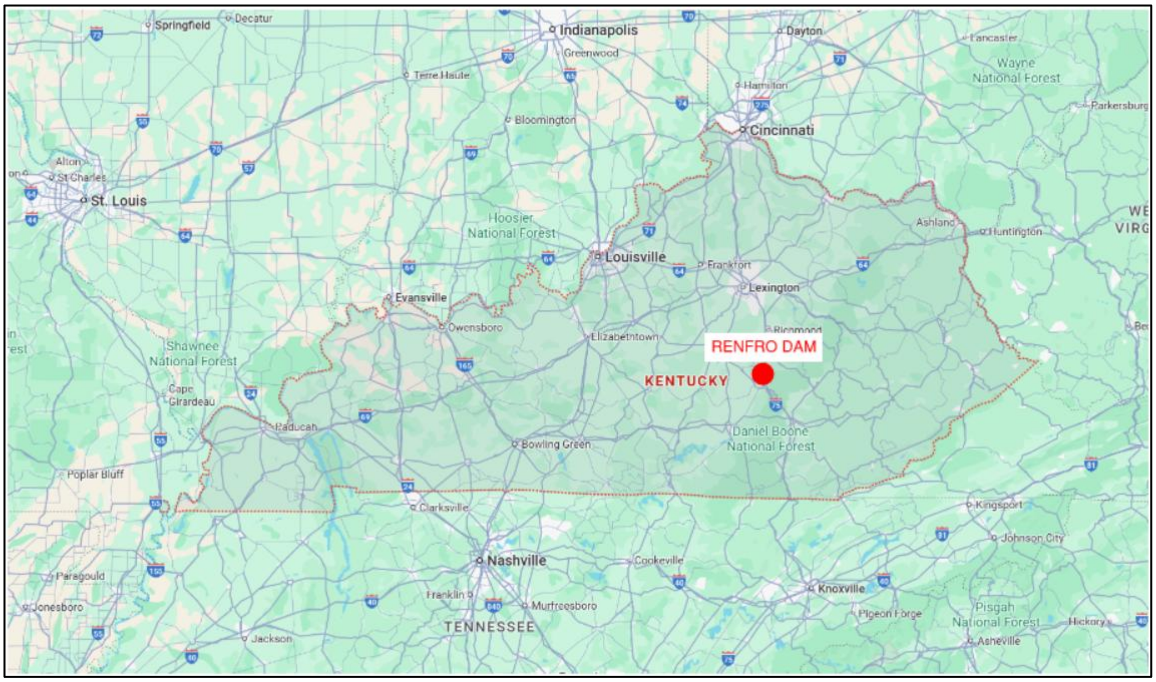
Appendix F
Renfro Dam

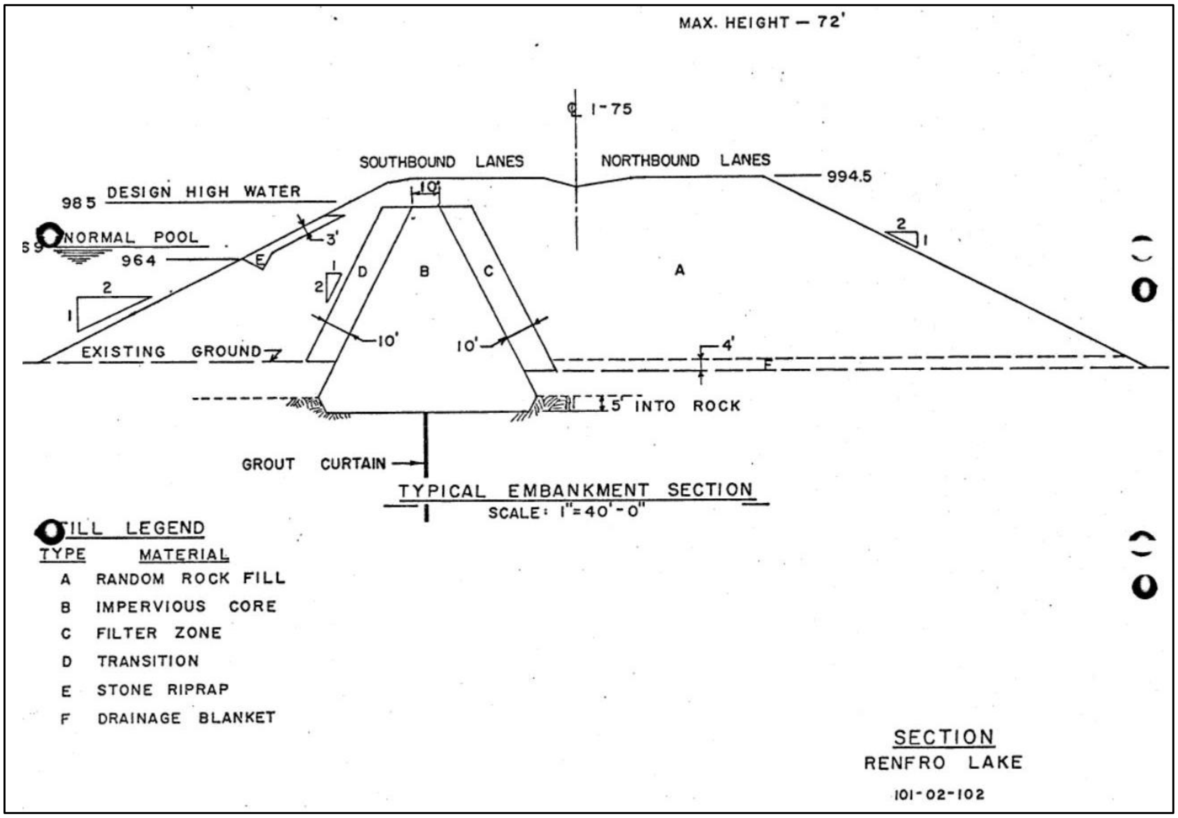
F.1 Dam and Appurtenant Features

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.

