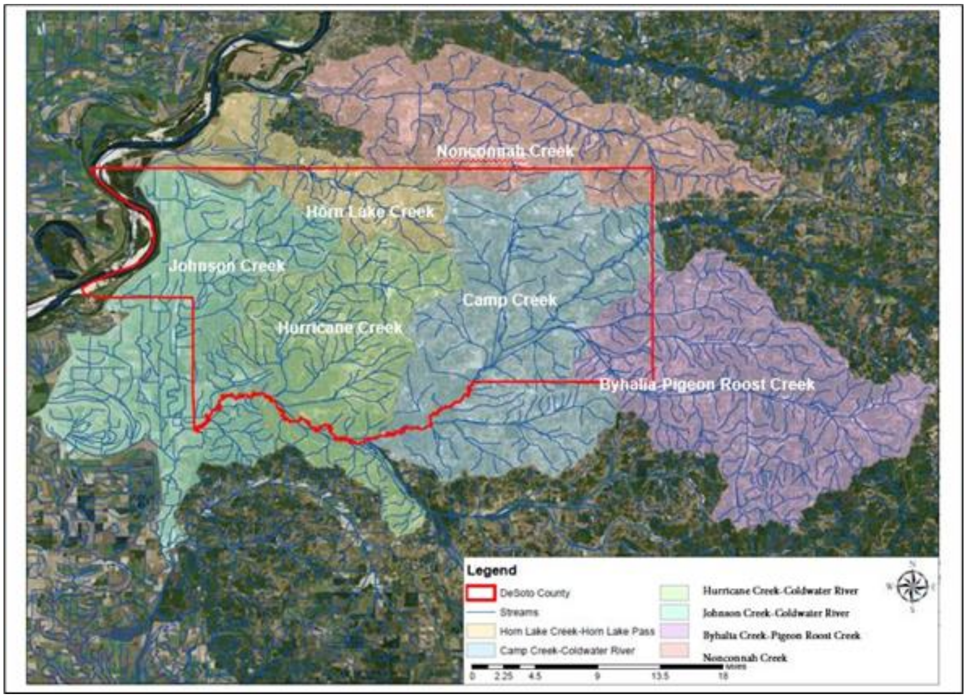
Memphis Metropolitan-Stormwater North DeSoto County, Mississippi Feasibility Study



Appendix E. Life Safety

February 2023

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1. Life Safety Risk Assessment

The United States Army Corps of Engineers (USACE) recognizes that risks to human life are a fundamental component of all flood risk management studies and must receive explicit consideration in the planning process. Current USACE guidance (PCB 2019-4, ECB 2019-03, ECB 2019-15, and the January 2021 Policy Directive – Comprehensive Documentation of Benefits in Decision Documents) on risk assessments in planning studies specifies how studies should be performed on new or existing dams and levees. This risk assessment's purpose is to make sure that the feasibility level designs follow the four Tolerable Risk Guidelines:

a. TRG 1 – Understanding the Risk
b. TRG 2 – Building Risk Awareness
c. TRG 3 – Fulfilling Daily Responsibilities
d. TRG 4 – Actions to Reduce Risk

While all these guidelines are important, TRGs 1 and 4 are critical to Planning studies. The risk assessment below is the first step to Understanding the Risk (TRG 1) of the proposed features and makes recommendations on changes that could Reduce the Risk (TRG 4).

An additional benefit of the risk assessment is the identification of areas of concern in the proposed design that may require extra attention during design or changes to design to ensure minimal risk to the public.

For this study, the life safety risk consideration was accomplished by performing an abbreviated Life Safety Consequence Assessment and a feasibility screening level Potential Failure Mode Analysis.

As part of this life safety analysis the primary alternative being evaluated is a levee-floodwall feature (Plan 8). The integrated feasibility report and environmental impact statement (IFR-EIS) covers the other alternatives and provides the context for this specific aspect of the study. The consequence evaluation deals with both the with and without project condition for the Plan 8 alternative as well as delves into the breach and non-breach scenarios for the with project condition.

2. Project Summary - Current Level of Design

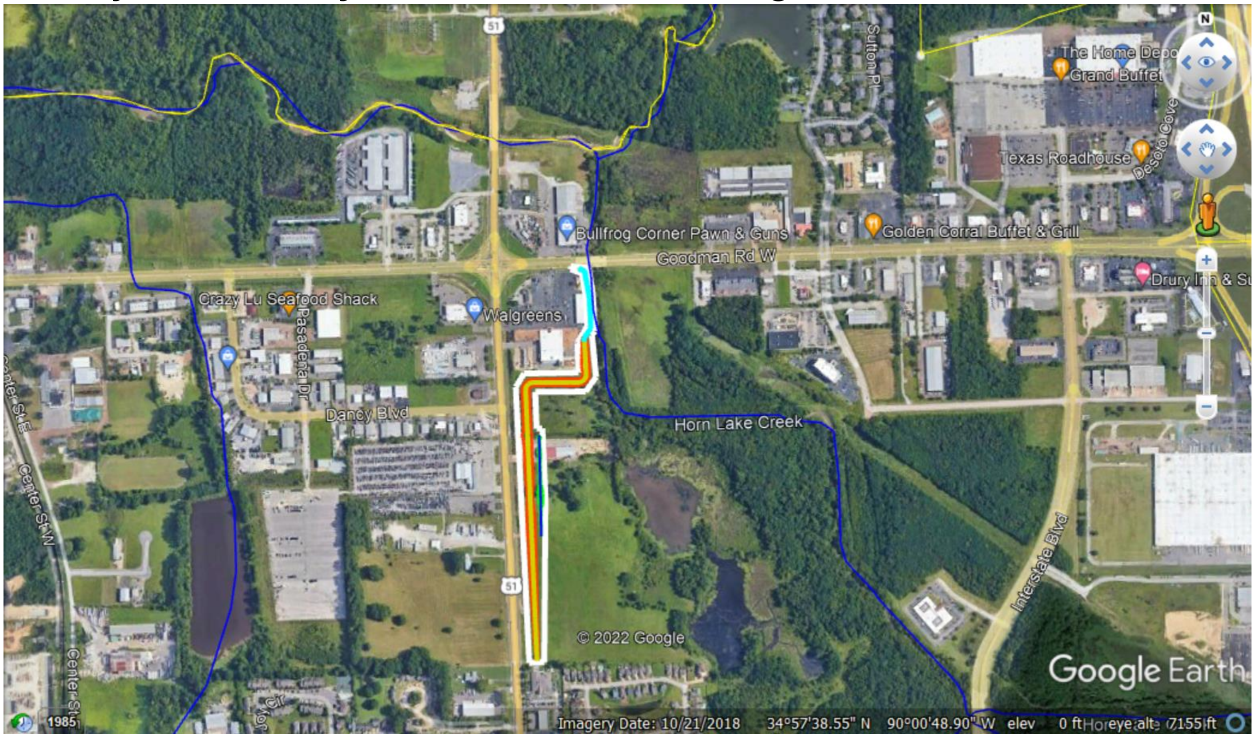


Figure 1: Plan 8 Levee Floodwall Alignment, DeSoto County, Mississippi. Yellow feature is levee and the turquoise feature is the floodwall. Horn Lake Creek flows from Southeast to the Northwest across Goodman Road and Hwy. 51.

The main body of the IFR-EIS covers in greater detail how USACE and the Non-Federal sponsor have arrived at evaluating the Plan 8 alternative and provides greater context for the alternative formulation and final arrays that have been developed.

The IFR-EIS includes a regional level understanding of the geology, with the near surface soils based on US Department of Agriculture – Natural Resource Conservation Survey (USDA – NRCS) soils survey maps. Figure 1 shows the alignment of Plan 8. Design is currently at the conceptual level at approximately 5 - 10% level of completion with plan view CADD alignments and crude typical cross-sections sufficient to estimate ROM quantities. Figure 2 shows an example of actual sections of the design that exemplify the infancy of the design.

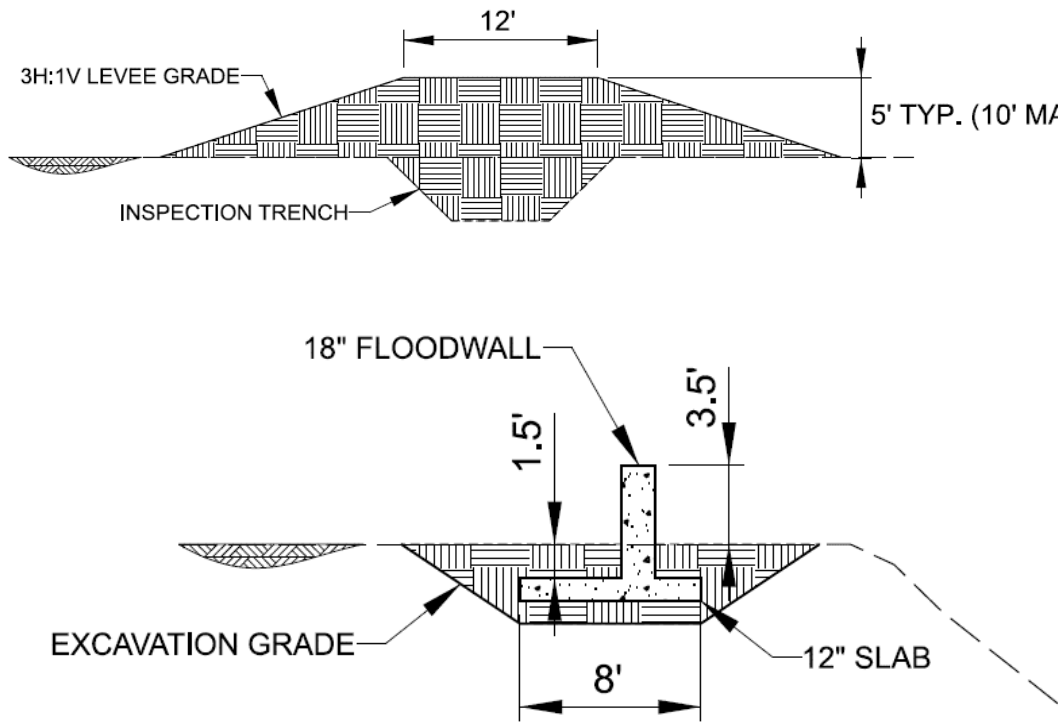


Figure 2: Example Design Cross Section from Plan 8.

