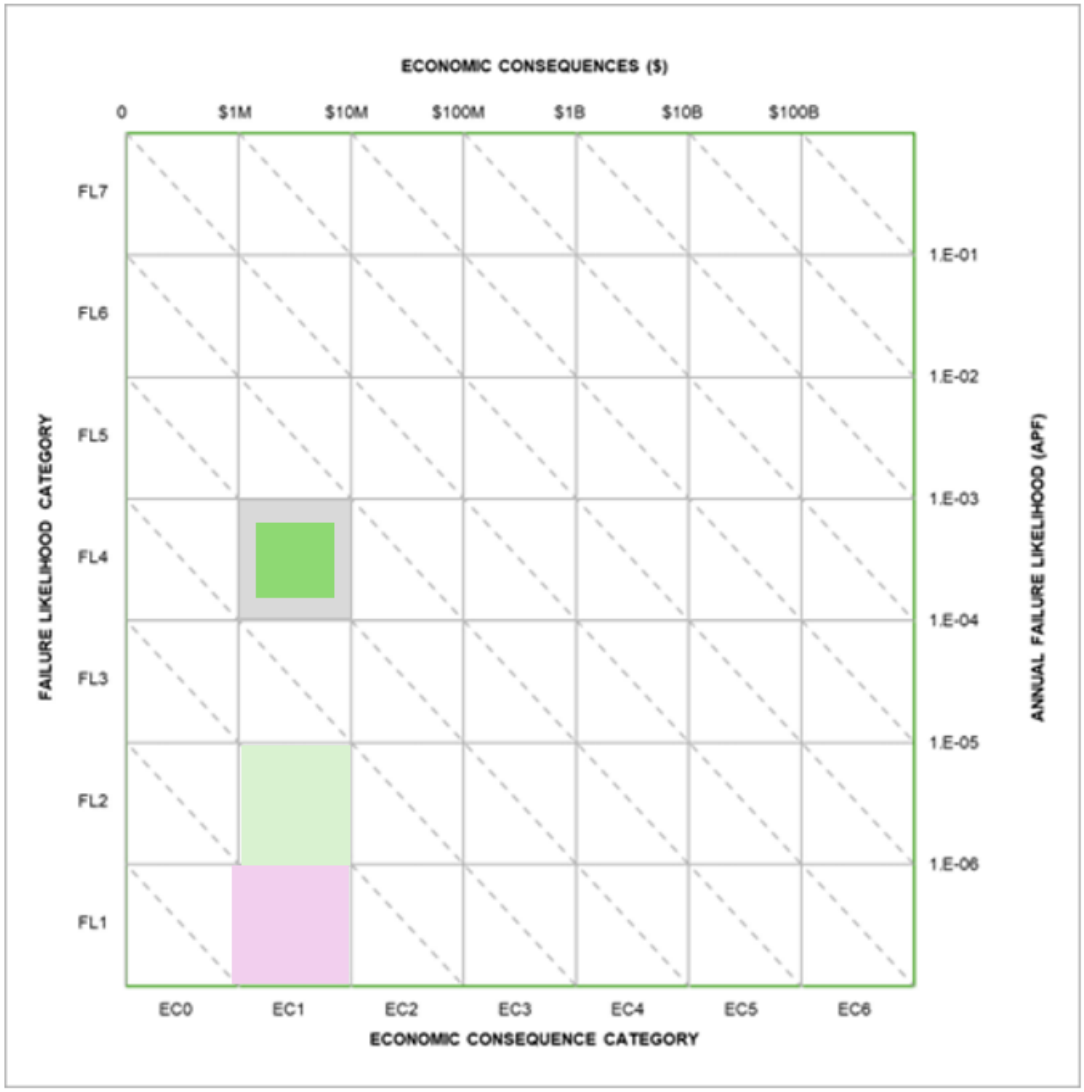
Life Safety Risk Matrix:



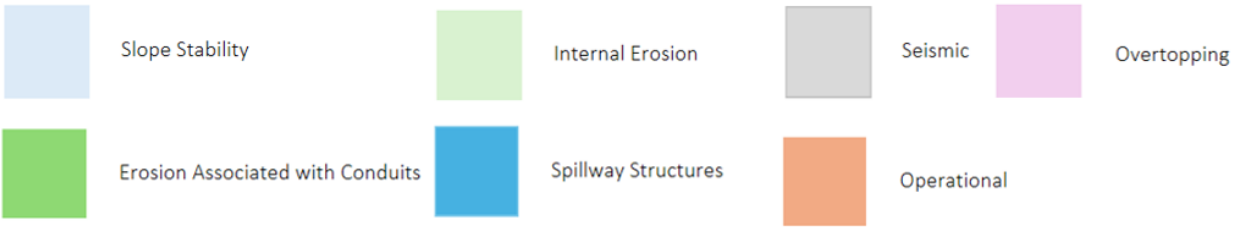
Legend:



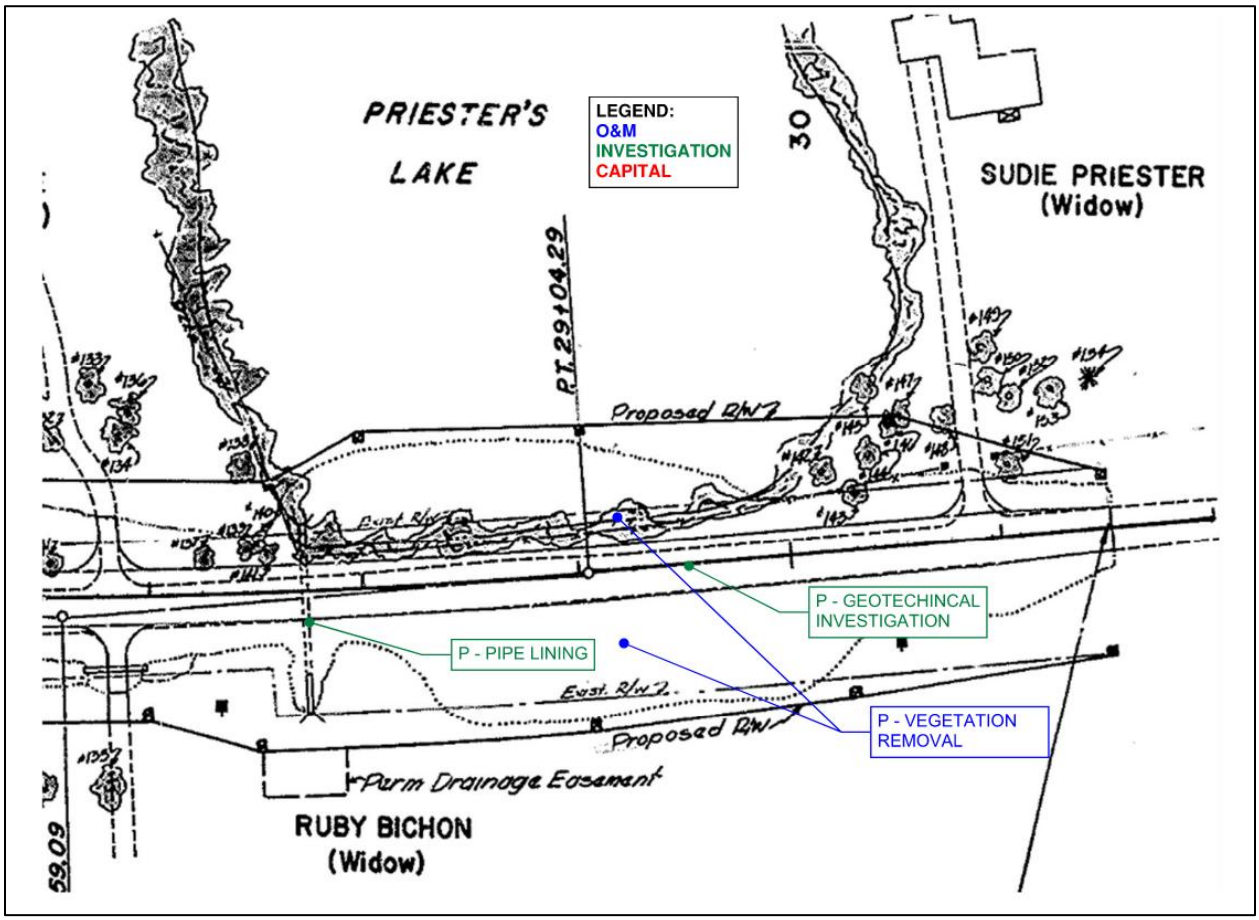
Economic Consequences Risk Matrix:



Legend:



B.7 Recommendations



Recommendations – Priester Lake Dam								
CODE	**Recommendation**	**Type**	**Life Loss Risk**	**Economic & Transportation Risk**	**Regulatory Compliance**	**Cost Range**	**Planning Horizon**	**Priority**
P – VEGETATION REMOVAL	Remove vegetation, cut trees, and grub out stumps on the face of the dam and within 25-feet of the dam abutments.	O&M	0	0	Yes	10K-100K	Short Term	1
P – PIPE LINING	Line the CMP pipes that cross the dam crest. Improve the inlet to mitigate potential clogging. Improve scour protection along the spillway discharge channel.	O&M	0	4	No	10K-100K	Intermediate	2
P – GEOTECH INVESTIGATION	Perform geotechnical investigation (borings and piezometers) and seismic and liquefaction analyses.	Investigation	0	4	No	10K-100K	Intermediate	3

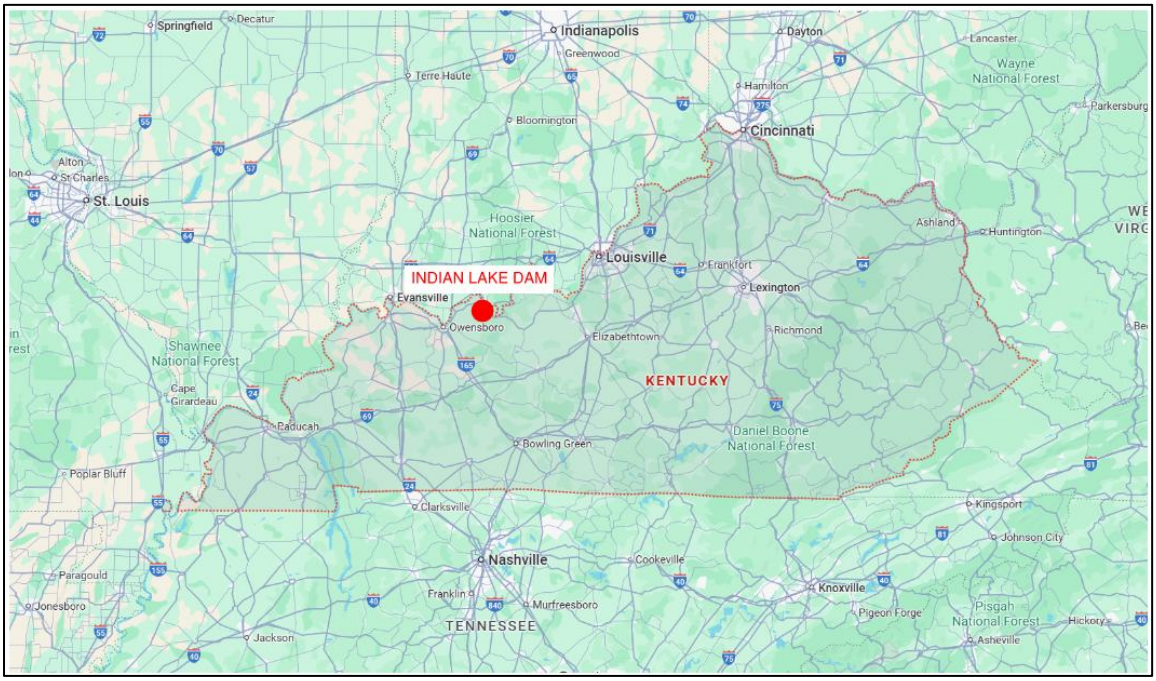
B.8 Cost Opinions for Capital Projects

No capital projects recommended for this dam.

Appendix C
Indian Lake Dam

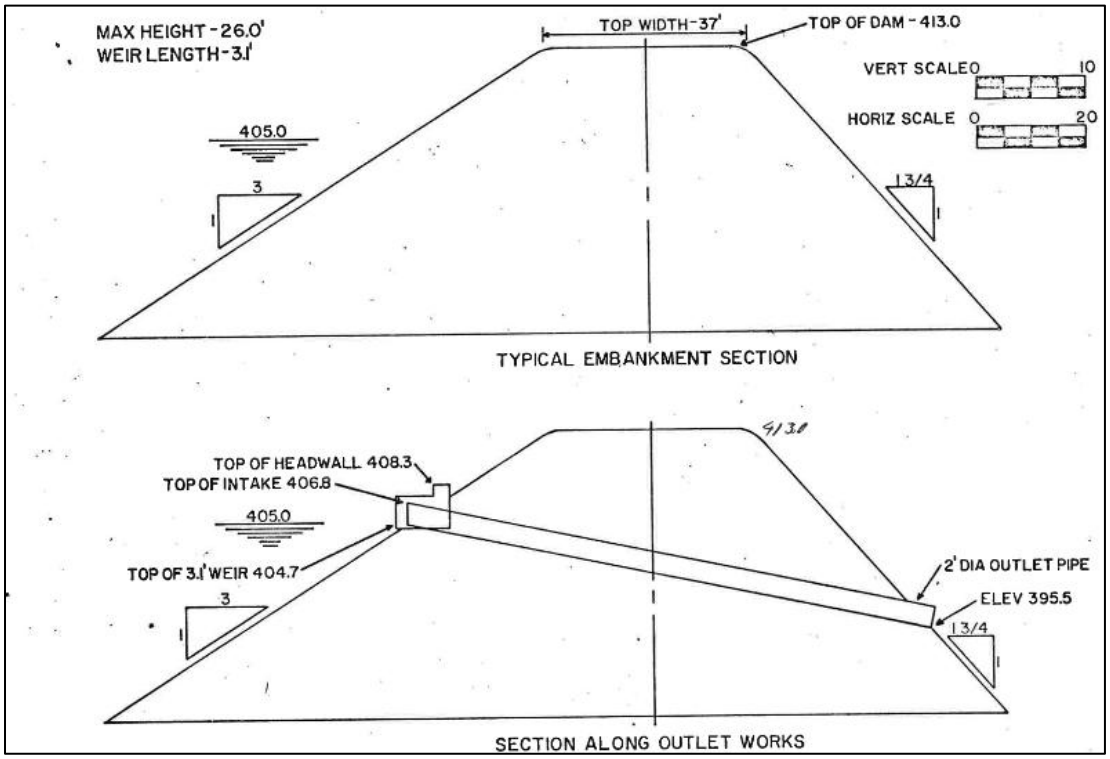
C.1 Dam and Appurtenant Features

Indian Lake Dam is located in Hancock County (location map below). The National Inventory of Dams (NID) lists the purpose of the dam as recreation and classifies it as low hazard. According to NID, this dam was constructed in 1940, but the record plans for the road show Indian Lake in 1931. The dam crest elevation is 413 ft, and KY-3199 runs along the entire crest. The normal pool elevation is 405 ft. The height of the dam is 26 ft, and the crest width is 37 ft.

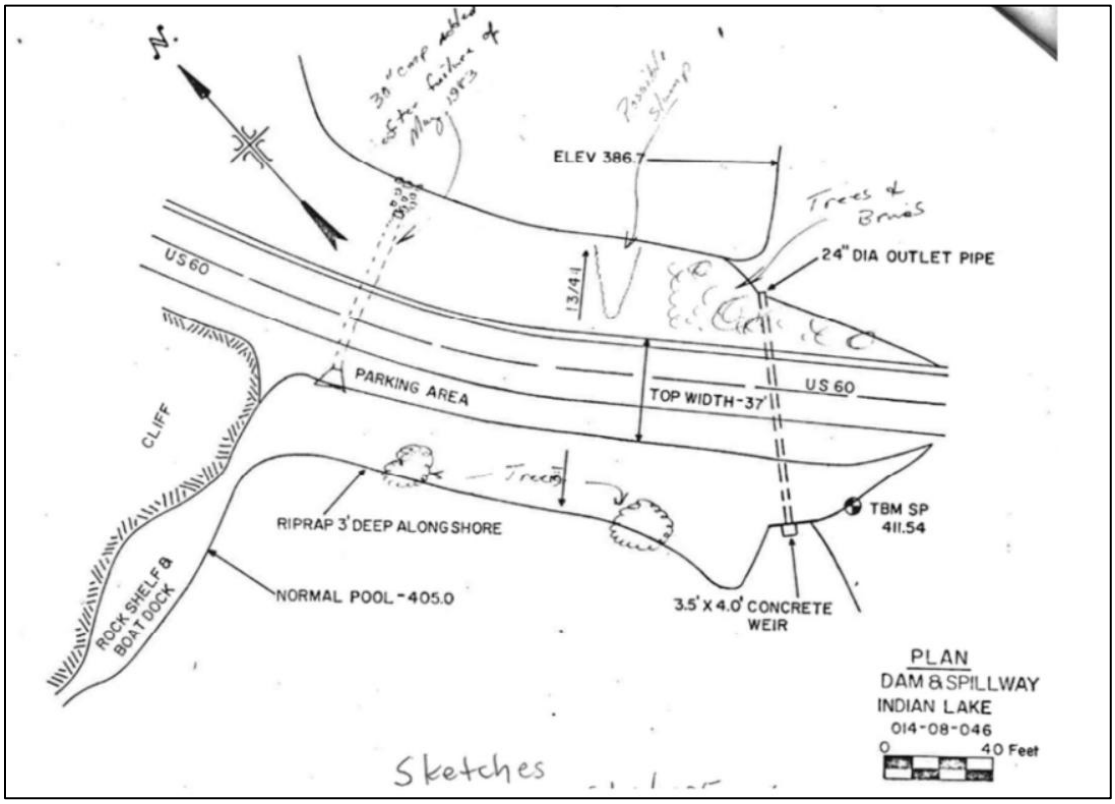


Indian Lake Dam - Vicinity Map

The principal spillway of this dam is a 24-inch diameter CMP running through the dam along the right abutment with an orifice plate affixed to the inlet. The auxiliary spillway is a 2 ft x 3 ft elliptical CMP, which was added after the dam was overtopped in 1983. The figures below show the cross section and plan view of the dam components.



Indian Lake Dam – Typical Cross Section



Indian Lake Dam – Plan View

C.2 Data Catalog

FILE #	DATA TYPE	TITLE	FILE DESCRIPTION
10.02.001	H & H	Emergency Action Plan	***
10.02.002	H & H	Evacuation Map	***
10.02.003	H & H	Inundation Map	***
10.03.001	Inspections	Inspection Report	2013
10.06.001	Transportation Docs	Traffic Counts	
10.06.002	Transportation Docs	Road Plans	
10.03.101	Inspections	Inspection Report	2006 Division of Water
10.03.102	Inspections	Inspection Report	2009 Division of Water
10.03.103	Inspections	Inspection Report	2014 Division of Water
10.03.104	Inspections	Inspection Report	2004 Division of Water
10.03.105	Inspections	Inspection Report	2002 Division of Water
10.03.106	Inspections	Inspection Report	2000 Division of Water
10.03.107	Inspections	Inspection Report	1998 Division of Water
10.03.108	Inspections	Inspection Report	1995 Division of Water
10.03.109	Inspections	Inspection Report	1994 Division of Water
10.03.110	Inspections	Inspection Report	1992 Division of Water
10.03.111	Inspections	Inspection Report	1989 Division of Water
10.03.112	Inspections	Inspection Report	1985 Division of Water
10.03.113	Inspections	Inspection Report	1981-1989 Division of Water
10.03.114	Inspections	Inspection Report	2010-2011 Division of Water
10.03.115	Inspections	Inspection Report	2009 Division of Water
10.03.116	Inspections	Inspection Report	2009 Division of Water
10.03.117	Inspections	Inspection Report	1993-1999 Division of Water
10.03.118	Inspections	Inspection Report	2006 Division of Water
10.03.119	Inspections	Inspection Report	2004 Division of Water
10.03.120	Inspections	Inspection Report	2013 Division of Water

10.03.121	Inspections	Inspection Report Photos	2013 Division of Water
10.02.201	H & H	Dam Breach Scenario Analysis	1990 USACE Louisville District
10.02.202	H & H	H & H Report	1996 Dam Safety Section
10.04.201	Drawings	Cross Section Exhibit	

C.3 Hydrologic and Hydraulic Analyses

Elevation-Frequency Analysis

Previous hydrologic and hydraulic analyses were performed by the Kentucky Division of Water using the Soil Conservation Service (SCS) DAMS2 model in 1996. The input data from the DAMS2 model was used to generate a new U. S. Army Corps of Engineers (USACE) Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) model (version 4.12) to estimate water surface elevations associated with various precipitation depths. The following information was taken from the DAMS2 model:

- Curve Number
- Drainage Area
- Time of Concentration
- Stage-Storage Information

Stage-discharge information was not included in the 1996 DAMS2 model summary. A rating curve for the principal spillway was calculated using weir, orifice, and pipe flow equations. A rating curve for the emergency spillway was calculated directly in HEC-HMS.

NOAA Atlas 14 was used to generate precipitation depths for frequencies ranging from the 10-year (10-percent-annual-chance) up to the 500-year (0.2-percent-annual-chance) storm. For the Probable Maximum Precipitation (PMP), Kentucky Engineering Memorandum No. 2 was used to determine the PMP rainfall depth. A 24-hour SCS Type II rainfall distribution was applied to the precipitation depths from NOAA Atlas 14, and a 6-hour SCS Type II rainfall distribution was applied to the PMP rainfall depth within the HEC-HMS model. The probability associated with the PMP was estimated using two methods:

- The FEMA Spillway Capacity and Extreme Flood Discharge Estimator (which uses flow-frequency data input by the user along with extrapolation using a power function to estimate the return period of the PMP)
- The Australian Rainfall Runoff method (which uses drainage area to estimate a return period of the PMP).

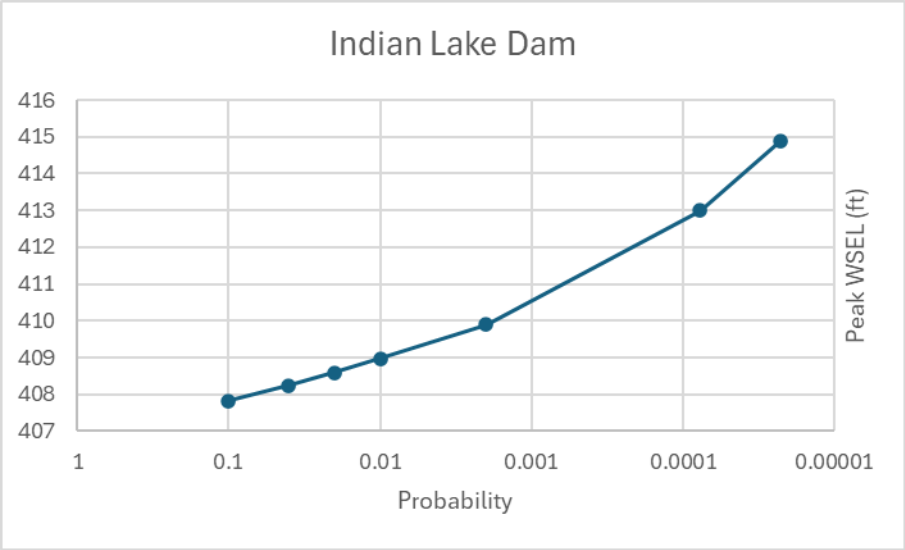
The results of the two methods were averaged to estimate the PMP probability.

Using trial and error, additional storms were run at various rainfall depths until a rainfall depth that produced a water surface elevation that would just overtop the dam was obtained. A log-log curve was fit to the flow frequency data (including the PMP) and interpolated to approximate a return period associated with this rainfall depth.

The resulting water surface elevations from the model runs are tabulated and plotted below .

Indian Lake Dam Model Results

Indian Lake (Dam Crest = 413.0 feet)				
Precip (inches)	**Peak Inflow (cfs)**	**Peak WSEL (feet)**	**Return Interval**	**Notes**
3.3	323	407.8	0.1	10yr
3.9	473	408.2	0.04	25yr
4.5	607	408.6	0.02	50yr
5.0	757	409.0	0.01	100yr
6.5	1173	409.9	0.002	500yr
13.2	3298	413.0	7.7E-5	**Overtopping**
28.2	8121	414.9	2.3E-5	**PMP**



Indian Lake Dam Elevation-Frequency Curve

Consequences Analysis

Previous inundation mapping (Stantec, 2013) that modeled a sunny-day breach of the dam was reviewed. Inundation extents were reviewed along with aerial imagery to evaluate consequences. Structures identified in the inundation area included one road crossing. A population at risk of less than 5 was estimated, assuming 2 people per road crossing. The consequences are summarized in the table below.

Consequences Associated with a Failure of Indian Lake Dam

INDIAN LAKE	
NID_ID	KY00014
Number of Residences	0
Number of Non-Residential Structures	0
Description of Non-Residential Structures	N/A
Number of Critical Infrastructure Structures	0
Description of Critical Infrastructure Structures	N/A
Number of Road Crossings	1
List of Roads Affected	KY-3199
Estimated PAR	Less than 5
PAR Assumptions	Only PAR would be associated with road crossings, limited areas of the road are inundated.
Inundation Mapping Source	Prior Stantec Analysis (Simplified Dam Breach Run)
Life Loss Notes	Life Loss would be associated with roads/transient population only

C.4 Potential Failure Modes

PFM NUMBER	PFM GROUP	PFM DESCRIPTION	RISK ASSESSMENT
I-1	SLOPE STABILITY	Under normal pool conditions, a slope failure triggers a mass movement of soil on the downstream face of the dam. Pore pressures at the downstream toe are elevated by the downstream pond. Successive slope failures retrogress back to the crest, then to the upstream side of the crest. Material is pushed into the failure from the crest, but the intervention fails. The crest drops below the pool elevation, which overtops the dam breach. The resulting flows scour downward through the dam embankment, releasing the reservoir.	NEGLIGIBLE
I-2a	INTERNAL EROSION	Beneath the dam - The dam was constructed on top of a thick alluvial deposit. Under normal pool conditions, seepage develops in the sandy soils beneath the dam and exits unfiltered at the submerged toe. The exit gradients are high enough to cause uplift or sand boils. An eroded pipe forms at the exit and progresses backward under the dam, toward the upstream pool. The embankment over the seepage path does not collapse. The seepage is not detected and there is no intervention. The flow rate increases rapidly through the eroded pipe, scouring a large void within the foundation. The embankment collapses into the void, the dam is breached, and there is an uncontrolled release of the reservoir.	CREDIBLE

I-2b	INTERNAL EROSION	Through the dam - Under normal pool conditions, seepage develops through lifts of sandy material in the dam embankment. The downstream exit is not filtered. The seepage erodes the soil and exits on the downstream face of the dam. An eroded pipe forms and progresses through the dam toward the upstream pool. The embankment over the seepage path does not collapse. The flow path expands and the flow accelerates. The seepage is not detected and there is no intervention. The flow scours a larger void in the embankment, leading to a collapse of the dam crest. The dam is breached and there is an uncontrolled release of the reservoir.	CREDIBLE
I-2c	INTERNAL EROSION	Along abutments - There is an exposure of highly irregular sandstone with caves and open joints in the left abutment. The surface was not treated or smoothed during construction. Under normal pool conditions, seepage develops along the embankment-abutment interface, potentially through low-stress areas within rock cavities or overhanging ledges. The seepage exits on the downstream groin. An eroded pathway forms and progresses along the abutment interface toward the upstream pool. The seepage is not detected and there is no intervention. The flow rate increases, eroding more soil, forming a void. The embankment collapses into the void, the dam is breached, and there is an uncontrolled release of the reservoir.	CREDIBLE
I-3	SEISMIC	A strong earthquake occurs near the dam site. The seismic shaking triggers liquefaction in the foundation sands under the dam embankment. The strength of the foundation soil drops significantly, resulting in upstream and/or downstream slope failures. During and after the earthquake, the failure progresses across the width of the dam crest. There is no time for intervention. The crest drops below normal pool and the reservoir overtops. The resulting flows scour downward through the dam embankment, releasing the reservoir.	CREDIBLE

I-4	OVERTOPPING	A heavy precipitation event occurs in the watershed, causing the reservoir level to rise. Water is released through the two spillway pipes, but the entrance to one or both becomes clogged. The reduced spillway capacity is insufficient to pass the stormwater inflow. The water levels continue to rise and overtop the dam crest. Efforts to raise the dam crest are unsuccessful. The overtopping flows begin to erode the downstream slope of the dam embankment. The flow causes head cutting, which progresses backward across the width of the dam crest. The dam is breached when the crest erosion reaches the upstream pool. The resulting flows scour downward through the dam embankment, releasing the reservoir.	CREDIBLE
I-5a	EROSION ASSOCIATED WITH CONDUITS	The principal and auxiliary spillway pipes are corrugated metal pipe (CMP); one or both pipes are corroded and deteriorated. At normal pool conditions, eroded soil enters the principal spillway CMP and is carried away with the discharge flow. The erosion and loss of soil is accelerated during flood events. Flood levels also initiate erosion into the auxiliary spillway CMP. A void develops along one or both pipes, and enlarges and lengthens over time. The erosion and void are not detected and there is no intervention. Water flows through the void along the pipe, scouring downward through the dam embankment. The dam is breached and there is an uncontrolled release of the reservoir.	CREDIBLE

I-5b	EROSION ASSOCIATED WITH CONDUITS	When reservoir levels are above normal pool, seepage develops within the backfill along the outside of the principal or auxiliary spillway pipes. Over multiple events, the seepage erodes the soil and an open flow path develops along the pipe. The erosion and void are not detected and there is no intervention. During a flood, water flows through the void along the pipe, scouring downward through the dam embankment. The dam is breached and there is an uncontrolled release of the reservoir.	CREDIBLE
I-6	SPILLWAY STRUCTURES	See I-8	NEGLIGIBLE
I-7	OPERATIONAL	The entrance to the principal spillway has been modified with a steel orifice plate. The lake level is several inches higher than the design normal condition, and the inlet is constricted. As a result, the auxiliary spillway is activated for smaller, more frequent storm events. The annual probability of overtopping is increased. A heavy precipitation event occurs in the watershed, causing the reservoir level to rise. Water is released through the two spillway pipes, but the entrance to one or both becomes clogged. The reduced spillway capacity is insufficient to pass the stormwater inflow. The water levels continue to rise and overtop the dam crest. Efforts to raise the dam crest are unsuccessful. The overtopping flows begin to erode the downstream slope of the dam embankment. The flow causes head cutting, which	CREDIBLE

		progresses backward across the width of the dam crest. The dam is breached when the crest erosion reaches the upstream pool. The resulting flows scour downward through the dam embankment, releasing the reservoir.	
I-8	SURFACE EROSION	The principal spillway pipe, auxiliary spillway pipe, the 18-inch drain pipe on the right abutment, and stormwater runoff from the roadway discharge onto the downstream slope of the dam. Over time and repeated storm events, the downstream face of the dam is eroded by concentrated flows from these sources. The localized erosion over-steepens the slope and triggers a slope failure. The slope fails and then successive failures occur, retrogressing up the slope and across the width of the crest. Material is pushed into the failure from the crest, but the intervention fails. The crest drops below the pool elevation, which overtops the dam breach. The resulting flows scour downward through the dam embankment, releasing the reservoir.	NEGLIGIBLE

C.5 Evaluation of PFMs

Potential Failure Mode Analysis Table:

PFM No.:	I-1	**Dam:**	Indian Lake (I)
PFM Group:	Slope Stability		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*

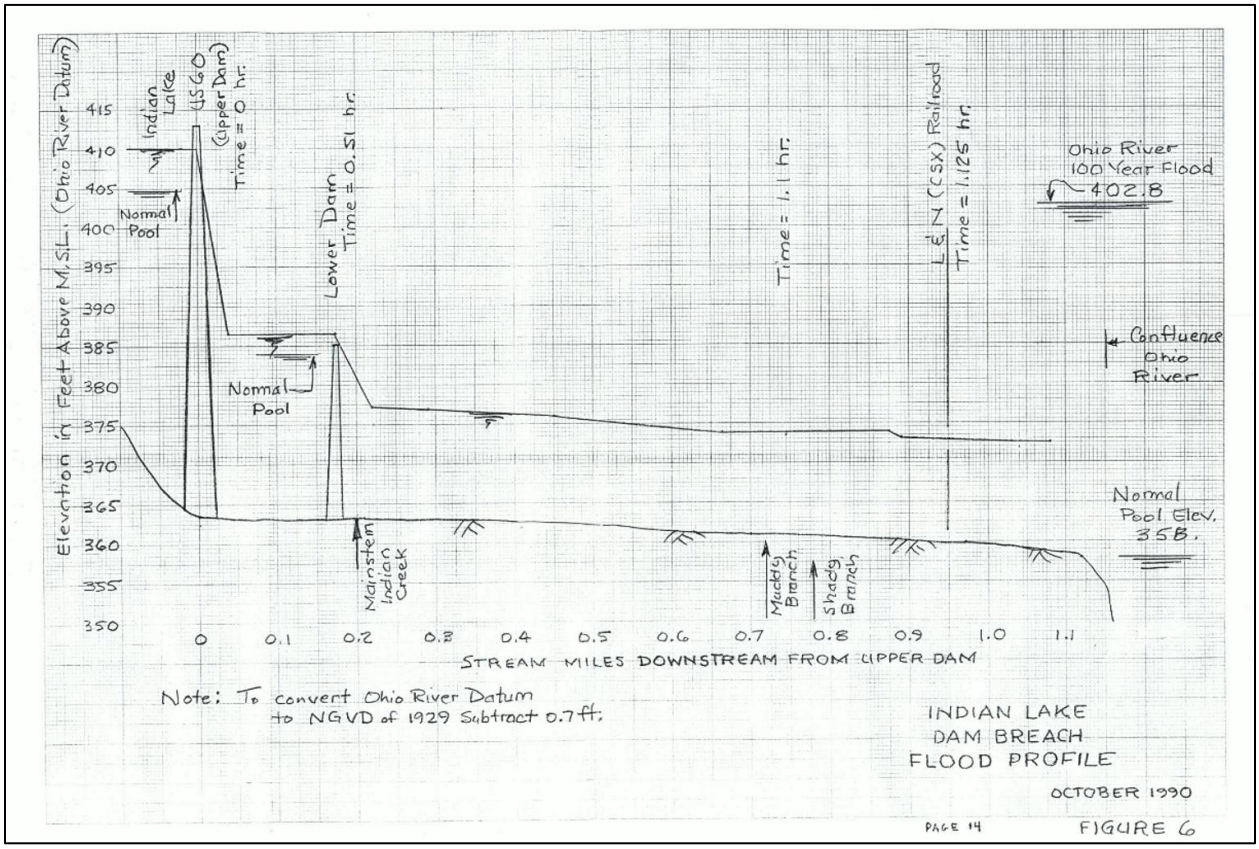
Under normal pool conditions, a slope failure triggers a mass movement of soil on the downstream face of the dam. Pore pressures at the downstream toe are elevated by the downstream pond. Successive slope failures retrogress back to the crest, then to the upstream side of the crest. Material is pushed into the failure from the crest, but the intervention fails. The crest drops below the pool elevation, which overtops the dam breach. The resulting flows scour downward through the dam embankment, releasing the reservoir.

More Likely (Adverse) Factors	Less Likely (Favorable) Factors
• **No information on the geotechnical conditions** • **No slope stability analysis** • **The downstream slope is steep (1.75:1)** • **Heavy vegetation growth and trees on the slope** • Historical documentation identifies a slump at the toe • Currently a slope failure on the right downstream hillside, adjacent to groin • Embankment was built pre-1921 and is not well compacted • Downstream reservoir has raised water pressures in the base of the dam • Cannot draw pool down (no lake drain)	• May have rock in the embankment fill (based on rock exposure we see at top of the dam) • **Progression of slope failures would be relatively slow, almost certain it would be reported** • **Chances of intervention are very high** • **Dam crest is very wide** • The sediment in the downstream reservoir has buried the toe of the dam

Risk Assessment	Category	Notes
Negligible? Credible?	Negligible	Detection and intervention is almost certain to prevent a dam failure
Failure Likelihood		
Life Safety Consequences		

Economic Consequences		
Risk Reduction Measures		
Studies and Investigations	Geotechnical analysis	
Maintenance and Monitoring	Remove vegetation and inspect for slope deformations	
Design and Modifications	Downstream berm	

Supporting Figures:



Profile from 1980 Dam Breach Analysis (Louisville District Corps of Engineers, 1990)

Potential Failure Mode Analysis Table:

PFM No.:	I-2a	**Dam:**	Indian Lake (I)
PFM Group:	Internal Erosion (Beneath the Dam)		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*

The dam was constructed on top of a thick alluvial deposit. Under normal pool conditions, seepage develops in the sandy soils beneath the dam and exits unfiltered at the submerged toe. The exit gradients are high enough to cause uplift or sand boils. An eroded pipe forms at the exit and progresses backward under the dam, toward the upstream pool. The embankment over the seepage path does not collapse. The seepage is not detected and there is no intervention. The flow rate increases rapidly through the eroded pipe, scouring a large void within the foundation. The embankment collapses into the void, the dam is breached, and there is an uncontrolled release of the reservoir.

More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
• This is a common failure mode • **The geologic maps indicate a deposit of alluvial material** • **The alluvial materials are likely silty sands and sands based on the geologic setting** • **The vegetation obscures the face of the dam** • **This failure mode could progress without detection** • There are no internal filtered drainage features • The composition of the embankment is unknown	• **The embankment soils may not have enough plasticity to hold a roof over the eroded pathway** • The tailwater reduces uplift pressures at the toe • **No direct observations of seepage exits** • **Wide and short embankment so hydraulic gradients are low** • Only certain soils are susceptible to backward erosion piping (uniform, fine sands)

Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Credible	
Failure Likelihood	FL3	Based on the geology, it is clear this condition could exist. The hydraulic gradient is relatively low. There are no reports of seepage but the exit is obscured by vegetation.
Life Safety Consequences	LS0	
Economic Consequences	EC1	KY3199 would likely not be replaced if it were destroyed. But must consider environmental

		damage. Possible economic consequences to the club for recreational purposes.
Risk Reduction Measures		
Studies and Investigations	Geotechnical investigation and analysis. Investigate information sources in relation to the 1983 breach.	
Maintenance and Monitoring	Tree and vegetation clearing	
Design and Modifications	Filter berm on the downstream slope.	

PFM No.:	I-2b	**Dam:**	Indian Lake (I)
PFM Group:	Internal Erosion (Through the Dam)		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*

Under normal pool conditions, seepage develops through lifts of sandy material in the dam embankment. The downstream exit is not filtered. The seepage erodes the soil and exits on the downstream face of the dam. An eroded pipe forms and progresses through the dam toward the upstream pool. The embankment over the seepage path does not collapse. The flow path expands and the flow accelerates. The seepage is not detected and there is no intervention. The flow scours a larger void in the embankment, leading to a collapse of the dam crest. The dam is breached and there is an uncontrolled release of the reservoir.

More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
• This is a common failure mode • **The source of the borrow for the embankment is unknown but source appears to be sandy** • **The alluvial materials are likely silty sands and sands based on the geologic setting** • **The vegetation obscures the face of the dam** • **This failure mode could progress without detection** • There are no internal filtered drainage features • The composition of the embankment is unknown	• **The embankment soils may not have enough plasticity to hold a roof over the eroded pathway** • **No direct observations of seepage exits** • **Wide and short embankment so hydraulic gradients are low** • Only certain soils are susceptible to backward erosion piping (uniform, fine sands) • Part of the embankment may have reconstructed after the 1983 breach

Risk Assessment	Category	Notes
Negligible? Credible?	Credible	
Failure Likelihood	FL2	This condition may exist. The hydraulic gradient is relatively low. There are no reports of seepage but the exit is obscured by vegetation.
Life Safety Consequences	LS0	
Economic Consequences	EC1	KY3199 would likely not be replaced if it were destroyed. But must consider environmental damage. Possible economic consequences to the club for recreational purposes.
Risk Reduction Measures		
Studies and Investigations	Geotechnical investigation and analysis. Investigate information sources in relation to the 1983 breach.	
Maintenance and Monitoring	Tree and vegetation clearing	
Design and Modifications	Filter berm on the downstream slope.	

PFM No.:	I-2c	**Dam:**	Indian Lake (I)
PFM Group:	Internal Erosion (Along Abutments)		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*

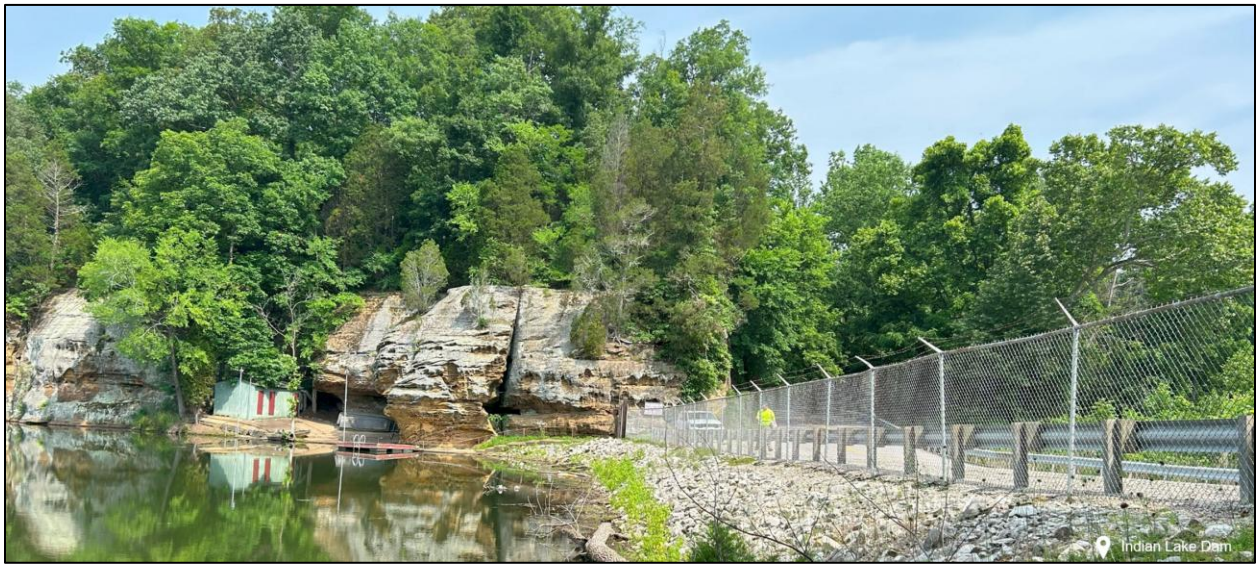
There is an exposure of highly irregular sandstone with caves and open joints in the left abutment. The surface was not treated or smoothed during construction. Under normal pool conditions, seepage develops along the embankment-abutment interface, potentially through low-stress areas within rock cavities or overhanging ledges. The seepage exits on the downstream groin. An eroded pathway forms and progresses along the abutment interface toward the upstream pool. The seepage is not detected and there is no intervention. The flow rate increases, eroding more soil, forming a void. The embankment collapses into the void, the dam is breached, and there is an uncontrolled release of the reservoir.

More Likely (Adverse) Factors	Less Likely (Favorable) Factors
• This is a common failure mode • **The exposure of the rock on the left abutment is highly irregular**	• **No direct observations of seepage exits** • **Wide and short embankment so hydraulic gradients are low**

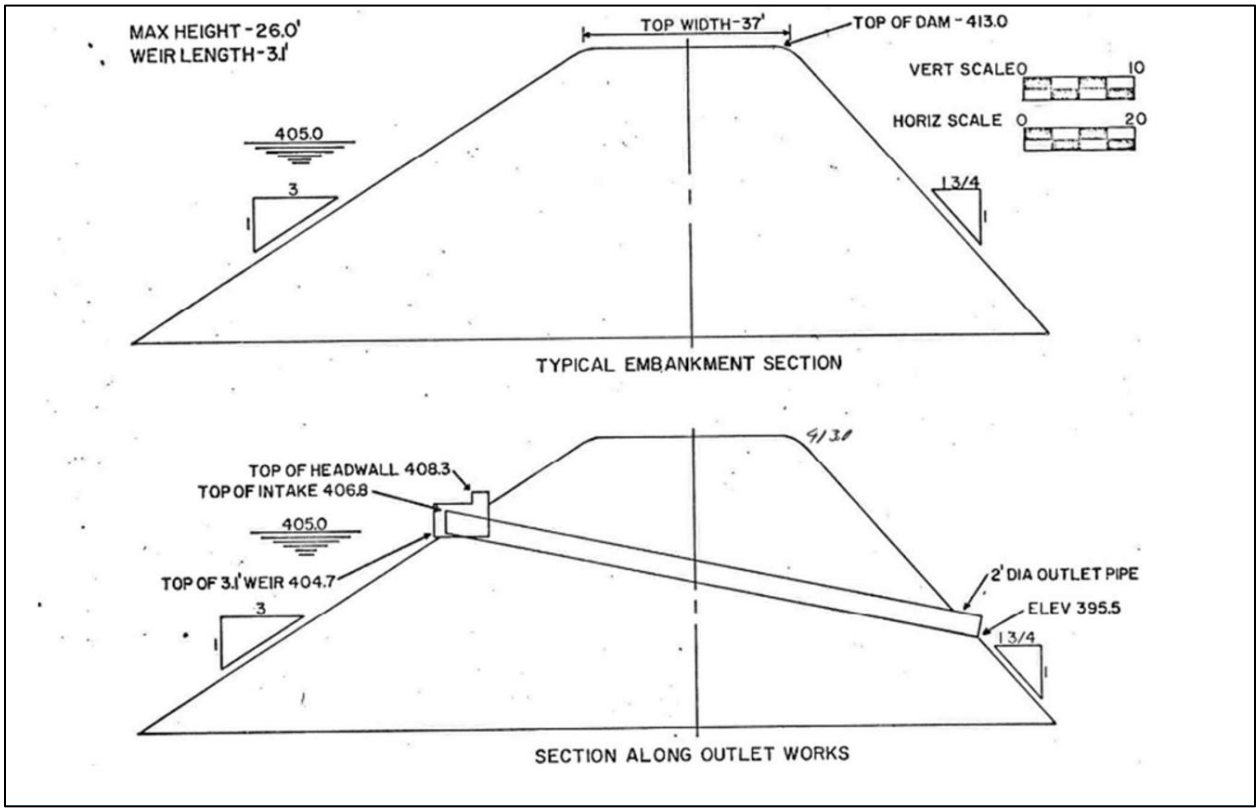
• The alluvial materials are likely silty sands and sands based on the geologic setting • **The vegetation obscures the face of the dam** • **This failure mode could progress without detection** • There are no internal filtered drainage features • The composition of the embankment is unknown • This could progress as concentrated leak erosion • Lack of compaction in the embankment based on the age of construction • Construction methods are more likely to have left an irregular rock surface	

Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Credible	
Failure Likelihood	FL3	Based on the geology, it is clear this condition could exist. The hydraulic gradient is relatively low. There are no reports of seepage but the exit is obscured by vegetation.
Life Safety Consequences	LS0	
Economic Consequences	EC1	KY3199 would likely not be replaced if it were destroyed. But must consider environmental damage. Possible economic consequences to the club for recreational purposes.
Risk Reduction Measures		
Studies and Investigations	Geotechnical investigation and analysis. Investigate information sources in relation to the 1983 breach.	
Maintenance and Monitoring	Tree and vegetation clearing	
Design and Modifications	Filter berm on the downstream slope.	

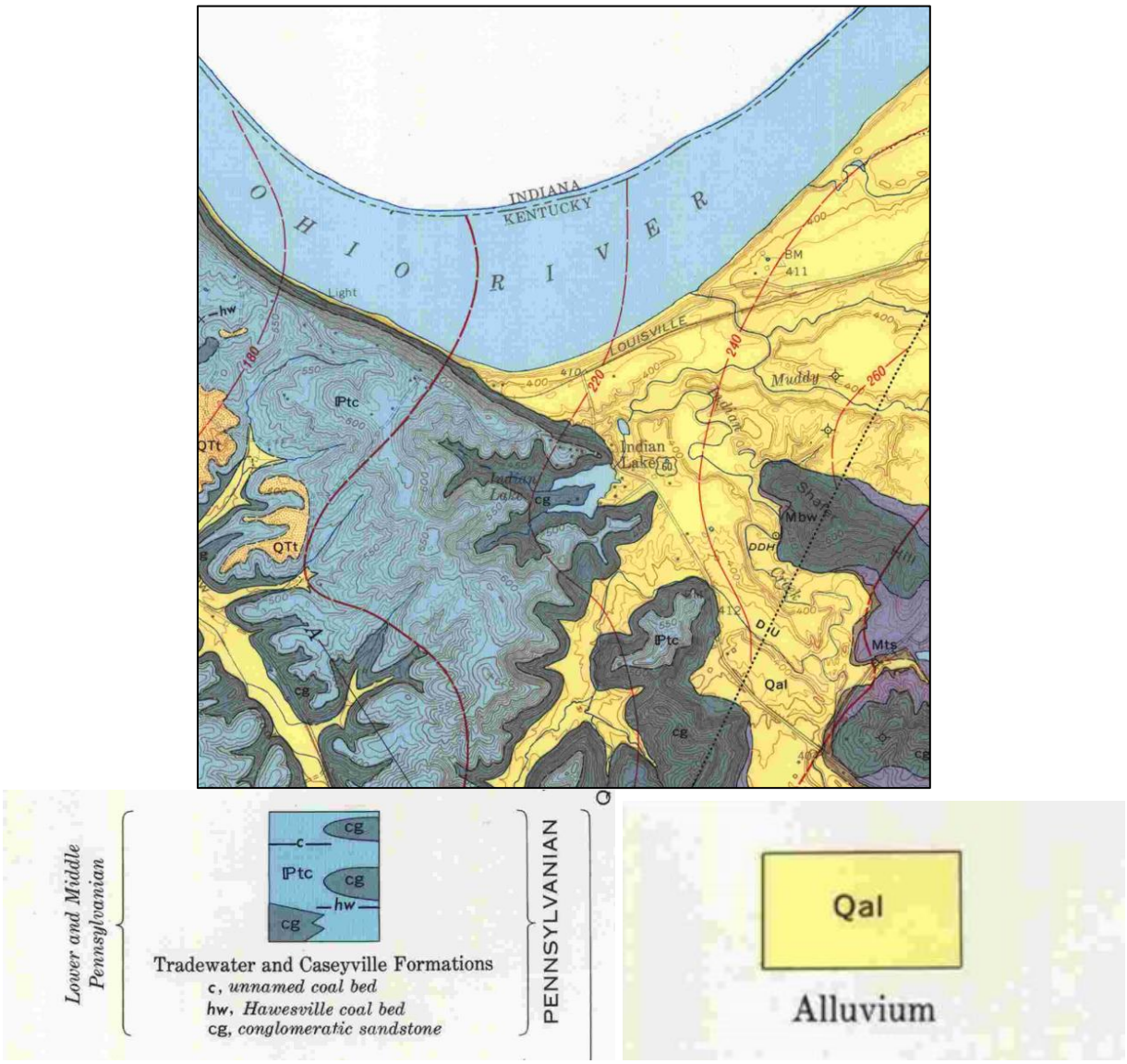
Supporting Figures:



Site Visit Photo



Cross Section (Louisville District Corps of Engineers, 1990)



GeoQuad Map (Commonwealth of Kentucky, 1965)

Potential Failure Mode Analysis Table:

PFM No.:	I-3	**Dam:**	Indian Lake (I)
PFM Group:	Seismic		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*

A strong earthquake occurs near the dam site. The seismic shaking triggers liquefaction in the foundation sands under the dam embankment. The strength of the foundation soil drops significantly, resulting in upstream and/or downstream slope failures. During and after the earthquake, the failure progresses across the width of the dam crest. There is no time for intervention. The crest drops below normal pool and the reservoir overtops. The resulting flows scour downward through the dam embankment, releasing the reservoir.

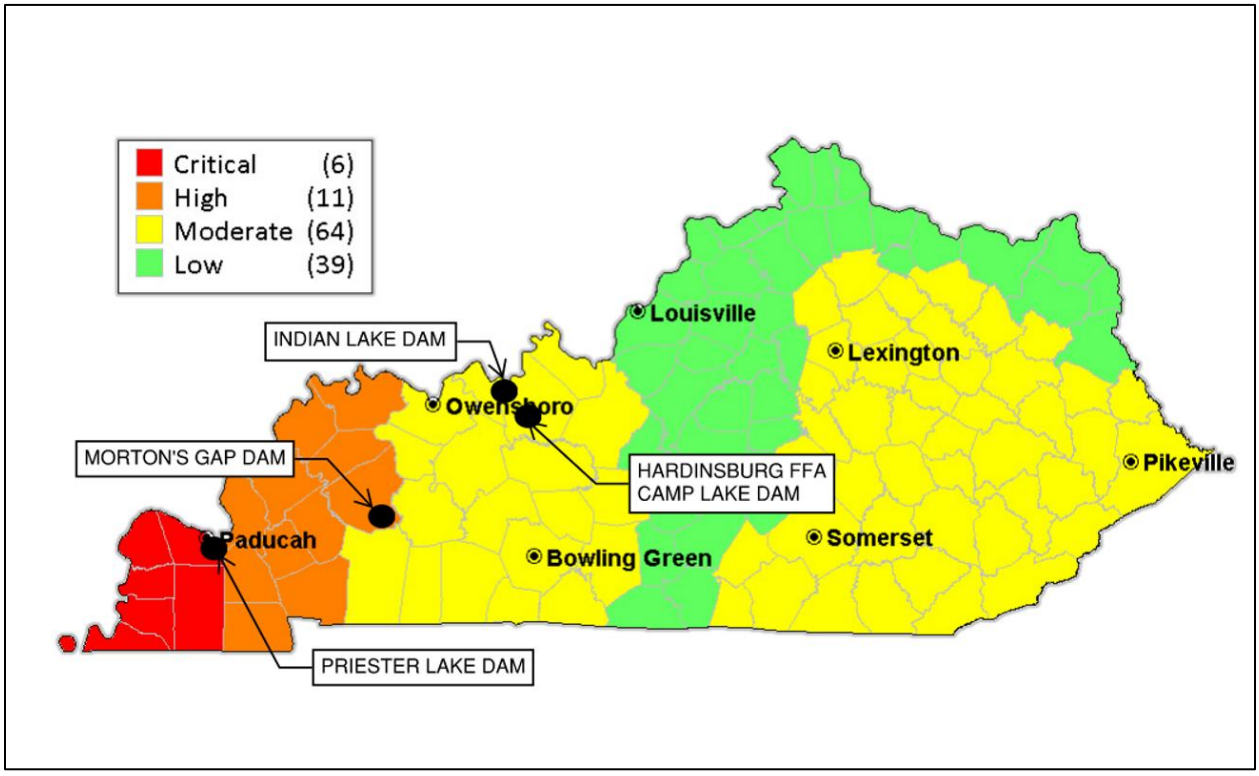
More Likely (Adverse) Factors	Less Likely (Favorable) Factors
• **There are no stability or liquefaction analyses** • **Located in Western Kentucky with higher seismic hazard** • **Liquifiable soils are present based on geologic setting** • AEP=9.54E-4 when g=0.103 • **Intervention is not possible** • **With liquification in the foundation, large slope movements are more likely** • Could have internal planes of weakness in the embankment due to construction history • Embankment soils are likely not well compacted	• **The failure must go all the way across the crest** • The liquified deposits may be deep (with respect to the height) beneath the dam

Risk Assessment	Category	Notes
Negligible? Credible?	Credible	
Failure Likelihood	FL3	Liquifiable soils known to be in the region, though specifically at the dam is unknown.
Life Safety Consequences	LS0	See I-2
Economic Consequences	EC1	See I-2

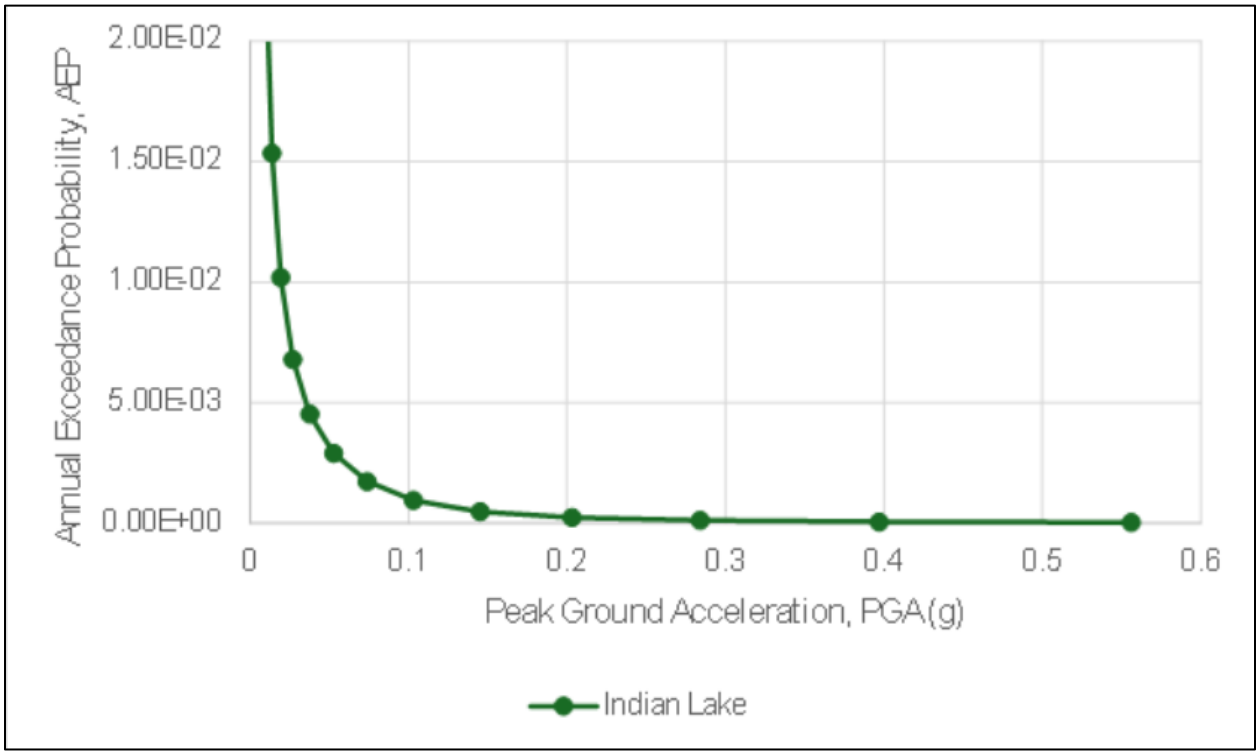
Risk Reduction Measures

Studies and Investigations	Geotechnical explorations and analysis
Maintenance and Monitoring	
Design and Modifications	Downstream berm

Supporting Figures:



Seismic Map



Peak Ground Acceleration versus Annual Exceedance Probability Graph

Potential Failure Mode Analysis Table:

PFM No.:	I-4	**Dam:**	Indian Lake (I)
PFM Group:	Overtopping		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*

A heavy precipitation event occurs in the watershed, causing the reservoir level to rise. Water is released through the two spillway pipes, but the entrance to one or both becomes clogged. The reduced spillway capacity is insufficient to pass the stormwater inflow. The water levels continue to rise and overtop the dam crest. Efforts to raise the dam crest are unsuccessful. The overtopping flows begin to erode the downstream slope of the dam embankment. The flow causes head cutting, which progresses backward across the width of the dam crest. The dam is breached when the crest erosion reaches the upstream pool. The resulting flows scour downward through the dam embankment, releasing the reservoir.

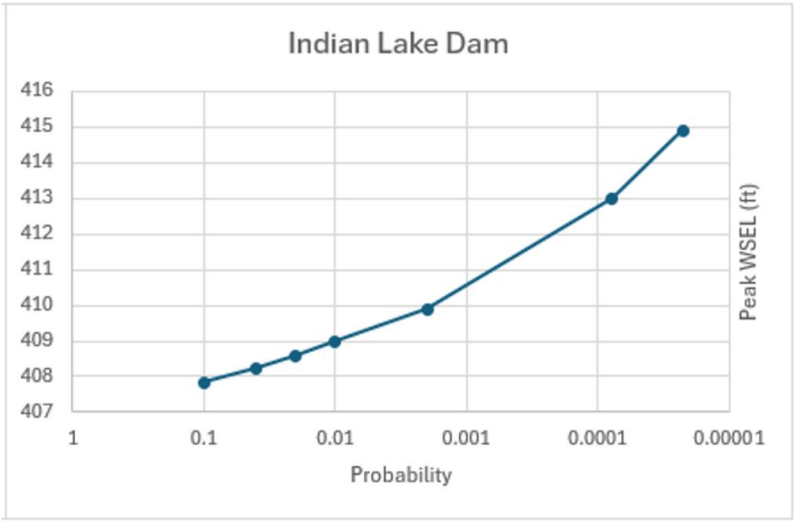
More Likely (Adverse) Factors	Less Likely (Favorable) Factors
• **The dam may have overtopping history** • **The reservoir is in a wooded area, increasing the chances for woody debris** • There is a potential for clogging due to small diameter. From regulatory perspective, this is not an "non-clogged spillway pipe". • **Flood storage capacity is reduced through current operations (orifice plate on principal spillway)** • **Embankment may be an erodible soil** • Potential for landslide downstream of the dam to block the discharge pipe • The shape of the crest would concentrate the flows to one location • Debris can be caught in chain-link fence on the upstream side	• Currently meets regulatory requirement for design flood for a significant hazard dam. • **Wider crest to breach vs. height of dam** • **Some redundancy against clogging due to two spillway pipes on either end of dam** • Crest is paved

Risk Assessment	Category	Notes
Negligible? Credible?	Credible	
Failure Likelihood	FL3	7.7e-5 return interval for overtopping
Life Safety Consequences	LS0	See I-2

Economic Consequences	EC1	See I-2
Risk Reduction Measures		
Studies and Investigations	Updated H&H analysis	
Maintenance and Monitoring	Routine debris removal	
Design and Modifications	Remove orifice plate	

Supporting Figures:

Indian Lake (Dam Crest = 413.0 ft)				
Precip (in)	**Peak Inflow (cfs)**	**Peak WSEL (ft)**	**Return Interval**	**Notes**
3.29	323.14	407.8328	0.1	10yr
3.93	473.06	408.2358	0.04	25yr
4.46	606.53	408.5864	0.02	50yr
5.02	756.91	408.9811	0.01	100yr
6.46	1172.77	409.8977	0.002	500yr
13.18	3298.09	412.9978	0.000077001	**Overtopping**
28.2	8120.72	414.8983	0.00002255	**PMP**



H&H Results

Freeboard Hydrograph

Class (A) $P_A = P_{100} + 0.12\ x\ (PMP - P_{100})$
Class (B) $P_B = P_{100} + 0.40\ x\ (PMP - P_{100})$
Class (C) $P_C = PMP$

Freeboard Formula from the KDOW Memo #5 (Department for Natural Resources and Environmental Protection)

Hydraulic Capacity: This structure is hydraulically sufficient. The dam is capable of passing 13.1 inches during a 6-hour One Percent Annual Storm.

Information from 2013 KDOW Inspection Report (KDOW, 2013)

Potential Failure Mode Analysis Table:

PFM No.:	I-5a	**Dam:**	Indian Lake (I)
PFM Group:	Erosion Associated with Conduits		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*

The principal and auxiliary spillway pipes are corrugated metal pipe (CMP); one or both pipes are corroded and deteriorated. At normal pool conditions, eroded soil enters the principal spillway CMP and is carried away with the discharge flow. The erosion and loss of soil is accelerated during flood events. Flood levels also initiate erosion into the auxiliary spillway CMP. A void develops along one or both pipes, and enlarges and lengthens over time. The erosion and void are not detected and there is no intervention. Water flows through the void along the pipe, scouring downward through the dam embankment. The dam is breached and there is an uncontrolled release of the reservoir.

More Likely (Adverse) Factors	Less Likely (Favorable) Factors
• **The pipe is demonstrating corrosion and deterioration** • **Failure mode is more common with CMP** • Exceeded the service life of CMP • Failure mode can accelerate under flood pool conditions • **Poor compaction around corrugated pipe**	• **The gradients are low under normal pool** • **Likely have time to intervene under normal pool**

Risk Assessment	Category	Notes
Negligible? Credible?	Credible	
Failure Likelihood	FL4	No evidence of erosion in the pipe
Life Safety Consequences	LS0	See I-2
Economic Consequences	EC1	See I-2
Risk Reduction Measures		
Studies and Investigations		
Maintenance and Monitoring	Monitor for depression in the road	
Design and Modifications	Lining or replacing the CMP pipe	

PFM No.:	I-5b	**Dam:**	Indian Lake (I)
PFM Group:	Erosion Associated with Conduits		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*

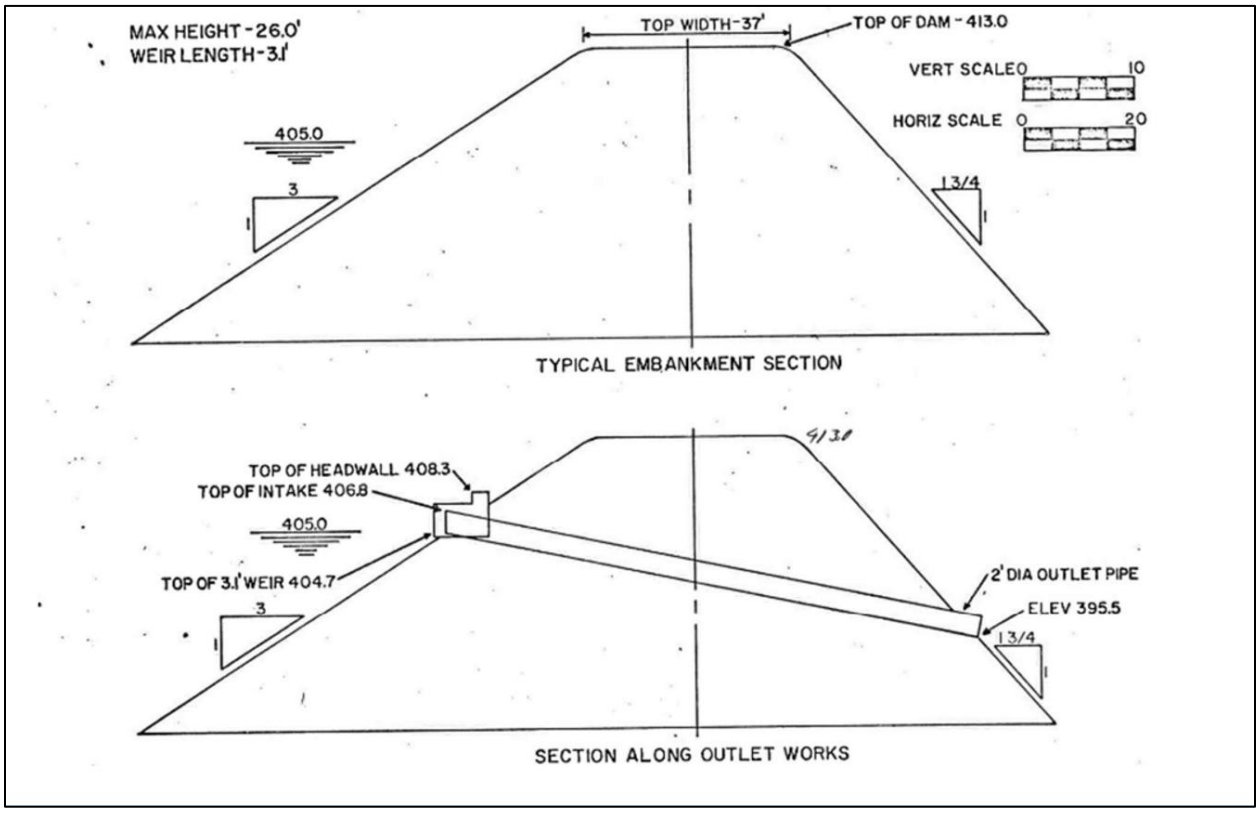
When reservoir levels are above normal pool, seepage develops within the backfill along the outside of the principal or auxiliary spillway pipes. Over multiple events, the seepage erodes the soil and an open flow path develops along the pipe. The erosion and void are not detected and there is no intervention. During a flood, water flows through the void along the pipe, scouring downward through the dam embankment. The dam is breached and there is an uncontrolled release of the reservoir.

More Likely (Adverse) Factors	Less Likely (Favorable) Factors
• **Poor compaction around corrugated pipe** • Slope of the pipe results in a higher gradient	• **The gradients are generally low** • **Likely have time to intervene under normal pool**

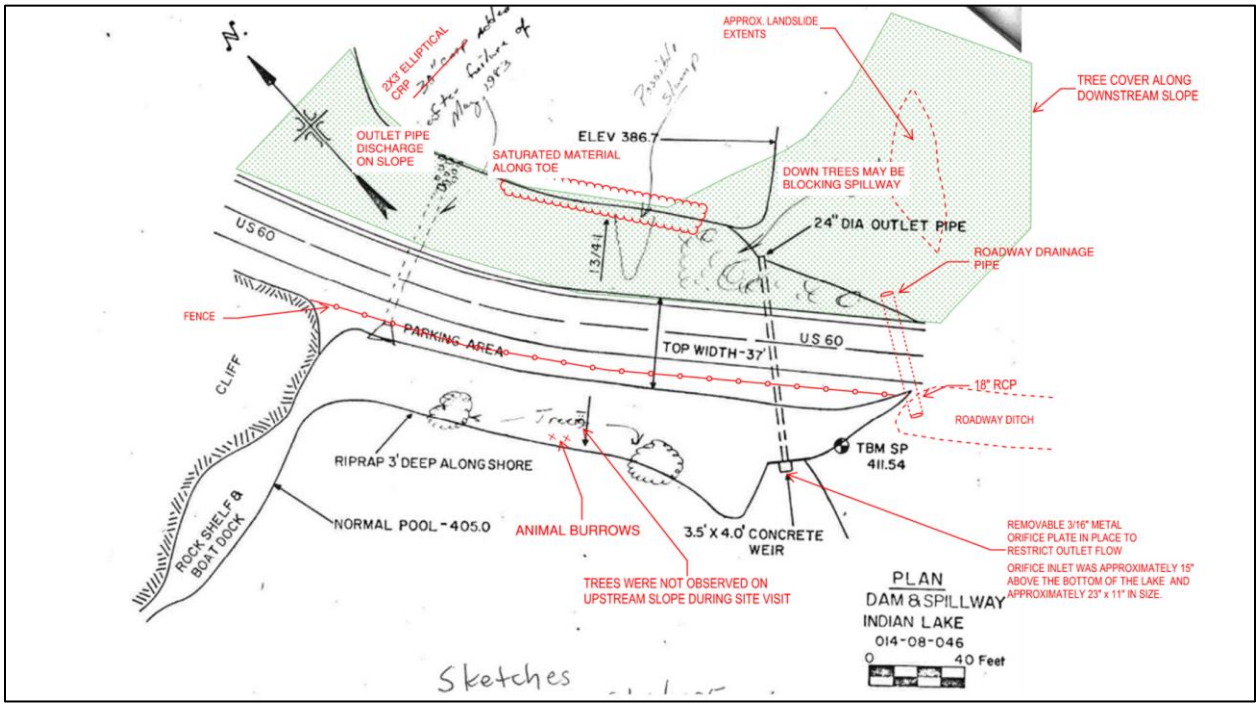
Risk Assessment	Category	Notes
Negligible? Credible?	Credible	
Failure Likelihood	FL1	Only occurs during flood events

Life Safety Consequences	LS0	See I-2
Economic Consequences	EC1	See I-2
Risk Reduction Measures		
Studies and Investigations		
Maintenance and Monitoring	Monitor for depression in the road	
Design and Modifications	Lining or replacing the concrete pipe	

Supporting Figures:



Cross Section (Louisville District Corps of Engineers, 1990)



Plan View with Site Visit Observations (Louisville District Corps of Engineers, 1990)

Potential Failure Mode Analysis Table:

PFM No.:	I-6	**Dam:**	Indian Lake (I)
PFM Group:	Spillway Structures		
PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*			
See I-8			
More Likely (Adverse) Factors		**Less Likely (Favorable) Factors**	
See I-8		See I-8	
Risk Assessment	**Category**	**Notes**	
Negligible? Credible?	Negligible		
Failure Likelihood			
Life Safety Consequences			
Economic Consequences			
Risk Reduction Measures			
Studies and Investigations			
Maintenance and Monitoring			
Design and Modifications			

Potential Failure Mode Analysis Table:

PFM No.:	I-7	**Dam:**	Indian Lake (I)
PFM Group:	Operational		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*

The entrance to the principal spillway has been modified with a steel orifice plate. The lake level is several inches higher than the design normal condition, and the inlet is constricted. As a result, the auxiliary spillway is activated for smaller, more frequent storm events. The annual probability of overtopping is increased.

A heavy precipitation event occurs in the watershed, causing the reservoir level to rise. Water is released through the two spillway pipes, but the entrance to one or both becomes clogged. The reduced spillway capacity is insufficient to pass the stormwater inflow. The water levels continue to rise and overtop the dam crest. Efforts to raise the dam crest are unsuccessful. The overtopping flows begin to erode the downstream slope of the dam embankment. The flow causes head cutting, which progresses backward across the width of the dam crest. The dam is breached when the crest erosion reaches the upstream pool. The resulting flows scour downward through the dam embankment, releasing the reservoir.

More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
• **The dam may have overtopping history** • **The reservoir is in a wooded area, increasing the chances for woody debris** • There is a potential for clogging due to small diameter. From regulatory perspective, this is not an "non-clogged spillway pipe". • **Flood storage capacity is reduced through current operations (orifice plate on principal spillway)** • **Embankment may be an erodible soil** • Potential for landslide downstream of the dam to block the discharge pipe • The shape of the crest would concentrate the flows to one location • Debris can be caught in chain-link fence on the upstream side • Orifice is easily accessible to the public • Evidence of modifications	• Currently meets regulatory requirement for design flood for a significant hazard dam. • **Wider crest to breach vs. height of dam** • **Some redundancy against clogging due to two spillway pipes on either end of dam** • Crest is paved

Risk Assessment	**Category**	**Notes**

Negligible? Credible?	Credible	
Failure Likelihood	FL4	Modifications have already been made
Life Safety Consequences	LC0	See I-2
Economic Consequences	EC1	See I-2
Risk Reduction Measures		
Studies and Investigations	H&H Analysis to quantify impacts of plate	
Maintenance and Monitoring	Add restrictive signage, install trash rack	
Design and Modifications		

Supporting Figures:



2025 Site Visit Photo



2013 Site Visit Photo

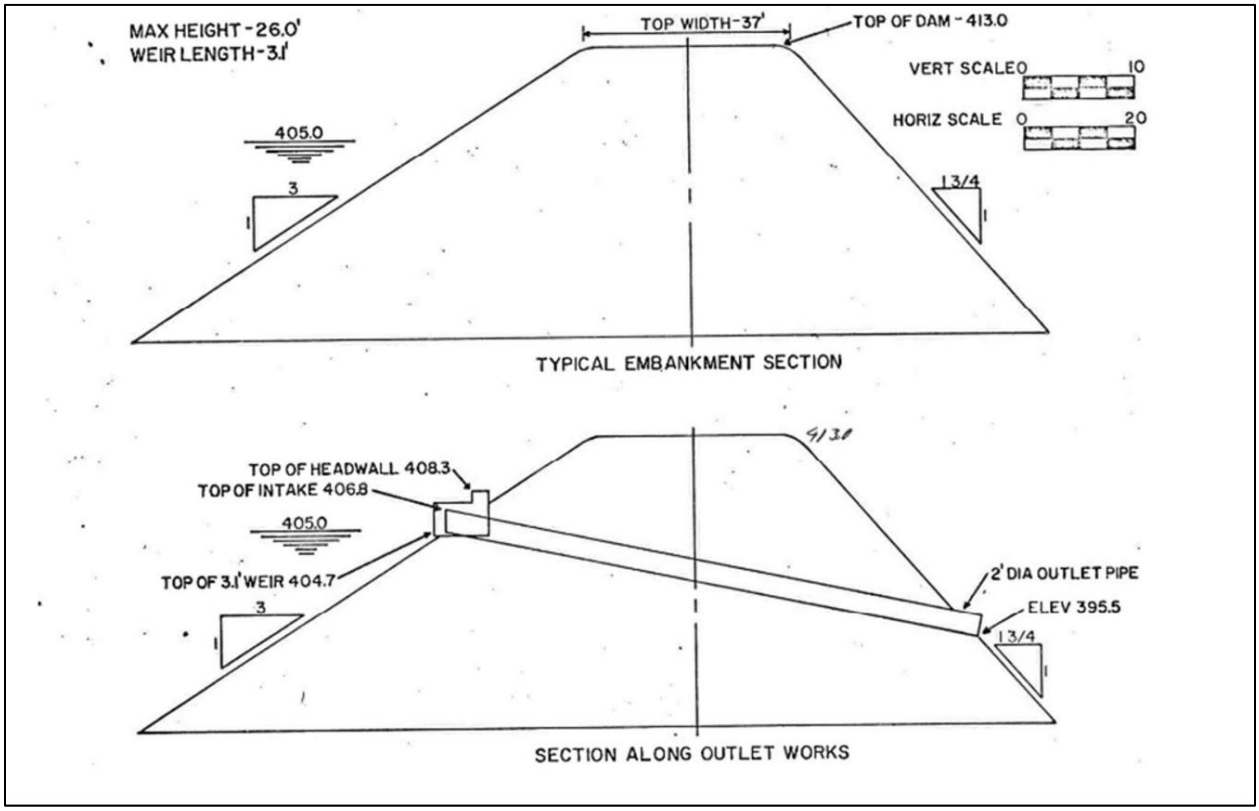
Potential Failure Mode Analysis Table:

PFM No.:	I-8	**Dam:**	Indian Lake (I)
PFM Group:	Surface Erosion		
PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*			
The principal spillway pipe, auxiliary spillway pipe, the 18-inch drain pipe on the right abutment, and stormwater runoff from the roadway discharge onto the downstream slope of the dam. Over time and repeated storm events, the downstream face of the dam is eroded by concentrated flows from these sources. The localized erosion over-steepens the slope and triggers a slope failure. The slope fails and then successive failures occur, retrogressing up the slope and across the width of the crest. Material is pushed into the failure from the crest, but the intervention fails. The crest drops below the pool elevation, which overtops the dam breach. The resulting flows scour downward through the dam embankment, releasing the reservoir.			
More Likely (Adverse) Factors		**Less Likely (Favorable) Factors**	
• **The downstream slope is steep (1.75:1)** • **Heavy vegetation growth and trees on the slope**		• **Progression of slope failures would be relatively slow, almost certain it would be reported** • **Chances of intervention are very high**	

• Currently a slope failure on the right downstream hillside, adjacent to groin • Embankment was built pre-1921 and is not well compacted • Cannot draw pool down (no lake drain) • Observed minor erosion from surface runoff and the primary spillway pipe	• **Dam crest is very wide** • **Outlet on two spillway pipes are protected with riprap**

Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Negligible	Detection and intervention is almost certain to prevent a dam failure
Failure Likelihood		
Life Safety Consequences		
Economic Consequences		
Risk Reduction Measures		
Studies and Investigations	Geotechnical analysis	
Maintenance and Monitoring	Remove vegetation and inspect for erosion	
Design and Modifications	Downstream berm	

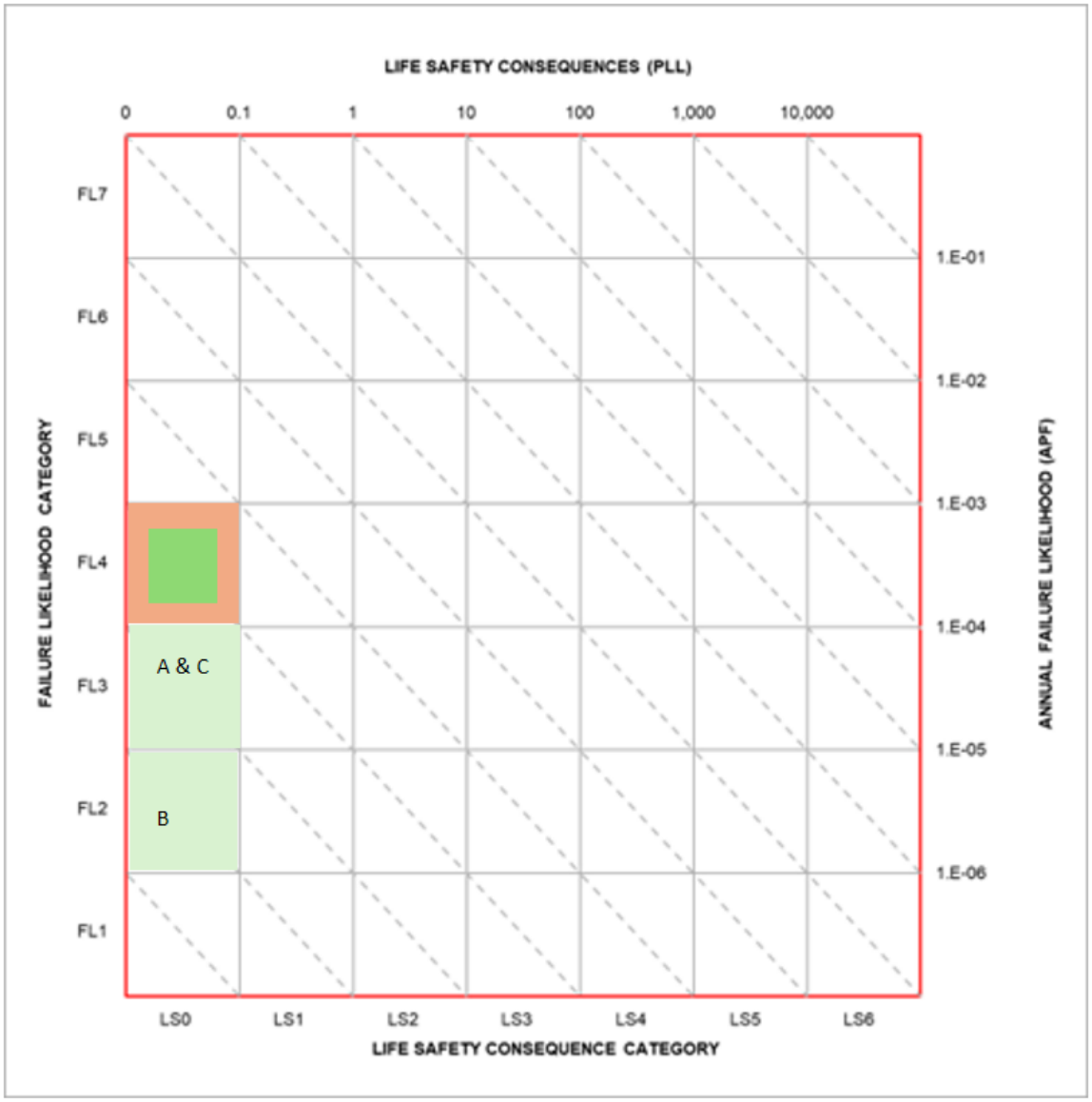
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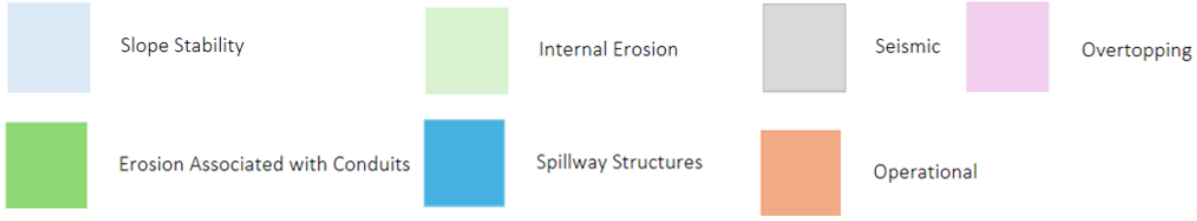
Cross Section (Louisville District Corps of Engineers, 1990)

C.6 Risk Matrices

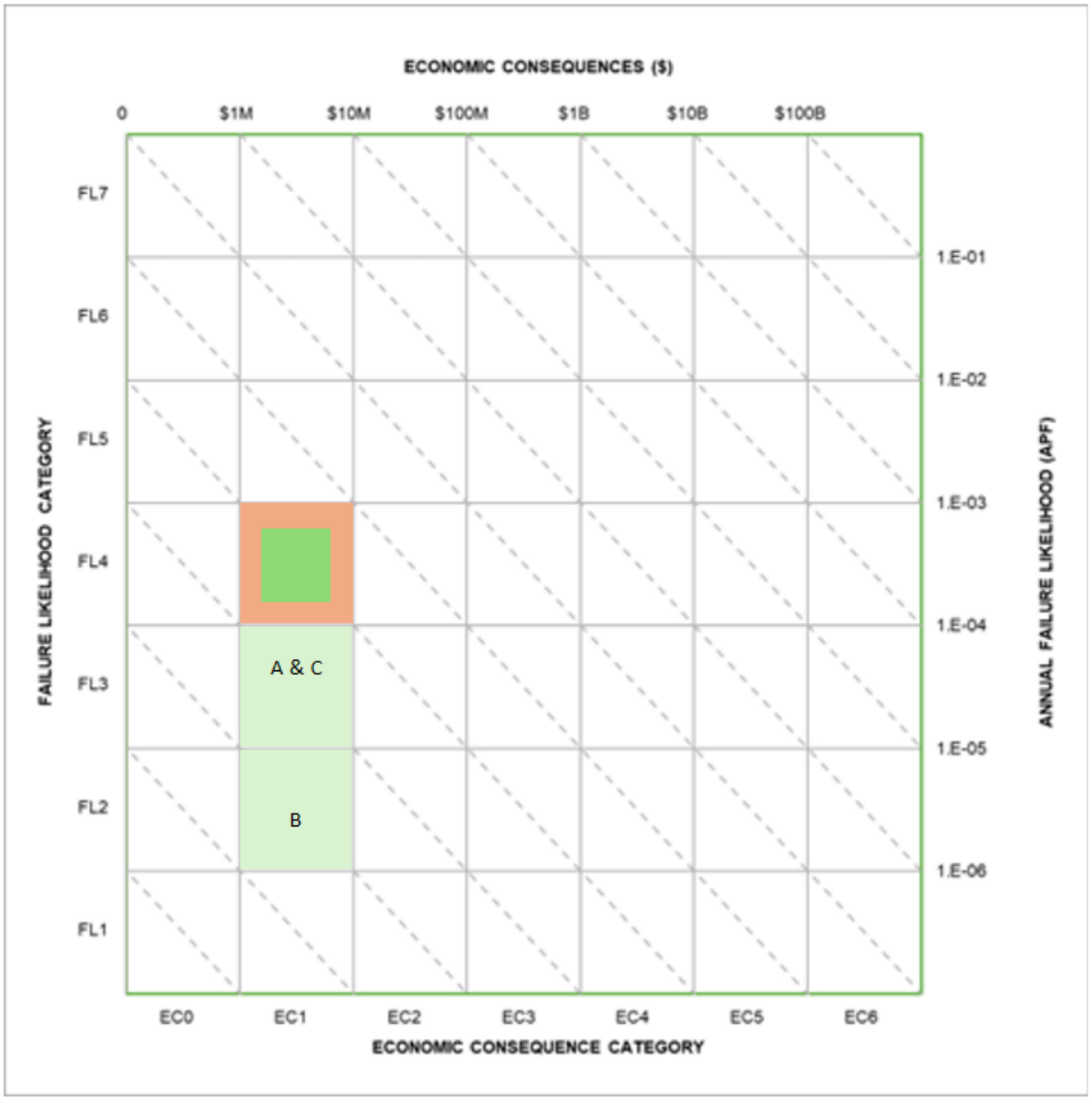
Life Safety Risk Matrix:



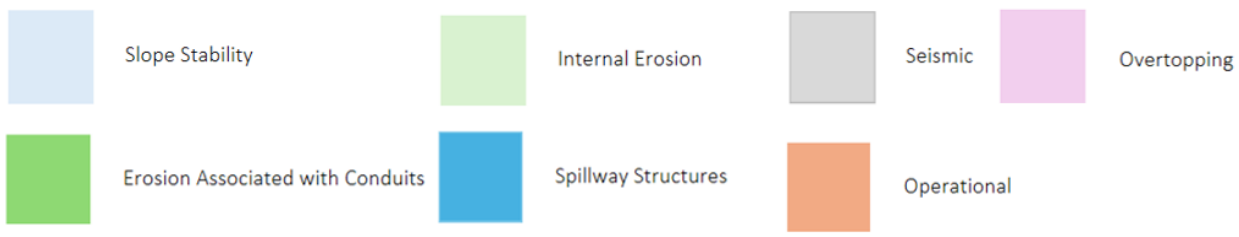
Legend:



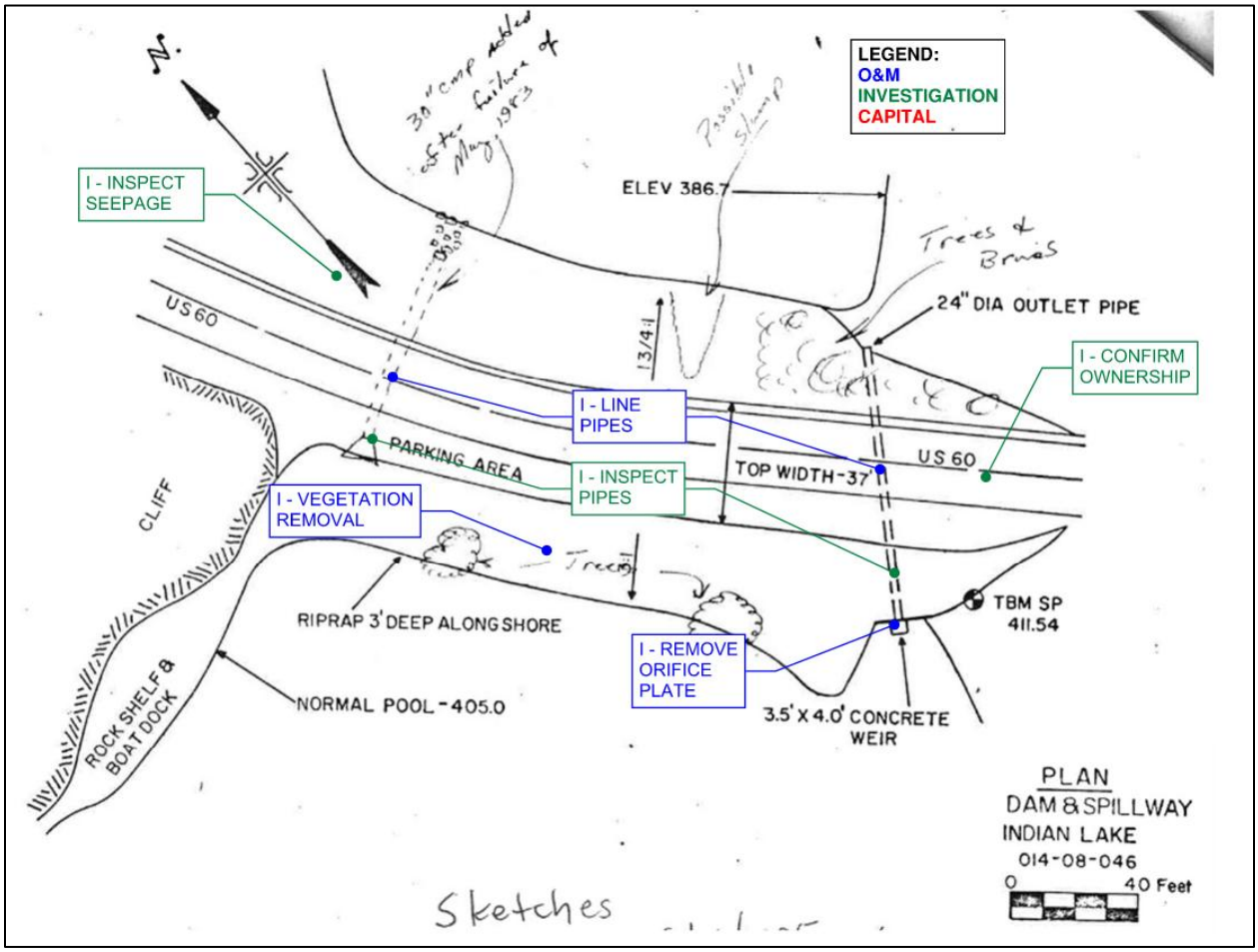
Economic Consequences Risk Matrix:



Legend:



C.7 Recommendations



Recommendations – Indian Lake Dam								
CODE	**Recommendation**	**Type**	**Life Loss Risk**	**Economic & Transportation Risk**	**Regulatory Compliance**	**Cost Range**	**Planning Horizon**	**Priority**
I - CONFIRM OWNERSHIP	Confirm ownership of the dam. Consider transfer of dam and roadway to county or other entity.	Investigation	-	-	No	<10K	Short Term	1
I - REMOVE ORIFICE PLATE	Remove all accessories associated with the orifice plate on the principal spillway entrance.	O&M	0	3	No	<10K	Short Term	2
I - VEGETATION REMOVAL	Remove vegetation, cut trees, and grub out stumps on the face of the dam and within 25-feet of the dam abutments.	O&M	0	0	Yes	10K-100K	Short Term	3
I - INSPECT SEEPAGE	Inspect and evaluate the dam and left abutment for potential seepage exits.	Investigation	0	3	No	10K-100K	Short Term	4
I - INSPECT PIPES	Inspect and evaluate the three pipes (principal spillway, auxiliary spillway, and stormwater) that cross the dam crest.	Investigation	0	4	No	<10K	Short Term	5
I - LINE PIPES	If the inspection shows excessive deterioration, then line the CMP pipes that cross the dam crest. Improve scour protection at the spillway and drainpipe outlets.	O&M	0	4	Yes	10K-100K	Intermediate	6

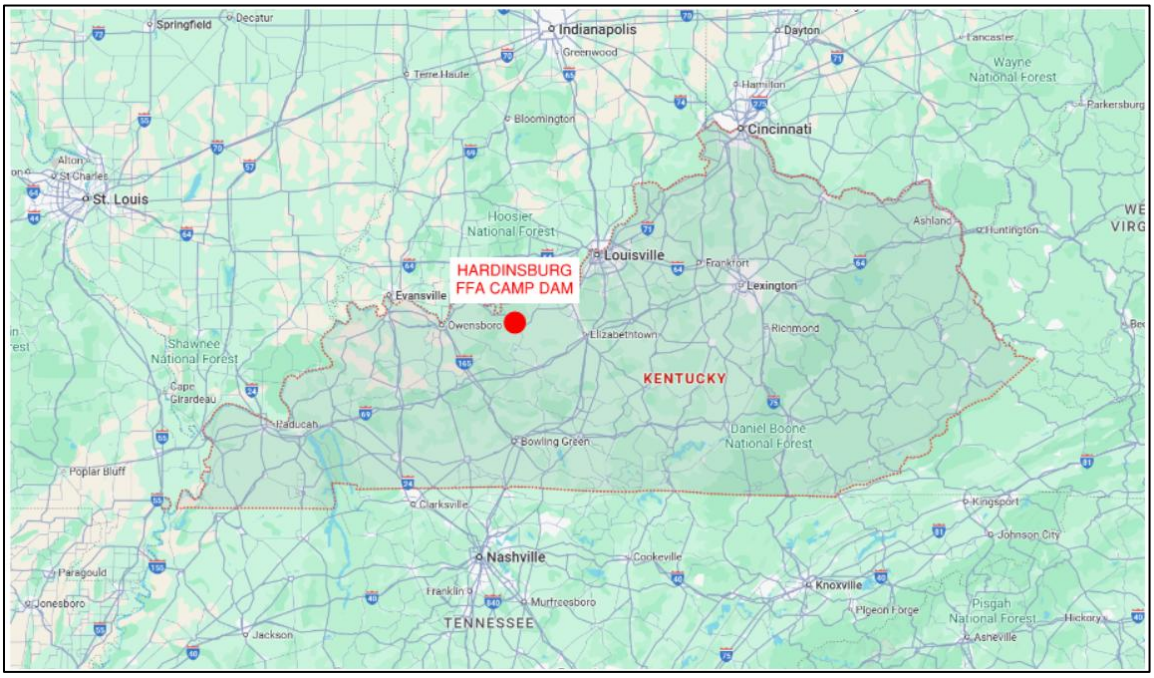
C.8 Cost Opinions for Capital Projects

No capital projects recommended for this dam.