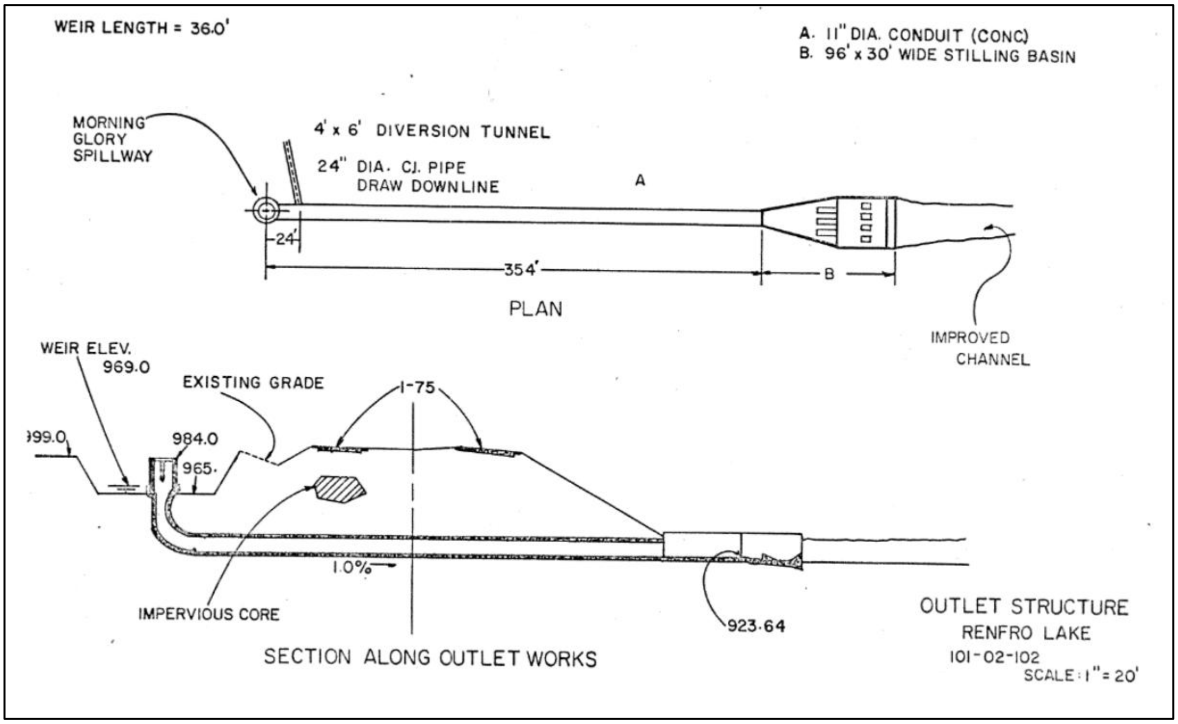


Renfro Dam – Vicinity Map

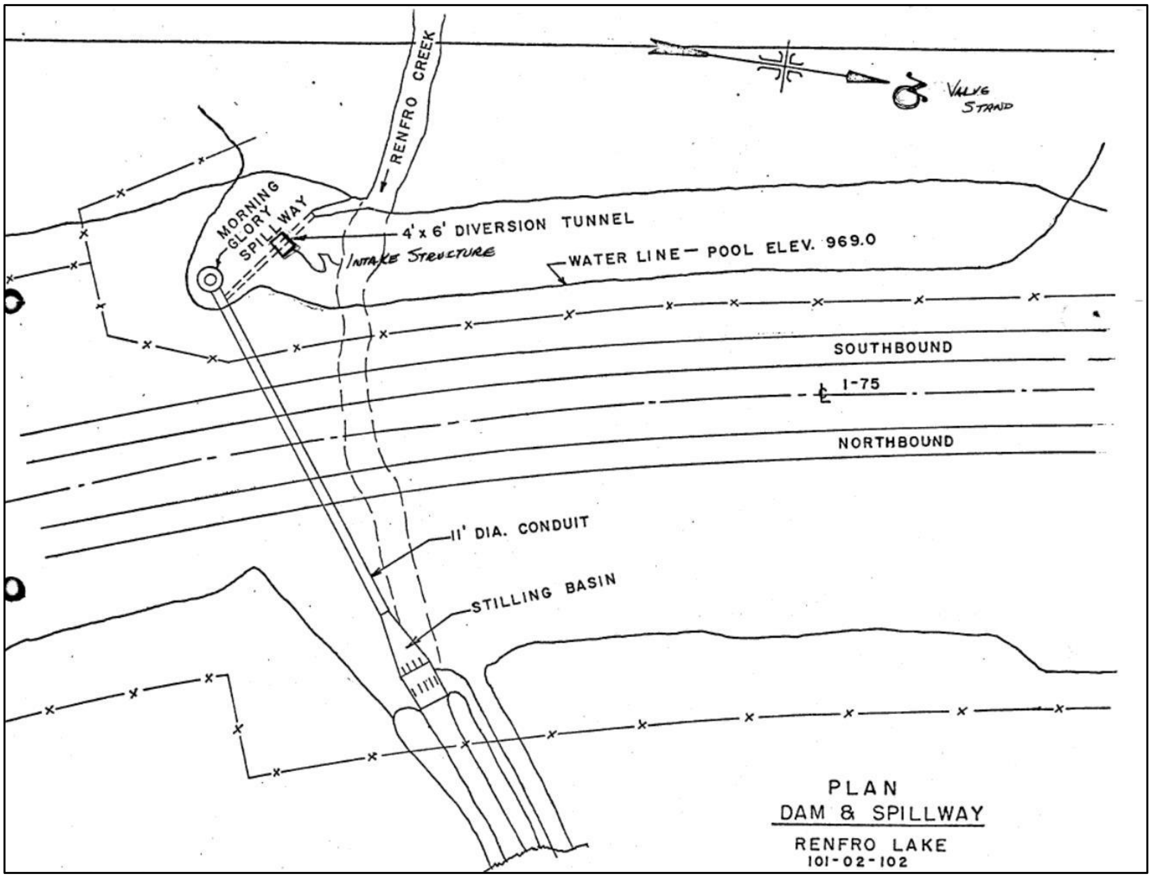
The principal spillway is a morning glory spillway connected to an 11 ft-diameter conduit that runs through the dam at the base of the embankment. The figures below show the cross sections and plan view for this dam.



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
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02.03.155	Inspections	Inspection Report	1975 Division of Water
02.03.156	Inspections	Inspection Report	1974 Division of Water
02.03.157	Inspections	Inspection Report	1974 Division of Water
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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02.03.171	Inspections	Inspection Report	1975 Division of Water

02.03.172	Inspections	Inspection Report	1977 Division of Water
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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
02.03.183	Inspections	Inspection Report	1982 Division of Water
02.03.184	Inspections	Inspection Report	1982 Division of Water
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02.03.186	Inspections	Inspection Report	1981 Division of Water
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02.03.188	Inspections	Inspection Report	1984 Division of Water
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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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02.03.204	Inspections	Inspection Report	1990 Division of Water
02.03.205	Inspections	Inspection Report	1991 Division of Water

02.03.206	Inspections	Inspection Report	1991 Division of Water
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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.

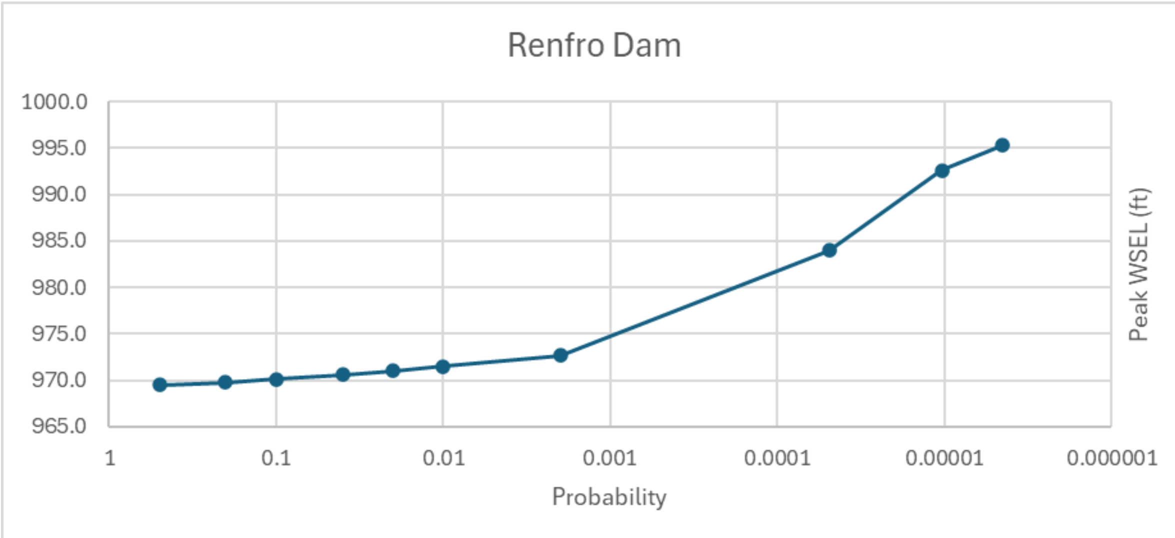
Renfro Dam Model Results

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

<u>Consequences Analysis</u>

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

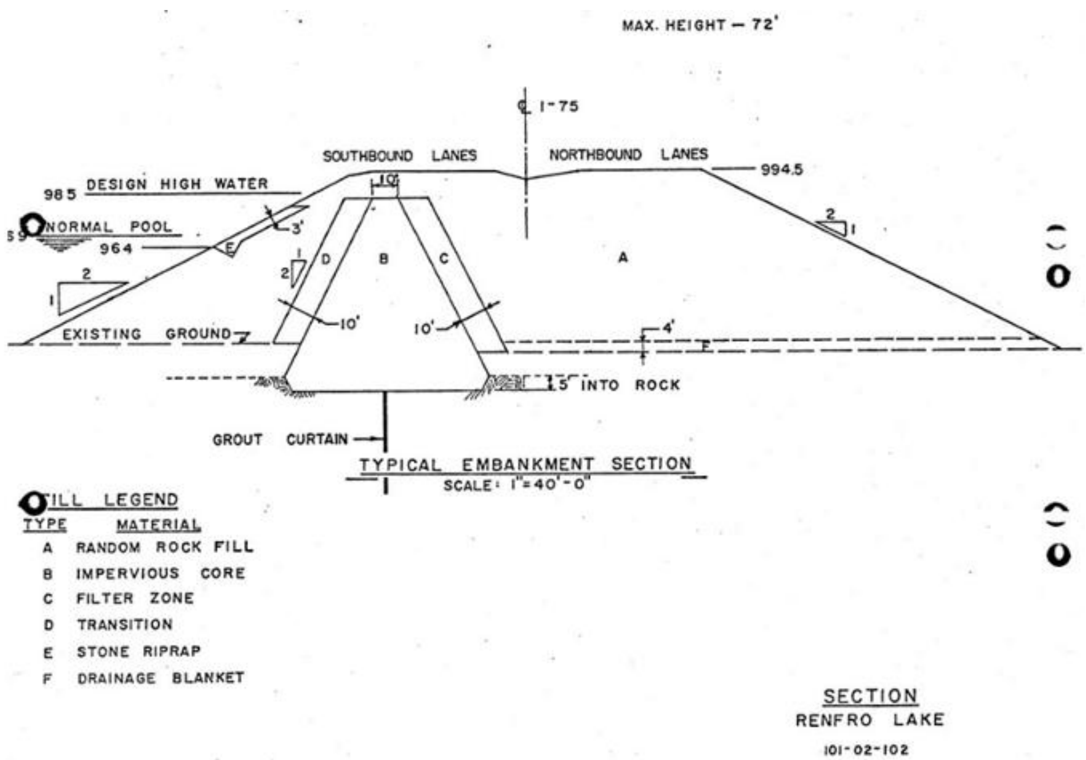
PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*
Storm event results in a flood pool. The flood pool approaches the crest and over a period of days, the pool drops as water drains through the morning glory spillway. This triggers a rapid drawdown slope failure on 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.**