3. Consequences

For the tentatively selected plan that has the construction of Plan 8 as the structural option, the worst-case breach condition was examined using HEC-RAS version 5.0.7. The worst-case condition hydraulically would be if a breach occurred due to piping at a location formed 1500 feet from the southernmost end of the levee. This location is inline with an existing ditch that will be cutoff by the levee and provides the lowest elevation for water to begin touching the levee and a likely location for piping to naturally form.

Horn Lake Creek is susceptible to high flow flashy storm events as well as prolonged high stages during wetter months of the year. Because of this both overtopping and piping breach scenarios were considered. In regard to the breach characteristics, degradation progression would have normally been used, but because of the typical flooding mechanism being short duration intense storms the levee would not adequately degrade. For this analysis, a complete blow-out breach with a width of 200 ft was simulated yielding the worst possibility of failure. Table 1 tabulates the results of the breach analysis as compared to the with and without project conditions.

Table 1 Water Surface Elevations Downstream of PLAN 8

AEP	Water Surface Elevation NAVD 88 (feet) XS 20402.2			Proposed Plan 8Difference	
	Existing	Proposed Plan 8 Alternative	Proposed Plan 8 Breached	Difference with Existing	Difference with Breach
0.2%	267.5	262.5	266.2	5.0	1.3

3.1. Breach Assumptions

There were performed two different breach scenario failure modes on the levee, piping and overtopping, for the 0.2% Annual Exceedance Probability (AEP) event. Breach locations for each failure mode were analyzed at locations along the centerline of the proposed levee at 800, 1500, and 1800 feet measured from the southernmost point of the proposed levee. The piping breach was initiated at a headwater surface elevation of 274.2. The overtopping breach initiated at a headwater surface elevation of 275.2.

3.2. EPZ

Figure 3. shows the Emergency Planning Zone (EPZ) for the North Desoto LifeSim model. The EPZ includes the population at risk of flooding if the proposed levee failed.

Figure 3. North Desoto EPZ

3.3. Population at Risk

Population at risk (PAR) is defined as the number of people within an affected area that would be subject to inundation during a flood hazard event. Estimates of PAR were generated using the National Structure Inventory 2.0 (NSI 2.0) for breach and non-breach inundation scenarios, as well as the existing without-project condition. The NSI 2.0 population data was developed in 2018 for both day and night population. The US Census Bureau estimates there has been no change in population in Desoto County. The estimated PAR by event is summarized in Table 2.

The PAR in this study area is largely residential with some small pockets of non-residential areas. The resident's awareness of their flood risk is unknown. Because the study is majority residential, the nighttime PAR is greater than the daytime PAR.

Table 2. Population and Structures at Risk.

Population and Structures at Risk						
Scenario	**AEP Event**	**Structures Inundated**	**Minimal Warning**		**Ample Warning**	
			PAR Day	**PAR Night**	**PAR Day**	**PAR Night**
Without-Project	1FT OT	808	2031	2763	2031	2755
	75% Loading	602	1080	2107	1081	2097
	50% Loading	225	405	630	405	629
Breach	1FT OT	811	2067	2769	2031	2755
	75% Loading	614	1167	2115	1081	2097
	50% Loading	71	133	211	133	211
Non-Breach	1FT OT	808	2031	2762	2067	2764
	75% Loading	602	1080	2107	1168	2106
	50% Loading	71	133	211	133	211

3.2. Life Loss Model Parameters

The consequence modeling was conducted with the Loss of Life Simulation software, LifeSim 2.0.1. To determine the percentage of population at risk (PAR) within a structure that is warned and mobilized over time, several parameters are used to estimate the probable values of warning and mobilization percentages as time passes. These include when warnings will be issued (hazard identification and communication delay), how long they will take to become effective (warning issuance and warning diffusion), and the rate at which PAR will mobilize in response (mobilization). Figure shows an example breach warning and response timeline.

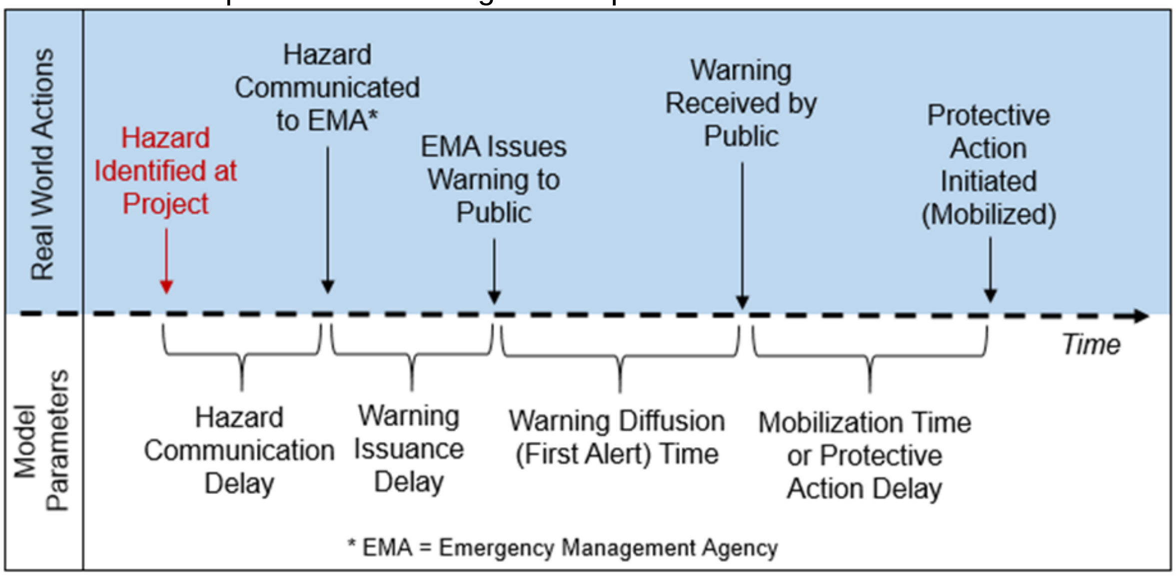


Figure 4. Example Breach Warning and Response Timeline.

Relative Hazard Identification

The Hazard Identification time is the time at which a hazard is identified (levee breach or major flooding) relative to when it occurs (actual breach time). The standard operating procedures from the USACE Mapping, Modeling and Consequence (MMC) production center uses two different warning scenarios with different distributions of hazard identification time: minimal warning and ample warning. Minimal warning scenarios have the hazard identification relative time set as a uniform distribution between 3 hours prior to the event and half an hour after the event occurs. Ample warning scenarios have the hazard identification relative time set as 24 hours prior to the event. The Relative Hazard Identification Times used for this study are summarized in Table 3.

Table 3. Relative Hazard Identification Times.

Warning Scenario	Distribution Type	Minimum (hours)	Maximum (hours)
Minimal	Uniform	-2	0
Ample	Uniform	-24	

Hazard Communication Delay

The Hazard Communication Delay is the time that it would take from when the hazard is identified to when the emergency planning zone (EPZ) representatives is notified. For example, if a breach occurs when no one is observing the project then the emergency managers would be notified after the hazard is identified. The hazard communication delay is set as a uniform distribution between 0.01 hours and 0.5 hours.

Warning Issuance Delay

The Warning Issuance Delay is the time it takes from when the emergency managers receive the notification of the imminent hazard to when they issue the first evacuation order to the public.

For this model, Preparedness Unknown was selected from among LifeSim's preset distributions for Warning Issuance Delay. In the absence of a Mileti & Sorenson interview, the distribution with the greatest uncertainty was chosen. This means the time it takes the emergency managers to issue the first evacuation order is most likely within 30 minutes of receiving the notification of an imminent hazard from the official monitoring storm activity. The Preparedness Unknown curve is shown in Figure .