Appendix D
Hardinsburg FFA Camp Lake Dam

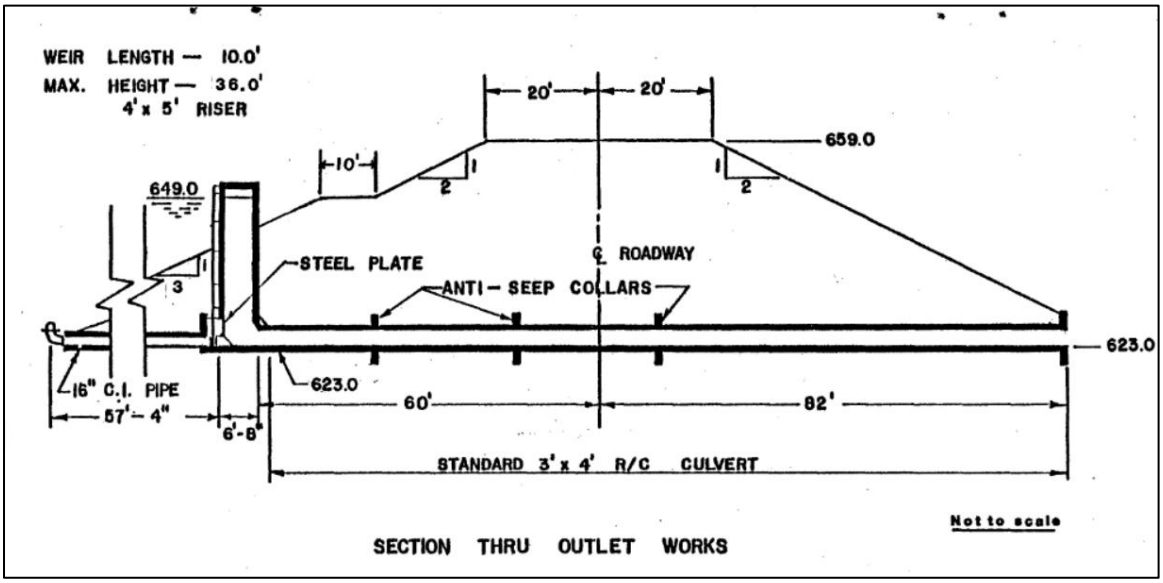
D.1 Dam and Appurtenant Features

Hardinsburg FFA Camp Lake Dam is located in Breckinridge County (location map below). The National Inventory of Dams lists the purpose of the dam as recreation. This dam was constructed in 1963 and is classified as significant hazard. The dam crest elevation is 659 ft, and KY-259 runs along the entire crest. The normal pool elevation is 649 ft. The height of the dam is 36 ft, and the crest width is 40 ft.

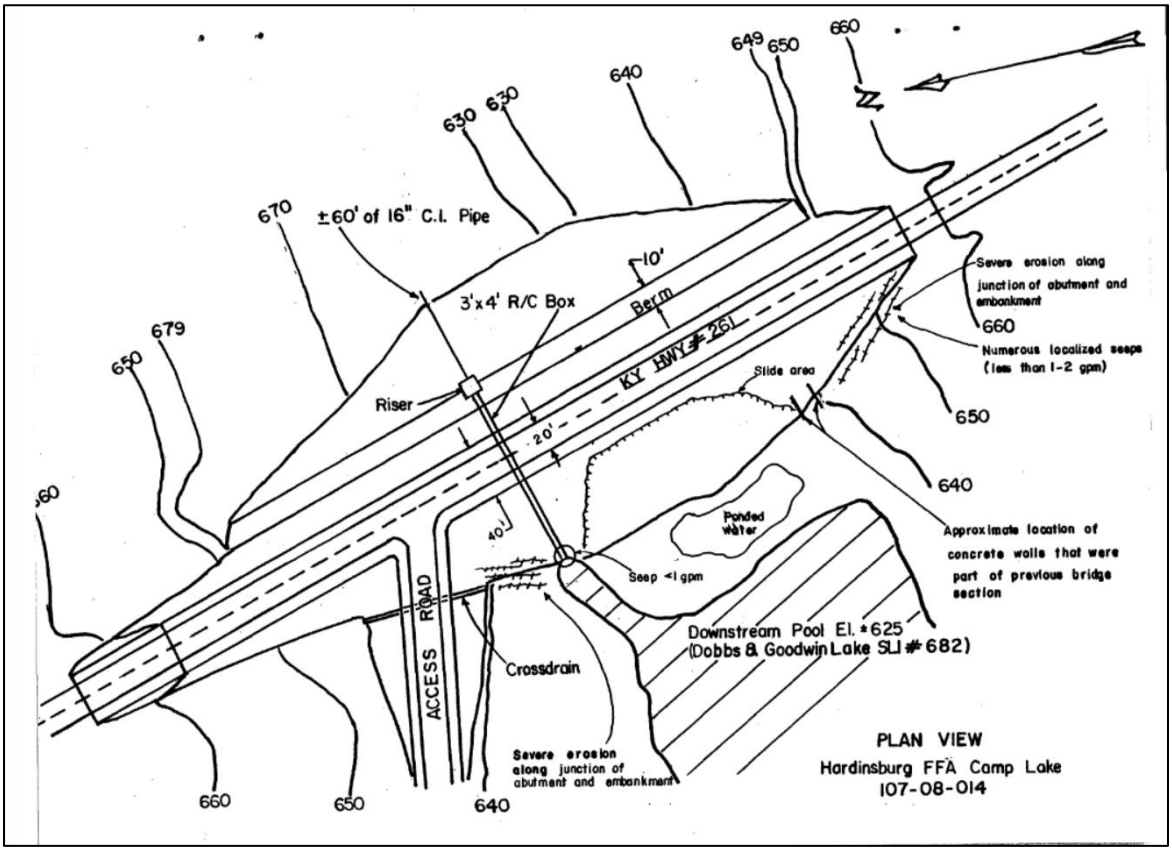


Hardinsburg FFA Camp Lake Dam - Vicinity Map

The principal spillway of this dam is a 4 ft x 5 ft concrete drop inlet with a weir at normal pool. The outlet discharges into a downstream reservoir. The figures below show the cross section and plan view of the dam components.



Hardinsburg FFA Camp Lake Dam – Typical Cross Section



Hardinsburg FFA Camp Lake Dam – Plan View

D.2 Data Catalog

FILE #	DATA TYPE	TITLE	FILE DESCRIPTION
09.02.001	H & H	Emergency Action Plan	***
09.02.002	H & H	Evacuation Map	***
09.02.003	H & H	Inundation Map	***
09.03.001	Inspections	Inspection Report	2013 Division of Water
09.03.002	Inspections	Inspection Report	2016 Division of Water
09.03.003	Inspections	Inspection Report	2017 Division of Water
09.03.004	Inspections	Inspection Report	2019 Division of Water
09.06.001	Transportation Docs	Traffic Counts	
09.06.002	Transportation Docs	Road Plans	
09.03.101	Inspections	Phase I Inspection Report	1980 Dam Safety Program
09.03.102	Inspections	Inspection Report	1974 Division of Water
09.03.103	Inspections	Inspection Report	1982 Division of Water
09.03.104	Inspections	Inspection Report	1981/1982 Division of Water
09.03.105	Inspections	Inspection Report	1982 Division of Water
09.03.106	Inspections	Inspection Report	1983 Division of Water
09.03.107	Inspections	Inspection Report	1985 Division of Water
09.03.108	Inspections	Inspection Report	1985 Division of Water
09.03.109	Inspections	Inspection Report	1982 Division of Water
09.03.110	Inspections	Inspection Report	1983 Division of Water
09.03.111	Inspections	Inspection Report	1985 Division of Water
09.03.112	Inspections	Inspection Report	1985 Division of Water
09.03.113	Inspections	Inspection Report	1985-1992 Division of Water
09.03.114	Inspections	Inspection Report	1990 Division of Water
09.03.115	Inspections	Inspection Report	1993 Division of Water
09.03.116	Inspections	Inspection Report	1993-1996 Division of Water
09.03.117	Inspections	Inspection Report	1997 Division of Water
09.03.118	Inspections	Inspection Report	1998-1999 Division of Water
09.03.119	Inspections	Inspection Report	1999 Division of Water
09.03.120	Inspections	Inspection Report	2001 Division of Water
09.03.121	Inspections	Inspection Report	2005 Division of Water
09.03.122	Inspections	Inspection Report	2012 Division of Water
09.03.123	Inspections	Inspection Report	2015 Division of Water

09.03.124	Inspections	Inspection Report	2003 Division of Water
09.03.125	Inspections	Inspection Report	1994 Division of Water
09.03.126	Inspections	Inspection Report	2009 Division of Water
09.03.127	Inspections	Inspection Report	2011 Division of Water
09.03.128	Inspections	Inspection Report	2013 Division of Water
09.03.129	Inspections	Inspection Report	2007 Division of Water
09.03.130	Inspections	Inspection Report	1974-1981 Division of Water
09.03.131	Inspections	Inspection Report	2019 Division of Water
09.04.101	Drawings	Section Drawing	2004
09.02.201	H & H	Dam Breach Scenario Analysis	1986 USACE Louisville District
09.02.202	H & H	H & H Review	1995 Dam Safety Section
09.02.203	H & H	H & H Review	2013

D.3 Hydrologic and Hydraulic Analyses

Elevation-Frequency Analysis

Previous hydrologic and hydraulic analyses were performed by the Kentucky Division of Water using the Soil Conservation Service (SCS) DAMS2 model in 1995. The input data from the DAMS2 model was used to generate a new U. S. Army Corps of Engineers (USACE) Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) model (version 4.12) to estimate water surface elevations associated with various precipitation depths. The following information was taken from the DAMS2 model:

- Curve Number
- Drainage Area
- Time of Concentration
- Stage-Storage-Discharge Information

NOAA Atlas 14 was used to generate precipitation depths for frequencies ranging from the 10-year (10-percent-annual-chance) up to the 500-year (0.2-percent-annual-chance) storm. For the Probable Maximum Precipitation (PMP), Kentucky Engineering Memorandum No. 2 was used to determine the PMP rainfall depth. A 24-hour SCS Type II rainfall distribution was applied to the precipitation depths from NOAA Atlas 14, and a 6-hour SCS Type II rainfall distribution was applied to the PMP rainfall depth within the HEC-HMS model. The probability associated with the PMP was estimated using two methods:

- The FEMA Spillway Capacity and Extreme Flood Discharge Estimator (which uses flow-frequency data input by the user along with extrapolation using a power function to estimate the return period of the PMP)
- The Australian Rainfall Runoff method (which uses drainage area to estimate a return period of the PMP).

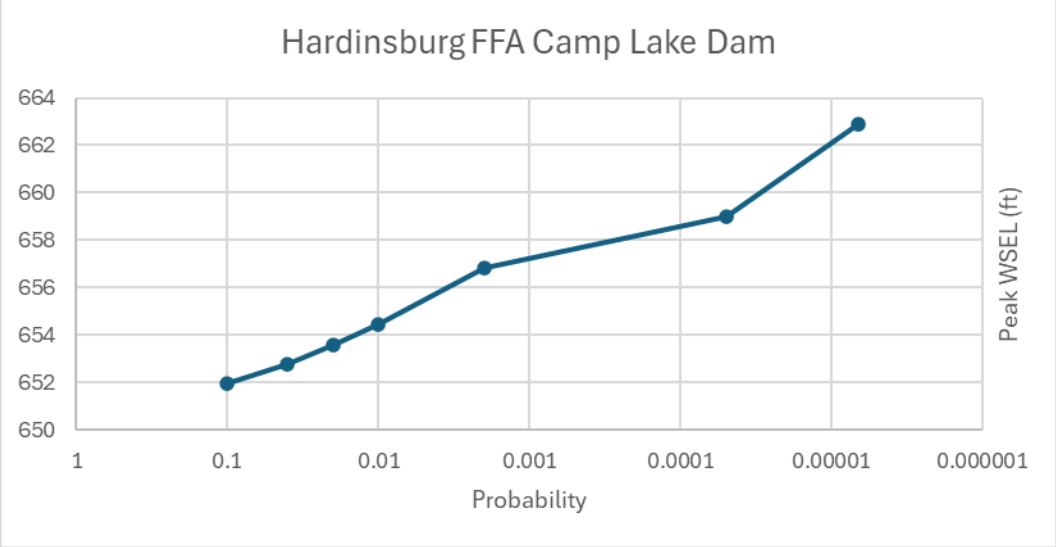
The results of the two methods were averaged to estimate the PMP probability.

Using trial and error, additional storms were run until a rainfall depth that produced a water surface elevation that would just overtop the dam was obtained. A log-log curve was fit to the flow frequency data (including the PMP) and interpolated to approximate a return period associated with this rainfall depth.

The resulting water surface elevations from the model runs are tabulated and plotted below .

Hardinsburg FFA Camp Lake Dam Model Results

Hardinsburg (Dam Crest = 659.0 feet)				
Precip. (inches)	**Peak Inflow (cfs)**	**Peak WSEL (feet)**	**Return Interval**	**Notes**
3.3	885	651.9	0.1	10yr
4.0	1195	652.8	0.04	25yr
4.5	1455	653.6	0.02	50yr
5.0	1736	654.4	0.01	100yr
6.4	2482	656.8	0.002	500yr
7.8	3237	659.0	0.00005	**Overtopping**
28.3	14332	662.9	6.55E-6	**PMP**



Hardinsburg FFA Camp Lake Dam Elevation-Frequency Curve

Consequences Analysis

Previous inundation mapping (Stantec, 2013) that modeled a sunny-day breach of the dam was reviewed. Inundation extents were reviewed along with aerial imagery to evaluate consequences. Structures identified in the inundation area included 2 residences, 6 non-residential structures (barns/storage buildings) and three road crossings. A population at risk of approximately 11 was estimated based on the following assumptions:

- 2.5 people per home inundated
- 2 people per road crossing

The consequences are summarized in the table below.

Consequences Associated with a Failure of Hardinsburg FFA Camp Lake Dam

HARDINSBURG	
NID_ID	KY00107
Number of Residences	2
Number of Non-Residential Structures	6
Description of Non-Residential Structures	Barns/Storage Buildings
Number of Critical Infrastructure Structures	0
Description of Critical Infrastructure Structures	N/A
Number of Road Crossings	3
List of Roads Affected	Main Street (two locations), Second Street
Estimated PAR	11
PAR Assumptions	Assumes 2.5 people per home, and 2 people per road crossing.
Inundation Mapping Source	Prior Stantec Analysis (Simplified Dam Breach Run)
Life Loss Notes	Residential structures are on the fringe of the inundation boundary. Travel time estimated as 25-30 minutes to first residence and 45 minutes to second residence.

D.4 Potential Failure Modes

PFM NUMBER	PFM GROUP	PFM DESCRIPTION	RISK ASSESSMENT
H-1	SLOPE STABILITY	Under normal pool conditions, a slope failure triggers a mass movement of soil on the downstream face of the dam. Successive slope failures retrogress back to the crest, then to the upstream side of the crest. Material is pushed into the failure from the crest, but the intervention fails. The crest drops below the pool elevation, which overtops the dam breach. The resulting flows scour downward through the dam embankment, releasing the reservoir.	CREDIBLE
H-2A	INTERNAL EROSION	Beneath the dam - The dam was constructed on top of a thick alluvial deposit. Under normal pool conditions, seepage develops in the sandy soils beneath the dam and exits unfiltered at the submerged toe. The exit gradients are high enough to cause uplift or sand boils. An eroded pipe forms at the exit and progresses backward under the dam, toward the upstream pool. The seepage is not detected and there is no intervention. The flow rate increases rapidly through the eroded pipe, scouring a large void within the foundation. The embankment collapses into the void, the dam is breached, and there is an uncontrolled release of the reservoir.	CREDIBLE
H-2B	INTERNAL EROSION	Along Abutments - Under normal pool conditions, seepage develops along the embankment-abutment interface on the left side. The seepage exits on the downstream groin where the exit is not filtered. An eroded pathway forms and progresses along the abutment interface toward the upstream pool. The seepage is not detected and there is no intervention. The flow rate increases, eroding more soil, forming a void. The embankment collapses into the void, the dam is breached, and there is an uncontrolled release of the reservoir.	CREDIBLE
H-3	SEISMIC	A strong earthquake occurs near the dam site. The seismic shaking triggers liquefaction in the foundation sands under the dam embankment. The strength of the foundation soil drops significantly, resulting in upstream and/or downstream slope failures. During and after the earthquake, the failure progresses across the	CREDIBLE

		width of the dam crest. There is no time for intervention. The crest drops below normal pool and the reservoir overtops. The resulting flows scour downward through the dam embankment, releasing the reservoir.	
H-4	OVERTOPPING	A heavy precipitation event occurs in the watershed, causing the reservoir level to rise. Water is released through the spillway, but the entrance becomes clogged. The reduced spillway capacity is insufficient to pass the stormwater inflow. There is no auxiliary spillway. The water levels continue to rise and overtop the dam crest. Efforts to raise the dam crest are unsuccessful. The overtopping flows begin to erode the downstream slope of the dam embankment. The flow causes head cutting, which progresses backward across the width of the dam crest. The dam is breached when the crest erosion reaches the upstream pool. The resulting flows scour downward through the dam embankment, releasing the reservoir.	CREDIBLE
H-5	EROSION ASSOCIATED WITH CONDUITS	Under normal conditions, seepage develops along the outside of the reinforced concrete culvert (principal spillway). The anti-seep collars are ineffective. Flow develops in cracks or other defects in the backfill, leading to concentrated leak erosion of the soil. The seepage exit is not filtered, and erosion of the embankment soils continues. The erosion and loss of soil is accelerated during flood events. The flow and erosion are not detected and there is no intervention. On the upstream side, a vertical stope forms above the conduit. A direct connection develops between the reservoir and a void running the length of the conduit. The increased flow velocity erodes the dam embankment, leading to breach and an controlled release of the reservoir.	CREDIBLE
H-6	SPILLWAY STRUCTURES	Considered a seismic failure toppling of the riser structure. In the worst case, the reservoir would drain through the 3x4 culvert. This would not cause any consequences - life loss or economic. It would raise the pool levels downstream. We also discussed collapse of the culvert which would clog the outlet. The pool would rise and overtop. But the culvert is cast in place and the	NEGLIGIBLE

		embankment height is moderate so it is unlikely the concrete would collapse. Both cases were considered non credible.	
H-7	OPERATIONAL	Mis operation of the low level drawdown gate or the gate gets stuck in the open position, resulting in uncontrolled release of the reservoir through the principal spillway culvert. It was determined this is negligible because the restricted flow through the culvert. This does not result in a failure, just a loss of the pool.	NEGLIGIBLE

D.5 Evaluation of PFMs

Potential Failure Mode Analysis Table:

PFM No.:	H-1	**Dam:**	Hardinsburg FFA (H)
PFM Group:	Slope Stability		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*

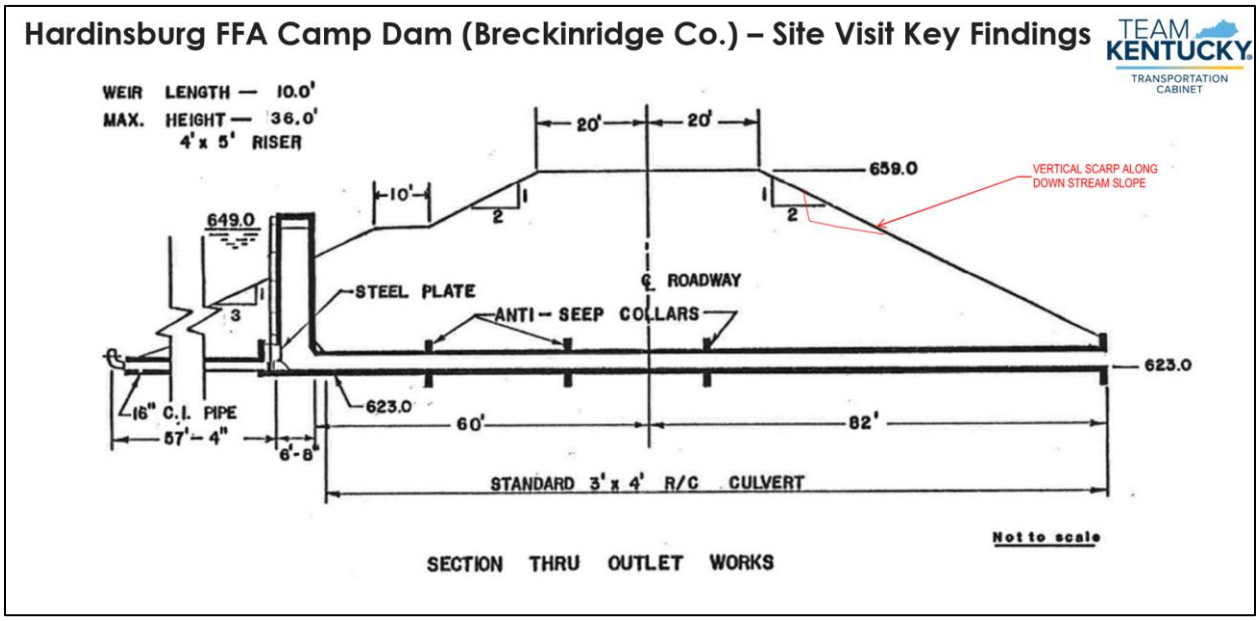
Under normal pool conditions, a slope failure triggers a mass movement of soil on the downstream face of the dam. Successive slope failures retrogress back to the crest, then to the upstream side of the crest. Material is pushed into the failure from the crest, but the intervention fails. The crest drops below the pool elevation, which overtops the dam breach. The resulting flows scour downward through the dam embankment, releasing the reservoir.

More Likely (Adverse) Factors	Less Likely (Favorable) Factors
• **The downstream slope is 2:1** • **Observed slide area on the downstream slope in the current inspection and past reports. Due to the brush and the trees, it was difficult to characterize the dimension and depth of sliding.** • Irregularities in surface on downstream slope • **The geotechnical properties are unknown** • **No stability analysis available** • May not be able to drawdown the lake	• **The crest is 40' wide and the dam is 36' tall** • **It would take a long time to retrogress across the crest** • May be able to draw down the lake • **KYTC could readily repair a slide** • The guardrail appeared to be in a straight alignment • The pavement is in good condition - no longitudinal cracking. (re-paved 2 years ago) • Likely well compacted based on date of construction (1947-1953)

Risk Assessment	Category	Notes
Negligible? Credible?	Credible	It would take a long time to breach and it is almost certain we would be able to intervene successfully. But considering failure likelihood since inspection reports states structural concern.
Failure Likelihood	FL3	Slope failure was observed in 1979 and we see movement today, but progression to a full breach across the 40' wide crest is unlikely.

Life Safety Consequences	LS1	
Economic Consequences	EC1	
Risk Reduction Measures		
Studies and Investigations	Geotechnical information and stability analysis needed.	
Maintenance and Monitoring	Remove trees and brush	
Design and Modifications	Assess the slides, determine if repairs are needed.	

Supporting Figures:



Cross Section (G. Reynolds Watkins / Atec Associates, 1979)



Site Visit Photo



Historical Inspection Photo (G. Reynolds Watkins / Atec Associates, 1979)

Potential Failure Mode Analysis Table:

PFM No.:	H-2a	**Dam:**	Hardinsburg FFA (H)
PFM Group:	Internal Erosion (Beneath the Dam)		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*

The dam was constructed on top of a thick alluvial deposit. Under normal pool conditions, seepage develops in the sandy soils beneath the dam and exits unfiltered at the submerged toe. The exit gradients are high enough to cause uplift or sand boils. An eroded pipe forms at the exit and progresses backward under the dam, toward the upstream pool. The seepage is not detected and there is no intervention. The flow rate increases rapidly through the eroded pipe, scouring a large void within the foundation. The embankment collapses into the void, the dam is breached, and there is an uncontrolled release of the reservoir.

More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
• This is a common failure mode • **The geologic maps indicate a deposit of alluvial material** • **The alluvial materials are likely silty sands and sands based on the geologic setting** • **The vegetation obscures the face of the dam** • **This failure mode could progress without detection** • There are no internal filtered drainage features • The composition of the embankment is unknown • The toe of the dam was soft. However, the tailwater is in the reservoir of the lower dam.	• **The embankment soils may not have enough plasticity to hold a roof over the eroded pathway** • The tailwater reduces uplift pressures at the toe • **Wide and short embankment so hydraulic gradients are low** • Only certain soils are susceptible to backward erosion piping (uniform, fine sands)

Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Credible	
Failure Likelihood	FL3	Based on the geology, it is clear this condition could exist. The hydraulic gradient is relatively low.

Life Safety Consequences	LS1	
Economic Consequences	EC1	
Risk Reduction Measures		
Studies and Investigations	Geotechnical investigation and analysis.	
Maintenance and Monitoring	Tree and vegetation clearing	
Design and Modifications	Filter berm on the downstream slope.	

PFM No.:	H-2b	**Dam:**	Hardinsburg FFA (H)
PFM Group:	Internal Erosion (Along Abutments)		

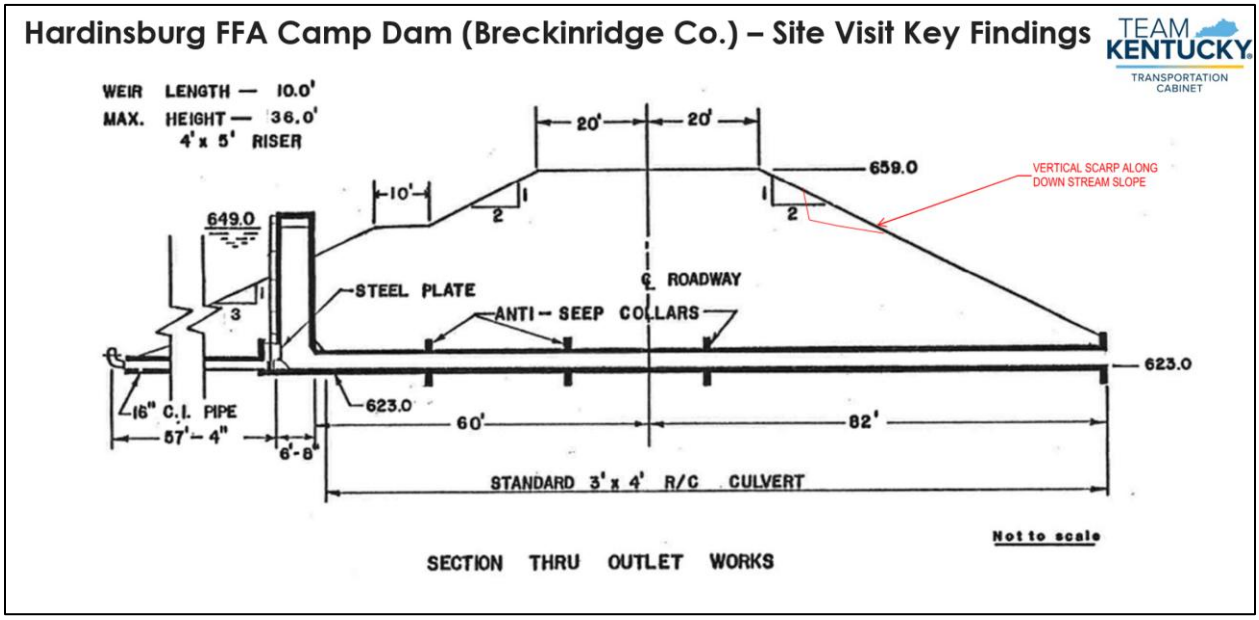
PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*

Under normal pool conditions, seepage develops along the embankment-abutment interface on the left side. The seepage exits on the downstream groin where the exit is not filtered. An eroded pathway forms and progresses along the abutment interface toward the upstream pool. The seepage is not detected and there is no intervention. The flow rate increases, eroding more soil, forming a void. The embankment collapses into the void, the dam is breached, and there is an uncontrolled release of the reservoir.

More Likely (Adverse) Factors	Less Likely (Favorable) Factors
• **The vegetation obscures the face of the dam** • **This failure mode could progress without detection** • There are no internal filtered drainage features • The composition of the embankment is unknown • This could progress as concentrated leak erosion • The abutment conditions are unknown • Historic inspections note seepage up to 10 gal/min • The groin is wet	• **Wide and short embankment so hydraulic gradients are low** • Could be surface runoff • Seepage through the abutment could be occurring without erosion • Municipal water like that crosses the dam in this area (potentially leaking)

• Abutments could be sandstone or limestone		
Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Credible	
Failure Likelihood	FL2	Based on the geology, it is clear this condition could exist.
Life Safety Consequences	LS1	
Economic Consequences	EC1	
Risk Reduction Measures		
Studies and Investigations	Geotechnical investigation and analysis.	
Maintenance and Monitoring	Tree and vegetation clearing	
Design and Modifications	Filter berm on the downstream slope.	

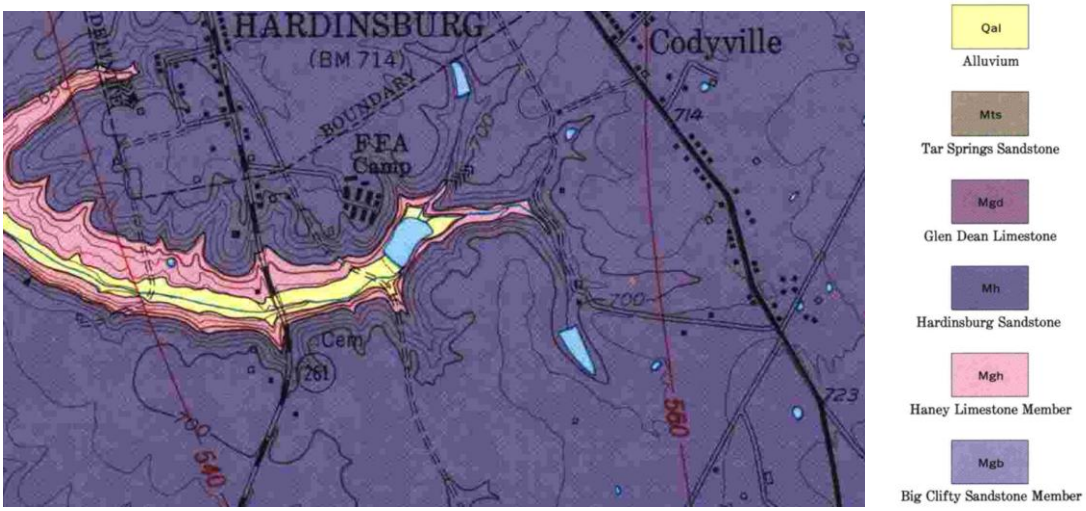
Supporting Figures:



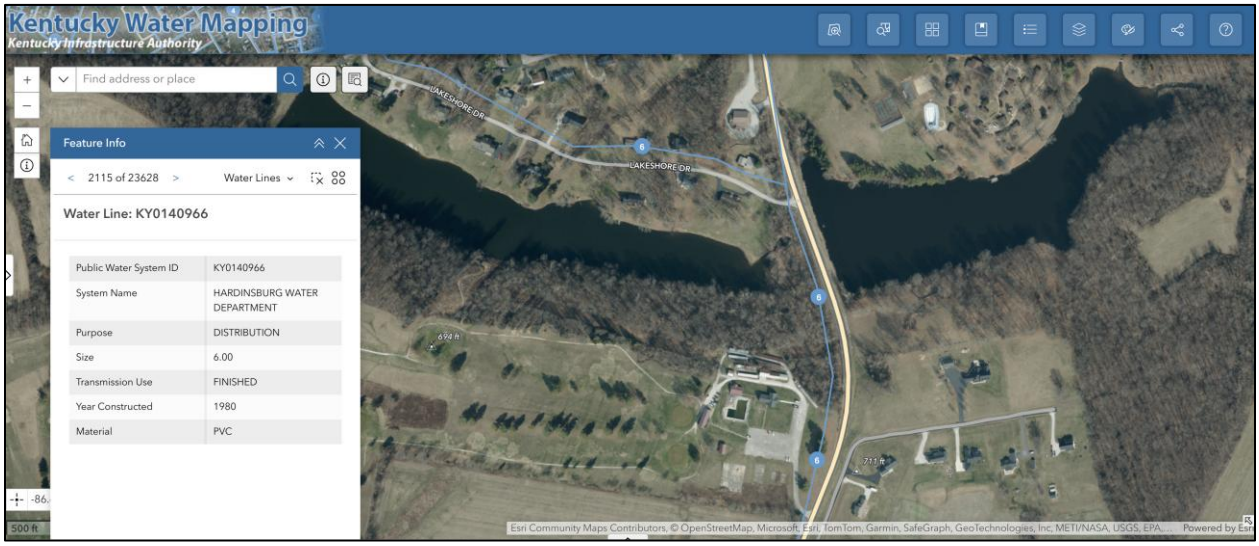
Cross Section (G. Reynolds Watkins / Atec Associates, 1979)



Site Visit Photo



Geo Quad Map (Commonwealth of Kentucky, 1975)



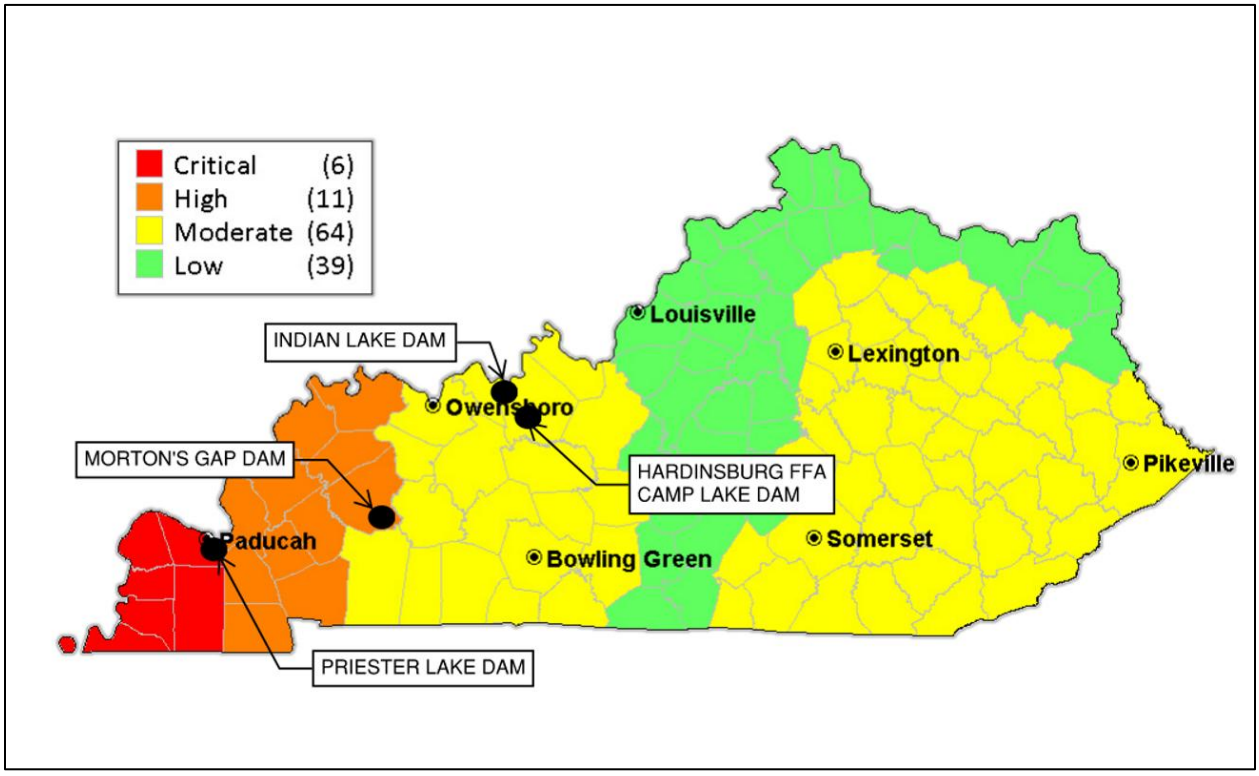
Kentucky Water Mapping of Waterline Adjacent to Dam (Kentucky Water Mapping, n.d.)

Potential Failure Mode Analysis Table:

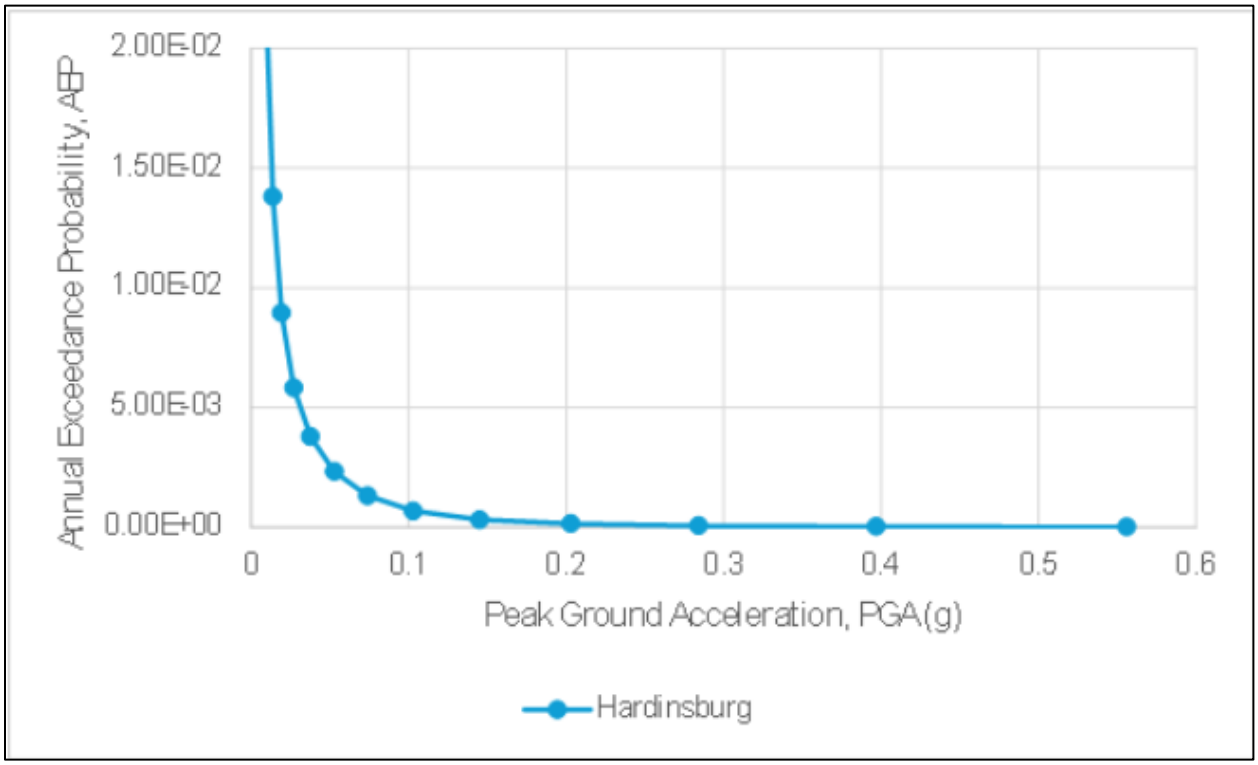
PFM No.:	**H-3**	**Dam:**	**Hardinsburg FFA (H)**
PFM Group:	**Seismic**		
PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure*)			
A strong earthquake occurs near the dam site. The seismic shaking triggers liquefaction in the foundation sands under the dam embankment. The strength of the foundation soil drops significantly, resulting in upstream and/or downstream slope failures. During and after the earthquake, the failure progresses across the width of the dam crest. There is no time for intervention. The crest drops below normal pool and the reservoir overtops. The resulting flows scour downward through the dam embankment, releasing the reservoir.			
More Likely (Adverse) Factors		**Less Likely (Favorable) Factors**	
• **There are no stability or liquefaction analyses** • **Located in Western Kentucky with higher seismic hazard** • **Liquifiable soils are present based on geologic setting** • **AEP=6.82E-4 when g=0.103** • **Intervention is not possible**		• **The failure must go all the way across the crest** • **Liquefiable alluvial soils may not be in continuous deposits**	

• **With liquification in the foundation, large slope movements are more likely**		
Risk Assessment	**Category**	**Notes**
Negligible? Credible?	**Credible**	
Failure Likelihood	**FL2**	**Liquefiable soils known to be in the region, though specifically at the dam is unknown.**
Life Safety Consequences	**LS1**	**See H-2**
Economic Consequences	**EC1**	**See H-2**
Risk Reduction Measures		
Studies and Investigations	**Geotechnical explorations and analysis**	
Maintenance and Monitoring		
Design and Modifications	**Downstream berm**	

Supporting Figures:



Seismic Map



Peak Ground Acceleration versus Annual Exceedance Probability Graph

Potential Failure Mode Analysis Table:

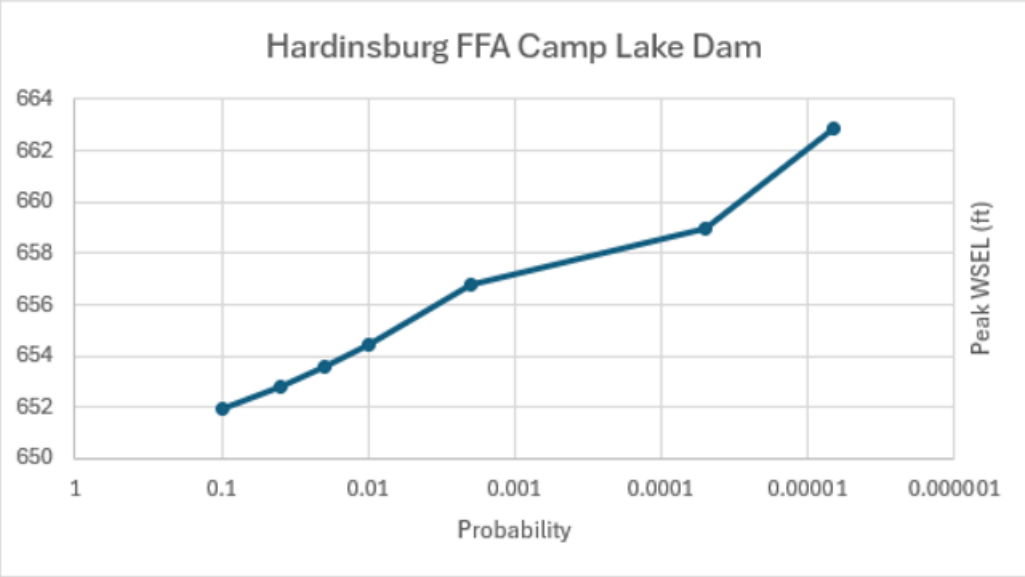
PFM No.:	**H-4**	**Dam:**	**Hardinsburg FFA (H)**
PFM Group:	**Overtopping**		
PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure*)			
A heavy precipitation event occurs in the watershed, causing the reservoir level to rise. Water is released through the spillway, but the entrance becomes clogged. The reduced spillway capacity is insufficient to pass the stormwater inflow. There is no auxiliary spillway. The water levels continue to rise and overtop the dam crest. Efforts to raise the dam crest are unsuccessful. The overtopping flows begin to erode the downstream slope of the dam embankment. The flow causes head cutting, which progresses backward across the width of the dam crest. The dam is breached when the crest erosion reaches the upstream pool. The resulting flows scour downward through the dam embankment, releasing the reservoir.			
More Likely (Adverse) Factors		**Less Likely (Favorable) Factors**	
• **The reservoir is in a wooded area, increasing the chances for woody debris** • **Embankment may be an erodible soil**		• **Wider crest to breach vs. height of dam** • **Crest is paved**	

• **Trash rack bars appear to be spaced too far apart to prevent large, woody debris from entering the riser structure** • **Currently does not meet regulatory requirement for design flood for a significant hazard dam.** • **Based on latest site visit observations, there is a possibility of timber in the riser.** • **Partially submerged outlet conditions of spillway** • **Operability and accessibility of the drawdown valve and the condition of the riser structure is unknown.**	

Risk Assessment	**Category**	**Notes**
Negligible? Credible?	**Credible**	
Failure Likelihood	**FL4**	**4.9e-5 return interval for overtopping. There is uncertainty in the current hydraulic analysis accounting for how the lower reservoir responds during a flood event.**
Life Safety Consequences	**LS1**	**See H-2**
Economic Consequences	**EC1**	**See H-2**
Risk Reduction Measures		
Studies and Investigations	**Updated H&H analysis, Investigate the capacity of the partially submerged culvert, modeling needs to consider the downstream lake**	
Maintenance and Monitoring	**Routine debris removal, inspection of the riser and outlet conduit**	
Design and Modifications	**Redesign the trash racks, increase hydraulic capacity, install additional spillway**	

Supporting Figures:

Hardinsburg (Dam Crest = 659.0 ft)				
Precip (in)	Peak Inflow (cfs)	Peak WSEL (ft)	Return Interval	Notes
3.32	885.23	651.9381	0.1	10yr
3.95	1195.26	652.7888	0.04	25yr
4.46	1455.28	653.5556	0.02	50yr
5.00	1736.37	654.4473	0.01	100yr
6.40	2481.71	656.8184	0.002	500yr
7.79	3237.3	658.9912	0.0000495	**Overtopping**
28.3	14332.29	662.8678	0.00000655	**PMP**



H&H Results

Hydraulic Capacity: The minimum hydraulic requirements set forth in 401 KAR 4:030 section 3 for Significant hazard dams in Breckinridge County is to pass and/or hold 14.1 in/6 hr, and this structure was rated at 8.5 in/6 hr in a 2013 hydraulic review. This is 60% of the minimum requirement and is considered hydraulically deficient.

Text from the 2019 KDOW Inspection Report (KDOW, 2019)

Potential Failure Mode Analysis Table:

PFM No.:	**H-5**	**Dam:**	**Hardinsburg FFA (H)**
PFM Group:	**Erosion Associated with Conduits**		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*

Under normal conditions, seepage develops along the outside of the reinforced concrete culvert (principal spillway). The anti-seep collars are ineffective. Flow develops in cracks or other defects in the backfill, leading to concentrated leak erosion of the soil. The seepage exit is not filtered, and erosion of the embankment soils continues. The erosion and loss of soil is accelerated during flood events. The flow and erosion are not detected and there is no intervention. On the upstream side, a vertical stope forms above the conduit. A direct connection develops between the reservoir and a void running the length of the conduit. The increased flow velocity erodes the dam embankment, leading to breach and an controlled release of the reservoir.

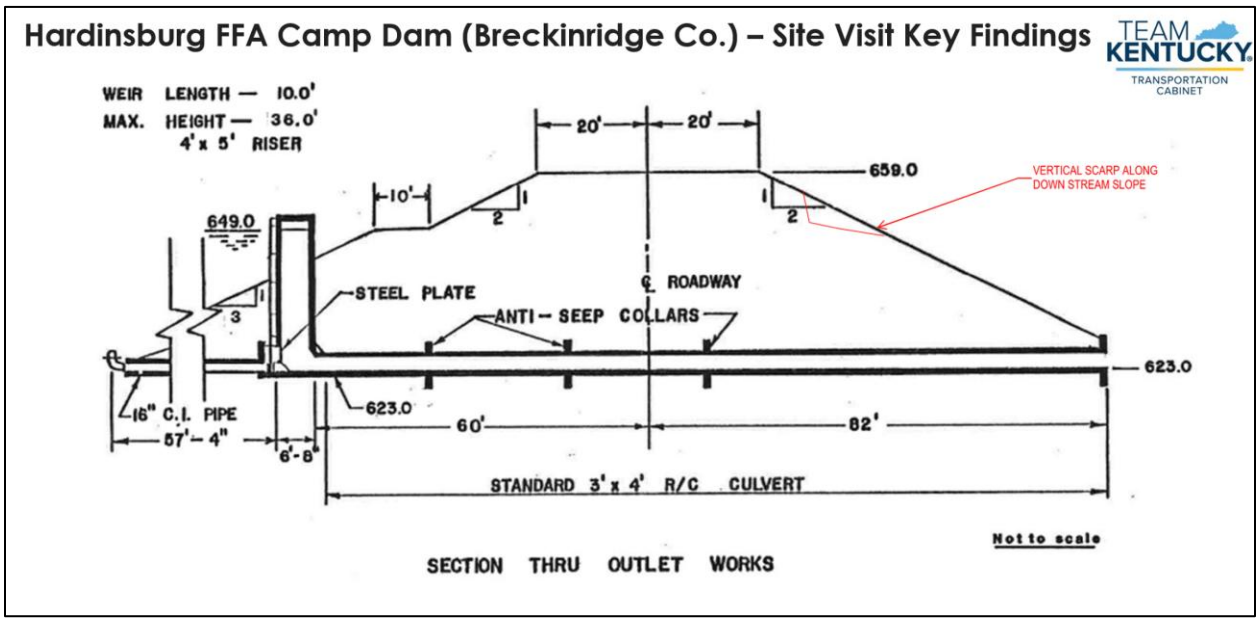
More Likely (Adverse) Factors	Less Likely (Favorable) Factors
• This is a common failure mode • May have poor compaction around the anti-seep collars • Foundation of principal spillway culvert could be alluvium left in place during construction • We lack a filter diaphragm • A seep noted along the conduit in historic inspection reports • Difficult to observe the downstream end of the culvert due to vegetation and culvert being half submerged	• It is a square conduit so compaction would have been easier to achieve • Gradients are relatively small • Cast in place concrete culvert and embankment height is modest so cracking is less likely

Risk Assessment	Category	Notes
Negligible? Credible?	Credible	
Failure Likelihood	FL2	It is possible but there is not a lot of evidence to suggest it can be initiated
Life Safety Consequences	LS1	
Economic Consequences	EC1	

Risk Reduction Measures	
Studies and Investigations	Inspection of the riser and culvert
Maintenance and Monitoring	Clear the debris, monitor for seepage outbreaks

Design and Modifications	**Diaphragm filter**

Supporting Figures:



Cross Section (G. Reynolds Watkins / Atec Associates, 1979)

Potential Failure Mode Analysis Table:

PFM No.:	H-6	**Dam:**	Hardinsburg FFA (H)
PFM Group:	Spillway Structures		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*
Considered a seismic failure toppling of the riser structure. In the worst case, the reservoir would drain through the 3x4 culvert. This would not cause any consequences - life loss or economic. It would raise the pool levels downstream. We also discussed collapse of the culvert which would clog the outlet. The pool would rise and overtop. But the culvert is cast in place, and the embankment height is moderate so it is unlikely the concrete would collapse. Both cases were considered non credible.

More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
•	•

Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Negligible	
Failure Likelihood		
Life Safety Consequences		
Economic Consequences		
Risk Reduction Measures		
Studies and Investigations		
Maintenance and Monitoring		
Design and Modifications		

Supporting Figures:



Site Visit Photo

Potential Failure Mode Analysis Table:

PFM No.:	H-7	**Dam:**	Hardinsburg FFA (H)
PFM Group:	Operational		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*
Mis operation of the low level drawdown gate or the gate gets stuck in the open position, resulting in uncontrolled release of the reservoir through the principal spillway culvert. It was determined this is negligible because the restricted flow through the culvert. This does not result in a failure, just a loss of the pool.

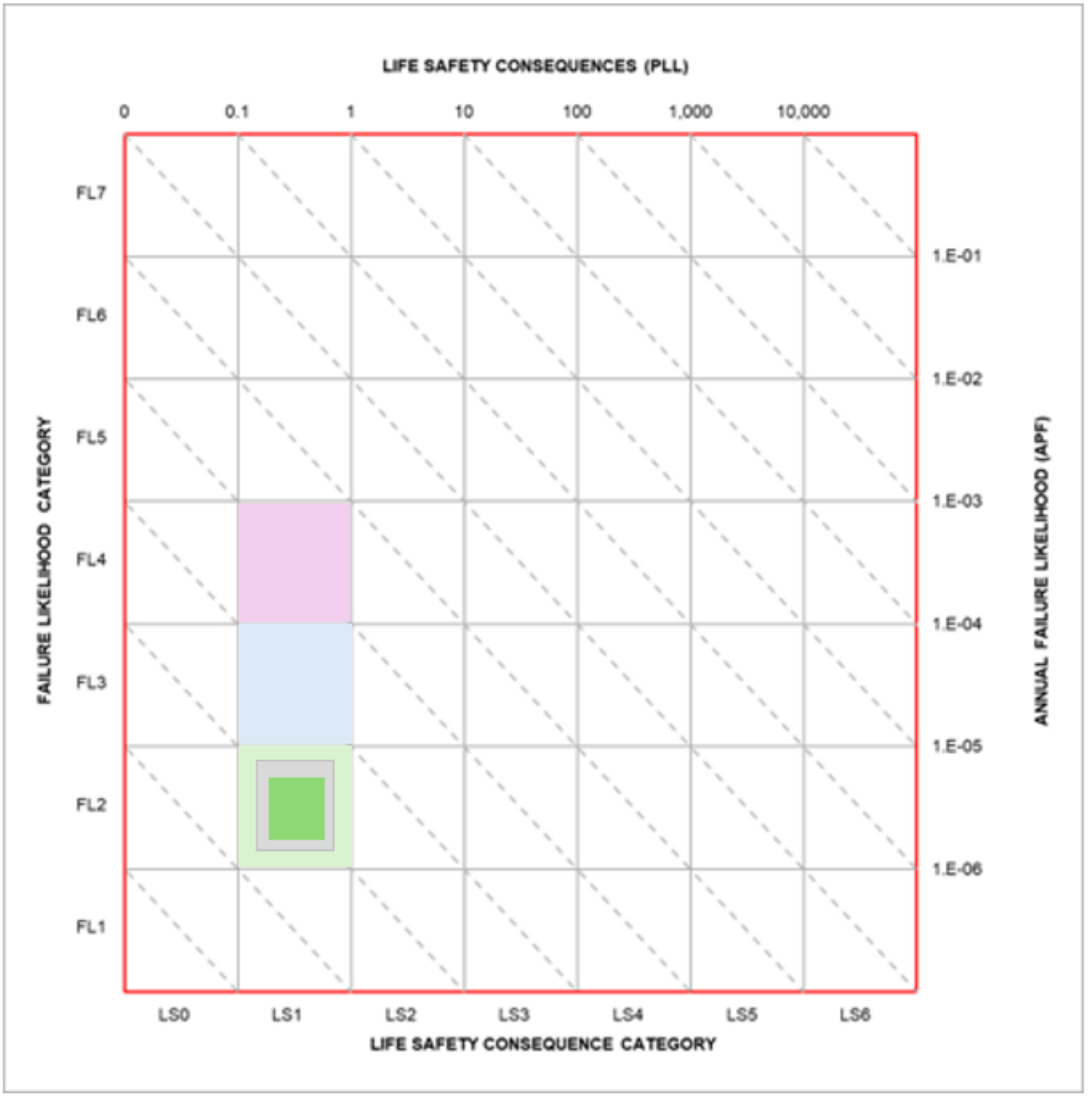
More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
•	•

Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Negligible	
Failure Likelihood		
Life Safety Consequences		
Economic Consequences		

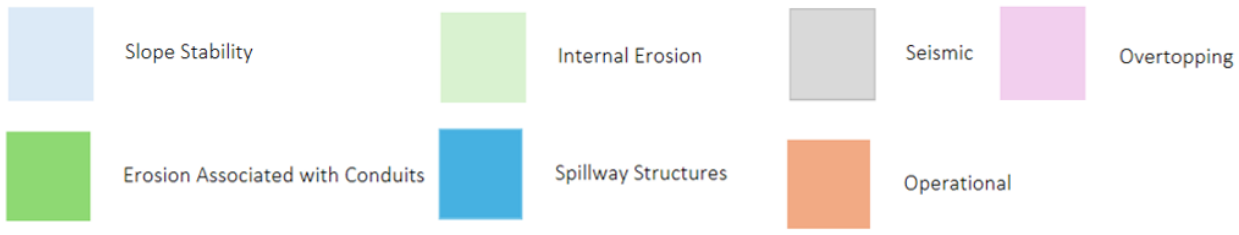
Risk Reduction Measures	
Studies and Investigations	
Maintenance and Monitoring	
Design and Modifications	

D.6 Risk Matrices

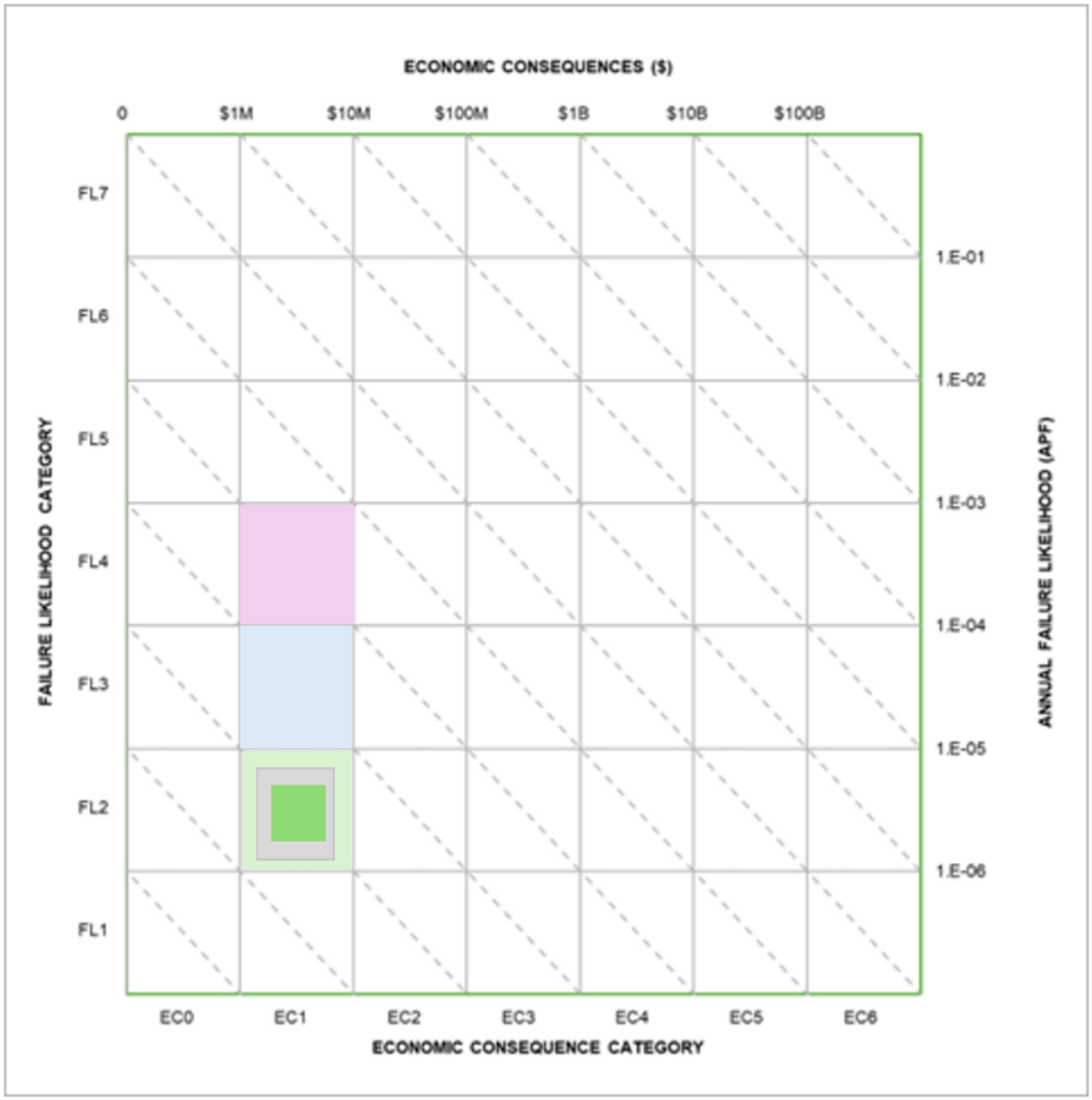
Life Safety Risk Matrix:



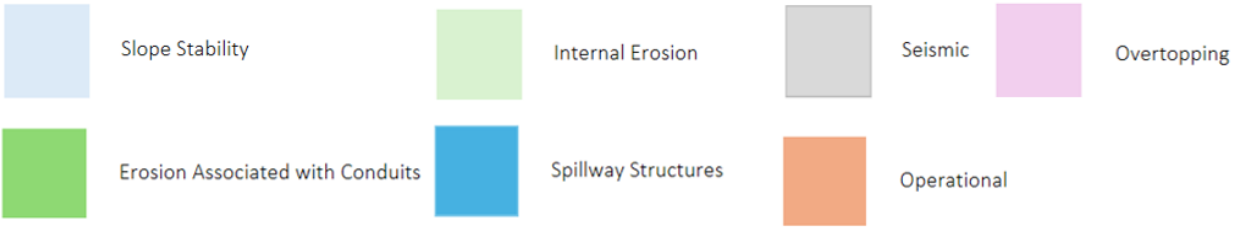
Legend:



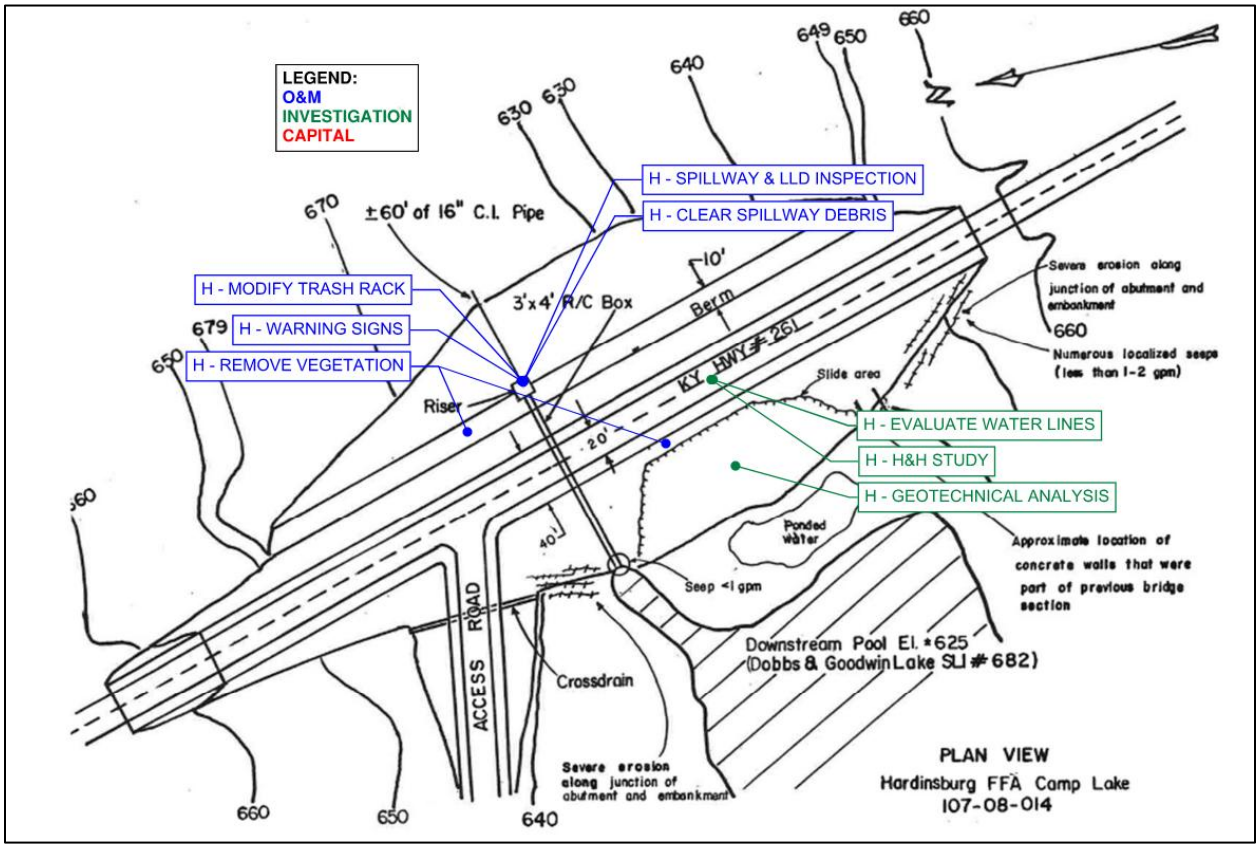
Economic Consequences Risk Matrix:



Legend:



D.7 Recommendations



Recommendations – Hardinsburg FFA Camp Lake Dam								
CODE	**Recommendation**	**Type**	**Life Loss Risk**	**Economic & Transportation Risk**	**Regulatory Compliance**	**Cost Range**	**Planning Horizon**	**Priority**
H - VEGETATION REMOVAL	Remove vegetation, cut trees, and grub out stumps on the face of the dam and within 25-feet of the dam abutments.	O&M	3	3	Yes	10K-100K	Short Term	1
H - H&H STUDY	Re-evaluate hydraulic deficiencies indicated by current H&H study. Consider the lower reservoir in the H&H study.	Investigation	4	4	Yes	10K-100K	Short Term	2
H - WARNING SIGNS	Install multiple warning signs on spillway structure (DANGER - KEEP BACK).	O&M	0	0	No	<10K	Short Term	3
H - CLEAR SPILLWAY DEBRIS	Clear debris out of the spillway and inlet.	O&M	4	4	Yes	<10K	Short Term	4
H - MODIFY TRASH RACK	Modify the trash rack to mitigate potential clogging.	O&M	4	4	No	10K-100K	Intermediate	5
H - SPILLWAY & LLD INSPECTION	Inspect the spillway riser and conduit. Evaluate operation of the low-level drawdown and perform maintenance.	O&M	2	2	Yes	10K-100K	Intermediate	6
H - GEOTECHNICAL ANALYSIS	Investigate slope failures on the downstream face, perform geotechnical stability analyses.	Investigation	3	3	Yes	100K-1M	Intermediate	7
H - EVALUATE WATER LINES	Locate and evaluate water lines or other buried utilities that may be on or near the dam.	Investigation	2	2	No	10K-100K	Intermediate	8

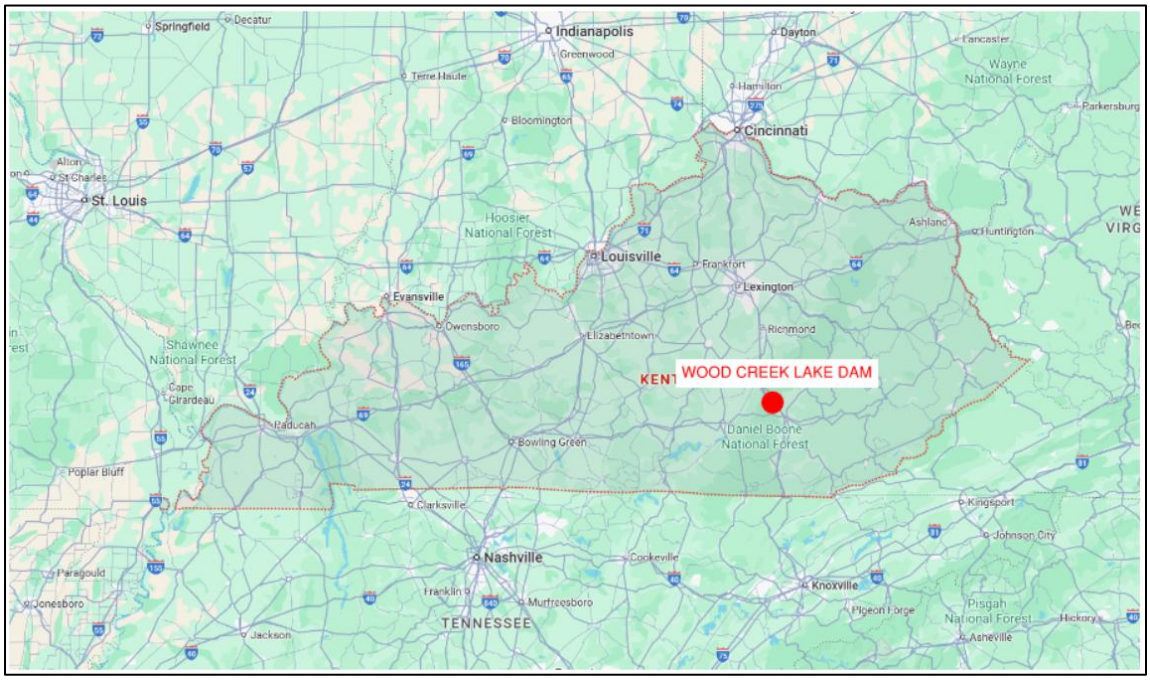
D.8 Cost Opinions for Capital Projects

No capital projects recommended for this dam.

Appendix E
Wood Creek Lake Dam

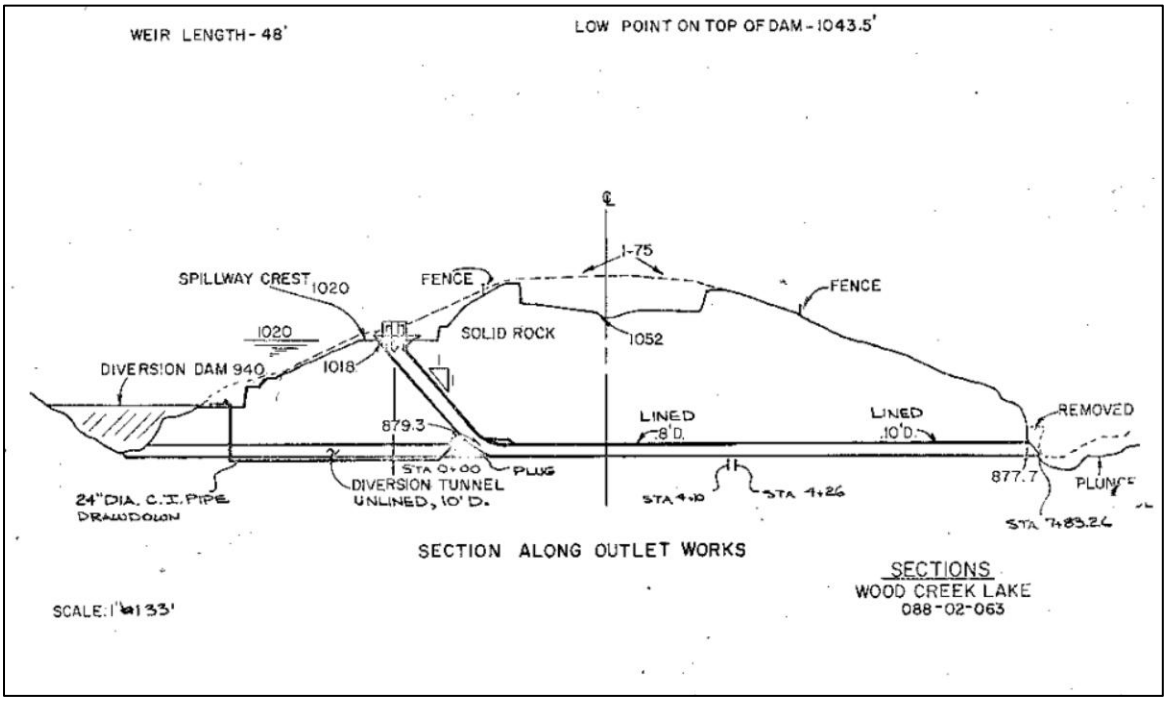
E.1 Dam and Appurtenant Features

Wood Creek Lake Dam is a high hazard dam located in Laurel County (location map below). The National Inventory of Dams lists the purpose of the dam as water-supply. This dam was constructed in 1969 and was modified in 1994. The dam crest elevation is 1050.3 ft, and I-75 runs along the entire crest. The normal pool elevation is 1020 ft. The height of the dam is 172 ft, and the crest width is 140 ft.

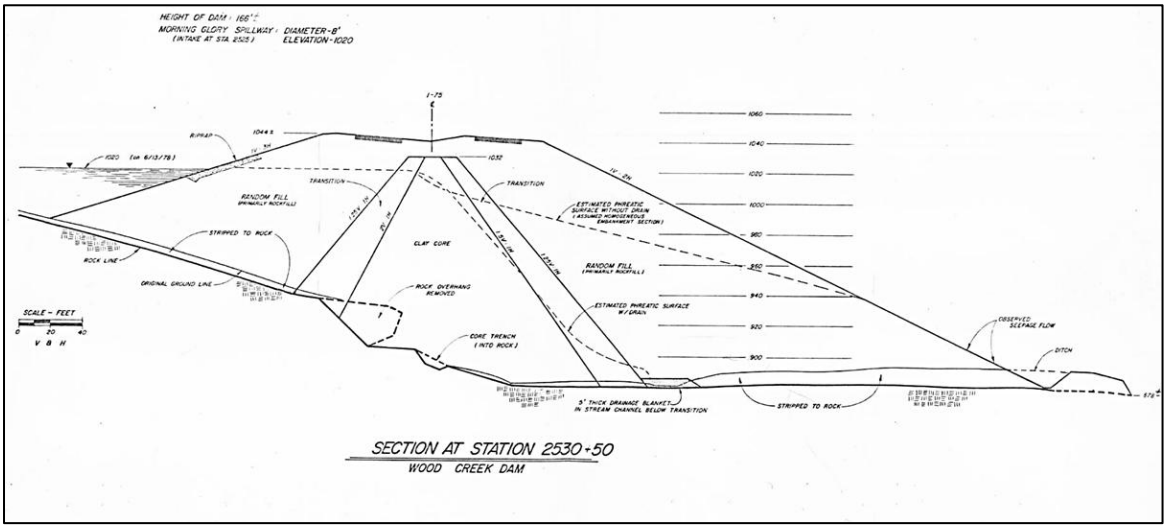


Wood Creek Lake Dam – Vicinity Map

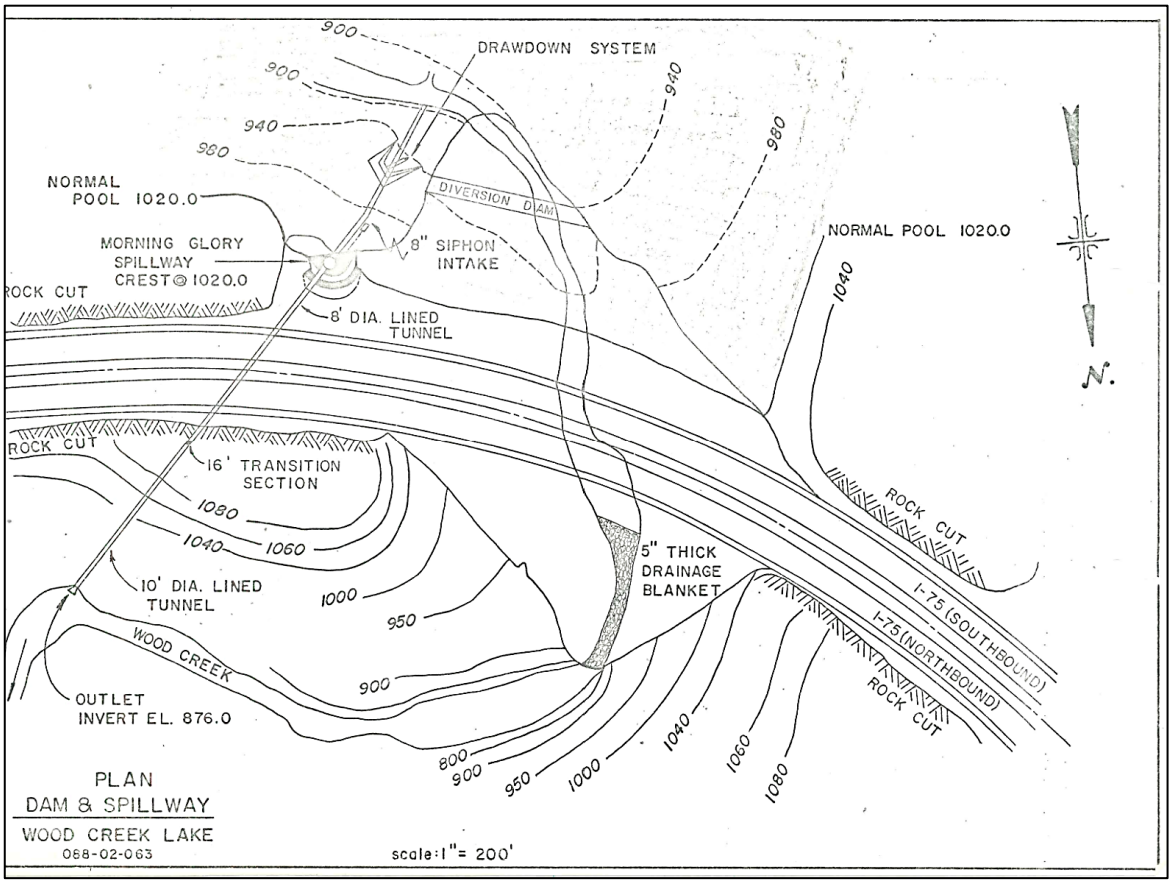
The principal spillway is a morning glory spillway connected to an 8 ft-diameter tunnel that runs through rock on the right abutment. The figures below show the cross sections and plan view for this dam.