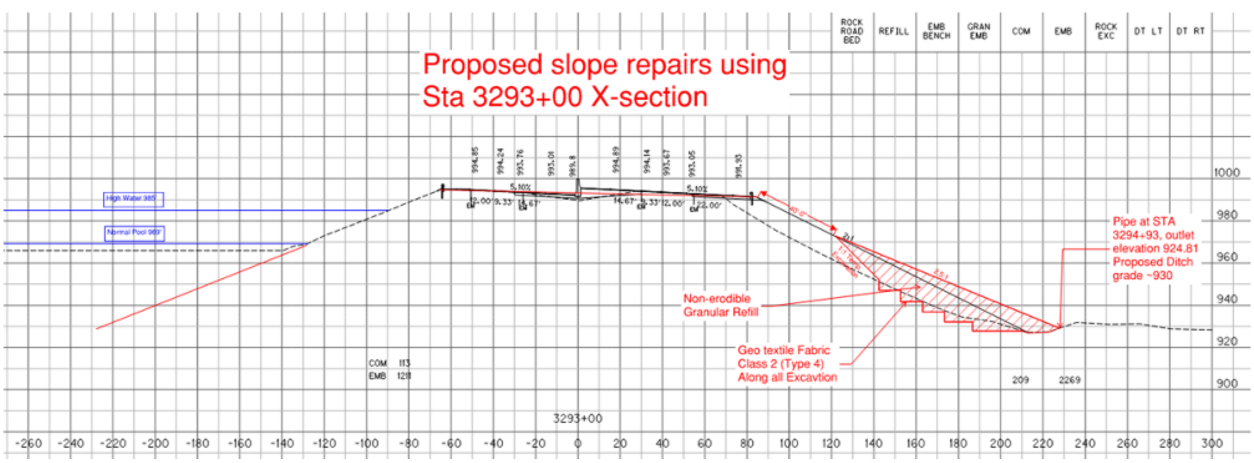
Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Negligible	Due to the size of the embankment and the certainty that we would observe and intervene.
Failure Likelihood		
Life Safety Consequences		

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)		

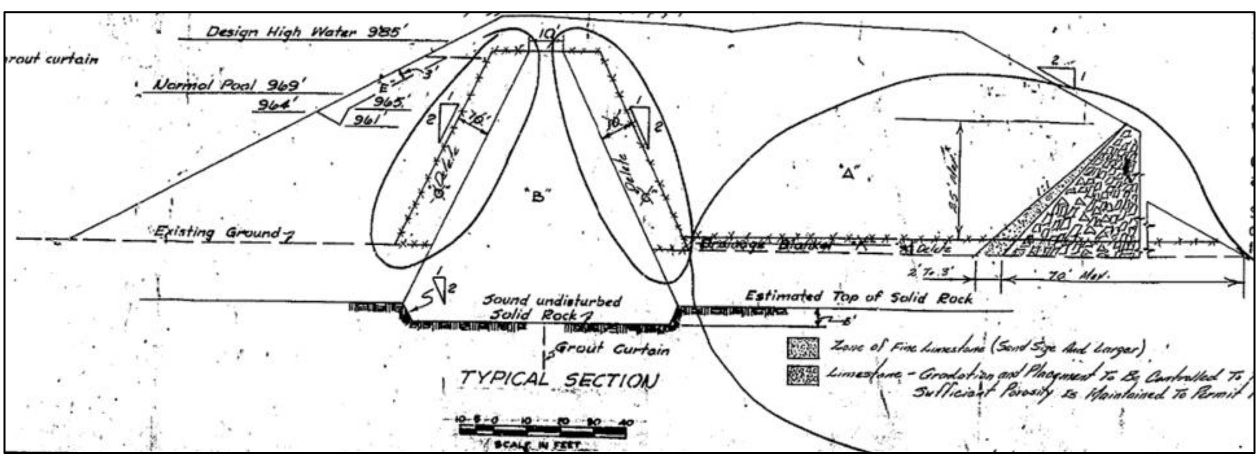
PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*
Downward seepage erodes foundation or embankment soils into open karst features in the bedrock. Erosion progresses until there is a breach of the dam.

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

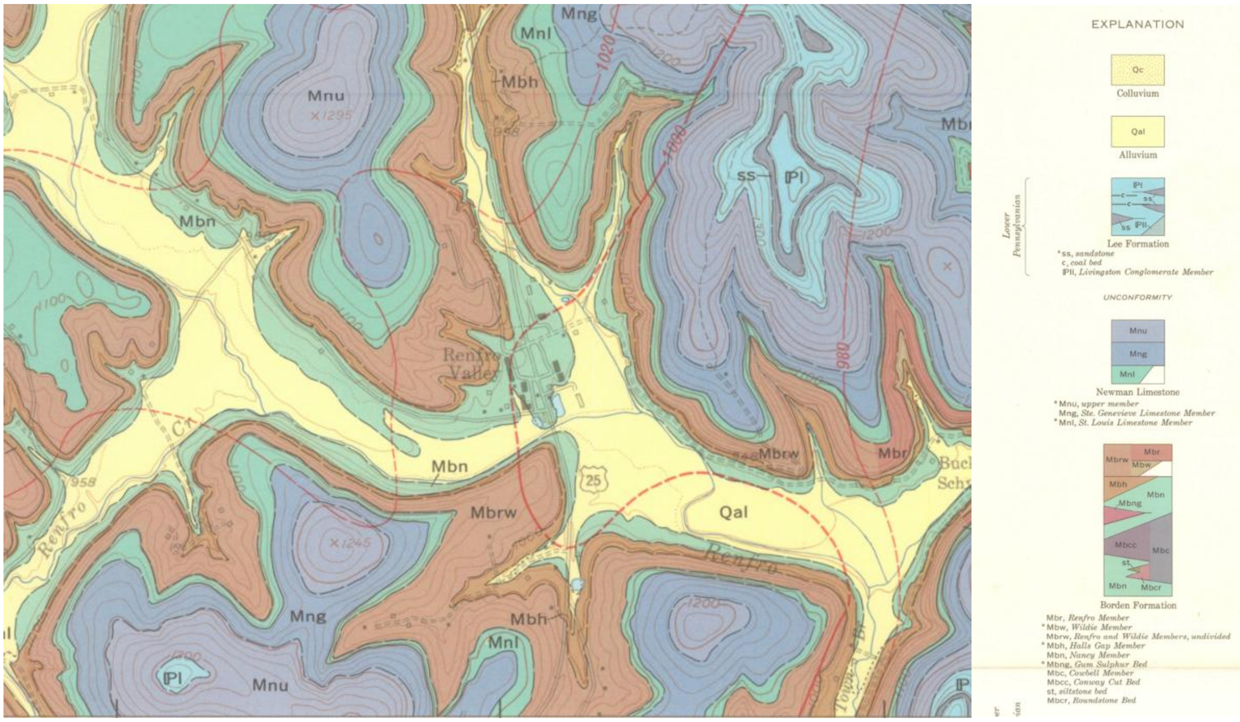
Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Negligible	
Failure Likelihood		

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

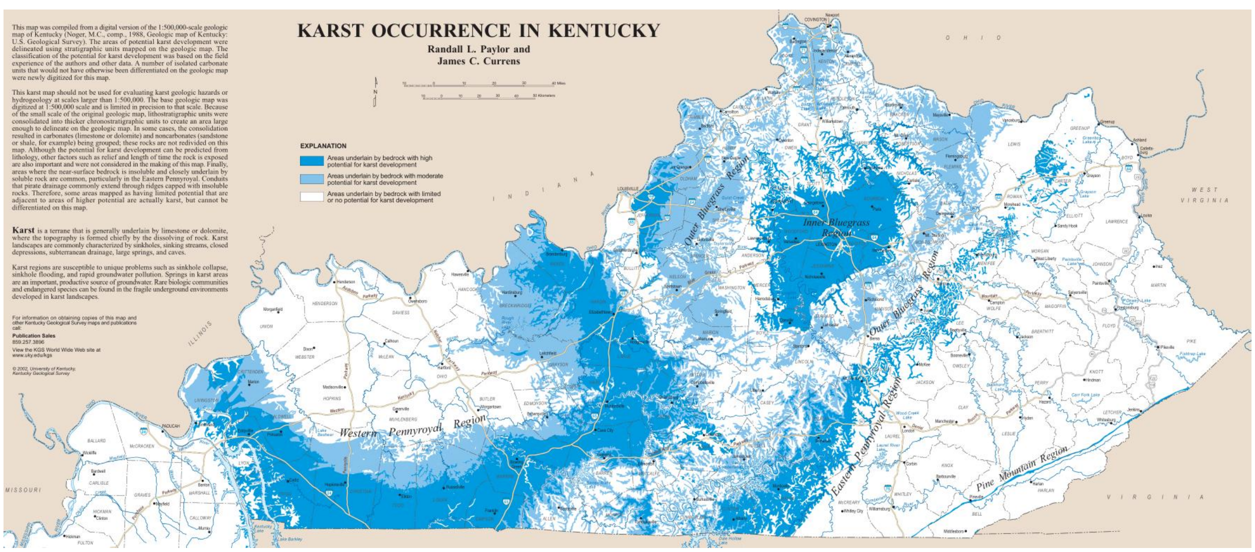
Supporting Figures:



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 diverson tunnel portal allowing enough room to build drawdown structure.*
2. *Install 24" Cast Iron Pipe.*
3. *Plug opening at main spillway tunnel and grout diverson 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~~, E 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.