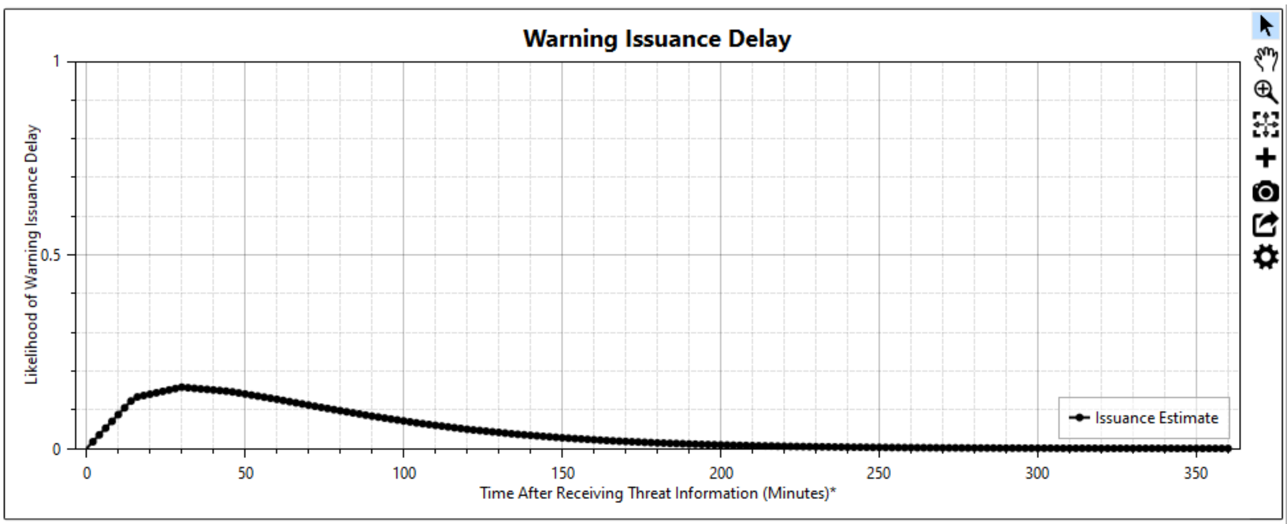


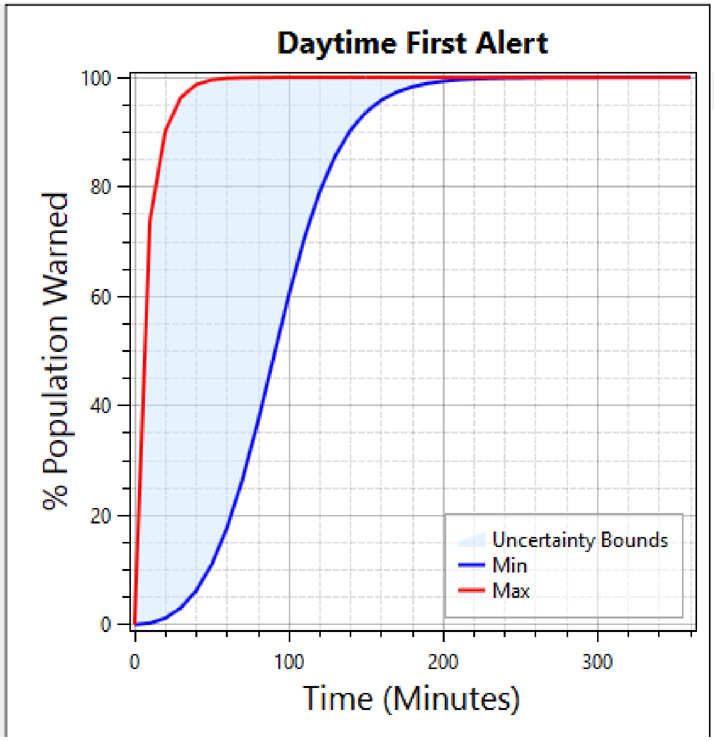
Figure 5. Warning Issuance Delay.

Warning Diffusion (First Alert)

Warning diffusion is the time between a first alert or warning issuance and the time that PAR receive that warning. It is primarily dependent on what type of warning systems and procedures are in place and the ability of the population to receive the warning via those systems. The warning diffusion curve represents the efficiency of a warning after it is issued.

The Warning Diffusion curves in Figure, set to LifeSim's Unknown/Unknown preset due to the absence of a Mileti & Sorenson Interview, provide a distribution for warning dissemination at 2am and 2pm. The daytime diffusion curve represents the percentage of the population which will receive a first alert warning over time during daytime hours after the warning is issued. The nighttime diffusion curve represents the percentage of the population which will receive a first alert warning over time during nighttime hours after the warning is issued.

Time (Minutes)	Minimum % Warned	Maximum % Warned
0	0	0
10	0.28	73.75
20	1.21	90.199997
30	3.06	96.32
40	6.19	98.68
50	10.96	99.540001
60	17.700001	99.839996
70	26.49	99.940002
80	37.060001	99.980003
90	48.639999	99.989998
100	60.130001	100
110	70.489998	100
120	79.040001	100
130	85.589996	100
140	90.330002	100
150	93.629997	100



Time (Minutes)	Minimum % Warned	Maximum % Warned
0	0	0
10	0.18	39.889999
20	0.73	72.139999
30	1.73	83.360001
40	3.24	89.400002
50	5.33	93.360001
60	8.07	95.910004
70	11.51	97.510002
80	15.67	98.489998
90	20.52	99.089996
100	26.030001	99.449997
110	32.07	99.669998
120	38.490002	99.800003
130	45.119999	99.879997
140	51.740002	99.93
150	58.16	99.959999

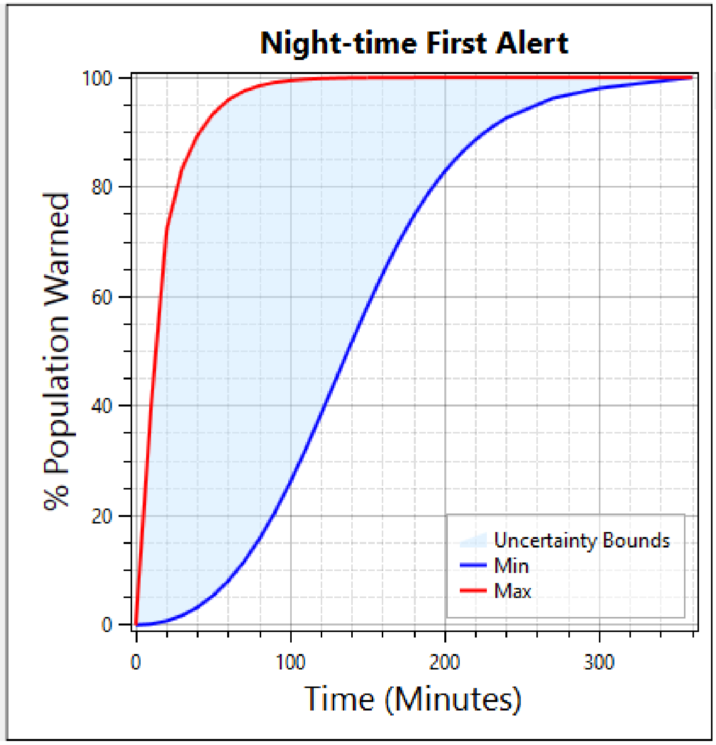


Figure 6. Warning Diffusion Curves for Daytime and Night-Time First Alert.

Protective Action Initiation

Protective Action Initiation (PAI) is the rate at which PAR take action after receiving an evacuation order (warning) (Figure). Unlike the warning diffusion curves, the PAI curves include a perception element as well. The perception element describes the relative awareness of the PAR. Preparedness: Unknown/Perception: Unknown was again selected for this study area.

Time (Minutes)	Minimum % Mobilized	Maximum % Mobilized
0	0	0
10	0.07	14.79
20	0.14	47.27
30	0.31	76.309998
40	0.54	92.269997
50	0.85	98.169998
60	1.21	99.68
70	1.64	99.949997
80	2.12	99.949997
90	2.66	99.949997
100	3.26	99.949997
110	3.9	99.949997
120	4.59	99.949997
180	9.48	99.949997
240	14.99	99.949997
300	20.32	99.949997
360	24.870001	99.949997
420	28.379999	99.949997

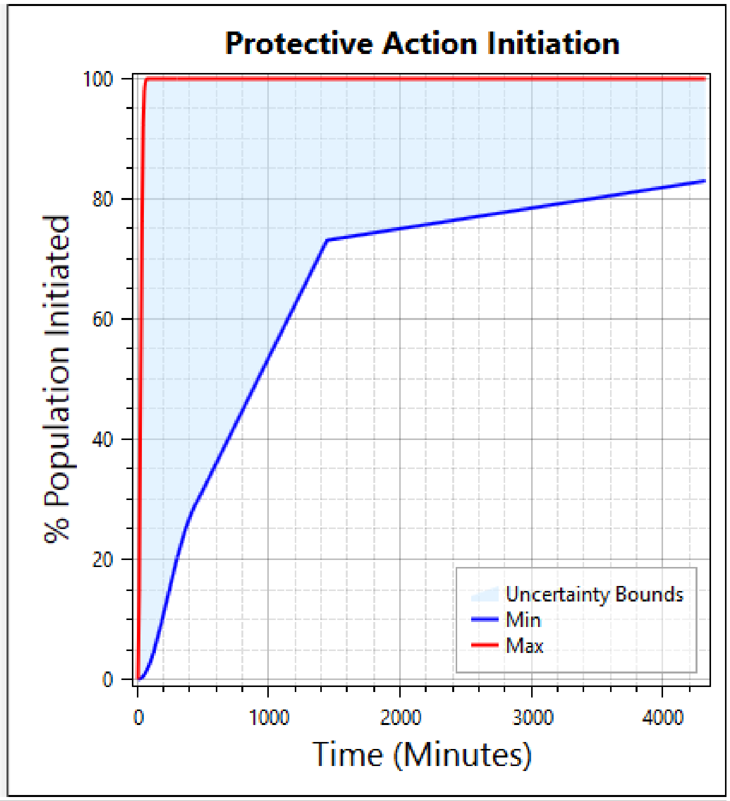


Figure 7. Protective Action (PAI) Curve.