Wood Creek Lake Dam – Typical Cross Section



Wood Creek Lake Dam – Cross Section



Wood Creek Lake Dam – Plan View

E.2 Data Catalog

FILE #	DATA TYPE	TITLE	FILE DESCRIPTION
01.02.001	H & H	Emergency Action Plan	***
01.02.002	H & H	Inundation Map	***
01.02.003	H & H	Evacuation Map	***
01.03.001	INSPECTIONS	Phase I Inspection Report	1978 National Dam Safety Program
01.03.002	INSPECTIONS	Inspection Report	1993 DOWR
01.03.003	INSPECTIONS	Inspection Report	1996 DOWR
01.03.004	INSPECTIONS	Inspection Report	2011 DOWR
01.03.005	INSPECTIONS	Inspection Report	2011 DOWR***
01.03.006	INSPECTIONS	Inspection Report	2021 DOWR
01.03.007	INSPECTIONS	Inspection Report	2023 DOWR
01.03.008	INSPECTIONS	Inspection Report	2024 DOWR
01.04.001	DRAWINGS	Plan and Profile of Proposed State Highway	1971 Dept of Highways As Built
01.04.002	DRAWINGS	Dam Improvements	1994 MSE As Built
01.04.003	DRAWINGS	Cross Section	
01.04.004	DRAWINGS	Plan View	
01.06.001	TRANSPORTATION DOCS	Traffic Counts	
01.06.002	TRANSPORTATION DOCS	Roadway Plans	1969 drawing set
01.01.101	GEOTECH / GEOLOGY INFO.	Design of Dam Modifications	1988 MSE
01.01.102	GEOTECH / GEOLOGY INFO.	Subsurface Investigation and Geotech Invest.	1986 ATEC Associates
01.02.101	H & H	Design of Dam Modifications	1988 MSE
01.02.102	H & H	Project Data Sheet	1974 Dept of Highways
01.03.101	INSPECTIONS	Phase I Inspection Report	1978 National Dam Safety Program
01.03.102	INSPECTIONS	Dive Inspection Report	1969 Vogt, Ivers and Associates

01.03.103	INSPECTIONS	Dive Inspection Report	1976 Division of Maintenance
01.03.104	INSPECTIONS	Dive Inspection Report	1976 Division of Maintenance
01.03.105	INSPECTIONS	Dive Inspection Report	1991 Division of Maintenance
01.03.106	INSPECTIONS	Dive Inspection Report	1976-1992 Lexington Dive Shop
01.03.107	INSPECTIONS	Dive Inspection Report	1993
01.03.108	INSPECTIONS	Dive Inspection Report	1994 KYTC Division of Design
01.03.109	INSPECTIONS	Dive Inspection Report	1994 FMSM Engineers
01.03.110	INSPECTIONS	Dive Inspection Report	1994 FMSM Engineers
01.03.111	INSPECTIONS	Dive Inspection Report	1994 FMSM Engineers
01.03.112	INSPECTIONS	Dive Inspection Report	1995 MSE
01.03.113	INSPECTIONS	Dive Inspection Report	1996 MSE
01.03.114	INSPECTIONS	Dive Inspection Report	1996 KYTC
01.03.115	INSPECTIONS	Dive Inspection Report	1996 FMSM Engineers
01.03.116	INSPECTIONS	Dive Inspection Report	1996 FMSM Engineers
01.03.117	INSPECTIONS	Dive Inspection Report	1996 FMSM Engineers
01.03.118	INSPECTIONS	Dive Inspection Report	1997 FMSM Engineers
01.03.119	INSPECTIONS	Dive Inspection Report	1997 Division of Water
01.03.120	INSPECTIONS	Dive Inspection Report	1997 Division of Operations
01.03.121	INSPECTIONS	Dive Inspection Report	2000 FMSM Engineers
01.03.122	INSPECTIONS	Dive Inspection Report	2000 FMSM Engineers
01.03.123	INSPECTIONS	Dive Inspection Report	2001 FMSM Engineers
01.03.124	INSPECTIONS	Dive Inspection Report	2001 FMSM Engineers
01.03.125	INSPECTIONS	Dive Inspection Report	2003 FMSM Engineers
01.03.126	INSPECTIONS	Inspection Report	1974 Division of Water
01.03.127	INSPECTIONS	Inspection Report	1975 Division of Water
01.03.128	INSPECTIONS	Inspection Report	1983 Division of Water
01.03.129	INSPECTIONS	Inspection Report	1986 Division of Water
01.03.130	INSPECTIONS	Inspection Report	1972-1991 Division of Maintenance

01.03.131	INSPECTIONS	Inspection Report	1983-1990 Division of Maintenance
01.03.132	INSPECTIONS	Inspection Report	1992 Division of Maintenance
01.03.133	INSPECTIONS	Inspection Report	1992
01.03.134	INSPECTIONS	Inspection Report	1992 Division of Water
01.03.135	INSPECTIONS	Inspection Report	1992
01.03.136	INSPECTIONS	Inspection Report	1993
01.03.137	INSPECTIONS	Inspection Report	1993 Division of Water
01.03.138	INSPECTIONS	Inspection Report	1993 Division of Operations
01.03.139	INSPECTIONS	Inspection Report	1995 Division of Water
01.03.140	INSPECTIONS	Inspection Report	1993 & 1995 FMSM Engineers
01.03.141	INSPECTIONS	Inspection Report	1996 Division of Water
01.03.142	INSPECTIONS	Inspection Report	1981-1996 Division of Water
01.03.143	INSPECTIONS	Inspection Report	1997 Division of Water
01.03.144	INSPECTIONS	Inspection Report	1998 Division of Water
01.03.145	INSPECTIONS	Inspection Report	2003 Division of Water
01.03.146	INSPECTIONS	Inspection Report	2000-2003 FMSM Engineers
01.03.147	INSPECTIONS	Inspection Report	2003 Division of Water
01.03.148	INSPECTIONS	Inspection Report	2008 FMSM Engineers
01.03.149	INSPECTIONS	Inspection Report	2008 Stantec
01.03.150	INSPECTIONS	Inspection Report	2009 Stantec
01.03.151	INSPECTIONS	Inspection Report	2009 Division of Water
01.03.152	INSPECTIONS	Inspection Report	2011 Division of Water
01.03.153	INSPECTIONS	Inspection Report	2012 Stantec
01.03.154	INSPECTIONS	Inspection Report	2013 Stantec
01.03.155	INSPECTIONS	Inspection Report	2013 Division of Water
01.03.156	INSPECTIONS	Tunnel Inspection Video	2008 Division of Maintenance
01.03.157	INSPECTIONS	Tunnel Inspection Video	2008 Division of Maintenance

01.03.158	INSPECTIONS	Tunnel Inspection Video	2008 Division of Maintenance
01.03.159	INSPECTIONS	Tunnel Inspection Video	2008 Division of Maintenance
01.03.160	INSPECTIONS	Tunnel Inspection Video	2008 Division of Maintenance
01.03.161	INSPECTIONS	Tunnel Inspection Video	2009 Division of Maintenance
01.03.162	INSPECTIONS	Tunnel Inspection Video	2010 Division of Maintenance
01.03.163	INSPECTIONS	Tunnel Inspection Video	2010 Division of Maintenance
01.03.164	INSPECTIONS	Tunnel Inspection Video	2013 Division of Maintenance
01.03.165	INSPECTIONS	Tunnel Inspection Video	2013 Division of Maintenance
01.03.166	INSPECTIONS	Tunnel Inspection Video	2017 Division of Maintenance
01.03.167	INSPECTIONS	Tunnel Inspection Video	2023 Division of Maintenance
01.03.168	INSPECTIONS	Dive Inspection Report	2022 Stantec
01.03.169	INSPECTIONS	Dive Inspection Report	2023 Collins Engineers
01.03.170	INSPECTIONS	Dive Inspection Report	2024 Collins Engineers
01.03.171	INSPECTIONS	Inspection Report	2021 Division of Water
01.03.172	INSPECTIONS	Inspection Report	2023 Division of Water
01.03.173	INSPECTIONS	Inspection Report	2024 Division of Water
01.04.101	DRAWINGS	Site and Section Drawings	1972 Division of Water
01.04.102	DRAWINGS	Site and Section Drawings	1972 Division of Water
01.04.103	DRAWINGS	Site Drawing	
01.02.201	H & H	Safety Inspection Analysis	1967 & 1974
01.02.202	H & H	Hydraulic Curves	
01.02.203	H & H	Dam Breach Analysis	1985 USACE Louiville District
01.04.201	DRAWINGS	Plan and Section Exhibit	1993

E.3 Hydrologic and Hydraulic Analyses

Elevation-Frequency Analysis

Previous hydrologic and hydraulic analyses were performed by Mayes, Sudderth & Etheredge, Inc., using the Soil Conservation Service (SCS) DAMS2 model in 1988. The input data from the DAMS2 model was used to generate a new U. S. Army Corps of Engineers (USACE) Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) model (version 4.12) to estimate water surface elevations associated with various precipitation depths. The following information was taken from the DAMS2 model:

- Curve Number
- Drainage Area
- Time of Concentration
- Stage-Storage-Discharge Information

Two scenarios were modeled – one where the principal spillway was assumed to be flowing and operating as intended and one where the principal spillway was clogged and not flowing.

NOAA Atlas 14 was used to generate precipitation depths for frequencies ranging from the 2-year (50-percent-annual-chance) up to the 500-year (0.2-percent-annual-chance) storm. For the Probable Maximum Precipitation (PMP), Kentucky Engineering Memorandum No. 2 was used to determine the PMP rainfall depth. A 24-hour SCS Type II rainfall distribution was applied to the precipitation depths from NOAA Atlas 14, and a 6-hour SCS Type II rainfall distribution was applied to the PMP rainfall depth within the HEC-HMS model. The probability associated with the PMP was estimated using two methods:

- The FEMA Spillway Capacity and Extreme Flood Discharge Estimator (which uses flow-frequency data input by the user along with extrapolation using a power function to estimate the return period of the PMP)
- The Australian Rainfall Runoff method (which uses drainage area to estimate a return period of the PMP).

The results of the two methods were averaged to estimate the PMP probability.

Using trial and error, additional storms were run with higher rainfall depths until a rainfall depth that produced a water surface elevation that would just overtop the dam and a water surface elevation that overtopped the dam by two feet was obtained. A power curve was fit to the flow frequency data (including the PMP) and extrapolated to approximate a return period associated with these higher rainfall depths. The duration of overtopping for the PMP event and the rainfall event resulting in two feet of overtopping was also estimated by reviewing the time-series results of the HMS model and noting the period of time where the water surface elevation was above the dam crest.

The resulting water surface elevations from the model runs are tabulated and plotted below.

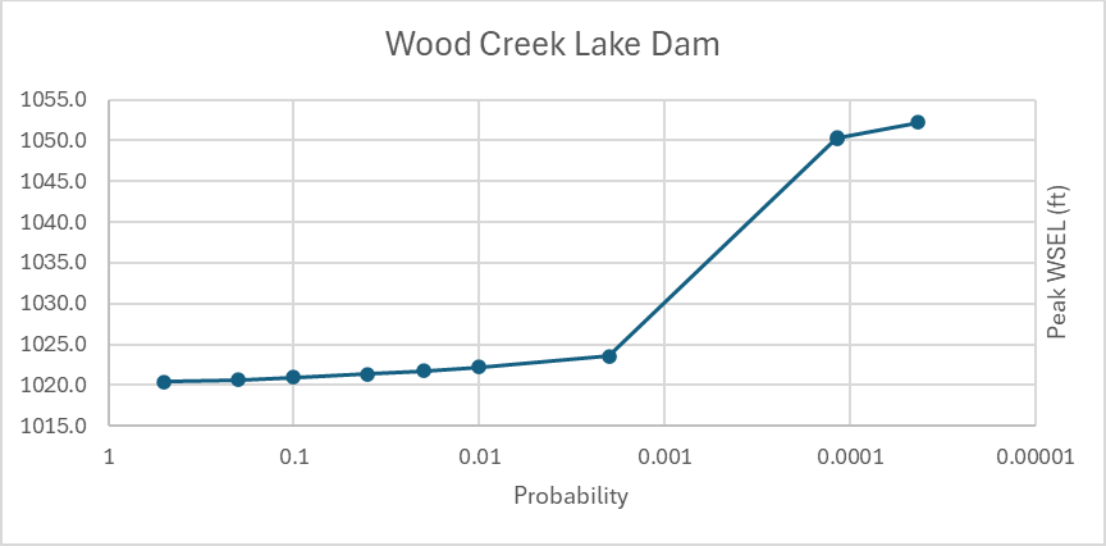
Wood Creek Lake Dam Model Results

Wood Creek Lake Dam (Dam Crest = 1050.3 feet)					
Precip. (inches)	**Peak Inflow (cfs)**	**Peak WSEL (feet)**	**Peak WSEL (clogged) (feet)**	**Return Interval**	**Notes**
2.0	1,546	1020.4	1020.5	0.5	2yr
2.5	2,994	1020.7	1020.8	0.2	5yr
2.9	4,531	1020.9	1021.1	0.1	10yr
3.4	7,055	1021.4	1021.7	0.04	25yr
3.8	9,441	1021.8	1022.2	0.02	50yr
4.3	12,272	1022.2	1022.7	0.01	100yr
5.6	20,242	1023.5	1024.2	0.002	500yr
28.7	202,640	1050.2	1051.2	1.18E-04	**PMP**
28.8	203,686	1050.4	1051.3	1.18E-04	**Overtopping**
31.7	226,920	1052.3	1052.8	4.28E-05	**~2' overtopping**

Note: Duration of overtopping for the 31.7" rainfall event estimated to be 10 hours,

Note: Duration of overtopping for the 28.8" rainfall event with the spillway clogged estimated to be 18 hours.

Note: Duration of overtopping for the 31.7" rainfall event with the spillway clogged estimated to be two days.



Wood Creek Lake Dam Elevation-Frequency Curve

Consequences Analysis

Previous inundation mapping for a sunny-day breach of the dam publicly available on Kentucky's Dam Inundation Viewer (watermaps.ky.gov) was reviewed. An additional flood-day breach hydrograph for the dam was modeled in HEC-HMS for the PMP rainfall event. Empirical equations were utilized to define breach width, formation time, and side slopes. The resulting breach hydrograph was input into the USACE Dam Screening Tool (DST) and routed downstream. Inundation extents for the sunny-day and flood-day breaches were reviewed along with aerial imagery to evaluate consequences.

Structures identified in the sunny-day inundation area included seven residences, approximately 25 non-residential structures (barns/storage buildings and an RV lot with 20 spaces) and 12 road crossings. A population at risk of approximately 42 was estimated based on the following assumptions:

- 2.5 people per home inundated
- 2 people per road crossing

The flood-day inundation extents were similar to the sunny-day breach extents. The estimated life loss in DST was 4 (and associated estimated PAR was 76). The consequences are summarized in the table below.

Consequences Associated with a Failure of Wood Creek Lake Dam

Wood Creek Lake Dam	
NID_ID	KY00088
Number of Residences	7 (approximate)
Number of Non-Residential Structures	~25
Description of Non-Residential Structures	Barns/Storage Buildings and one RV Lot (20 spaces)
Number of Critical Infrastructure Structures	0
Description of Critical Infrastructure Structures	N/A
Number of Road Crossings	12
List of Roads Affected	~12 road crossings (including I-75 and US-25)
Estimated PAR	42
PAR Assumptions	Assumes 2.5 people per home and 2 people per road crossing.
Inundation Mapping Source	KY Dam Inundation Viewer + Aerial Imagery + DST (flood breach)
Estimated Life Loss	1-10
Life Loss Notes	Closest resident is ~1.5 mile downstream of the dam. Estimated life loss in DST is 4 (PAR = 76)

E.4 Potential Failure Modes

PFM NUMBER	PFM GROUP	PFM DESCRIPTION	RISK ASSESSMENT
WC-1A	SLOPE STABILITY	Downstream slope - Under normal pool conditions, a slope failure triggers a mass movement of soil on the downstream face of the dam. Successive slope failures retrogress back to the crest, then to the upstream side of the crest. Material is pushed into the failure from the crest, but the intervention fails. The crest drops below the pool elevation (1020'), which overtops the dam breach. The resulting flows scour downward through the dam embankment, releasing the reservoir.	NEGLIGIBLE
WC-1B	SLOPE STABILITY	Upstream Slope - Storm event results in a flood pool. The flood pool approaches the crest and over a period of days, the pool drops as water drains through the morning glory spillway. This triggers a rapid drawdown slope failure on the upstream side of the dam. Successive slope failures retrogress across the crest of the downstream side. Material is pushed into the failure from the crest, but the intervention fails. The crest drops below the pool elevation (1020'), which overtops the dam breach. The resulting flows scour downward through the dam embankment, releasing the reservoir.	NEGLIGIBLE
WC-2A	INTERNAL EROSION	Seepage through a defect in the core - Under normal pool conditions, seepage develops along a defect through the dam core. The defect may be a permeable lift, a smooth lift surface, a poorly compacted lift, or a frozen lift surface. The transition zone is not an effective filter. The flow scours the soil to either side of the defect. The embankment over the seepage path does not collapse. The flow path expands and the flow accelerates. The seepage is not detected and there is no intervention. The flow scours a larger void in the embankment, leading to a collapse of the dam crest. The dam is breached and there is an uncontrolled release of the reservoir.	CREDIBLE

WC-2B	INTERNAL EROSION	Seepage and erosion into the drainage blanket - Under normal pool conditions, seepage discharges into the blanket drain. The drainage blanket apparently consists of coarse rock fill that was placed within the old stream channel. There is no effective filter between the drainage blanket and the embankment. The seepage erodes soil into the drainage blanket. The embankment over the seepage path does not collapse. The flow path expands and the flow accelerates. The seepage is not detected and there is no intervention. The flow scours a larger void in the embankment, leading to a collapse of the dam crest. The dam is breached and there is an uncontrolled release of the reservoir.	CREDIBLE
WC-2C	INTERNAL EROSION	Seepage along the foundation/ abutment rock interface - Under normal pool conditions, seepage through right abutment through sandstone or discontinuities below the extent of the cutoff trench into the embankment. It is an unfiltered seepage exit and erosion of the downstream slope initiates. The seepage erodes the soil on the downstream slope, inducing slope failure. Successive slope failures retrogress back to the crest, then to the upstream side of the crest. Material is pushed into the failure from the crest, but the intervention fails. The crest drops below the pool elevation (1020'), which overtops the dam breach.	NEGLIGIBLE
WC-2D	INTERNAL EROSION	Seepage through cracks caused by settlement - Under normal pool conditions, seepage develops along a defect through the dam core. The defect is a transverse crack through the core (upstream to downstream) that develops due to differential settlement and/or soil arching. The transition zone is not an effective filter. The flow scours the soil to either side of the defect. The embankment over the seepage path does not collapse. The flow path expands and the flow accelerates. The seepage is not detected and there is no intervention. The flow scours a larger void in the embankment, leading to a collapse of the dam crest. The dam is breached and there is an uncontrolled release of the reservoir.	CREDIBLE

WC-3	SEISMIC	A strong earthquake is felt at the dam site. The dynamic loads on the dam embankment cause slope displacements and possible slope failures. The deformations are larger on the downstream face, which is steeper than the upstream slope. Successive slope movements during and after the earthquake progress across the width of the dam crest. There is no time for intervention. The crest drops below normal pool and the reservoir overtops. The resulting flows scour downward through the dam embankment, releasing the reservoir.	NEGLIGIBLE
WC-4	OVERTOPPING	A heavy precipitation event occurs in the watershed, causing the reservoir level to rise. Water is released through the spillway, but the spillway capacity is partially blocked by floating debris. The water levels continue to rise and overtop the dam crest. The median barrier wall fails to retain the water. No plausible effort is made to raise the crest of the dam. The overtopping flows begin to erode the downstream slope of the dam embankment. The flow causes head cutting, which progresses backward across the width of the dam crest. The dam is breached when the crest erosion reaches the upstream pool. The resulting flows scour downward through the dam embankment, releasing the reservoir.	CREDIBLE
WC-5	EROSION ASSOCIATED WITH CONDUITS	There is one 8' diameter conduit and it was tunneled through rock and lined with concrete. Without a soil backfill, there is no identifiable failure mode for an erosion of soil along, into, or out of conduits.	NEGLIGIBLE
WC-6	SPILLWAY STRUCTURES	The morning glory spillway structure is in rock. Annual inspections are performed and no plausible failure mode has been documented.	NEGLIGIBLE
WC-7	OPERATIONAL	The valve is opened during annual operation. Due to continued corrosion, the valve is unable to be closed. Attempt to close the inlet is unsuccessful. The dam does not fail but the lake is slowly drained through the 24" cast iron low level drawdown pipe.	CREDIBLE

E.5 Evaluation of PFMs

Potential Failure Mode Analysis Table:

PFM No.:	WC-1A	**Dam:**	Wood Creek Lake Dam
PFM Group:	Slope Stability-Downstream Slope		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*

Under normal pool conditions, a slope failure triggers a mass movement of soil on the downstream face of the dam. Successive slope failures retrogress back to the crest, then to the upstream side of the crest. Material is pushed into the failure from the crest, but the intervention fails. The crest drops below the pool elevation (1020'), which overtops the dam breach. The resulting flows scour downward through the dam embankment, releasing the reservoir.

More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
• **Really steep on the downstream face (2:1)** • 1994 - a berm and drainage feature were added to the downstream slope • **We observed wet areas on the downstream face, indicating high ground water conditions which would adversely affect stability.**	• **Wide (140' wide at the crest)** • 30' of freeboard at normal pool • Successful intervention is almost certain

Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Negligible	Due to the size of the embankment and the certainty that we would observe and intervene.
Failure Likelihood		

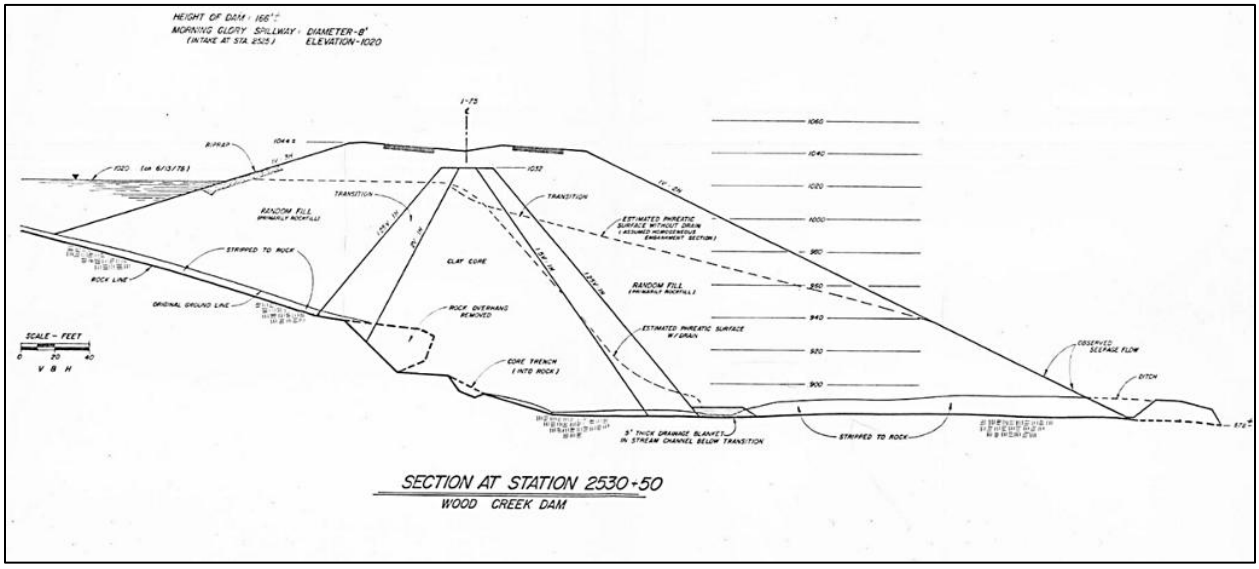
Life Safety Consequences		
Economic Consequences		
Risk Reduction Measures		
Studies and Investigations		
Maintenance and Monitoring	Observe and note the location of the wet area on the downstream face. Continue DOW annual inspections.	
Design and Modifications		

PFM No.:	WC-1B	**Dam:**	Wood Creek Lake Dam
PFM Group:	Slope Stability - Upstream Slope		
PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*			
Storm event results in a flood pool. The flood pool approaches the crest and over a period of days, the pool drops as water drains through the morning glory spillway. This triggers a rapid drawdown slope failure on the upstream side of the dam. Successive slope failures retrogress across the crest of the downstream side. Material is pushed into the failure from the crest, but the intervention fails. The crest drops below the pool elevation (1020'), which overtops the dam breach. The resulting flows scour downward through the dam embankment, releasing the reservoir.			
More Likely (Adverse) Factors		**Less Likely (Favorable) Factors**	

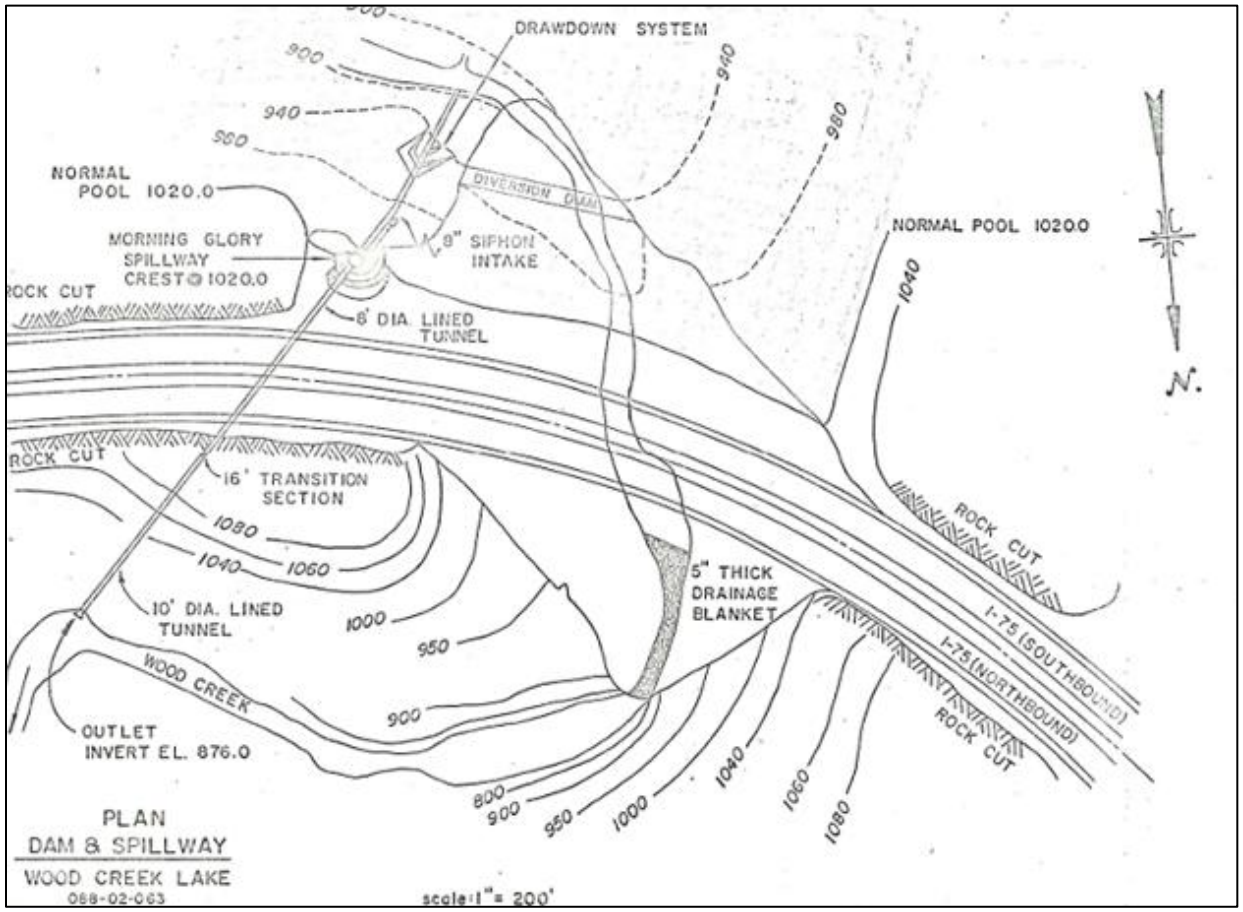
• There is a steel sheet pile retaining structure along the upstream side of the dam crest • The sheet piles are embedded only a few feet and would not provide resistance to an upstream slope failure.	• **Wide (140' wide at the crest)** • 30' of freeboard at normal pool • 3:1 slope on upstream side • The size of the morning glory will slow the rate of drawdown • The upstream shell is rocky and may be relatively permeable. • **Low frequency of storm event where the reservoir reaches the upstream slope.**

Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Negligible	Due to the size of the embankment and the certainty that we would observe and intervene.
Failure Likelihood		
Life Safety Consequences		
Economic Consequences		
Risk Reduction Measures		
Studies and Investigations		
Maintenance and Monitoring		
Design and Modifications		

Supporting Figures:



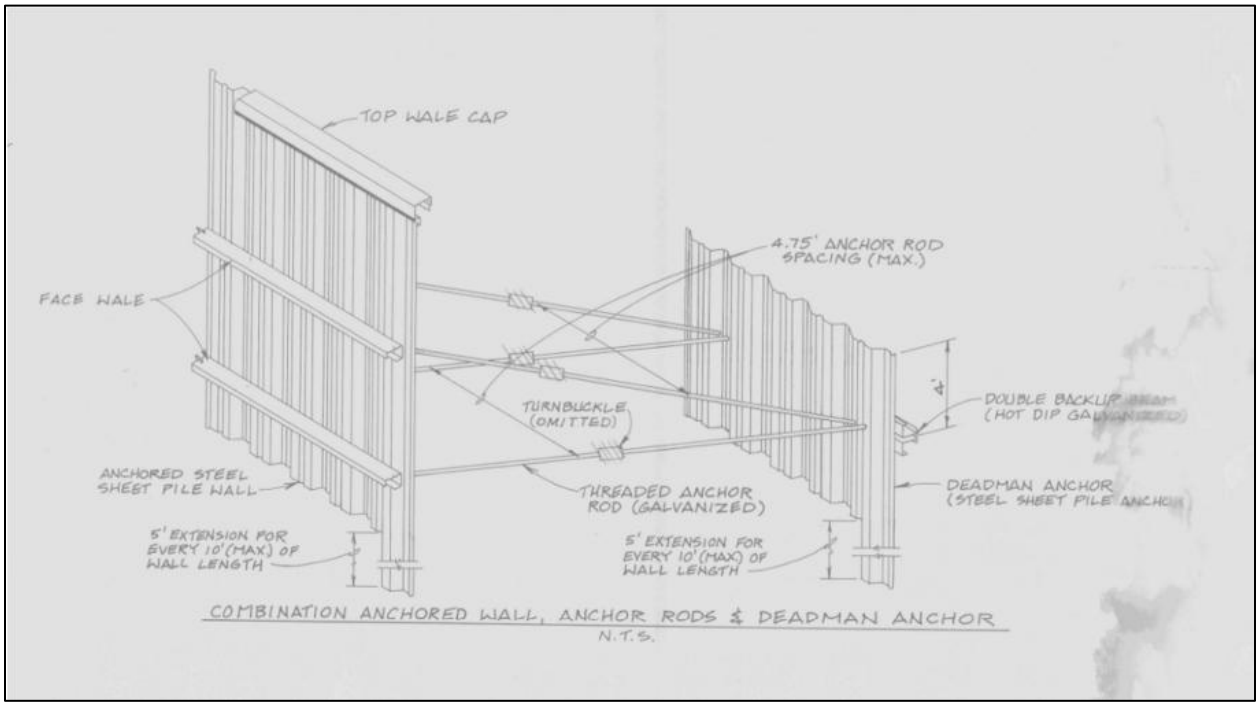
Cross Section (G Reynolds Watkins / Atec Associates, 1978)



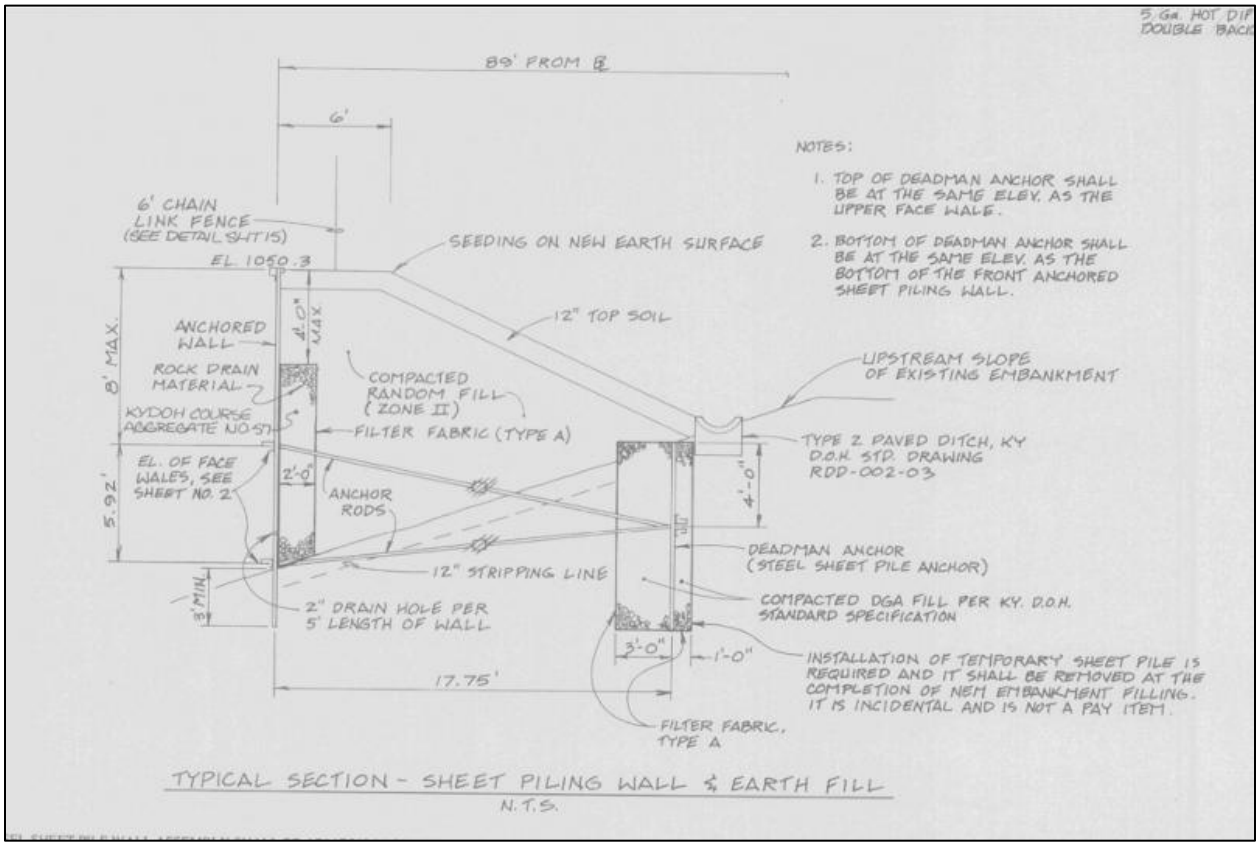
Plan View (G Reynolds Watkins / Atec Associates, 1978)



Site Visit Photo



Anchored Detail from 1994 Design Modification As-Built Drawings (MSE, 1988)



Anchored Detail from 1994 Design Modification As-Built Drawings (MSE, 1988)

SUMMARY

Modifications to the Wood Creek Lake Dam includes a new earth embankment to be placed on the upstream slope and a toe drain system to be installed on the downstream slope. The purposes of the dam modifications are to increase the freeboard of the reservoir to meet the State criteria for Class "C" high hazard potential dams and to stabilize the downstream slope of the dam where seepage effluence has been observed.

The new embankment would have a top elevation of 1050.3 feet which is about 6.8 feet higher than the existing crest of the dam (1043.5 feet). The new embankment would be supported with a vertical steel sheet piling wall.

The downstream toe drain system would be composed of a drainage blanket and perforated pipes for controlling the seepage flow. The drainage blanket would be enclosed with filter fabric.

The design of the dam modifications is intended to comply with 401KAR 4:030 for high hazard potential dams (Class "C" dams). In a probable maximum precipitation (PMP) event, or a 6-hour 28.7 inch storm event, the maximum water level in the lake was computed to reach 1049.99 foot elevation and the modified dam would not be overtopped by the flood water.

Text from 1988 Dam Modification Report (Mayes, Sudderth and Etheredge Inc., 1988)

Potential Failure Mode Analysis Table:

PFM No.:	WC-2A	**Dam:**	Wood Creek Lake Dam
PFM Group:	Internal Erosion - Seepage through a defect in the core		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure*)

Under normal pool conditions, seepage develops along a defect through the dam core. The defect may be a permeable lift, a smooth lift surface, a poorly compacted lift, or a frozen lift surface. The transition zone is not an effective filter. The flow scours the soil to either side of the defect. The embankment over the seepage path does not collapse. The flow path expands and the flow accelerates. The seepage is not detected and there is no intervention. The flow scours a larger void in the embankment, leading to a collapse of the dam crest. The dam is breached and there is an uncontrolled release of the reservoir.

More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
• **Observed wet areas on the downstream face of the dam** • **Historic records indicate seepage on the downstream face of the dam** • Built as a highway embankment, not a dam. Less control of the core and transition zone construction. • Index properties of embankment fill unknown • **The gradation of the transition zone is unknown. As-built drawing notes do not specify gradation.**	• The dam is very wide so the seepage path is long. • **The dam is wide so it would take a long time to breach.** • **More time to intervene since longer time to breach.** • Other than wet areas on downstream face, there is no physical evidence that this failure mode has initiated.

Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Credible	

Failure Likelihood	FL3	Evidence of the wet areas and the confidence in the intervention
Life Safety Consequences	LS1	Assuming 8-12 hours to evacuate
Economic Consequences	EC4	I75, 25, Water supply loss, long detour route, cost to rebuild temporary and replacement dam.
Risk Reduction Measures		
Studies and Investigations	Sample the embankment materials and install instrumentation	
Maintenance and Monitoring	Observe and note the location of the wet area on the downstream face. Continue DOW annual inspections. Address back flooding on the weir at the toe so that we can quantify and monitor seepage rates.	
Design and Modifications	Increase crest of weir	

PFM No.:	WC-2B	**Dam:**	Wood Creek Lake Dam
PFM Group:	Internal Erosion - Seepage and erosion into the drainage blanket		
PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*			
Under normal pool conditions, seepage discharges into the blanket drain. The drainage blanket apparently consists of coarse rock fill that was placed within the old stream channel. There is no effective filter between the drainage blanket and the embankment. The seepage erodes soil into the drainage blanket. The embankment over the seepage path does not collapse. The flow path expands and the flow accelerates. The seepage is not detected and there is no intervention. The flow scours a larger void in			

the embankment, leading to a collapse of the dam crest. The dam is breached and there is an uncontrolled release of the reservoir.

More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
• Built as a highway embankment, not a dam. Less control of the core, transition zone, filter zone, and drainage blanket construction. • Index properties of embankment fill unknown • **The gradation of the blanket drain is unknown. As-built drawing notes do not specify gradation.** • **Historic drawing notes indicate 2.5-3' maximum size material** • Unable to monitor seepage out of the drainage blanket • The 1994 modifications with the drain may be effectively draining the lower half of the dam face.	• The dam is very wide so the seepage path is long. • **The dam is wide so it would take a long time to breach.** • **More time to intervene since longer time to breach.**

Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Credible	
Failure Likelihood	FL3	The apparent lack of filter for the drainage blanket and the confidence in the intervention
Life Safety Consequences	LS1	Assuming 8-12 hours to evacuate
Economic Consequences	EC4	I75, 25, Water supply loss, long detour route, cost to rebuild temporary and replacement dam.

Risk Reduction Measures	
Studies and Investigations	Sample the embankment materials - determine whether material can hold a roof. Install instrumentation. Drilling access will be very difficult.
Maintenance and Monitoring	Observe and note the location of the wet area on the downstream face. Continue DOW annual inspections. Address back flooding on the weir at the toe so that we can quantify and monitor seepage rates.
Design and Modifications	Increase crest of weir

PFM No.:	WC-2C	**Dam:**	Wood Creek Lake Dam
PFM Group:	Internal Erosion - Seepage along the foundation/abutment rock interface.		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*

Under normal pool conditions, seepage through right abutment through sandstone or discontinuities below the extent of the cutoff trench into the embankment. It is an unfiltered seepage exit and erosion of the downstream slope initiates. The seepage erodes the soil on the downstream slope, inducing slope failure. Successive slope failures retrogress back to the crest, then to the upstream side of the crest. Material is pushed into the failure from the crest, but the intervention fails. The crest drops below the pool elevation (1020'), which overtops the dam breach.

More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
• Built as a highway embankment, not a dam. Less control of the core, transition zone, filter zone, and drainage blanket construction. • Index properties of embankment fill unknown	• The dam is very wide so the seepage path is long. • **The dam is wide so it would take a long time to breach.**

• **Wet area observed on the downstream slope near the right abutment**	• **More time to intervene since longer time to breach.** • **The design drawings show removal of the rock overhangs and excavation of a cut off trench to a minimum of 5' or sound rock.** • Sandstone is erosion resistant and permeable • Successful intervention is almost certain • Hand compaction along rock interface required per as-built drawing notes for clay core.

Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Negligible	Starts as erosion but progresses as a slope failure. There would be adequate time for intervention.
Failure Likelihood		
Life Safety Consequences		
Economic Consequences		
Risk Reduction Measures		
Studies and Investigations		
Maintenance and Monitoring		

Design and Modifications	

PFM No.:	WC-2D	**Dam:**	Wood Creek Lake Dam
PFM Group:	Internal Erosion - Seepage through cracks caused by settlement		

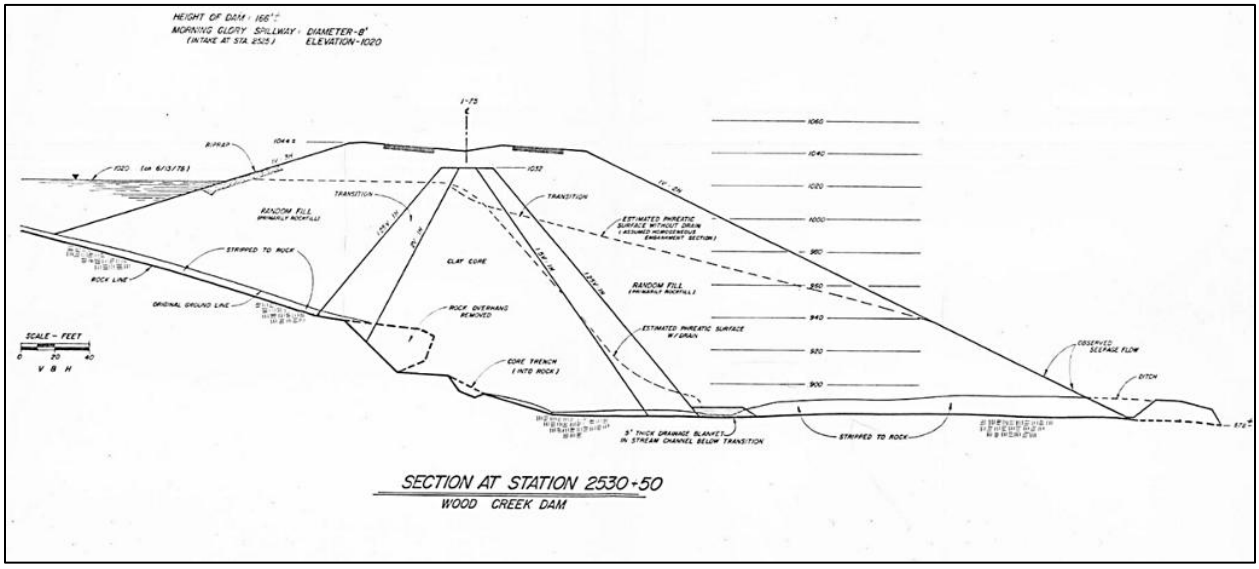
PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*

Under normal pool conditions, seepage develops along a defect through the dam core. The defect is a transverse crack through the core (upstream to downstream) that develops due to differential settlement and/or soil arching. The transition zone is not an effective filter. The flow scours the soil to either side of the defect. The embankment over the seepage path does not collapse. The flow path expands and the flow accelerates. The seepage is not detected and there is no intervention. The flow scours a larger void in the embankment, leading to a collapse of the dam crest. The dam is breached and there is an uncontrolled release of the reservoir.

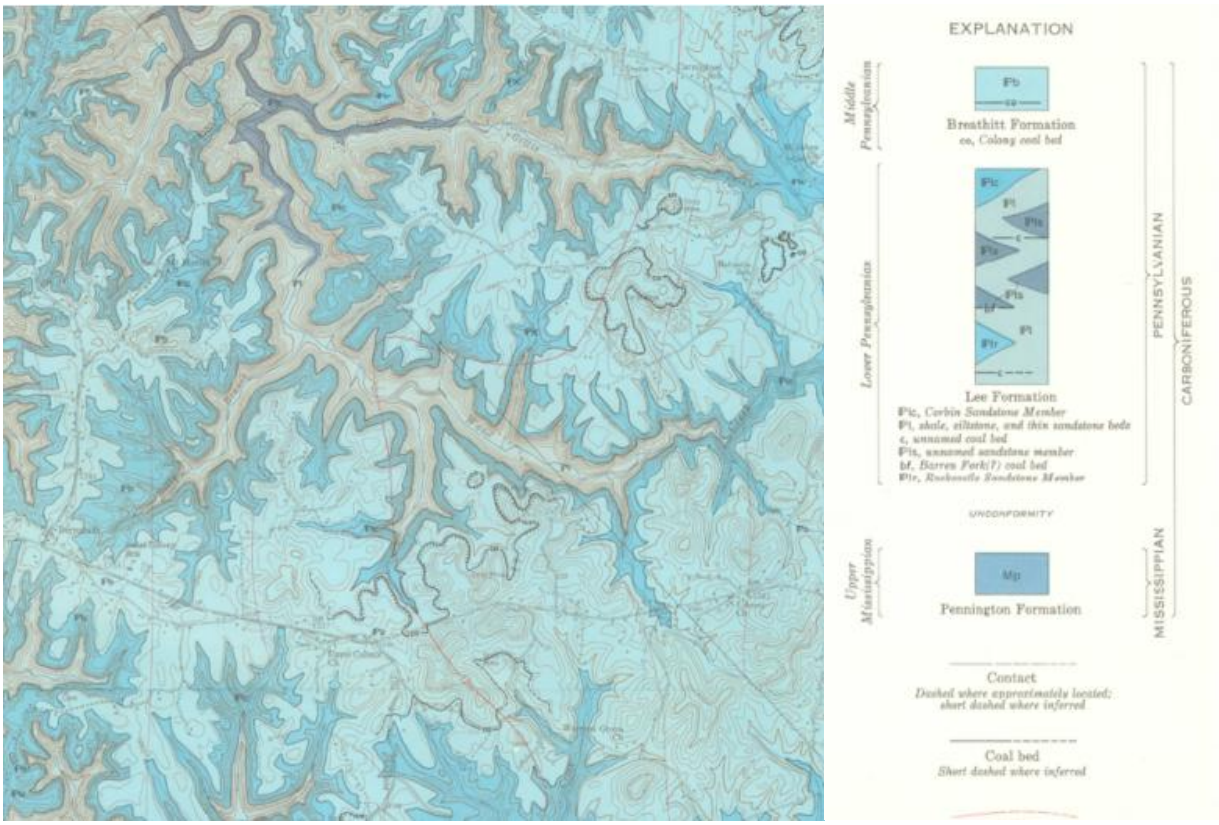
More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
• **Observed wet areas on the downstream face of the dam** • **Historic records indicate seepage on the downstream face of the dam** • Built as a highway embankment, not a dam. Less control of the core and transition zone construction. • Index properties of embankment fill unknown • **The gradation of the transition zone is unknown. As-built drawing notes do not specify gradation.** • Uncertain how much the dam has settled and when	• The dam is very wide so the seepage path is long. • **The dam is wide so it would take a long time to breach.** • **More time to intervene since longer time to breach.** • Other than wet areas on downstream face, there is no physical evidence that this failure mode has initiated. • **Should have good compaction within the clay core during construction based on the as-built drawing notes.**

Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Credible	
Failure Likelihood	FL3	We know that settlement has occurred, so the defect likely exists.
Life Safety Consequences	LS1	Assuming 8-12 hours to evacuate
Economic Consequences	EC4	I75, 25, Water supply loss, long detour route, cost to rebuild temporary and replacement dam.
Risk Reduction Measures		
Studies and Investigations	Drilling and sampling to install piezometers	
Maintenance and Monitoring	Observe and note the location of the wet area on the downstream face. Continue DOW annual inspections. Address back flooding on the weir at the toe so that we can quantify and monitor seepage rates.	
Design and Modifications	Increase crest of weir	

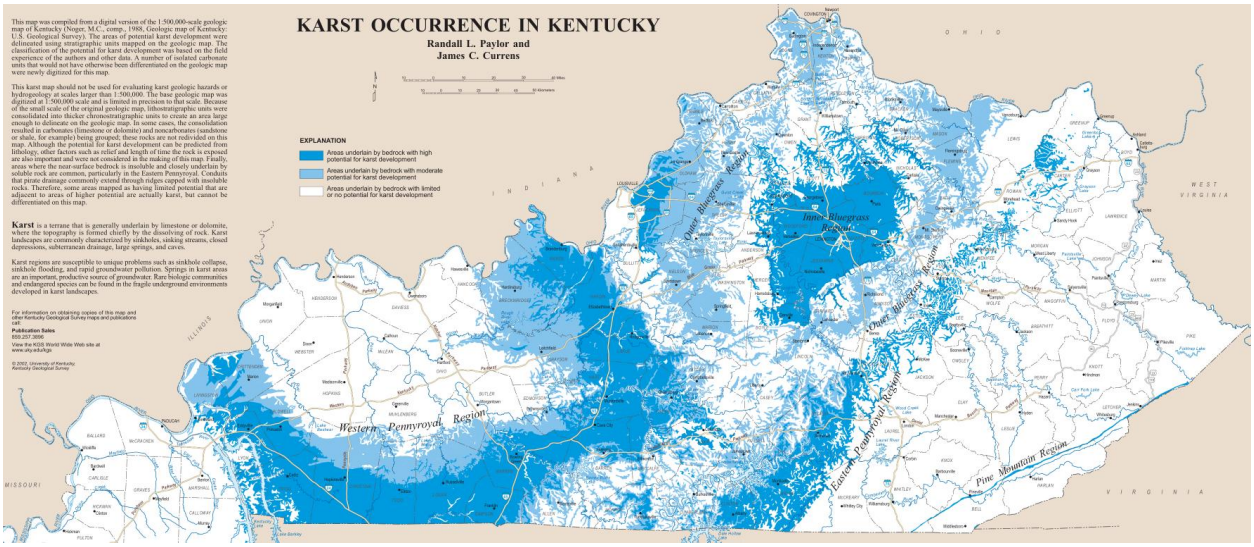
Supporting Figures:



Cross Section (G Reynolds Watkins / Atec Associates, 1978)



GeoQuad Map (Commonwealth of Kentucky, 1963)



Karst Map (Paylor & Currens, 1988)

2.5 General Geology

(Ref. Geologic Quadrangle Map, Bernstadt Quadrangle, Kentucky CQ-202).

This dam is located in the Kentucky Physiographic Region known as Eastern Coal Region which is typified by a highly dissected and fairly rugged terrain.

The soils at the dam site are primarily residual and colluvial in nature with minor amounts of alluvium in the valley bottom.

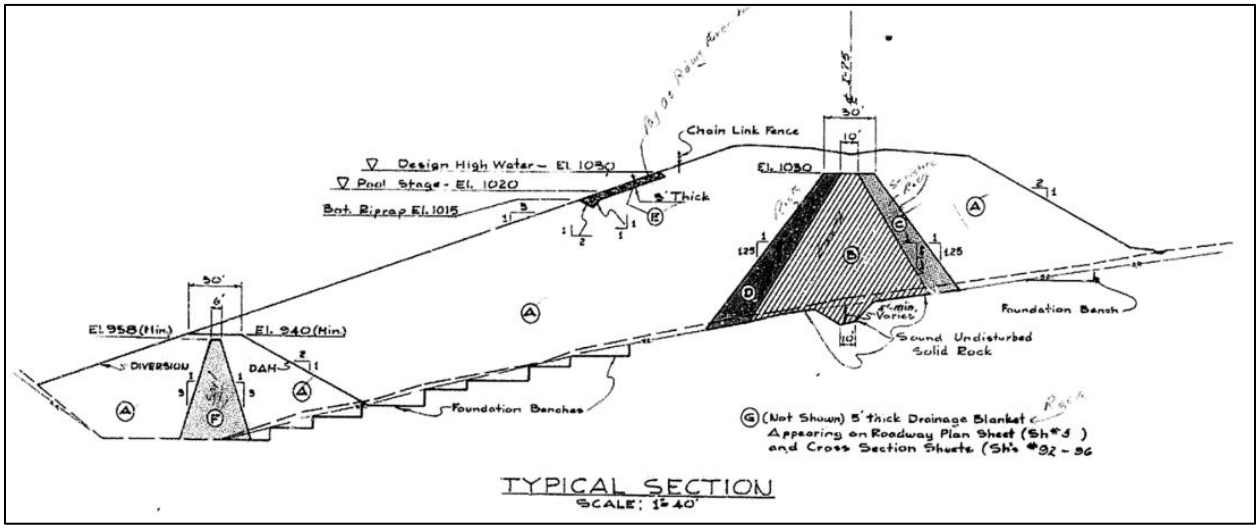
The bedrock at this dam site is the Pennsylvanian Age Lee Formation which consists primarily of sandstone, shale, siltstone and minor amounts of coal. From the base of the valley up to about El. 980 the Rockcastle Sandstone Member is present. Above this unit there are alternating layers of shale, siltstone and sandstone. Thin coal beds are also present within the bedrock units in this area. An unnamed coal bed, which is located at the base of the Rockcastle Sandstone Member, has been mined from drifts in the valley sides about 1000 ft. upstream from the dam.

The bedrock present at this dam site dips to the east at about 55 ft. per mile. The altitude of the bedrock is controlled by the region structural feature known as the Appalachian Basin.

No faults have been mapped in the vicinity of the dam site. At the dam site--in the road cut above the left abutment (upstream)--what appeared to be either a fault or a large block failure was observed which had a vertical displacement of about 8 ft.

According to the Seismic Zone Map (Appendix IV), this dam is in Zone 1 which indicates that minor damage would result from the expected seismic activity in this area.

Phase 1 Report Text (G Reynolds Watkins / Atec Associates, 1978)



Cross Section (Commonwealth of Kentucky, 1971)

Potential Failure Mode Analysis Table:

PFM No.:	WC-3	**Dam:**	Wood Creek Lake Dam
PFM Group:	Seismic		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure*)

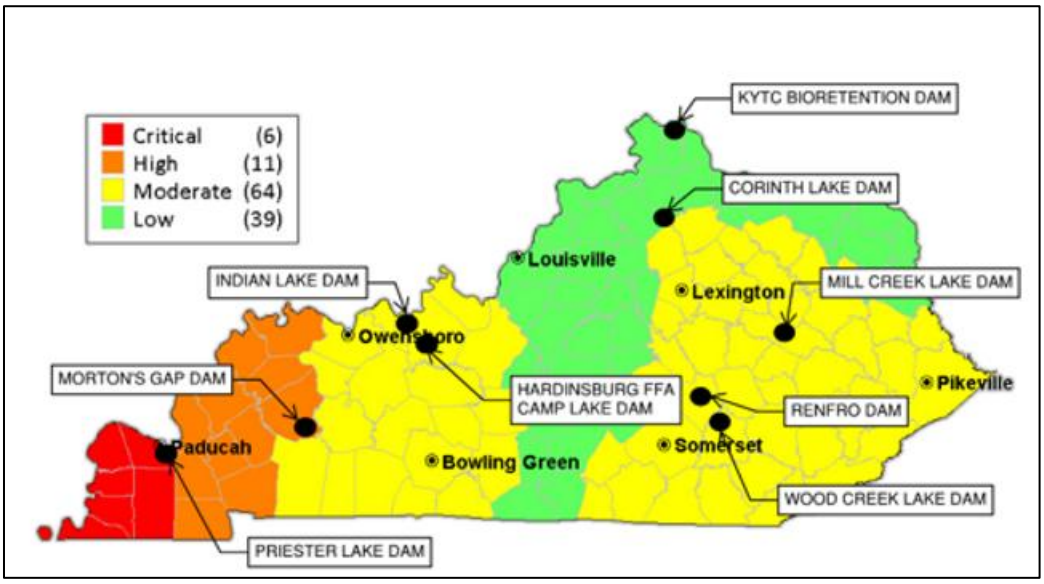
A strong earthquake is felt at the dam site. The dynamic loads on the dam embankment cause slope displacements and possible slope failures. The deformations are larger on the downstream face, which is steeper than the upstream slope. Successive slope movements during and after the earthquake progress across the width of the dam crest. There is no time for intervention. The crest drops below normal pool and the reservoir overtops. The resulting flows scour downward through the dam embankment, releasing the reservoir.

More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
• Slopes are steep (2:1) • Intervention would be impossible during the earthquake • There was a 3.7 magnitude earthquake at the dam about 20 years ago	• We are in a moderate seismic zone • Compacted embankment • The dam has a very wide crest • No indication of liquifiable or soft embankment or foundation materials

Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Negligible	Probability of the loading is very low. There are no soft materials. The dam embankment is very wide.
Failure Likelihood		
Life Safety Consequences		

Economic Consequences		
Risk Reduction Measures		
Studies and Investigations	Review seismic hazard curve for the dam site	
Maintenance and Monitoring		
Design and Modifications		

Supporting Figures:



Seismic Map

Potential Failure Mode Analysis Table:

PFM No.:	WC-4	**Dam:**	Wood Creek Lake Dam
PFM Group:	Overtopping		
PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*			
A heavy precipitation event occurs in the watershed, causing the reservoir level to rise. Water is released through the spillway, but the spillway capacity is partially blocked by floating debris. The water levels continue to rise and overtop the dam crest. The median barrier wall fails to retain the water. No plausible effort is made to raise the crest of the dam. The overtopping flows begin to erode the downstream slope of the dam embankment. The flow causes head cutting, which progresses backward across the width of the dam crest. The dam is breached when the crest erosion reaches the upstream pool. The resulting flows scour downward through the dam embankment, releasing the reservoir.			
More Likely (Adverse) Factors		**Less Likely (Favorable) Factors**	

• **The morning glory spillway is prone to clogging from floating debris** • **There are large trees on the lake shore near the morning glory spillway** • The top of the barrier wall appears to be below the crest at the upstream shoulder so the barrier wall would be overtopped.	• The hydraulic modeling shows a return period of 1e10-4 for the unclogged condition • The median barrier wall is robust, it is a continuous concrete wall across the entire dam crest. • The surface water along the crest drains in a pipe to the upstream • Debris boom helps to prevent clogging • The probability of clogging is less than 1 • It currently safely conveys the PMP • No evidence of debris in the 2024 inspection videos within the tunnel • **Wide crest (140')** • **The crest is paved in an erosion resistant material** • **Overtopping might be 2' for 18-36 hours**

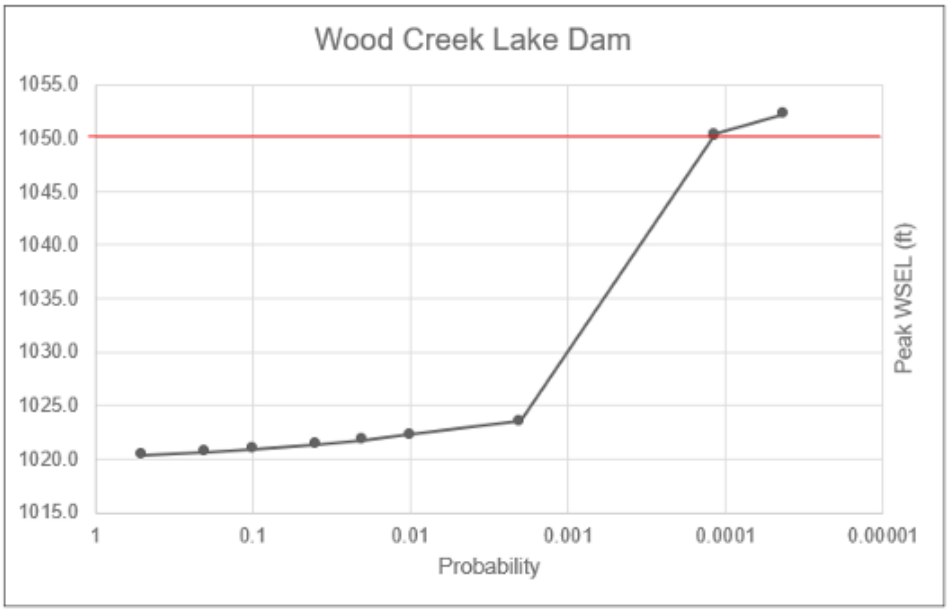
Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Credible	
Failure Likelihood	FL3	Could be FL2-FL4, decided on the middle (FL3)
Life Safety Consequences	LS2	The dam breech model indicated 1-10
Economic Consequences	EC4	
Risk Reduction Measures		

Studies and Investigations	Survey of the crest elements, details regarding the barrier wall, analysis of structure. Re-evaluate trash rack.
Maintenance and Monitoring	Recommend removing the trees in the vicinity of the morning glory spillway. Provide signs to warn of danger and contact information in case of emergency.
Design and Modifications	Increase hydraulic capacity

Supporting Figures:

Wood Creek Lake Dam (Dam Crest = 1050.3 ft)					
Precip	Peak Inflow	Peak WSEL	Peak WSEL (clogged)	Return Interval	Notes
2.0	1,546	1020.4	1020.5	0.5	2yr
2.5	2,994	1020.7	1020.8	0.2	5yr
2.9	4,531	1020.9	1021.1	0.1	10yr
3.4	7,055	1021.4	1021.7	0.04	25yr
3.8	9,441	1021.8	1022.2	0.02	50yr
4.3	12,272	1022.2	1022.7	0.01	100yr
5.6	20,242	1023.5	1024.2	0.002	500yr
28.7	202,640	1050.2	1051.2	1.18E-04	PMP
28.8	203,686	1050.4	1051.3	1.18E-04	**Overtopping**
31.7	226,920	1052.3	1052.8	4.28E-05	**~2' overtopping**

*Note: Duration of overtopping for the 31.7" rainfall event estimated to be **10 hours***
*Note: Duration of overtopping for the 28.8" rainfall event with the **spillway clogged** estimated to be **18 hours***
*Note: Duration of overtopping for the 31.7" rainfall event with the **spillway clogged** estimated to be **2 days***



H&H Results



Site Visit Photo

Potential Failure Mode Analysis Table:

PFM No.:	WC-5	**Dam:**	Wood Creek Lake Dam
PFM Group:	Erosion Associated with Conduits		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure*)
There is one 8' diameter conduit and it was tunneled through rock and lined with concrete. Without a soil backfill, there is no identifiable failure mode for an erosion of soil along, into, or out of conduits.

More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
•	•

Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Negligible	
Failure Likelihood		
Life Safety Consequences		
Economic Consequences		

Risk Reduction Measures	
Studies and Investigations	

Maintenance and Monitoring	
Design and Modifications	

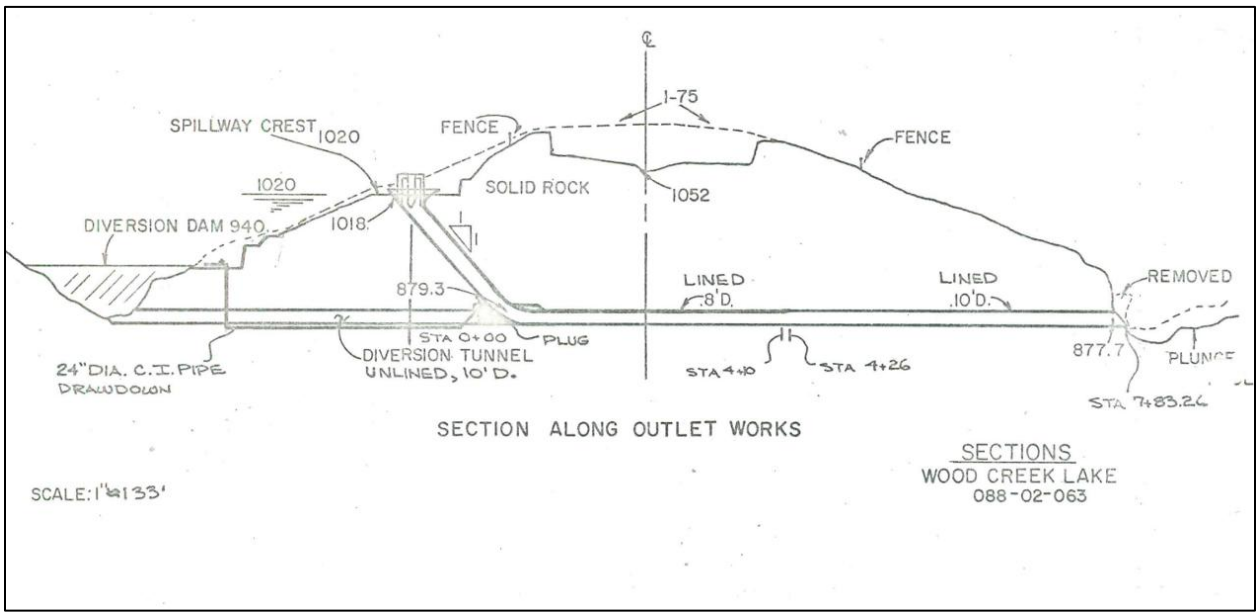
Potential Failure Mode Analysis Table:

PFM No.:	WC-6	**Dam:**	Wood Creek Lake Dam
PFM Group:	Spillway Structures		
PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*			
The morning glory spillway structure is in rock. Annual inspections are performed and no plausible failure mode has been documented.			
More Likely (Adverse) Factors		**Less Likely (Favorable) Factors**	
•		•	

Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Negligible	
Failure Likelihood		
Life Safety Consequences		
Economic Consequences		

Risk Reduction Measures	
Studies and Investigations	
Maintenance and Monitoring	
Design and Modifications	

Supporting Figures:



Cross Section (G Reynolds Watkins / Atec Associates, 1978)

Potential Failure Mode Analysis Table:

PFM No.:	WC-7	**Dam:**	Wood Creek Lake Dam
PFM Group:	Operational		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure*)

The valve is opened during annual operation. Due to continued corrosion, the valve is unable to be closed. Attempt to close the inlet is unsuccessful. The dam does not fail but the lake is slowly drained through the 24" cast iron low level drawdown pipe.

More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
• Age of cast iron valve system (beyond service life) • The inlet and the valve are submerged 80' in the lake • Inspections have identified corrosion deterioration of the drawdown components	• The flow is limited by the 24" pipe • The system is operated every year • The flow discharges into the 8' diameter tunnel. • The pipe is in rock

Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Credible	Does not progress to a dam breach
Failure Likelihood	FL6	We estimate a 1-10% chance each year when the system is operated/inspected.
Life Safety Consequences	LS0	
Economic Consequences	EC1	Water supply for Laurel Co. at an intake elevation of _____'.

Risk Reduction Measures	
Studies and Investigations	Determine the intake elevation for Wood Creek Water District.
Maintenance and Monitoring	Replace the corroded valve, ensure the buoy is present.
Design and Modifications	Relocate low level drawdown valve.

Supporting Figures:

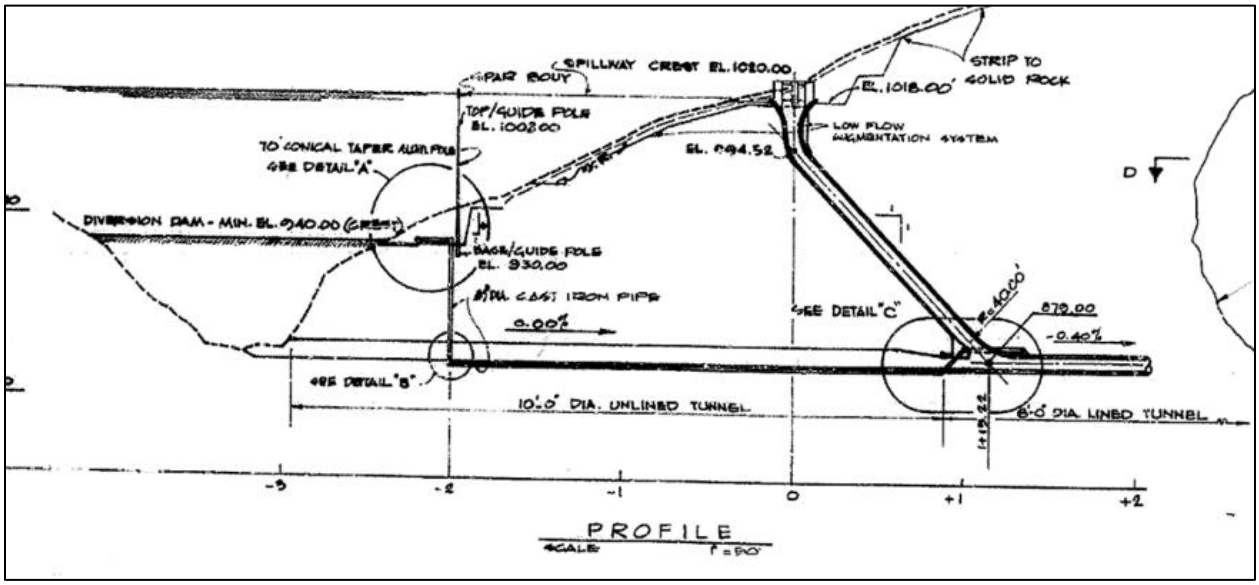
Drawdown System: Drawdown operation scheduled for divers August 2024. The drawdown location is identified by the buoy right of the morning glory. The 8" low flow/base flow line is at elevation 970.0' and is always open. The low flow operates with a lever controlled eccentric plug valve that has been reported as stuck in the open position. The 24" CIP drawdown has a 24" butterfly valve located at 940.0' and can only be operated by divers using a handwheel on the valve.

Text from 2024 KDOW Inspection Report (KDOW, 2024)

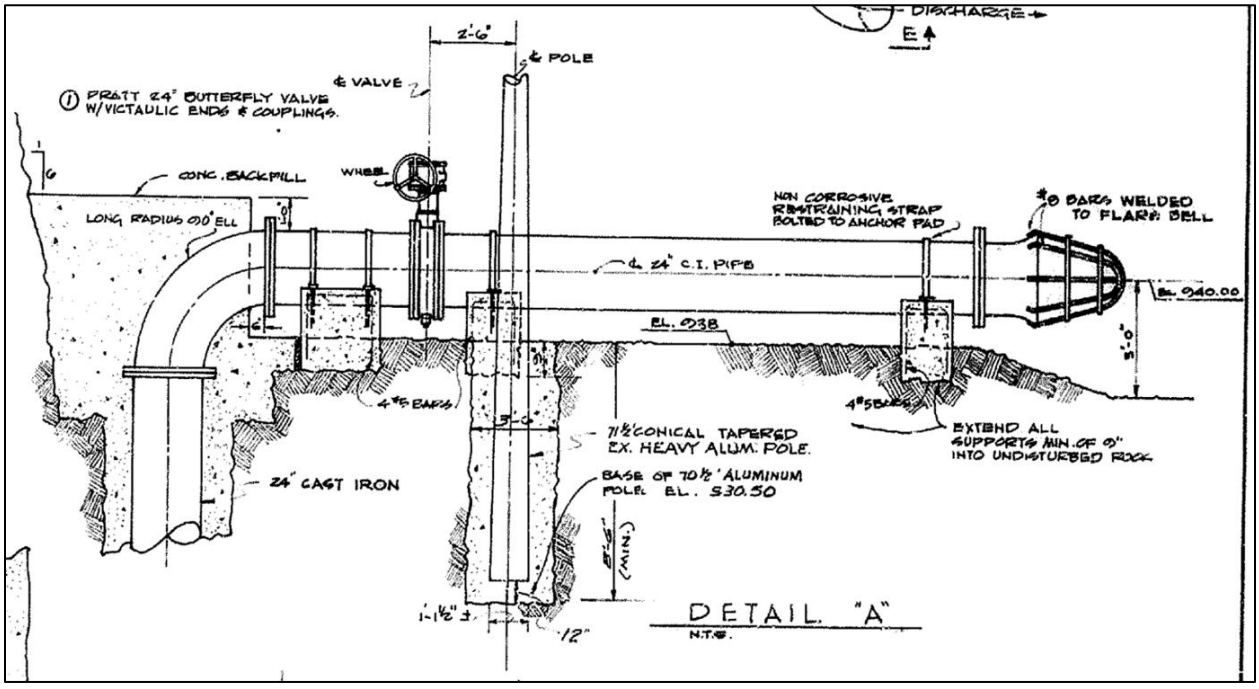
Inspection Findings

1. The hazard buoy and marker buoy rope failed and disconnected from the top of the riser pipe during the underwater inspection. The buoys must be reconnected during the next underwater inspection of the structure. The top of the riser pipe was located at approximately 17 ft below the waterline at the time of inspection.
2. The channel bottom material consisted of soft silt with up to 2 ft of penetration.
3. Marine growth was observed on the riser pipe typically measuring up to 1/4 in. thick and extended from 30 ft below the waterline to the channel bottom.
4. The dam valve was successfully opened and closed by inspectors.
5. At approximately 18 ft below the waterline, the top of the riser pipe consisted of a short section of 2 in. diameter riser pipe which connected into a 4 in. diameter section of riser pipe. This 4 in. diameter section of riser pipe expanded to a 6 in. diameter pipe at approximately 40 ft below the waterline, which then connected to an elbow at the channel bottom and ran horizontal towards the dam. The dam valve was located approximately 5 ft from the elbow at the channel bottom.
6. A steel chain, consisting of multiple connected lengths of steel chain, was observed to be connected to the top of the riser pipe and followed the pipe to the channel bottom. This length of chain was not connected to the base of the riser pipe and appeared to be abandoned.
7. At the time of inspection, the dam valve riser pipe exhibited corrosion with steel pitting typically measuring up to 1/16 in. deep with scattered rust nodules throughout typically measuring up to 1 in. diameter.
8. The upper section of 2 in. diameter steel pipe exhibited edge loss. The original section could not be determined due to the typical loss of section throughout.

Dive Inspection Report 2024 (Collins Engineers Inc., 2024)



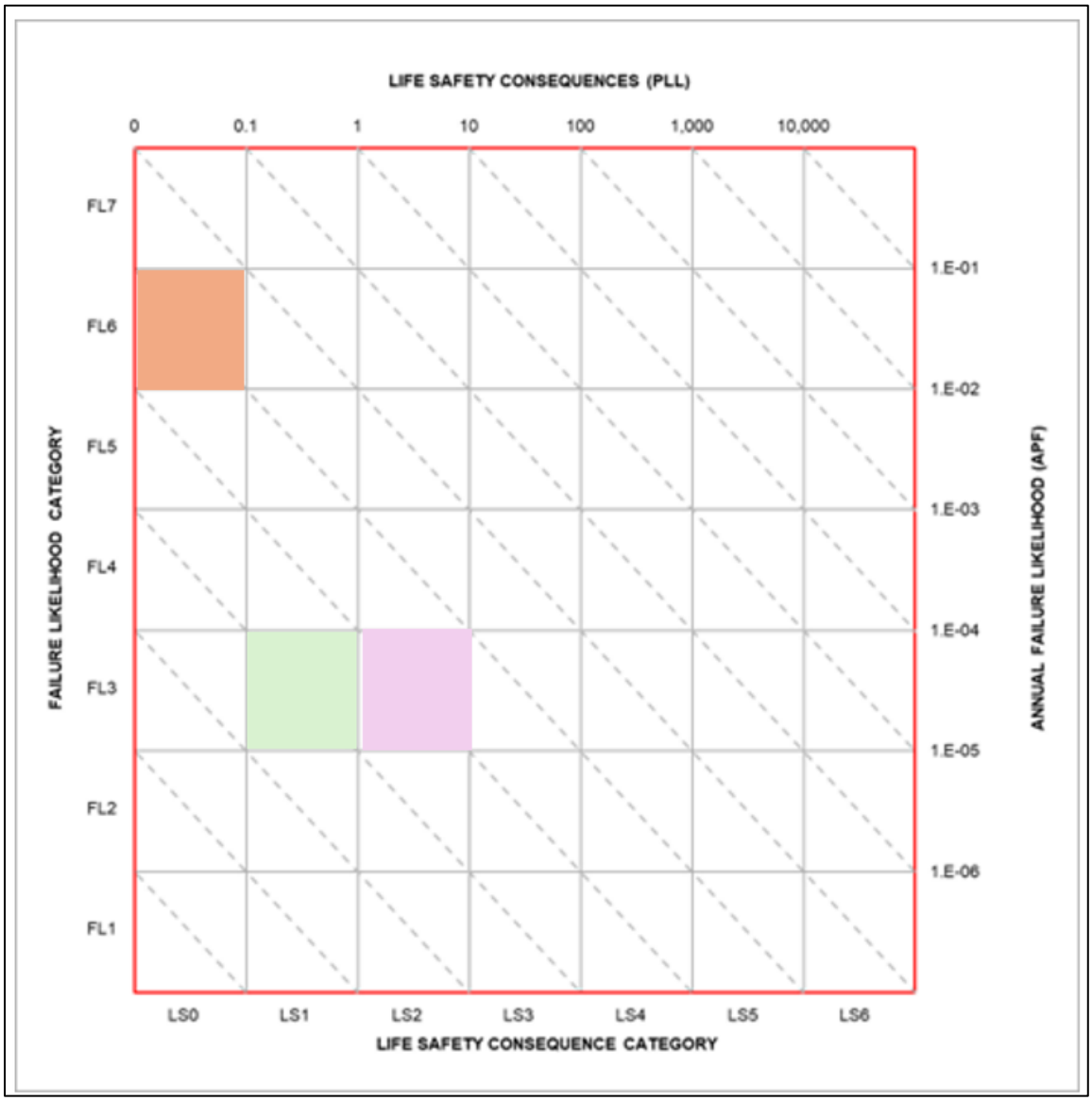
Profile from 1971 Design Drawings (Commonwealth of Kentucky, 1971)



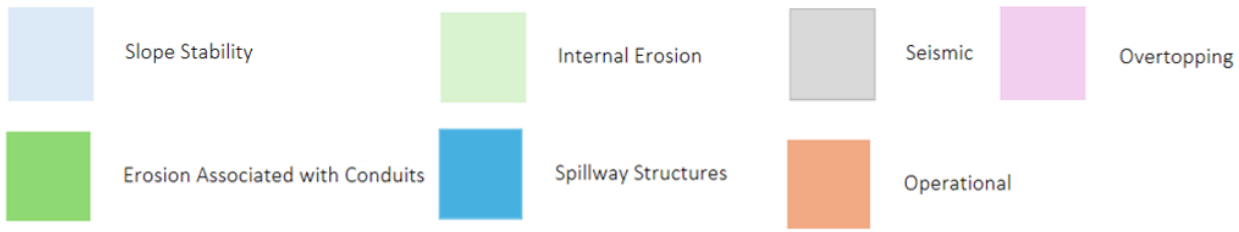
Detail from 1971 Design Drawings (Commonwealth of Kentucky, 1971)

E.6 Risk Matrices

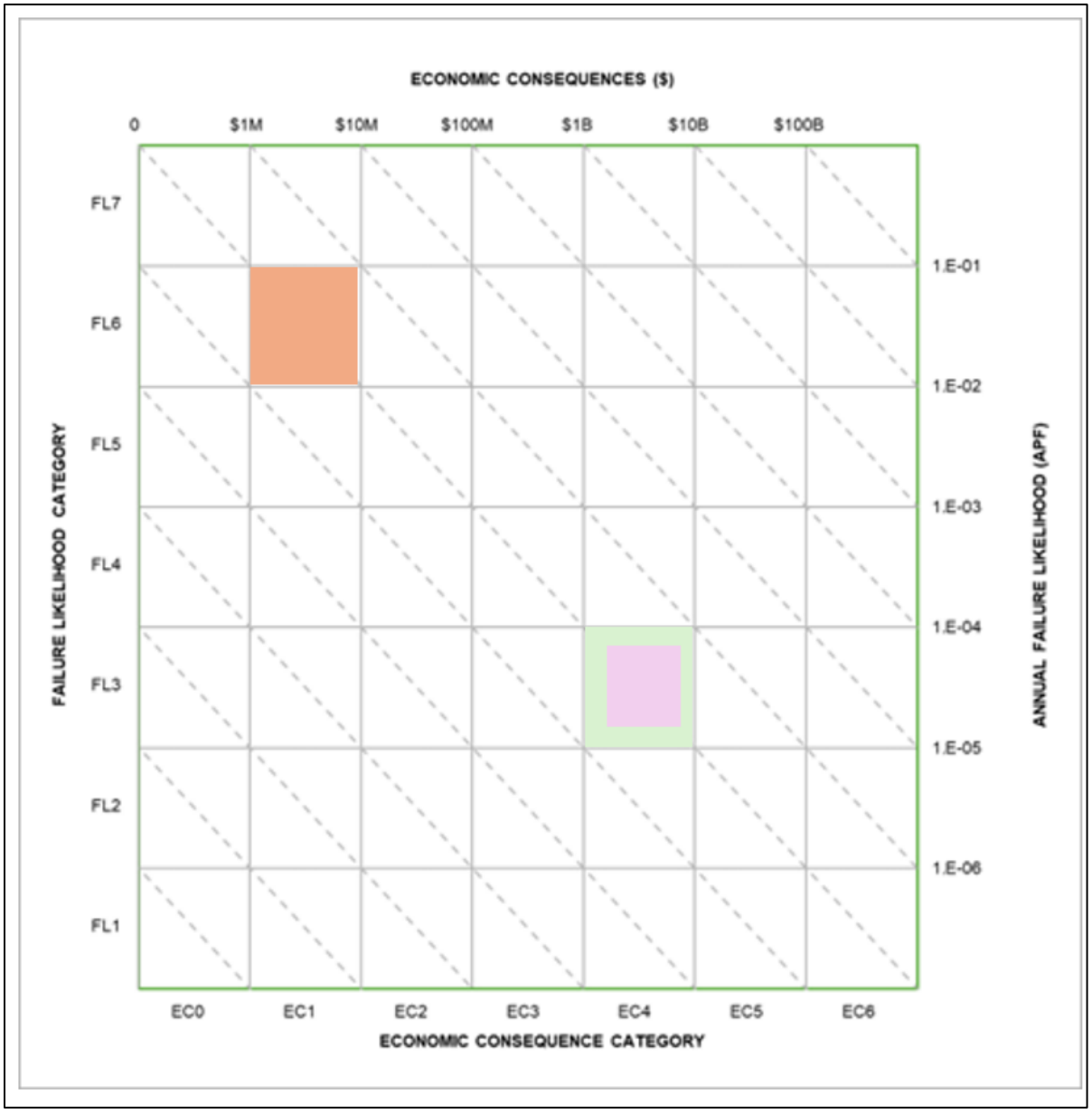
Life Safety Risk Matrix:



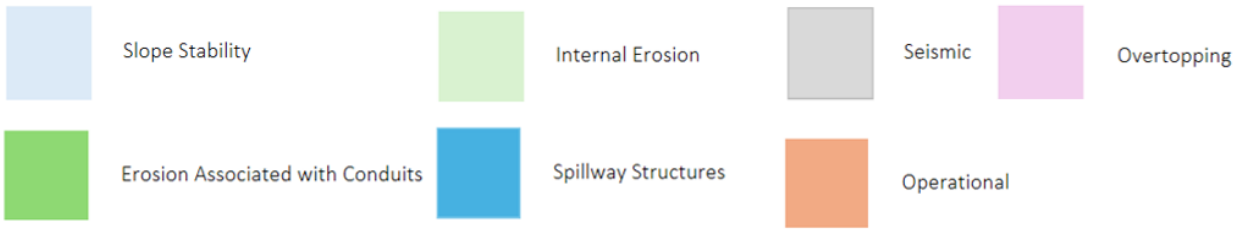
Legend:



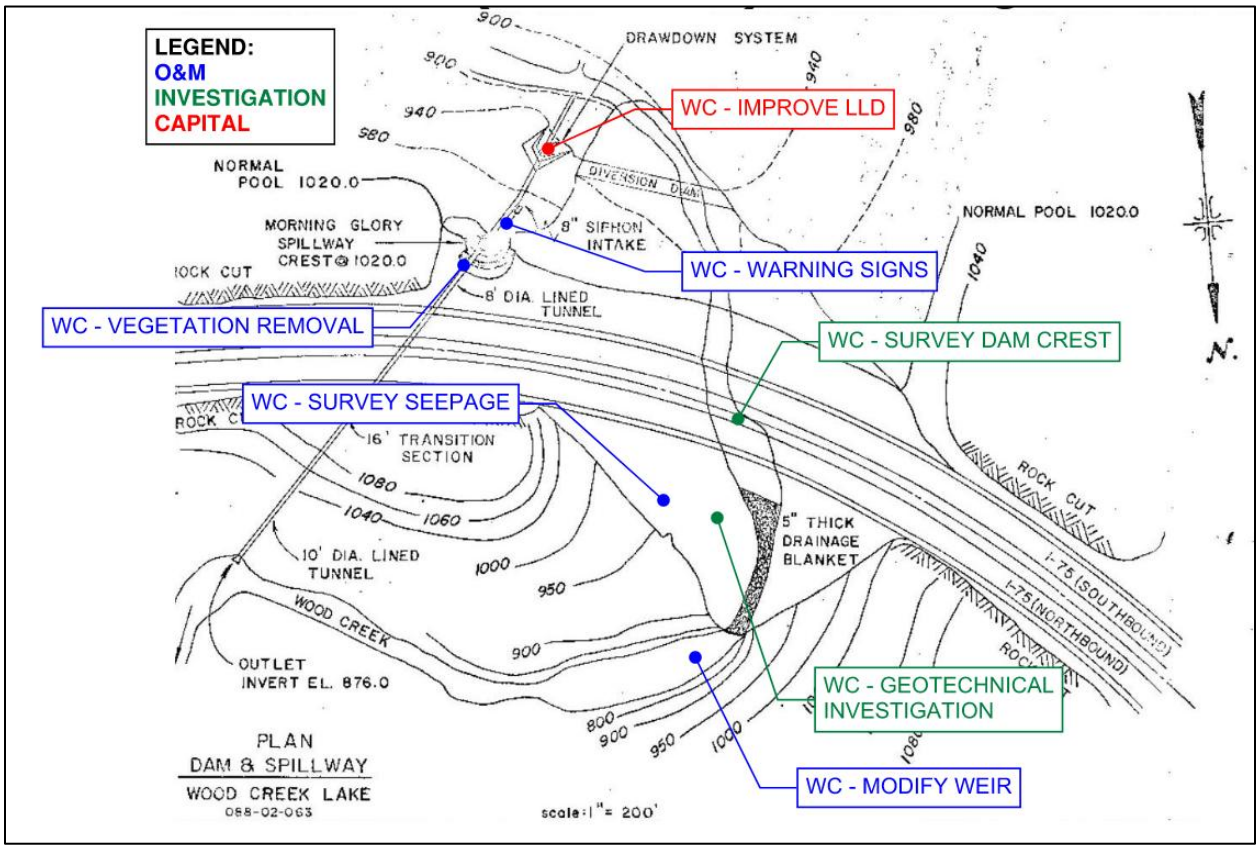
Economic Consequences Risk Matrix:



Legend:



E.7 Recommendations



Recommendations - Wood Creek Lake Dam								
CODE	**Recommendation**	**Type**	**Life Loss Risk**	**Economic & Transportation Risk**	**Regulatory Compliance**	**Cost Range**	**Planning Horizon**	**Priority**
WC – VEGETATION REMOVAL	Remove trees in the area surrounding the morning glory spillway entrance.	O&M	6	12	Yes	<10K	Short Term	1
WC – SURVEY SEEPAGE	Mark or survey the seepage locations on the downstream face for future monitoring.	O&M	3	12	Yes	<10K	Short Term	2
WC – WARNING SIGNS	Install multiple warning signs on spillway structure (DANGER - KEEP BACK).	O&M	0	0	No	<10K	Short Term	3
WC – SURVEY DAM CREST	Survey or otherwise establish the profile elevation of the dam crest and median barrier wall. If there is a hydraulic deficiency, evaluate the median crash barrier for performance as a temporary floodwall.	Investigation	6	12	Yes	10K-100K	Intermediate	4
WC – MODIFY WEIR	Modify the weir and/or remove channel obstructions at the dam toe to facilitate accurate measurements of surface flow rates.	O&M	3	12	Yes	10K-100K	Intermediate	5
WC – GEOTECHNICAL INVESTIGATION	Perform geotechnical investigation (borings and piezometers) and seepage analyses.	Investigation	3	12	Yes	100K-1M	Intermediate	6
WC – IMPROVE LLD	Improve reliability and operability of existing low level drawdown valve and system.	Capital	0	6	Yes	1M-10M	Long Term	7

E.8 Cost Opinions for Capital Projects

Stantec developed the following cost opinions for constructing capital improvements for each dam. The costs listed below are very approximate, as they are based only on broad concepts, without even preliminary designs. The costs should be used only for planning, and not for budgeting specific improvements.