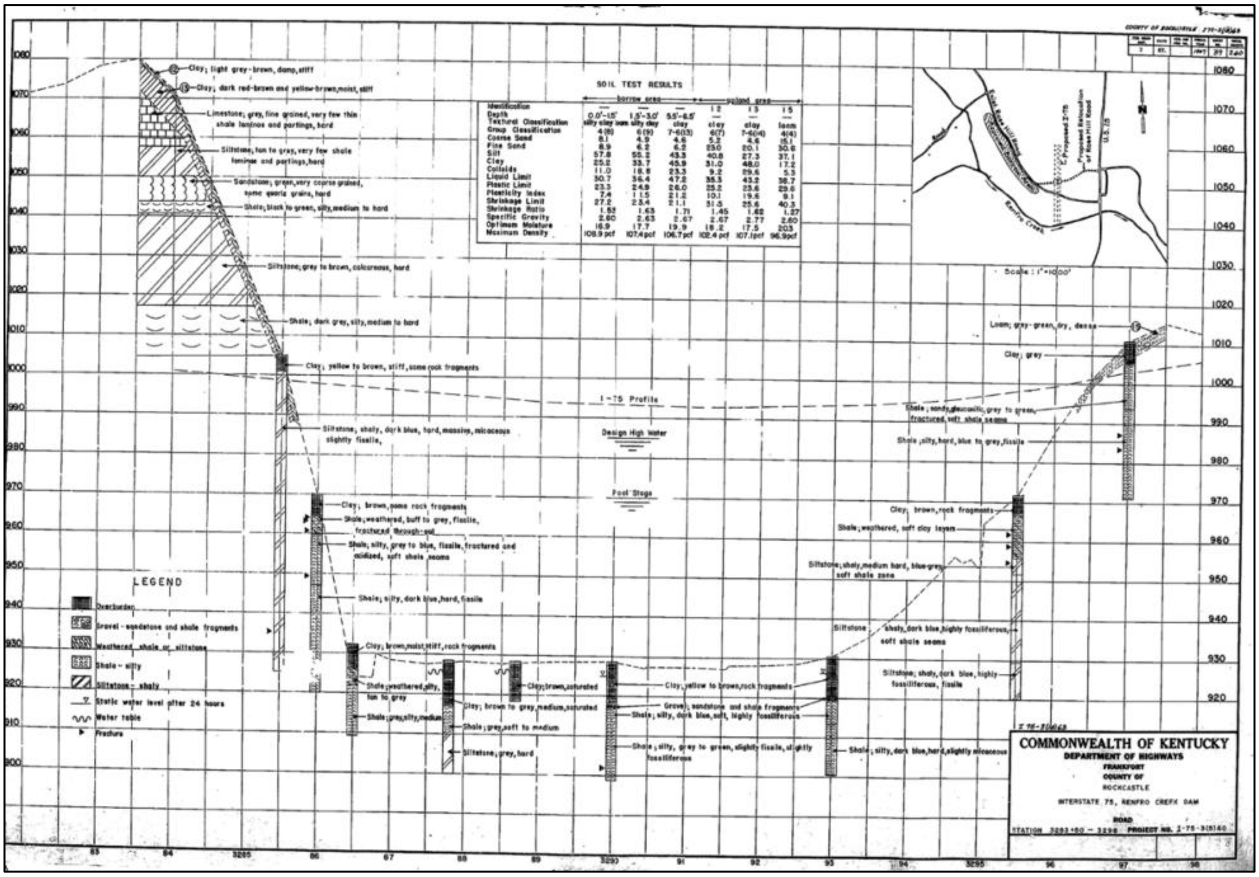
As a result of the sandstone not being available and substantially more limestone being present than originally anticipated, it has been concluded by the Consultant, Vogt-Ives and Associates, that an acceptable means for controlling the seepage pattern through the dam, with the materials that are actually available, would be to provide a rock toe on the downstream side of variable dimensions, maximum height of 25 feet and maximum width of 70 feet, along the downstream face of the rdwy. 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 E.B. Gaither, Jr., Director, Division of Design, dated May 18, 1967.

Since sandstone and placement thereof, including all incidental work for Zones C, D & F was to be paid for at the unit price bid for roadway embankment and since design is being changed to use limestone that is available as shown by Sheet 2H 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:

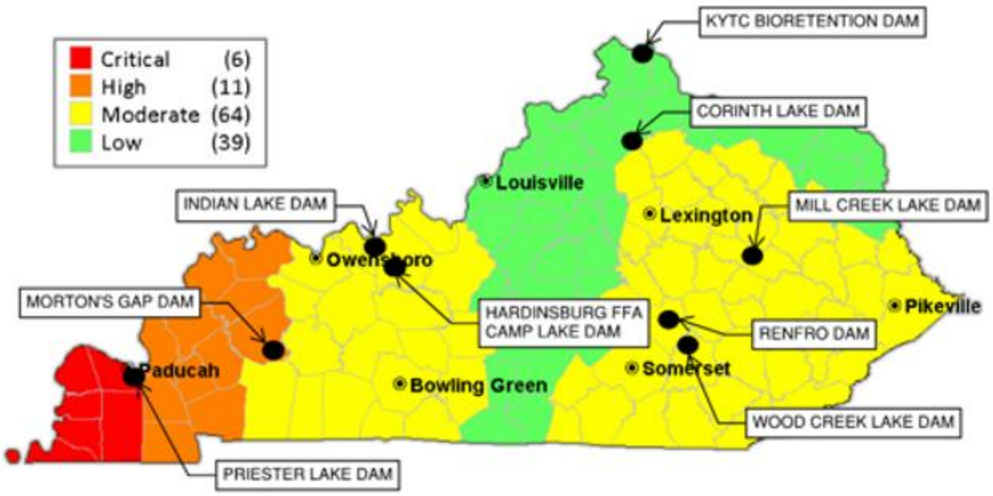
PFM No.:	R-3	**Dam:**	Renfro
PFM Group:	Seismic		
PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*			
A strong earthquake is felt at the dam site. The dynamic loads on the dam embankment cause slope displacements and possible slope failures. The deformations are 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

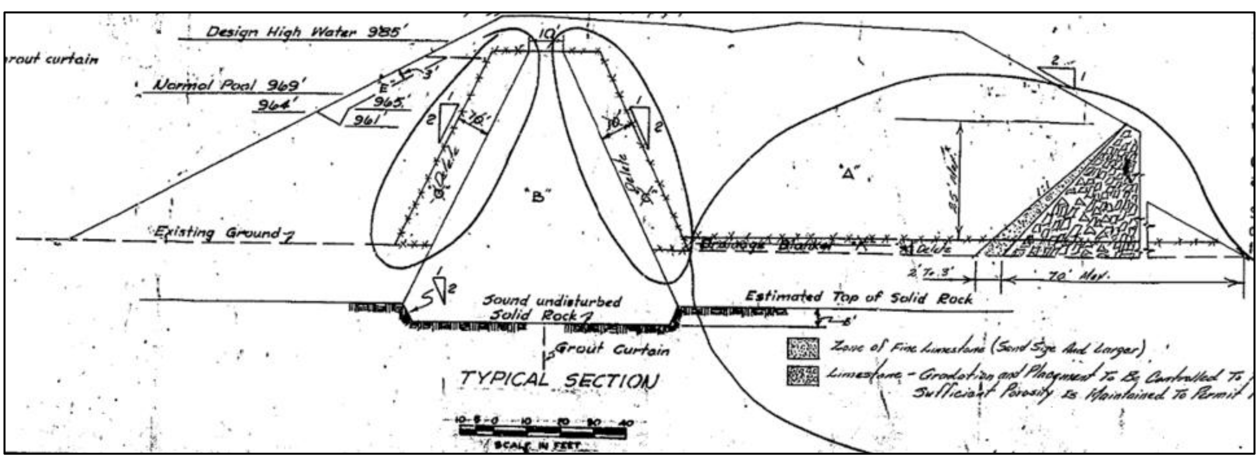
Risk Assessment	**Category**	**Notes**
Negligible? Credible?	Negligible	Probability of the loading is very low. The dam embankment is very wide. Breach is unlikely. The intervention is likely to be successful.
Failure Likelihood		
Life Safety Consequences		
Economic Consequences		

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	

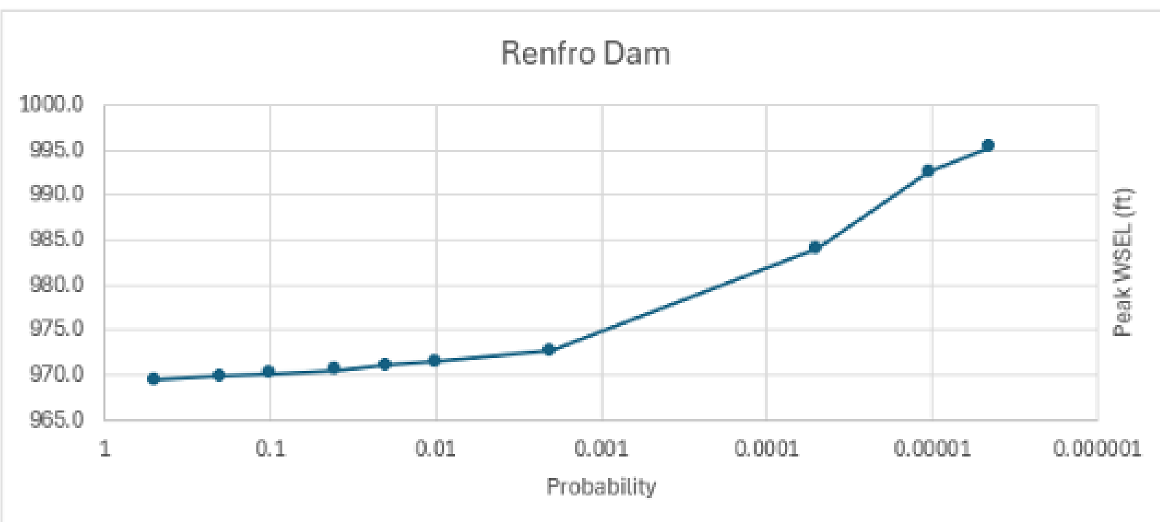
Supporting Figures:

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**

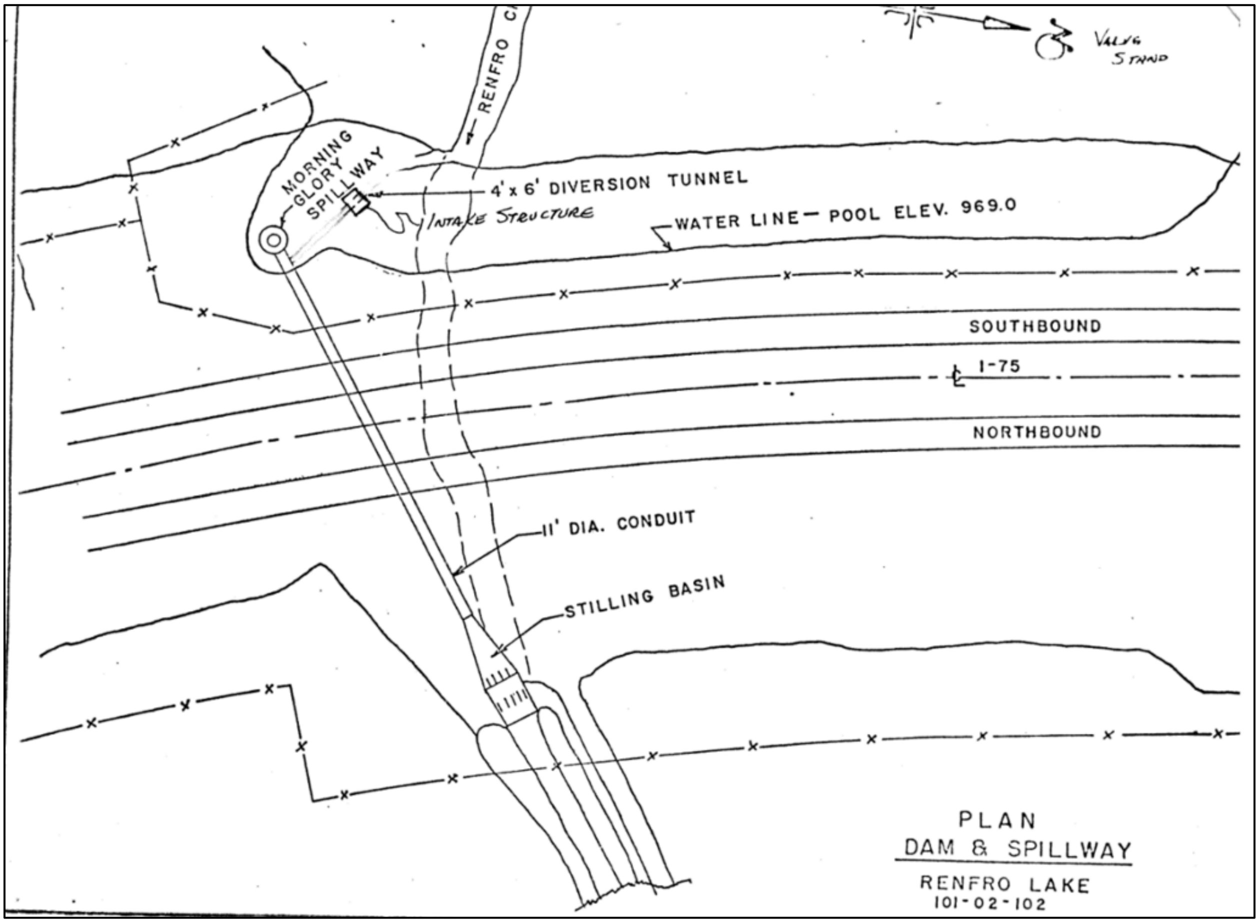
Note: Duration of overtopping for the PMP estimated to be ***7 hours***

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

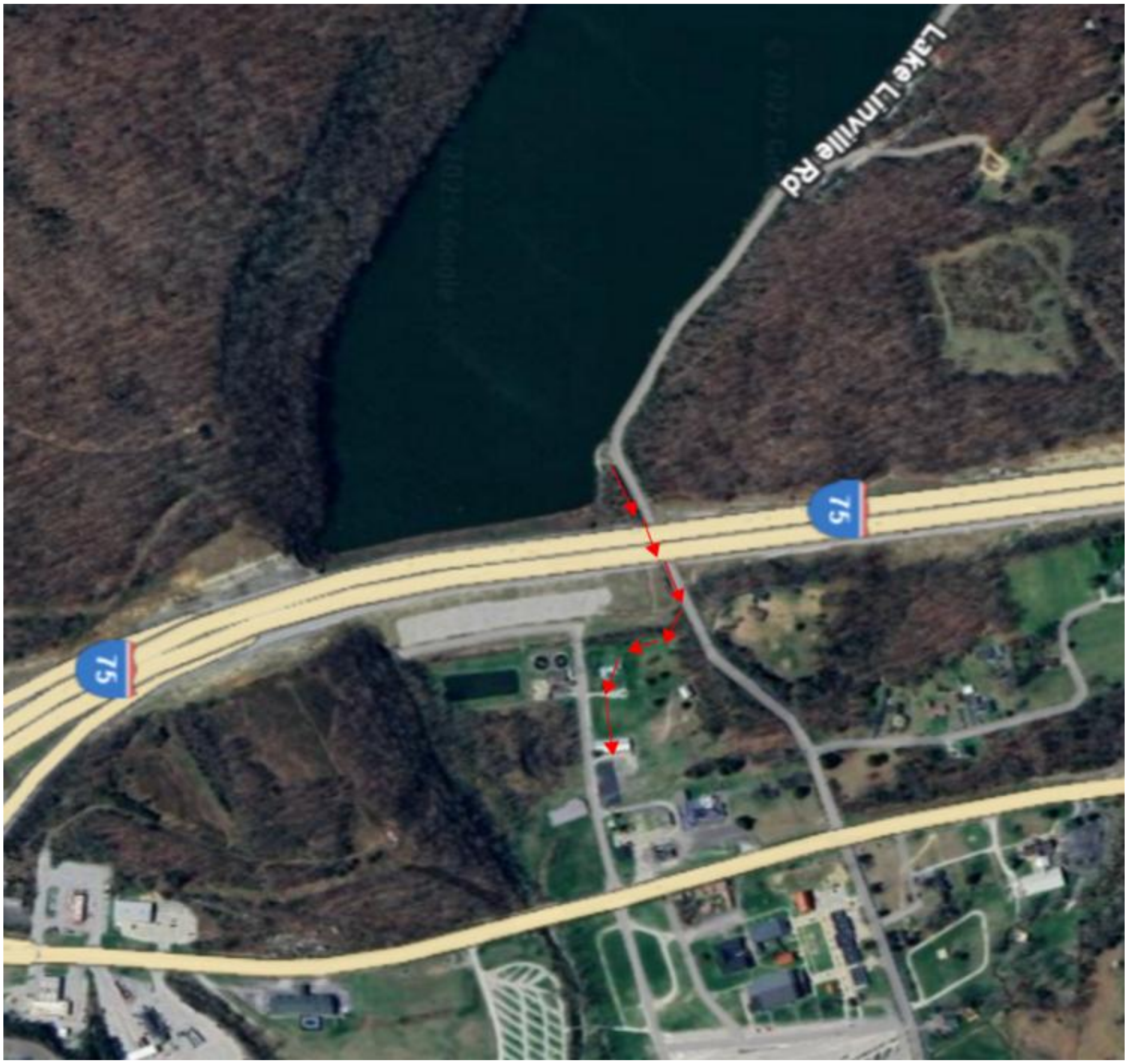
Note: Duration of overtopping for the PMP rainfall event with the ***spillway clogged*** *estimated to be* ***9 hours***