3.3. Life Loss

Existing Without-Project Condition

Estimates of life loss were generated using HEC-LifeSim for without-project, breach, and non-breach inundation scenarios. HEC-LifeSim utilizes Monte Carlo uncertainty analysis, and 1,000 Monte Carlo iterations were run for each scenario. The estimated life loss totals in the existing without-project condition by warning time are summarized below in Table 4. The life loss statistics for each run are shown in the Figure and Figure box-and-whisker plots. The ranges only reflect the uncertainty parameters for life loss as modeled in the HEC-LifeSim scenarios and do not include uncertainties for the breach parameters or other hydraulic/hydrologic factors.

Table 4. Without Project Life Loss with Minimal and Ample Warning

Without Project Life Loss								
Minimal Warning								
Scenario Name	Median Total Life Loss		Life Loss Total 25th Percentile		Life Loss Total 75th Percentile		Life Loss Total Max	
	Day	Night	Day	Night	Day	Night	Day	Night
1FT OT	0	0	0	0	0	0	4	3
100% Loading	0	0	0	0	0	0	1	2
50% Loading	0	0	0	0	0	0	0	0
Ample Warning								
Scenario Name	Median Total Life Loss		Life Loss Total 25th Percentile		Life Loss Total 75th Percentile		Life Loss Total Max	
	Day	Night	Day	Night	Day	Night	Day	Night
1FT OT	0	0	0	0	0	0	1	2
100% Loading	0	0	0	0	0	0	0	0
50% Loading	0	0	0	0	0	0	1	1

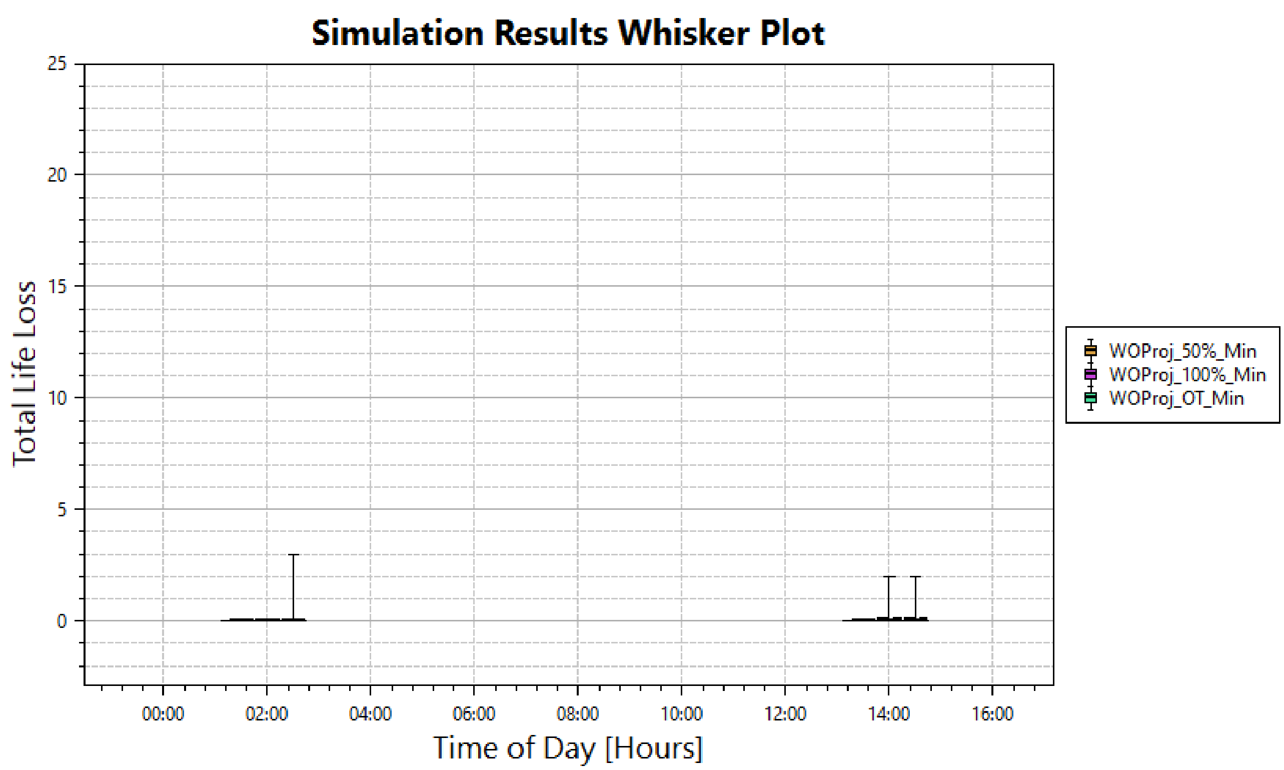


Figure 8. Life Loss with Minimal Warning in the Existing Condition.

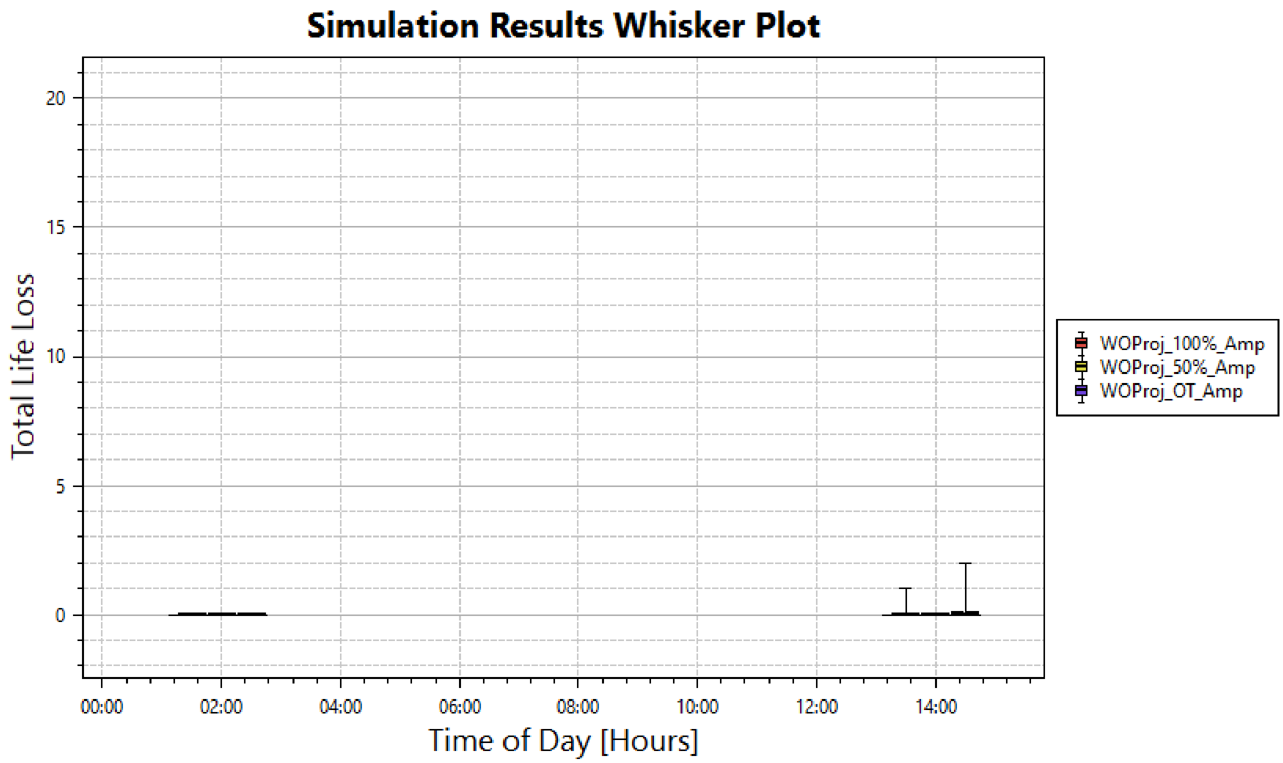


Figure 9. Life Loss with Ample Warning in the Existing Condition.

With-Project Condition – Non-Breach Scenario

The estimated life loss totals in the non-breach scenario by warning time are summarized in Table 5, Figure, and Figure.

Table 5. Life Loss and PAR with Minimal Warning and Ample Warning, With Project, Non-Breach.