The work recommended for Wood Creek would improve reliability and operability of existing low level drawdown valve and system. Specifically, installing a new valve within the spillway conduit would eliminate the need to use divers to open the lake outlet.

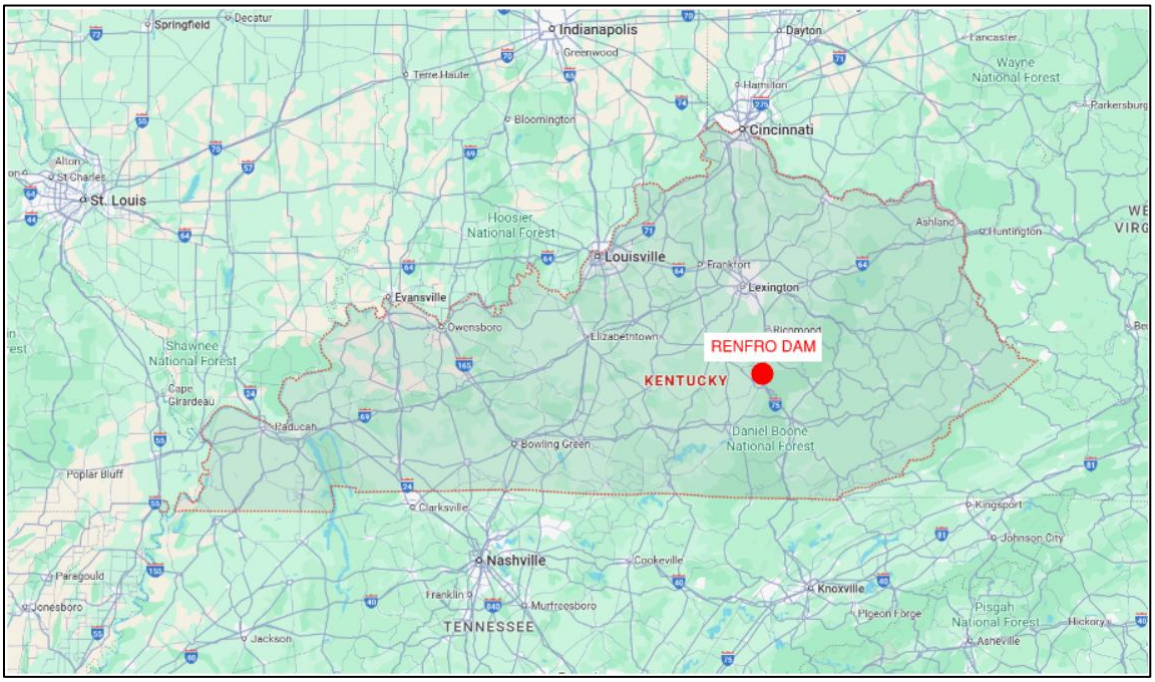
Low Level Drawdown

Contractor Work Item	Quantity	Unit of Measure	Operating Cost	Total Cost
Replace Existing Valve and Stem	1	LS	$50,000	$50,000
Dive Work	2	Week	$25,000	$50,000
12" DIP Extension	165	LF	$170	$28,050
12" Core into 8' Tunnel	1	EA	$1,350	$1,350
12" Drilling	230	LF	$5,000	$1,150,000
Stem Extension	1	EA	$50,000	$50,000
New Valve	1	EA	$5,500	$5,500
			Total	$1,600,000

Appendix F
Renfro Dam

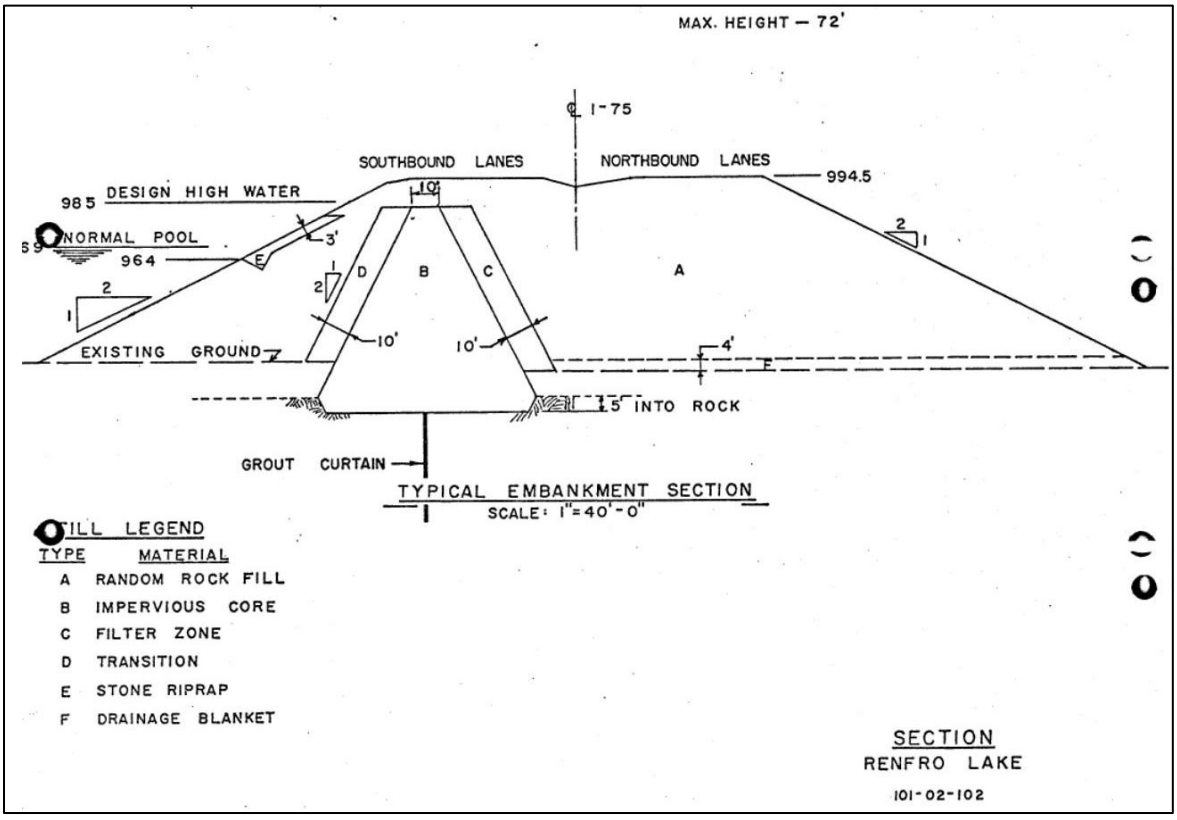
F.1 Dam and Appurtenant Features

Renfro Dam is a high hazard dam located in Rockcastle County (location map below). The National Inventory of Dams lists the purpose of the dam as water-supply. This dam was constructed in 1968. The dam crest elevation is 992.6 ft, and I-75 runs along the entire crest. The normal pool elevation is 969 ft. The height of the dam is 72 ft, and the crest width is 140 ft.

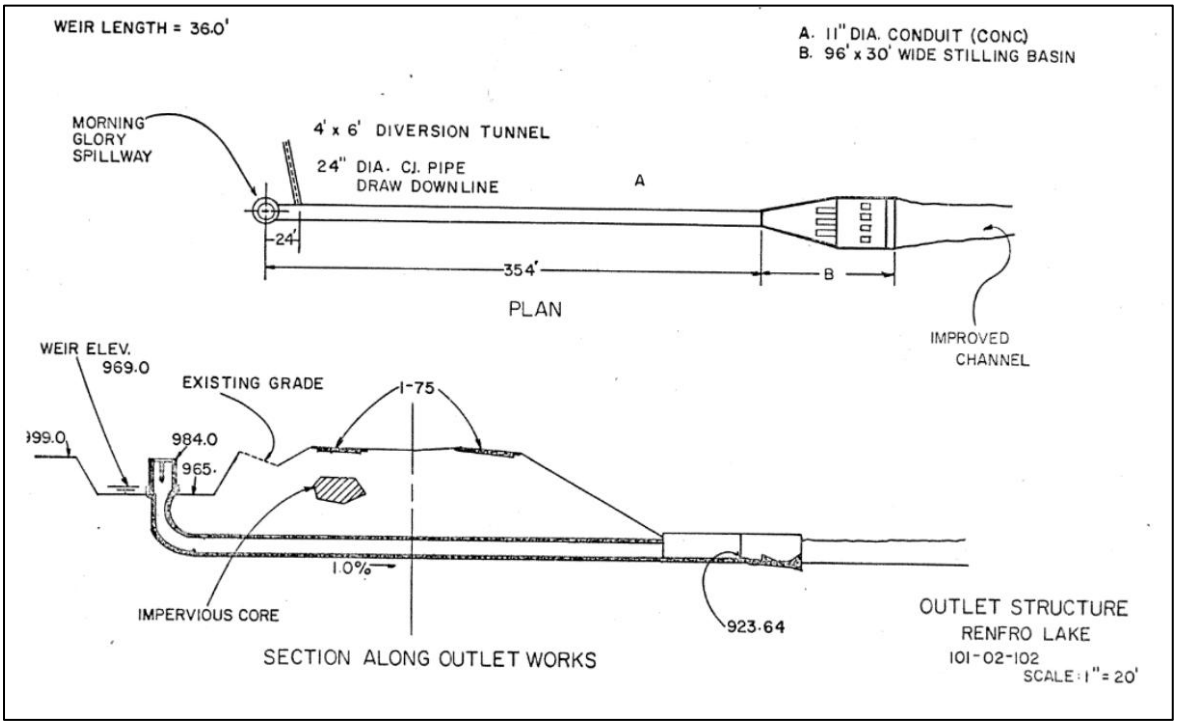


Renfro Dam – Vicinity Map

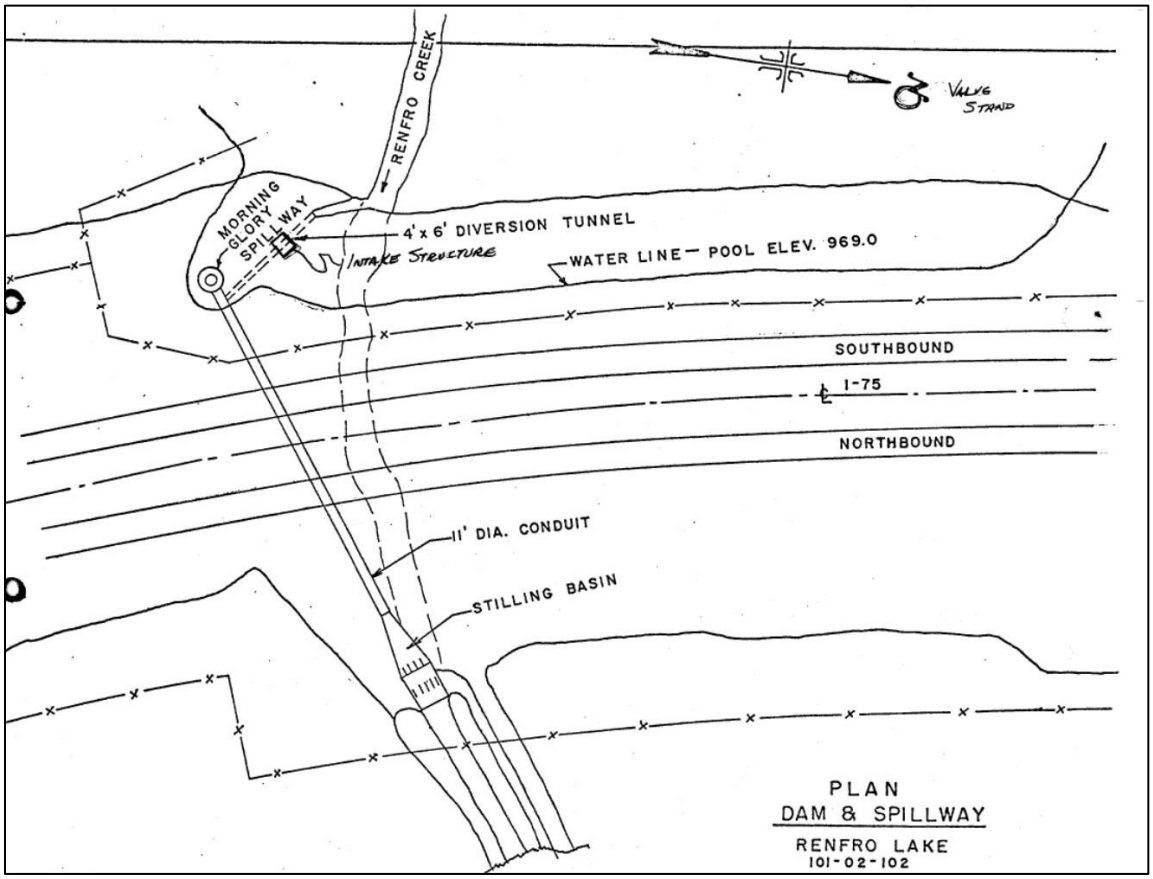
The principal spillway is a morning glory spillway connected to an 11 ft-diameter conduit that runs through the dam at the base of the embankment. The figures below show the cross sections and plan view for this dam.



Renfro Dam – Typical Cross Section



Renfro Dam – Cross Section and Conduit Schematic



Renfro Dam – Plan View

F.2 Data Catalog

FILE #	DATA TYPE	TITLE	FILE DESCRIPTION
02.02.001	H & H	Emergency Action Plan	2013 KDOW***
02.02.002	H & H	Evacuation Map	***
02.02.003	H & H	Inundation Map	***
02.02.004	H & H	H & H report	1994 Review of Hydrology
02.03.001	Inspections	Phase I inspection Report	1978 USACE Louisville District
02.03.002	Inspections	Inspection Report	1991 DOWR
02.03.003	Inspections	Inspection Report	1996 DOWR
02.03.004	Inspections	Inspection Report	2009 DOWR
02.03.005	Inspections	Inspection Report	2011 DOWR***
02.03.006	Inspections	Inspection Report	2020 DOWR
02.03.007	Inspections	Inspection Report	2021 DOWR
02.03.008	Inspections	Inspection Report	2022 DOWR
02.03.009	Inspections	Inspection Report	2023 DOWR
02.03.010	Inspections	Inspection Report	2024 DOWR
02.04.001	Drawings	Plan and Profile of Proposed State Highway	1967 Dept of Highways
02.04.002	Drawings	Cross Section Exhibit	
02.04.003	Drawings	Plan View Exhibit	
02.06.001	Transportation docs	Traffic Counts	
02.06.002	Transportation docs	Roadway Plans	
02.03.101	Inspections	Dive Inspection Report	2003 Division of Operations
02.03.102	Inspections	Dive Inspection Report	1995 FMSM Engineers
02.03.103	Inspections	Dive Inspection Report	1995 FMSM Engineers
02.03.104	Inspections	Dive Inspection Report	1994 FMSM Engineers
02.03.105	Inspections	Dive Inspection Report	1994 Division of Operations
02.03.106	Inspections	Dive Inspection Report	1994 FMSM Engineers
02.03.107	Inspections	Dive Inspection Report	1993 FMSM Engineers
02.03.108	Inspections	Dive Inspection Report	1996
02.03.109	Inspections	Dive Inspection Report	1982 Mid-Eastern Enterprises

02.03.110	Inspections	Dive Inspection Report	1996 FMSM Engineers
02.03.111	Inspections	Dive Inspection Report	1996 FMSM Engineers
02.03.112	Inspections	Dive Inspection Report	1996 FMSM Engineers
02.03.113	Inspections	Dive Inspection Report	1974
02.03.114	Inspections	Dive Inspection Report	1993 FMSM Engineers
02.03.115	Inspections	Dive Inspection Report	1992
02.03.116	Inspections	Dive Inspection Report	1992 Laurel Diving Headquarters
02.03.117	Inspections	Dive Inspection Report	1991 Lexington Dive Shop
02.03.118	Inspections	Dive Inspection Report	1991 Lexington Dive Shop
02.03.119	Inspections	Dive Inspection Report	1990 Lexington Dive Shop
02.03.120	Inspections	Dive Inspection Report	1989 Dept of Highways
02.03.121	Inspections	Dive Inspection Report	1977-1987 Division of Water
02.03.122	Inspections	Inspection Report	2013 Division of Water
02.03.123	Inspections	Inspection Report	2011 Division of Water
02.03.124	Inspections	Inspection Report	2007 Division of Water
02.03.125	Inspections	Inspection Report	2009 Division of Water
02.03.126	Inspections	Inspection Report	1993 Division of Water
02.03.127	Inspections	Inspection Report	1987 Division of Water
02.03.128	Inspections	Inspection Report	2005 Division of Water
02.03.129	Inspections	Inspection Report	1996
02.03.130	Inspections	Inspection Report	1981 Division of Design
02.03.131	Inspections	Inspection Report	1983 KYTC Bureau of Highways
02.03.132	Inspections	Inspection Report	1987 Division of Maintenance
02.03.133	Inspections	Inspection Report	1987 Dept of Highways
02.03.134	Inspections	Inspection Report	1974
02.03.135	Inspections	Inspection Report	1974
02.03.136	Inspections	Inspection Report	2005 KYTC
02.03.137	Inspections	Inspection Report	2004 FMSM Engineers
02.03.138	Inspections	Inspection Report	2005 FMSM Engineers
02.03.139	Inspections	Inspection Report	1975 DOWR

02.03.140	Inspections	Inspection Report	2003 Division of Water
02.03.141	Inspections	Inspection Report	1979 DNREP
02.03.142	Inspections	Inspection Report	1974 VIA
02.03.143	Inspections	Inspection Report	1983 Division of Maintenance
02.03.144	Inspections	Inspection Report	1995 Division of Operations
02.03.145	Inspections	Inspection Report	1997 Division of Water
02.03.146	Inspections	Inspection Report	1975 VIA
02.03.147	Inspections	Inspection Report	1997 Division of Water
02.03.148	Inspections	Inspection Report	1991 Division of Maintenance
02.03.149	Inspections	Inspection Report	1981 Division of Water
02.03.150	Inspections	Inspection Report	1978 Division of Water
02.03.151	Inspections	Inspection Report	1983 Division of Water
02.03.152	Inspections	Inspection Report	1983 Division of Water
02.03.153	Inspections	Inspection Report	1986 Division of Maintenance
02.03.154	Inspections	Inspection Report	1977 Division of Water
02.03.155	Inspections	Inspection Report	1975 Division of Water
02.03.156	Inspections	Inspection Report	1974 Division of Water
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02.03.158	Inspections	Inspection Report	2000 Division of Water
02.03.159	Inspections	Inspection Report	1975 Division of Water
02.03.160	Inspections	Inspection Report	1972 Division of Water
02.03.161	Inspections	Inspection Report	1974 Division of Water
02.03.162	Inspections	Inspection Report	1973 Division of Water
02.03.163	Inspections	Inspection Report	1973 Division of Water
02.03.164	Inspections	Inspection Report	1973 Division of Water
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02.03.166	Inspections	Inspection Report	1972 Division of Water
02.03.167	Inspections	Inspection Report	1972 Division of Water
02.03.168	Inspections	Inspection Report	1972 Division of Water
02.03.169	Inspections	Inspection Report	1972 Division of Water
02.03.170	Inspections	Inspection Report	1971 Division of Water
02.03.171	Inspections	Inspection Report	1975 Division of Water

02.03.172	Inspections	Inspection Report	1977 Division of Water
02.03.173	Inspections	Inspection Report	1976 Division of Water
02.03.174	Inspections	Inspection Report	1976 Division of Water
02.03.175	Inspections	Inspection Report	1976 Division of Water
02.03.176	Inspections	Inspection Report	1978 Division of Water
02.03.177	Inspections	Inspection Report	1979 Division of Water
02.03.178	Inspections	Inspection Report	1979 Division of Water
02.03.179	Inspections	Inspection Report	1979 Division of Water
02.03.180	Inspections	Inspection Report	1980 Division of Water
02.03.181	Inspections	Inspection Report	1980 Division of Water
02.03.182	Inspections	Inspection Report	1982 Division of Water
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02.03.184	Inspections	Inspection Report	1982 Division of Water
02.03.185	Inspections	Inspection Report	1981 Division of Water
02.03.186	Inspections	Inspection Report	1981 Division of Water
02.03.187	Inspections	Inspection Report	1983 Division of Water
02.03.188	Inspections	Inspection Report	1984 Division of Water
02.03.189	Inspections	Inspection Report	1984 Division of Water
02.03.190	Inspections	Inspection Report	1985 Division of Water
02.03.191	Inspections	Inspection Report	1986 Division of Water
02.03.192	Inspections	Inspection Report	1986 Division of Water
02.03.193	Inspections	Inspection Report	1987 Division of Water
02.03.194	Inspections	Inspection Report	1987 Division of Water
02.03.195	Inspections	Inspection Report	1987 Division of Water
02.03.196	Inspections	Inspection Report	1988 Division of Water
02.03.197	Inspections	Inspection Report	1988 Division of Water
02.03.198	Inspections	Inspection Report	1988 Division of Water
02.03.199	Inspections	Inspection Report	1987 Division of Water
02.03.200	Inspections	Inspection Report	1989 Division of Water
02.03.201	Inspections	Inspection Report	1989 Division of Water
02.03.202	Inspections	Inspection Report	1990 Division of Water
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02.03.210	Inspections	Inspection Report	1992 Division of Water
02.03.211	Inspections	Inspection Report	1992 Division of Water
02.03.212	Inspections	Inspection Report	1993 Division of Water
02.03.213	Inspections	Inspection Report	1998 Division of Water
02.03.214	Inspections	Inspection Report	
02.03.215	Inspections	Inspection Report	1995 Division of Water
02.03.216	Inspections	Inspection Report	1995 Division of Water
02.03.217	Inspections	Inspection Report	1996 Division of Water
02.03.218	Inspections	Inspection Report	1982 Division of Maintenance
02.03.219	Inspections	Inspection Report	1995 Division of Water
02.03.220	Inspections	Inspection Report	1996 Division of Operations
02.03.221	Inspections	Tunnel Inspection Video	2021 Division of Maintenance
02.03.222	Inspections	Tunnel Inspection Video	2018 Division of Maintenance
02.03.223	Inspections	Tunnel Inspection Video	2019 Division of Maintenance
02.03.224	Inspections	Tunnel Inspection Video	2020 Division of Maintenance
02.03.225	Inspections	Tunnel Inspection Video	2022 Division of Maintenance
02.03.226	Inspections	Tunnel Inspection Video	2022 Division of Maintenance
02.03.227	Inspections	Tunnel Inspection Video	2023 Division of Maintenance
02.03.228	Inspections	Tunnel Inspection Video	2023 Division of Maintenance
02.03.229	Inspections	Tunnel Inspection Video	2024 Division of Maintenance
02.03.230	Inspections	Tunnel Inspection Video	2024 Division of Maintenance
02.03.231	Inspections	Tunnel Inspection Video	2009 Division of Maintenance

02.03.232	Inspections	Tunnel Inspection Video	2010 Division of Maintenance
02.03.233	Inspections	Tunnel Inspection Video	2013 Division of Maintenance
02.03.234	Inspections	Tunnel Inspection Video	2013 Division of Maintenance
02.03.235	Inspections	Dive Inspection Report	2023 Collins Engineers
02.03.236	Inspections	Dive Inspection Report	2024 Collins Engineers
02.03.237	Inspections	Dive Inspection Report	2022 Stantec
02.03.238	Inspections	Inspection Report	2020 Divsion of Water
02.03.239	Inspections	Inspection Report	2021 Divsion of Water
02.03.240	Inspections	Inspection Report	2022 Divsion of Water
02.03.241	Inspections	Inspection Report	2023 Divsion of Water
02.03.242	Inspections	Inspection Report	2024 Divsion of Water
02.03.243	Inspections	Inspection Report	2012 Division of Maintenance
02.03.244	Inspections	Inspection Report	1983 Division of Maintenance
02.03.245	Inspections	Dive Inspection Report	1997 FMSM Engineers
02.03.246	Inspections	Dive Inspection Report	1990 Lexington Dive Shop
02.03.247	Inspections	Dive Inspection Report	1995 FMSM Engineers
02.04.101	Drawings	Plan View Exhibit	1995
02.04.102	Drawings	Plan View Exhibit	
02.04.103	Drawings	Outlet Structure	
02.04.104	Drawings	Cross Section Exhibit	
02.04.105	Drawings	Cross Section Exhibit	
02.04.106	Drawings	Cross Section Exhibit	
02.04.107	Drawings	Cross Section Exhibit	
02.04.108	Drawings	Cross Section Exhibit	
02.04.109	Drawings	Cross Section Exhibit	
02.04.110	Drawings	Plan and Cross Section Exhibit	
02.01.201	Geotech / geology info.	Geological Investigation	1965 KDOH
02.02.201	H & H	Dam Breach Scenario Analysis	1983 USACE Louisville District
02.02.202	H & H	Dam Breach Scenario Analysis	2020 AECOM
02.02.203	H & H	H & H Report	2006

02.02.204	H & H	Emergency Action Plan	2020 AECOM
02.02.205	H & H	Hydraulic Curve	
02.02.206	H & H	Hydrologic and Hydraulic Review	2020 Dam Safety Section
02.02.207	H & H	Hydrologic and Hydraulic Review	2020 Dam Safety Section
02.04.201	Drawings	Cross Section and Stability Slope Repair	2017
02.04.202	Drawings	Plan and Cross Section Exhibit	

F.3 Hydrologic and Hydraulic Analyses

Elevation-Frequency Analysis

Previous hydrologic and hydraulic analyses were performed by the Kentucky Division of Water using the National Resources Conservation Service (NRCS) SITES model in 2020, and for the Kentucky Transportation Cabinet using the U. S. Army Corps of Engineers (USACE) Hydrologic Engineering Center River Analysis System (HEC-RAS) software in 2020. The input data from the SITES and HEC-RAS models was used to generate a new USACE Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) model (version 4.12) to estimate water surface elevations associated with various precipitation depths. The following information was taken from the SITES model:

- Curve Number
- Drainage Area
- Time of Concentration

The following information was taken from the HEC-RAS model:

- Stage-Storage-Discharge Information

Two scenarios were modeled – one where the principal spillway was assumed to be flowing and operating as intended and one where the principal spillway was clogged and not flowing.

NOAA Atlas 14 was used to generate precipitation depths for frequencies ranging from the 2-year (50-percent-annual-chance) up to the 500-year (0.2-percent-annual-chance) storm. For the Probable Maximum Precipitation (PMP), Kentucky Engineering Memorandum No. 2 was used to determine the PMP rainfall depth. A 24-hour SCS Type II rainfall distribution was applied to the precipitation depths from NOAA Atlas 14, and a 6-hour SCS Type II rainfall distribution was applied to the PMP rainfall depth within the HEC-HMS model. The probability associated with the PMP was estimated using two methods:

- The FEMA Spillway Capacity and Extreme Flood Discharge Estimator (which uses flow-frequency data input by the user along with extrapolation using a power function to estimate the return period of the PMP)
- The Australian Rainfall Runoff method (which uses drainage area to estimate a return period of the PMP).

The results of the two methods were averaged to estimate the PMP probability.

Using trial and error, additional storms were run with higher rainfall depths until a rainfall depth that produced a water surface elevation that would activate the auxiliary spillway, a water surface elevation that would just overtop the dam and a water surface elevation that overtopped the dam by two feet was obtained. A power curve was fit to the flow frequency data (including the PMP) and interpolated/extrapolated to approximate a return period associated with these rainfall depths. The duration of overtopping for the PMP event, the PMP event where the principal spillway was assumed to be clogged, and the 21.6” rainfall event where the principal spillway was assumed to be clogged was also

estimated by reviewing the time-series results of the HMS model and noting the period of time where the water surface elevation was above the dam crest.

The resulting water surface elevations from the model runs are tabulated and plotted below.

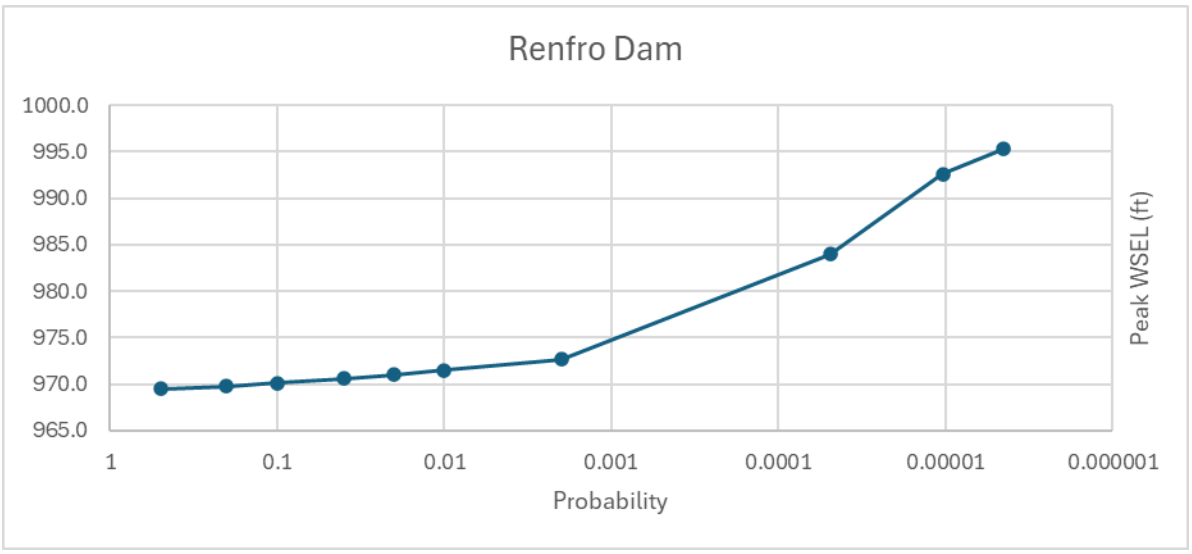
Renfro Dam Model Results

Renfro Dam (Dam Crest = 992.6 feet; Auxiliary Spillway Crest = 984 feet)					
Precipitation (inches)	**Peak Inflow (cfs)**	**Peak WSEL (feet)**	**Peak WSEL (clogged) (feet)**	**Return Interval**	**Notes**
2.1	732	969.5	970.0	0.5	2yr
2.6	1,155	969.8	970.6	0.2	5yr
3.0	1,547	970.1	971.1	0.1	10yr
3.5	2,165	970.6	971.9	0.04	25yr
4.0	2,708	971.0	972.6	0.02	50yr
4.5	3,314	971.5	973.3	0.01	100yr
5.7	4,982	972.7	975.3	0.002	500yr
11.2	13,112	----	984.1	1.09E-04	**Aux. Spillway Activated (PS Clogged)**
13.8	17,259	984.0	----	4.92E-05	**Aux. Spillway Activated**
21.6	29,682	992.6	993.9	1.04E-05	**Overtopping**
28.5	40,770	995.3	995.8	4.53E-06	**PMP**

Note: Duration of overtopping for the PMP estimated to be 7 hours

Note: Duration of overtopping for the 21.6” rainfall event with the spillway clogged estimated to be 7 hours

Note: Duration of overtopping for the PMP rainfall event with the spillway clogged estimated to be 9 hours.



Renfro Dam Elevation-Frequency Curve

Consequences Analysis

Previous inundation mapping for a sunny-day breach of the dam publicly available on Kentucky's Dam Inundation Viewer (watermaps.ky.gov) was reviewed, along with sunny-day and flood-day breach inundation mapping from the 2020 EAP.

Structures identified in the sunny-day inundation area included 18 townhomes, eight apartment complexes, and approximately 5 residences, the Renfro Valley Complex (music venue, barn, tourist attractions), one treatment plant, and approximately 15 road crossings. A population at risk of greater than 1,000 was estimated based on the seating capacity of Renfro Valley Barn being 1,500.

The flood-day inundation extents were similar to the sunny-day breach extents. The PAR would be mostly transient and associated with the Renfro Valley Complex located a quarter mile from the base of the dam. Estimating life loss is difficult due to the transient/seasonal nature of the PAR. The consequences are summarized in the table below.

Consequences Associated with a Failure of Renfro Dam

Renfro Dam	
NID_ID	KY00101
Number of Residences	~5 (approximate)
Number of Non-Residential Structures	1
Description of Non-Residential Structures	Renfro Valley complex (music venue, barn, tourist attractions)
Number of Critical Infrastructure Structures	1
Description of Critical Infrastructure Structures	Treatment Plant
Number of Road Crossings	~15
List of Roads Affected	~10 road crossings (including I-75 and US-25) and portions of Hummel Road
Estimated PAR	> 1,000
PAR Assumptions	Renfro Valley Barn has a seating capacity of 1500
Inundation Mapping Source	KY Dam Inundation Viewer + Aerial Imagery + EAP
Estimated Life Loss	10-1000
Life Loss Notes	PAR would be mostly transient, with the music venue (New Barn Theatre) having a stated seating capacity of 1500 people. The New Barn Theatre is located 0.25 miles downstream of the base of the dam. Difficult to estimate life loss because of the transient/seasonal nature of the PAR.

F.4 Potential Failure Modes

PFM NUMBER	PFM GROUP	PFM DESCRIPTION	RISK ASSESSMENT
R-1A	SLOPE STABILITY	Downstream - Under normal pool conditions, a slope failure triggers a mass movement of soil on the downstream face of the dam. Successive slope failures retrogress back to the crest, then to the upstream side of the crest. Material is pushed into the failure from the crest, but the intervention fails. The crest drops below the pool elevation (969'), which overtops the dam breach. The resulting flows scour downward through the dam embankment, releasing the reservoir.	NEGLIGIBLE
R-1B	SLOPE STABILITY	Upstream - Storm event results in a flood pool. The flood pool approaches the crest and over a period of days, the pool drops as water drains through the morning glory spillway. This triggers a rapid drawdown slope failure on the upstream side of the dam. Successive slope failures retrogress across the crest of the downstream side. Material is pushed into the failure from the crest, but the intervention fails. The crest drops below the pool elevation (969'), which overtops the dam breach. The resulting flows scour downward through the dam embankment, releasing the reservoir.	NEGLIGIBLE
R-2A	INTERNAL EROSION	Seepage through a defect in the core - Under normal pool conditions, seepage develops along a defect through the dam core. The defect may be a permeable lift, a smooth lift surface, a poorly compacted lift, or a frozen lift surface. No transition zone constructed. The flow scours the soil to either side of the defect. The embankment over the seepage path does not collapse. The flow path expands and the flow accelerates. The seepage is not detected and there is no intervention. The flow scours a larger void in the embankment, leading to a collapse of the dam crest. The dam is breached and there is an uncontrolled release of the reservoir.	CREDIBLE

R-2B	INTERNAL EROSION	Seepage and erosion in the toe drain - Under normal pool conditions, seepage discharges into the toe drain. The toe drain apparently consists of a zone of fine limestone and a zone of limestone. The filter between the toe drain and the embankment is not effective. The seepage erodes soil into the toe drain. The embankment over the seepage path does not collapse. The flow path expands and the flow accelerates. The seepage is not detected and there is no intervention. The flow scours a larger void in the embankment, leading to a collapse of the dam crest. The dam is breached and there is an uncontrolled release of the reservoir.	CREDIBLE
R-2C	INTERNAL EROSION	Seepage and erosion through the foundation soils - Under normal pool conditions, seepage develops through the bottom of the core and in the sandy foundation soils beneath the dam. The seepage exits unfiltered beneath the toe drain. The exit gradients are high enough to cause uplift or sand boils. An eroded pipe forms at the exit and progresses backward under the dam, toward the upstream pool. The embankment over the seepage path does not collapse. The seepage is not detected and there is no intervention. The flow rate increases rapidly through the eroded pipe, scouring a large void within the foundation. The embankment collapses into the void, the dam is breached, and there is an uncontrolled release of the reservoir.	NEGLIGIBLE

R-2D	INTERNAL EROSION	Seepage into foundation defects (Karst) - Downward seepage erodes foundation or embankment soils into open karst features in the bedrock. Erosion progresses until there is a breach of the dam.	NEGLIGIBLE
R-3	SEISMIC	A strong earthquake is felt at the dam site. The dynamic loads on the dam embankment cause slope displacements and possible slope failures. The deformations are larger on the upstream face, which is steeper than the downstream slope. Successive slope movements during and after the earthquake progress across the width of the dam crest. There is no time for intervention. The crest drops below normal pool and the reservoir overtops. The resulting flows scour downward through the dam embankment, releasing the reservoir.	NEGLIGIBLE
R-4A	OVERTOPPING	Lake Linville Road (storm event less than PMP) - A heavy precipitation event occurs in the watershed, causing the reservoir level to rise. Water is released through Lake Linville Road (KY 2793) at an approximate AEP event of 2E-5 (peak elevation of 988', 4' of water on the road). The flow goes along the road, through the underpass and then turns South, down the left abutment of the dam, towards the water treatment plant. The road cut is in rock and does not erode. However, the flow begins to erode the toe of the dam but does not lead to breach of the dam. Flow then spreads out in the valley downstream of the dam, impacting the treatment plant and some residences.	CREDIBLE

R-4B	OVERTOPPING	A heavy precipitation event occurs in the watershed, causing the reservoir level to rise. Water is released through the spillway, but the spillway capacity is partially blocked by floating debris. Water also flows through Lake Linville Road underpass. The water levels continue to rise and overtop the dam crest. The median barrier wall fails to retain the water. No plausible effort is made to raise the crest of the dam. The overtopping flows begin to erode the downstream slope of the dam embankment. The flow causes head cutting, which progresses backward across the width of the dam crest. The dam is breached when the crest erosion reaches the upstream pool. The resulting flows scour downward through the dam embankment, releasing the reservoir.	CREDIBLE
R-5	EROSION ASSOCIATED WITH CONDUITS	3 potential conduits: 1. Low level drawdown valve a. Discharges into the primary spillway conduit and does not traverse the dam 2. Morning Glory Spillway a. 2/3 of the morning glory spillway tunnel is estimated to be tunneled within rock which is not an erodible material so there is no seepage and erosion path along the outside b. Could have erosion of soil into the pipe but recent inspections demonstrate that the concrete lined section is in good shape. Inspections are performed annually. Those inspections have stated no observations of erosion of embankment material into the spillway tunnel and no defects in the concrete lining. 3. Intake for the water treatment plant a. Water treatment intake is near the left abutment. The water intake runs through the underpass, above the elevation of the lake at normal pool. It is not subject to seepage and erosion along the pipe. b. Failure of a pressurized intake pipe under the dam. The drawings we have and the	NEGLIGIBLE

		site photos suggest the pipe line does not pass under any section of the dam embankment.	
R-6	SPILLWAY STRUCTURES	The morning glory spillway structure is in rock. Annual inspections are performed and no plausible failure mode has been documented.	NEGLIGIBLE
R-7	OPERATIONAL	The valve is opened during annual operation. Due to continued corrosion, the valve is unable to be closed. Attempt to close the inlet is unsuccessful. The dam does not fail but the lake is slowly drained through the 24" cast iron low level drawdown pipe.	CREDIBLE

F.5 Evaluation of PFMs

Potential Failure Mode Analysis Table:

PFM No.:	R-1A	**Dam:**	Renfro
PFM Group:	Slope Stability-Downstream Slope		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*

Under normal pool conditions, a slope failure triggers a mass movement of soil on the downstream face of the dam. Successive slope failures retrogress back to the crest, then to the upstream side of the crest. Material is pushed into the failure from the crest, but the intervention fails. The crest drops below the pool elevation (969'), which overtops the dam breach. The resulting flows scour downward through the dam embankment, releasing the reservoir.

More Likely (Adverse) Factors	Less Likely (Favorable) Factors
• **Reports of shallow sliding prior to the 2001 modifications** • Bulge observed in the 2024 KDOW inspection	• **Wide (140' wide at the crest)** • 25' of freeboard at normal pool • Successful intervention is almost certain

• Toe drain consists of native limestone rock which is susceptible to clogging	• **Moderately steep on the downstream face (2.5:1)** • **Lower portion of the downstream slope has been covered in riprap** • No bulge observed in 2025 inspection

Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Negligible	Due to the size of the embankment and the certainty that we would observe and intervene.
Failure Likelihood		
Life Safety Consequences		
Economic Consequences		
Risk Reduction Measures		
Studies and Investigations		
Maintenance and Monitoring		
Design and Modifications		

PFM No.:	R-1B	**Dam:**	Renfro

PFM Group:	Slope Stability - Upstream Slope

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*

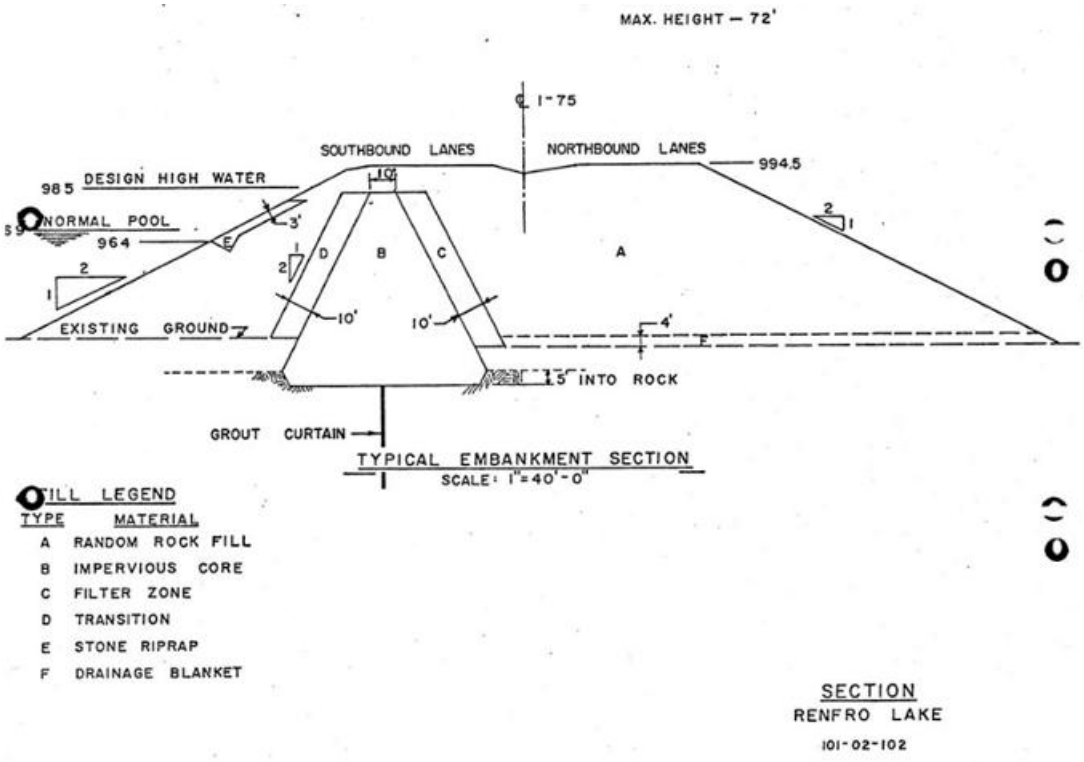
Storm event results in a flood pool. The flood pool approaches the crest and over a period of days, the pool drops as water drains through the morning glory spillway. This triggers a rapid drawdown slope failure on the upstream side of the dam. Successive slope failures retrogress across the crest of the downstream side. Material is pushed into the failure from the crest, but the intervention fails. The crest drops below the pool elevation (969'), which overtops the dam breach. The resulting flows scour downward through the dam embankment, releasing the reservoir.

More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
• 2:1 slope on upstream side	• **Wide (140' wide at the crest)** • 25' of freeboard at normal pool • The size of the morning glory will slow the rate of drawdown • The upstream shell is rocky and may be relatively permeable. • **Low frequency of storm event where the reservoir reaches the upstream slope.**

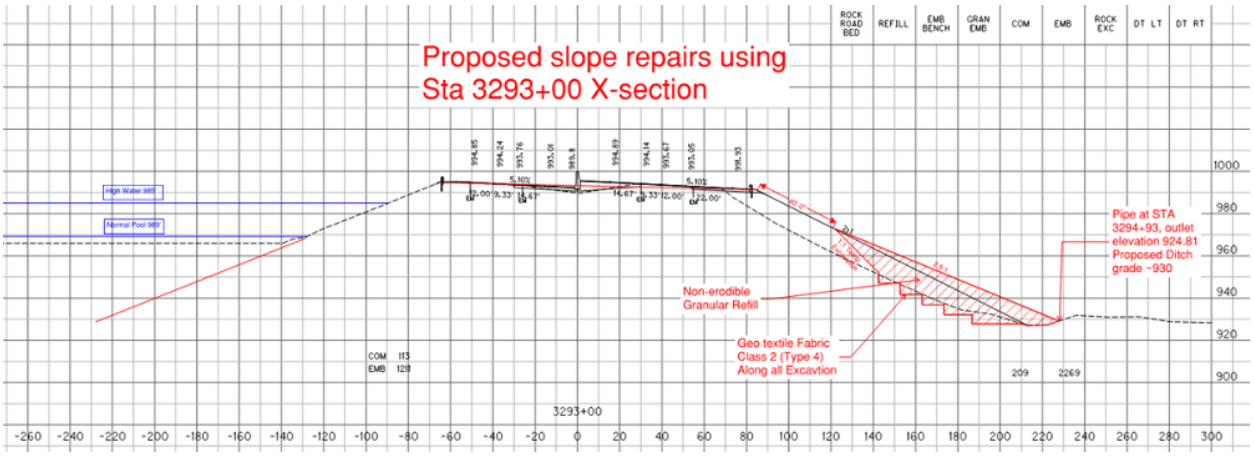
Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Negligible	Due to the size of the embankment and the certainty that we would observe and intervene.
Failure Likelihood		
Life Safety Consequences		

Economic Consequences		
Risk Reduction Measures		
Studies and Investigations		
Maintenance and Monitoring		
Design and Modifications		

Supporting Figures:



Cross Section (USACE Louisville District, 1978)



Cross Section for Slope Repair

Potential Failure Mode Analysis Table:

PFM No.:	R-2A	**Dam:**	Renfro
PFM Group:	Internal Erosion - Seepage through a defect in the core		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure*)

Under normal pool conditions, seepage develops along a defect through the dam core. The defect may be a permeable lift, a smooth lift surface, a poorly compacted lift, or a frozen lift surface. No transition zone constructed. The flow scours the soil to either side of the defect. The embankment over the seepage path does not collapse. The flow path expands and the flow accelerates. The seepage is not detected and there is no intervention. The flow scours a larger void in the embankment, leading to a collapse of the dam crest. The dam is breached and there is an uncontrolled release of the reservoir.

More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
• Built as a highway embankment, not a dam. Less control of the core and transition zone construction. • Limit gradation and index properties of borrow sources • **There is no filter on the downstream side of the core** • Lack of information on compaction criteria required for clay core on drawing notes. • Wet areas reported in the 2024 KDOW inspection.	• The dam is very wide so the seepage path is long. • **The dam is wide so it would take a long time to breach.** • **More time to intervene since longer time to breach.** • No wet area observed in the 2025 inspection • **The gross gradient is relatively low because it is very wide given the depth of the reservoir.**

Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Credible	

Failure Likelihood	FL2	There are no downstream filters in the embankment. The condition is known to exist, lending itself to a classification of FL3. However, the failure mode is estimated to progress slowly, allowing time for successful intervention.
Life Safety Consequences	LS3	The life loss is estimated as 10-1000. However, due to slow progression of the failure mode, there is enough time to evacuate.
Economic Consequences	EC4	Water treatment plant, supply, town
Risk Reduction Measures		
Studies and Investigations	Sample the embankment materials and install instrumentation	
Maintenance and Monitoring	Continue DOW annual inspections.	
Design and Modifications		

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PFM No.:	R-2B	**Dam:**	Renfro
PFM Group:	Internal Erosion - Seepage and erosion into the toe drain		
PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*			
Under normal pool conditions, seepage discharges into the toe drain. The toe drain apparently consists of a zone of fine limestone and a zone of limestone. The filter between the toe drain and the embankment is not effective. The seepage erodes soil into the toe drain. The embankment over the seepage path does not collapse. The flow path expands and the flow accelerates. The seepage is not detected and			

there is no intervention. The flow scours a larger void in the embankment, leading to a collapse of the dam crest. The dam is breached and there is an uncontrolled release of the reservoir.

More Likely (Adverse) Factors	Less Likely (Favorable) Factors
• The transition zone between the core and the shell was omitted. • Limited gradation and index properties of borrow sources • **The gradation of the toe drain materials is not well defined (unlikely to meet filter compatibility)**	• The dam is very wide so the seepage path is long. • **The dam is wide so it would take a long time to breach.** • **More time to intervene since longer time to breach.** • **The gross gradient is relatively low because it is very wide given the depth of the reservoir.**

Risk Assessment	Category	Notes
Negligible? Credible?	Credible	
Failure Likelihood	FL2	There are no downstream filters in the embankment. The condition is known to exist, lending itself to a classification of FL3. However, the failure mode is estimated to progress slowly, allowing time for successful intervention.
Life Safety Consequences	LS3	The life loss is estimated as 10-1000. However, due to slow progression of the failure mode, there is enough time to evacuate.
Economic Consequences	EC4	Water treatment plant, supply, town
Risk Reduction Measures		

Studies and Investigations	Sample the embankment materials and install instrumentation
Maintenance and Monitoring	Continue DOW annual inspections.
Design and Modifications	

PFM No.:	R-2C	**Dam:**	Renfro
PFM Group:	Internal Erosion - Seepage and erosion through the foundation soils		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*

Under normal pool conditions, seepage develops through the bottom of the core and in the sandy foundation soils beneath the dam. The seepage exits unfiltered beneath the toe drain. The exit gradients are high enough to cause uplift or sand boils. An eroded pipe forms at the exit and progresses backward under the dam, toward the upstream pool. The embankment over the seepage path does not collapse. The seepage is not detected and there is no intervention. The flow rate increases rapidly through the eroded pipe, scouring a large void within the foundation. The embankment collapses into the void, the dam is breached, and there is an uncontrolled release of the reservoir.

More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
• This is a common failure mode • **The geologic maps indicate a deposit of alluvial material** • **This failure mode could progress without detection** • There is no transition zone or filter zone on the downstream side of the core.	• **No direct observations of seepage exits** • Only certain soils are susceptible to backward erosion piping (uniform, fine sands) • The borings do not show any sandy soils in the foundation.

• The toe drain was not excavated to rock at the toe.	• **The dam is wide so it would take a long time to breach.** • **More time to intervene since longer time to breach.** • The alignment of the core was excavated to rock so there is no continuous sand stratum upstream

Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Negligible	The base of the core was excavated to rock so there is no continuous sand layer upstream to downstream. Intervention is almost certain.
Failure Likelihood		
Life Safety Consequences		
Economic Consequences		
Risk Reduction Measures		
Studies and Investigations		
Maintenance and Monitoring		
Design and Modifications		

PFM No.:	R-2D	**Dam:**	Renfro
PFM Group:	Internal Erosion - Seepage into foundation defects (Karst)		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*

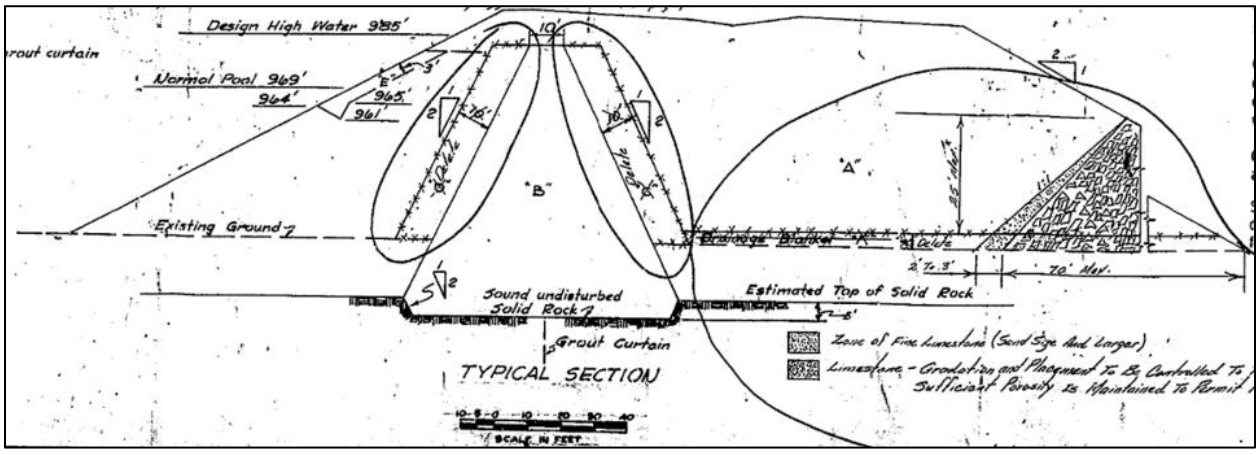
Downward seepage erodes foundation or embankment soils into open karst features in the bedrock. Erosion progresses until there is a breach of the dam.

More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
• The geologic map of Kentucky suggests we are in an area of moderate to high karst activity. • Fissures and discontinuities were observed in the rock abutments in 2025 that could indicate weathering. • There is a possible sinkhole above the reservoir, to the west of the dam. However, that sinkhole appears to be in a higher formation.	• The foundation rock is siltstones with some fracturing. No indication of soluble limestones. • The geologic map of Kentucky suggests we are in an area of moderate to high karst activity. However, when you zoom into the dam site, it appears that the karstic rock formations are above the elevations of the dam. • There are no sinkholes at the dam mapped on the KGS lidar survey • No karst features were observed in the 2025 inspection

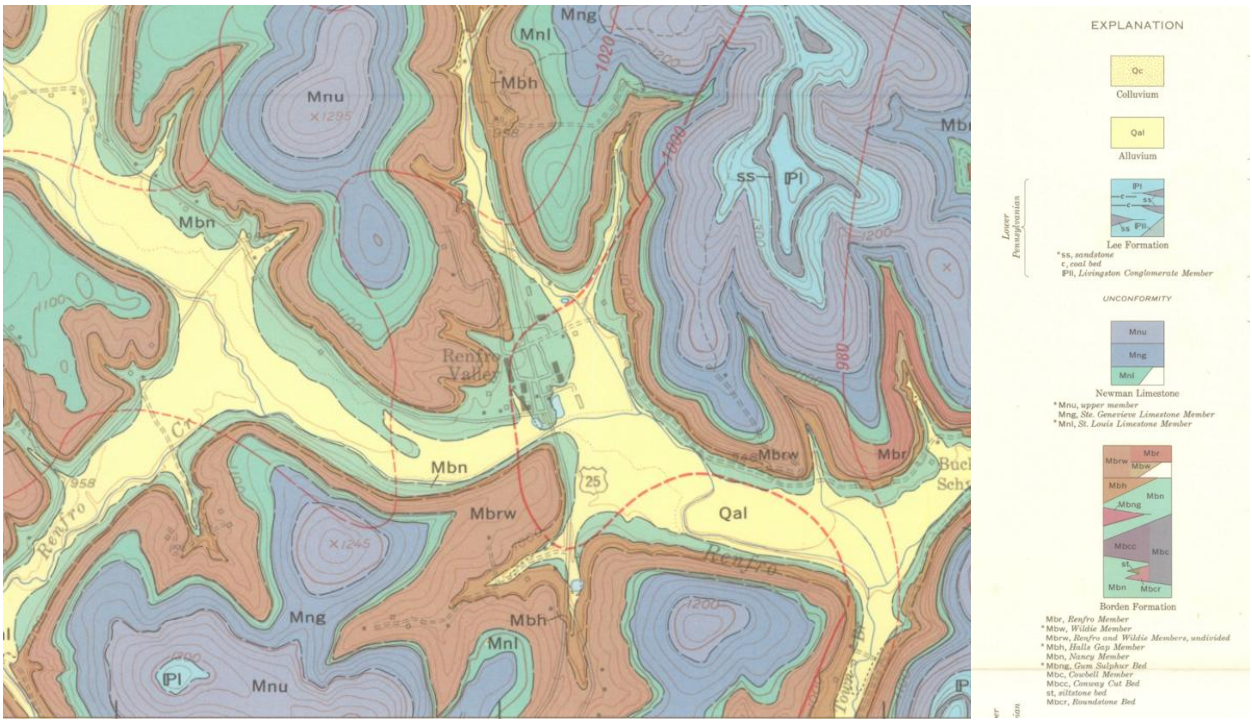
Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Negligible	
Failure Likelihood		

Life Safety Consequences		
Economic Consequences		
Risk Reduction Measures		
Studies and Investigations		
Maintenance and Monitoring		
Design and Modifications		

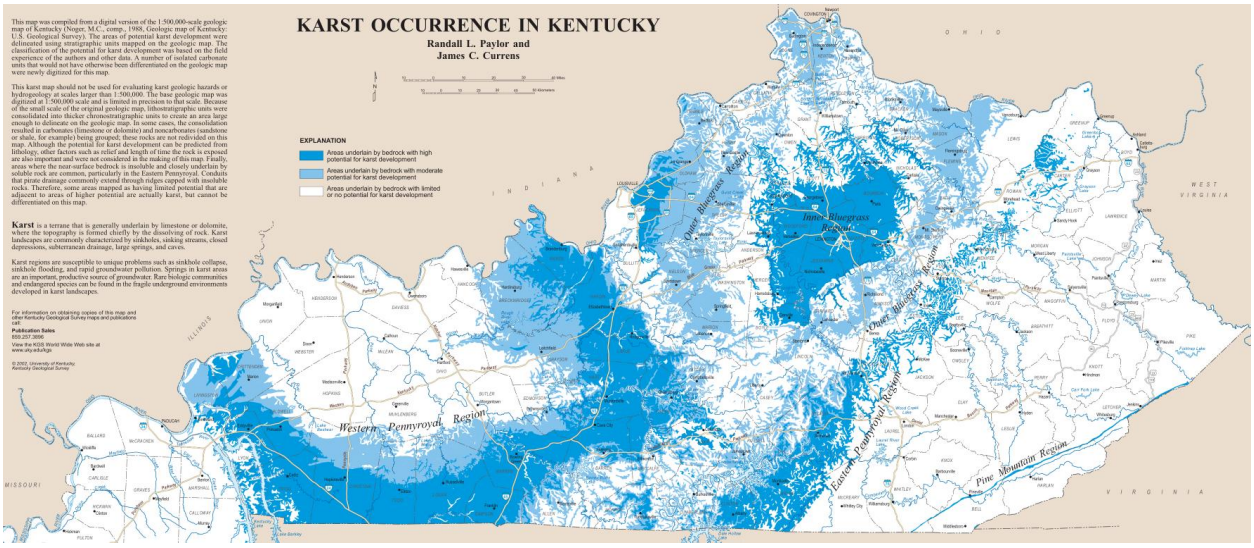
Supporting Figures:



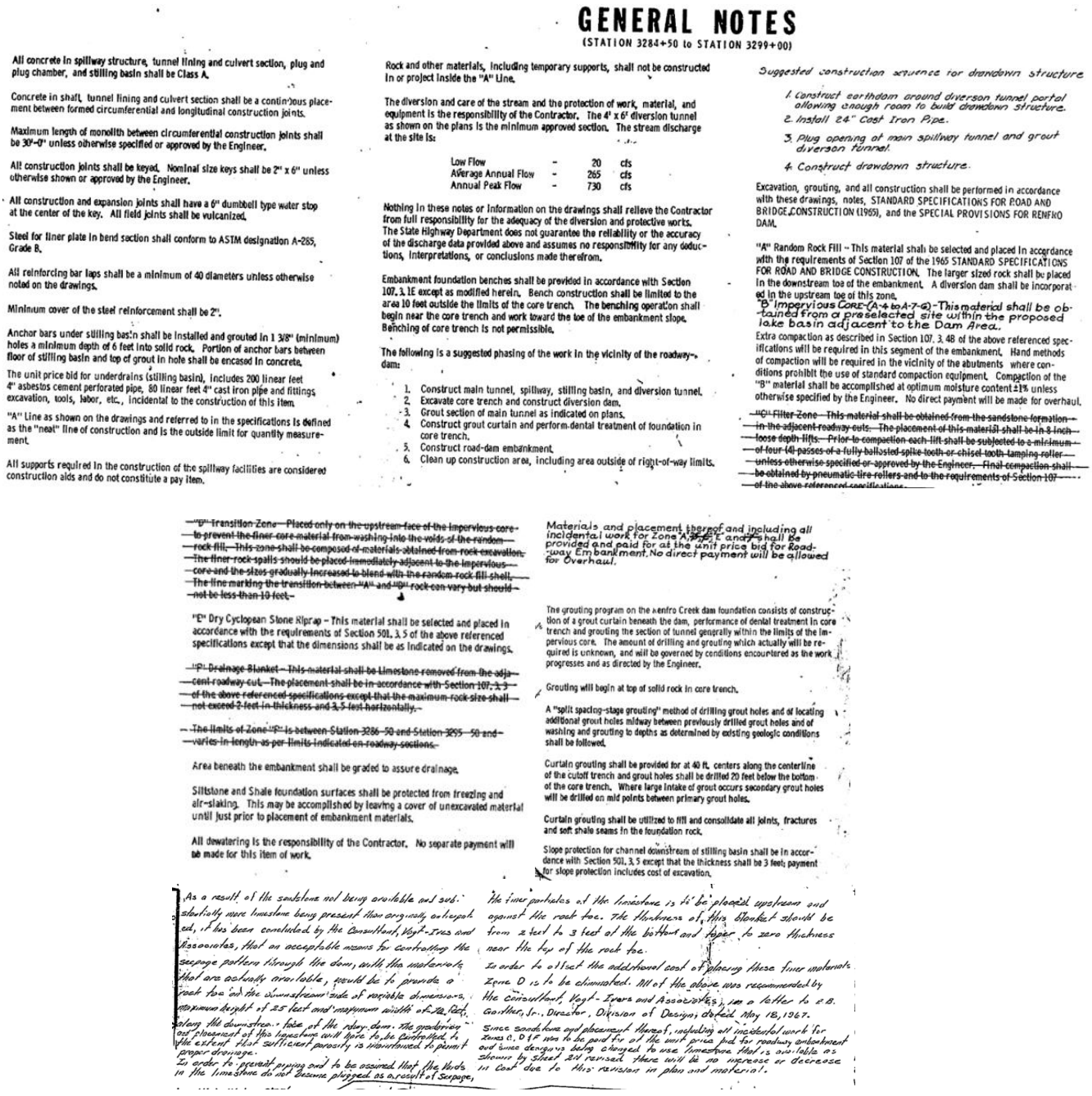
Cross Section (Commonwealth of Kentucky, 1967)



GeoQuad Map (Commonwealth of Kentucky, 1968)



Karst Map (Paylor & Currens, 1988)



GENERAL NOTES

(STATION 3284+50 to STATION 3299+00)

All concrete in spillway structure, tunnel lining and culvert section, plug and plug chamber, and stilling basin shall be Class A.

Concrete in shaft, tunnel lining and culvert section shall be a continuous placement between formed circumferential and longitudinal construction joints.

Maximum length of monolith between circumferential construction joints shall be 30'-0" unless otherwise specified or approved by the Engineer.

All construction joints shall be keyed. Nominal size keys shall be 2" x 6" unless otherwise shown or approved by the Engineer.

All construction and expansion joints shall have a 6" dumbbell type water stop at the center of the key. All field joints shall be vulcanized.

Steel for liner plate in bend section shall conform to ASTM designation A-285, Grade B.

All reinforcing bar laps shall be a minimum of 40 diameters unless otherwise noted on the drawings.

Minimum cover of the steel reinforcement shall be 2".

Anchor bars under stilling basin shall be installed and grouted in 1 3/8" (minimum) holes a minimum depth of 6 feet into solid rock. Portion of anchor bars between floor of stilling basin and top of grout in hole shall be encased in concrete.

The unit price bid for underdrains (stilling basin), includes 200 linear feet 4" asbestos cement perforated pipe, 80 linear feet 4" cast iron pipe and fittings excavation, tools, labor, etc., incidental to the construction of this item.

"A" Line as shown on the drawings and referred to in the specifications is defined as the "neat" line of construction and is the outside limit for quantity measurement.

All supports required in the construction of the spillway facilities are considered construction aids and do not constitute a pay item.

Rock and other materials, including temporary supports, shall not be constructed in or project inside the "A" Line.

The diversion and care of the stream and the protection of work, material, and equipment is the responsibility of the Contractor. The 4' x 6' diversion tunnel as shown on the plans is the minimum approved section. The stream discharge at the site is:

Low Flow	-	20	cfs
Average Annual Flow	-	265	cfs
Annual Peak Flow	-	730	cfs

Nothing in these notes or information on the drawings shall relieve the Contractor from full responsibility for the adequacy of the diversion and protective works. The State Highway Department does not guarantee the reliability or the accuracy of the discharge data provided above and assumes no responsibility for any deductions, interpretations, or conclusions made therefrom.

Embankment foundation benches shall be provided in accordance with Section 107.3.1E except as modified herein. Bench construction shall be limited to the area 10 feet outside the limits of the core trench. The benching operation shall begin near the core trench and work toward the toe of the embankment slope. Benching of core trench is not permissible.

The following is a suggested phasing of the work in the vicinity of the roadway-dam:

1. Construct main tunnel, spillway, stilling basin, and diversion tunnel.
2. Excavate core trench and construct diversion dam.
3. Grout section of main tunnel as indicated on plans.
4. Construct grout curtain and perform dental treatment of foundation in core trench.
5. Construct road-dam embankment.
6. Clean up construction area, including area outside of right-of-way limits.

Suggested construction sequence for drawdown structure

1. Construct earthdam around diversion tunnel portal allowing enough room to build drawdown structure.
2. Install 24" Cast Iron Pipe.
3. Plug opening at main spillway tunnel and grout diversion tunnel.
4. Construct drawdown structure.

Excavation, grouting, and all construction shall be performed in accordance with these drawings, notes, STANDARD SPECIFICATIONS FOR ROAD AND BRIDGE CONSTRUCTION (1965), and the SPECIAL PROVISIONS FOR RENFRO DAM.

"A" Random Rock Fill - This material shall be selected and placed in accordance with the requirements of Section 107 of the 1965 STANDARD SPECIFICATIONS FOR ROAD AND BRIDGE CONSTRUCTION. The larger sized rock shall be placed in the downstream toe of the embankment. A diversion dam shall be incorporated in the upstream toe of this zone.

"B" Impervious Core-(A-4 to A-7-6)-This material shall be obtained from a preselected site within the proposed lake basin adjacent to the Dam Area.

Extra compaction as described in Section 107.3.4B of the above referenced specifications will be required in this segment of the embankment. Hand methods of compaction will be required in the vicinity of the abutments where conditions prohibit the use of standard compaction equipment. Compaction of the "B" material shall be accomplished at optimum moisture content ±1% unless otherwise specified by the Engineer. No direct payment will be made for overhaul.

~~"C" Filter Zone - This material shall be obtained from the sandstone formation in the adjacent roadway cuts. The placement of this material shall be in 8 inch loose depth lifts. Prior to compaction each lift shall be subjected to a minimum of four (4) passes of a fully ballasted spike tooth or chisel tooth tamping roller unless otherwise specified or approved by the Engineer. Final compaction shall be obtained by pneumatic tire rollers and to the requirements of Section 107 of the above referenced specifications.~~

~~"D" Transition Zone - Placed only on the upstream face of the impervious core to prevent the finer core material from washing into the voids of the random rock fill. This zone shall be composed of materials obtained from rock excavation. The finer rock spalls should be placed immediately adjacent to the impervious core and the sizes gradually increased to blend with the random rock fill shell. The line marking the transition between "A" and "D" rock can vary but should not be less than 10 feet.~~

"E" Dry Cyclopean Stone Riprap - This material shall be selected and placed in accordance with the requirements of Section 501.3.5 of the above referenced specifications except that the dimensions shall be as indicated on the drawings.

~~"F" Drainage Blanket - This material shall be Limestone removed from the adjacent roadway cut. The placement shall be in accordance with Section 107.3.3 of the above referenced specifications except that the maximum rock size shall not exceed 2 feet in thickness and 3.5 feet horizontally.~~

~~The limits of Zone "F" is between Station 3286+50 and Station 3295+50 and varies in length as per limits indicated on roadway sections.~~

Area beneath the embankment shall be graded to assure drainage.

Siltstone and Shale foundation surfaces shall be protected from freezing and air-slaking. This may be accomplished by leaving a cover of unexcavated material until just prior to placement of embankment materials.

All dewatering is the responsibility of the Contractor. No separate payment will be made for this item of work.

Materials and placement thereof and including all incidental work for Zone A, B, C and F shall be provided and paid for at the unit price bid for Roadway Embankment. No direct payment will be allowed for Overhaul.

The grouting program on the Renfro Creek dam foundation consists of construction of a grout curtain beneath the dam, performance of dental treatment in core trench and grouting the section of tunnel generally within the limits of the impervious core. The amount of drilling and grouting which actually will be required is unknown, and will be governed by conditions encountered as the work progresses and as directed by the Engineer.

Grouting will begin at top of solid rock in core trench.

A "split spacing-stage grouting" method of drilling grout holes and of locating additional grout holes midway between previously drilled grout holes and of washing and grouting to depths as determined by existing geologic conditions shall be followed.

Curtain grouting shall be provided for at 40 ft. centers along the centerline of the cutoff trench and grout holes shall be drilled 20 feet below the bottom of the core trench. Where large intake of grout occurs secondary grout holes will be drilled on mid points between primary grout holes.

Curtain grouting shall be utilized to fill and consolidate all joints, fractures and soft shale seams in the foundation rock.

Slope protection for channel downstream of stilling basin shall be in accordance with Section 501.3.5 except that the thickness shall be 3 feet; payment for slope protection includes cost of excavation.

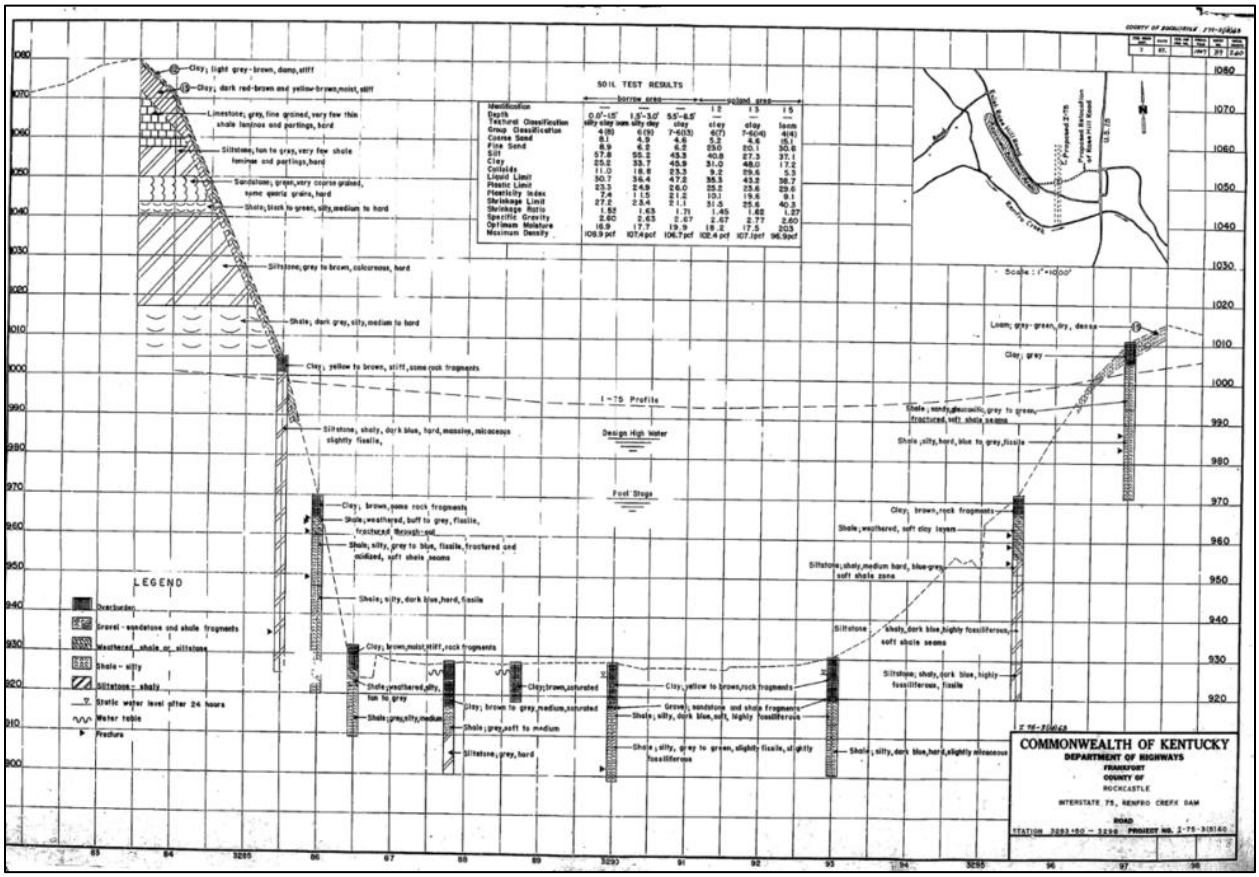
As a result of the sandstone not being available and substantially more limestone being present than originally anticipated, it has been concluded by the Consultant, Vogt-Ivers and Associates, that an acceptable means for controlling the seepage pattern through the dam, with the materials that are actually available, would be to provide a toe for the downstream side of variable dimensions, a minimum height of 25 feet and maximum width of 75 feet along the downstream toe of the dry dam. The gradation and placement of this limestone will have to be controlled to the extent that sufficient porosity is maintained to permit proper drainage.

In order to prevent piping and to be assured that the voids in the limestone do not become plugged as a result of seepage, the finer particles of the limestone is to be placed upstream and against the rock toe. The thickness of this blanket should be from 2 feet to 3 feet at the bottom and taper to zero thickness near the top of the rock toe.

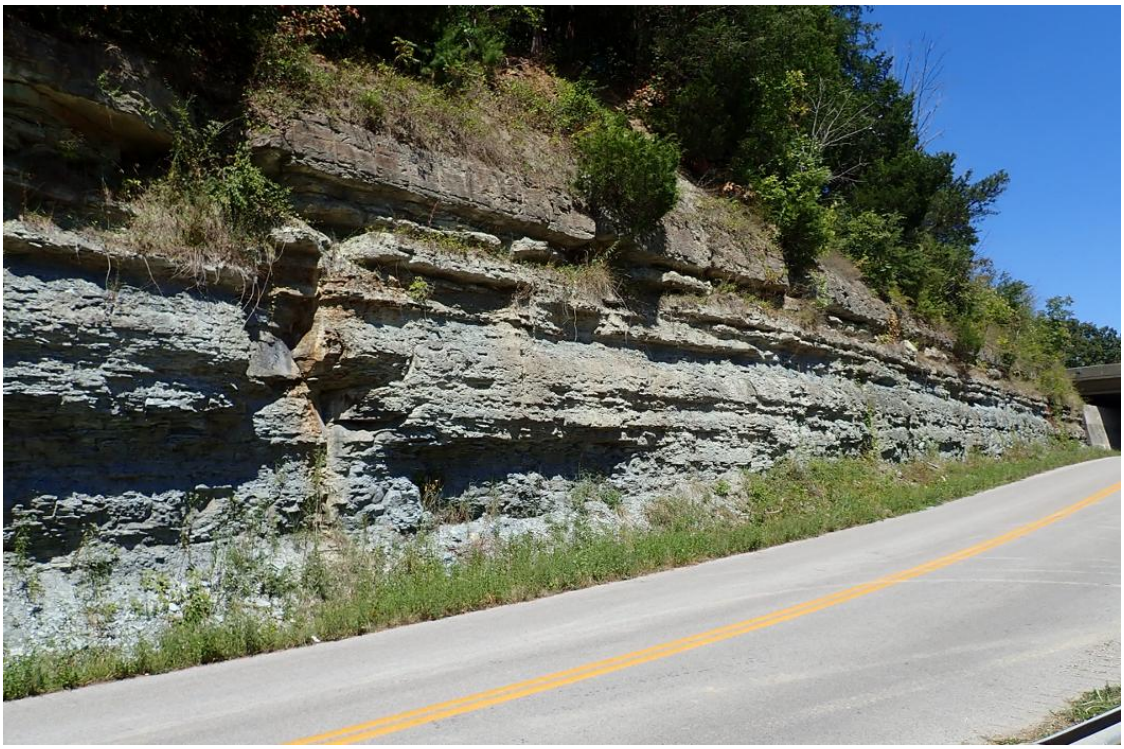
In order to offset the additional cost of placing these finer materials Zone D is to be eliminated. All of the above was recommended by the Consultant, Vogt-Ivers and Associates, in a letter to R.B. Gardner, Jr., Director, Division of Design, dated May 18, 1967.

Since sandstone and placement thereof, including all incidental work for zones D, E & F was to be paid for at the unit price bid for roadway embankment and since designers being changed to use limestone that is available as shown by Sheet 2A revised there will be no increase or decrease in cost due to this revision in plan and material.

General Notes 1967 Design Drawings (Commonwealth of Kentucky, 1967)



Soil Profile from 1967 Design Drawings (Commonwealth of Kentucky, 1967)



Site Visit Photo



Site Visit Photo

Potential Failure Mode Analysis Table:

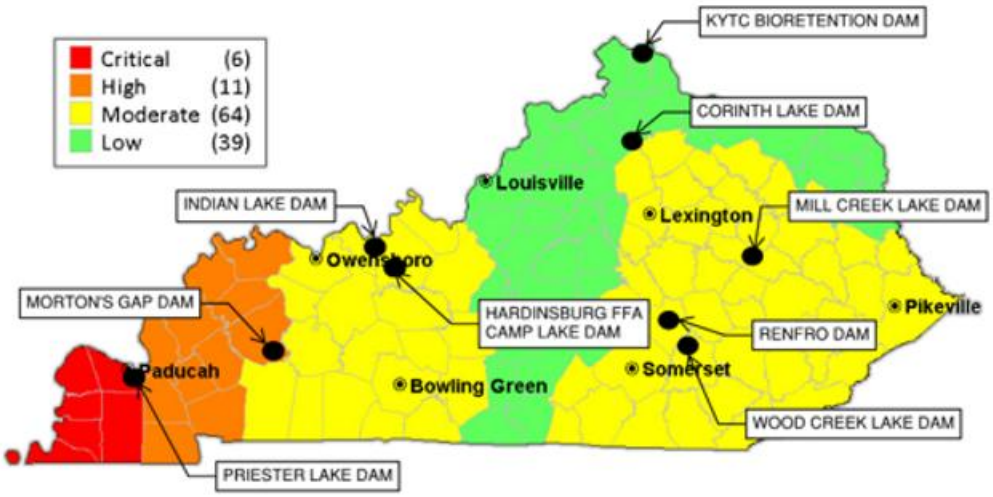
PFM No.:	R-3	**Dam:**	Renfro
PFM Group:	Seismic		
PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*			
A strong earthquake is felt at the dam site. The dynamic loads on the dam embankment cause slope displacements and possible slope failures. The deformations are larger on the upstream face, which is steeper than the downstream slope. Successive slope movements during and after the earthquake progress across the width of the dam crest. There is no time for intervention. The crest drops below normal pool and the reservoir overtops. The resulting flows scour downward through the dam embankment, releasing the reservoir.			