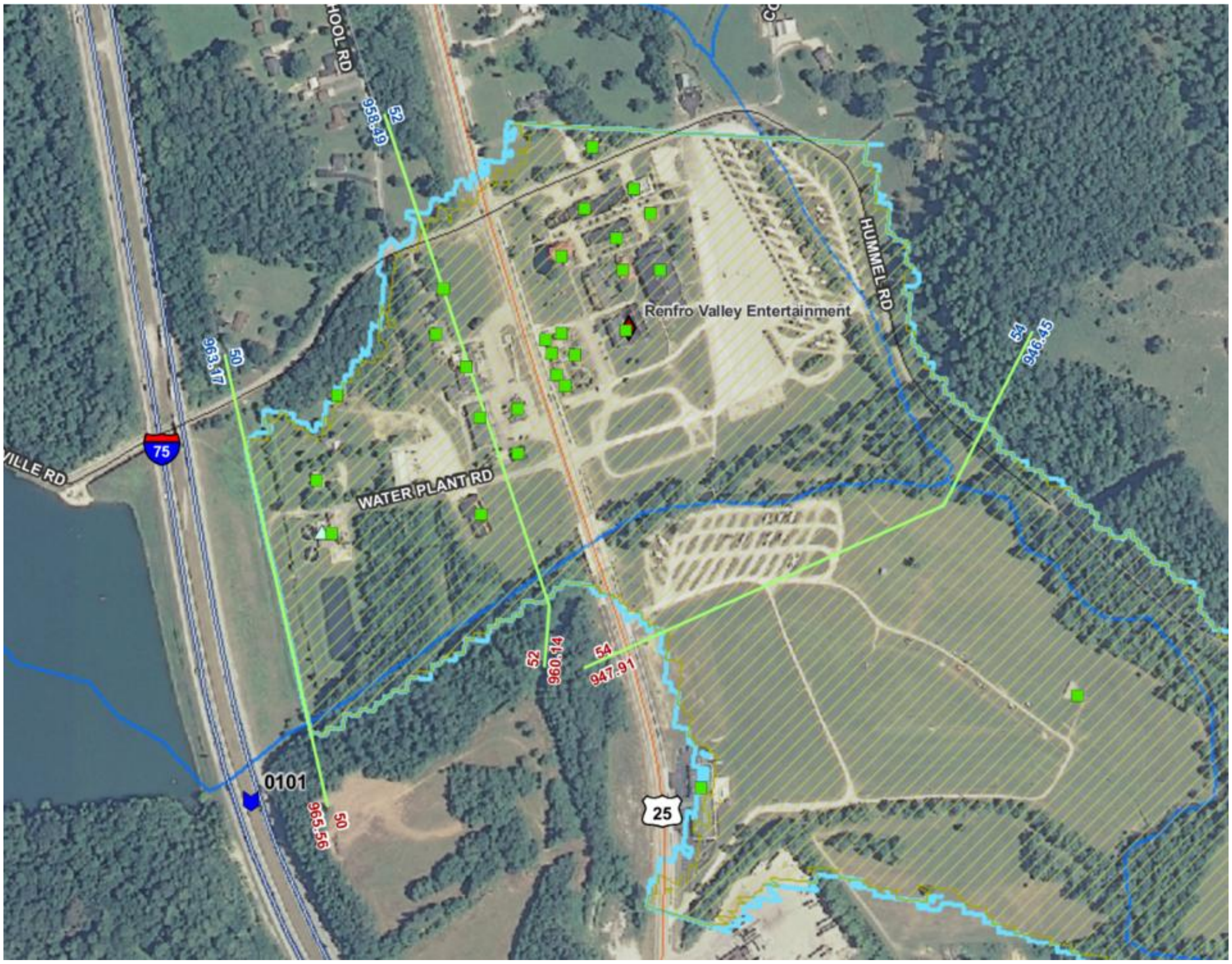
H&H Results



Plan View (USACE Louisville District, 1978)



Auxiliary Spillway Estimated Flow Path



Inundation Map

Potential Failure Mode Analysis Table:

<table>
<tr><td>PFM No.:</td><td>R-5</td><td>Dam:</td><td>Renfro</td></tr>
<tr><td>PFM Group:</td><td colspan="3">Erosion Associated with Conduits</td></tr>
<tr><td colspan="4">PFM Description (Flaw, Initiation, Continuation, Progression, Intervention, Failure)</td></tr>
<tr><td colspan="4">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.</td></tr>
<tr><td colspan="2">More Likely (Adverse) Factors</td><td colspan="2">Less Likely (Favorable) Factors</td></tr>
<tr><td colspan="2">•</td><td colspan="2">•</td></tr>
</table>

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

Failure Likelihood		
Life Safety Consequences		
Economic Consequences		

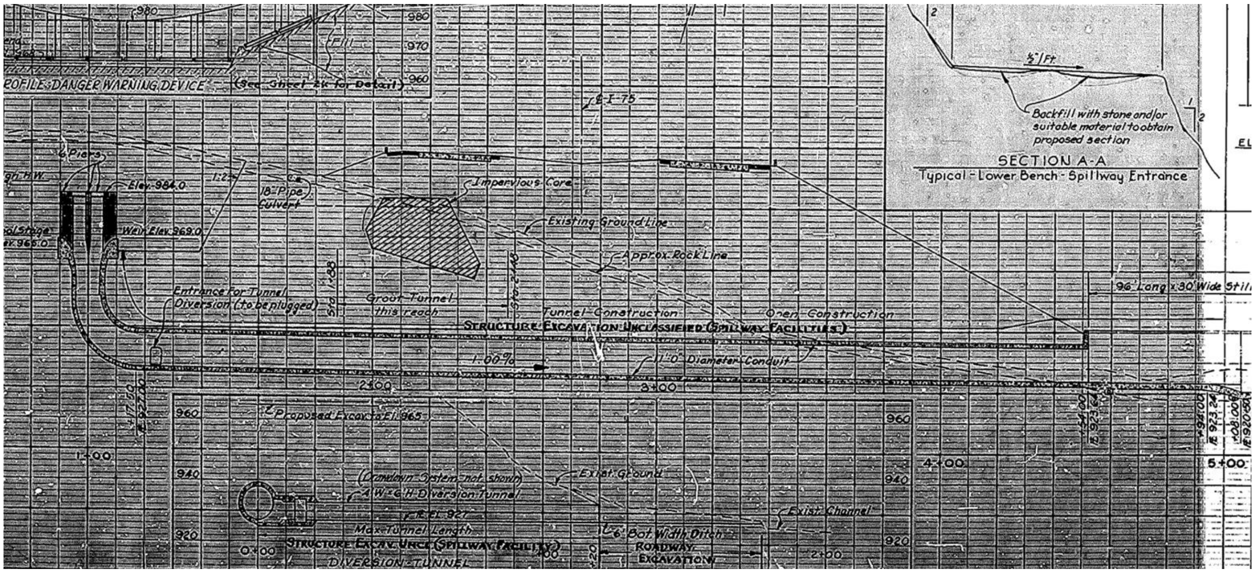
Risk Reduction Measures	
Studies and Investigations	Verification of raw water line alignment.
Maintenance and Monitoring	
Design and Modifications	

PFM No.:	R-6	**Dam:**	Renfro
PFM Group:	Spillway Structures - Morning Glory Spillway		

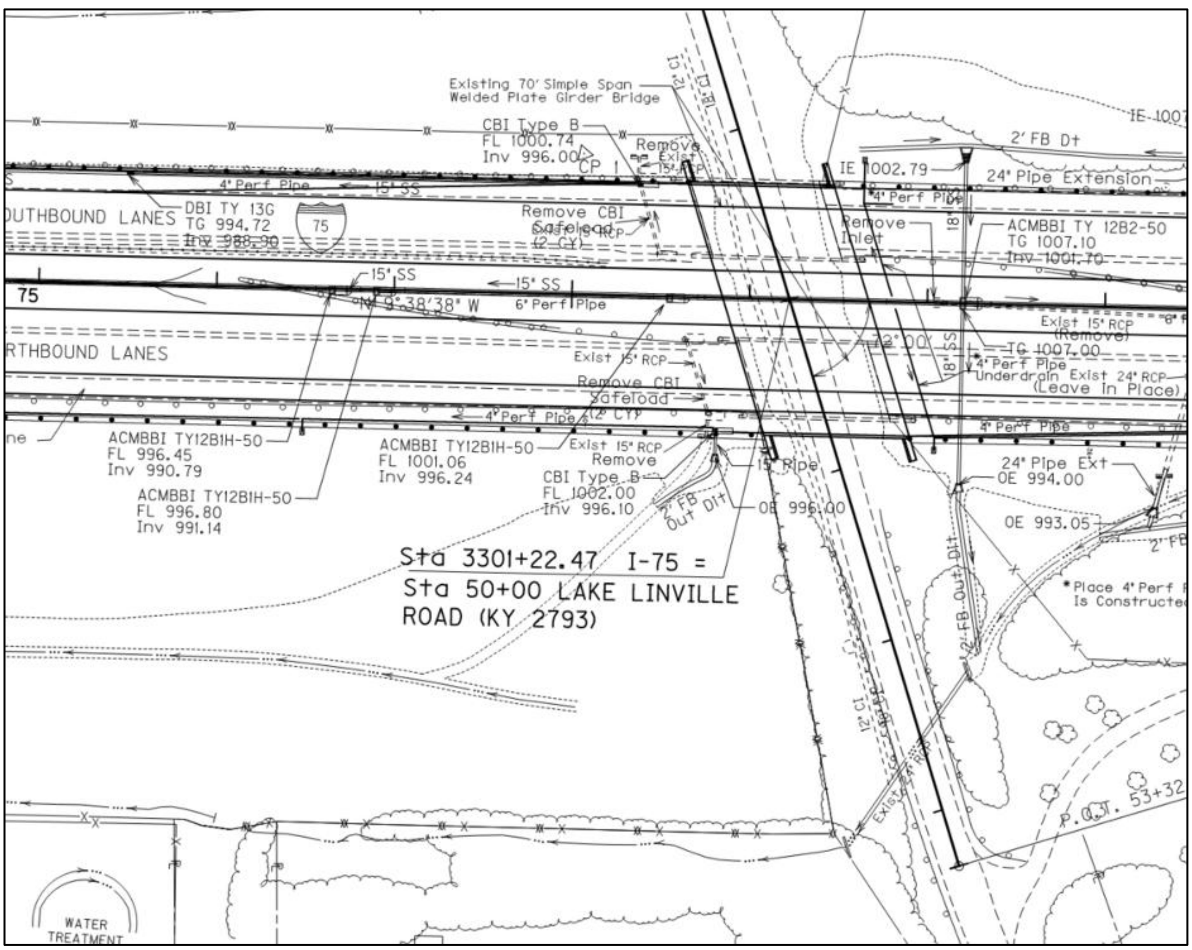
PFM Description (*Flaw, Initiation, Continuation, Progression, Intervention, Failure)*	
The morning glory spillway structure is in rock. Annual inspections are performed and no plausible failure mode has been documented.	
More Likely (Adverse) Factors	**Less Likely (Favorable) Factors**
•	•