Non-Breach Life Loss								
Minimal Warning								
Scenario Name	Median Total Life Loss		Life Loss Total 25th Percentile		Life Loss Total 75th Percentile		Life Loss Total Max	
	Day	Night	Day	Night	Day	Night	Day	Night
1 FT OT	0	0	0	0	0	0	4	3
100% Loading	0	0	0	0	0	0	1	2
50% Loading	0	0	0	0	0	0	0	1
Ample Warning								
Scenario Name	Median Total Life Loss		Life Loss Total 25th Percentile		Life Loss Total 75th Percentile		Life Loss Total Max	
	Day	Night	Day	Night	Day	Night	Day	Night
1FT OT	0	0	0	0	0	0	1	3
100% Loading	0	0	0	0	0	0	0	0
50% Loading	0	0	0	0	0	0	1	1

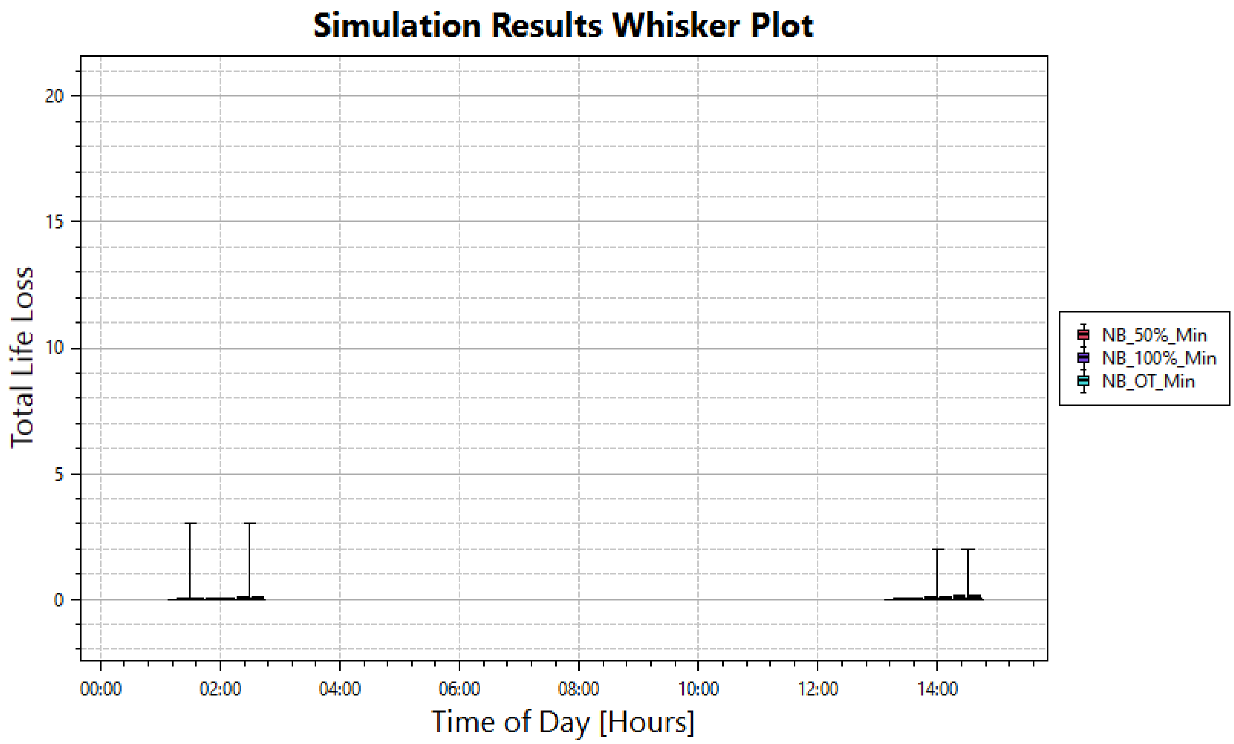


Figure 10. Life Loss with Minimal Warning, With Project, Non-Breach.

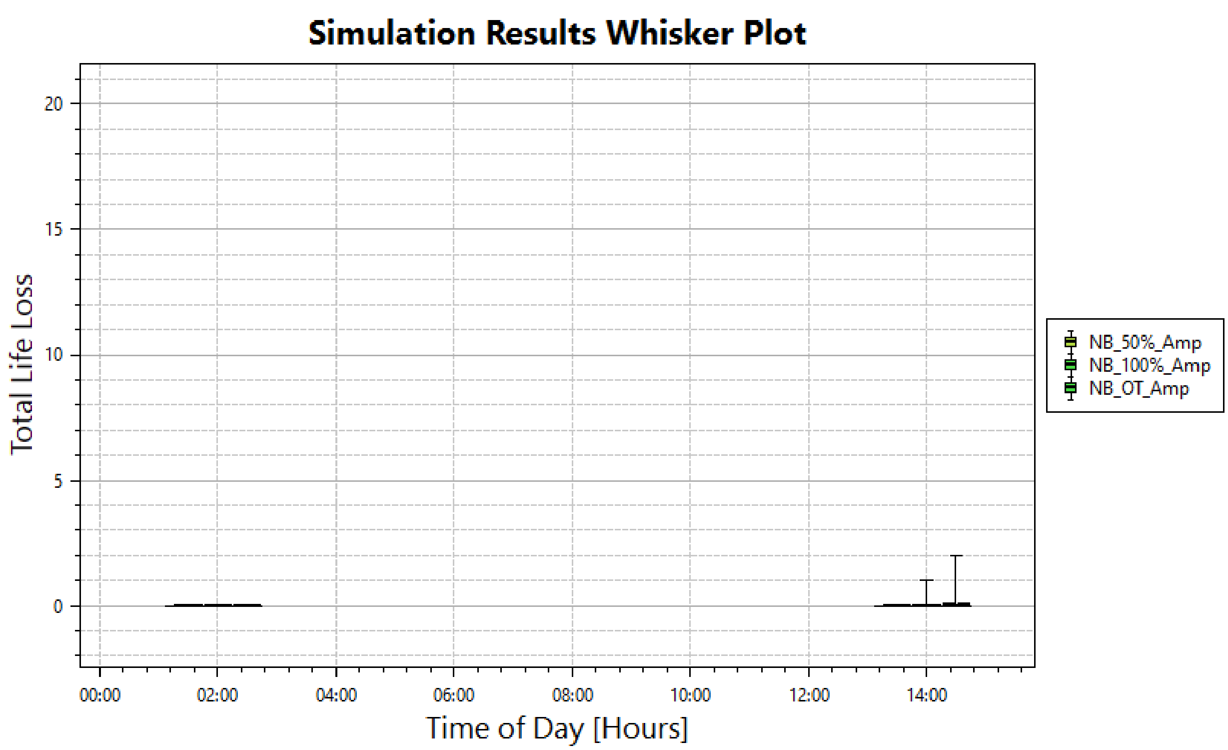


Figure 11. Life Loss with Ample Warning, With Project, Non-Breach.

With-Project Condition – Breach Scenario

The estimated life loss totals in the breach scenario by warning time are summarized in Table 6, Figure, and **Error! Reference source not found.**.

Table 6. Life Loss and PAR with Minimal Warning, With Project, Breach St 800 Scenario.

Breach St 800 Life Loss								
Minimal Warning								
Scenario Name	Median Total Life Loss		Life Loss Total 25th Percentile		Life Loss Total 75th Percentile		Life Loss Total Max	
	Day	Night	Day	Night	Day	Night	Day	Night
1FT OT	0	0	0	0	0	0	3	3
100% Loading	0	0	0	0	0	0	2	2
50% Loading	0	0	0	0	0	0	0	0
Ample Warning								
Scenario Name	Median Total Life Loss		Life Loss Total 25th Percentile		Life Loss Total 75th Percentile		Life Loss Total Max	
	Day	Night	Day	Night	Day	Night	Day	Night
OT	0	0	0	0	0	0	1	0
100% Loading	0	0	0	0	0	0	1	1
50% Loading	0	0	0	0	0	0	0	0

Table 7. Life Loss and PAR with Minimal Warning, With Project, Breach St 1800 Scenario.

Breach St 1800 Life Loss								
Minimal Warning								
Scenario Name	Median Total Life Loss		Life Loss Total 25th Percentile		Life Loss Total 75th Percentile		Life Loss Total Max	
	Day	Night	Day	Night	Day	Night	Day	Night
1FT OT	0	0	0	0	0	0	4	3
100% Loading	0	0	0	0	0	0	2	2
50% Loading	0	0	0	0	0	0	0	0
Ample Warning								
Scenario Name	Median Total Life Loss		Life Loss Total 25th Percentile		Life Loss Total 75th Percentile		Life Loss Total Max	
	Day	Night	Day	Night	Day	Night	Day	Night
1FT OT	0	0	0	0	0	0	1	2
100% Loading	0	0	0	0	0	0	1	1
50% Loading	0	0	0	0	0	0	0	0

Table 8. Life Loss and PAR with Minimal Warning, With Project, Breach St 1500 Scenario.