More Likely (Adverse) Factors	Less Likely (Favorable) Factors
• Slopes are steep (2:1 Upstream side) • Intervention would be impossible during the earthquake • The dam is resting on fine grain alluvial deposit • There are approximately 10' of foundation soils	• We are in a moderate seismic zone • Compacted embankment • The dam has a very wide crest • Intervention is likely to be successful

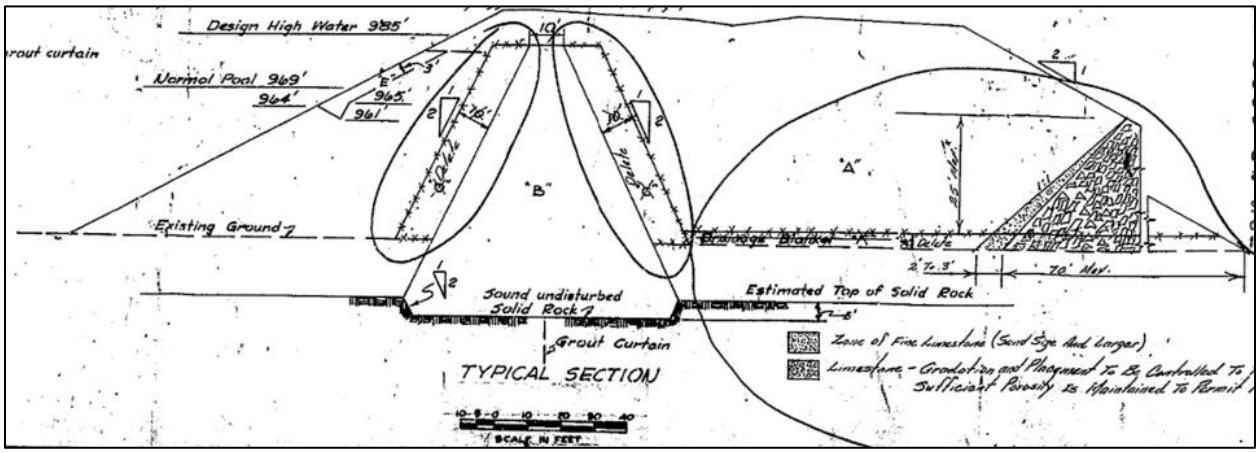
Risk Assessment	Category	Notes
Negligible? Credible?	Negligible	Probability of the loading is very low. The dam embankment is very wide. Breach is unlikely. The intervention is likely to be successful.
Failure Likelihood		
Life Safety Consequences		
Economic Consequences		

Risk Reduction Measures	
Studies and Investigations	
Maintenance and Monitoring	
Design and Modifications	

Supporting Figures:



Seismic Map



Cross Section (Commonwealth of Kentucky, 1967)

Potential Failure Mode Analysis Table:

PFM No.:	R-4A	**Dam:**	Renfro
PFM Group:	Overtopping of Lake Linville Road (Storm event less than PMP)		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*

A heavy precipitation event occurs in the watershed, causing the reservoir level to rise. Water is released through Lake Linville Road (KY 2793) at an approximate AEP event of 2E-5 (peak elevation of 988', 4' of water on the road). The flow goes along the road, through the underpass and then turns South, down the left abutment of the dam, towards the water treatment plant. The road cut is in rock and does not erode. However, the flow begins to erode the toe of the dam but does not lead to breach of the dam. Flow then spreads out in the valley downstream of the dam, impacting the treatment plant and some residences.

More Likely (Adverse) Factors	Less Likely (Favorable) Factors
• **It does not currently convey the PMP** • The flow path and crest elevations are uncertain • The underpass was not designed to perform as a spillway	• The hydraulic modeling shows a return period of 1e-5 to 5e-5 for the unclogged condition • **The road is cut through rock that is not erodible** • The road on the lake side is lower and will flood before water discharges under the underpass. • There is a ditch along the toe of the dam that will direct some flow towards the creek at the right side.

Risk Assessment	Category	Notes
Negligible? Credible?	Credible	Predicted by the H&H model
Failure Likelihood	FL3	Between 1e-5 and 5e-5 based on the modeling
Life Safety Consequences	LS1	The flows may impact 1-5 residential buildings. There is no sudden release of the reservoir.
Economic Consequences	EC1	The flow may impact the water treatment plant, and KY 2793 may be damaged.
Risk Reduction Measures		
Studies and Investigations	Study the hydraulics and flow path, further evaluate the roads ability to resist erosion, verify the rock conditions in the underpass.	
Maintenance and Monitoring		
Design and Modifications	Design entrance channel, crest, and discharge channel. Evaluate potential impacts to residential buildings and if they are incremental.	

PFM No.:	R-4B	**Dam:**	Renfro
PFM Group:	Overtopping		
PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*			
A heavy precipitation event occurs in the watershed, causing the reservoir level to rise. Water is released through the spillway, but the spillway capacity is partially blocked by floating debris. Water also flows			

through Lake Linville Road underpass. The water levels continue to rise and overtop the dam crest. The median barrier wall fails to retain the water. No plausible effort is made to raise the crest of the dam. The overtopping flows begin to erode the downstream slope of the dam embankment. The flow causes head cutting, which progresses backward across the width of the dam crest. The dam is breached when the crest erosion reaches the upstream pool. The resulting flows scour downward through the dam embankment, releasing the reservoir.

More Likely (Adverse) Factors	Less Likely (Favorable) Factors
• **The morning glory spillway is prone to clogging from floating debris** • **There are large trees on the lake shore near the morning glory spillway** • **The dam does not currently convey the PMP and it overtops at 1e-5** • The debris boom is damaged • **Median barrier wall was not designed as a flood wall** • The stormwater in the sag of the road flows in a 24" pipe that discharges on the downstream face.	• The median barrier wall is robust, it is a continuous concrete wall across the entire dam crest. • The lowest elevation of the median barrier wall is 998.5', the PMP event is 995.3' (3' of freeboard) • Estimated 4-5' of water on the barrier wall for up to one day. Without looking at the details of the wall design, we feel that the will can support that. There will be water discharging from the storm water system. • No evidence of debris in the 2024 inspection videos within the tunnel • **Wide crest (140')** • **The crest is paved in an erosion resistant material**

Risk Assessment	Category	Notes
Negligible? Credible?	Credible	
Failure Likelihood	FL3	The probability of overtopping is 1e-5. We are also accounting for the performance of the median barrier wall.

Life Safety Consequences	LS3	The life loss is estimated as 10-1000. However, due to slow progression of the failure mode, there is enough time to evacuate.
Economic Consequences	EC4	Water treatment plant, supply, town
Risk Reduction Measures		
Studies and Investigations	Evaluate the stability of the barrier wall for the anticipated flood loading.	
Maintenance and Monitoring		
Design and Modifications	Increase hydraulic capacity	

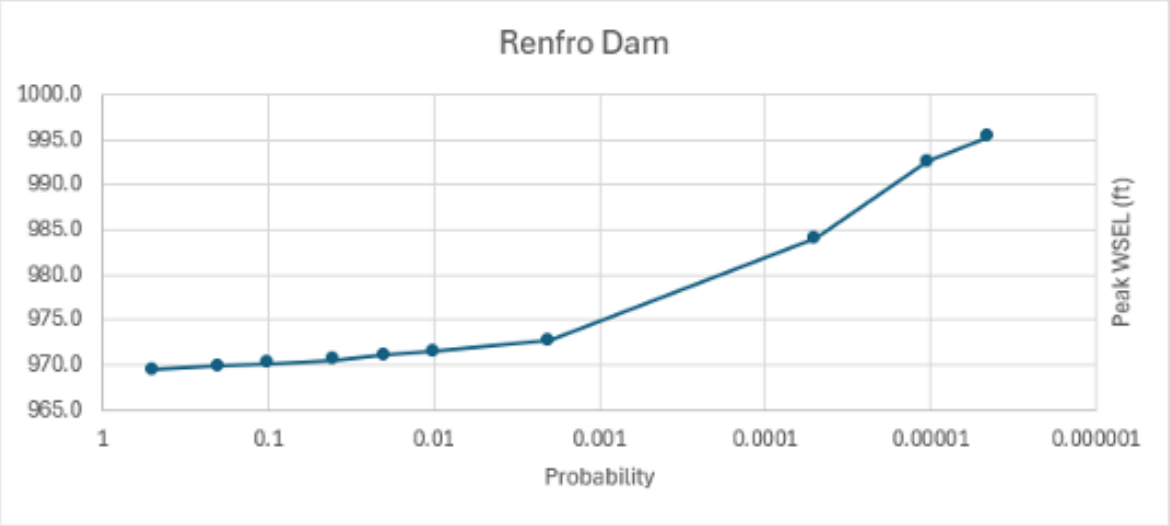
Supporting Figures:

Renfro Dam (Dam Crest = 992.6 ft; Auxiliary Spillway Crest = 984)					
Precip	Peak Inflow	Peak WSEL	Peak WSEL (clogged)	Return Interval	Notes
2.1	732	969.5	970.0	0.5	2yr
2.6	1,155	969.8	970.6	0.2	5yr
3.0	1,547	970.1	971.1	0.1	10yr
3.5	2,165	970.6	971.9	0.04	25yr
4.0	2,708	971.0	972.6	0.02	50yr
4.5	3,314	971.5	973.3	0.01	100yr
5.7	4,982	972.7	975.3	0.002	500yr
11.2	13,112	----	984.1	1.09E-04	**Aux. Spillway Activated (PS Clogged)**
13.8	17,259	984.0	----	4.92E-05	**Aux. Spillway Activated**
21.6	29,682	992.6	993.9	1.04E-05	**Overtopping**
28.5	40,770	995.3	995.8	4.53E-06	**PMP**

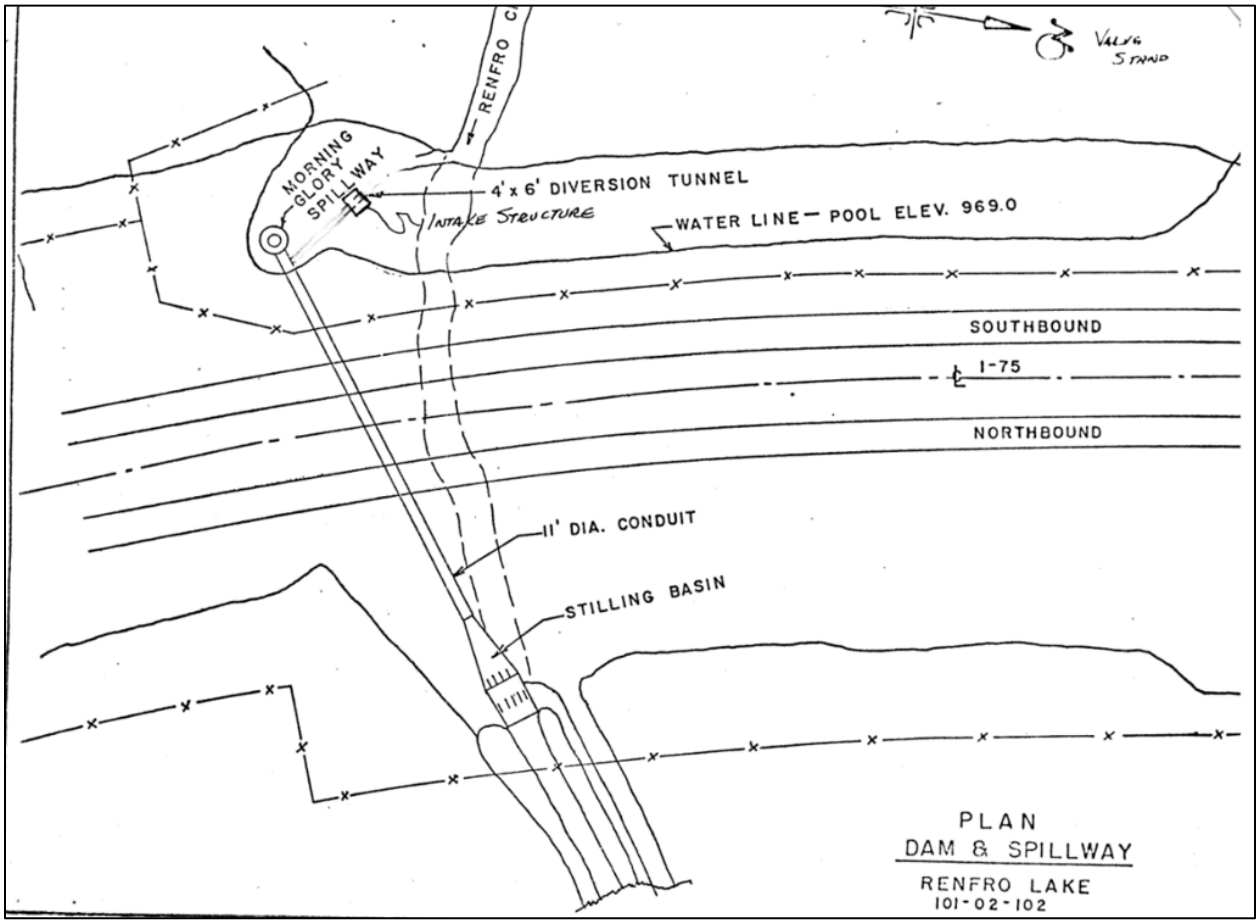
*Note: Duration of overtopping for the PMP estimated to be **7 hours***

*Note: Duration of overtopping for the 21.6" rainfall event with the **spillway clogged** estimated to be **7 hours***

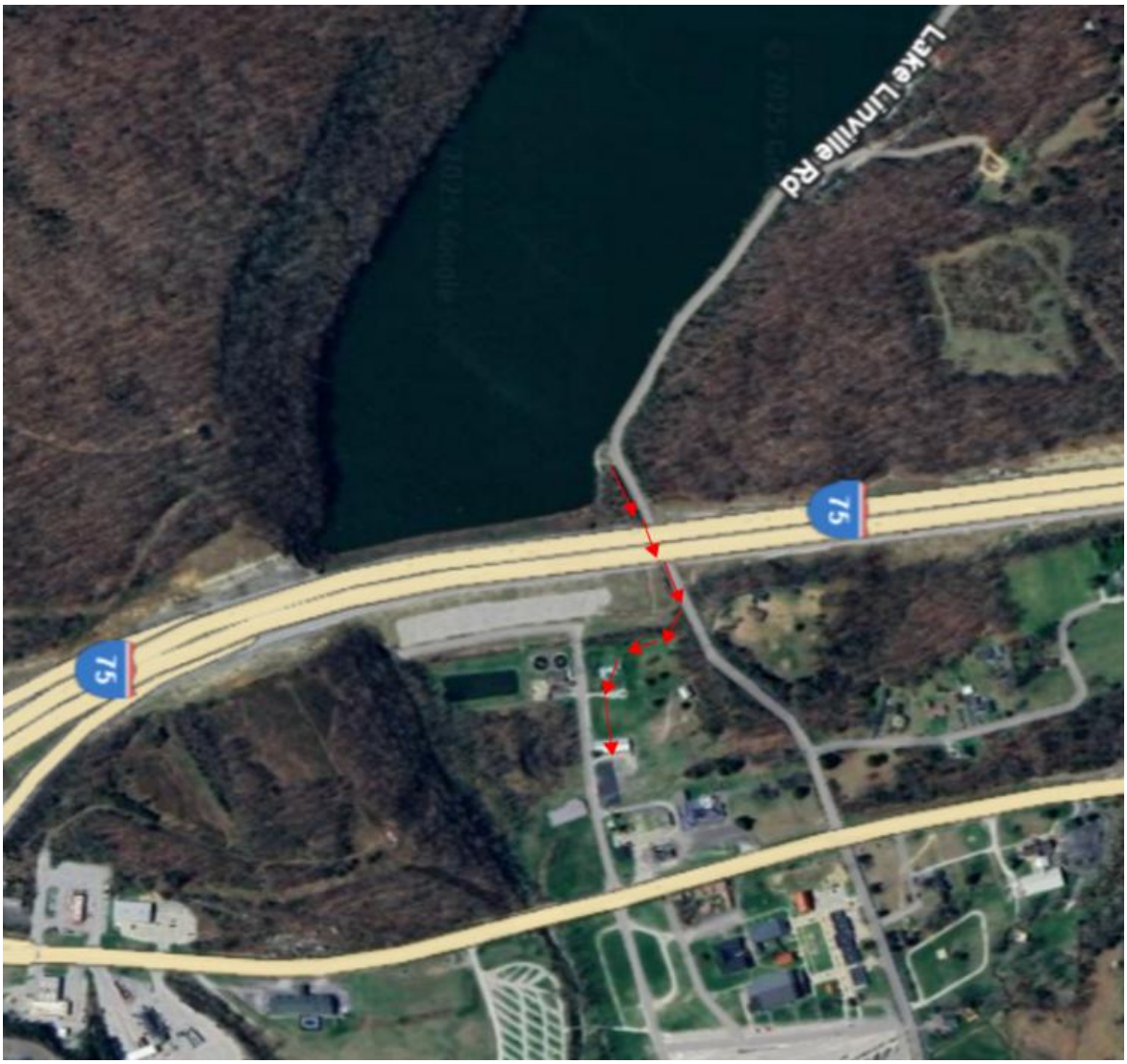
*Note: Duration of overtopping for the PMP rainfall event with the **spillway clogged** estimated to be **9 hours***



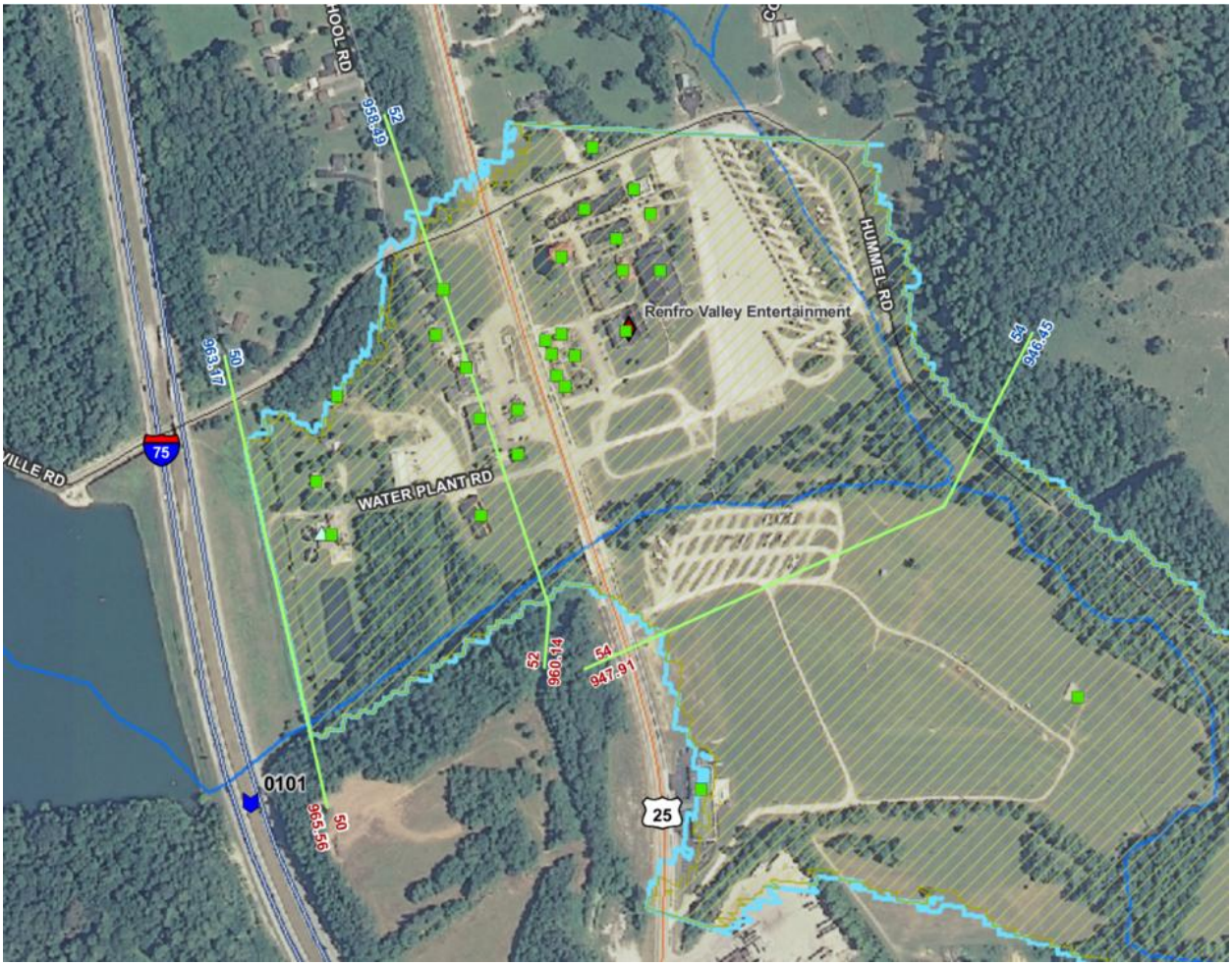
H&H Results



Plan View (USACE Louisville District, 1978)



Auxiliary Spillway Estimated Flow Path



Inundation Map

Potential Failure Mode Analysis Table:

PFM No.:	R-5	**Dam:**	Renfro
PFM Group:	Erosion Associated with Conduits		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure*)

3 potential conduits:

1. Low level drawdown valve
    a. Discharges into the primary spillway conduit and does not traverse the dam
2. Morning Glory Spillway
    a. 2/3 of the morning glory spillway tunnel is estimated to be tunneled within rock which is not an erodible material so there is no seepage and erosion path along the outside
    b. Could have erosion of soil into the pipe but recent inspections demonstrate that the concrete lined section is in good shape. Inspections are performed annually. Those inspections have stated no observations of erosion of embankment material into the spillway tunnel and no defects in the concrete lining.
3. Intake for the water treatment plant
    a. Water treatment intake is near the left abutment. The water intake runs through the underpass, above the elevation of the lake at normal pool. It is not subject to seepage and erosion along the pipe.
    b. Failure of a pressurized intake pipe under the dam. The drawings we have and the site photos suggest the pipe line does not pass under any section of the dam embankment.

More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
•	•

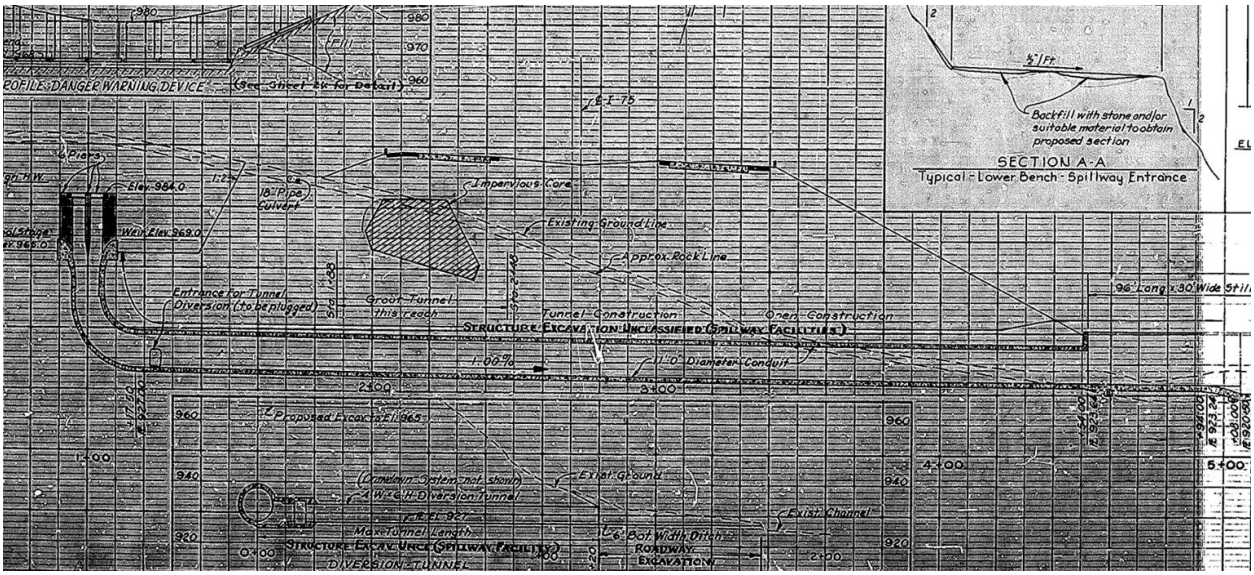
Risk Assessment	**Category**	**Notes**
Negligible? Credible?	NEGLIGIBLE	

Failure Likelihood		
Life Safety Consequences		
Economic Consequences		
Risk Reduction Measures		
Studies and Investigations	Verification of raw water line alignment.	
Maintenance and Monitoring		
Design and Modifications		

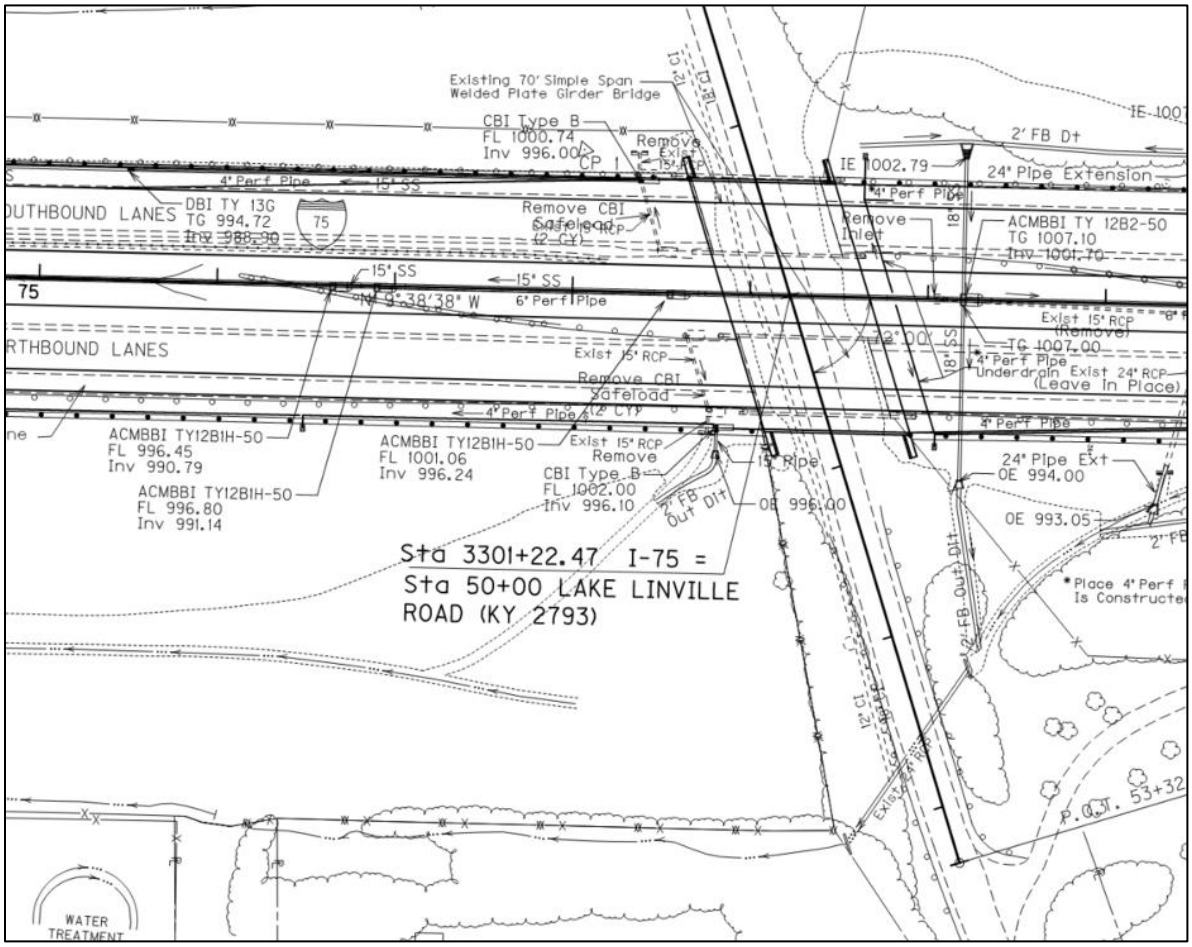
PFM No.:	R-6	**Dam:**	Renfro
PFM Group:	Spillway Structures - Morning Glory Spillway		
PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*			
The morning glory spillway structure is in rock. Annual inspections are performed and no plausible failure mode has been documented.			
More Likely (Adverse) Factors		**Less Likely (Favorable) Factors**	
•		•	

Risk Assessment	**Category**	**Notes**
Negligible? Credible?	NEGLIGIBLE	
Failure Likelihood		
Life Safety Consequences		
Economic Consequences		
Risk Reduction Measures		
Studies and Investigations		
Maintenance and Monitoring		
Design and Modifications		

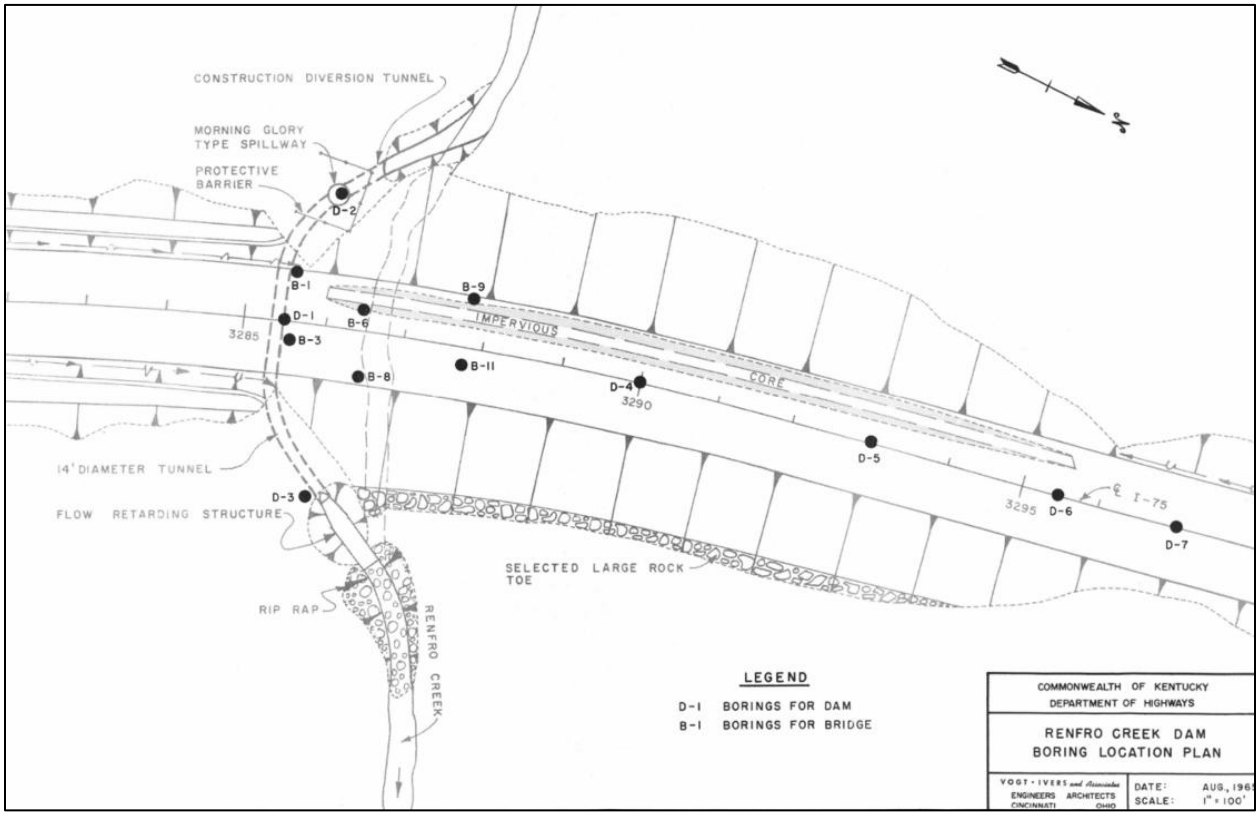
Supporting Figures:



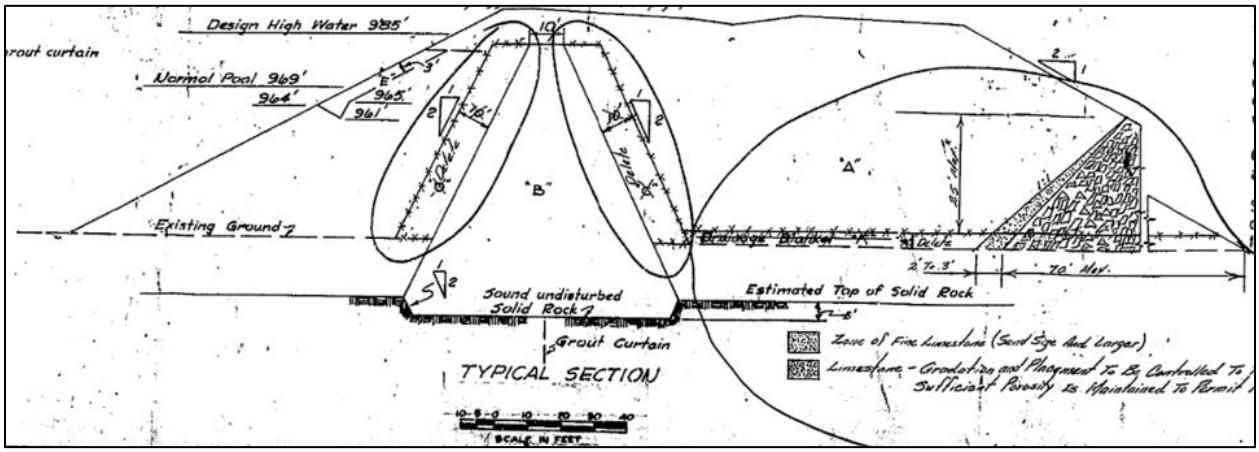
Conduit Profile from 1973 As-built Drawings (Commonwealth of Kentucky, 1967)



Plan View from 2017 Roadway Plans (Commonwealth of Kentucky, 2017)



Boring Log Locations From 1965 Geological Investigation Report (Commonwealth of Kentucky Department of Highways, 1965)



Cross Section (Commonwealth of Kentucky, 1967)

Potential Failure Mode Analysis Table:

PFM No.:	R-7	**Dam:**	Renfro
PFM Group:	Operational		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure*)

The valve is opened during annual operation. Due to continued corrosion, the valve is unable to be closed. Attempt to close the inlet is unsuccessful. The dam does not fail but the lake is slowly drained through the 24" cast iron low level drawdown pipe.

More Likely (Adverse) Factors	Less Likely (Favorable) Factors
• Age of cast iron valve system (beyond service life) • The inlet and the valve are submerged in the lake, on the outside of the riser structure • Inspections have identified corrosion deterioration of the drawdown components	• The flow is limited by the 24" pipe • The system is operated every year • The flow discharges into the 11' diameter tunnel. • The 24" pipe is inside the 4'x6' conduit and backfilled with concrete. • Intervention is more feasible because it is possible to bulkhead the outlet inside the riser structure

Risk Assessment	Category	Notes
Negligible? Credible?	Credible	Does not progress to a dam breach
Failure Likelihood	FL6	We estimate a 1-10% chance each year when the system is operated/inspected. We have a long stem that has potential for damage.

Life Safety Consequences	LS0	Slow drawdown, within the pipe
Economic Consequences	EC1	
Risk Reduction Measures		
Studies and Investigations	Determine the intake elevation for Water supply.	
Maintenance and Monitoring	Replace the slide gate, implement recommendations from 2024 inspections.	
Design and Modifications	Replace low level drawdown system.	

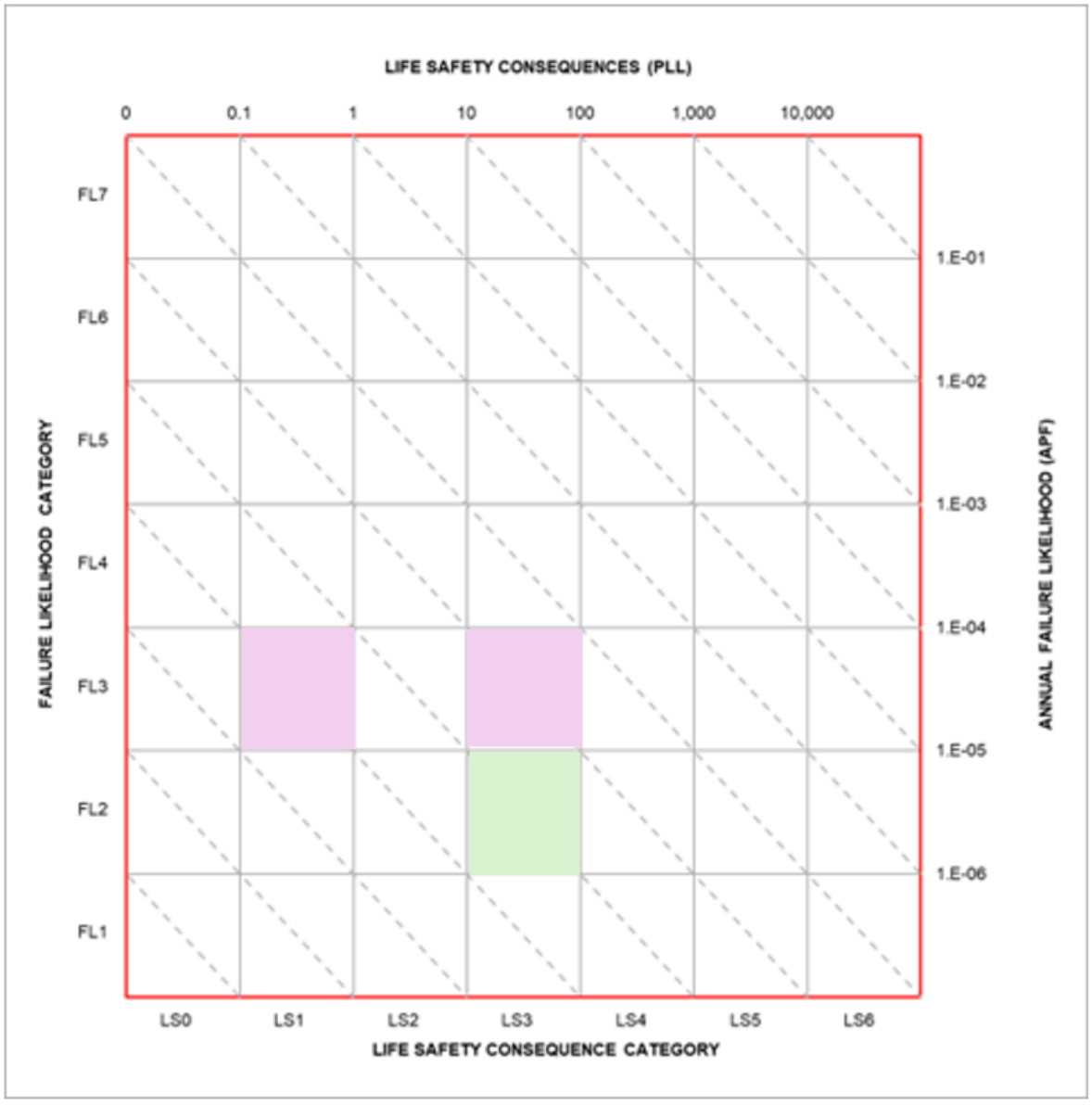
Supporting Figures:



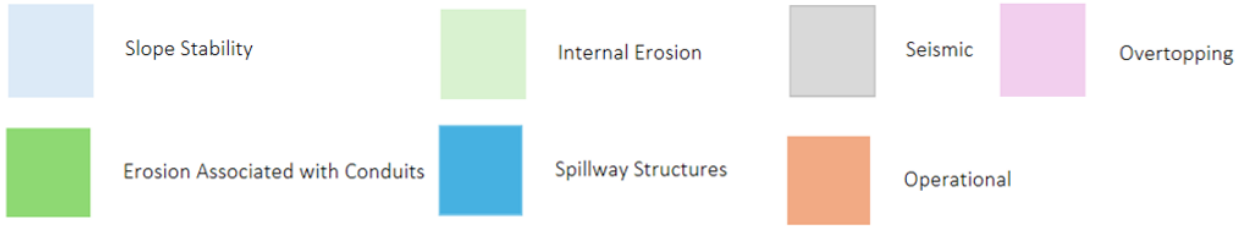
Site Visit Photo

F.6 Risk Matrices

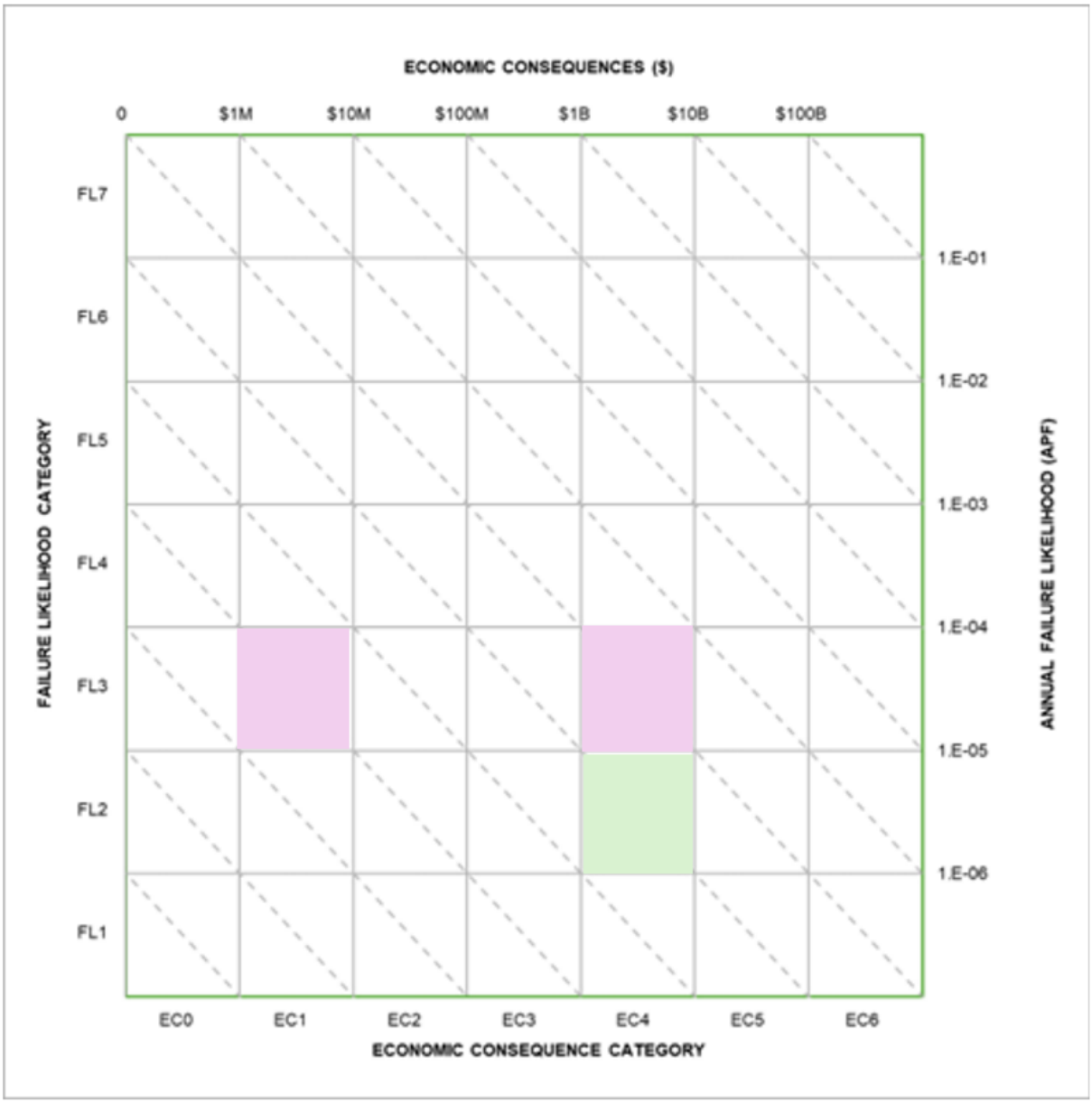
Life Safety Risk Matrix:



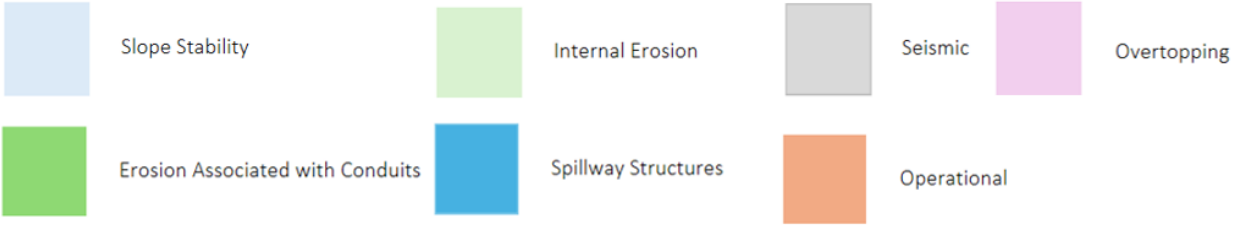
Legend:



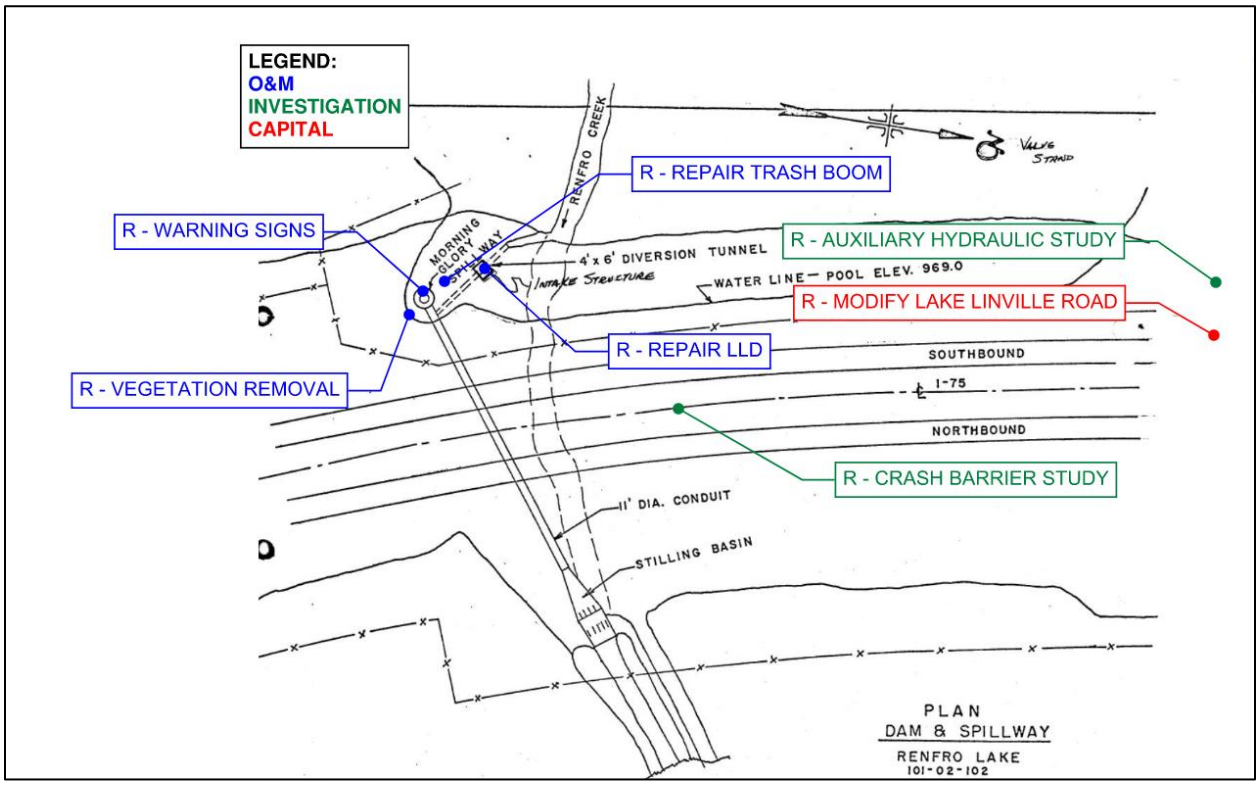
Economic Consequences Risk Matrix:



Legend:



F.7 Recommendations



Recommendations – Renfro Dam								
CODE	**Recommendation**	**Type**	**Life Loss Risk**	**Economic & Transportation Risk**	**Regulatory Compliance**	**Cost Range**	**Planning Horizon**	**Priority**
R- REPAIR TRASH BOOM	Repair the floating boom on the upstream side of the morning glory spillway entrance.	O&M	9	12	Yes	<10K	Short Term	1
R - VEGETATION REMOVAL	Remove trees in the area surrounding the morning glory spillway entrance.	O&M	9	12	Yes	<10K	Short Term	2
R - WARNING SIGNS	Install multiple warning signs on riser and spillway structures (DANGER - KEEP BACK).	O&M	0	0	No	<10K	Short Term	3
R - CRASH BARRIER STUDY	Evaluate the median crash barrier for performance as a temporary floodwall. [To be performed in conjunction with study of the under pass.]	Investigation	9	12	Yes	10K-100K	Short Term	4
R - AUXILIARY HYDRAULIC STUDY	Study the performance of the Lake Linville Road underpass as a auxiliary spillway (hydraulics, flow path, erodibility). [To be performed in conjunction with study of the barrier wall.]	Investigation	3	3	Yes	10K-100K	Short Term	5
R - REPAIR LLD	Implement repairs identified in the 2024 low level inspection, replace the slide gate if necessary.	O&M	0	6	Yes	100K-1M	Intermediate	6
R - MODIFY LAKE LINVILLE ROAD	Modify Lake Linville Road underpass to perform as an auxiliary spillway and/or modify the median crash barrier.	Capital	3	3	Yes	1M-10M	Long Term	7

F.8 Cost Opinions for Capital Projects

Stantec developed the following cost opinions for constructing capital improvements for each dam. The costs listed below are very approximate, as they are based only on broad concepts, without even preliminary designs. The costs should be used only for planning, and not for budgeting specific improvements.

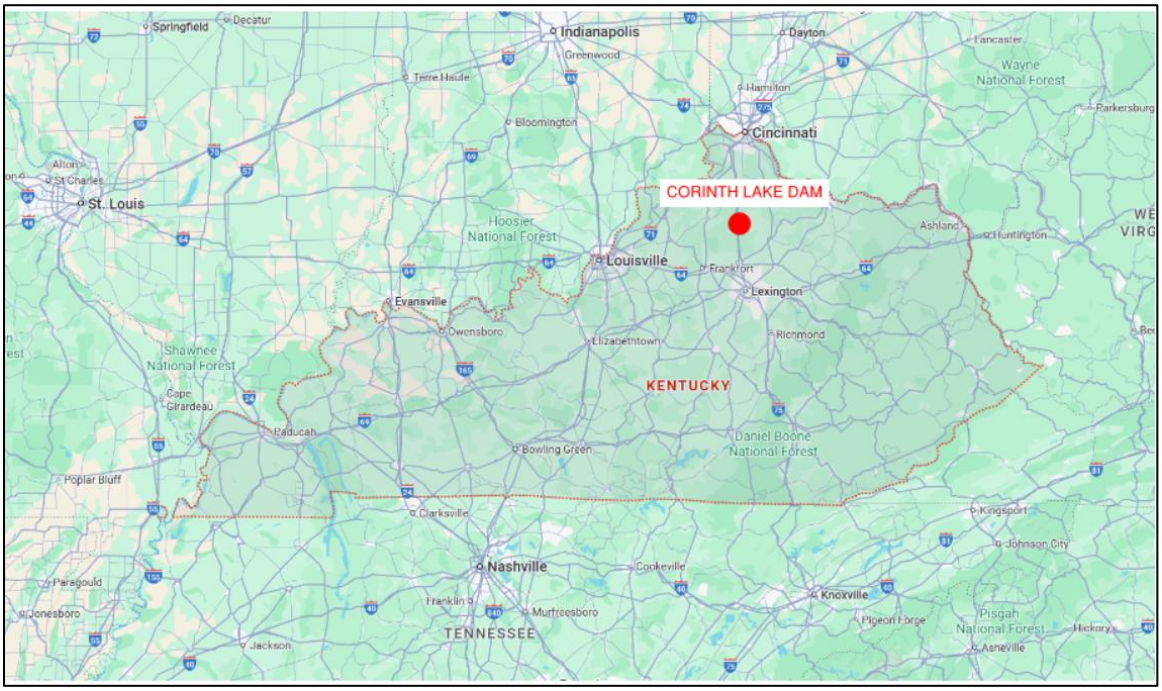
The work recommended for Renfro Dam is to modify Lake Linville Road underpass to perform as an auxiliary spillway and/or modify the median crash barrier.

Contractor Work Item	Quantity	Unit of Measure	Operating Cost	Total Cost
Construction	11644	SF	$450	$5,239,800
Maintenance of Traffic	1	EA	$2,000,000	$2,000,000
Design				$1,085,970
Filter Fabric	266.6	SY	$7.50	$ 2,000
No. 57 Stone (2' Depth)	177.7	CY	$95	$16,882
			Total	$10,000,000

Appendix G
Corinth Lake Dam

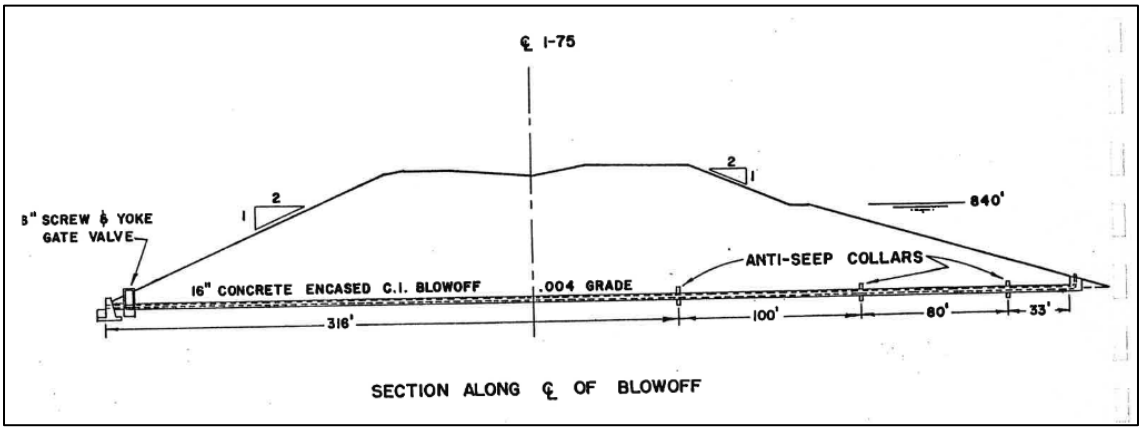
G.1 Dam and Appurtenant Features

Corinth Lake Dam is a high hazard dam located in Grant County (location map below). The National Inventory of Dams lists the purpose of the dam as recreation. This dam was constructed in 1962. The dam crest elevation is 852.5 ft, and I-75 runs along the entire crest. The normal pool elevation is 840 ft. The height of the dam is 73 ft, and the crest width is 140 ft.

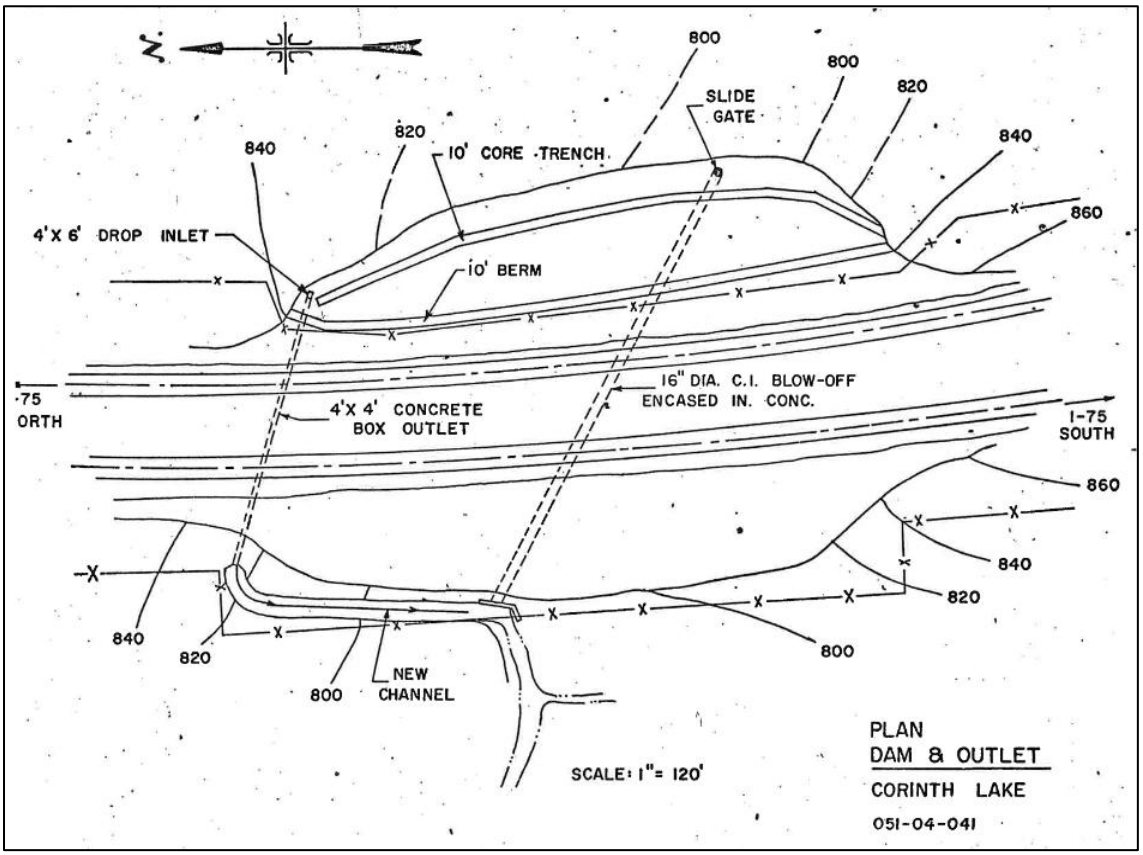


Corinth Lake Dam – Vicinity Map

The principal spillway is a 4 ft x 6 ft concrete drop inlet connected to a 4 ft x 4 ft box conduit that runs through the dam along the right abutment. The original drawdown pipe is a 16-inch diameter pipe running through the left side of the dam. The pipe has a valve within a concrete riser structure on the downstream slope. The outlet of this pipe discharges into the stream channel. The figures below show the cross sections and plan view for this dam.



Corinth Lake Dam – Typical Cross Section



Corinth Lake Dam – Plan View

G.2 Data Catalog

FILE #	DATA TYPE	TITLE	FILE DESCRIPTION
05.02.001	H & H	H & H Report	1996 Hydrology Review
05.02.002	H & H	Emergency Action Plan	***
05.02.003	H & H	Evacuation Map	***
05.02.004	H & H	Inundation Map	***
05.03.001	Inspections	Phase I Report	1979 Dam Safety Program
05.03.002	Inspections	Inspection Report	2009 Inspection
05.03.003	Inspections	Inspection Report	2012 Inspection***
05.03.004	Inspections	Inspection Report	2021 Inspection
05.03.005	Inspections	Inspection Report	2022 Inspection
05.03.006	Inspections	Inspection Report	2022 Inspection
05.03.007	Inspections	Inspection Report	2023 Inspection
05.03.008	Inspections	Inspection Report	2024 Inspection
05.03.009	Inspections	Inspection Report	2024 Inspection
05.04.001	Drawings	As Built Plans	1961 drawing set
05.06.001	Transportation Docs	Traffic Counts	
05.06.002	Transportation Docs	Road Plans	
05.06.003	Transportation Docs	Road Plans	
05.01.101	Geotech / Geology Info.	Driller's Subsurface Log	2024
05.01.102	Geotech / Geology Info.	Landslide Report	2013
05.01.103	Geotech / Geology Info.	Geologist's Subsurface Log	2024 KYTC
05.03.101	Inspections	Phase I Inspection Report	1979 Dam Safety Program
05.03.102	Inspections	Inspection Report	1994 Division of Water
05.03.103	Inspections	Inspection Report	2002 Division of Water
05.03.104	Inspections	Inspection Report	1979 Division of Water
05.03.105	Inspections	Inspection Report	2004 Division of Water
05.03.106	Inspections	Inspection Report	2004 Division of Water
05.03.107	Inspections	Inspection Report	2004 Division of Water
05.03.108	Inspections	Inspection Report	2006 Division of Water
05.03.109	Inspections	Inspection Report	2011 Division of Water
05.03.110	Inspections	Inspection Report	2018 Division of Water

05.03.111	Inspections	Inspection Report	2013 Division of Water
05.03.112	Inspections	Inspection Report	2013 Division of Water
05.03.113	Inspections	Inspection Report	2010 Division of Water
05.03.114	Inspections	Inspection Report	2000 Division of Water
05.03.115	Inspections	Inspection Report	1998 Division of Water
05.03.116	Inspections	Inspection Report	1996 Division of Water
05.03.117	Inspections	Inspection Report	1994 Division of Water
05.03.118	Inspections	Inspection Report	1993 Division of Water
05.03.119	Inspections	Inspection Report	1993 Division of Water
05.03.120	Inspections	Inspection Report	1992 Division of Water
05.03.121	Inspections	Inspection Report	1992 Division of Water
05.03.122	Inspections	Inspection Report	1991 Division of Water
05.03.123	Inspections	Inspection Report	1991 Division of Water
05.03.124	Inspections	Inspection Report	1990 Division of Water
05.03.125	Inspections	Inspection Report	1990 Division of Water
05.03.126	Inspections	Inspection Report	1990 Division of Water
05.03.127	Inspections	Inspection Report	1987 Division of Water
05.03.128	Inspections	Inspection Report	1987 Division of Water
05.03.129	Inspections	Inspection Report	1986 Division of Water
05.03.130	Inspections	Inspection Report	1986 Division of Water
05.03.131	Inspections	Inspection Report	1984 Division of Water
05.03.132	Inspections	Inspection Report	1983 Division of Water
05.03.133	Inspections	Inspection Report	1983 Division of Water
05.03.134	Inspections	Inspection Report	1983 Division of Water
05.03.135	Inspections	Inspection Report	1982 Division of Water
05.03.136	Inspections	Inspection Report	1982 Division of Water
05.03.137	Inspections	Inspection Report	1980 Division of Water
05.03.138	Inspections	Inspection Report	1977 Division of Water
05.03.139	Inspections	Inspection Report	1977 Division of Water
05.03.140	Inspections	Inspection Report	1976 Division of Water
05.03.141	Inspections	Inspection Report	1975 Division of Water
05.03.142	Inspections	Inspection Report	1975 Division of Water
05.03.143	Inspections	Inspection Report	1975 Division of Water
05.03.144	Inspections	Inspection Report	1974 Division of Water

05.03.145	Inspections	Inspection Report	1974 Division of Water
05.03.146	Inspections	Inspection Report	1974 Division of Water
05.03.147	Inspections	Inspection Report	1974 Division of Water
05.03.148	Inspections	Inspection Report	1973 Division of Water
05.03.149	Inspections	Inspection Report	1972 Division of Water
05.03.150	Inspections	Inspection Report	2021 Division of Water
05.03.151	Inspections	Inspection Report	2022 Division of Water
05.03.152	Inspections	Inspection Report	2023 Division of Water
05.03.153	Inspections	Inspection Report	2024 Division of Water
05.04.101	Drawings	Spillway Drawing	2006 spillway section drawing
05.01.201	Geotech / Geology Info.	Phase I Stability Inspection	1980
05.02.201	H & H	Dam Breach Scenario Analysis	1985 USACE Louisville District
05.02.202	H & H	H & H Report	1974 Hydrology Review
05.02.203	H & H	Hydraulic Curves	1994 Dam Safety Section
05.02.204	H & H	H & H Report	2019
05.03.201	Inspections	Phase I Inspection Report	1979 FMSM & Kenvirons
05.04.201	Drawings	Plan and Section Exhibit	
05.04.202	Drawings	Cross Section Exhibit	
05.06.201	Transportation Docs	Road Plans	2006 FMSM H&H & Road Plans

G.3 Hydrologic and Hydraulic Analyses

Elevation-Frequency Analysis

Previous hydrologic and hydraulic analyses were performed by the Kentucky Division of Water using the National Resources Conservation Service (NRCS) SITES model in 2019. The input data from the SITES model was used to generate a new U. S. Army Corps of Engineers (USACE) Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) model (version 4.12) to estimate water surface elevations associated with various precipitation depths. The following information was taken from the SITES model:

- Curve Number
- Drainage Area
- Time of Concentration
- Stage-Storage-Discharge Information
    - Stage-storage-discharge information for elevations 840 feet to 852.53 feet was taken from the 2019 SITES model
    - Stage-storage-discharge information for elevations 854.5 feet to 855 feet was estimated by linear extrapolation from the 2019 SITES model
    - Stage-storage information for elevations 857 feet to 860 feet was taken from the stage-storage curve provided by KYTC dated 1994

NOAA Atlas 14 was used to generate precipitation depths for frequencies ranging from the 2-year (50-percent-annual-chance) up to the 500-year (0.2-percent-annual-chance) storm. For the Probable Maximum Precipitation (PMP), Kentucky Engineering Memorandum No. 2 was used to determine the PMP rainfall depth. A 24-hour SCS Type II rainfall distribution was applied to the precipitation depths from NOAA Atlas 14, and a 6-hour SCS Type II rainfall distribution was applied to the PMP rainfall depth within the HEC-HMS model. The probability associated with the PMP was estimated using two methods:

- The FEMA Spillway Capacity and Extreme Flood Discharge Estimator (which uses flow-frequency data input by the user along with extrapolation using a power function to estimate the return period of the PMP)
- The Australian Rainfall Runoff method (which uses drainage area to estimate a return period of the PMP).

The results of the Australian Rainfall Runoff method were used.

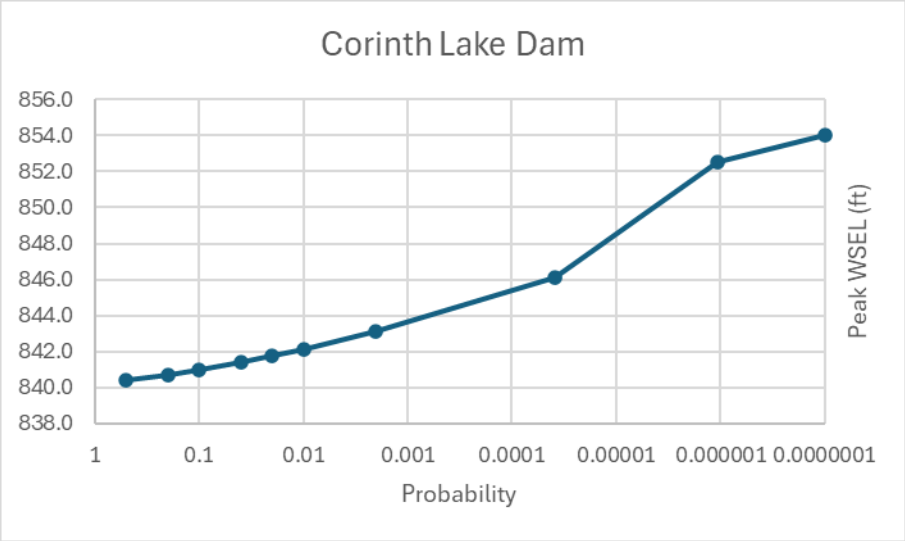
Using trial and error, additional storms were run with varying rainfall depths until a rainfall depth that produced a water surface elevation that would activate the auxiliary spillway and a water surface elevation that would overtop the dam was obtained. A power curve was fit to the flow frequency data (including the PMP) and interpolated to approximate a return period associated with these rainfall depths. The duration of overtopping for the PMP event was also estimated by reviewing the time-series results of the HMS model and noting the period of time where the water surface elevation was above the dam crest.

The resulting water surface elevations from the model runs are tabulated and plotted below.

Corinth Lake Dam Model Results

Corinth Lake Dam (Dam Crest = 852.5 feet; Auxiliary Spillway Crest = 846 feet)				
Precipitation (inches)	**Peak Inflow (cfs)**	**Peak WSEL (feet)**	**Return Interval**	**Notes**
2.2	513	840.4	0.5	2yr
2.7	934	840.7	0.2	5yr
3.1	1,346	841.0	0.1	10yr
3.7	1,986	841.4	0.04	25yr
4.2	2,561	841.7	0.02	50yr
4.7	3,214	842.1	0.01	100yr
6.1	5,006	843.1	0.002	500yr
9.7	9,945	846.1	3.92E-05	**Aux. Spillway Activated**
20.1	24,832	852.5	1.08E-06	**Overtopping**
27.7	35,528	854.0	1.00E-07	**PMP**

Note: Duration of overtopping for the PMP estimated to be 3 hours



Corinth Lake Dam Elevation-Frequency Curve

Consequences Analysis

Previous inundation mapping (Stantec, 2013) that modeled a sunny-day breach of the dam was reviewed along with inundation mapping publicly available on Kentucky's Dam Inundation Viewer (watermaps.ky.gov). An additional flood-day breach hydrograph for the dam was modeled in HEC-HMS for the PMP rainfall event. Empirical equations were utilized to define breach width, formation time, and side slopes. The resulting breach hydrograph was input into the USACE Dam Screening Tool (DST) and routed downstream. Inundation extents for the sunny-day and flood-day breaches were reviewed along with aerial imagery to evaluate consequences.

Structures identified in the sunny-day inundation area included one residence, two non-residential structures (barns/storage buildings) and four road crossings. A population at risk of approximately 11 was estimated based on the following assumptions:

- 2.5 people per home inundated
- 2 people per road crossing

The flood-day inundation extents were similar to the sunny-day breach extents but were extended an additional five miles downstream. An additional three residences were identified in the flood-day inundation zone approximately 10 miles downstream of the dam. The consequences are summarized in the table below.

Consequences Associated with a Failure of Corinth Lake Dam

CORINTH DAM	
NID_ID	KY00051
Number of Residences	1 (approximate)
Number of Non-Residential Structures	2
Description of Non-Residential Structures	Barns/Storage Buildings
Number of Critical Infrastructure Structures	0
Description of Critical Infrastructure Structures	N/A
Number of Road Crossings	4
List of Roads Affected	I-75, Keefer Road, Lusby Mill Road/Cross Road Pike crossings - also impacts Ragtown Road (runs parallel to floodplain just downstream of dam)
Estimated PAR	11
PAR Assumptions	Assumes 2.5 people per home and 2 people per road crossing.
Inundation Mapping Source	KY Dam Inundation Viewer + Aerial Imagery + DST (flood breach)
Estimated Life Loss	1-10
Life Loss Notes	Previous Stantec inundation analysis (sunny-day) stops at a point approximately 5 miles downstream where the travel time (to peak) is about 90 minutes. The residence inundated under sunny-day conditions is about 3.5 miles downstream and is located in the fringe of the inundation zone on the KY Dam Inundation Viewer. The additional residences located in the PMF breach are ~10 miles downstream. The DST life loss estimate is 2 (PAR = 4).

G.4 Potential Failure Modes

PFM NUMBER	PFM GROUP	PFM DESCRIPTION	RISK ASSESSMENT
C-1A	SLOPE STABILITY	Rapid Drawdown (Upstream) - Storm event results in a flood pool. The flood pool approaches the crest (852.5') and over a period of days, the pool drops as water drains through principal spillway (4'x4' culvert). This triggers a rapid drawdown slope failure within the blanket on the upstream side of the dam. Successive slope failures retrogress across the crest of the downstream side. Material is pushed into the failure from the crest, but the intervention fails. The crest drops below the pool elevation (840'), which overtops the dam breach. The resulting flows scour downward through the dam embankment, releasing the reservoir.	NEGLIGIBLE
C-1B	SLOPE STABILITY	Normal Pool (Downstream) - Under normal pool conditions, a slope failure triggers a mass movement of soil on the downstream face of the dam. Successive slope failures retrogress back to the crest, then to the upstream side of the crest. Material is pushed into the failure from the crest, but the intervention fails. The crest drops below the pool elevation (840'), which overtops the dam breach. The resulting flows scour downward through the dam embankment, releasing the reservoir.	CREDIBLE
C-2A	INTERNAL EROSION	Through the Dam - Under normal pool conditions, seepage develops along a defect through the dam. The defect may be a permeable lift, a smooth lift surface, a poorly compacted lift, or a frozen lift surface. No transition zone or internal filters were constructed. The flow scours the soil to either side of the defect. The embankment over the seepage path does not collapse. The flow path expands and the flow accelerates. The seepage is not detected and there is no intervention. The flow scours a larger void in the embankment, leading to a collapse of the dam crest. The dam is breached and there is an uncontrolled release of the reservoir.	CREDIBLE
C-2B	INTERNAL EROSION	Through the Foundation Soils - Under normal pool conditions, seepage develops through the bottom of the core and in the sandy foundation soils beneath the dam. The seepage exits unfiltered beneath the toe drain. The exit gradients are high enough to cause uplift or sand boils. An eroded pipe forms at the exit and progresses backward under the dam, toward the upstream pool. The	NEGLIGIBLE

		embankment over the seepage path does not collapse. The seepage is not detected and there is no intervention. The flow rate increases rapidly through the eroded pipe, scouring a large void within the foundation. The embankment collapses into the void, the dam is breached, and there is an uncontrolled release of the reservoir.	
C-2C	INTERNAL EROSION	Karst Features - Downward seepage erodes foundation or embankment soils into open karst features in the bedrock. Erosion progresses until there is a breach of the dam.	NEGLIGIBLE
C-3	SEISMIC	A strong earthquake is felt at the dam site. The dynamic loads on the dam embankment cause slope displacements and possible slope failures. Successive slope movements during and after the earthquake progress across the width of the dam crest. There is no time for intervention. The crest drops below normal pool and the reservoir overtops. The resulting flows scour downward through the dam embankment, releasing the reservoir.	NEGLIGIBLE
C-4	OVERTOPPING	A heavy precipitation event occurs in the watershed, causing the reservoir level to rise. Water is released through the spillway, but the spillway capacity is partially blocked by floating debris. Water also discharges through the auxiliary spillway ditch at elevation 836.9'. The water levels continue to rise and overtop the dam crest. The median barrier walls fail to retain the water. No plausible effort is made to raise the crest of the dam. The overtopping flows begin to erode the downstream slope of the dam embankment. The flow causes head cutting, which progresses backward across the width of the dam crest. The dam is breached when the crest erosion reaches the upstream pool. The resulting flows scour downward through the dam embankment, releasing the reservoir.	CREDIBLE
C-5A	EROSION ASSOCIATED WITH CONDUITS	16” LLD - There is a 16" low level drawdown intake from the upstream pool to the toe of the dam. The inlet elevation is 792'. Water in the pipe is at headwater pressure. A leak develops in the pipe, causing higher piezometric pressures at the toe of the dam. A slope failure is initiated at the downstream toe of the dam. Successive slope failures retrogress back to the crest, then to the upstream side of the crest. Material is pushed into the failure from the crest, but the intervention fails. The crest drops below the pool elevation (840'), which overtops the dam breach.	CREDIBLE

C-5B	EROSION ASSOCIATED WITH CONDUITS	Principal Spillway - Seepage develops along the outside of the principal spillway. The seepage exit is not filtered, and erosion of the embankment soils continues. A direct connection develops between the reservoir and a void running the length of the conduit. The flow and erosion are not detected and there is no intervention. Seepage continues, resulting in gross enlargement, leading to breach and an uncontrolled release of the reservoir.	CREDIBLE
C-6A	SPILLWAY STRUCTURES	Principal Spillway - Reservoir levels rise during a flood event and the spillway is activated. The downstream channel, located on the embankment, is scoured by flows from the spillway discharge. Erosion progresses up to the end of the spillway culvert. The erosion is not detected and there is insufficient time to intervene. Head cutting of the embankment soils initiates slope failures. Slope failures retrogress back to the crest. The dam is breached and there is an uncontrolled release of the reservoir.	CREDIBLE
C-6B	SPILLWAY STRUCTURES	LLD - A slope deformation occurs, pushing over the circular concrete riser structure. The valve on the end of the 16" CIP is broken off. This allows full flow from the pipe at head water pressure. The flow discharges onto the toe of the dam and begins to erode and undermine the toe. This triggers a larger slope failure that progresses to the crest of the dam. The erosion is not detected and there is insufficient time to intervene. Head cutting of the embankment soils initiates slope failures. Slope failures retrogress back to the crest. The dam is breached and there is an uncontrolled release of the reservoir.	CREDIBLE
C-7	OPERATIONAL	Principal Spillway - The valve is opened but cannot be closed. The dam does not fail but the lake is slowly drained to elevation 829' through the secondary drawdown valve.	NEGLIGIBLE

G.5 Evaluation of PFMs

Potential Failure Mode Analysis Table:

PFM No.:	C-1A	**Dam:**	Corinth Lake Dam
PFM Group:	Slope Stability - Rapid Drawdown (Upstream)		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*
Storm event results in a flood pool. The flood pool approaches the crest (852.5') and over a period of days, the pool drops as water drains through principal spillway (4'x4' culvert). This triggers a rapid drawdown slope failure within the blanket on the upstream side of the dam. Successive slope failures retrogress across the crest of the downstream side. Material is pushed into the failure from the crest, but the intervention fails. The crest drops below the pool elevation (840'), which overtops the dam breach. The resulting flows scour downward through the dam embankment, releasing the reservoir.

More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
• Did not find a rapid drawdown stability analysis • Upstream blanket is constructed of plastic clays	• **Wide (140')** • Blanket is 3:1 slope • Intervention is likely

Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Negligible	Due to the size of the embankment and the certainty that we would observe and intervene.
Failure Likelihood		
Life Safety Consequences		
Economic Consequences		

Risk Reduction Measures	
Studies and Investigations	
Maintenance and Monitoring	
Design and Modifications	

PFM No.:	C-1B	**Dam:**	Corinth Lake Dam
PFM Group:	Slope Stability - Normal Pool (Downstream)		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*

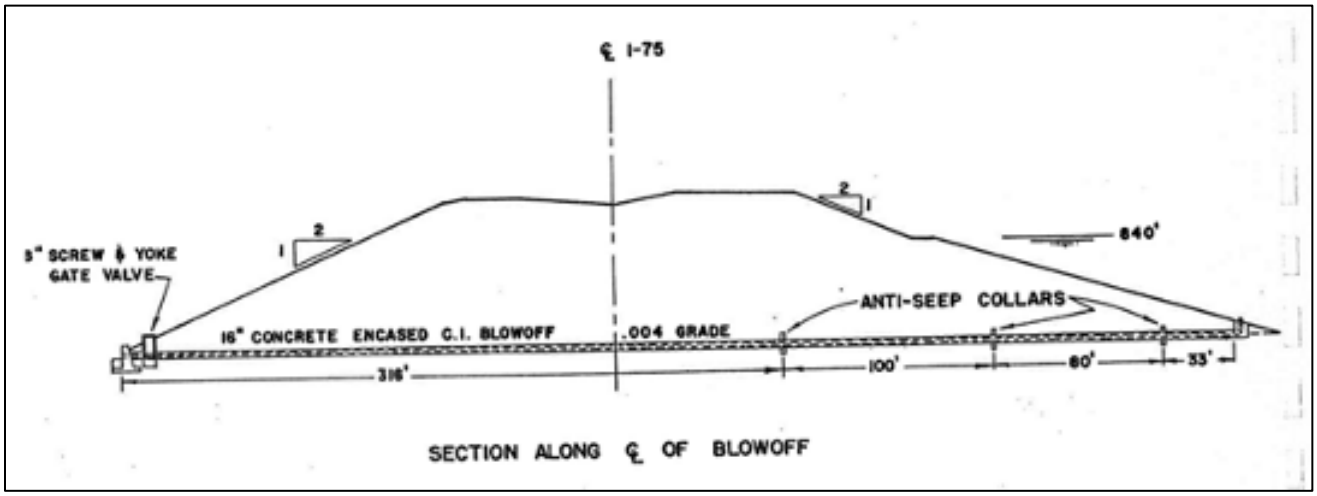
Under normal pool conditions, a slope failure triggers a mass movement of soil on the downstream face of the dam. Successive slope failures retrogress back to the crest, then to the upstream side of the crest. Material is pushed into the failure from the crest, but the intervention fails. The crest drops below the pool elevation (840'), which overtops the dam breach. The resulting flows scour downward through the dam embankment, releasing the reservoir.

More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
• **Historic observations of sloughs and seepage on downstream face** • **Steep slopes (2:1 or steeper downstream)** • Movements have been significant enough to damage other dam features • Noted irregular surfaces in 2025 site visit	• **Wide (140')** • **Intervention is likely - road likely impacted prior to crest of dam. KYTC likely to intervene when road moves.** • Instrumentation has been installed to monitor movement

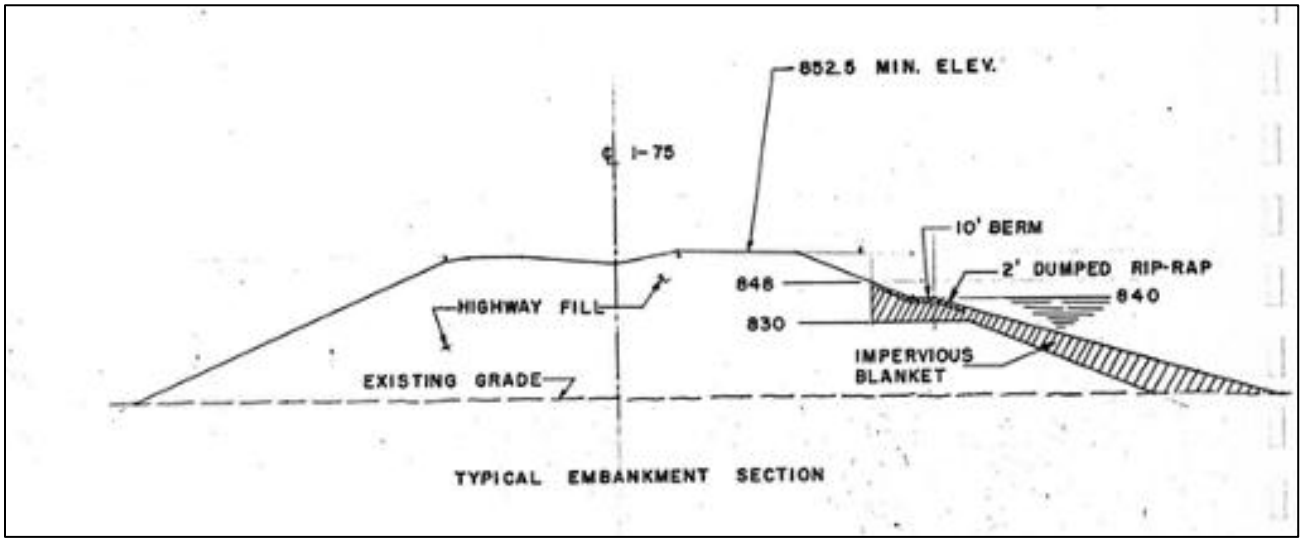
• Wet areas and shallow ground water near the low level drawdown outlet	

Risk Assessment	Category	Notes
Negligible? Credible?	Credible	We have observed slope movements in the past on the downstream slope.
Failure Likelihood	FL1	The propensity for slides to occur at the site are well documented historically. However, the FL1 categorization was made based on the limited likelihood of a slope failure progressing to a breach of the dam.
Life Safety Consequences	LS1	I-75, residence downstream. PAR is 11. No formal EAP. Sufficient time to evacuate the residents at one home.
Economic Consequences	EC3	Cost of interstate shut down per day.
Risk Reduction Measures		
Studies and Investigations	Geotechnical explorations, stability analyses	
Maintenance and Monitoring	Finalize an EAP.	
Design and Modifications	Buttress the downstream face or add a filter berm.	