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		

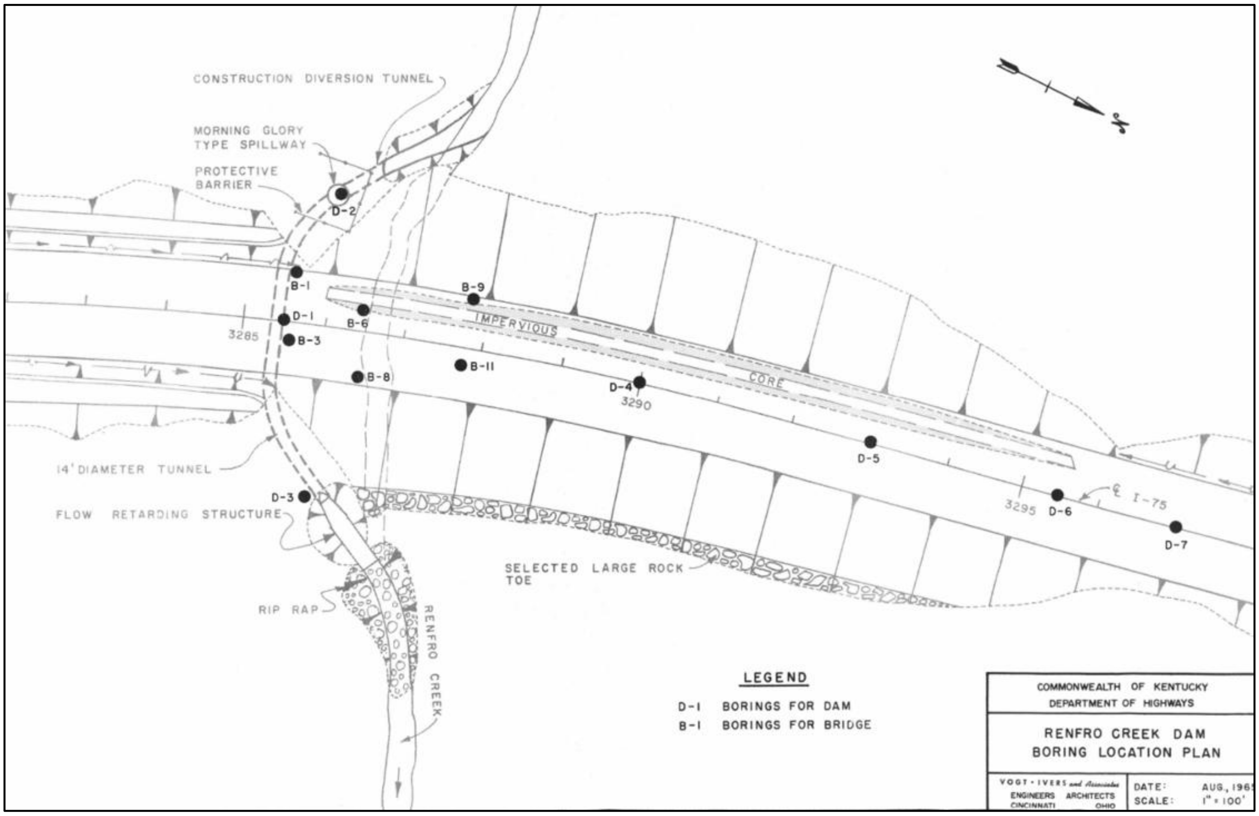
Supporting Figures:



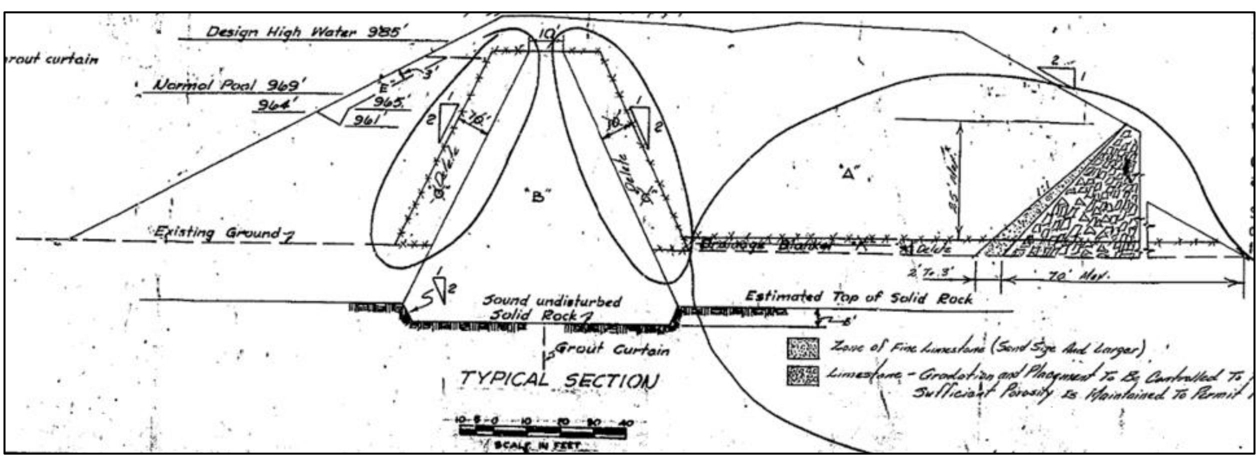
Conduit Profile from 1973 As-built Drawings (Commonwealth of Kentucky, 1967)



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.

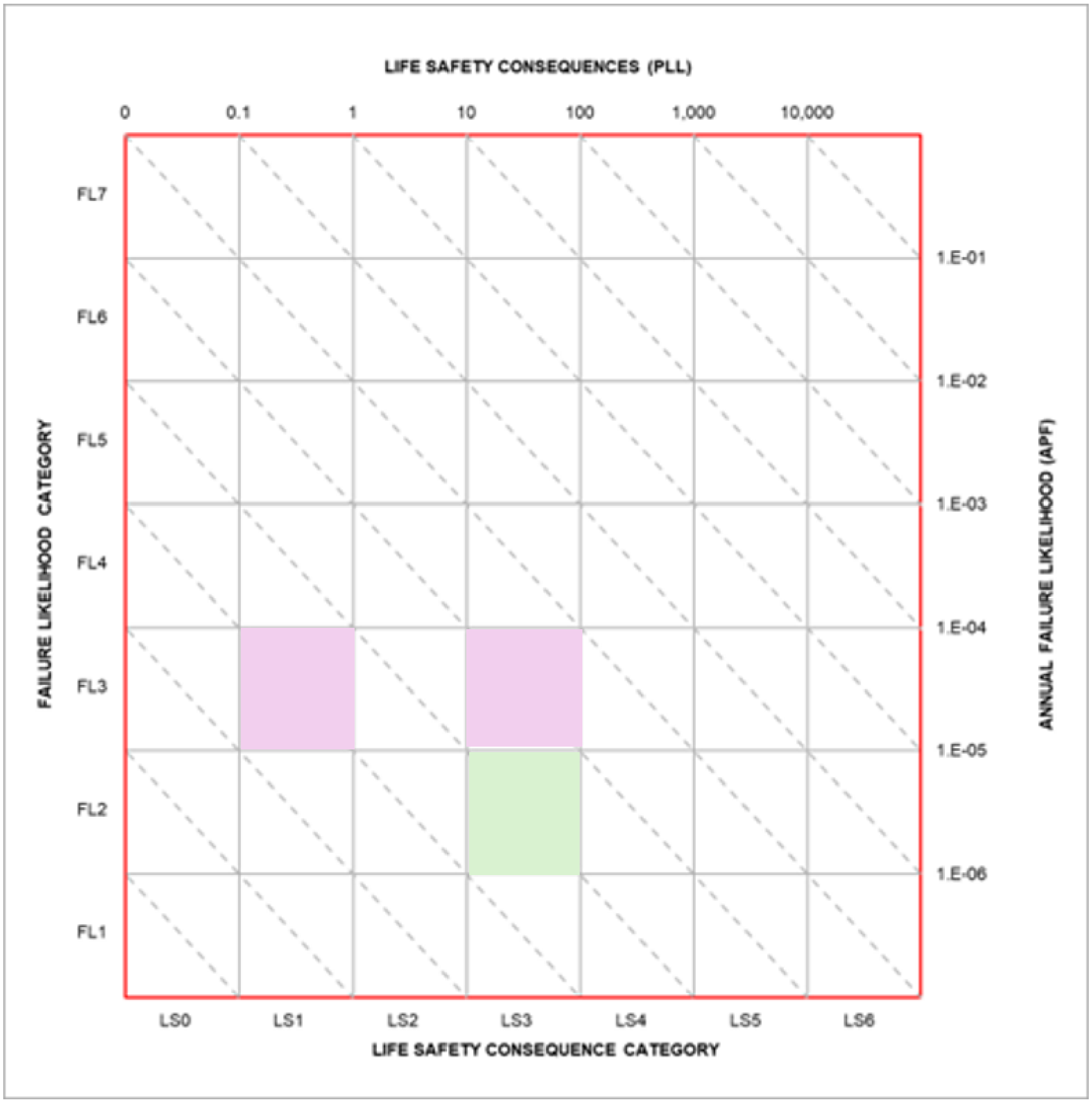
Life Safety Consequences	LS0	Slow drawdown, within the pipe
Economic Consequences	EC1	
Risk Reduction Measures		
Studies and Investigations	Determine the intake elevation for Water supply.	
Maintenance and Monitoring	Replace the slide gate, implement recommendations from 2024 inspections.	
Design and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