Breach St 1500 Life Loss

Minimal Warning								
Scenario Name	Median Total Life Loss		Life Loss Total 25th Percentile		Life Loss Total 75th Percentile		Life Loss Total Max	
	Day	Night	Day	Night	Day	Night	Day	Night
1FT OT	0	0	0	0	0	0	2	3
100% Loading	0	0	0	0	0	0	1	3
50% Loading	0	0	0	0	0	0	0	0

Ample Warning								
Scenario Name	Median Total Life Loss		Life Loss Total 25th Percentile		Life Loss Total 75th Percentile		Life Loss Total Max	
	Day	Night	Day	Night	Day	Night	Day	Night
1FT OT	0	0	0	0	0	0	3	2
100% Loading	0	0	0	0	0	0	1	3
50% Loading	0	0	0	0	0	0	0	0

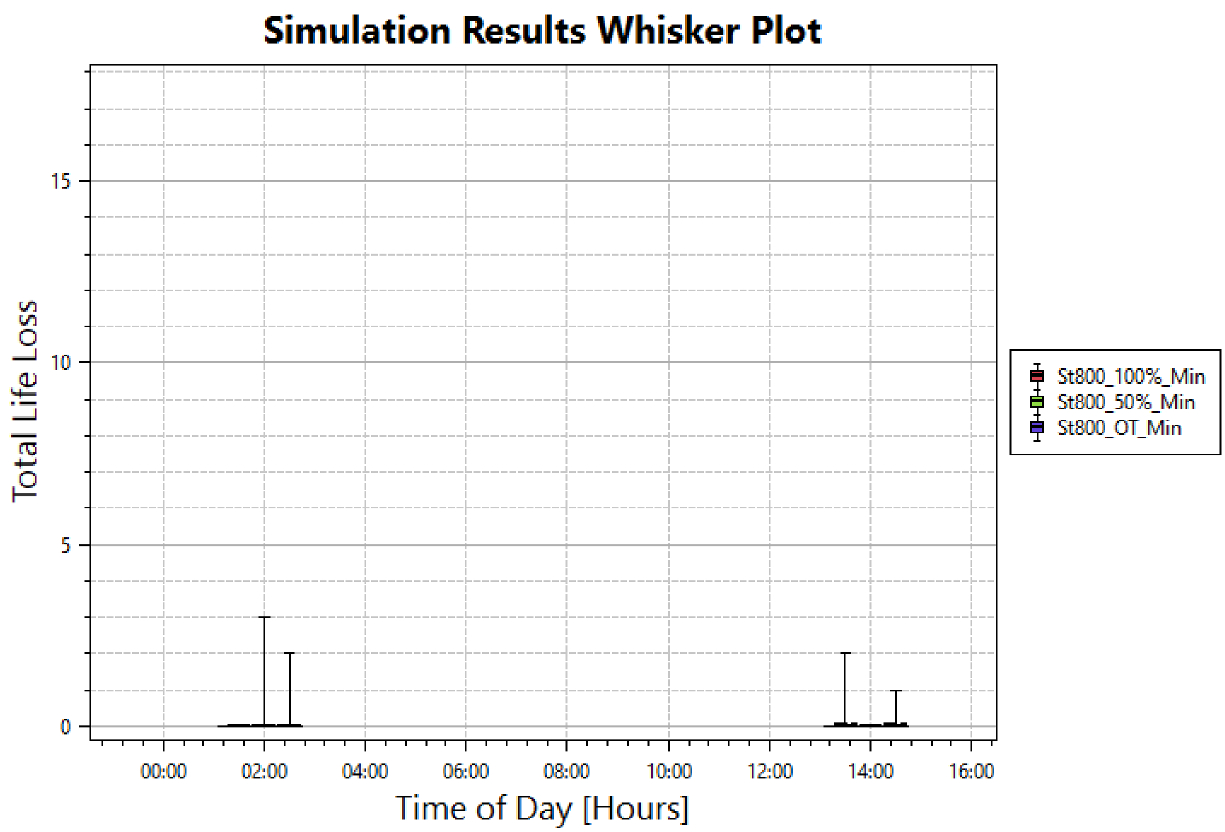


Figure 12. Life Loss with Minimal Warning, With Project, Breach Scenario.

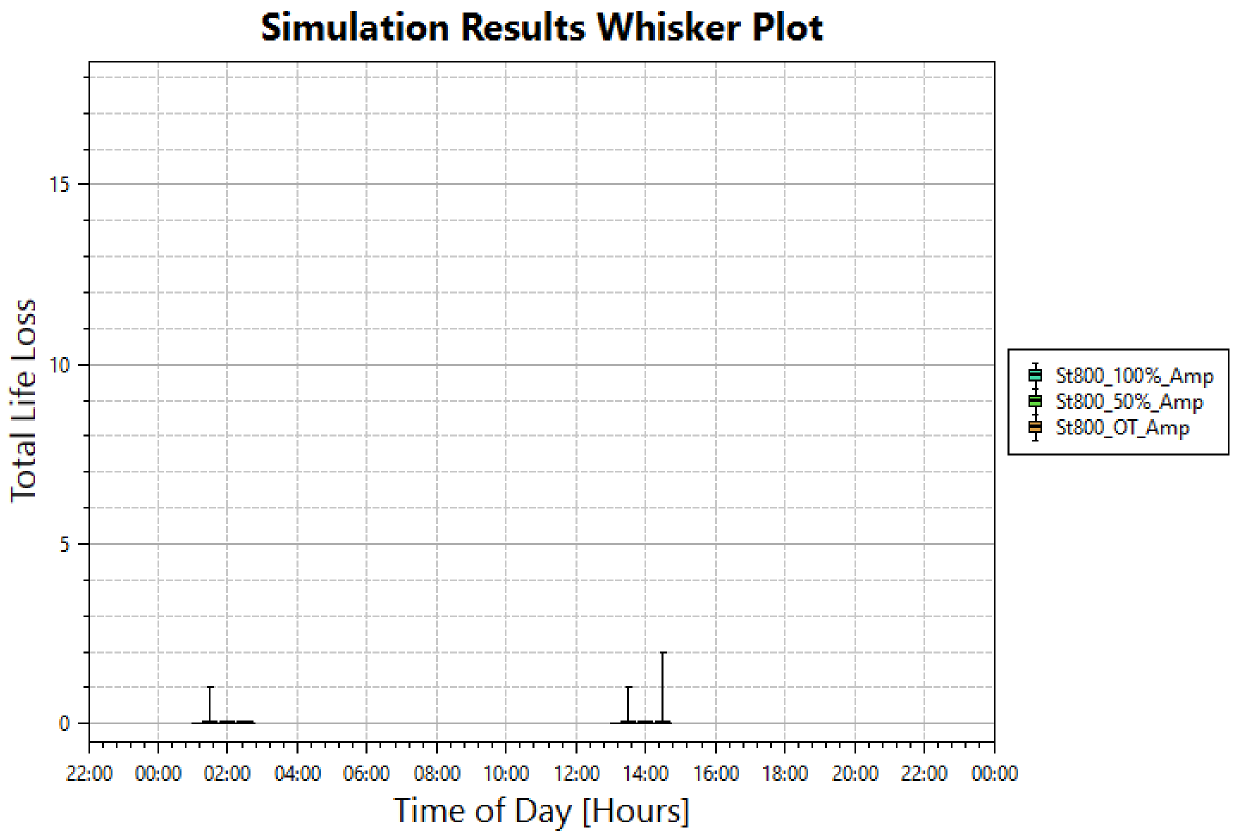


Figure 13. Life Loss with Ample Warning, With Project, Breach Scenario.

3.4. Incremental Life Loss

Incremental life loss is summarized below in **Error! Reference source not found.** and **Error! Reference source not found.**. In the minimal and ample warning scenario, median incremental life loss is approximately zero.

Incremental Life Loss						
Minimal Warning						
Scenario Name	Breach St 800		Breach St 1800		Breach St 1500	
	Day	Night	Day	Night	Day	Night
1FT OT	0	0	0	0	0	0
100% Loading	0	0	0	0	0	0
50% Loading	0	0	0	0	0	0
Ample Warning						
Scenario Name	Breach St 800		Breach St 1800		Breach St 1500	
	Day	Night	Day	Night	Day	Night
1FT OT	0	0	0	0	0	0
100% Loading	0	0	0	0	0	0
50% Loading	0	0	0	0	0	0

3.5. Key Limitations / Lessons Learned

For this model, evacuation simulation on roads was not included. Duration of flooding is short and therefore roadway inundation is minimal, but some uncertainty exists since evacuation is limited to vertical movement (i.e., to the attic or second floor) within structures. Additionally, the modeling parameters related to warning and protective action were all given distributions with the greatest uncertainty, absent data indicating otherwise. Finally, population estimates are based on NSI 2.0 values, without more detailed information of the study area demographics.

3.6. Conclusions

Life loss in the with-project condition (breach and non-breach) is less than the without-project condition, so there is unlikely to be any additional risk of life loss from the levee. Indeed, the risk of life loss is likely reduced from the presence of the proposed levee. Furthermore, incremental life loss is approximately zero, suggesting there is little-to-no additional risk of life loss due to failure of the levee. Table 5 and Table 6 summarize the minimal and ample warning scenarios respectively.

Table 5. Minimal Warning Scenario

Statistic	Life Loss for Minimal Warning Scenario					
	Breach (St. 800)		Non-Breach		Incremental	
	Day	Night	Day	Night	Day	Night
95th Percentile	1	0	1	0	0	0
75th Percentile	0	0	0	0	0	0
Median	0	0	0	0	0	0
25th Percentile	0	0	0	0	0	0
5th Percentile	0	0	0	0	0	0

Table 6. Ample Warning Scenario

Statistic	Life Loss for Ample Warning Scenario					
	Breach (St. 800)		Non-Breach		Incremental	
	Day	Night	Day	Night	Day	Night
95th Percentile	0	0	0	0	0	0
75th Percentile	0	0	0	0	0	0
Median	0	0	0	0	0	0
25th Percentile	0	0	0	0	0	0
5th Percentile	0	0	0	0	0	0

4. Potential Failure Mode Analysis (PFMA)

A failure mode is a unique set of conditions and/or sequence of events that could result in failure, where failure is "characterized by the sudden, rapid, and uncontrolled release of impounded water" (FEMA 2003). A Potential Failure Mode Analysis (PFMA) is the process of identifying and fully describing potential failure modes. A facilitator guided the team members in developing the potential failure modes, based on the team's understanding of the project vulnerabilities resulting from the data review and current field conditions.