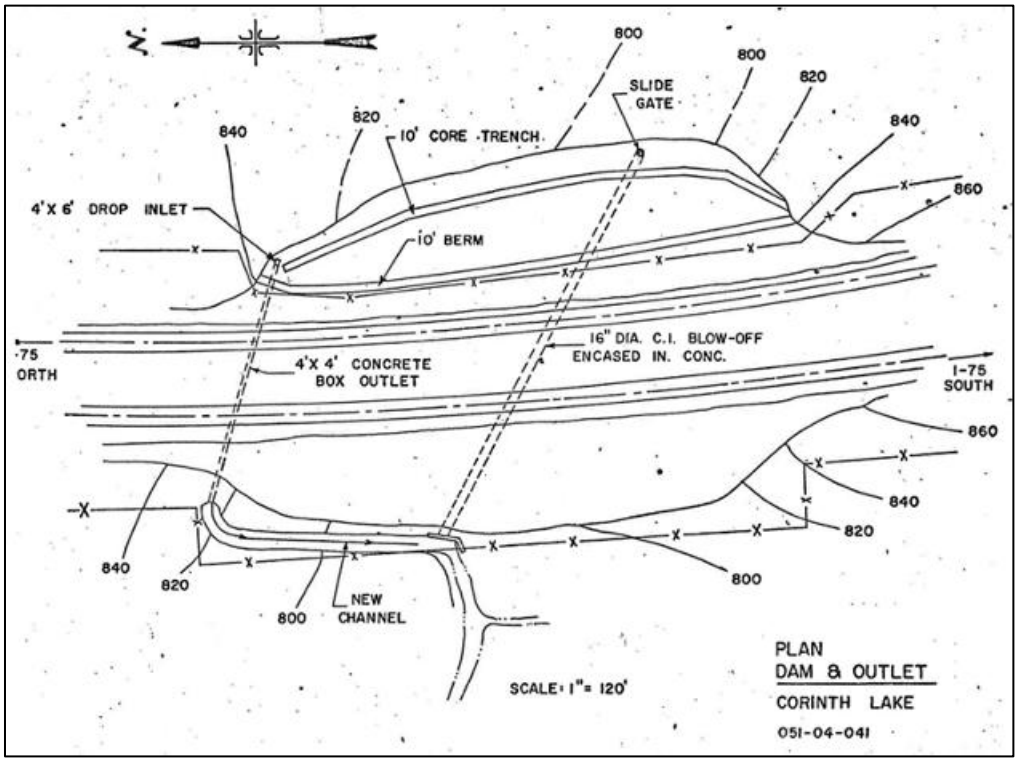
Supporting Figures:



Cross Section (Fuller, Mossbarger, Scott & May & Kenvirons, 1979)



Cross Section (Fuller, Mossbarger, Scott & May & Kenvirons, 1979)



Plan View (Fuller, Mossbarger, Scott & May & Kenvirons, 1979)

Potential Failure Mode Analysis Table:

PFM No.:	C-2A	**Dam**:	Corinth Lake Dam
PFM Group:	Internal Erosion - Through the Dam		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*

Under normal pool conditions, seepage develops along a defect through the dam. The defect may be a permeable lift, a smooth lift surface, a poorly compacted lift, or a frozen lift surface. No transition zone or internal filters were constructed. The flow scours the soil to either side of the defect. The embankment over the seepage path does not collapse. The flow path expands and the flow accelerates. The seepage is not detected and there is no intervention. The flow scours a larger void in the embankment, leading to a collapse of the dam crest. The dam is breached and there is an uncontrolled release of the reservoir.

More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
• **The dam embankment was constructed of borrow from the highway excavation and likely consists of gravely (shale fragments) sandy clays.** • A very limited subsurface investigation using hang auger borings was performed. • No laboratory testing or stability analyses from original design. • **No internal drainage features or filters. Not a zoned embankment.** • **Built as a highway embankment, not a dam. Likely good control of density within the embankment but likely less control on uniformity that we would desire in a dam embankment**.	• **The dam is 140' wide at the crest so the seepage path is very long** • 48' of head in the reservoir so the average gradients are about .2 • **The likelihood of intervention is good due to the time it would take for failure mode to develop.** • Cutoff trench +/- 8' into bedrock at the upstream toe. • Clayey blanket placed along upstream slope

Risk Assessment	**Category**	**Notes**

Negligible? Credible?	Credible	
Failure Likelihood	FL2	No compelling evidence to suggest the flaw exists.
Life Safety Consequences	LS1	I-75, residence downstream. PAR is 11. No formal EAP. Sufficient time to evacuate the residents at one home.
Economic Consequences	EC3	Cost of interstate shut down per day.
Risk Reduction Measures		
Studies and Investigations	Geotechnical explorations, stability analyses	
Maintenance and Monitoring	Finalize an EAP.	
Design and Modifications		

PFM No.:	C-2B	**Dam:**	Corinth Lake Dam
PFM Group:	Internal Erosion - Through the Foundation Soils		
PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*			
Under normal pool conditions, seepage develops through the bottom of the core and in the sandy foundation soils beneath the dam. The seepage exits unfiltered beneath the toe drain. The exit gradients are high enough to cause uplift or sand boils. An eroded pipe forms at the exit and progresses backward under the dam, toward the upstream pool. The embankment over the seepage path does not collapse. The seepage is not detected and there is no intervention. The flow rate increases rapidly through the			

eroded pipe, scouring a large void within the foundation. The embankment collapses into the void, the dam is breached, and there is an uncontrolled release of the reservoir.		
More Likely (Adverse) Factors		**Less Likely (Favorable) Factors**
•		•
Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Negligible	Considered a failure mode for seepage through the foundation soils. Based on the construction drawings, the upstream half of the dam footprint was excavated to rock. And a cutoff trench was excavated at the upstream toe under the upstream blanket. Therefore, there is not a continuous seepage path through the foundation soils. We considered this PFM to be negligible.
Failure Likelihood		
Life Safety Consequences		
Economic Consequences		
Risk Reduction Measures		
Studies and Investigations		
Maintenance and Monitoring		
Design and Modifications		

PFM No.:	C-2C	**Dam:**	Corinth Lake Dam
PFM Group:	Internal Erosion - Karst Features		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*

Downward seepage erodes foundation or embankment soils into open karst features in the bedrock. Erosion progresses until there is a breach of the dam.

More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
•	•

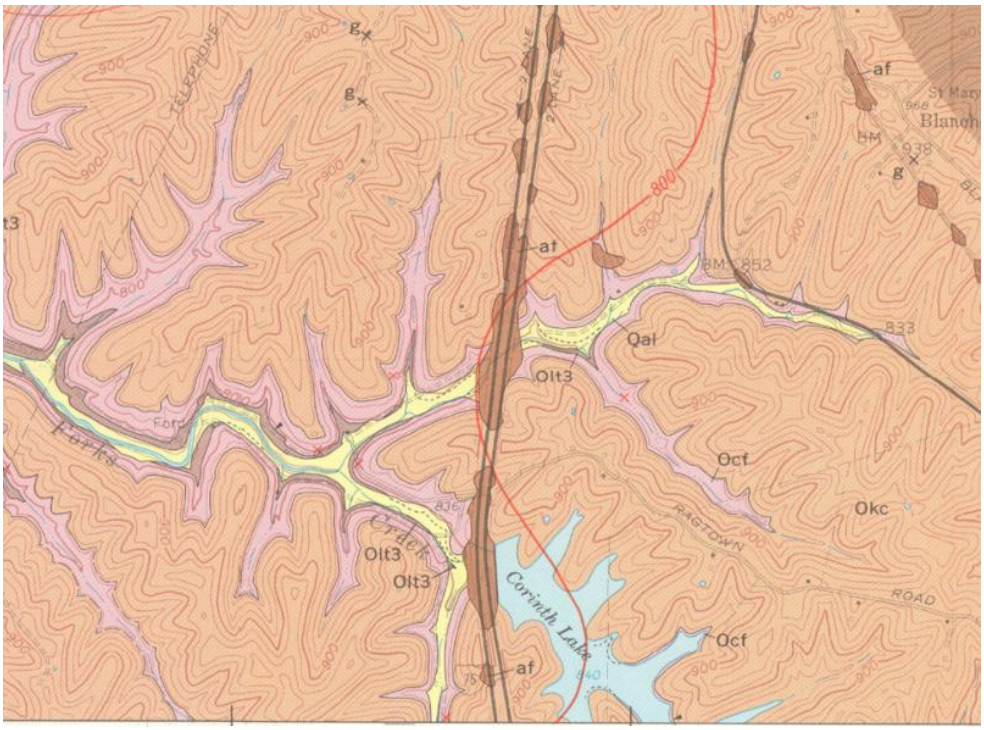
Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Negligible	According to the geologic mapping, we are in a low risk area for karstic activity. A failure mode was not developed.
Failure Likelihood		
Life Safety Consequences		
Economic Consequences		

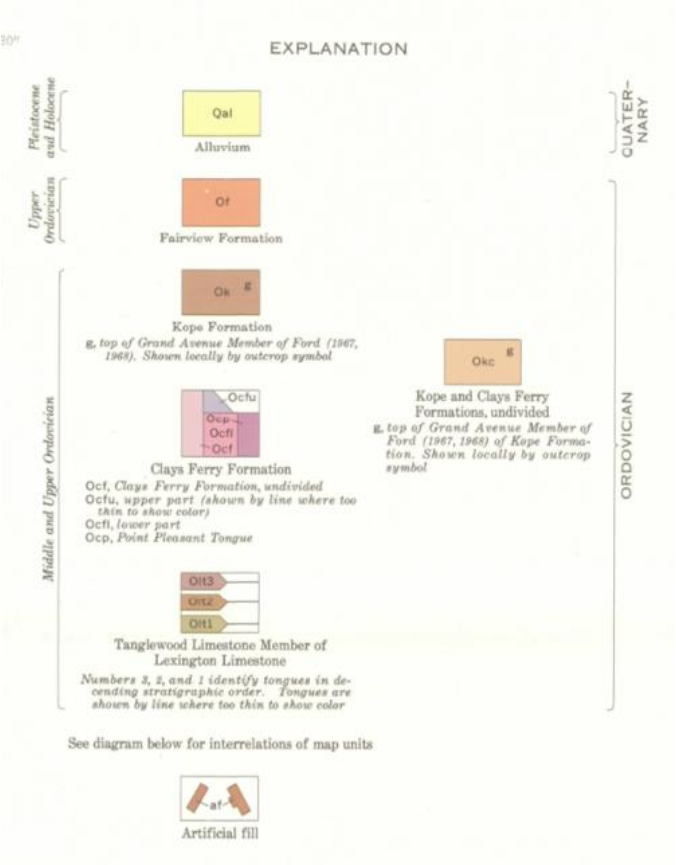
Risk Reduction Measures

Studies and Investigations	

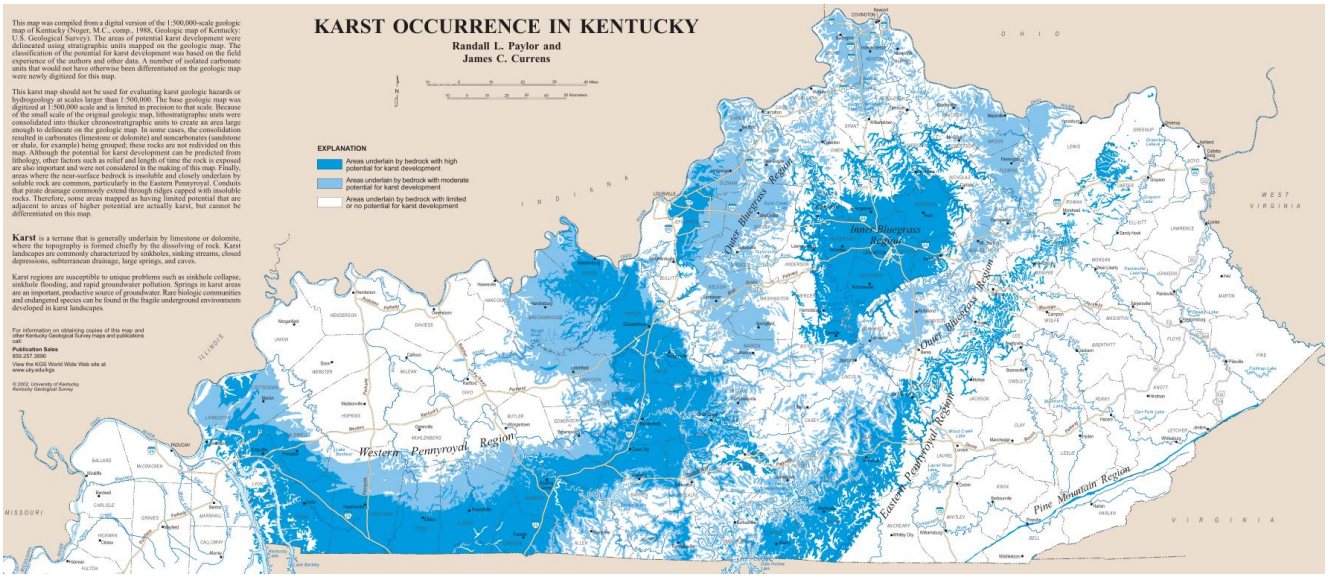
Maintenance and Monitoring	
Design and Modifications	

Supporting Figures:

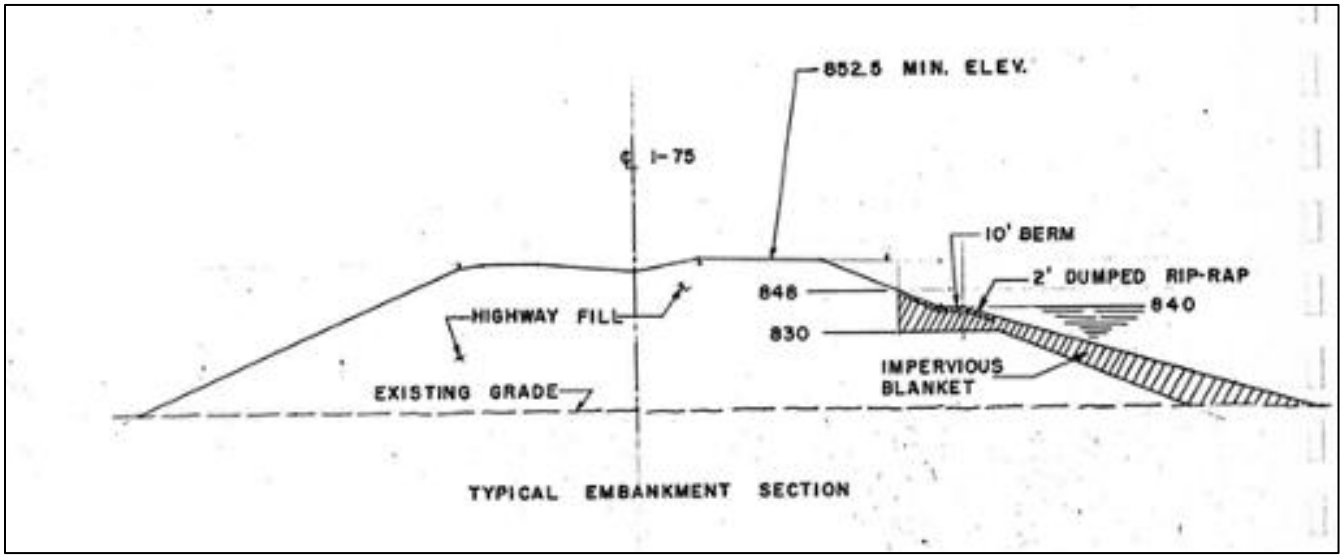




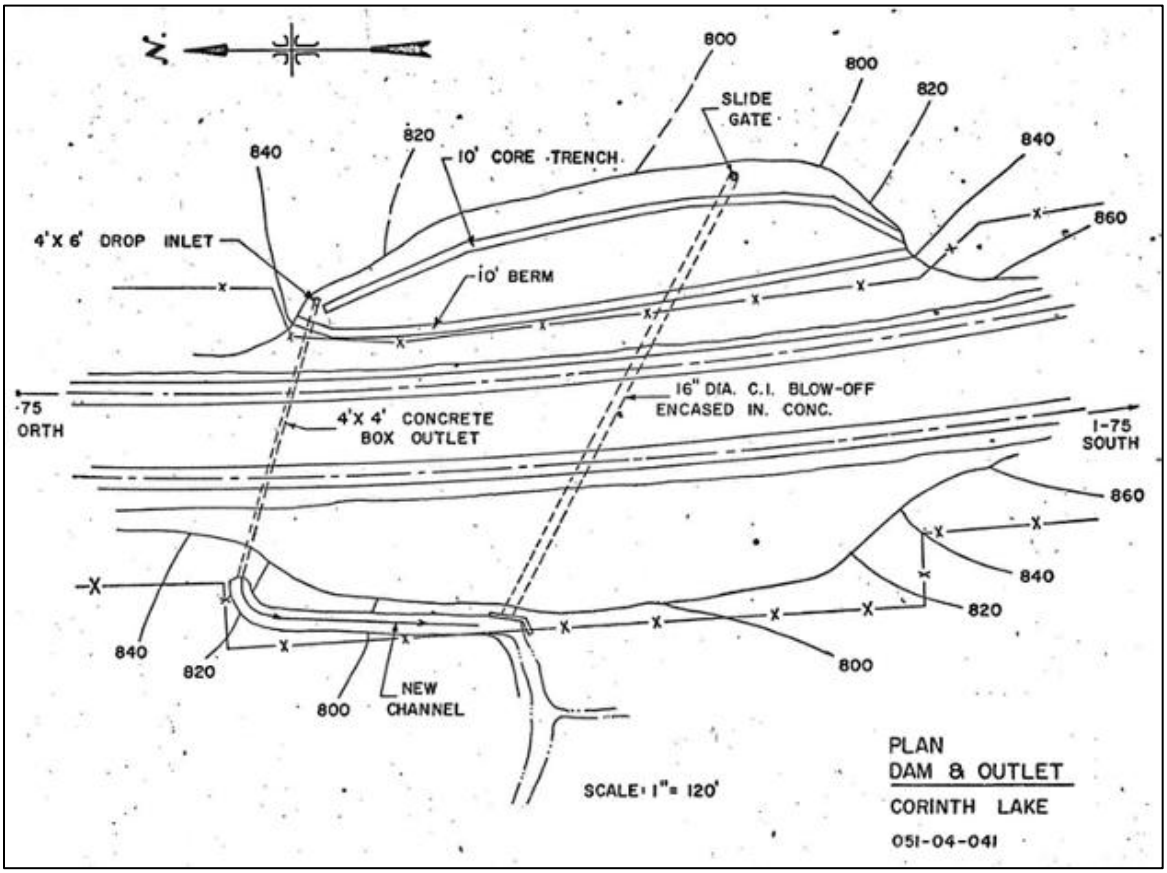
GeoQuad Map (Commonwealth of Kentucky, 1976)



Karst Map (Paylor & Currens, 1988)



Cross Section (Fuller, Mossbarger, Scott & May & Kenvirons, 1979)



Plan View (Fuller, Mossbarger, Scott & May & Kenvirons, 1979)

Potential Failure Mode Analysis Table:

PFM No.:	C-3	**Dam:**	Corinth Lake Dam
PFM Group:	Seismic		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*

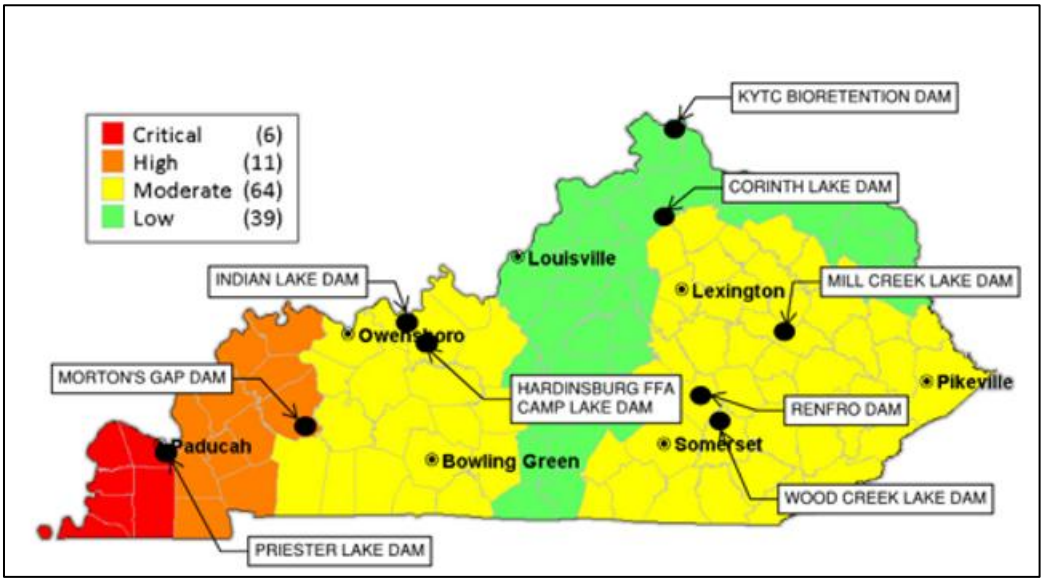
A strong earthquake is felt at the dam site. The dynamic loads on the dam embankment cause slope displacements and possible slope failures. Successive slope movements during and after the earthquake progress across the width of the dam crest. There is no time for intervention. The crest drops below normal pool and the reservoir overtops. The resulting flows scour downward through the dam embankment, releasing the reservoir.

More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
• Slopes are steep (2:1 Upstream side) and steeper where bulges have been noted • Intervention would be impossible during the earthquake • History of observed shallow slope failures • There may be granular soils under the downstream half of the dam	• We are in a low seismic zone • Compacted embankment • The dam has a very wide crest • Intervention is likely to be successful • Upstream half of the embankment is on rock. Foundation soils were removed under the upstream.

Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Negligible	Probability of the loading is very low. The dam embankment is very wide. Breach is unlikely. The intervention is likely to be successful.
Failure Likelihood		
Life Safety Consequences		

Economic Consequences		
Risk Reduction Measures		
Studies and Investigations		
Maintenance and Monitoring		
Design and Modifications		

Supporting Figures:



Seismic Map

Potential Failure Mode Analysis Table:

PFM No.:	C-4	**Dam**:	Corinth Lake Dam
PFM Group:	Overtopping		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*

A heavy precipitation event occurs in the watershed, causing the reservoir level to rise. Water is released through the spillway, but the spillway capacity is partially blocked by floating debris. Water also discharges through the auxiliary spillway ditch at elevation 836.9'. The water levels continue to rise and overtop the dam crest. The median barrier walls fail to retain the water. No plausible effort is made to raise the crest of the dam. The overtopping flows begin to erode the downstream slope of the dam embankment. The flow causes head cutting, which progresses backward across the width of the dam crest. The dam is breached when the crest erosion reaches the upstream pool. The resulting flows scour downward through the dam embankment, releasing the reservoir.

More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
• **The spillway is prone to clogging from floating debris** • **The dam does not currently convey the PMP and it overtops based on the historic crest elevation of 852.5' (AEP of 1e-6)** • Median barrier walls were not designed as a flood wall • Clogging reduces the capacity of the principal spillway. However, it may not affect the maximum water surface elevation	• **The 2014 drawings from the highway widening project indicate a dam crest elevation of 855' which would hold the PMP.** • The median barrier walls are robust, it is a continuous concrete wall across the entire dam crest. • **Wide crest (140')** • **The crest is paved in an erosion resistant material**

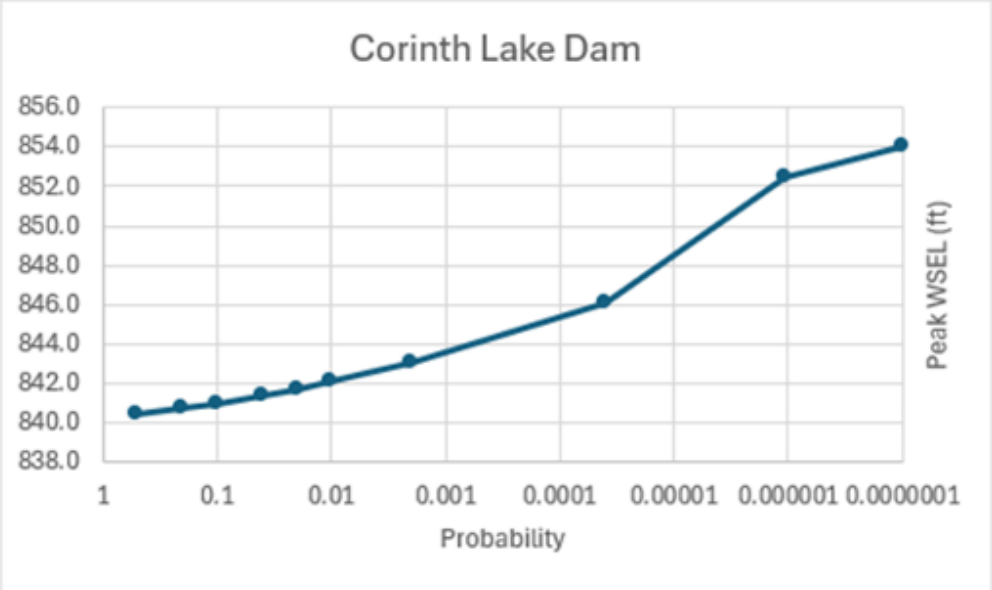
Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Credible	Need to verify the crest elevations of the dam.
Failure Likelihood	FL1	The return interval is 1e-7

Life Safety Consequences	LS2	I-75, residence downstream. PAR is 11. No formal EAP. No way to access to warn people downstream.
Economic Consequences	EC3	Cost of interstate shut down per day
Risk Reduction Measures		
Studies and Investigations	Confirm profile elevation of dam crest.	
Maintenance and Monitoring	Finalize an EAP	
Design and Modifications		

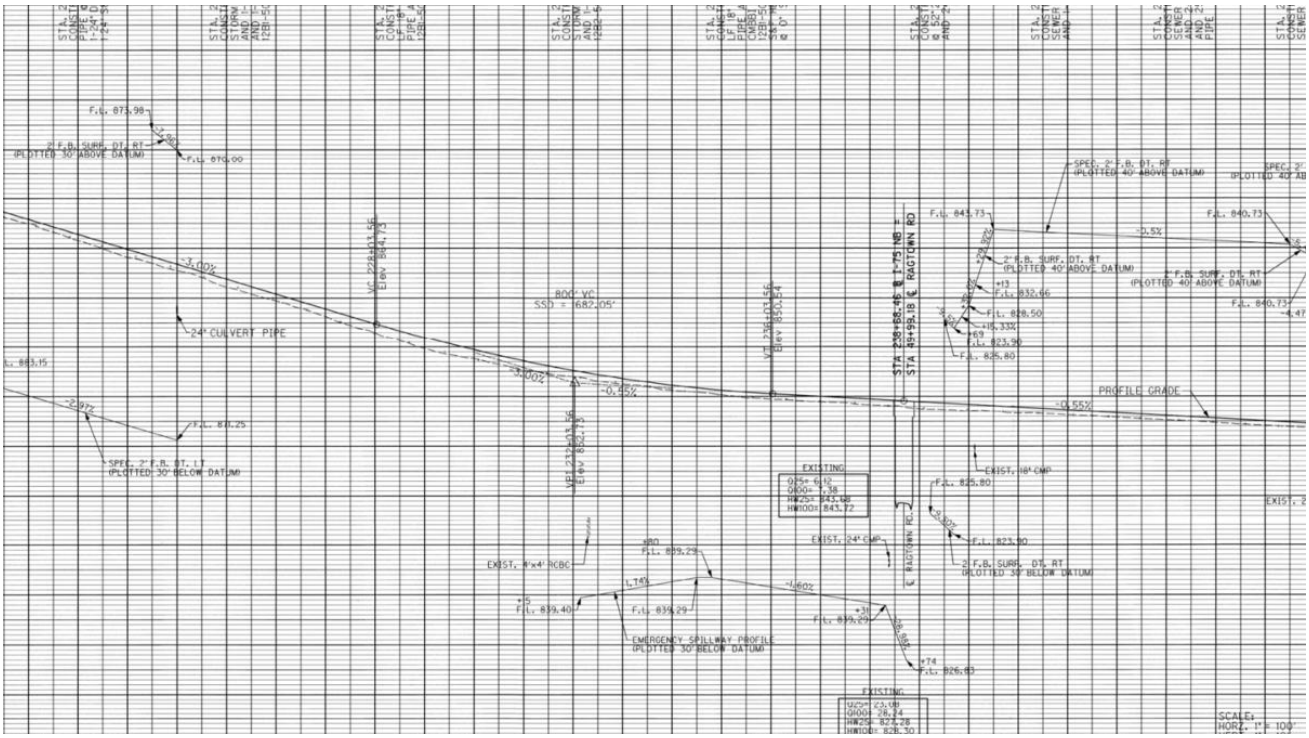
Supporting Figures:

Corinth Lake Dam (Dam Crest = 852.5 ft; Auxiliary Spillway Crest = 846)				
Precip	**Peak Inflow**	**Peak WSEL**	**Return Interval**	**Notes**
2.2	513	840.4	0.5	2yr
2.7	934	840.7	0.2	5yr
3.1	1,346	841.0	0.1	10yr
3.7	1,986	841.4	0.04	25yr
4.2	2,561	841.7	0.02	50yr
4.7	3,214	842.1	0.01	100yr
6.1	5,006	843.1	0.002	500yr
9.7	9,945	846.1	3.92E-05	**Aux. Spillway Activated**
20.1	24,832	852.5	1.08E-06	**Overtopping**
27.7	35,528	854.0	1.00E-07	**PMP**

*Note: Duration of overtopping for the PMP estimated to be **3 hours***



H&H Results



Roadway Centerline Profile from 2014 Roadway Plans (Commonwealth of Kentucky Department of Highways, 2014)

Potential Failure Mode Analysis Table:

PFM No.:	C-5A	**Dam**:	Corinth Lake Dam
PFM Group:	Erosion Associated with Conduits - 16" LLD		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*

There is a 16" low level drawdown intake from the upstream pool to the toe of the dam. The inlet elevation is 792'. Water in the pipe is at headwater pressure. A leak develops in the pipe, causing higher piezometric pressures at the toe of the dam. A slope failure is initiated at the downstream toe of the dam. Successive slope failures retrogress back to the crest, then to the upstream side of the crest. Material is pushed into the failure from the crest, but the intervention fails. The crest drops below the pool elevation (840'), which overtops the dam breach.

More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
• There is a wet area just beyond the downstream toe of the dam, in alignment with this pipe • A slope failure in this vicinity broke the existing operator of the valve, and is no longer operable. • The riser structure is tilting towards the downstream side and has water inside. • The downstream slope shows a steepened bulge near the outlet. • The pipe is cast iron so is subject to deterioration over time. • Condition of the drawdown systems unknown - backfill and construction is unknown • Pipe is pressurized to head water. No upstream valve.	• The cast iron pipe is encased in concrete. • **Wide (140')** • **Intervention is likely - road likely impacted prior to crest of dam. KYTC likely to intervene when road moves**.

Risk Assessment	**Category**	**Notes**

Negligible? Credible?	Credible	This has happened before but the failures are shallow
Failure Likelihood	FL3	There is history of failure. PFM would require intervention when road is impacted before failure occurs. Failure likelihood related to maintaining traffic along I-75 would be deemed higher than that assessed for the dam. Design and modification for both the dam and highway are discussed in the risk reduction measures.
Life Safety Consequences	LS1	I-75, residence downstream. PAR is 11. No formal EAP
Economic Consequences	EC3	Cost of interstate shut down per day
Risk Reduction Measures		
Studies and Investigations	Geotechnical analysis with slope stability evaluation	
Maintenance and Monitoring	Finalize an EAP	
Design and Modifications	Install an upstream gate or valve or replace the low level drawdown system.	

PFM No.:	C-5B	**Dam**:	Corinth
PFM Group:	Erosion Associated with Conduits - Principal Spillway		
PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*			

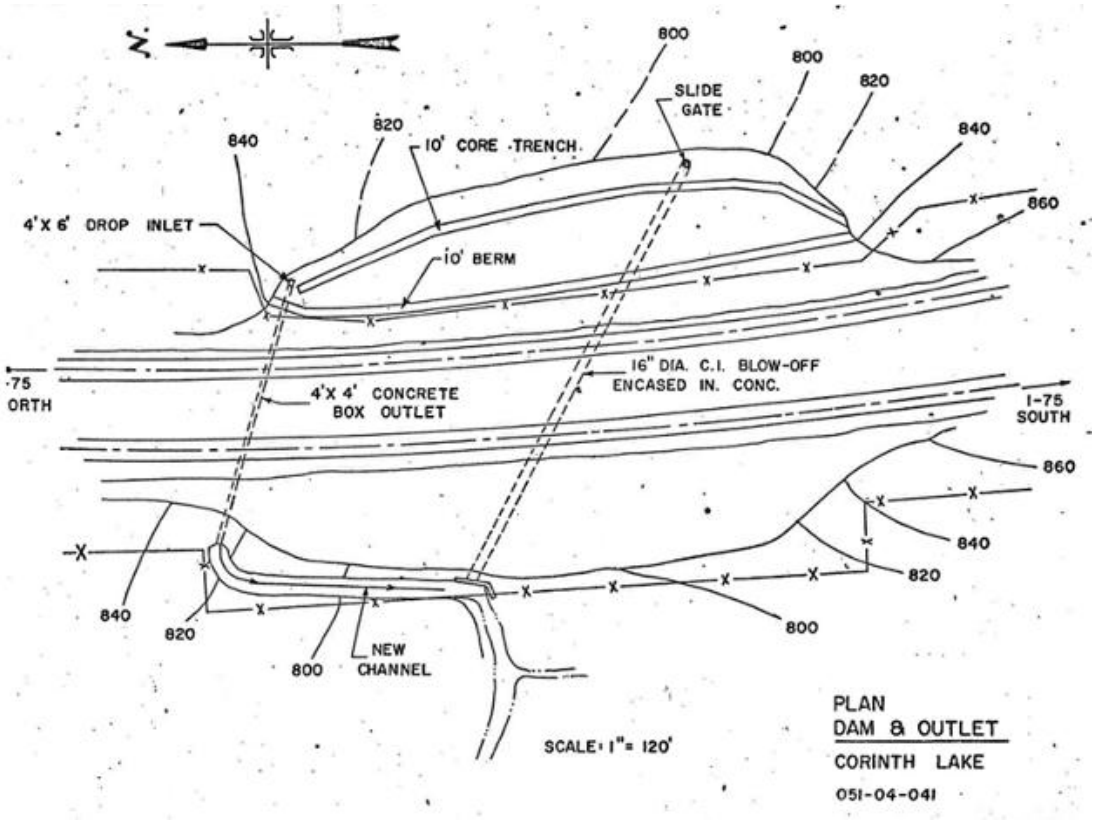
Seepage develops along the outside of the principal spillway. The seepage exit is not filtered, and erosion of the embankment soils continues. A direct connection develops between the reservoir and a void running the length of the conduit. The flow and erosion are not detected and there is no intervention. Seepage continues, resulting in gross enlargement, leading to breach and an uncontrolled release of the reservoir.

More Likely (Adverse) Factors	Less Likely (Favorable) Factors
• This is a common failure mode • We lack a filter diaphragm • The conduit may be constructed on a rock foundation, but we do not know • No inspection information from the interior of the pipe, there was an inspection in 1979 that found hairline cracks	• There are no anti-seepage collars • We assume the conduit is a square cast in place concrete. It would have been feasible to get good compaction against the concrete surface. • No indication of seepage along the outside of the pipe • The pipe is long so the average gradient is low

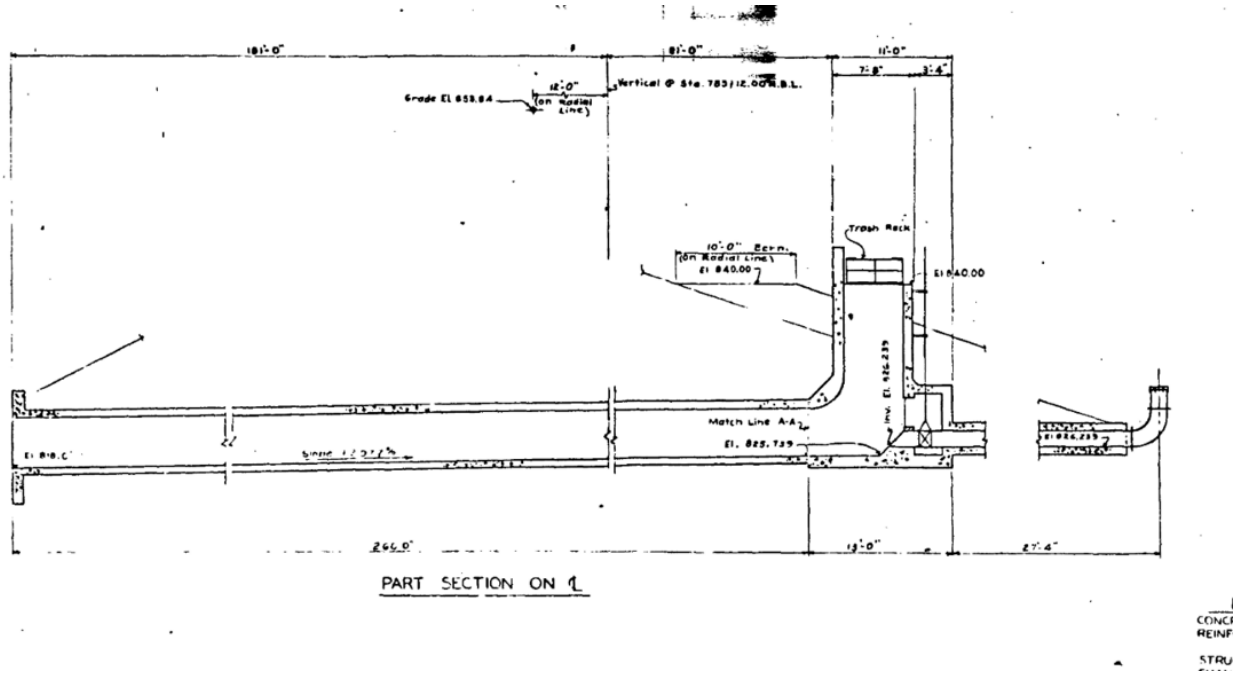
Risk Assessment	Category	Notes
Negligible? Credible?	Credible	This is a common failure mode
Failure Likelihood	FL1	No evidence that this is occurring and there is ample time to intervene
Life Safety Consequences	LS1	I-75, residence downstream. PAR is 11. No formal EAP. No way to access to warn people downstream.
Economic Consequences	EC3	Cost of interstate shut down per day
Risk Reduction Measures		

Studies and Investigations	Do an interior inspection
Maintenance and Monitoring	
Design and Modifications	Install a filter diaphragm along the downstream end

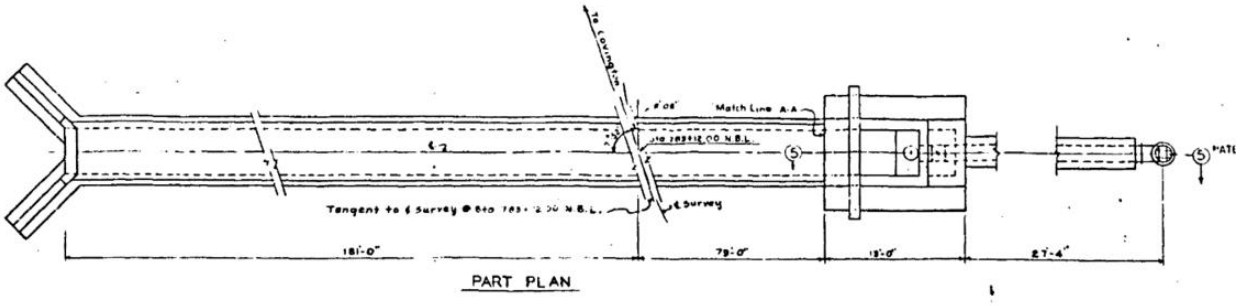
Supporting Figures:



Plan View (Fuller, Mossbarger, Scott & May & Kenvirons, 1979)



Detail from Phase 1 Report (Fuller, Mossbarger, Scott & May & Kenvirons, 1979)



Detail from Phase 1 Report (Fuller, Mossbarger, Scott & May & Kenvirons, 1979)

Potential Failure Mode Analysis Table:

PFM No.:	C-6A	**Dam:**	Corinth
PFM Group:	Spillway Structures - Principal Spillway		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*
Reservoir levels rise during a flood event and the spillway is activated. The downstream channel, located on the embankment, is scoured by flows from the spillway discharge. Erosion progresses up to the end of the spillway culvert. The erosion is not detected and there is insufficient time to intervene. Head cutting of the embankment soils initiates slope failures. Slope failures retrogress back to the crest. The dam is breached and there is an uncontrolled release of the reservoir.

More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
• **There is no concrete apron at the end of the spillway culvert** • **It appears that there has been scour of this channel in the past which has required repairs with riprap and gabion baskets.**	• **The channel is lined with a substantial thickness of class II riprap** • It appears that the culvert was constructed on native ground in the right abutment. • **The flows are limited by the 4x4 culvert** • The cast in place RCP may span sufficient distance over a head cut

Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Credible	
Failure Likelihood	FL3	Could affect the shoulder of the road but not likely to progress all the way across the dam to cause a breach. The fundamental condition is known to exist.
Life Safety Consequences	LS1	I-75, residence downstream. PAR is 11. No formal EAP. Sufficient time to evacuate the residents at one home.
Economic Consequences	EC3	Cost of interstate shut down per day.
Risk Reduction Measures		

Studies and Investigations	Evaluate the hydraulics and size of the stone.
Maintenance and Monitoring	
Design and Modifications	If needed, design a more scour resistant discharge.

PFM No.:	C-6B	**Dam:**	Corinth
PFM Group:	Spillway Structures - LLD		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*

A slope deformation occurs, pushing over the circular concrete riser structure. The valve on the end of the 16" CIP is broken off. This allows full flow from the pipe at head water pressure. The flow discharges onto the toe of the dam and begins to erode and undermine the toe. This triggers a larger slope failure that progresses to the crest of the dam. The erosion is not detected and there is insufficient time to intervene. Head cutting of the embankment soils initiates slope failures. Slope failures retrogress back to the crest. The dam is breached and there is an uncontrolled release of the reservoir.

More Likely (Adverse) Factors	Less Likely (Favorable) Factors
• We can observe that the circular concrete structure is leaning. • Slope deformations have been reported in the past in this area. • The valve stem has broken off in the past. • Headwaters pressures at the valve. • No riprap or scour protection in this area.	• **The flow would be limited by the 16" diameter pipe** • Intervention would be relatively easy

Risk Assessment	Category	Notes
Negligible? Credible?	Credible	The conditions for the initiation have been observed
Failure Likelihood	FL3	Could affect the shoulder of the road but not likely to progress all the way across the dam to cause a breach. The fundamental condition is known to exist.
Life Safety Consequences	LS1	I-75, residence downstream. No formal EAP. Sufficient time to evacuate the residents at one home.
Economic Consequences	EC3	Cost of interstate shut down per day.
Risk Reduction Measures		
Studies and Investigations	Geotechnical analysis with slope stability evaluation	
Maintenance and Monitoring	Finalize an EAP	
Design and Modifications	Install an upstream gate or valve or replace the low level drawdown system.	

Supporting Figures:



Site Visit Photo



Site Visit Photo



Site Visit Photo

Potential Failure Mode Analysis Table:

PFM No.:	C-7	**Dam:**	Corinth Lake Dam
PFM Group:	Operational - Principal Spillway		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*
The valve is opened but cannot be closed. The dam does not fail but the lake is slowly drained to elevation 829' through the secondary drawdown valve.

More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
• Very old	• Discharges through the 4x4 culvert • Not expected to cause erosion • It is reported that the slide gate is operated every 6 months

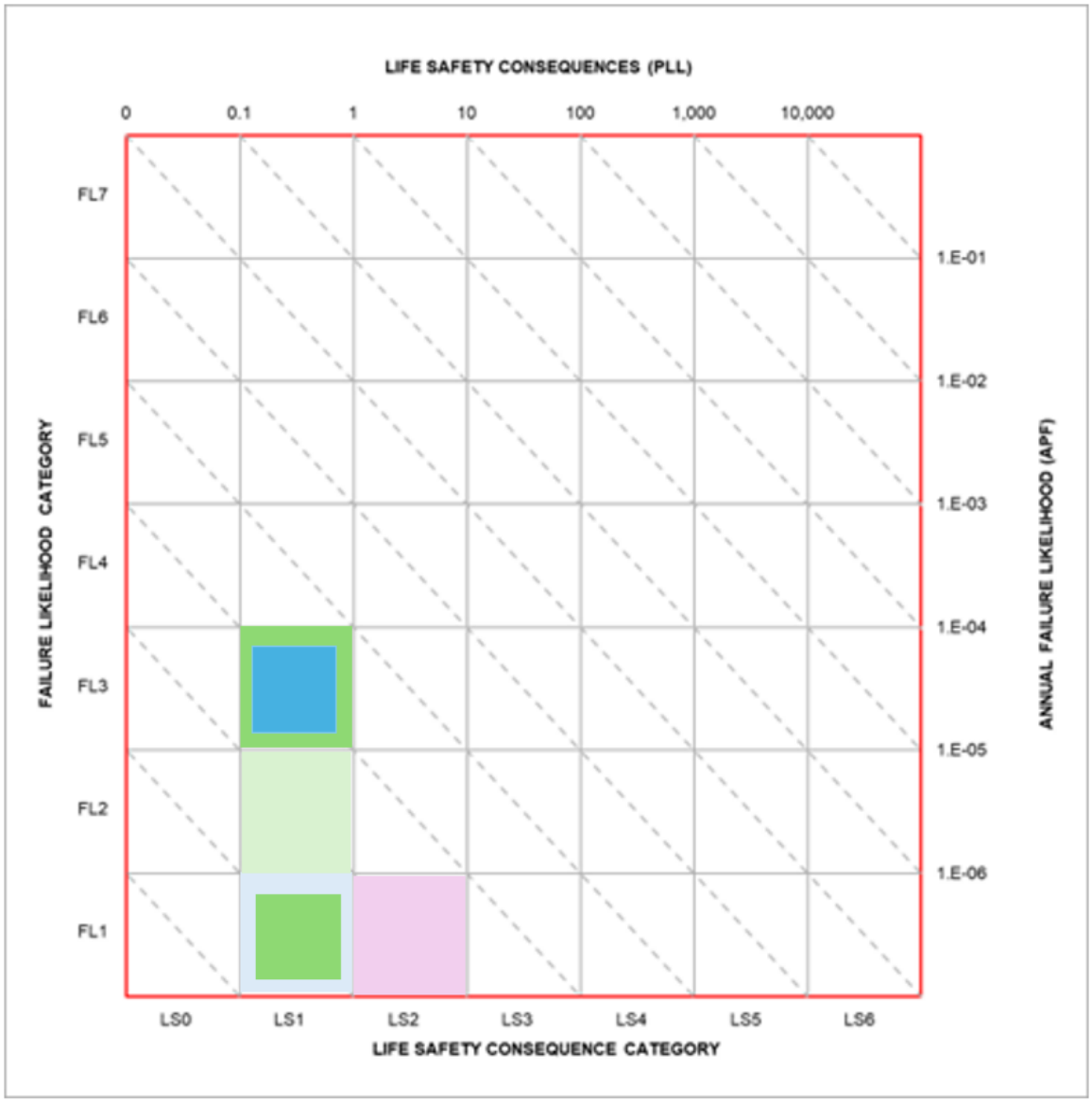
Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Negligible	recreational impacts
Failure Likelihood		
Life Safety Consequences	LS0	
Economic Consequences	EC0	Economic consequences are not significant

Risk Reduction Measures	
Studies and Investigations	

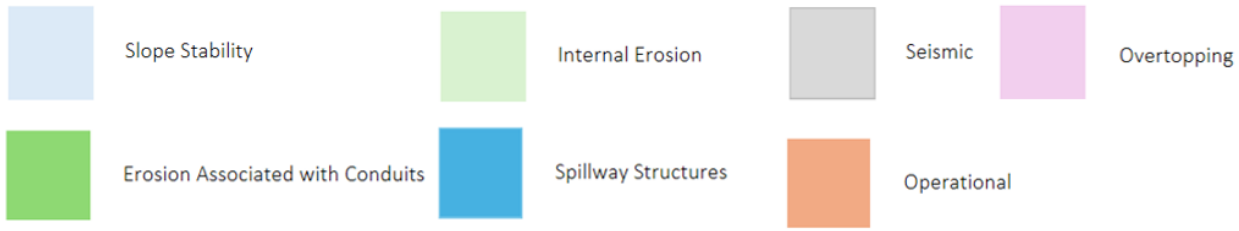
Maintenance and Monitoring	
Design and Modifications	

G.6 Risk Matrices

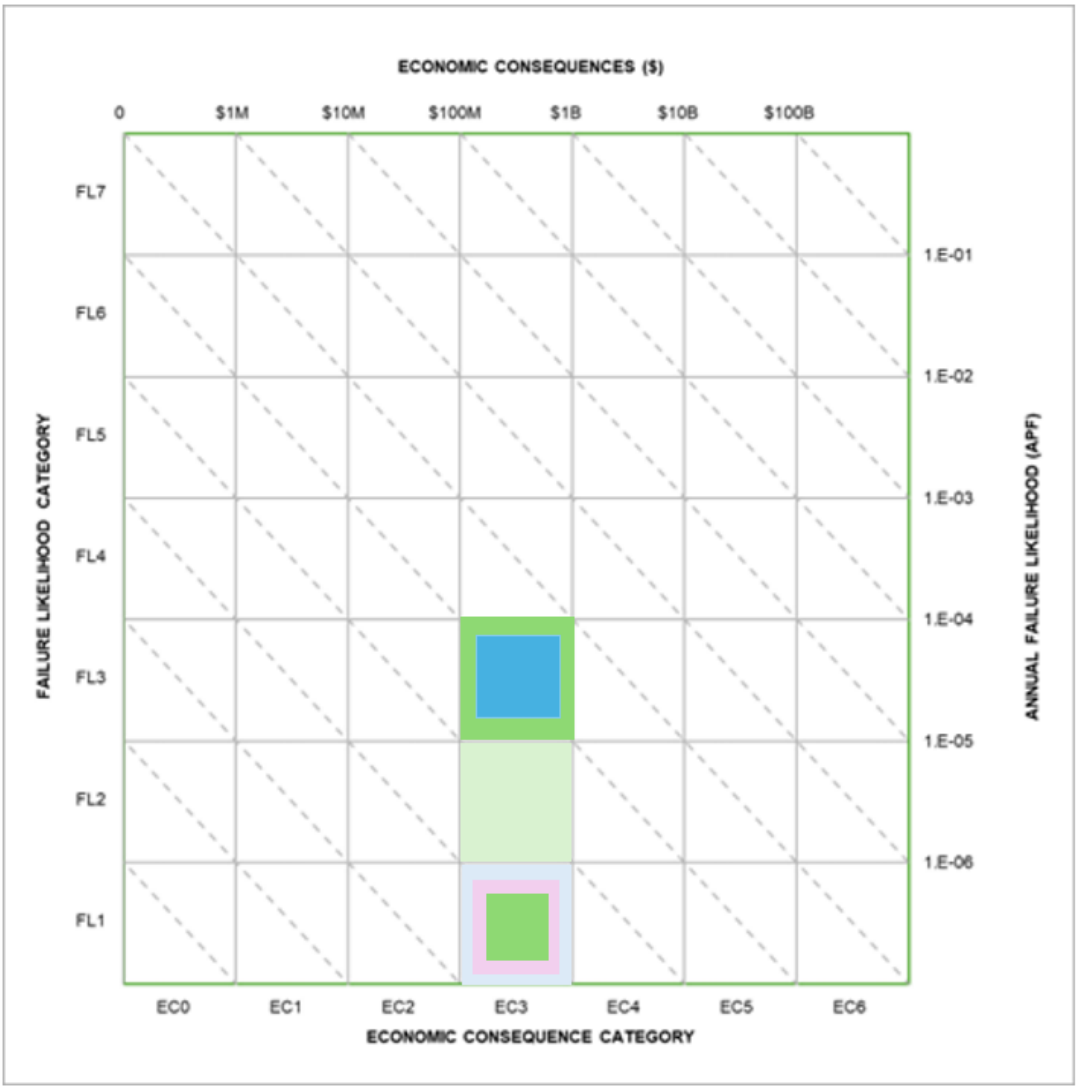
Life Safety Risk Matrix:



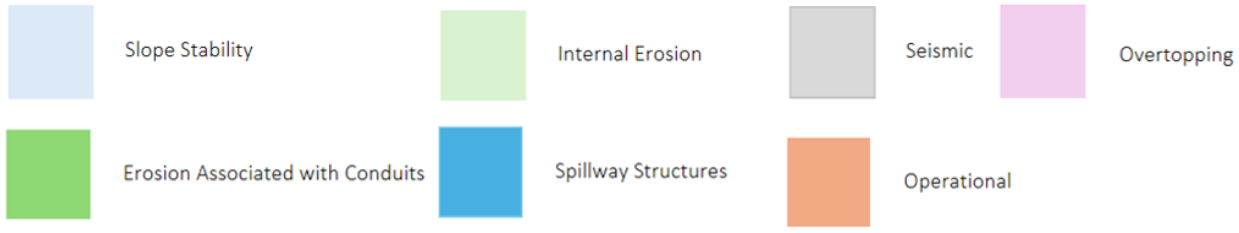
Legend:



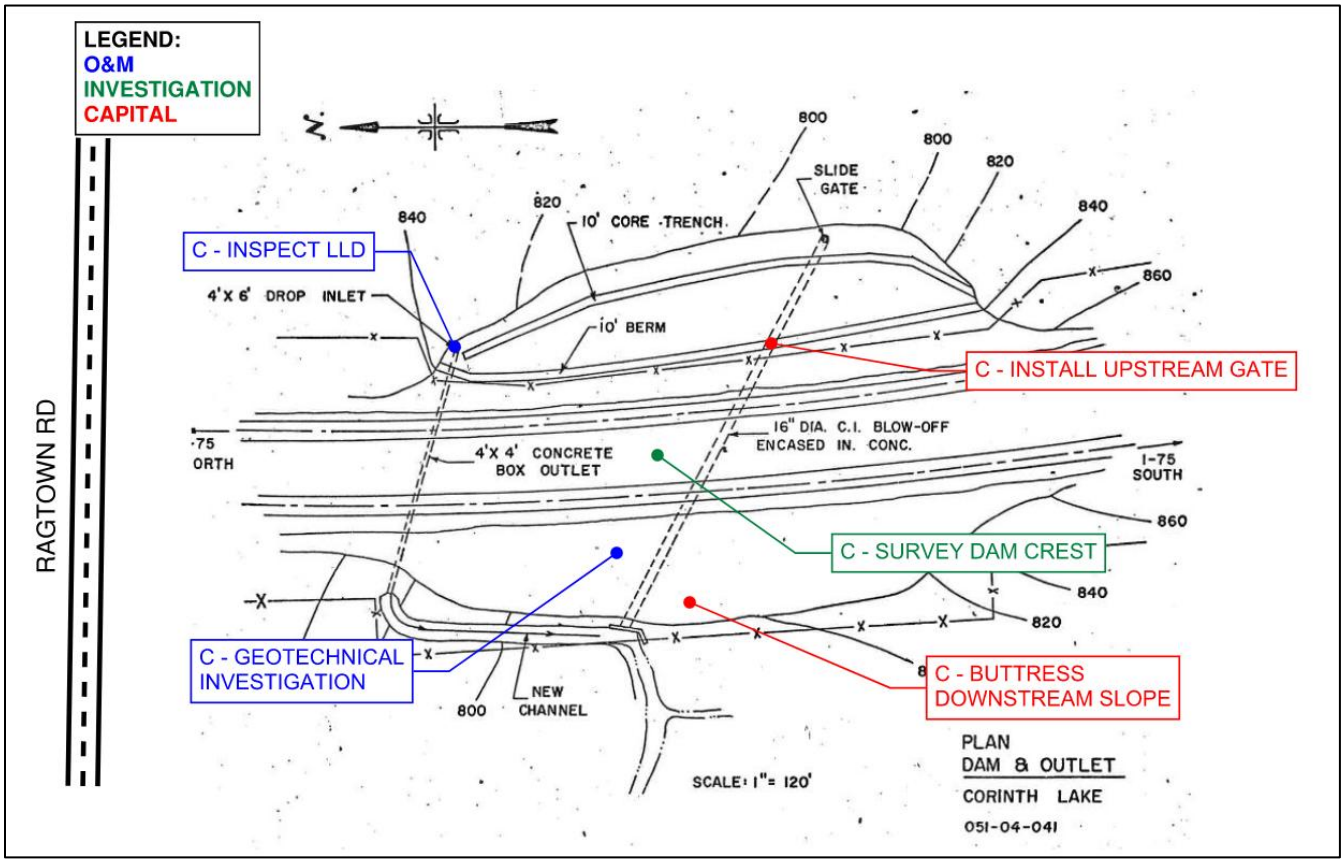
Economic Consequences Risk Matrix:



Legend:



G.7 Recommendations



Recommendations – Corinth Lake Dam								
CODE	**Recommendation**	**Type**	**Life Loss Risk**	**Economic & Transportation Risk**	**Regulatory Compliance**	**Cost Range**	**Planning Horizon**	**Priority**
C - INSPECT LLD	Inspect the submerged, low level drawdown gate at the principal spillway. Locate and inspect the inlet to the low-level outlet.	O&M	1	3	Yes	<10K	Short Term	1
C - SURVEY DAM CREST	Survey or otherwise establish the profile elevation of the dam crest and median barrier wall. If there is a hydraulic deficiency, evaluate the median crash barrier for performance as a temporary floodwall.	Investigation	2	3	Yes	10K-100K	Short Term	2
C - INSTALL UPSTREAM GATE	Install a gate or valve on the upstream side of the low-level outlet (16" Cast Iron pipe).	Capital	3	9	Yes	100K-1M	Long Term	3
C - GEOTECHNICAL INVESTIGATION	Perform geotechnical investigation (borings and instruments) and seepage and stability analyses.	Investigation	3	9	Yes	100K-1M	Intermediate	4
C - BUTTRESS DOWNSTREAM SLOPE	Buttress the downstream face or add a filter berm to address seepage and stability.	Capital	1	3	Yes	1M-10M	Long Term	5

G.8 Cost Opinions for Capital Projects

Stantec developed the following cost opinions for constructing capital improvements for each dam. The costs listed below are very approximate, as they are based only on broad concepts, without even preliminary designs. The costs should be used only for planning, and not for budgeting specific improvements.

Two capital improvement projects are recommended for Corinth Dam. One is to install a gate valve on the upstream side of the low-level outlet. The other is to strip and install a filter berm in order to address seepage and stability issues. The cost estimates are tabulated below.

Gate Valve Installation

Contractor Work Item	Quantity	Unit of Measure	Operating Cost	Total Cost
Low Level Drawdown Gate Replacement	1	LS	$50,000	$50,000
Dive Work	1.5	Week	$25,000	$37,500
Replace existing valve	1	LS	$20,000	$20,000
			Total	$100,000

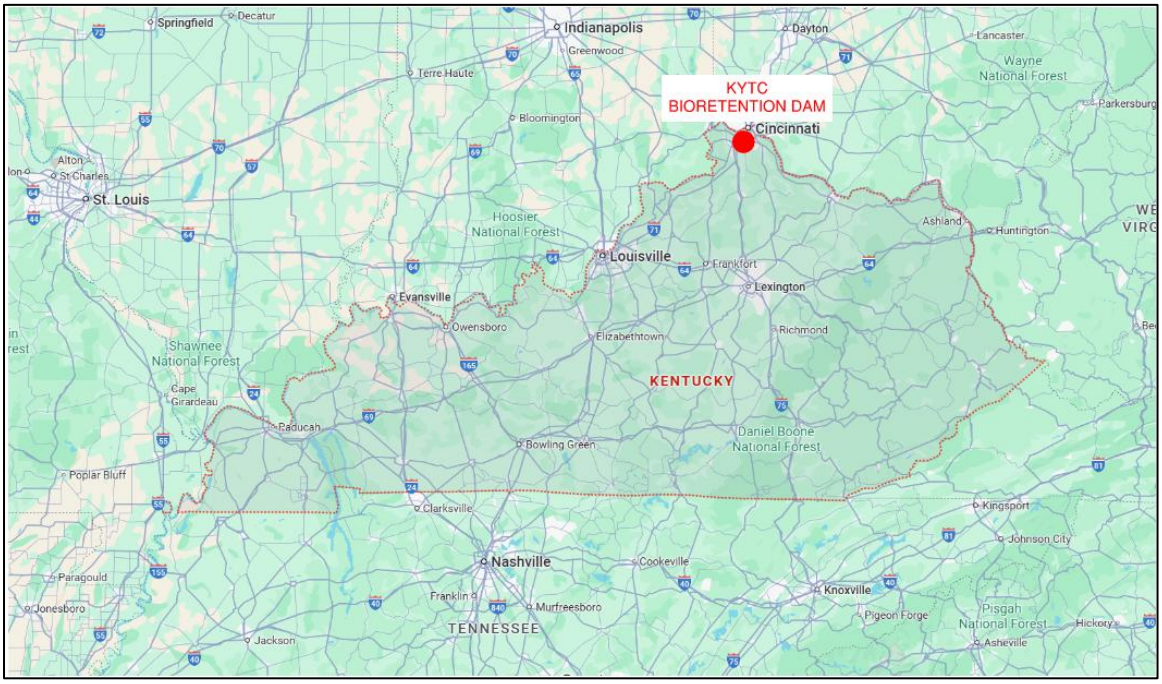
Filter Berm

Contractor Work Item	Quantity	Unit of Measure	Operating Cost	Total Cost
Sand (1' Depth)	832.98	CY	$100	$84,000
Filter Fabric	2,498.94	SY	$7.50	$18,750
No. 57 Stone (3' Depth)	2,498.94	CY	$95	$237,500
Class II Channel Lining (1.5' Depth)	1,249.47	CY	$90	$112,500
Excavation (1.5' Depth)	1,249.47	CY	$50	$62,500
			Total	$600,000

Appendix H
KYTC Bioretention Dam

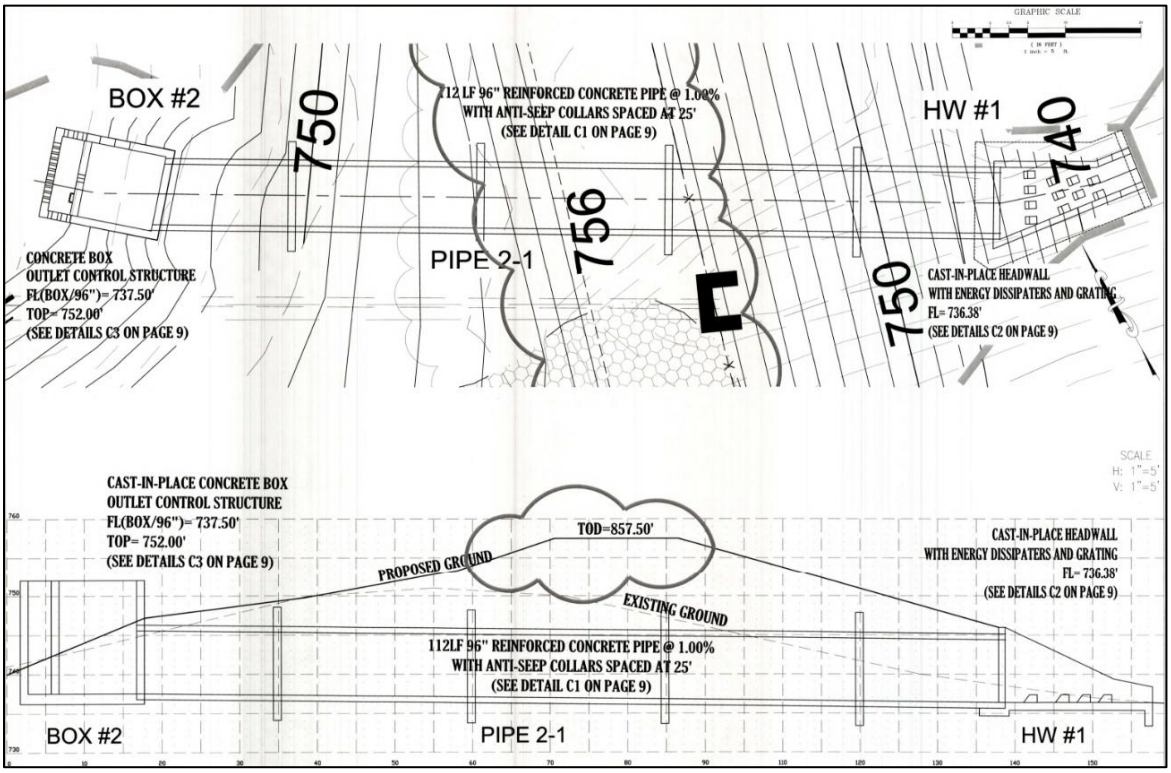
H.1 Dam and Appurtenant Features

The KYTC Bioretention Dam is a high hazard dam located in Kenton County (location map below). The National Inventory of Dams lists the purpose of the dam as flood-risk reduction. This dam was constructed in 2002 and modified in 2011. The dam crest elevation is 757.5 ft. The dam creates an upstream wetland but does not retain a normal pool. The height of the dam is 44 ft, and the crest width is 16 ft.

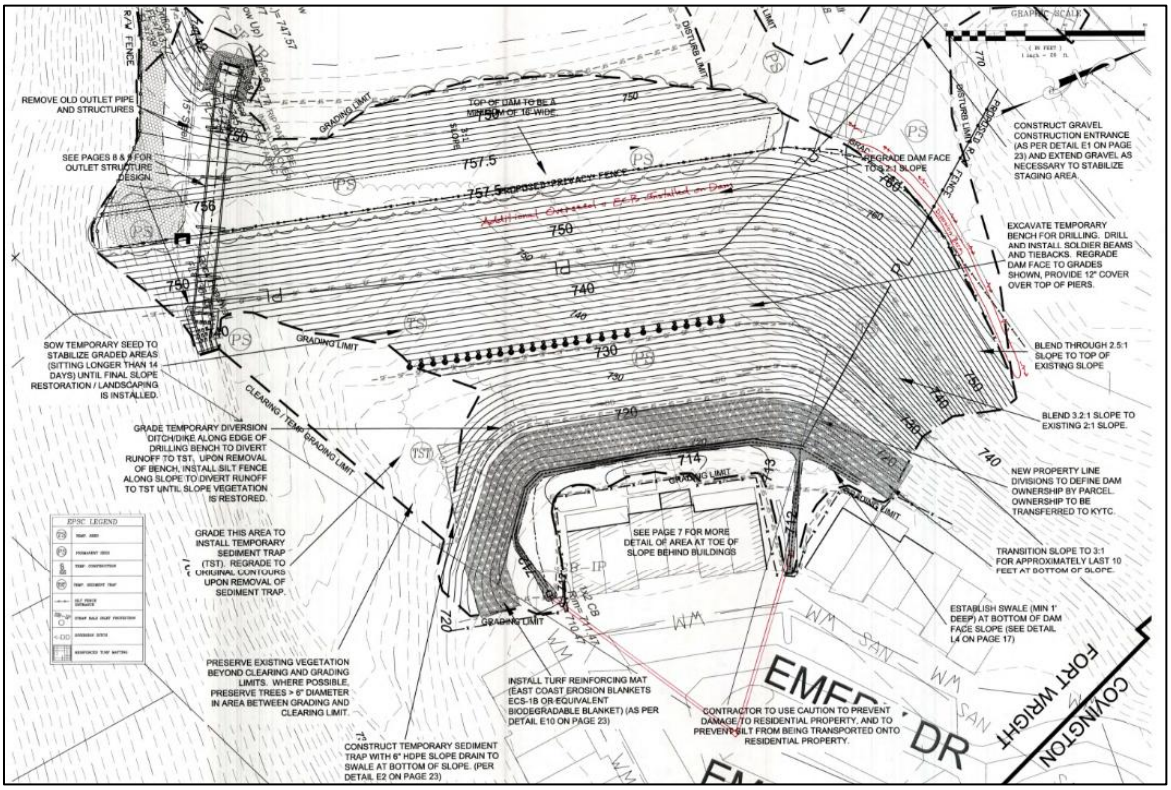


KYTC Bioretention Dam – Vicinity Map

The principal spillway is a 10 ft x 10 ft riser box connected to a 96-inch diameter reinforced concrete pipe running through the dam along the right abutment. The outlet of this pipe discharges into the stream channel downstream. The figures below show the cross sections and plan view for this dam.



KYTC Bioretention Dam – Typical Cross Section & Principal Spillway Overview



KYTC Bioretention Dam – Plan View

H.2 Data Catalog

FILE #	DATA TYPE	TITLE	FILE DESCRIPTION
07.03.001	Inspections	Inspection Report	2021
07.03.002	Inspections	Inspection Report	2023
07.03.003	Inspections	Inspection Report	2024
07.04.001	Drawings	As Built	2002 as built drawing set
07.06.001	Transportation Docs	Road Plans	2000 Dept of Highways
07.06.002	Transportation Docs	Road Plans	1958 Dept of Highways
07.03.101	Inspections	Inspection Report	2021 Division of Water
07.03.102	Inspections	Inspection Report	2023 Division of Water
07.03.103	Inspections	Inspection Report	2024 Division of Water
07.01.201	Geotech / Geology Info.	Geologic and Soil Map	
07.01.202	Geotech / Geology Info.	Geological Engineering Report	2009 Thelen
07.02.201	H & H	H & H Report	2010 Viox & Viox
07.02.202	H & H	H & H Report	
07.02.203	H & H	H & H Report	2010
07.02.204	H & H	H & H Info	2010 Dam Safety Section
07.04.201	Drawings	As Built	2011 Viox, Thelen, & Strand

H.3 Hydrologic and Hydraulic Analyses

Elevation-Frequency Analysis

Previous hydrologic and hydraulic analyses were performed by Viox & Viox using the Haestad PondPack (version 9) model in 2009. The input data from the PondPack model was used to generate a new U. S. Army Corps of Engineers (USACE) Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) model (version 4.12) to estimate water surface elevations associated with various precipitation depths. The following information was taken from the PondPack model:

- Curve Number
- Drainage Area
- Time of Concentration
- Stage-Storage-Discharge Information

NOAA Atlas 14 was used to generate precipitation depths for frequencies ranging from the 2-year (50-percent-annual-chance) up to the 500-year (0.2-percent-annual-chance) storm. For the Probable Maximum Precipitation (PMP), Kentucky Engineering Memorandum No. 2 was used to determine the PMP rainfall depth. A 24-hour SCS Type II rainfall distribution was applied to the precipitation depths from NOAA Atlas 14, and a 6-hour SCS Type II rainfall distribution was applied to the PMP rainfall depth within the HEC-HMS model. The probability associated with the PMP was estimated using two methods:

- The FEMA Spillway Capacity and Extreme Flood Discharge Estimator (which uses flow-frequency data input by the user along with extrapolation using a power function to estimate the return period of the PMP)
- The Australian Rainfall Runoff method (which uses drainage area to estimate a return period of the PMP).

The results of the two methods were averaged to estimate the PMP probability.

Using trial and error, additional storms were run with varying rainfall depths until a rainfall depth that produced a water surface elevation that would overtop the dam was obtained. A power curve was fit to the flow frequency data (including the PMP) and interpolated to approximate the return period associated with this rainfall depth. The duration of overtopping for the PMP event was also estimated by reviewing the time-series results of the HMS model and noting the period of time where the water surface elevation was above the dam crest.

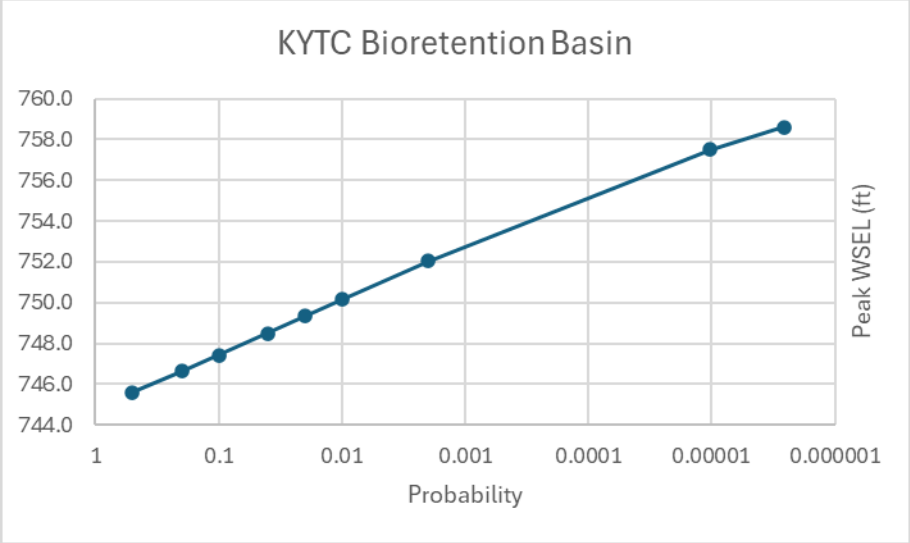
It is noted that the previous modeling showed that the dam is capable of passing the PMP without overtopping the dam, however the modeling performed for this effort shows overtopping at a lesser rainfall depth. This difference is believed to be due to the different software (HEC-HMS vs. SITES) being used, resulting in different inflow hydrographs. The HEC-HMS software predicts a higher inflow (though a similar volume) which results in overtopping of the dam for a short duration during the PMP event.

The resulting water surface elevations from the model runs are tabulated and plotted below.

Bioretention Basin Model Results

KYTC Bioretention Basin (Dam Crest = 757.5 feet)				
Precipitation (inches)	**Peak Inflow (cfs)**	**Peak WSEL (feet)**	**Return Interval**	**Notes**
2.1	160	745.6	0.5	2yr
2.6	202	746.6	0.2	5yr
3.0	234	747.4	0.1	10yr
3.5	279	748.5	0.04	25yr
3.9	316	749.3	0.02	50yr
4.3	353	750.2	0.01	100yr
5.3	441	752.0	0.002	500yr
18.2	1,587	757.5	1.03E-05	**Overtopping**
27.5	2,405	758.6	2.58E-06	**PMP**

Note: Duration of overtopping for the PMP estimated to be 20 minutes



KYTC Bioretention Basin Elevation-Frequency Curve

Consequences Analysis

Previous inundation mapping for a sunny-day breach of the dam publicly available on Kentucky's Dam Inundation Viewer (watermaps.ky.gov) was reviewed. An additional flood-day breach hydrograph for the dam was modeled in HEC-HMS for the PMP rainfall event. Empirical equations were utilized to define breach width, formation time, and side slopes. The resulting breach hydrograph was input into the USACE Dam Screening Tool (DST) and routed downstream. Inundation extents for the sunny-day and flood-day breaches were reviewed along with aerial imagery to evaluate consequences.

Structures identified in the sunny-day inundation area included 18 townhomes, eight apartment complexes, and approximately 115 residences, as well as a grocery store, an elementary school, and two road crossings. A population at risk of approximately 1,000 was estimated based on the following assumptions:

- 2.5 people per home inundated
- 25 people per apartment complex
- 450 people for the school
- 2 people per road crossing

The flood-day inundation extents were similar to the sunny-day breach extents. The DST estimated a similar PAR, but zero life loss which appeared to be due to low flood depths in the inundation area. The consequences are summarized in the table below.

Consequences Associated with Failure of KYTC Bioretention Basin

KYTC Bioretention Basin	
NID_ID	KY01224
Number of Residences	18 townhomes, 8 apartment complexes, ~115 homes (approximate)
Number of Non-Residential Structures	1
Description of Non-Residential Structures	Grocery Store (Bill's food Market)
Number of Critical Infrastructure Structures	1
Description of Critical Infrastructure Structures	Elementary School
Number of Road Crossings	3
List of Roads Affected	Emery Drive, Highland Avenue/W. 19th Street, and Hawthorne Street. Highland Avenue/W. 19th Street runs through the middle of the inundation area (length inundated = ~1 mile)
Estimated PAR	Approx. 1000
PAR Assumptions	Assuming 2.5 people per house/townhome, 25 people per apartment complex, and 450 people in the school (online sources list 407 students) puts the PAR at around 1,000.
Inundation Mapping Source	KY Dam Inundation Viewer + Aerial Imagery + DST (flood breach)
Estimated Life Loss	1-10
Life Loss Notes	Population is all close to the dam (population area starts at the base of the dam and extends about a mile downstream). DST estimated a PAR of 714 but zero life loss, which appears to be due to low flood depths. Considered that life loss would be low but is possible due to the high PAR.

H.4 Potential Failure Modes

PFM NUMBER	PFM GROUP	PFM DESCRIPTION	RISK ASSESSMENT
KYTC-1A	SLOPE STABILITY	Normal/Flood - A storm event occurs and fills the reservoir to elevation 752' or above. The flood pool puts additional load on the dam, causing a slope failure near the crest. It is a downstream slope failure. Successive failures retrogress back to the crest, then to the upstream side of the crest. We mobilize at the toe of the dam to stabilize it, but the intervention is unsuccessful. The crest drops below the elevation (752'), which overtops the dam breach. The resulting flows scour downward through the dam embankment, releasing the reservoir.	CREDIBLE
KYTC-1B	SLOPE STABILITY	Rapid Drawdown - The flood pools on the embankment are only going to present for about a day based on the hydraulic analyses. This is not long enough to saturate the silty clays in the embankment. Therefore, we do not develop a rapid drawdown slope stability case. This is negligible.	NEGLIGIBLE
KYTC-2	INTERNAL EROSION	This failure mode considers seepage through the dam, through foundation soils, along the abutments, or along the tiebacks in the soldier pile wall. Under normal conditions, there is no pool. But there is groundwater that goes from the bioretention area to the toe of the dam. The long term seepage causes erosion within the silty clays of the embankment or foundation. A storm event occurs and water rises in the detention basin, causing additional seepage. The seepage may discharge in the French drain at the toe of the slope, which does not meet filter criteria. Intervention is unsuccessful. The erosion of the soils lead to slope failures and a breach of the dam.	NEGLIGIBLE
KYTC-3	SEISMIC	A strong earthquake is felt at the dam site. The dynamic loads on the dam embankment cause	NEGLIGIBLE

		slope displacements and possible slope failures. Successive slope movements during and after the earthquake progress across the width of the dam crest. There is no time for intervention. The crest drops below normal pool and the reservoir overtops. The resulting flows scour downward through the dam embankment, releasing the reservoir.	
KYTC-4	OVERTOPPING	A heavy precipitation event occurs in the watershed, causing the reservoir level to rise. Water is released through the spillway. However, the spillway capacity is insufficient and/or subject to clogging. The water levels continue to rise in the reservoir. The water overtops the dam crest. No plausible effort is made to raise the crest of the dam. The overtopping flows begin to erode the downstream slope of the dam embankment. The flow causes head cutting, which progresses backward across the width of the dam crest. The dam is breached when the crest erosion reaches the upstream pool. The resulting flows scour downward through the dam embankment, releasing the reservoir.	CREDIBLE
KYTC-5	EROSION ASSOCIATED WITH CONDUITS	Along 96” RCP - During a storm event, the reservoir rises to elevation 752'. Seepage develops along the outside of the reinforced concrete culvert (principal spillway). Flow develops in poorly compacted backfill under the haunches of the pipe, leading to concentrated leak erosion of the soil. The anti-seep collars are ineffective. The seepage exit is not filtered, and erosion of the embankment soils continues. A direct connection develops between the reservoir and a void running the length of the conduit. The flow and erosion are not detected and there is no intervention. Seepage continues, resulting in gross enlargement, leading to breach and an uncontrolled release of the reservoir.	CREDIBLE
KYTC-6	SPILLWAY STRUCTURES	Not applicable, no failure modes identified.	NEGLIGIBLE
KYTC-7	OPERATIONAL	Not applicable, no failure modes identified.	NEGLIGIBLE

H.5 Evaluation of PFMs

Potential Failure Mode Analysis Table:

PFM No.:	KYTC-1A	**Dam:**	KYTC Bioretention
PFM Group:	Slope Stability - Normal/Flood		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*

A storm event occurs and fills the reservoir to elevation 752' or above. The flood pool puts additional load on the dam, causing a slope failure near the crest. It is a downstream slope failure. Successive failures retrogress back to the crest, then to the upstream side of the crest. We mobilize at the toe of the dam to stabilize it, but the intervention is unsuccessful. The crest drops below the elevation (752'), which overtops the dam breach. The resulting flows scour downward through the dam embankment, releasing the reservoir.

More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
• Did not have an analysis for this particular load combination • Solider pile wall and tiebacks are buried in downstream embankment, can't be observed. • The tiebacks are subject to deterioration • Had to install the piles to achieve stability • Intervention may be difficult due to access concerns	• Geotechnical analyses were performed for long term and seismic conditions • Slopes are 3:1 • **The flood loading is very infrequent (2e-3)** • **No observations of slope movement** • At the pool elevation, the width of the dam is significant • Detection is likely

Risk Assessment	**Category**	**Notes**

Negligible? Credible?	Credible	The Viox and Viox design of soldier pile wall was implemented to address slope stability issues.
Failure Likelihood	FL3	We do not have an analysis for the condition we are considering and repairs were implemented to address slope stability.
Life Safety Consequences	LS1	The PAR is 714 but 0 life loss due to low flood depths. The estimated life loss at breach is 1-10 which suggests LS2 but there should be enough time to evacuate, so LS1.
Economic Consequences	EC1	Residential damages, no impacts to major infrastructure.
Risk Reduction Measures		
Studies and Investigations	Geotechnical analyses for the flood loading conditions, assess the condition of the soldier pile tiebacks (future recommendation).	
Maintenance and Monitoring	Continue with annual inspections.	
Design and Modifications		

PFM No.:	KYTC-1B	**Dam:**	KYTC Bioretention
PFM Group:	Slope Stability - Rapid Drawdown		
PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*			

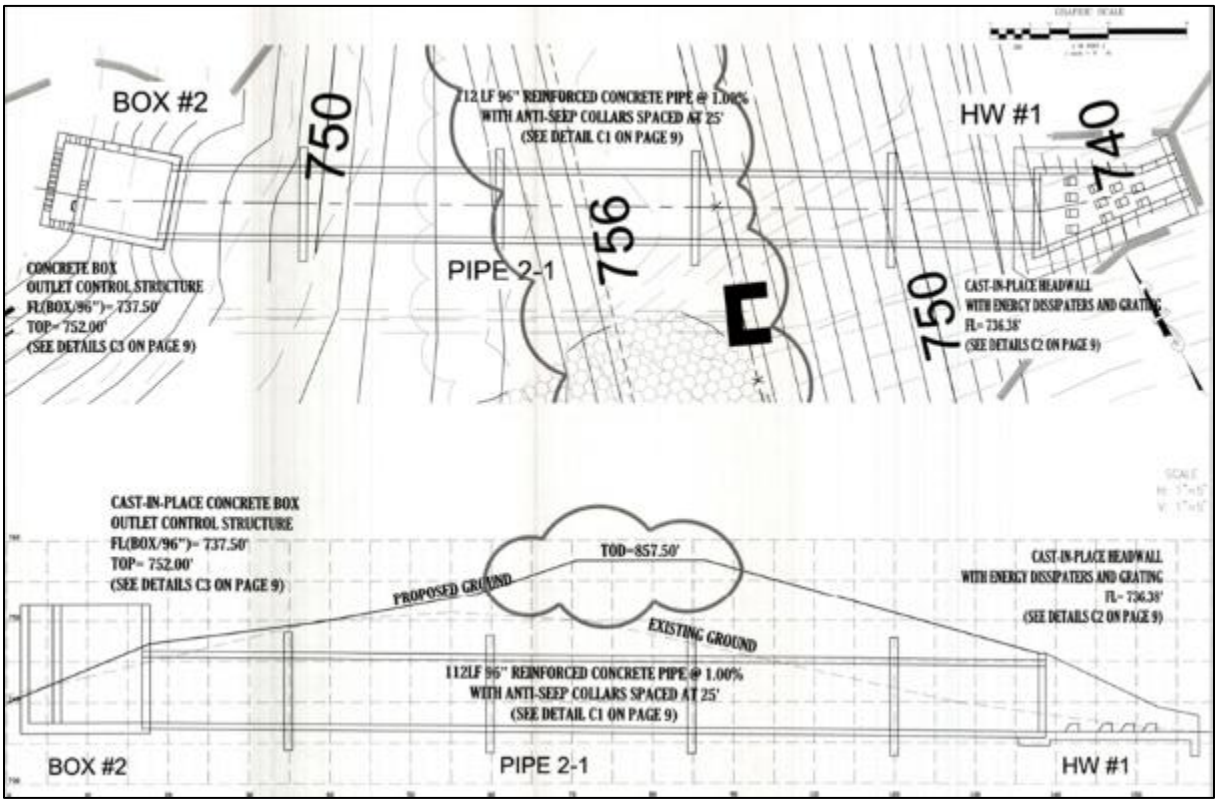
The flood pools on the embankment are only going to present for about a day based on the hydraulic analyses. This is not long enough to saturate the silty clays in the embankment. Therefore, we do not develop a rapid drawdown slope stability case. This is negligible.