Supporting Figures:

Site Visit Photo

F.6 Risk Matrices

Life Safety Risk Matrix:



Legend:

Slope Stability

Internal Erosion

Seismic

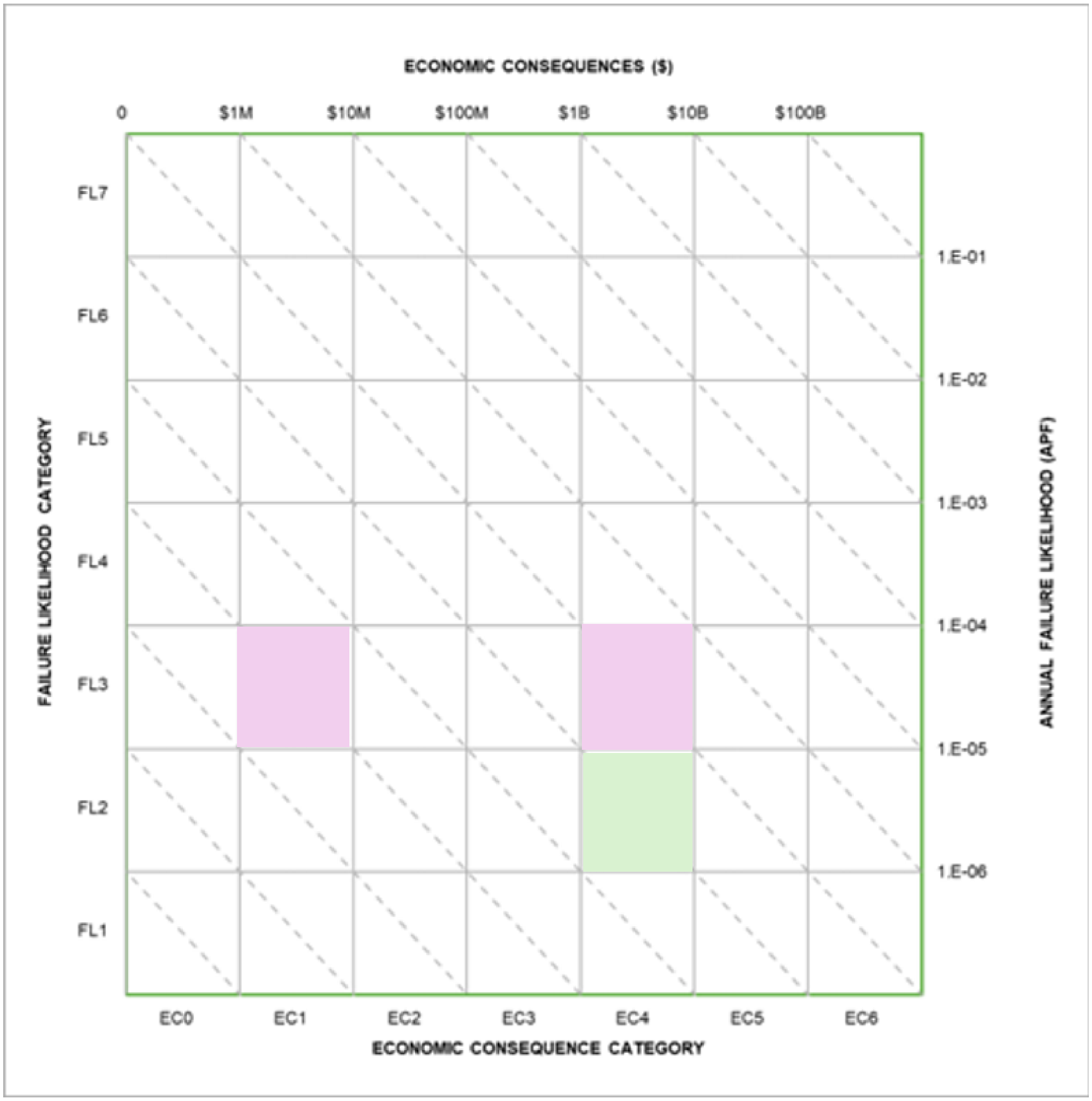
Overtopping

Erosion Associated with Conduits

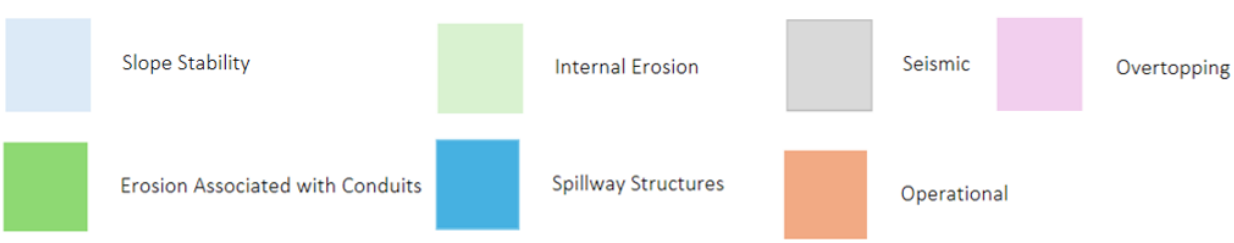
Spillway Structures

Operational

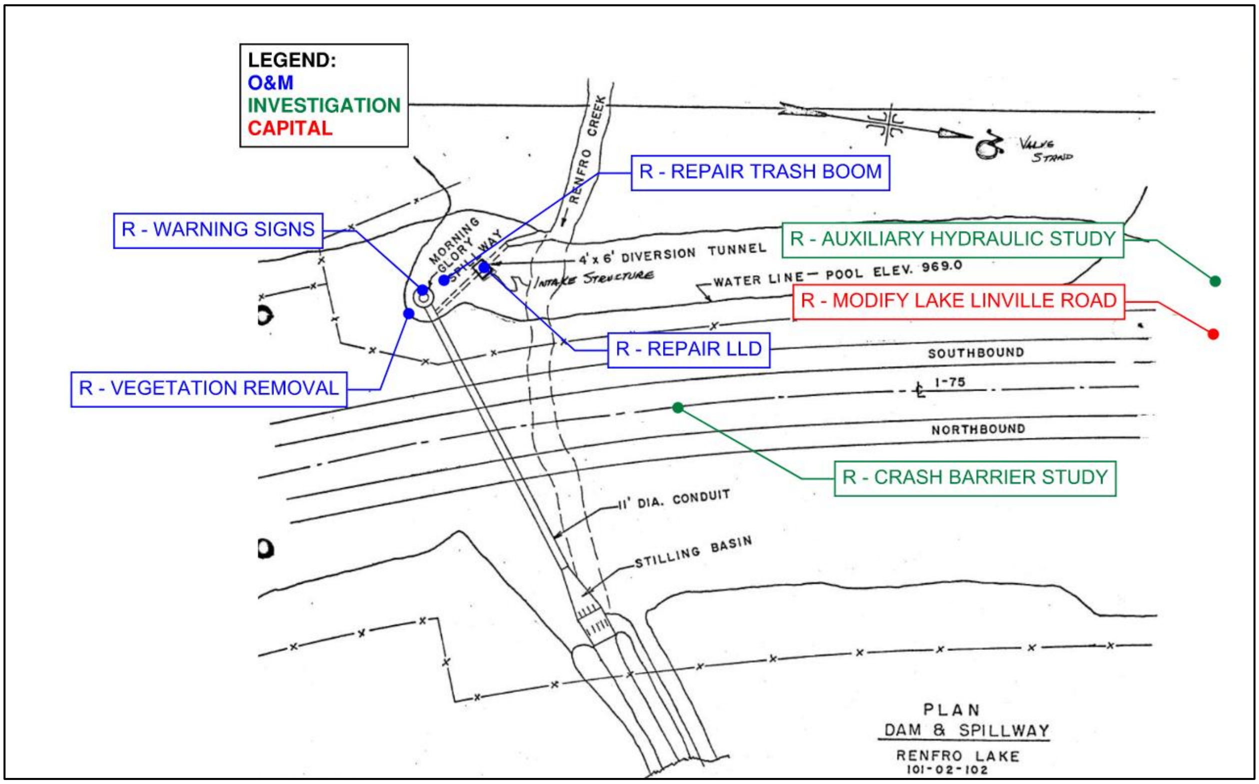
Economic Consequences Risk Matrix:



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