A PFMA was conducted by the following personnel (Table 7).

Table 7. Personnel Conducting the PFMA.

Name	Role	Organization
Troy Cosgrove, PE	Facilitator	MVD Levee Safety Center, Branch Chief
Jon Korneliussen, PE	Civil Engineer, Technical Lead	MVD Levee Safety Center
Cody Isbell	Geotechnical Engineer	MVM, Geotech Design
Nicholas Bidlack	Levee Safety	MVM, Levee Safety
Don Davenport	Hydraulic Engineer	MVM, Hydrologic Engineering Section
Andy Simmerman	Project Manager	MVM, Project Mgmt. Branch
Jennifer Roberts	Plan Formulator	RPEDS - South

On February 11, 2022, a scaled-down Potential Failure Mode Analysis (PFMA) was performed to inform the design of a levee and floodwall for the Memphis Metropolitan North Deo. The scaled-down nature of the analysis was used to meet project requirements while being commensurate with the size and scope of the study. No risk exists now because the project still has not been built. The intention of the PFMA session is to mitigate future risk by identifying key items of concern that should be addressed during design and cost risks in development of the total project cost.

4.1. Design Background

The proposed structure is a levee and floodwall that works to contain floodwaters within the designated floodway and prevent flooding in the southwest quadrant of the intersection of Goodman Rd and Hwy 51.

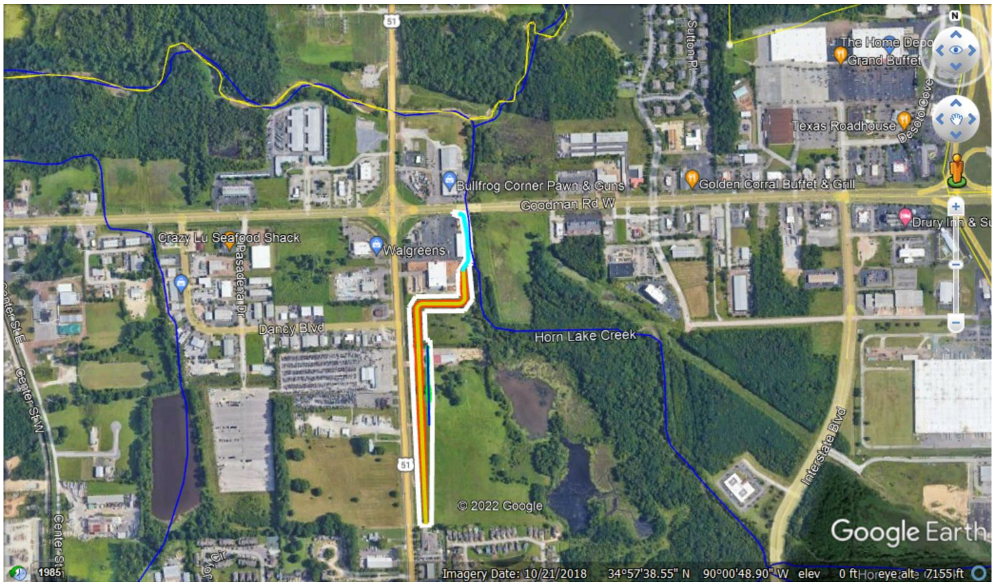


Figure 3: Levee-Floodwall (Plan 8) proposed geometry.

The new 3,000 linear foot levee and floodwall system will protect structures on the left-bank of Horn Lake Creek upstream of Goodman Rd. The levee will be constructed with 3-foot horizontal to 1-foot vertical (3H:1V) side slopes and a 12-foot-wide crown. The levee will run approx. 2,475 linear feet adjacent to US Hwy. 51 with an average height of 5’. A 600-linear-foot ditch will drain a depression on the riverside of the levee. Where development makes a levee infeasible, protection will transition to a 525 linear foot floodwall. The floodwall be 18” thick with an eight-foot-wide foundation. The wall will be five feet high and protrude 3.5 feet above ground level. The levee will require approx. 14,000 cubic yards of fill, and the floodwall will require 300 cubic yards of reinforced concrete. This alternative will require relocation of several utility poles and signs, removal and replacement of asphalt, and demolition of an existing building. The proposed geometry can be seen in Figure 3, where the floodwall is illustrated in blue and the levee is illustrated in yellow.

The levee and floodwall was conceptualized to reduce flood risk for events starting at the .002 (500 yr.) Annual Exceedance Probability (AEP) flood event. The levee and floodwall have a top elevation that is set at the .002 AEP stage resulting from estimated future flows. The levee and floodwall have a maximum elevation of 275.5 sloping down from south to north, ending at an elevation of 274.0 near the intersection of Goodman Rd and Hwy 51.

The peak head difference across the levee and flood wall during the 0.2% AEP event with a maximum height of 13.3 feet. The total head differential is influenced by an existing ditch along the northbound lanes of Hwy 51 that will remain. Figure 14 shows the river flood profiles adjacent to the levee and floodwall. Figure 15 shows the hydrograph of the 0.2% AEP breach scenario.

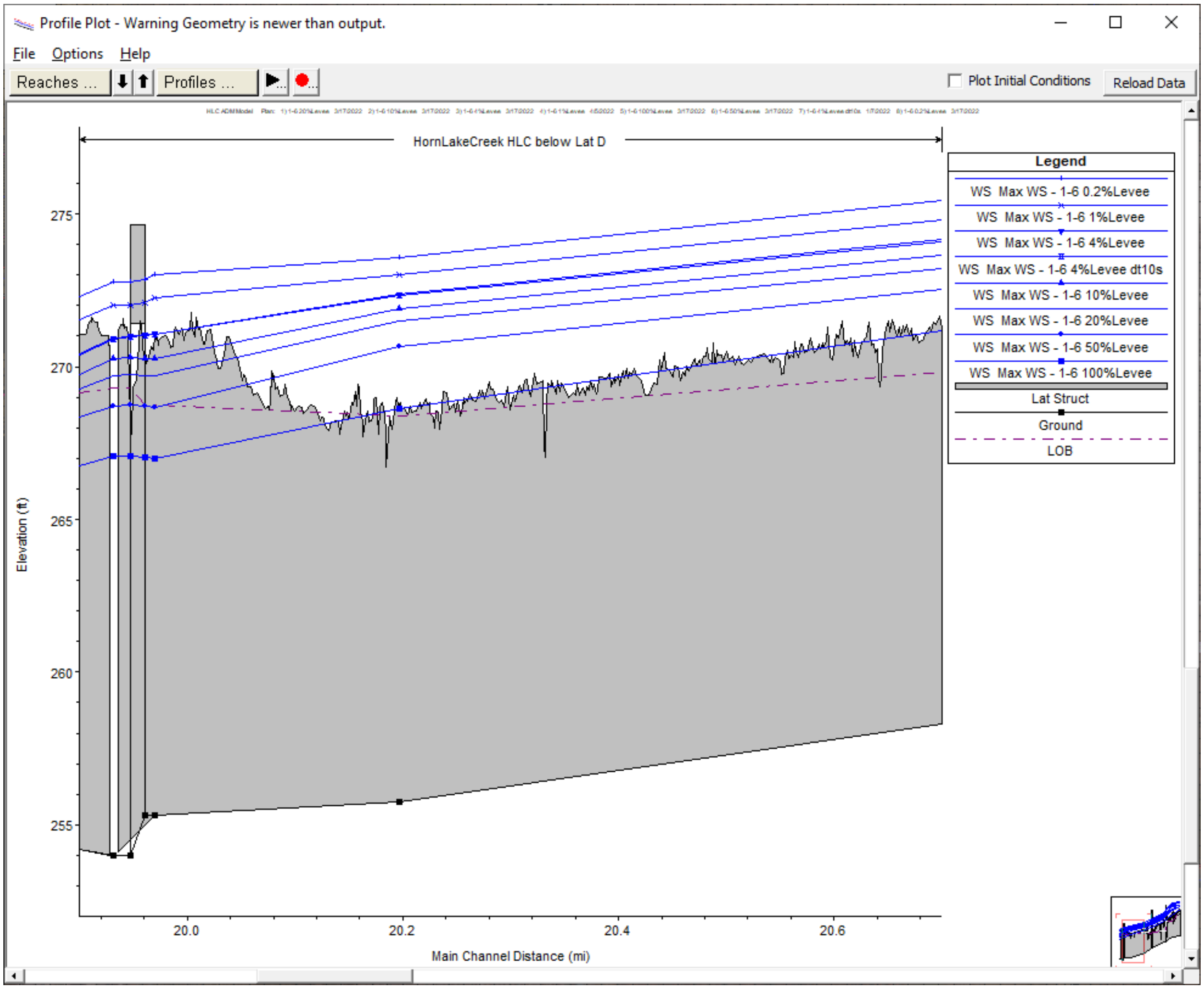


Figure 14. 99.99%, 50%, 20% 10% 4%, 2%, 1%, 0.2% AEP Flood Stages in Horn Lake Creek adjacent to the TSP Levee and Floodwall.