More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
•	

Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Negligible	
Failure Likelihood		
Life Safety Consequences		
Economic Consequences		

Risk Reduction Measures	
Studies and Investigations	
Maintenance and Monitoring	
Design and Modifications	

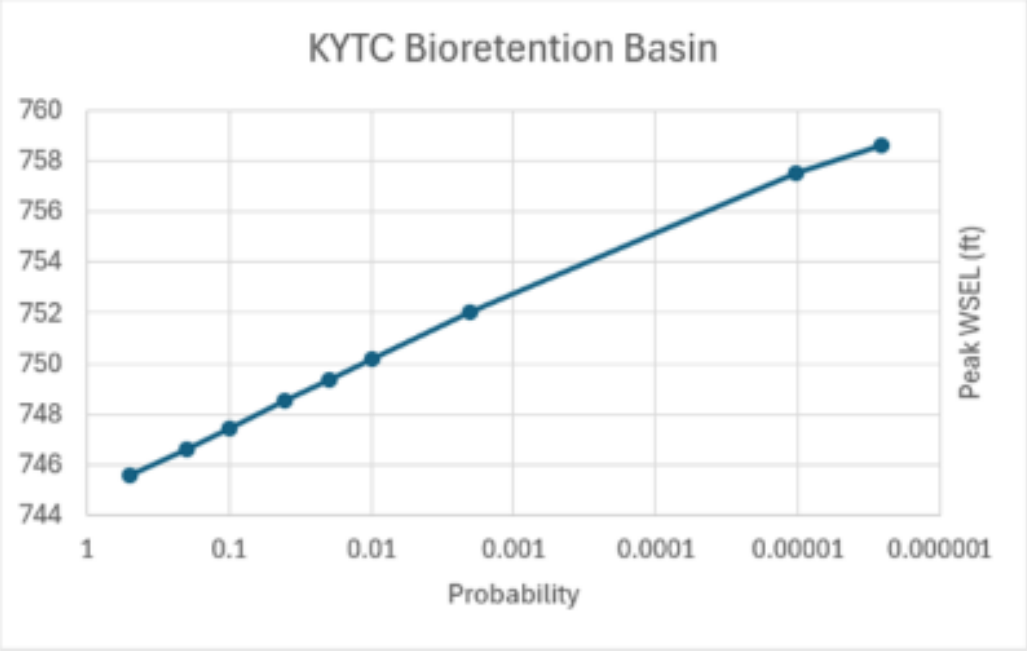
Supporting Figures:



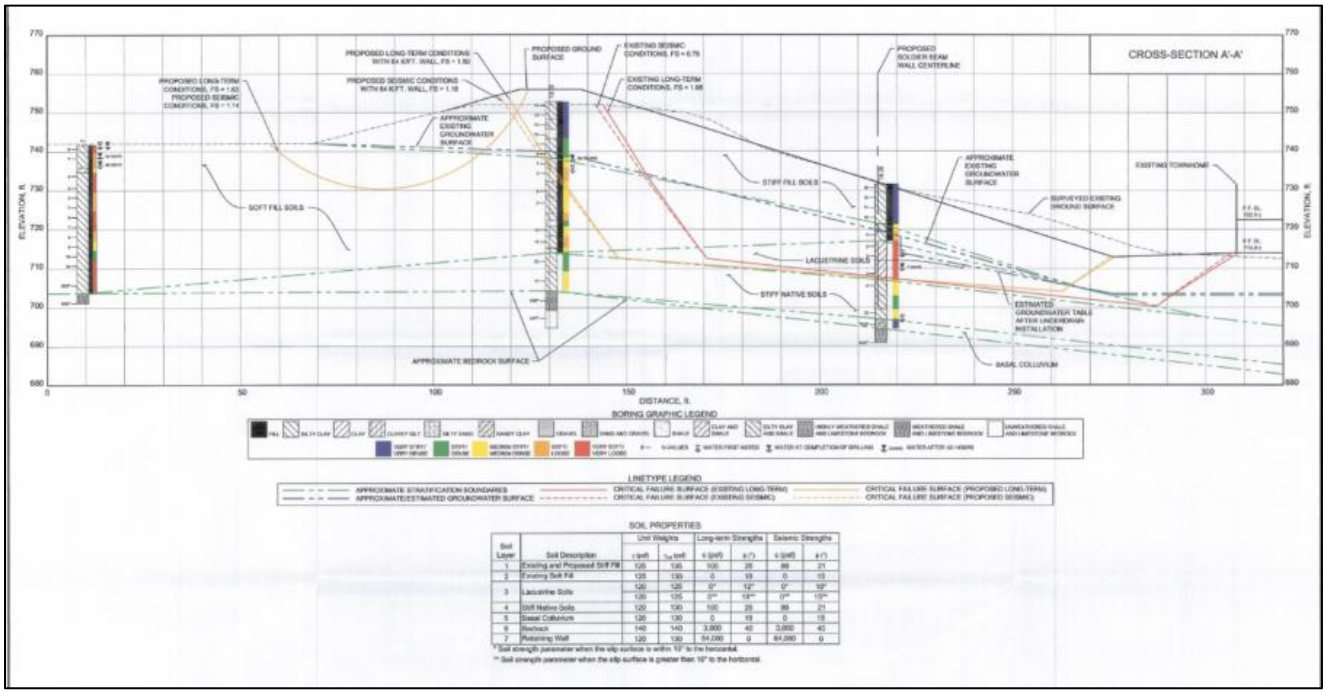
Cross Section (Viox & Viox, 2011)

KYTC Bioretention Basin (Dam Crest = 757.5 ft)				
Precip	**Peak Inflow**	**Peak WSEL**	**Return Interval**	**Notes**
2.11	160.1	745.6	0.5	2yr
2.59	201.7	746.6	0.2	5yr
2.96	234.5	747.4	0.1	10yr
3.47	279.5	748.5	0.04	25yr
3.88	316.1	749.3	0.02	50yr
4.29	353.0	750.2	0.01	100yr
5.28	440.6	752.0	0.002	500yr
18.20	1,587.1	757.5	1.03E-05	**Overtopping**
27.50	2,404.6	758.6	2.58E-06	**PMP**

*Note: Duration of overtopping for the PMP estimated to be **20 minutes***



H&H Results



2009 Geotechnical Report Cross Section (Thelen Associates Inc., 2009)

Potential Failure Mode Analysis Table:

PFM No.:	KYTC-2	**Dam:**	KYTC Bioretention
PFM Group:	Internal Erosion		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*

This failure mode considers seepage through the dam, through foundation soils, along the abutments, or along the tiebacks in the soldier pile wall. Under normal conditions, there is no pool. But there is groundwater that goes from the bioretention area to the toe of the dam. The long term seepage causes erosion within the silty clays of the embankment or foundation. A storm event occurs and water rises in the detention basin, causing additional seepage. The seepage may discharge in the French drain at the toe of the slope, which does not meet filter criteria. Intervention is unsuccessful. The erosion of the soils lead to slope failures and a breach of the dam.

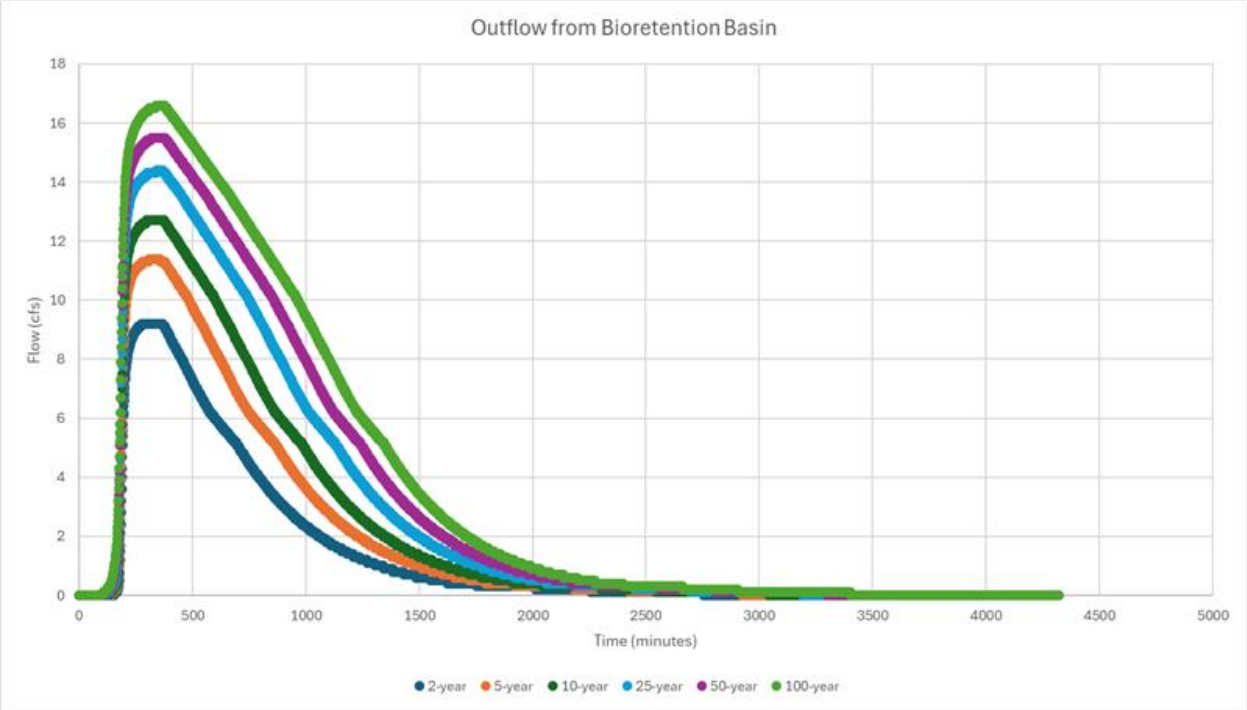
For these reasons, the risks are negligible.

More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
• There are some fill areas characterized as soft. • The French drain system is an indication that water is present at the toe of the dam.	• The flood pool is there for about 24 hours, maximum. That is not long enough to cause significant internal erosion. • The gradients under normal conditions are low and erosion is not expected.

Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Negligible	We do not have a normal pool to drive seepage and erosion. The flood pools are present for only about one day.
Failure Likelihood		

Life Safety Consequences		
Economic Consequences		
Risk Reduction Measures		
Studies and Investigations		
Maintenance and Monitoring		
Design and Modifications		

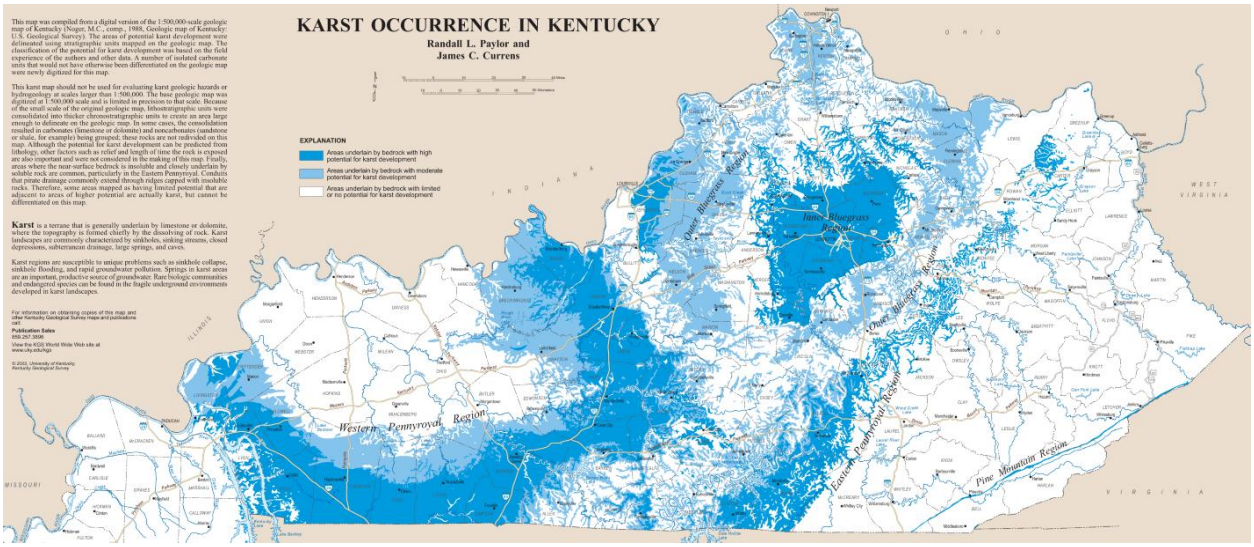
Supporting Figures:



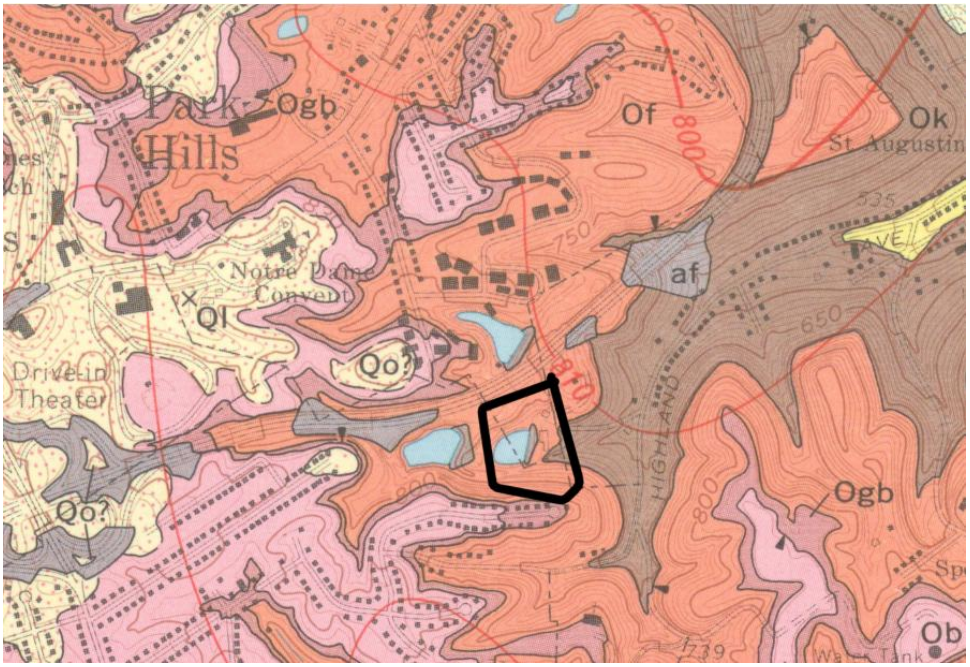
H&H Results

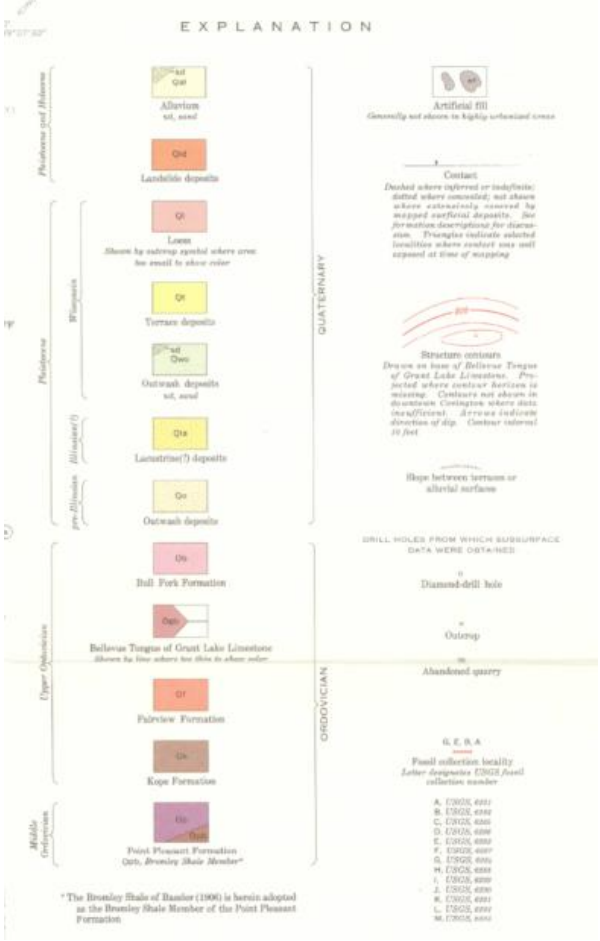
Bioretention Basin		
Event	**Inflow**	**Discharge**
2-year	160.1	9.2
5-year	201.6	11.4
10-year	234.5	12.7
25-year	279.5	14.4
50-year	316.1	15.5
100-year	353	16.6

H&H Results



Karst Map (Paylor & Currens, 1988)


Park Hills
Ogb
Of
Ok
St Augustin
800
750
650
535
AVE
Notre Dame Convent
Ql
af
Qo?
Drive-in Theater
HIGHLAND
Ogb
Ob
Qo?


EXPLANATION
Alluvium
Landslide deposits
Loess
Terrace deposits
Outwash deposits
Lacustrine(?) deposits
Outwash deposits
Bull Fork Formation
Bellevue Tongue of Grant Lake Limestone
Fairview Formation
Kope Formation
Point Pleasant Formation
Artificial fill
Contact
Structure contours
Slope between terraces or alluvial surfaces
DRILL HOLES FROM WHICH SUBSURFACE DATA WERE OBTAINED
Diamond-drill hole
Outcrop
Abandoned quarry
Fossil collection locality
QUATERNARY
ORDOVICIAN
Pleistocene and Holocene
Pleistocene
Illinoian(?)
pre-Illinoian
Upper Ordovician
Middle Ordovician
* The Bromley Shale of Bassler (1906) is herein adopted as the Bromley Shale Member of the Point Pleasant Formation

GeoQuad Map (Commonwealth of Kentucky, 1971)

Potential Failure Mode Analysis Table:

PFM No.:	KYTC-3	**Dam:**	KYTC Bioretention
PFM Group:	Seismic		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*

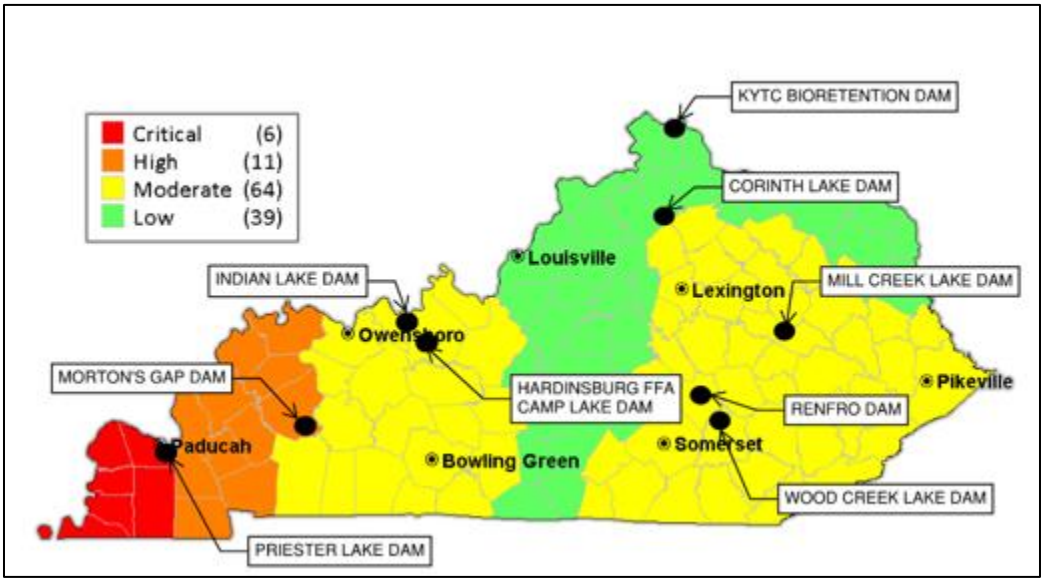
A strong earthquake is felt at the dam site. The dynamic loads on the dam embankment cause slope displacements and possible slope failures. Successive slope movements during and after the earthquake progress across the width of the dam crest. There is no time for intervention. The crest drops below normal pool and the reservoir overtops. The resulting flows scour downward through the dam embankment, releasing the reservoir.

More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
•	• Dam is located in a low seismic hazard zone • The design for the raise of the dam included slope stability analyses for the seismic load case and they showed adequate FOS • There is no pool under normal conditions. (no pull to discharge during seismic event)

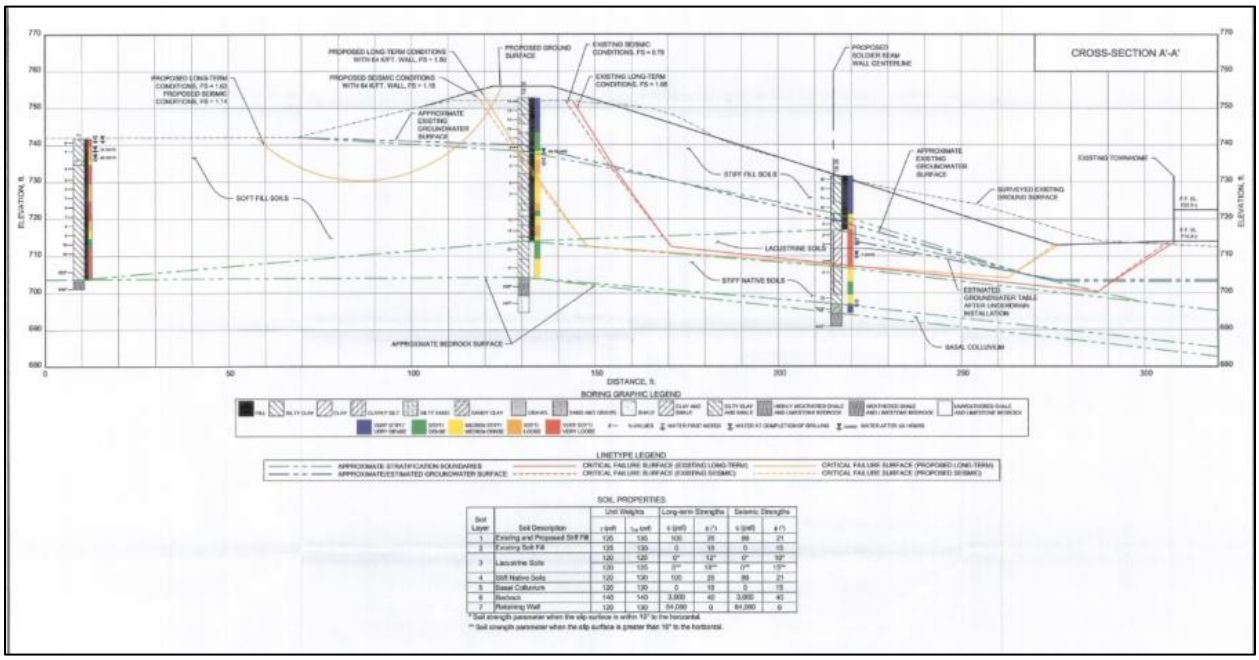
Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Negligible	Under normal conditions, there is no pool to breach.
Failure Likelihood		

Life Safety Consequences		
Economic Consequences		
Risk Reduction Measures		
Studies and Investigations		
Maintenance and Monitoring		
Design and Modifications		

Supporting Figures:



Seismic Map



2009 Geotechnical Investigation Report Cross Section (Thelen Associates Inc., 2009)

Potential Failure Mode Analysis Table:

PFM No.:	KYTC-4	**Dam:**	KYTC Bioretention
PFM Group:	Overtopping		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*

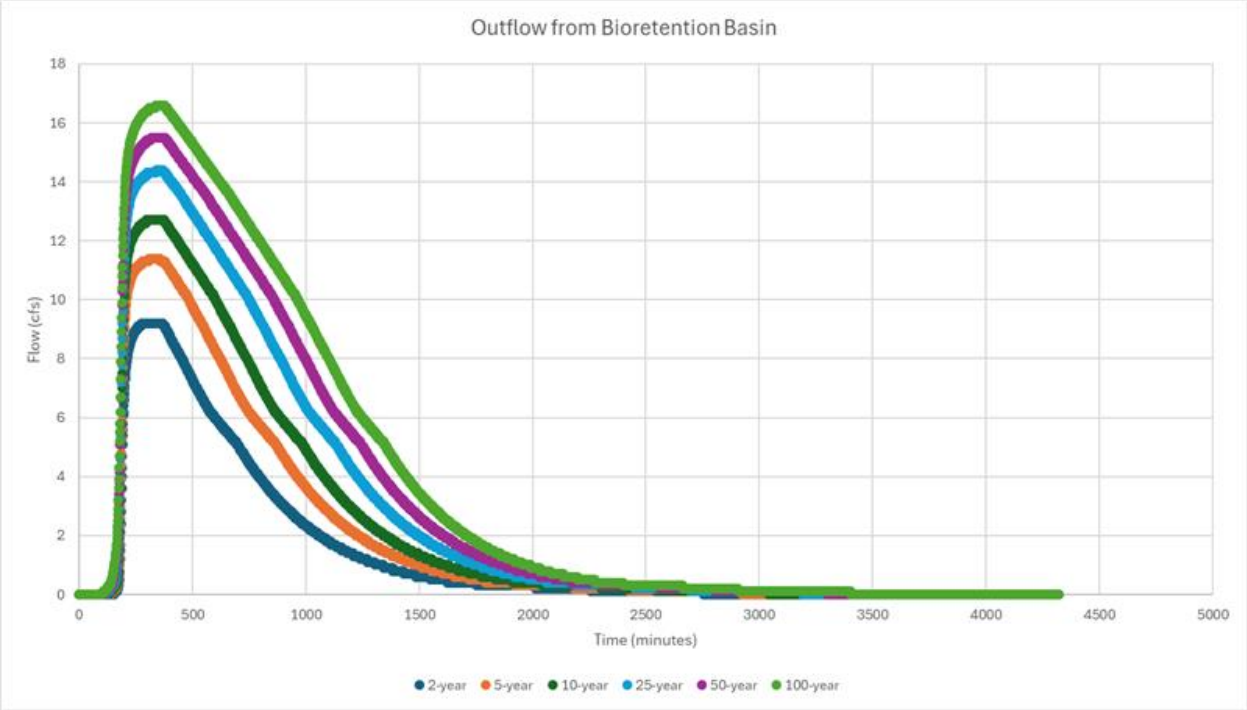
A heavy precipitation event occurs in the watershed, causing the reservoir level to rise. Water is released through the spillway. However, the spillway capacity is insufficient and/or subject to clogging. The water levels continue to rise in the reservoir. The water overtops the dam crest. No plausible effort is made to raise the crest of the dam. The overtopping flows begin to erode the downstream slope of the dam embankment. The flow causes head cutting, which progresses backward across the width of the dam crest. The dam is breached when the crest erosion reaches the upstream pool. The resulting flows scour downward through the dam embankment, releasing the reservoir.

More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
• The design report results are not clear regarding the details of the modeling • **There is potential for clogging - higher potential for events over 500 yr. There is not an auxiliary spillway.**	• 2009 design report report suggests the dam does not overtop with the PMP Event (approximately 2.5' of freeboard) (AEP of 2e-4) • **The flood waters could recede prior to the slope eroding back to the crest (Overtopping flow duration estimated to be less than 1 hour)** • Embankment is clayey and covered with turf

Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Credible	Spillway capacity may be insufficient and has potential to clog
Failure Likelihood	FL1	Several events must align for this to occur

Life Safety Consequences	LS3	The estimated life loss at breach is 1-10 which suggests LS2 but there may not be sufficient time to evacuate. LS3.
Economic Consequences	EC1	Residential damages, no impacts to major infrastructure.
Risk Reduction Measures		
Studies and Investigations	Recommend additional analyses to confirm spillway discharge characteristics and performance as it relates to the spillway.	
Maintenance and Monitoring	Remove the trees growing near the spillway riser. Add signage to keep off.	
Design and Modifications	Construct a small auxiliary spillway near the right abutment or a parapet wall.	

Supporting Figures:



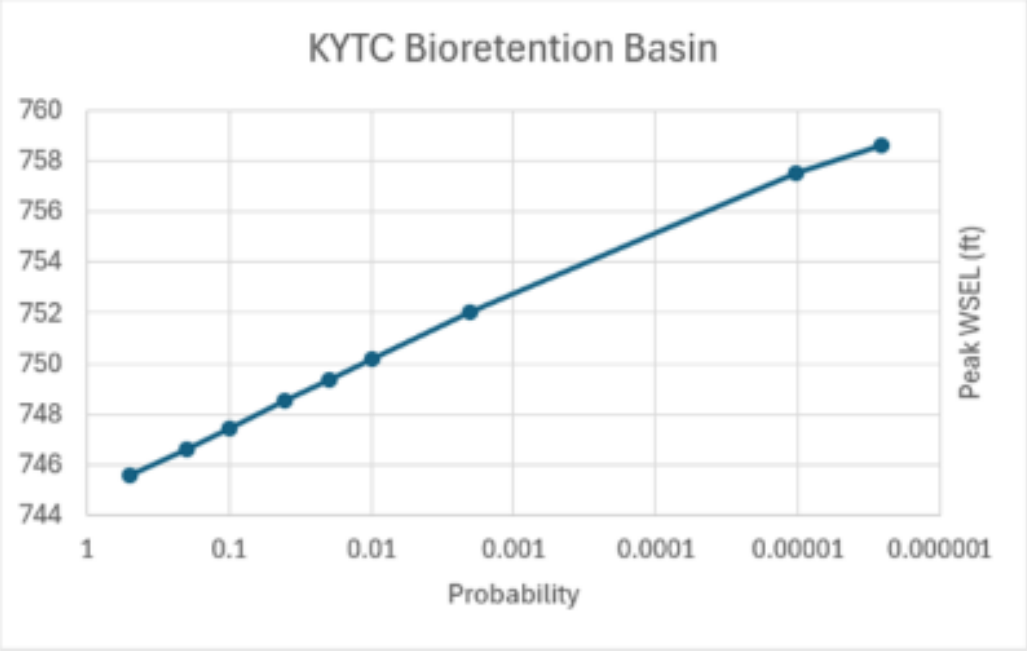
H&H Results

Bioretention Basin		
Event	**Inflow**	**Discharge**
2-year	160.1	9.2
5-year	201.6	11.4
10-year	234.5	12.7
25-year	279.5	14.4
50-year	316.1	15.5
100-year	353	16.6

H&H Results

KYTC Bioretention Basin (Dam Crest = 757.5 ft)				
Precip	**Peak Inflow**	**Peak WSEL**	**Return Interval**	**Notes**
2.11	160.1	745.6	0.5	2yr
2.59	201.7	746.6	0.2	5yr
2.96	234.5	747.4	0.1	10yr
3.47	279.5	748.5	0.04	25yr
3.88	316.1	749.3	0.02	50yr
4.29	353.0	750.2	0.01	100yr
5.28	440.6	752.0	0.002	500yr
18.20	1,587.1	757.5	1.03E-05	**Overtopping**
27.50	2,404.6	758.6	2.58E-06	**PMP**

*Note: Duration of overtopping for the PMP estimated to be **20 minutes***



H&H Results

DEFAULT Design Storm File,ID = PMP Kenton 1

Storm Tag Name = Dev000

Data Type, File, ID = Synthetic Storm PMP
Storm Frequency = 1000 yr
Total Rainfall Depth= 27.5000 in
Duration Multiplier = 6
Resulting Duration = 6.0000 hrs
Resulting Start Time= .0000 hrs Step= .3000 hrs End= 6.0000 hrs

Link ID	Type		HYG Vol ac-ft	Trun.	Peak Time hrs	Peak Q cfs	End Points	
42"CMP	PONDrt	UN	93.427		2.4500	487.01	BOX@42"	IN
42"CMP			93.427		2.4500	484.32	BOX@42"	OUT
	DIVERT	DL	48.871		2.4500	115.56		
		DN	95.521		2.4500	486.60	JUNC 20	
ADDLINK 10	ADD	UN	68.081		2.4500	531.93	WRIGHT SUMMIT	
		DL	68.081		2.4500	531.93		
		DN	89.817		2.4000	707.42	NDA POND	IN
ADDLINK 20	ADD	UN	21.736		2.4000	182.57	NDA	
		DL	21.736		2.4000	182.57		
		DN	89.817		2.4000	707.42	NDA POND	IN
ADDLINK 30	ADD	UN	45.575		2.4500	359.63	WRIGHT SUM DRO	
		DL	45.575		2.4500	359.63		
		DN	93.427		2.4500	487.01	BOX@42"	IN
ADDLINK 40	ADD	UN	41.536		2.4500	332.19	MARCELLA DR.	
		DL	41.536		2.4500	332.19		
		DN	95.521		2.4500	486.60	JUNC 20	
ADDLINK 50	ADD	UN	95.521		2.4500	486.60	JUNC 20	
		DL	95.521		2.4500	486.60		
		DN	169.096		2.4000	1106.56	BIO-RETENTIONIN	
ADDLINK 60	ADD	UN	37.651		2.4000	316.93	DIRECT TO BIO	
		DL	37.651		2.4000	316.93		
		DN	169.096		2.4000	1106.56	BIO-RETENTIONIN	

S/N:
PondPack Ver: Compute Time: Date:

2009 Stormwater Report (Viox & Viox, 2009)

Potential Failure Mode Analysis Table:

PFM No.:	KYTC-5	**Dam:**	KYTC Bioretention
PFM Group:	Erosion Associated with Conduits - Along 96" RCP		

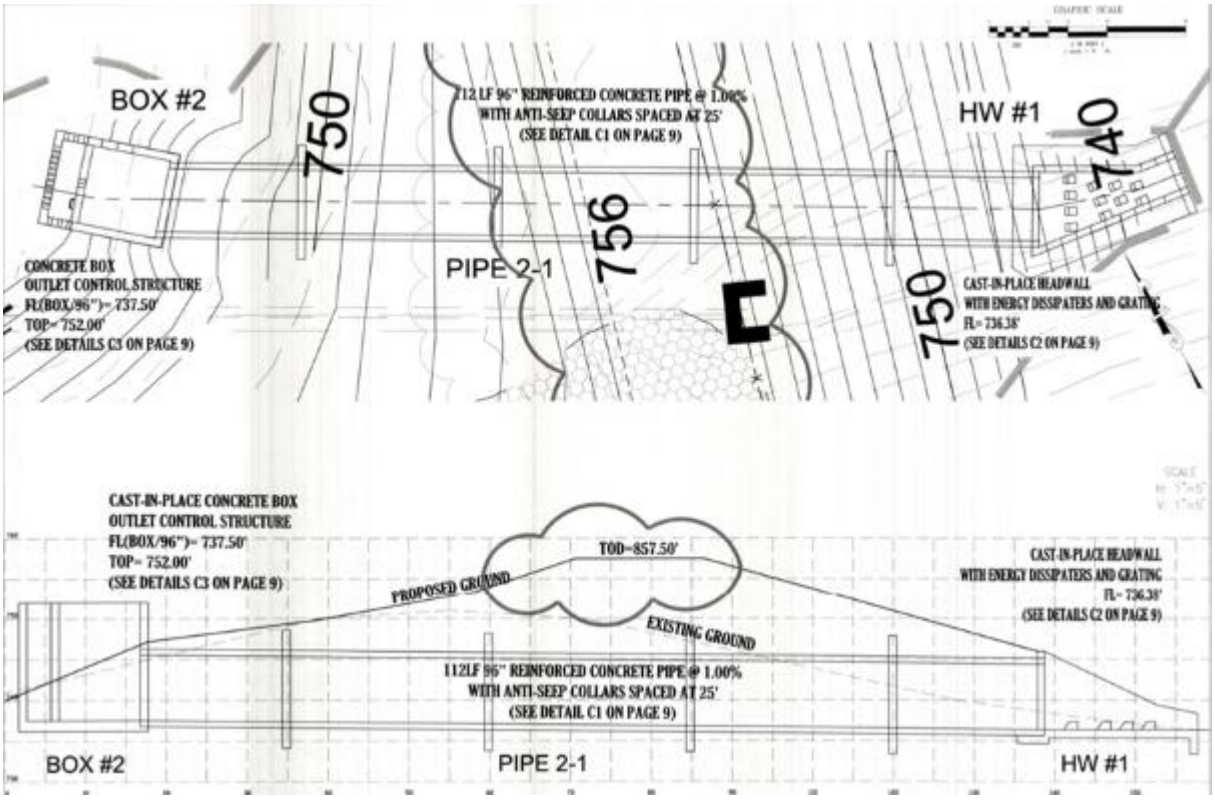
PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure*)
During a storm event, the reservoir rises to elevation 752'. Seepage develops along the outside of the reinforced concrete culvert (principal spillway). Flow develops in poorly compacted backfill under the haunches of the pipe, leading to concentrated leak erosion of the soil. The anti-seep collars are ineffective. The seepage exit is not filtered, and erosion of the embankment soils continues. A direct connection develops between the reservoir and a void running the length of the conduit. The flow and erosion are not detected and there is no intervention. Seepage continues, resulting in gross enlargement, leading to breach and an uncontrolled release of the reservoir.

More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
• **This is a common failure mode** • **May have poor compaction around the anti-seep collars and under the haunches of the pipe** • We lack a filter diaphragm • Difficult to observe the downstream end of the culvert due to vegetation	• Gradients are relatively small • **Steady state seepage is unlikely to develop during flood event** • As-built drawings specify backfill as clay or flowable fill • Anti-seep collars may have been effective in cutting off seepage path under the haunches • We assume there was construction observation that would lead to better construction quality • No physical observation of this failure mode currently existing

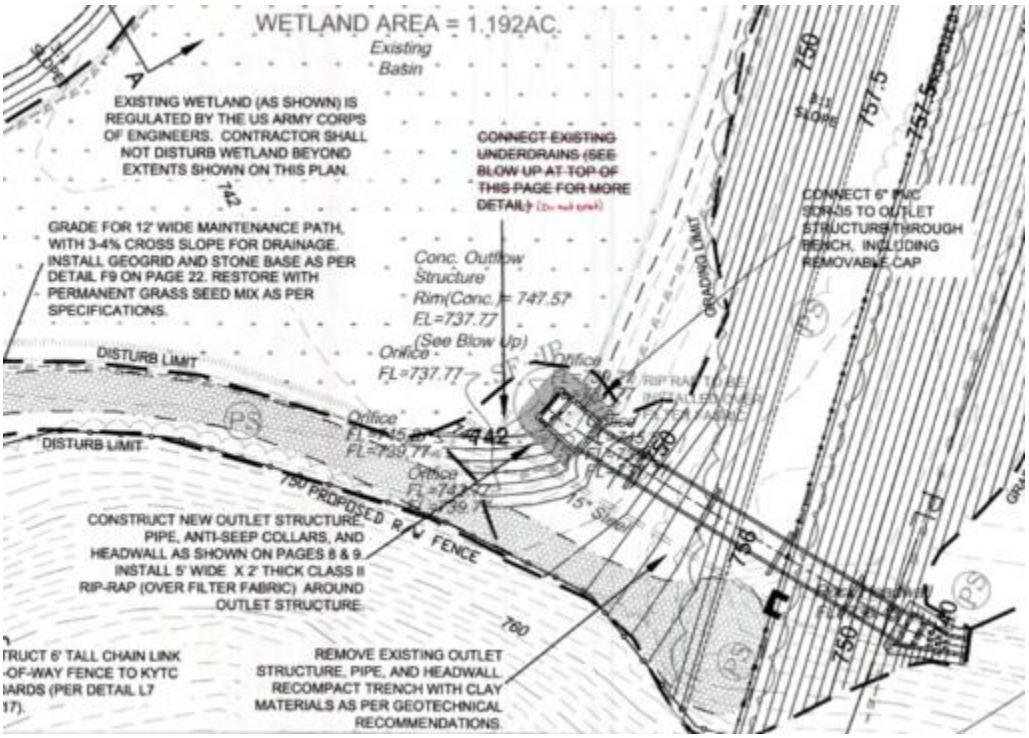
Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Credible	This is a common failure mode and there is potential for poor compaction.
Failure Likelihood	FL1	Steady state seepage would have to develop for this to occur. The compaction of the backfill for the circular pipe is of concern.

Life Safety Consequences	LS3	The estimated life loss at breach is 1-10 which suggests LS2 but there may not be sufficient time to evacuate. LS3.
Economic Consequences	EC1	Residential damages, no impacts to major infrastructure.
Risk Reduction Measures		
Studies and Investigations		
Maintenance and Monitoring	Remove the vegetation from the downstream outlet.	
Design and Modifications	Add filter diaphragm around the downstream section of the principal spillway pipe.	

Supporting Figures:



Cross Section and Plan View (Viox & Viox, 2011)



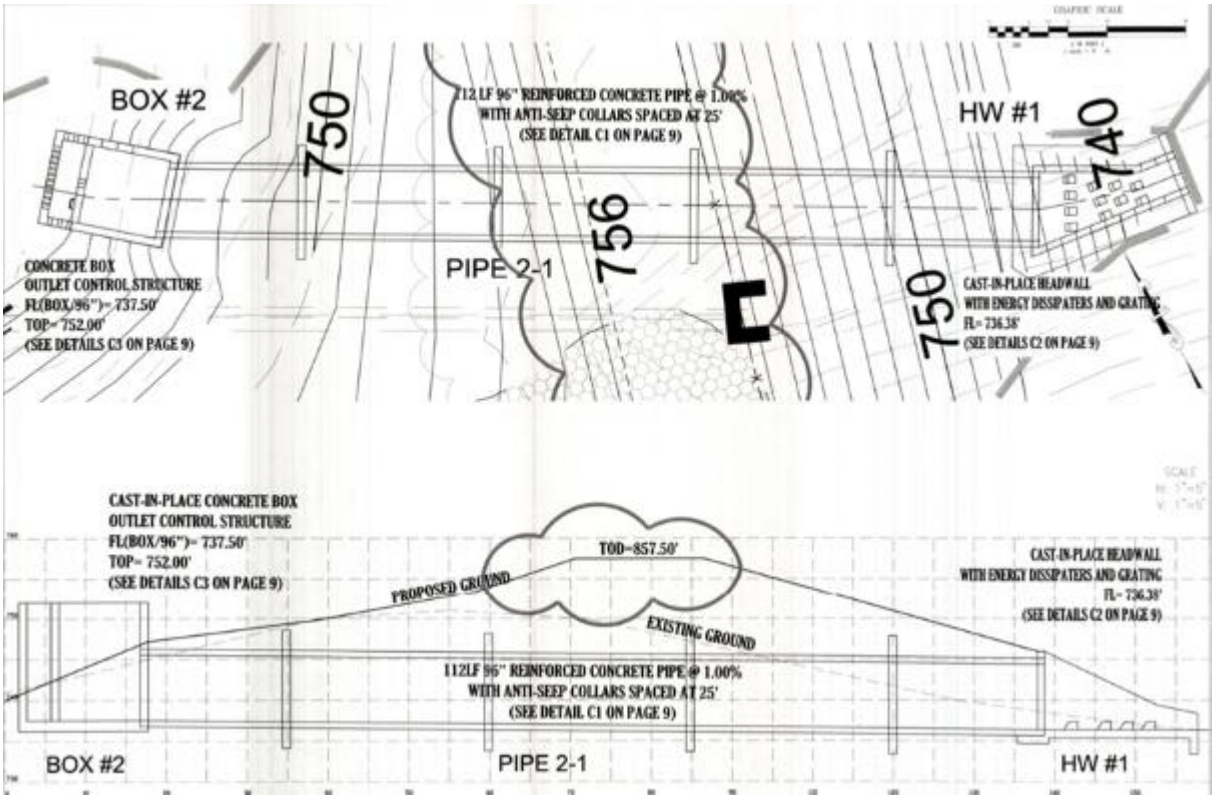
Plan View (Viox & Viox, 2011)

Potential Failure Mode Analysis Table:

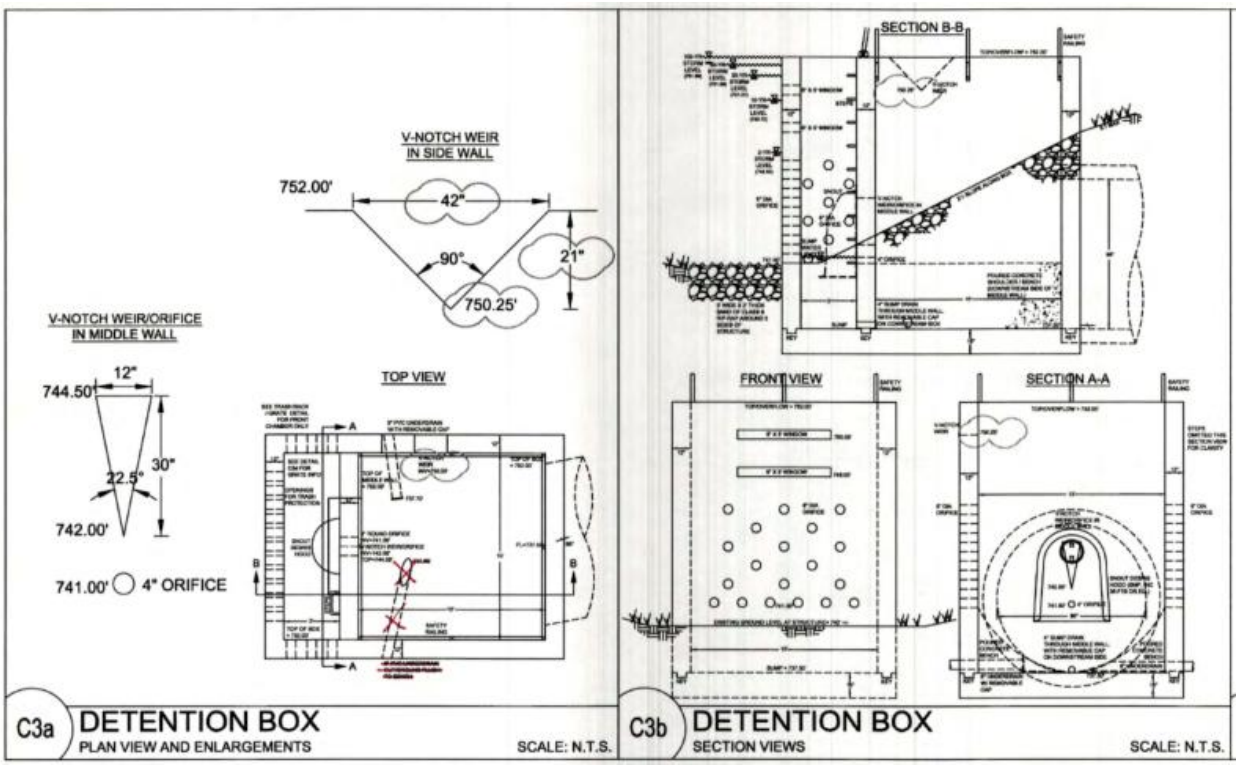
PFM No.:	KYTC-6	**Dam:**	KYTC Bioretention
PFM Group:	Spillway Structures		
PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*			
Not applicable, no failure modes identified.			
More Likely (Adverse) Factors		**Less Likely (Favorable) Factors**	
•		•	

Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Negligible	
Failure Likelihood		
Life Safety Consequences		
Economic Consequences		
Risk Reduction Measures		
Studies and Investigations		
Maintenance and Monitoring		
Design and Modifications		

Supporting Figures:



Cross Section and Plan View (Viox & Viox, 2011)



Detention Box Detail 2011 As-built Design Drawings (Viox & Viox, 2011)

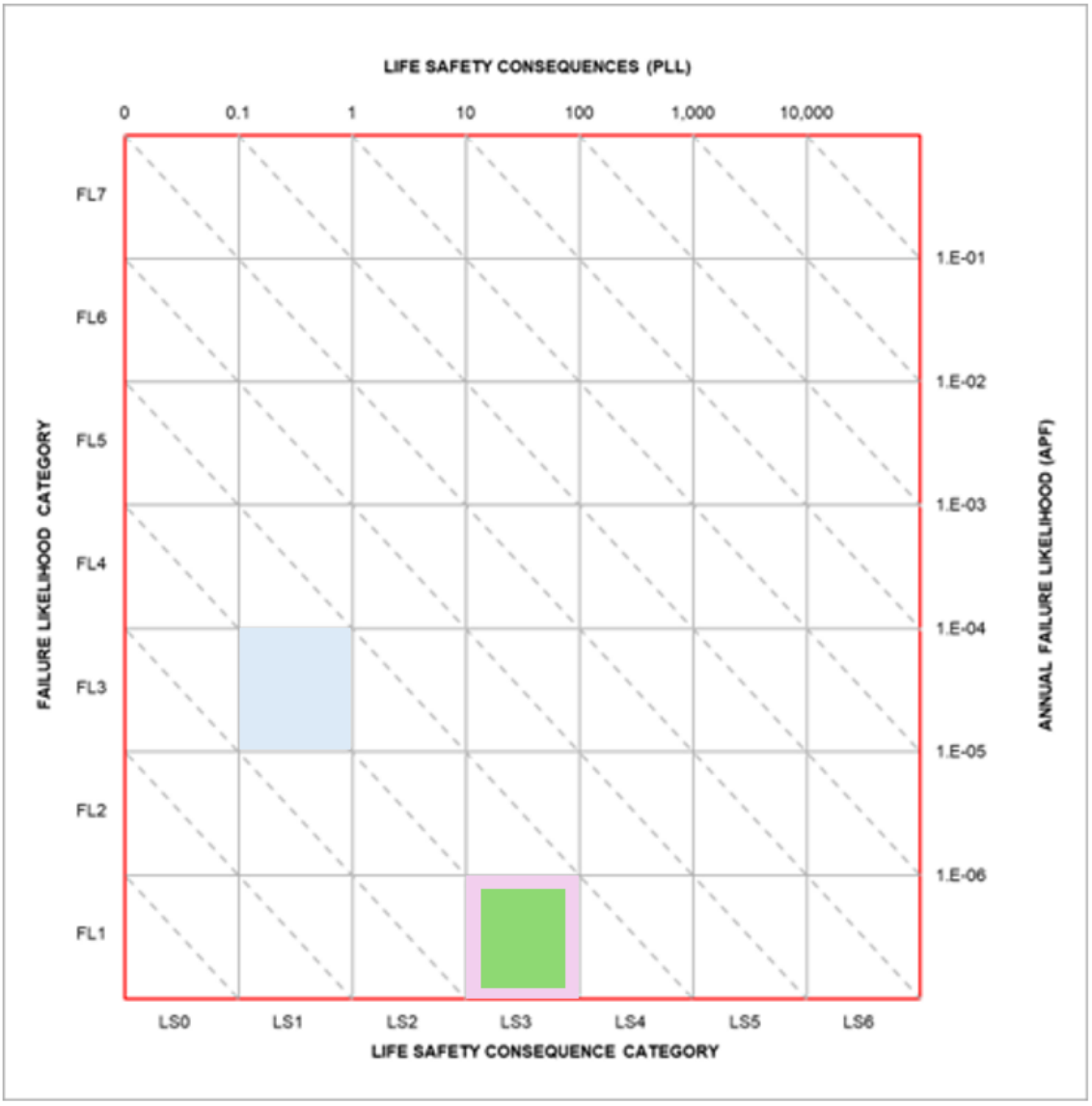
Potential Failure Mode Analysis Table:

PFM No.:	KYTC-7	**Dam:**	KYTC Bioretention
PFM Group:	Operational		
PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*			
Not applicable, no failure modes identified.			
More Likely (Adverse) Factors		**Less Likely (Favorable) Factors**	
•		•	
Risk Assessment	**Category**	**Notes**	

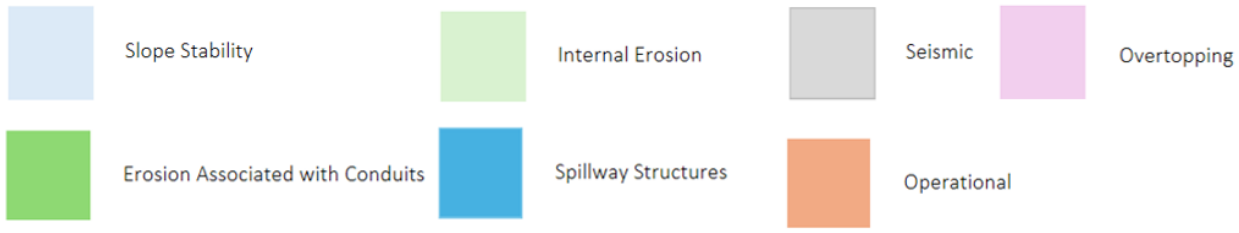
Negligible? Credible?	Negligible	
Failure Likelihood		
Life Safety Consequences		
Economic Consequences		
Risk Reduction Measures		
Studies and Investigations		
Maintenance and Monitoring		
Design and Modifications		

H.6 Risk Matrices

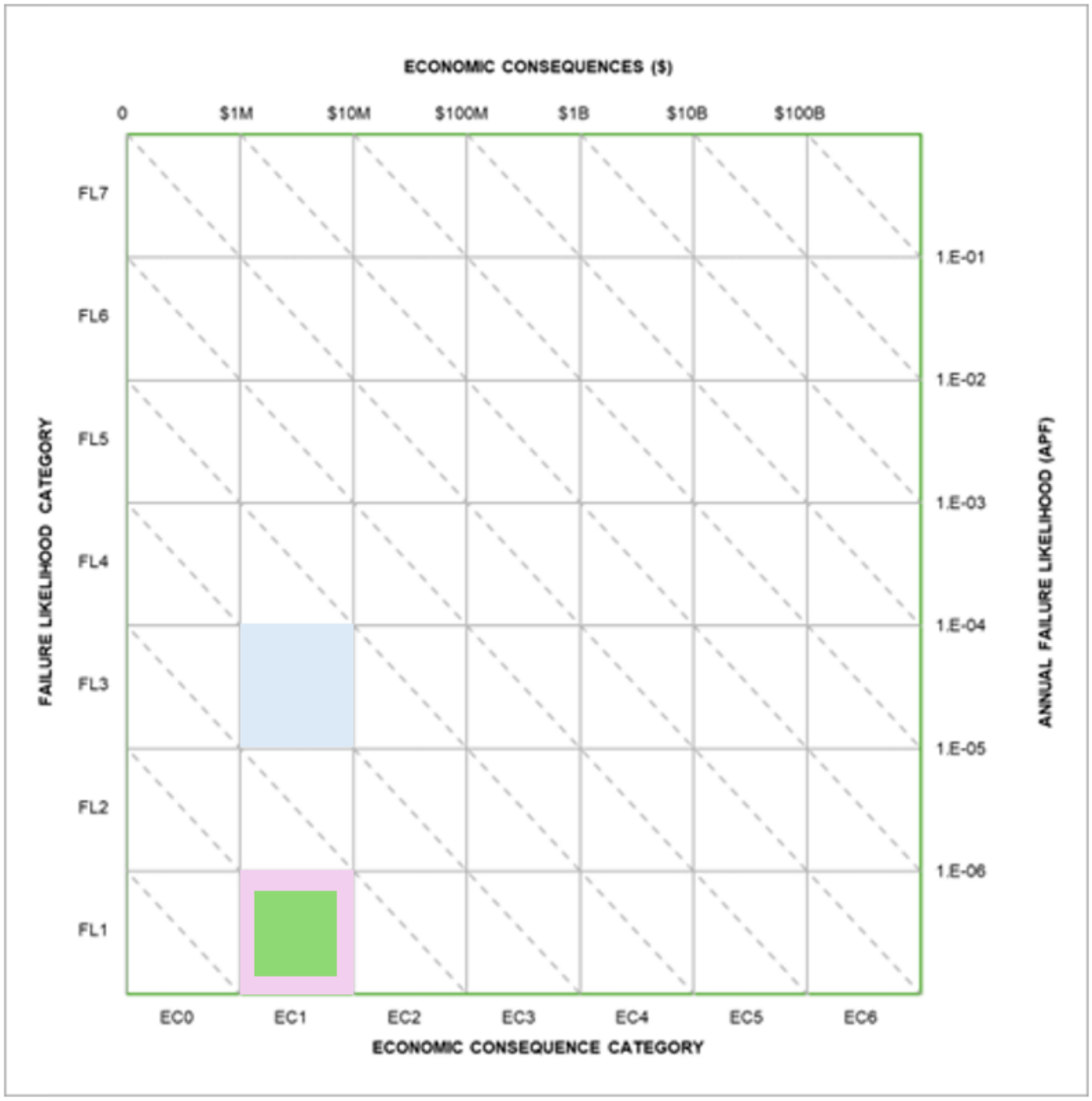
Life Safety Risk Matrix:



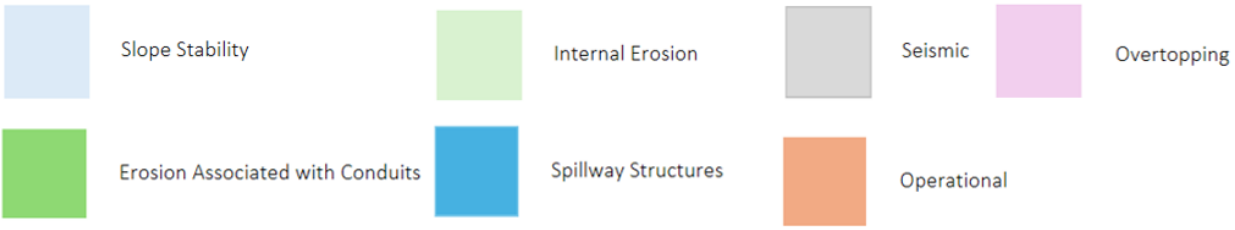
Legend:



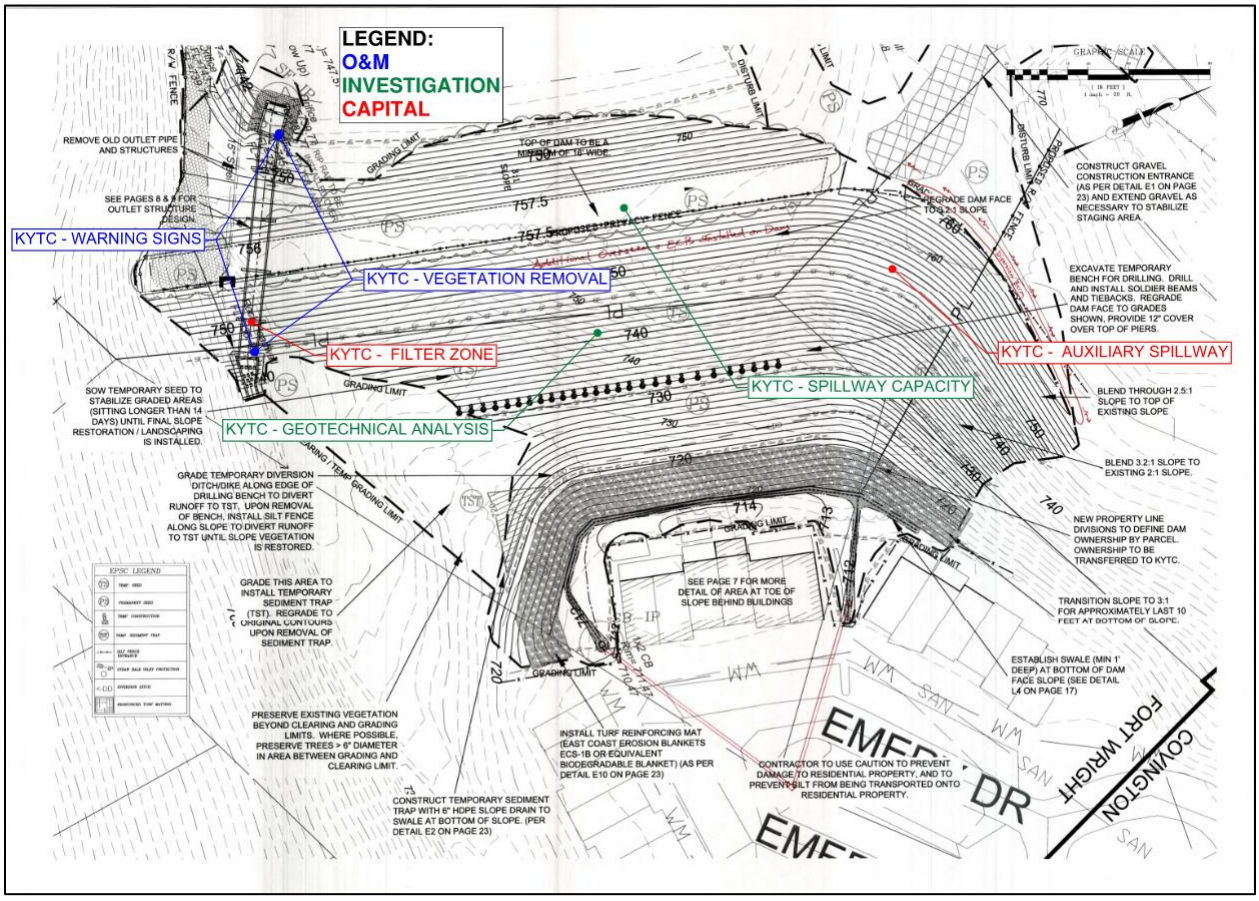
Economic Consequences Risk Matrix:



Legend:



H.7 Recommendations



Recommendations – KYTC Bioretention Dam								
CODE	**Recommendation**	**Type**	**Life Loss Risk**	**Economic & Transportation Risk**	**Regulatory Compliance**	**Cost Range**	**Planning Horizon**	**Priority**
KYTC - VEGETATION REMOVAL	Remove vegetation, cut trees, and grub out stumps on the face of the dam and within 25-feet of the dam abutments. Remove vegetation within 25-feet of the diversion box spillway inlet and outlet, and small trees on the dam crest.	O&M	8	4	Yes	<10K	Short Term	1
KYTC - WARNING SIGNS	Install multiple warning signs on outlet structure (DANGER - KEEP OFF).	O&M	0	0	No	<10K	Short Term	2
KYTC - GEOTECHNICAL ANALYSIS	Perform geotechnical analyses for the flood loading conditions.	Investigation	3	3	Yes	10K-100K	Intermediate	3
KYTC - SPILLWAY CAPACITY	Verify the spillway capacity, including the discharge channel.	Investigation	3	1	Yes	10K-100K	Intermediate	4
KYTC - AUXILIARY SPILLWAY	If the hydraulic analysis indicates a deficiency, then construct a small auxiliary spillway near the right abutment or a parapet wall.	Capital	3	1	Yes	100K-1M	Long Term	5
KYTC - FILTER ZONE	Install a zone of filter sand around the downstream end of the spillway culvert to address potential seepage and erosion.	Capital	3	1	No	100K-1M	Long Term	6

H.8 Cost Opinions for Capital Projects

Stantec developed the following cost opinions for constructing capital improvements for each dam. The costs listed below are very approximate, as they are based only on broad concepts, without even preliminary designs. The costs should be used only for planning, and not for budgeting specific improvements.

There are a few projects that are recommended for the KYTC Bioretention project. The first is an option of either creating an auxiliary spillway or a parapet wall to address overtopping risks. The other is to create a zone of filter sand around the downstream end of the spillway culvert to address seepage and erosion.

Auxiliary Spillway

Contractor Work Item	Quantity	Unit of Measure	Operating Cost	Total Cost
Sand (1' Depth)	227.03	CY	$100.00	$22,703.00
Filter Fabric	681.12	SY	$7.50	$5,108.40
No. 57 Stone (3' Depth)	684.12	CY	$95.00	$ 64,991.40
Class II Channel Lining (1.5' Depth)	340.56	CY	$90.00	$30,650.40
Cut for Notch (2' Depth)	54.69	CY	$50.00	$2,734.50
Excavation (1.5' Depth)	340.56	CY	$50.00	$17,028.00
			Total	$200,000

Parapet Wall

Contractor Work Item	Quantity	Unit of Measure	Operating Cost	Total Cost
Parapet Wall	350	LF	$2,750.00	$962,500.00
			Total	$1,200,000

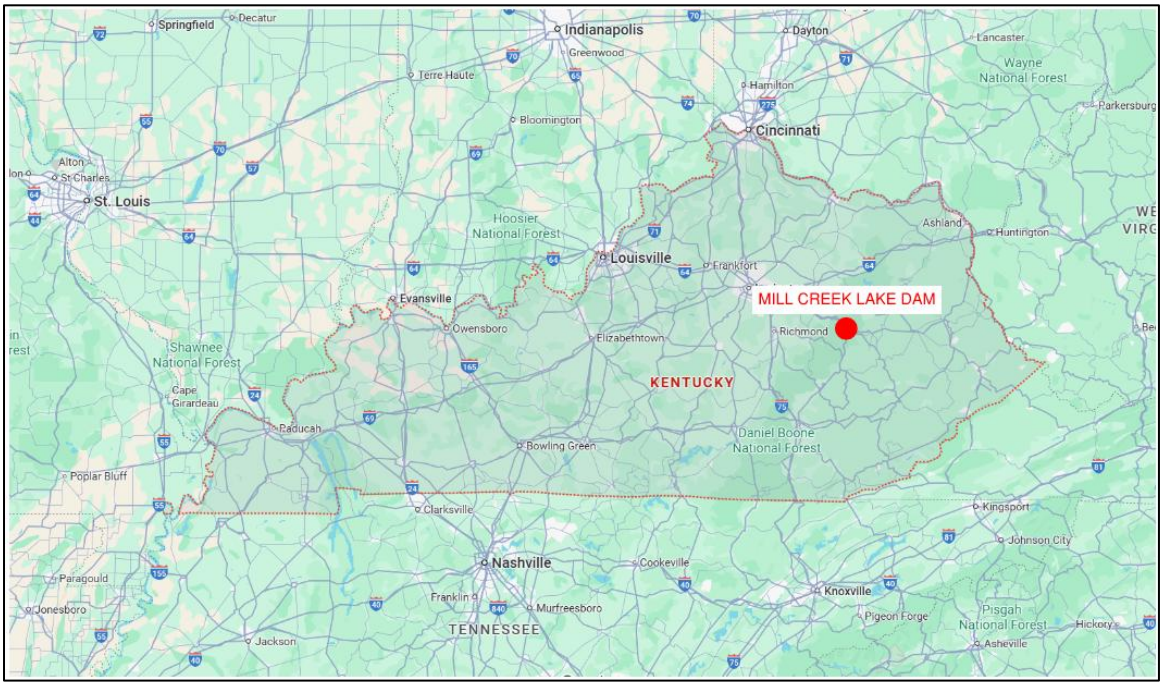
Filter Sand

Contractor Work Item	Quantity	Unit of Measure	Operating Cost	Total Cost
Sand (1' Depth)	77.43	CY	$100.00	$7,743.00
Filter Fabric	232.28	SY	$7.50	$1,742.10
No. 57 Stone (1.5' Depth)	232.28	CY	$95.00	$22,066.60
Excavation (1.5' Depth)	232.28	CY	$50.00	$11,614.00
			Total	$50,000

Appendix I
Mill Creek Lake Dam

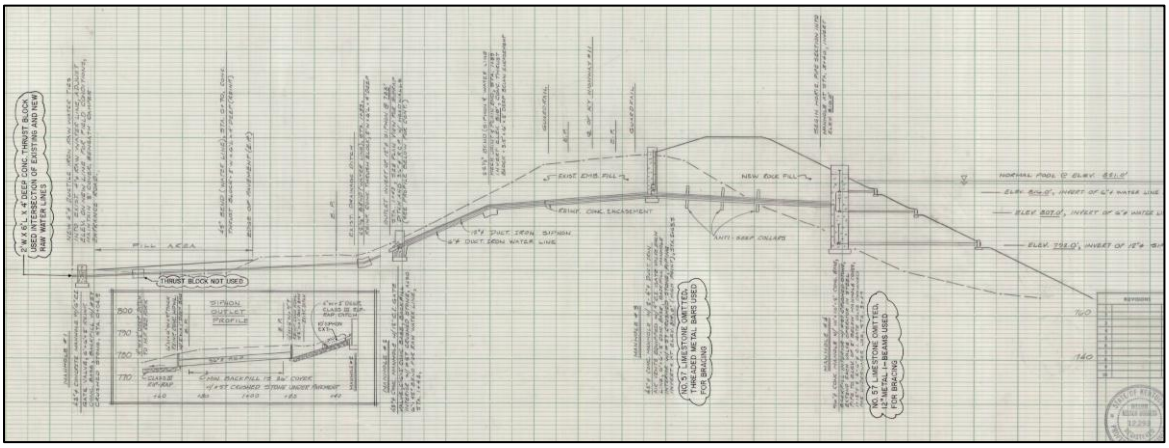
I.1 Dam and Appurtenant Features

Mill Creek Lake Dam is a high hazard dam located in Powell County (location map below). The National Inventory of Dams lists the purpose of the dam as recreation. This dam was constructed in 1964 and modified in 1986. The dam crest elevation is 841 ft, with KY-11 running along a bench on the downstream slope. The height of the dam is 65 ft, and the crest width is 25 ft.

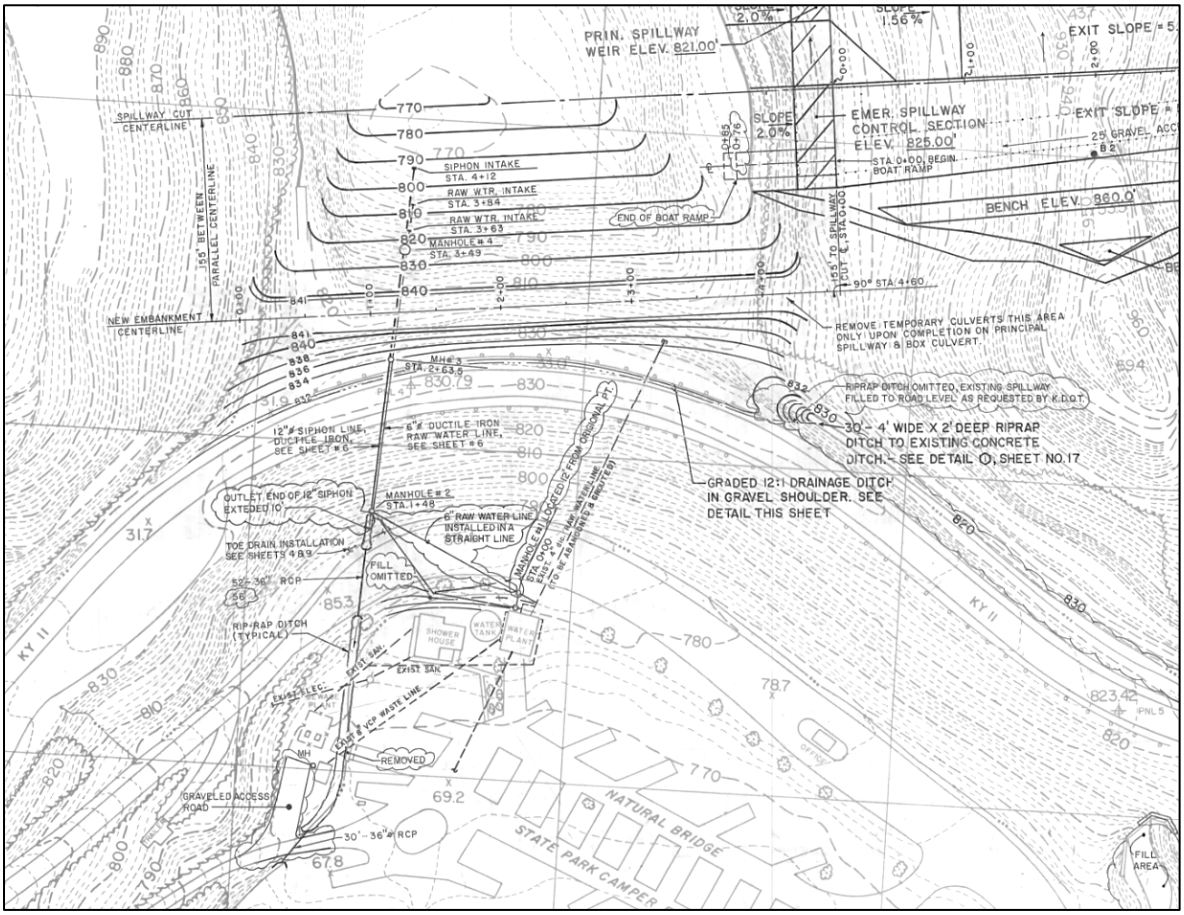


Mill Creek Lake Dam – Vicinity Map

The principal spillway is a 40-ft wide rock cut channel on the left abutment, with a weir at elevation 821 ft. The auxiliary spillway is a 100-ft wide rock cut channel next to the principal spillway channel with a weir at elevation 825 ft. A 6-inch ductile iron pipe runs through the right side of the dam embankment, with valves inside concrete risers on the upstream and downstream sides. The figures below show the cross sections and plan view for this dam.



Mill Creek Lake Dam – Modified 1986 Typical Cross Section



Mill Creek Lake Dam – Modified 1986 Plan View

I.2 Data Catalog

FILE #	DATA TYPE	TITLE	FILE DESCRIPTION
03.02.001	H & H	H & H Report	1996 Hydrology Review
03.02.002	H & H	Emergency Action Plan	***
03.02.003	H & H	Evacuation Map	***
03.02.004	H & H	Inundation Map	***
03.03.001	Inspections	Phase I Inspection Report	Dam Safety Program
03.03.002	Inspections	Inspection Report	2010 DOWR
03.03.003	Inspections	Inspection Report	2011 DOWR***
03.03.004	Inspections	Inspection Report	2016 DOWR
03.03.005	Inspections	Inspection Report	2020 DOWR
03.03.006	Inspections	Inspection Report	2021 DOWR
03.03.007	Inspections	Inspection Report	2022 DOWR
03.03.008	Inspections	Inspection Report	2023 DOWR
03.03.009	Inspections	Inspection Report	2024 DOWR
03.04.001	Drawings	Plan and Profile of Proposed Highway	1962 Dept of Highways
03.06.001	TRANSPORTATION DOCS	Traffic Counts	
03.06.002	TRANSPORTATION DOCS	Roadway Plans	
03.03.101	Inspections	Phase I Inspection Report	1978 Dam Safety Program
03.03.102	Inspections	Inspection Report	2003 Division of Water
03.03.103	Inspections	Inspection Report	2003 Division of Water
03.03.104	Inspections	Inspection Report	2005 Division of Water
03.03.105	Inspections	Inspection Report	2010 Division of Water
03.03.106	Inspections	Inspection Report	2012 Division of Water
03.03.107	Inspections	Inspection Report	2003 Division of Water
03.03.108	Inspections	Inspection Report	2018 Division of Water
03.03.109	Inspections	Inspection Report	2018 Division of Water
03.03.110	Inspections	Inspection Report	2014 Division of Water
03.03.111	Inspections	Inspection Report	1995 Division of Water
03.03.112	Inspections	Inspection Report	1993 Division of Water
03.03.113	Inspections	Inspection Report	1998 Division of Water

03.03.114	Inspections	Inspection Report	1995 Division of Water
03.03.115	Inspections	Inspection Report	1996 Division of Water
03.03.116	Inspections	Inspection Report	1992 Division of Water
03.03.117	Inspections	Inspection Report	1993 Division of Water
03.03.118	Inspections	Inspection Report	1987-1991 Division of Water
03.03.119	Inspections	Inspection Report	1985 Division of Water
03.03.120	Inspections	Inspection Report	1978-1982 Division of Water
03.03.121	Inspections	Inspection Report	1978 Division of Water
03.03.122	Inspections	Inspection Report	1976 Division of Water
03.03.123	Inspections	Inspection Report	1977 Division of Water
03.03.124	Inspections	Inspection Report	1971-1975 Division of Water
03.03.125	Inspections	Inspection Report	1974 Division of Water
03.03.126	Inspections	Inspection Report	1973-1992 Division of Water
03.03.127	Inspections	Inspection Report	1977 Division of Water
03.03.128	Inspections	Inspection Report	1986 Division of Water
03.03.129	Inspections	Inspection Report	1994 Division of Water
03.03.130	Inspections	Inspection Report	1982-1983 Division of Water
03.03.131	Inspections	Inspection Report	1983 Division of Water
03.03.132	Inspections	Inspection Report	1980 Division of Water
03.03.133	Inspections	Inspection Report	1975 Division of Water
03.03.134	Inspections	Inspection Report	1975 Division of Water
03.03.135	Inspections	Inspection Report	1976 Division of Water
03.03.136	Inspections	Inspection Report	1984-2011 Division of Water
03.03.137	Inspections	Inspection Report	2016 Division of Water
03.03.138	Inspections	Inspection Report	2020 Division of Water
03.03.139	Inspections	Inspection Report	2021 Division of Water
03.03.140	Inspections	Inspection Report	2022 Division of Water
03.03.141	Inspections	Inspection Report	2023 Division of Water
03.03.142	Inspections	Inspection Report	2024 Division of Water
03.01.201	Geotech / Geology Info	Geotechnical & H & H Investigation	1983 University of Kentucky

03.02.201	H & H	Dam Breach Scenario Analysis	1985 USACE Louisville District
03.02.202	H & H	Hydraulic Review Memo	2022 Dam Safety Section
03.02.203	H & H	HydroCAD Report	2022 COT
03.02.204	H & H	Hydraulic Review	2022 Dam Safety Section
03.03.201	Inspections	Phase I Inspection Report	1978 ATEC
03.04.201	Drawings	Repair Plans and As-Built Drawings	1986 KDOW

I.3 Hydrologic and Hydraulic Analyses

Elevation-Frequency Analysis

Previous hydrologic and hydraulic analyses were performed by the Kentucky Division of Water using the National Resources Conservation Service (NRCS) SITES model in 2022. The input data from the SITES model was used to generate a new U. S. Army Corps of Engineers (USACE) Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) model (version 4.12) to estimate water surface elevations associated with various precipitation depths. The following information was taken from the SITES model:

- Curve Number
- Drainage Area
- Time of Concentration
- Stage-Storage-Discharge Information

An alternative rating curve was estimated for the auxiliary spillway using a weir equation to account for the presence of a trailer blocking part of the auxiliary spillway. Using this rating curve resulted in an increase in the reported water surface elevations by 1' for storms above the 500-year recurrence interval but did not affect the water surface elevation results for the more frequent storms.

NOAA Atlas 14 was used to generate precipitation depths for frequencies ranging from the 2-year (50-percent-annual-chance) up to the 500-year (0.2-percent-annual-chance) storm. For the Probable Maximum Precipitation (PMP), Kentucky Engineering Memorandum No. 2 was used to determine the PMP rainfall depth. A 24-hour SCS Type II rainfall distribution was applied to the precipitation depths from NOAA Atlas 14, and a 6-hour SCS Type II rainfall distribution was applied to the PMP rainfall depth within the HEC-HMS model. The probability associated with the PMP was estimated using two methods:

- The FEMA Spillway Capacity and Extreme Flood Discharge Estimator (which uses flow-frequency data input by the user along with extrapolation using a power function to estimate the return period of the PMP)
- The Australian Rainfall Runoff method (which uses drainage area to estimate a return period of the PMP).

The results of the two methods were averaged to estimate the PMP probability.

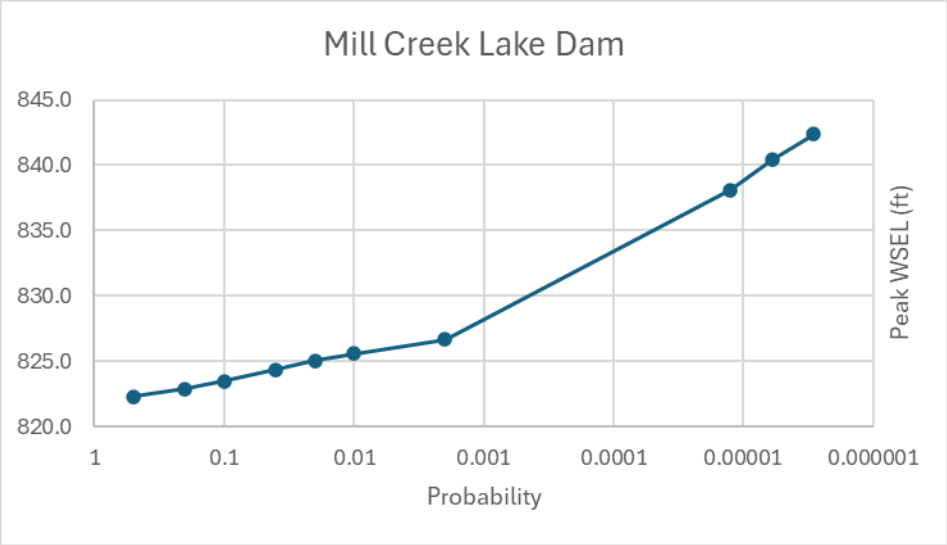
Using trial and error, additional storms were run with higher rainfall depths until a rainfall depth that produced a water surface elevation that would just overtop the dam and a water surface elevation that overtopped the dam by two feet was obtained. A power curve was fit to the flow frequency data (including the PMP) and extrapolated to approximate a return period associated with these rainfall depths. The duration of overtopping for the highest evaluated rainfall event (45.5 inches, overtopping the dam by two feet) was also estimated by reviewing the time-series results of the HMS model and noting the period of time where the water surface elevation was above the dam crest.

The resulting water surface elevations from the model runs are tabulated and plotted below.

Mill Creek Lake Dam Model Results

Mill Creek Lake Dam (Dam Crest = 840.4 feet)				
Precipitation (Inches)	**Peak Inflow (cfs)**	**Peak WSEL (feet)**	**Return Interval**	**Notes**
2.1	513	840.4	0.5	2yr
2.5	934	840.7	0.2	5yr
2.9	1,346	841.0	0.1	10yr
3.4	1,986	841.4	0.04	25yr
3.9	2,561	841.7	0.02	50yr
4.4	3,214	842.1	0.01	100yr
5.6	5,006	843.1	0.002	500yr
28.2	9,945	846.1	3.92E-05	**PMP**
34.4	24,832	852.5	1.08E-06	**Overtopping**
45.5	35,528	854.0	1.00E-07	**~2' overtopping**

Note: Duration of overtopping for the 45.5" rainfall event estimated to be 2 hours



Mill Creek Lake Dam Elevation-Frequency Curve

Consequences Analysis

Previous inundation mapping for a sunny-day breach of the dam publicly available on Kentucky's Dam Inundation Viewer (watermaps.ky.gov) was reviewed. An additional flood-day breach hydrograph for the dam was modeled in HEC-HMS for the PMP rainfall event. Empirical equations were utilized to define breach width, formation time, and side slopes. The resulting breach hydrograph was input into the USACE Dam Screening Tool (DST) and routed downstream. Inundation extents for the sunny-day and flood-day breaches were reviewed along with aerial imagery to evaluate consequences.

Structures identified in the sunny-day inundation area included eight residences, approximately 50 non-residential structures (campgrounds, gas stations, hotels, restaurants, etc.) and 15 road crossings. A population at risk of approximately 600 was estimated based on the following assumptions:

- 2.5 people per campsite
- 50 people per parking lot
- 10 people in picnic shelters
- 200 people in various hotels, stores, restaurants, and tourist attractions
- 50 people in the church
- 2 people per road crossing

The population at risk would be largely tourists and vary seasonally.

The flood-day inundation extents were similar to the sunny-day breach extents. The DST estimated a lower PAR (246), a life loss of one when evacuation was considered, and a life loss of 12 when not simulating evacuation. The consequences are summarized in the table below.

Consequences Associated with a Failure of Mill Creek Lake Dam

Mill Creek Lake Dam	
NID_ID	KY00259
Number of Residences	8 (approximate)
Number of Non-Residential Structures	~50
Description of Non-Residential Structures	Middle Fork Campground, Hoedown Island, Natural Bridge Parking Lot, Picnic Shelters, Miguel's Pizza/Campground, Storage Buildings/Old Treatment Plant, stores/restaurants/hotels, tourist attractions (petting zoo, adventure park), Natural Bridge Campground, gas stations, RV park, church
Number of Critical Infrastructure Structures	0
Description of Critical Infrastructure Structures	N/A

Number of Road Crossings	~10 road crossings and portions of Route 11/Natural Bridge Road, and campground roads
List of Roads Affected	~15
Estimated PAR	577.5
PAR Assumptions	Assuming 2.5 people per campsite, 50 people for Hoedown Island/Natural Bridge Parking Lot, 10 people in picnic shelters, 100 people at Miguel's Pizza/Campground, 100 people at the various hotels, stores, restaurants, and tourist attractions, and 50 people for the church would put the PAR around 600.
Inundation Mapping Source	KY Dam Inundation Viewer + Aerial Imagery + DST (flood breach)
Estimated Life Loss	10-100
Life Loss Notes	PAR would be mainly tourist populations and would vary seasonally. Middle Fork Campground is located at the base of the dam. Estimated life loss from DST is 1 when assuming evacuation is possible; Estimated life loss from DST is 12 when not simulating evacuation. (PAR of 246)

I.4 Potential Failure Modes

PFM NUMBER	PFM GROUP	PFM DESCRIPTION	RISK ASSESSMENT
MC-1	SLOPE STABILITY	Under normal pool conditions, a slope failure triggers a mass movement of soil on the downstream face of the dam. Successive slope failures retrogress back to the crest, then to the upstream side of the crest. Material is pushed into failure from the crest, but the intervention fails. The crest drops below the pool elevation (821'), which overtops the dam breach. The resulting flows scour downward through the dam embankment, releasing the reservoir.	CREDIBLE
MC-2A	INTERNAL EROSION	Seepage through a defect in the core - Under normal pool conditions, seepage develops along a defect through the dam core. The defect may be a permeable lift, a smooth lift surface, a poorly compacted lift, or a frozen lift surface. No transition zone constructed. The flow scours the soil to either side of the defect. The embankment over the seepage path does not collapse. The flow path expands and the flow accelerates. The seepage is not detected and there is no intervention. The flow scours a larger void in the embankment, leading to a collapse of the dam crest. The dam is breached and there is an uncontrolled release of the reservoir.	CREDIBLE
MC-2B	INTERNAL EROSION	Seepage and erosion through the foundation soils - Under normal pool conditions, seepage develops through the bottom of the core and in the sandy foundation soils beneath the dam. The seepage exits unfiltered at the downstream toe. The exit gradients are high enough to cause uplift or sand boils. An eroded pipe forms at the exit and progresses backward under the dam, toward the upstream pool. The embankment over the seepage path does not collapse. The seepage is not detected and there is no intervention. The flow rate increases rapidly through the eroded pipe, scouring a large void within the foundation. The embankment collapses into the void, the dam is breached, and there is an uncontrolled release of the reservoir.	CREDIBLE
MB-2C	INTERNAL EROSION	Seepage into foundation defects (Karst) - Downward seepage erodes foundation or embankment soils into open karst features in the bedrock. Erosion progresses until there is a breach of the dam.	NEGLIGIBLE

MC-2D	INTERNAL EROSION	Abutment - Under normal pool conditions, seepage develops along the left abutment and below the extent of the cutoff trench. The water exits to the downstream face of the roadway embankment near the campground entrance station. It is an unfiltered seepage exit and erosion of the downstream slope initiates. The seepage erodes the soil on the downstream slope, inducing slope failure. Successive slope failures retrogress back to the crest, then to the upstream side of the crest. Material is pushed into the failure from the crest, but the intervention fails. The crest drops below the pool elevation (821'), which overtops the dam breach.	NEGLIGIBLE
MC-3	SEISMIC	A strong earthquake is felt at the dam site. The dynamic loads on the dam embankment cause slope displacements and possible slope failures. Successive slope movements during and after the earthquake progress across the width of the dam crest. There is no time for intervention. The crest drops below normal pool and the reservoir overtops. The resulting flows scour downward through the dam embankment, releasing the reservoir.	NEGLIGIBLE
MC-4	OVERTOPPING	A heavy precipitation event occurs in the watershed, causing the reservoir level to rise. Water is released through the spillways, which may further inundate the downstream toe of the slope. The water levels continue to rise and overtop the dam crest. No plausible effort is made to raise the crest of the dam. The overtopping flows begin to erode the downstream slope of the dam embankment. The flow causes head cutting, which progresses backward across the width of the dam crest. The dam is breached when the crest erosion reaches the upstream pool. The resulting flows scour downward through the dam embankment, releasing the reservoir.	CREDIBLE
MC-5	EROSION ASSOCIATED WITH CONDUITS	Leakage - There is a 6" raw water line intake from the upstream pool to the toe of the dam. Water in the pipe is at headwater pressure. A leak develops in the pipe, causing higher piezometric pressures at the toe of the dam. A slope failure is initiated at the downstream toe of the dam. Successive slope failures retrogress back to the crest, then to the upstream side of the crest. Material is pushed into the failure from the crest, but the intervention fails. The crest drops below the	CREDIBLE

		pool elevation (821'), which overtops the dam breach.	
MC-6	SPILLWAY STRUCTURES	Principal spillway cut in rock Auxiliary spillway - rock cut with paved parking area on top. The container is present but it does not have any adverse effects in the spillway function. No overtopping, even with the container in place The riser structure with siphon and water line Founded on the original embankment but encapsulated in the new portions of the embankment. Riser filled with crushed stone	NEGLIGIBLE
MC-7	OPERATIONAL	The valve on the 12" siphon pipe is opened but cannot be closed. The dam does not fail but the lake is slowly drained to elevation 792' through the 12" ductile iron low level drawdown pipe.	CREDIBLE

I.5 Evaluation of PFMs

Potential Failure Mode Analysis Table:

PFM No.:	MC-1	**Dam:**	Mill Creek
PFM Group:	Slope Stability		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*

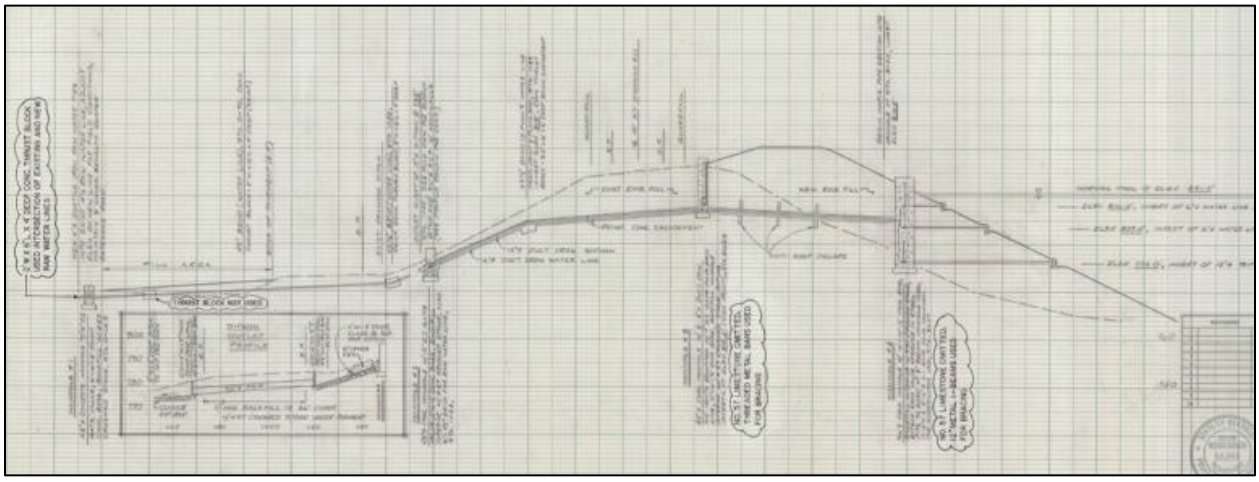
Under normal pool conditions, a slope failure triggers a mass movement of soil on the downstream face of the dam. Successive slope failures retrogress back to the crest, then to the upstream side of the crest. Material is pushed into the failure from the crest, but the intervention fails. The crest drops below the pool elevation (821'), which overtops the dam breach. The resulting flows scour downward through the dam embankment, releasing the reservoir.

More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
• **Observations of sloughs and seepage** • **Steep slopes (2:1)** • Slumps were observed on the downstream slope but they were beyond the limits of the left abutment • The TRM repairs were not intended to improve stability • Surface erosion was noted in historic inspections • Seepage observed on the downstream slope, at the toe, indicative of high groundwater levels • Manhole joint offset indicative of slope movement	• **Crest width is 25' but the embankment is wide (316')** • **If the 1986 berm were to slide off into the lake, the lake would still be retained by the older section** • **Intervention is likely - road likely impacted prior to crest of dam. KYTC likely to intervene when road moves.**

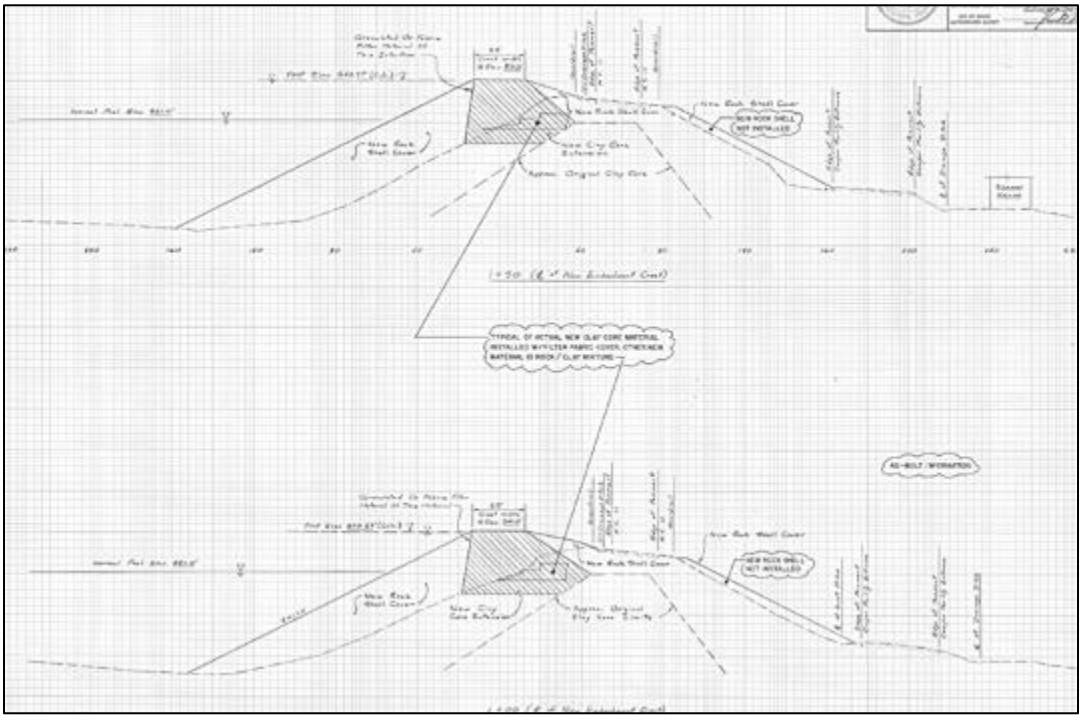
Risk Assessment	**Category**	**Notes**

Negligible? Credible?	Credible	The crest width, recent, and historical information observed slope movements, which contribute to the category of credible
Failure Likelihood	FL3	Both FL2 and FL3 were considered, FL2 was considered due to likelihood of intervention being successful. FL3 was favored due to historical observations.
Life Safety Consequences	LS2	When evacuation is possible, life loss is estimated as 1. When evacuation is not possible, estimated as 12.
Economic Consequences	EC2	Facilities at campground, road, assumes parkway floods, may or may not cause damage to parkway
Risk Reduction Measures		
Studies and Investigations	Geotechnical explorations and slope stability analysis	
Maintenance and Monitoring	Continuance of annual inspections	
Design and Modifications		

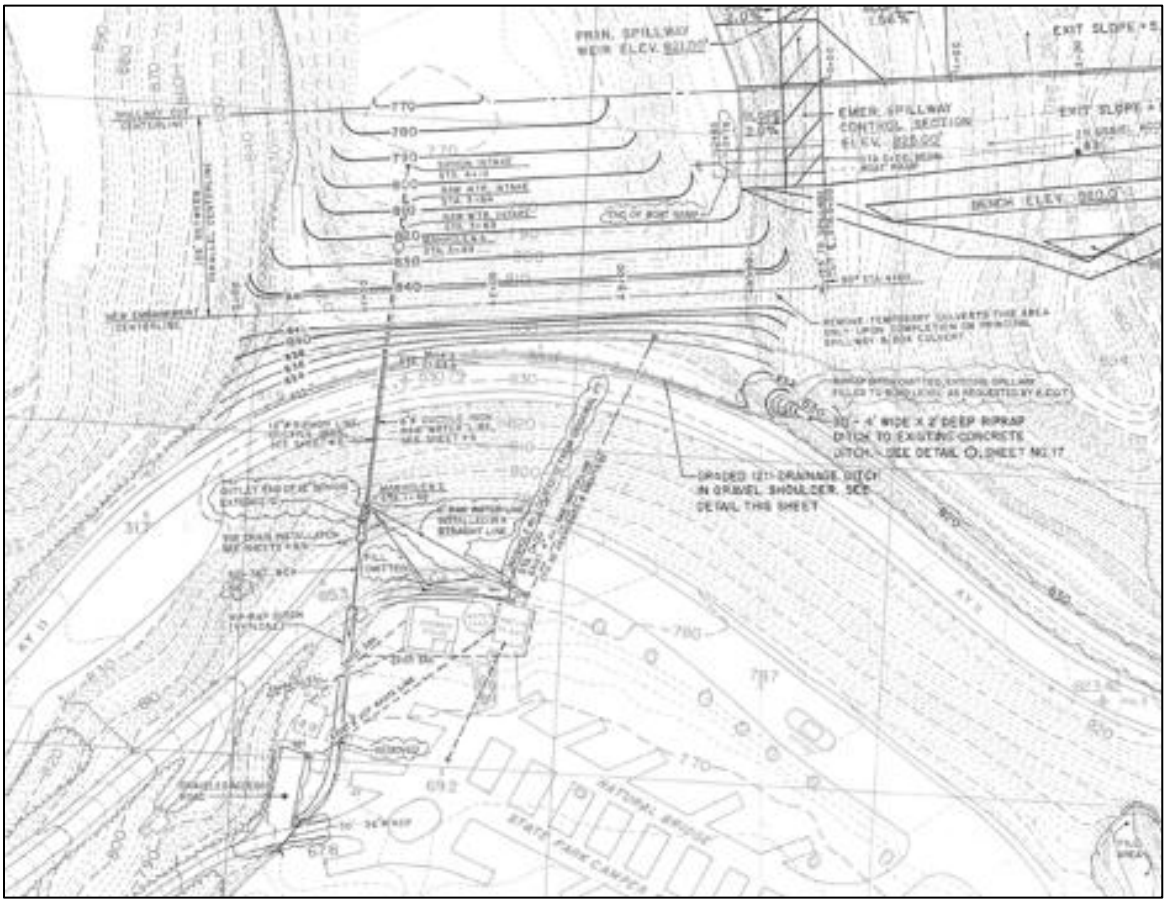
Supporting Figures:



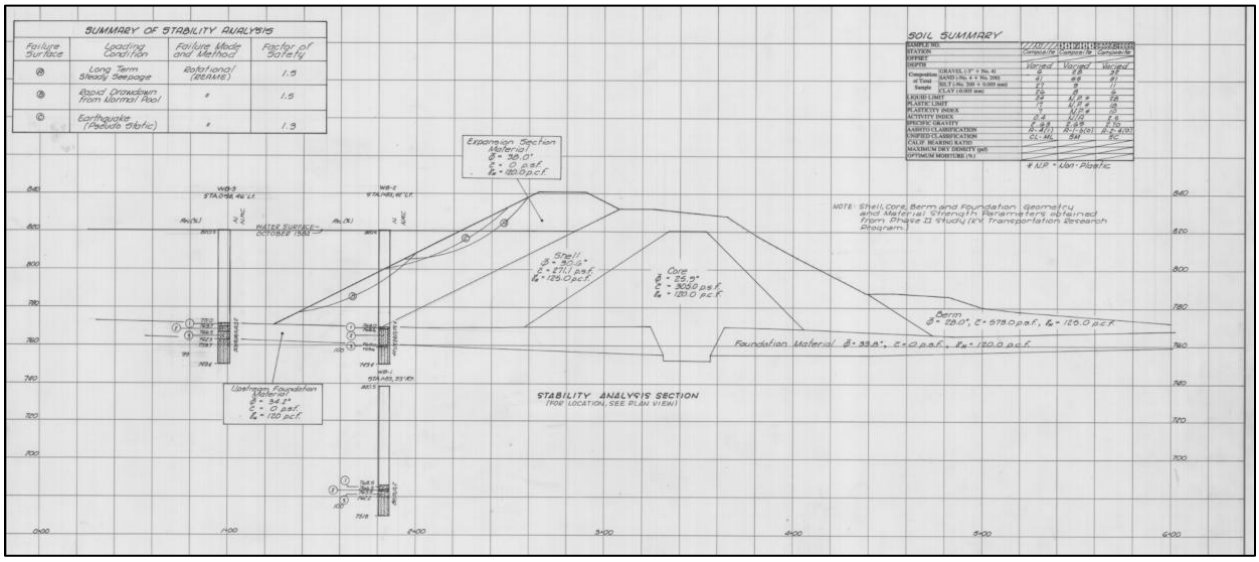
Cross Section 1986 Modification Drawings (Commonwealth of Kentucky, 1986)



Cross Section 1986 Modification Drawings (Commonwealth of Kentucky, 1986)



Plan View 1986 Modification Drawings (Commonwealth of Kentucky, 1986)



Cross Section 1986 Modification Drawings (Commonwealth of Kentucky, 1986)

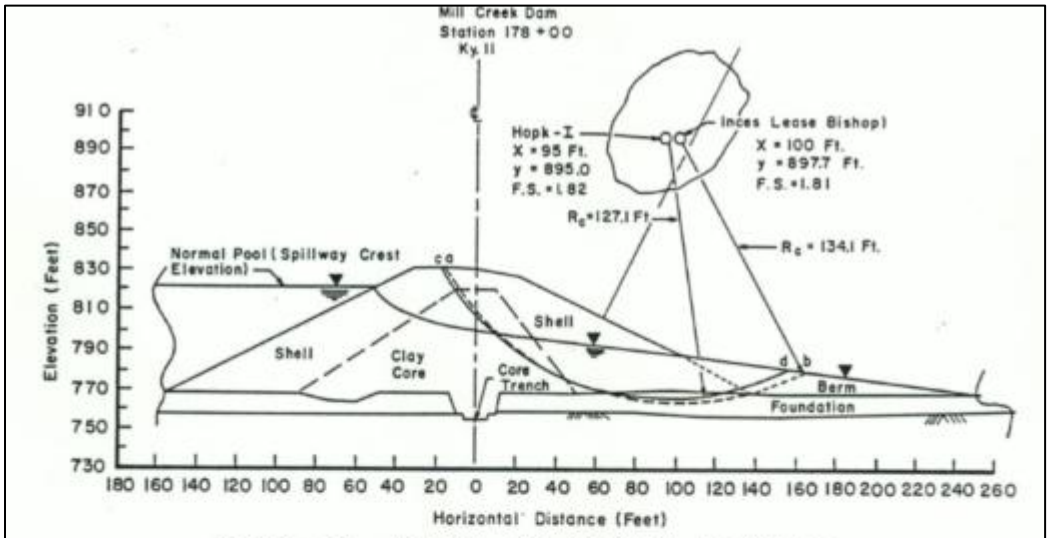


Figure 16. Results of Circular Stability Analyses of the Downstream Slope of Mill Creek Dam, Station 178+00.

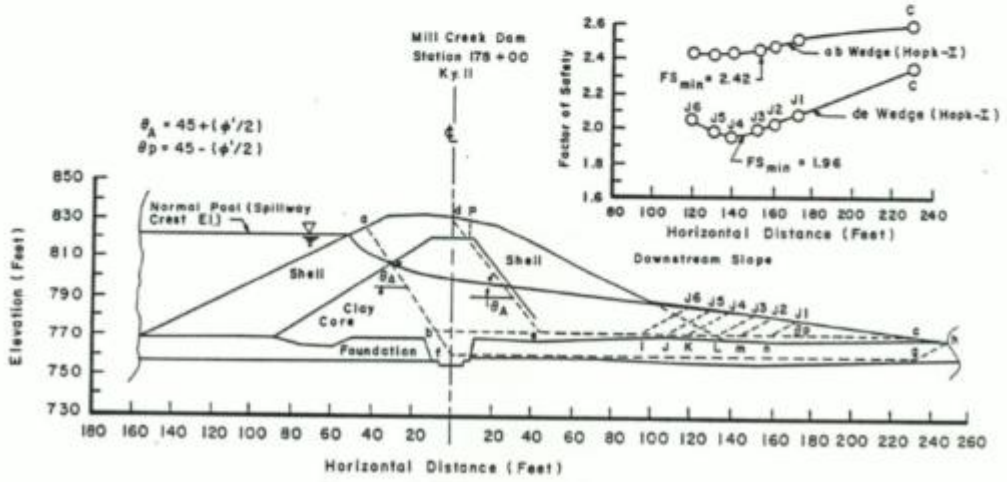


Figure 17. Results of Stability Analyses of the Downstream Slope of Mill Creek Dam, Station 178+00, Assuming Various Wedge-Shaped Configurations.

Stability Analysis Drawings from Phase 2 Inspection Report (Tommy Hopkins, Ronald Hughes, David Allen, 1983)

Potential Failure Mode Analysis Table:

PFM No.:	MC-2A	**Dam:**	Mill Creek
PFM Group:	Internal Erosion - Seepage through a defect in the core		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*

Under normal pool conditions, seepage develops along a defect through the dam core. The defect may be a permeable lift, a smooth lift surface, a poorly compacted lift, or a frozen lift surface. No transition zone constructed. The flow scours the soil to either side of the defect. The embankment over the seepage path does not collapse. The flow path expands and the flow accelerates. The seepage is not detected and there is no intervention. The flow scours a larger void in the embankment, leading to a collapse of the dam crest. The dam is breached and there is an uncontrolled release of the reservoir.

More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
• Built as a highway embankment, not a dam. Less control of the core • Limited gradation and index properties of borrow sources used for the core • **There is no filter on the downstream side of the core** • No information on compaction criteria required for clay core on drawing notes. • Wet areas reported in the 2024 KDOW inspection • **Wet areas observed in the 2025 site visit in the road ditch, at the toe** • **There is no internal drainage system**	• **The dam is wide so it would take a long time to breach.** • **More time to intervene since longer time to breach.** • It is a zoned embankment that would have been well compacted

Risk Assessment	**Category**	**Notes**

Negligible? Credible?	Credible	
Failure Likelihood	FL4	There are no downstream filters in the embankment. The failure mode is estimated to progress slowly, allowing time for successful intervention. If the condition exists, there would be no filter to prevent the progression.
Life Safety Consequences	LS2	When evacuation is possible, life loss is estimated as 1. When evacuation is not possible, estimated as 12.
Economic Consequences	EC2	Facilities at campground, road, assumes parkway floods, may or may not cause damage to parkway
Risk Reduction Measures		
Studies and Investigations	Sample the embankment materials and install instrumentation	
Maintenance and Monitoring	Continue DOW annual inspections.	
Design and Modifications	Design of a filter on the downstream slope	

PFM No.:	MC-2B	**Dam:**	Mill Creek
PFM Group:	Internal Erosion - Seepage and erosion through the foundation soils		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure*)	
Under normal pool conditions, seepage develops through the bottom of the core and in the sandy foundation soils beneath the dam. The seepage exits unfiltered at the downstream toe. The exit gradients are high enough to cause uplift or sand boils. An eroded pipe forms at the exit and progresses backward under the dam, toward the upstream pool. The embankment over the seepage path does not collapse. The seepage is not detected and there is no intervention. The flow rate increases rapidly through the eroded pipe, scouring a large void within the foundation. The embankment collapses into the void, the dam is breached, and there is an uncontrolled release of the reservoir.	
More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
• This is a common failure mode • **There is direct evidence of seepage at the toe of the dam** • **The geologic maps indicate a deposit of alluvial material** • **This failure mode could progress without detection** • There is no transition zone or filter zone on the downstream side of the core. • The original low level drawdown penetrated through the core • **Possible defects in the core from original low level drawdown pipe construction** • Boring logs and geological data suggest the presence of low plasticity silty sands	• Only certain soils are susceptible to backward erosion piping (uniform, fine sands) • **The dam is wide so it would take a long time to breach.** • **More time to intervene since longer time to breach.** • There are fines present in the foundation soils

Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Credible	

Failure Likelihood	FL3	Likely lack of continuity of the erodible sand in the foundation. Lined up with a pipe penetration through the core trench.
Life Safety Consequences	LS2	When evacuation is possible, life loss is estimated as 1. When evacuation is not possible, estimated as 12.
Economic Consequences	EC2	Facilities at campground, road, assumes parkway floods, may or may not cause damage to parkway
Risk Reduction Measures		
Studies and Investigations	Sample the embankment materials and install instrumentation, survey seepage points, survey and mark	
Maintenance and Monitoring	Continue DOW annual inspections, survey and mark, document if seepage has increased or decreased.	
Design and Modifications	Design of a filter on the downstream slope	

PFM No.:	MC-2C	**Dam:**	Mill Creek
PFM Group:	Internal Erosion - Seepage into foundation defects (Karst)		
PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*			
Downward seepage erodes foundation or embankment soils into open karst features in the bedrock. Erosion progresses until there is a breach of the dam.			

More Likely (Adverse) Factors	Less Likely (Favorable) Factors
	• The geologic map of Kentucky suggests we are in an area of low karst activity. • The foundation rock is siltstones with some fracturing. No indication of soluble limestones. • There are no sinkholes at the dam mapped on the KGS lidar survey • No karst features were observed in the 2025 inspection

Risk Assessment	Category	Notes
Negligible? Credible?	Negligible	See table of factors
Failure Likelihood		
Life Safety Consequences		
Economic Consequences		
Risk Reduction Measures		
Studies and Investigations		
Maintenance and Monitoring		

Design and Modifications	

PFM No.:	MC-2D	**Dam:**	Mill Creek
PFM Group:	Internal Erosion - Abutment		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*

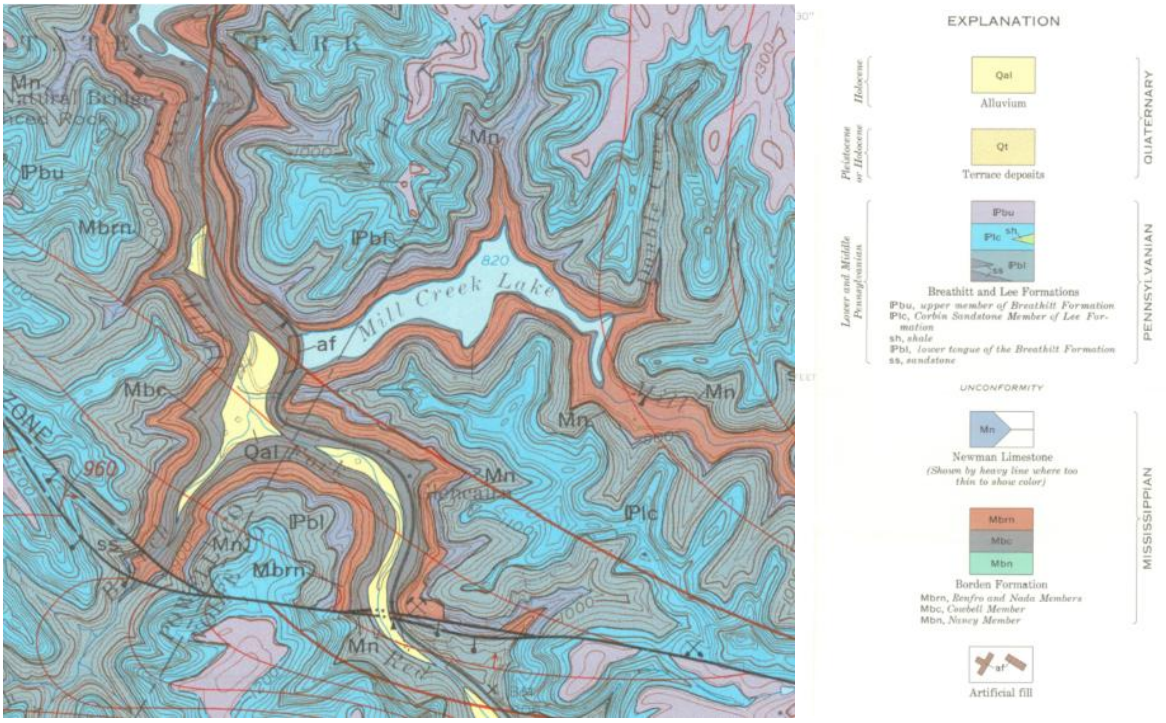
Under normal pool conditions, seepage develops along the left abutment and below the extent of the cutoff trench. The water exits to the downstream face of the roadway embankment near the campground entrance station. It is an unfiltered seepage exit and erosion of the downstream slope initiates. The seepage erodes the soil on the downstream slope, inducing slope failure. Successive slope failures retrogress back to the crest, then to the upstream side of the crest. Material is pushed into the failure from the crest, but the intervention fails. The crest drops below the pool elevation (821'), which overtops the dam breach.

More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
• **Wet area observed on the downstream slope near the left abutment. The wet area extends about halfway up the slope and shows different vegetation.**	• The seepage exit may be beyond the limits of the dam • The slope failure may progress to the abutment and not the crest. • **The dam is wide so it would take a long time to breach.** • **More time to intervene since longer time to breach.** • **Successful intervention is almost certain**

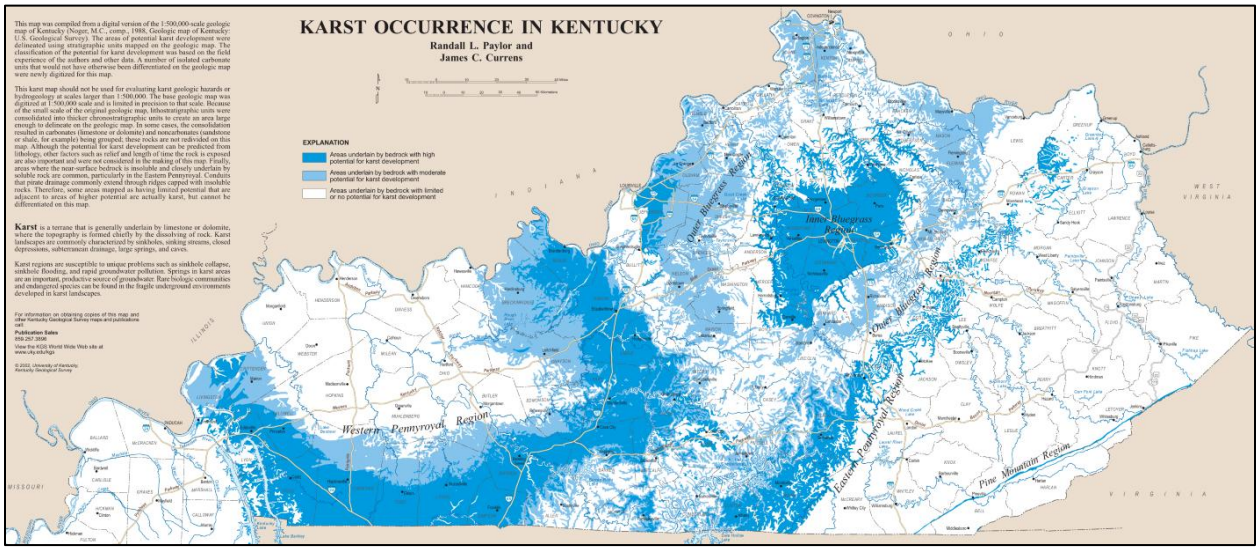
Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Negligible	If the slope failure was induced, it is unlikely to progress to the crest of the dam.

Failure Likelihood		
Life Safety Consequences		
Economic Consequences		
Risk Reduction Measures		
Studies and Investigations		
Maintenance and Monitoring		
Design and Modifications		

Supporting Figures:



GeoQuad Map (Commonwealth of Kentucky, 1974)



Karst Map (Paylor & Currens, 1988)

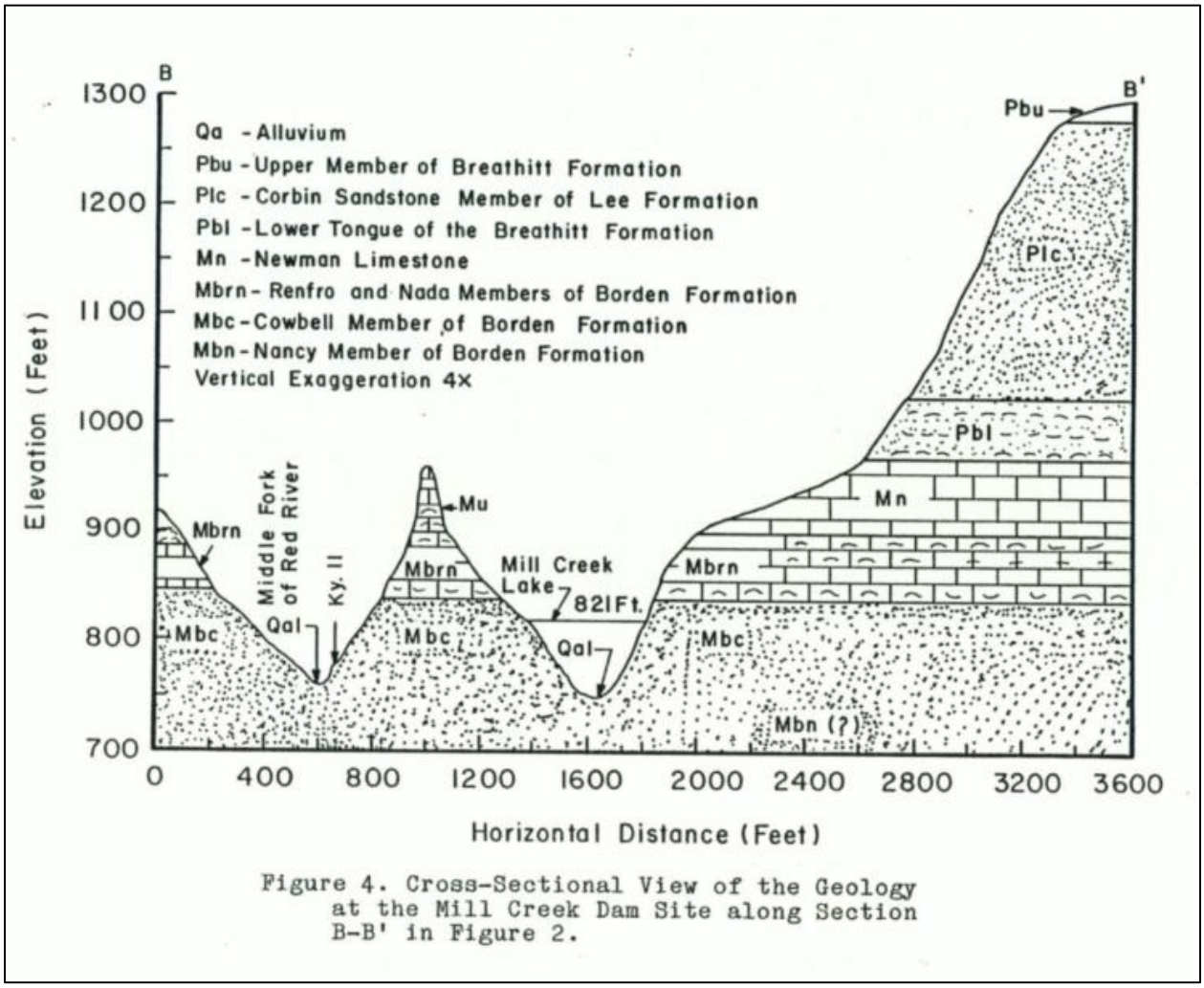


Figure 4. Cross-Sectional View of the Geology at the Mill Creek Dam Site along Section B-B' in Figure 2.

Cross Section from Phase 2 Inspection Report (Tommy Hopkins, Ronald Hughes, David Allen, 1983)

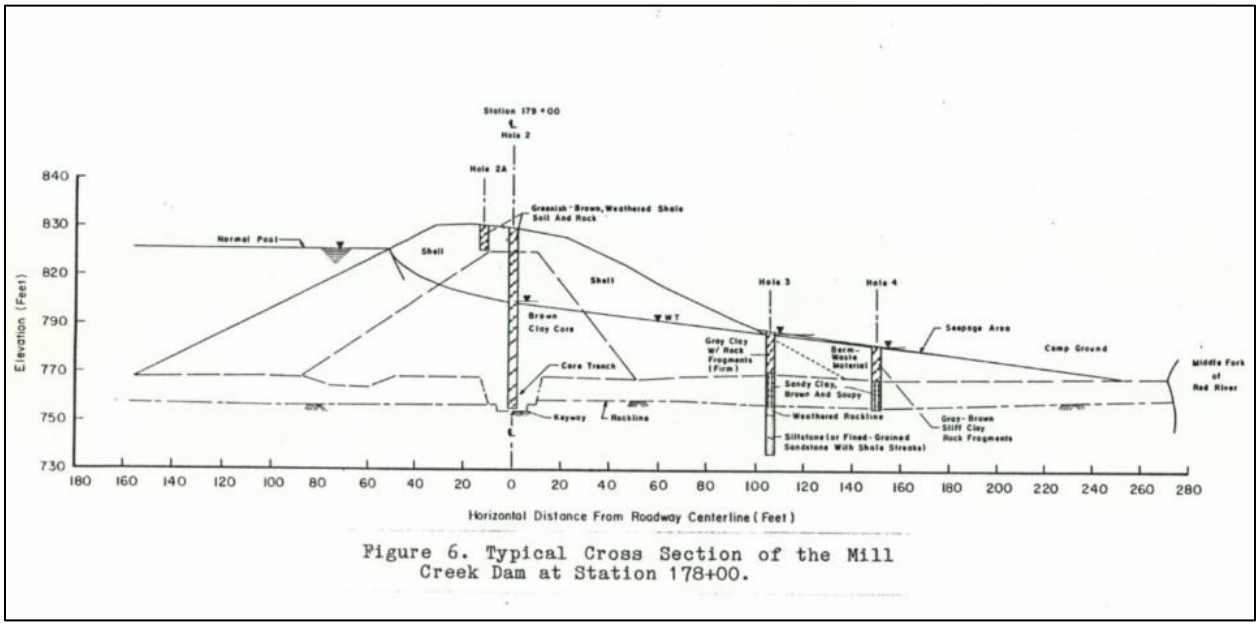
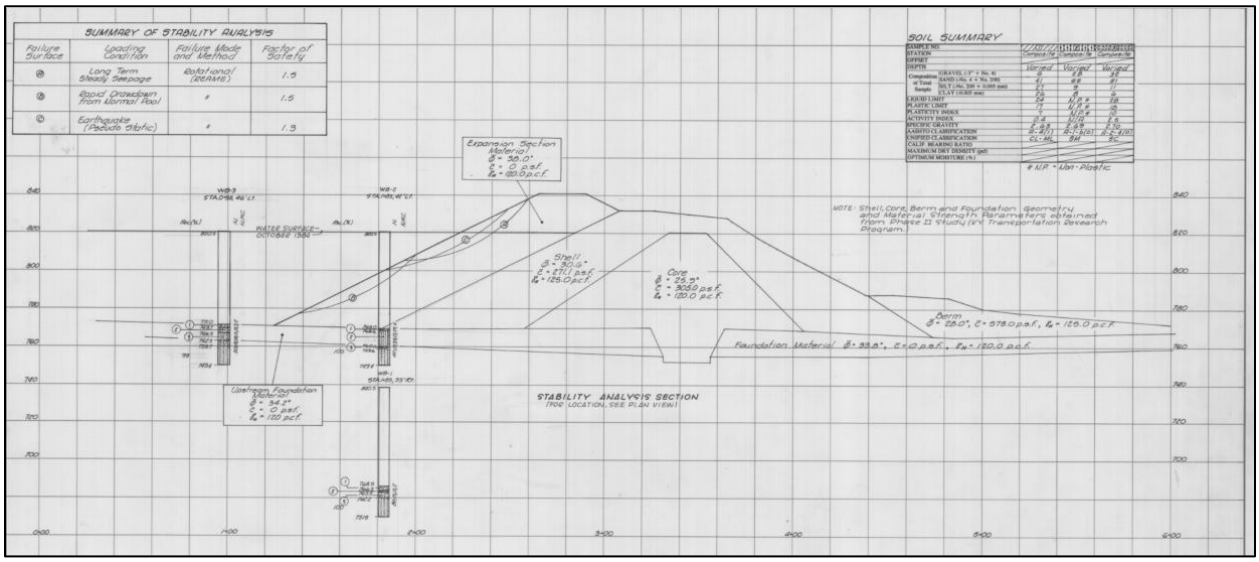


Figure 6. Typical Cross Section of the Mill Creek Dam at Station 178+00.

Cross Section from Phase 2 Inspection Report (Tommy Hopkins, Ronald Hughes, David Allen, 1983)



Cross Section from 1986 Modification Drawings (Commonwealth of Kentucky, 1986)



Site Visit Photo



Site Visit Photo

Potential Failure Mode Analysis Table:

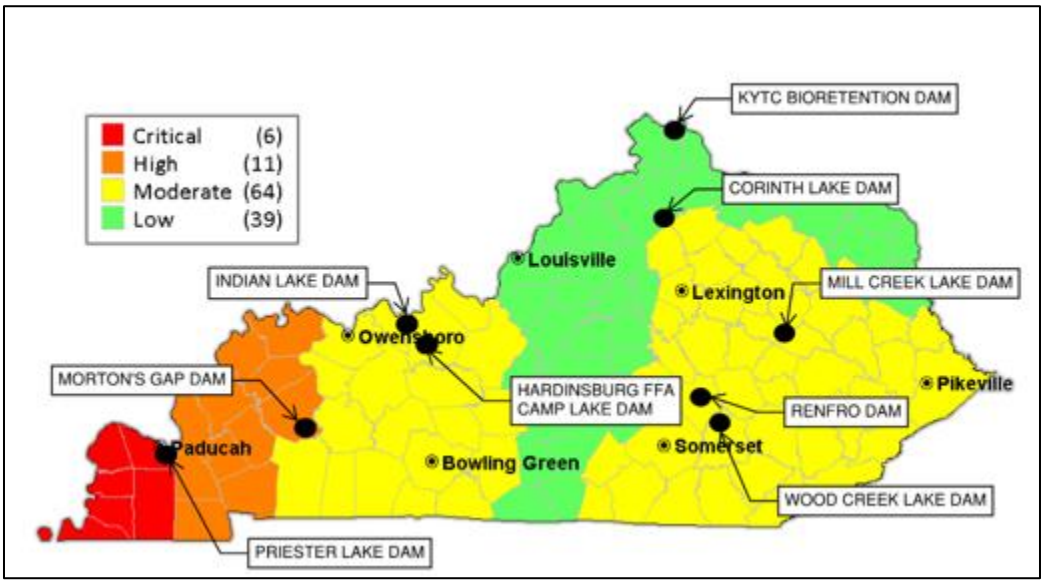
PFM No.:	MC-3	**Dam:**	Mill Creek
PFM Group:	Seismic		
PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*			
A strong earthquake is felt at the dam site. The dynamic loads on the dam embankment cause slope displacements and possible slope failures. Successive slope movements during and after the earthquake progress across the width of the dam crest. There is no time for intervention. The crest drops below normal pool and the reservoir overtops. The resulting flows scour downward through the dam embankment, releasing the reservoir.			

More Likely (Adverse) Factors	Less Likely (Favorable) Factors
• Slopes are steep (2:1) • Intervention would be impossible during the earthquake • The dam is resting on sandy alluvial deposit	• We are in a moderate seismic zone • Compacted embankment • Intervention is likely to be successful • Based on our location, recognizing we do not have any data, we assume no liquification risk • Pseudo static FOS is 1.3 for shallow upstream failures only. There are additional analyses in the phase 2 Geotechnical, Hydrologic, and hydraulic investigation (1983) • The dam is very wide at the elevation of the normal pool

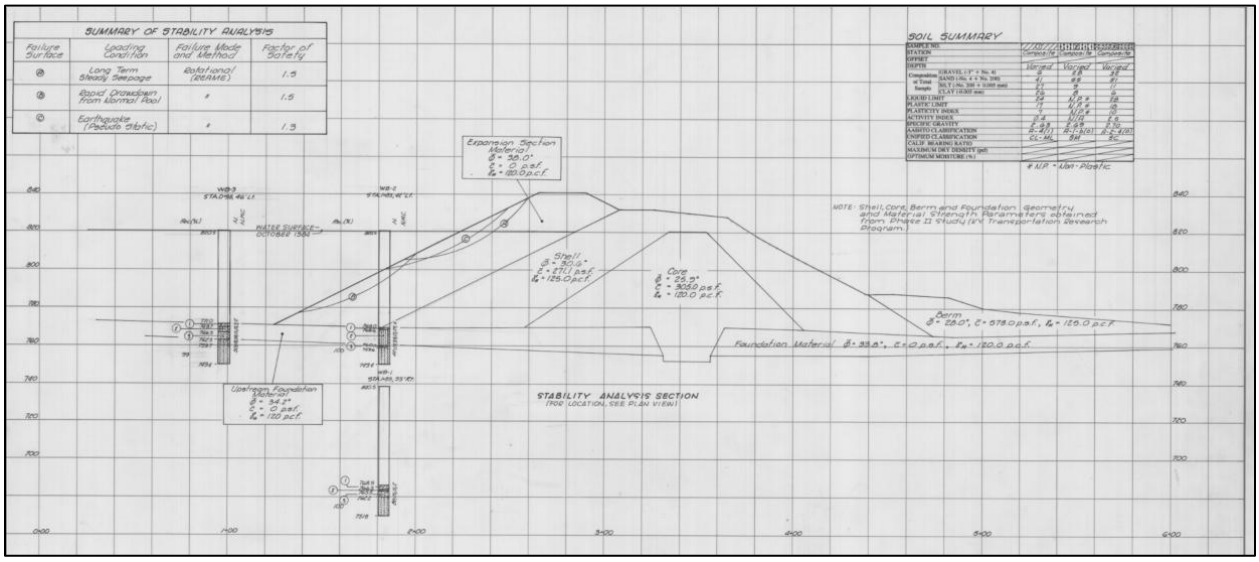
Risk Assessment	Category	Notes
Negligible? Credible?	Negligible	The earthquake loading has a low probability, and we have old stability analyses that indicate it is stable.
Failure Likelihood		
Life Safety Consequences		
Economic Consequences		
Risk Reduction Measures		

Studies and Investigations	
Maintenance and Monitoring	
Design and Modifications	

Supporting Figures:



Seismic Map



Cross Section from 1986 Modification Drawings (Commonwealth of Kentucky, 1986)

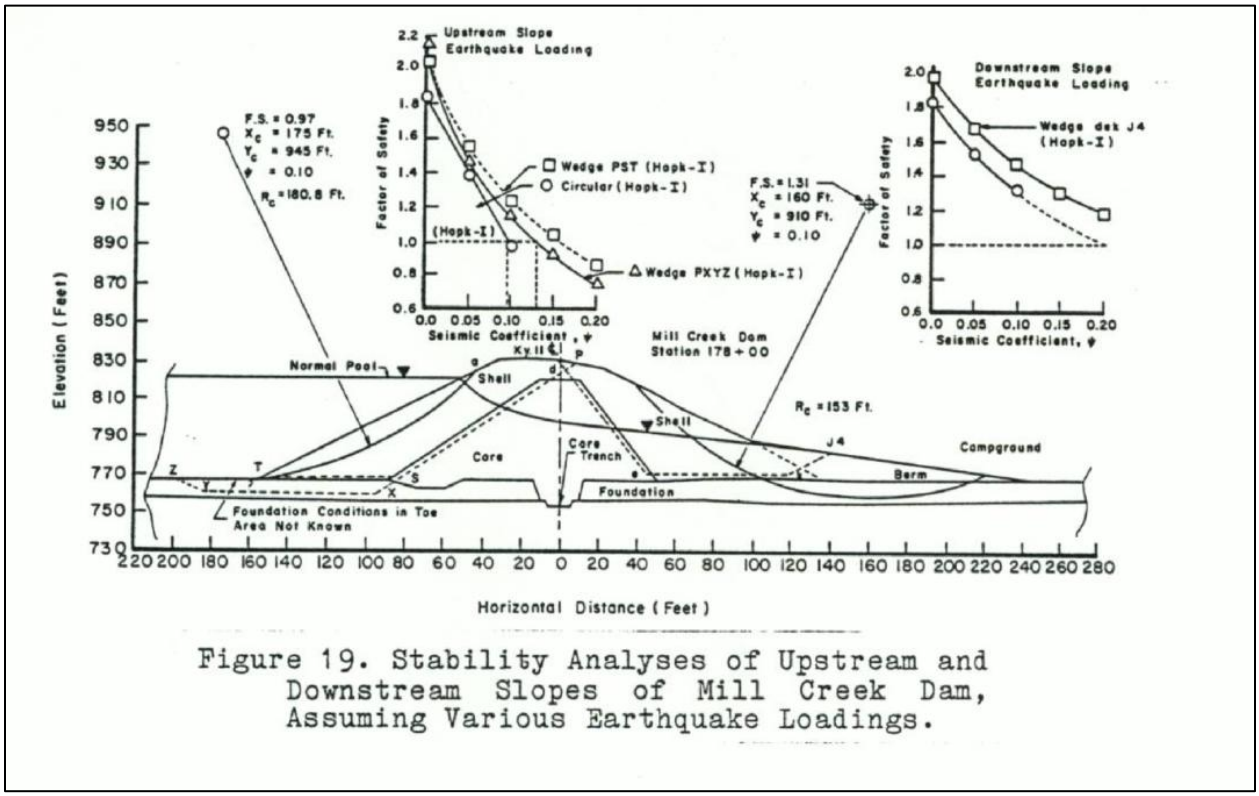


Figure 19. Stability Analyses of Upstream and Downstream Slopes of Mill Creek Dam, Assuming Various Earthquake Loadings.

Cross Section from Phase 2 Inspection Report (Tommy Hopkins, Ronald Hughes, David Allen, 1983)

Potential Failure Mode Analysis Table:

PFM No.:	MC-4	**Dam:**	Mill Creek
PFM Group:	Overtopping		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*

A heavy precipitation event occurs in the watershed, causing the reservoir level to rise. Water is released through the spillways, which may further inundate the downstream toe of the slope. The water levels continue to rise and overtop the dam crest. No plausible effort is made to raise the crest of the dam. The overtopping flows begin to erode the downstream slope of the dam embankment. The flow causes head cutting, which progresses backward across the width of the dam crest. The dam is breached when the crest erosion reaches the upstream pool. The resulting flows scour downward through the dam embankment, releasing the reservoir.

More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
• There is an obstruction of a shipping container at the entrance of the auxiliary spillway. However, the modeling shows that it does not result in overtopping the embankment. The container is likely to be displaced. • There have been significant precipitation events in Eastern Kentucky recently. (14"-16" in 5 days, while most of the rain fell within 12 hours. It was classified as a 1000-yr event)	• **It currently safely conveys the PMP (1.25e-5). This modeling includes the shipping container at the entrance of the auxiliary spillway.** • **The return period for an overtopping event is 6e-6.** • **The return interval for auxiliary spillway activation is .02.**

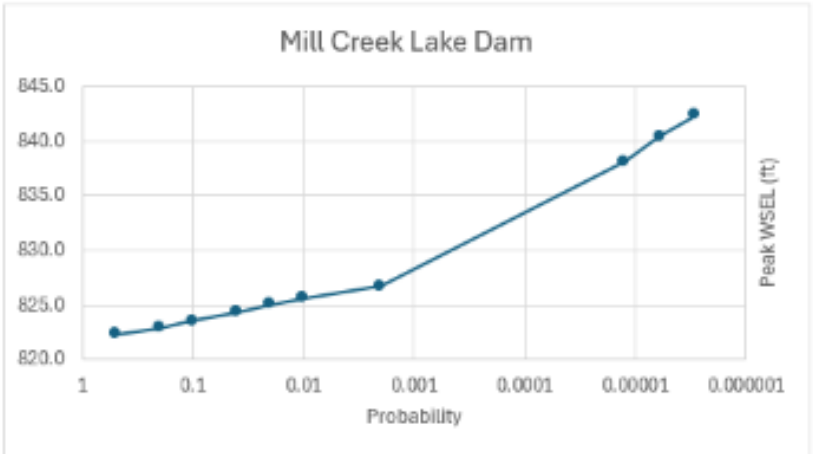
Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Credible	
Failure Likelihood	FL1	To overtop the dam, we are starting at a 6e-6 event. There will be further reductions when you account for erosion on the embankment dam.

Life Safety Consequences	LS2	When evacuation is possible, life loss is estimated as 1. When evacuation is not possible, estimated as 12.
Economic Consequences	EC2	Facilities at campground, road, assumes parkway floods, may or may not cause damage to parkway
Risk Reduction Measures		
Studies and Investigations		
Maintenance and Monitoring	Relocate the storage container, this would not change our conclusion.	
Design and Modifications		

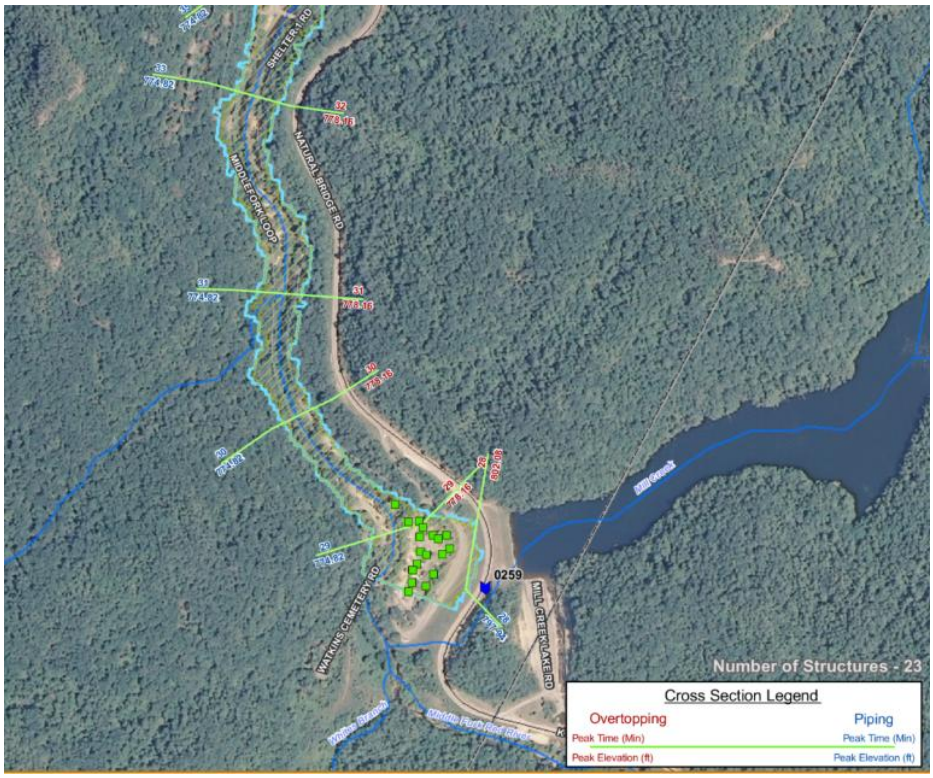
Supporting Figures:

Mill Creek Lake Dam (Dam Crest = 840.4 ft)				
Precip	**Peak Inflow**	**Peak WSEL**	**Return Interval**	**Notes**
2.1	328	822.3	0.5	2yr
2.5	555	822.9	0.2	5yr
2.9	785	823.5	0.1	10yr
3.4	1,142	824.4	0.04	25yr
3.9	1,475	825.1	0.02	50yr
4.4	1,844	825.6	0.01	100yr
5.6	2,884	826.7	0.002	500yr
28.2	25,404	838.1	1.25E-05	PMP
34.4	31,682	840.4	5.99E-06	**Overtopping**
45.5	43,042.5	842.4	2.88E-06	**~2' overtopping**

*Note: Duration of overtopping for the 45.5" rainfall event estimated to be **2 hours***



H&H Results



Inundation Mapping

Potential Failure Mode Analysis Table:

PFM No.:	MC-5	**Dam:**	Mill Creek
PFM Group:	Erosion Associated with Conduits - Leakage		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*

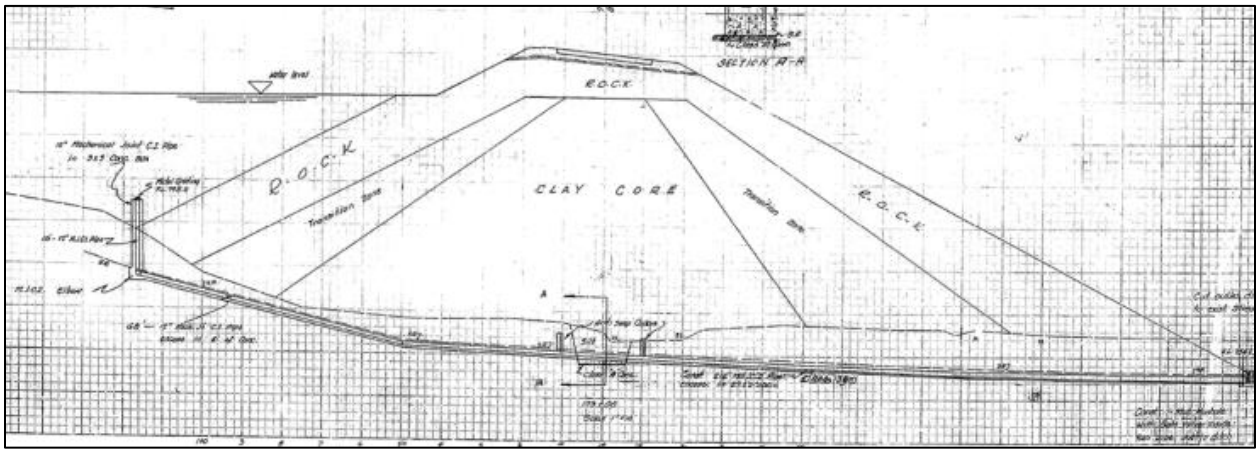
There is a 6" raw water line intake from the upstream pool to the toe of the dam. Water in the pipe is at headwater pressure. A leak develops in the pipe, causing higher piezometric pressures at the toe of the dam. A slope failure is initiated at the downstream toe of the dam. Successive slope failures retrogress back to the crest, then to the upstream side of the crest. Material is pushed into the failure from the crest, but the intervention fails. The crest drops below the pool elevation (821'), which overtops the dam breach.

More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
• The condition of the pipe is not well understood. • There is a wet area on the downstream of the dam that may align with this pipe. • Minor sloughing in the embankment may cause enough displacement to cause pipe leakage. • There has been some movement as noted in the displaced joint in the manhole most downstream.	• The dam is wide so it would take a series of failures to breach the dam. • It is a 6" ductile iron pipe, which is less susceptible to leakage.

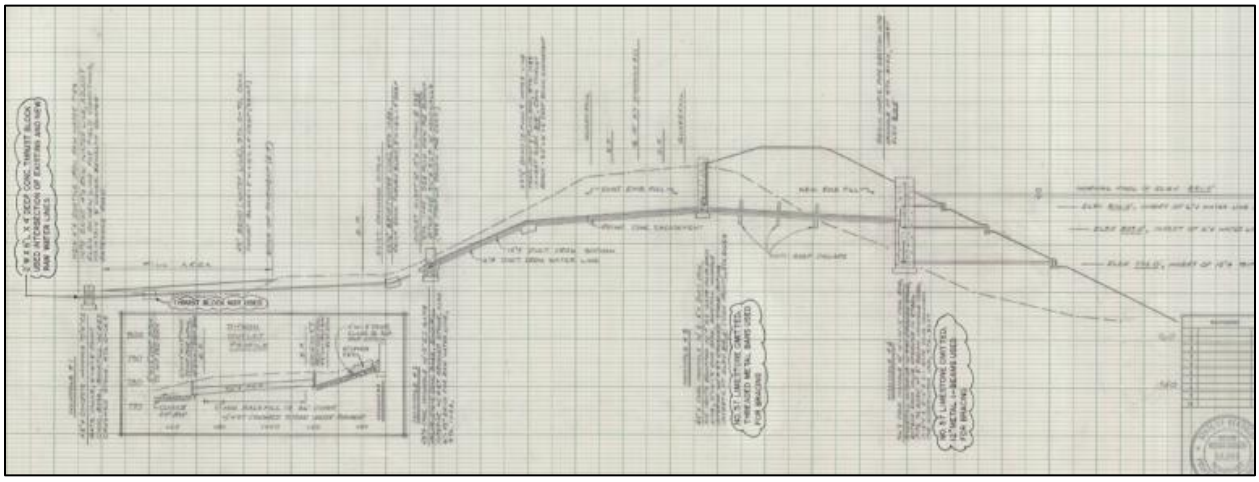
Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Credible	
Failure Likelihood	FL2	The wet spot has been observed during several inspections.

Life Safety Consequences	LS2	When evacuation is possible, life loss is estimated as 1. When evacuation is not possible, estimated as 12.
Economic Consequences	EC2	Facilities at campground, road, assumes parkway floods, may or may not cause damage to parkway
Risk Reduction Measures		
Studies and Investigations		
Maintenance and Monitoring	Investigate the 6" raw water line and repair if it is leaking.	
Design and Modifications		

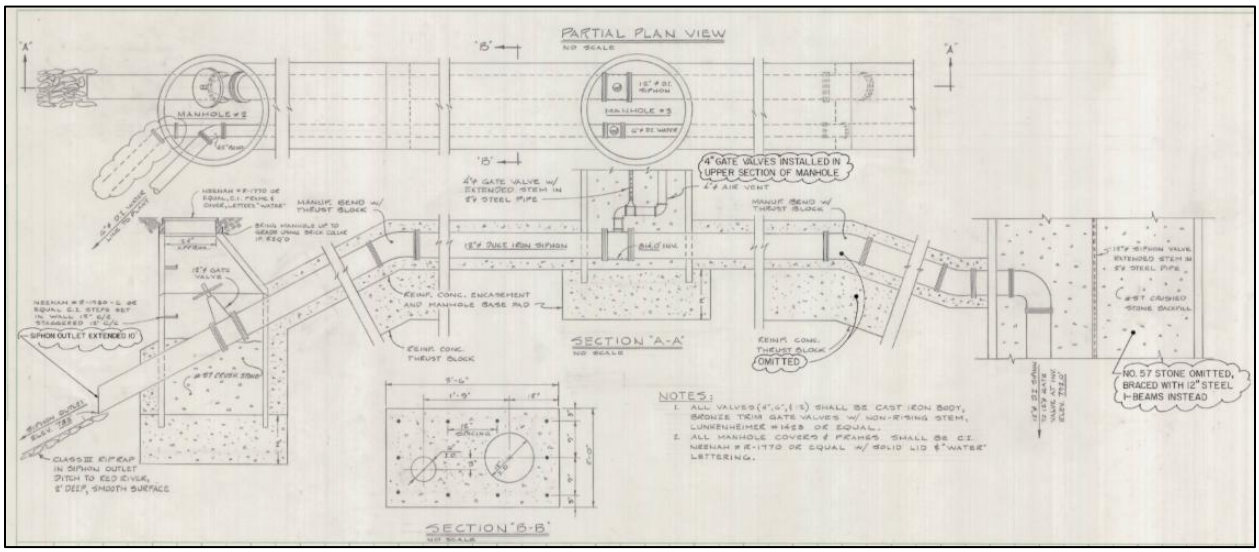
Supporting Figures:



Cross Section 1962 Design Drawings (Commonwealth of Kentucky Department of Highways, 1962)

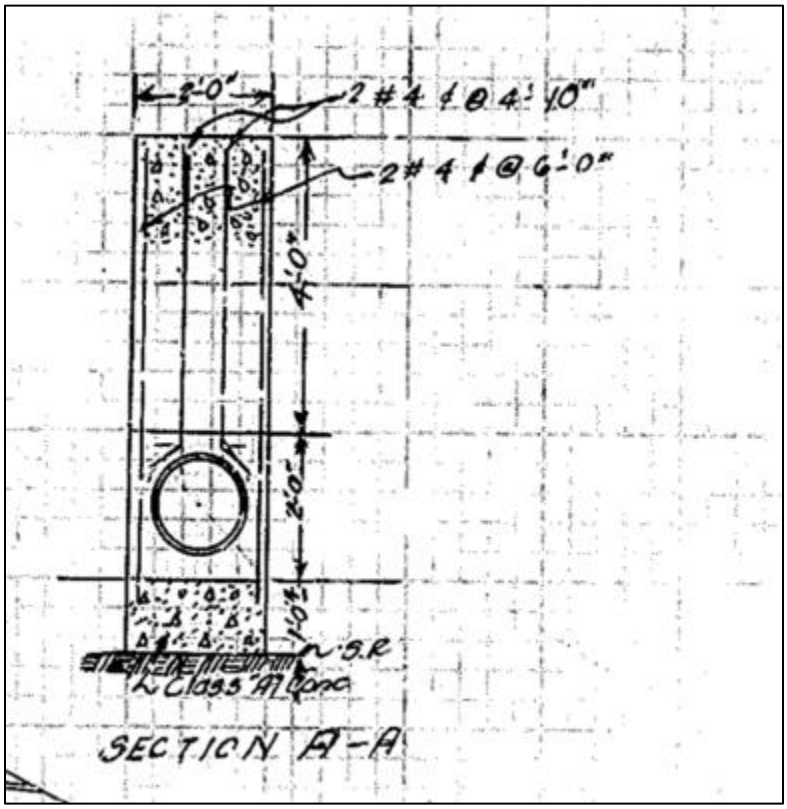


Cross Section from 1986 Modification Drawings (Commonwealth of Kentucky, 1986)



Detail from 1986 Modification Drawings

(Commonwealth of Kentucky, 1986)



Detail from 1962 Design Drawings (Commonwealth of Kentucky Department of Highways, 1962)

Potential Failure Mode Analysis Table:

PFM No.:	**MC-6**	**Dam:**	Mill Creek
PFM Group:	Spillway Structures		
PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*			

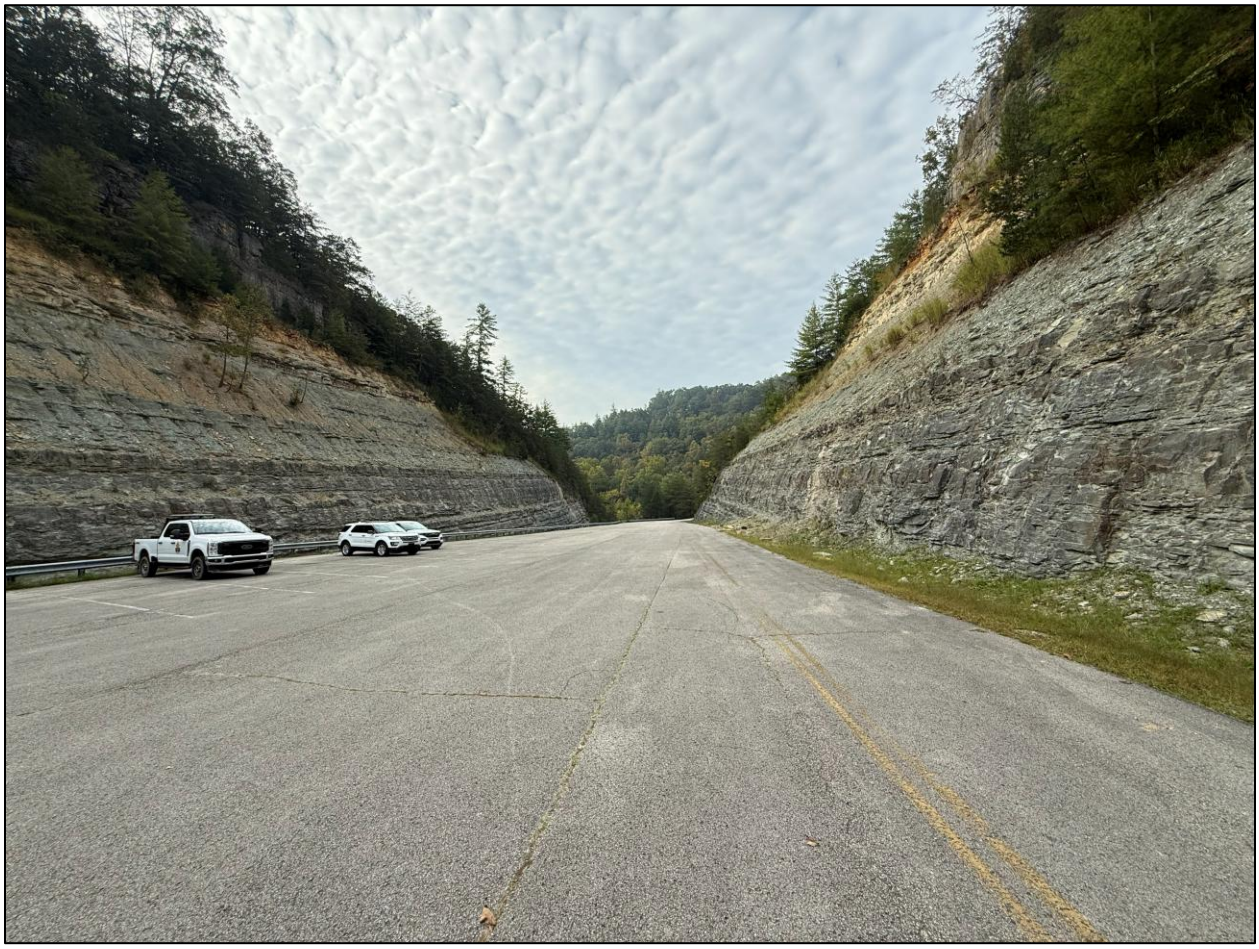
1. Principal spillway cut in rock
2. Auxiliary spillway - rock cut with paved parking area on top.
    a. The container is present but it does not have any adverse effects in the spillway function. No overtopping, even with the container in place
3. The riser structure with siphon and water line
    a. Founded on the original embankment but encapsulated in the new portions of the embankment.
    b. Riser filled with crushed stone

More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
•	•

Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Negligible	
Failure Likelihood		
Life Safety Consequences		
Economic Consequences		
Risk Reduction Measures		
Studies and Investigations		
Maintenance and Monitoring		

Design and Modifications	

Supporting Figures:



Site Visit Photo

Potential Failure Mode Analysis Table:

PFM No.:	MC-7	**Dam:**	Mill Creek
PFM Group:	Operational		

PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*

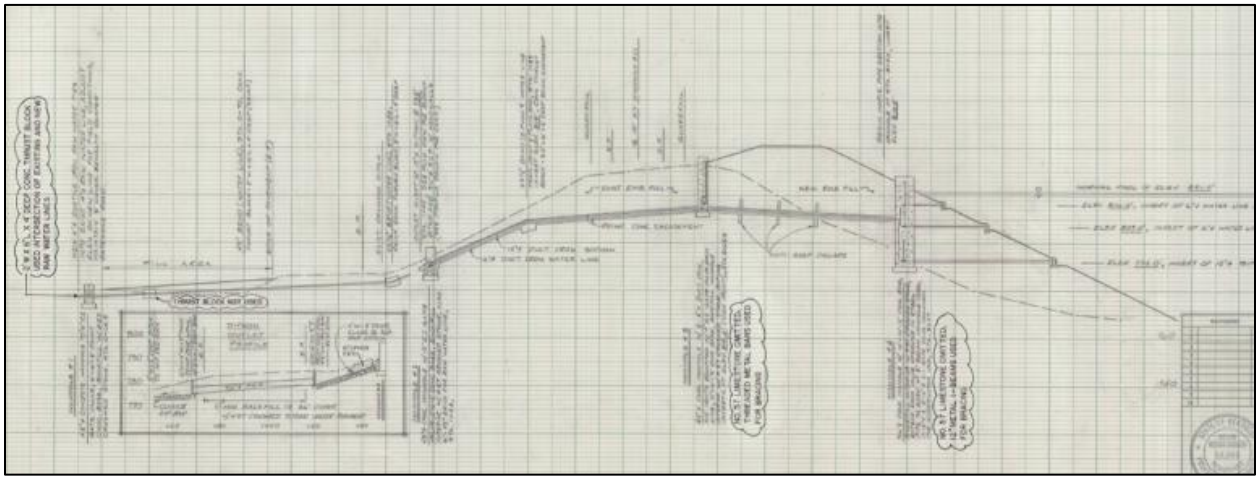
The valve on the 12" siphon pipe is opened but cannot be closed. The dam does not fail but the lake is slowly drained to elevation 792' through the 12" ductile iron low level drawdown pipe.

More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
• The gate is not regularly operated • Condition of the valve and pipe are unknown • Almost 40 years old • Detection of the 6" water intake will be delayed because no one is monitoring or using the water being used	• The configuration of the pipes limits the drawdown to about 792' • The downstream discharge would not cause damage, life loss, or flooding • Appears the 6" water intake is not being used. • There does not seem to be any water users for the reservoir

Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Credible	There are insignificant impacts to drawing down the pool, this is a temporary condition.
Failure Likelihood	FL1	No failure - just bringing the lake to elevation 792'. A series of events must occur for this to be a concern.
Life Safety Consequences	LS0	No failure, so should not impact life.

Economic Consequences	EC0	No significant economic consequences.
Risk Reduction Measures		
Studies and Investigations		
Maintenance and Monitoring	Low level drawdown should be annually inspected and operated.	
Design and Modifications		

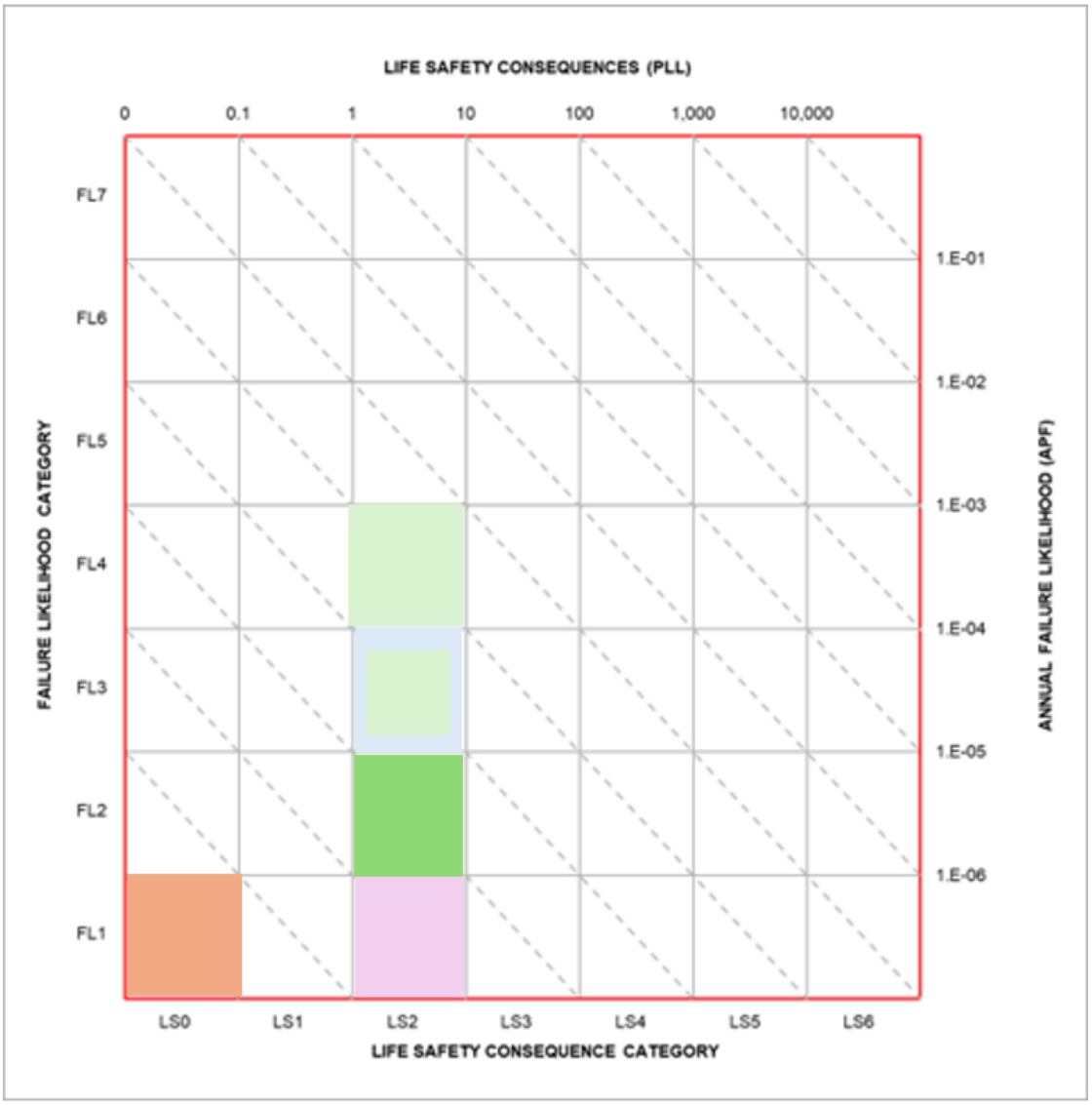
Supporting Figures:



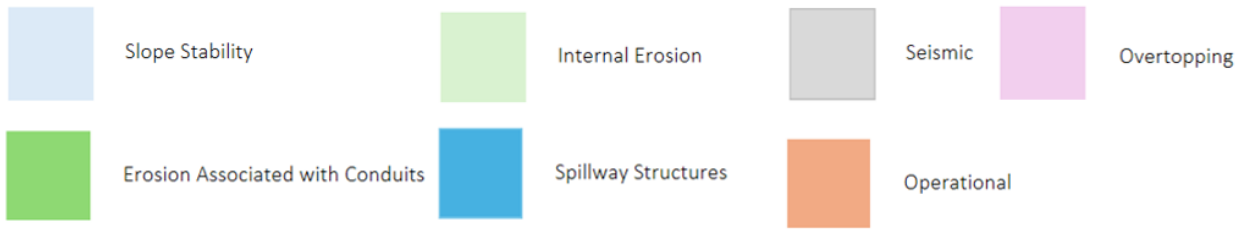
Cross Section from 1986 Modification Drawings (Commonwealth of Kentucky, 1986)

I.6 Risk Matrices

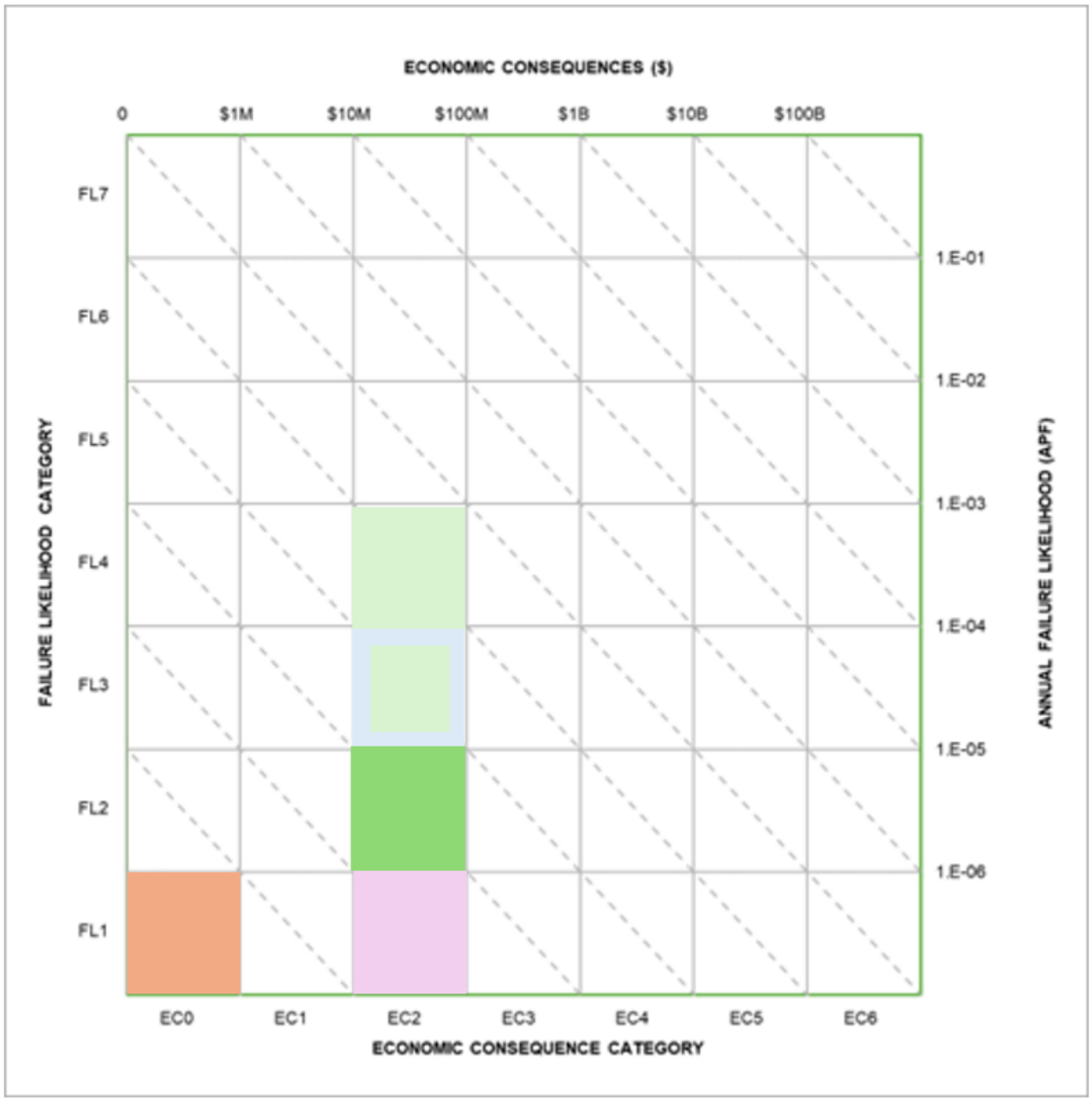
Life Safety Risk Matrix:



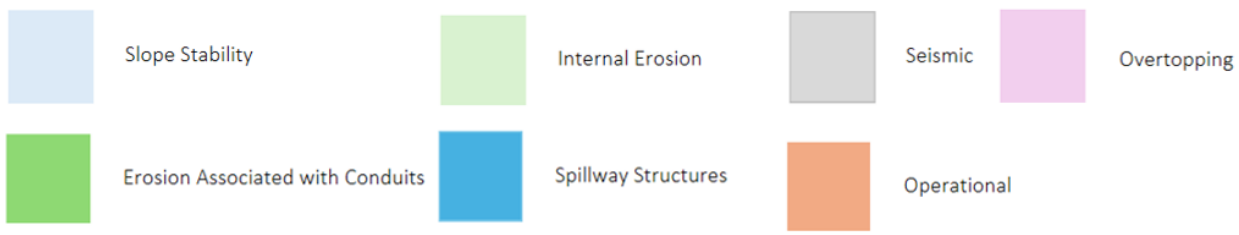
Legend:



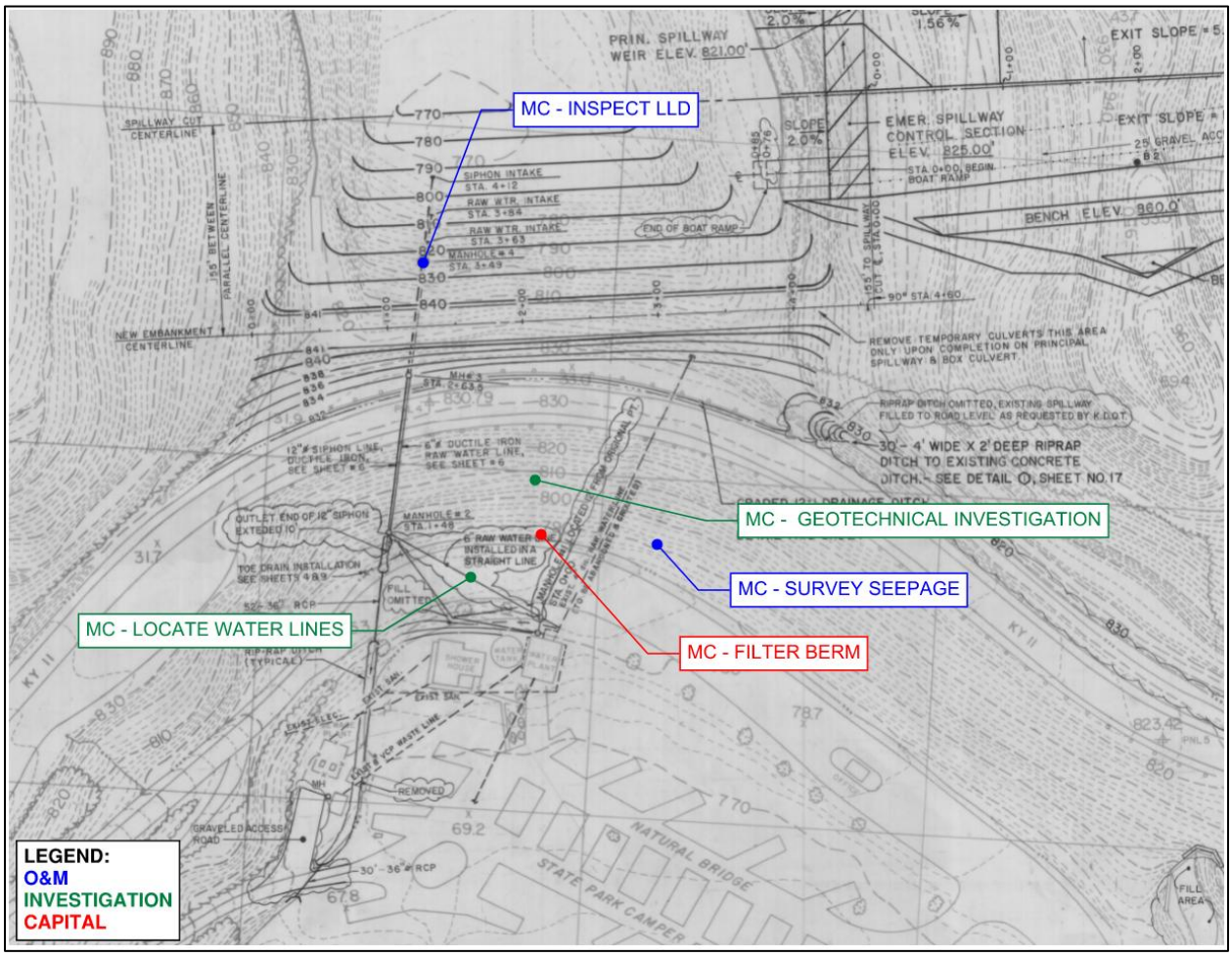
Economic Consequences Risk Matrix:



Legend:



I.7 Recommendations



Recommendations – Mill Creek Lake Dam								
CODE	**Recommendation**	**Type**	**Life Loss Risk**	**Economic & Transportation Risk**	**Regulatory Compliance**	**Cost Range**	**Planning Horizon**	**Priority**
MC - SURVEY SEEPAGE	Mark or survey the seepage locations on the downstream face for future monitoring.	O&M	6	6	Yes	<10K	Short Term	1
MC - LOCATE WATER LINES	Investigate all of the water lines that pass under the dam, repair if leaking, abandon if not being used.	Investigation	4	4	Yes	10K-100K	Short Term	2
MC - INSPECT LLD	Operate and inspect the low-level drawdown and raw water intake valves.	O&M	0	0	Yes	10K-100K	Intermediate	3
MC - GEOTECHNICAL INVESTIGATION	Perform geotechnical investigation (borings and piezometers) and seepage and stability analyses.	Investigation	8	8	Yes	100K-1M	Intermediate	4
MC - FILTER BERM	Construct a filter berm or sub-surface drainage features on the downstream slope to address seepage.	Capital	8	8	Yes	1M-10M	Long Term	5

I.8 Cost Opinions for Capital Projects

Stantec developed the following cost opinions for constructing capital improvements for each dam. The costs listed below are very approximate, as they are based only on broad concepts, without even preliminary designs. The costs should be used only for planning, and not for budgeting specific improvements.

The work that is recommended for Mill Creek is to construct a filter berm or sub-surface drainage features on the downstream slope to address seepage.

Filter Berm

Contractor Work Item	Quantity	Unit of Measure	Operating Cost	Total Cost
Sand (1' Depth)	1,290.63	CY	$100	$129,063
Filter Fabric	3,871.88	SY	$7.50	$29,039
No. 57 Stone (3' Depth)	3,871.88	CY	$95	$367,829
Class II Channel Lining (1.5' Depth)	1,935.94	CY	$90	$174,235
Excavation (1.5' Depth)	1,935.94	CY	$50	$96,797
			Total	$1,000,000