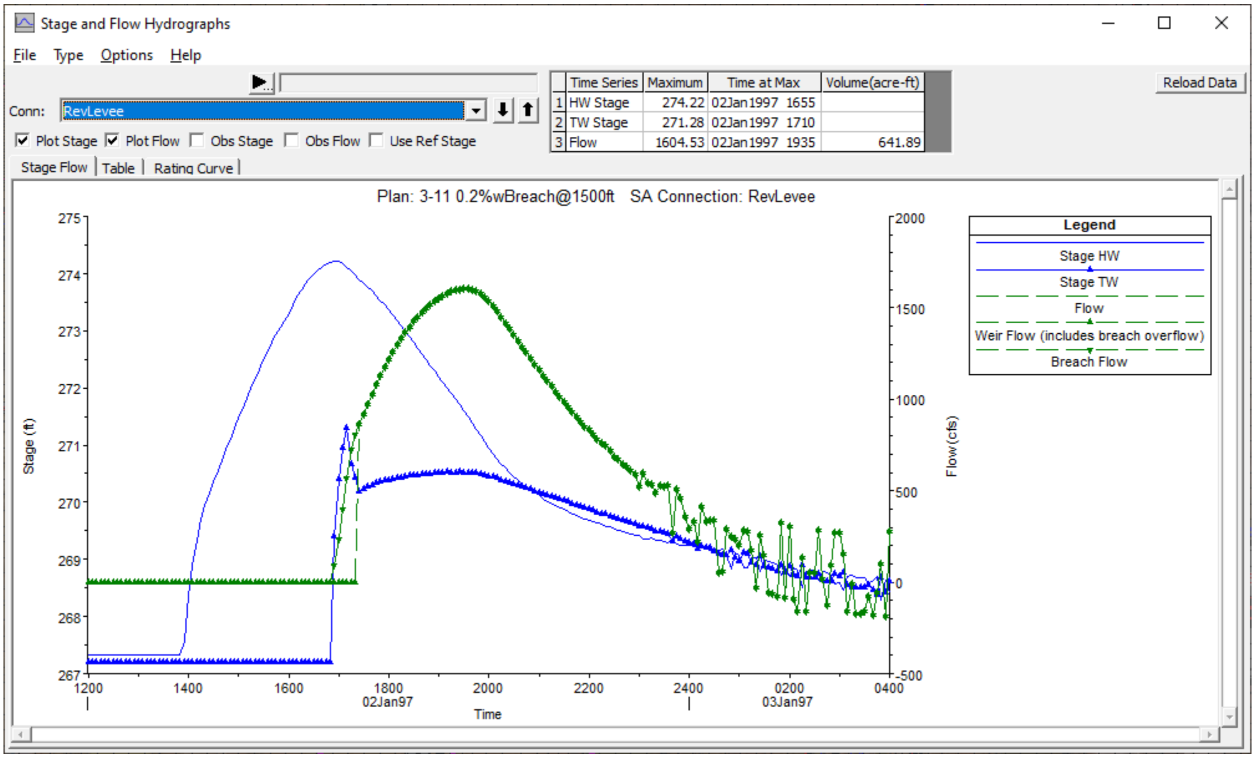


Figure 15. Hydrograph for the 0.2% (500-year) flood at station 15+00 along the levee alignment.

Worst case scenario for loading conditions on the levee and floodwall will occur during the 0.2% AEP event when Horn Lake Creek is at it's peak stage and very minimal water is in the roadside ditch along Hwy 51. The maximum possible head difference is approximately 13.3 feet. This specific event is highly unlikely to occur, but was analyzed to consider the highest theoretically possible head difference across the levee.

For the failure scenarios, breaching causing a 200' wide failure triggered at the peak stage of the 0.2% AEP. Both overtopping and piping failures were considered. A piping failure at STA 15+00 provided the greatest downstream stages and flows across the levee and floodwall. The failure scenario shows that the without project condition is worse than a breach in the project condition.

4.2. Brainstorming PFMs

- PFM-1: Overtopping with breach of the levee
- PFM-2: Overtopping with breach of the floodwall
- PFM-3: Vehicle impacting floodwall causing breach
- PFM-4: Sliding/overturning leads to breach of the floodwall
- PFM-5: Failure of internal stability of floodwall leads to breach
- PFM-6: CLE under the floodwall (seepage) leads to breach
- PFM-7: CLE at the floodwall levee tie in leads to breach

- PFM-8: Streambank erosion along the floodwall/HL creek leads to slope instability and failure of the wall
- PFM-9: Settlement due to groundwater extraction leads to breach (settlement/consolidation of aquifer due to groundwater extraction)
- PFM-10: CLE between the floodwall highway embankment tie in leads to breach
- PFM-11: Global stability failure of the floodwall leads to breach
- PFM-12: Differential settlement of floodwall leads to breach
- PFM-13: CLE along a crack in the levee embankment leads to breach
- PFM-14: BEP through the levee foundation leads to breach
- PFM-15: BEP through the floodwall foundation leads to breach
- PFM-16: Slope stability failure of the levee leads to breach
- PFM-17: CLE through abandoned utility under levee leads to breach
- PFM-18: Streambank erosion at the levee leads to breach
- PFM-19: Erosion of levee embankment during a flood leads to breach
- PFM-20: Debris build up at Goodman Road causing premature overtopping of the levee and floodwall
- PFM-21: CLE through an animal burrow leads to breach
- PFM-22: CLE through the embankment due to tree roots leads to breach
- PFM-23: Tree collapse or excessive vegetation causes turbulence and erosion of streambank leading to breach
- PFM-24: CLE along waterline under floodwall leads to breach

4.3. Evaluating PFMs

Many of the brainstormed PFMs are typically managed with designed defensive measures, adhering to published engineering standards, construction Quality Assurance (QA), or Emergency Action Plans (EAP). A more thorough risk assessment (i.e., Semi-Quantitative Risk Assessment – SQRA) will occur during the pre-construction engineering and design (PED) phase of the project.

For this screening-level assessment, qualitative methods were used to determine life loss likelihoods if that failure mode occurred. This evaluation did not consider the actual failure likelihood (i.e., reliability) from this level of design. The ease of prevention via design considerations was evaluated, and a decision was made if further evaluation was required. Even if the potential for failure was high, if the evaluation states that it is a typical design consideration, no additional evaluation is required at this stage.

Table 8: Potential Failure Modes Analysis.

Failure Modes	Evaluations/factors	Mitigation	Uncertainties	Other considerations
PFM-1: Overtopping with breach of the levee	Overtop for any event greater than 500 yr. Height of the levee is 5-7' and will not likely have high overtopping velocities .5' of overtopping duration is ~6 hrs.	Turfing of embankment	Current results are from hydraulic computer models	If further evaluation during PED that overtopping velocities are significant additional mitigation may be needed.
PFM-2: Overtopping with breach of the floodwall	Overtop for any event greater than 500 yr. Height of the floodwall is 3.5' and this results in a reduced plunge depth of overtopping .5' of overtopping duration is ~6 hrs.	Due to the location of the floodwall (parking lot) there will be asphalt up to the floodwall	Current results are from hydraulic computer models	If further evaluation during PED that overtopping plunge forces are significant additional mitigation may be needed.
PFM-3: Vehicle impacting floodwall causing breach	Less traffic anticipated near floodwall located at rear of building, a low-speed area. Likelihood of short duration of flood and vehicle impact coinciding	During design the wall will be evaluated for vehicle impacts Implement temporary flood protection if wall were damaged Install bollards or guiderails	Unsure what impact loads are accounted for in design of the floodwall	
PFM-4: Global stability failure (sliding/overturning/bearing) leads to breach of the floodwall	No foundation information nor design has been completed	Sliding, overturning, and bearing will be designed and analyzed during design phase to ensure meeting appropriate factors of safety	Due to the lack of subsurface investigations, there is uncertainty on the foundation conditions	Alternate design considerations could be an i-wall if RE is an issue, since the wall is under 4'
PFM-5: failure of internal stability of floodwall leads to breach	Design has not been completed	Wall will be designed and analyzed to ensure meeting appropriate factors of safety	Unsure of actual layout of wall	

Failure Modes	**Evaluations/factors**	**Mitigation**	**Uncertainties**	**Other considerations**
PFM-6: CLE under the floodwall (seepage) leads to breach	No foundation information nor design has been completed	Wall will be analyzed for seepage pressures to ensure that they fall within the proper factors of safety Due to the low head differential and short duration of the flood, seepage would likely not be an issue. However, a short seepage cutoff could be installed (i.e. sheet pile)	Due to the lack of subsurface investigations, there is uncertainty on the foundation conditions and need for a seepage cutoff	Waterline parallel to Goodman Rd. (~30ft from edge of roadway), could be a complicating factor
PFM-7: CLE at the floodwall levee tie in leads to breach	Current wall levee layout has a 25'overlap between the wall and the levee Compaction may be difficult between the levee floodwall interface Depending on borrow source it may make this failure mode more or less likely Most likely path to develop seepage, due to void space	Needs to be evaluated during design to ensure embedment length is sufficient Specifications should address any special compaction at this interface	Due to the lack of information on the borrow, unsure permeability parameters of borrow material	
PFM-8: Streambank erosion along the floodwall/HL creek leads to slope instability and failure of the wall	Streambank is well vegetated, with steep slopes (maybe 1:1). Horn Lake Creek has reaches of instability	Evaluate during design to determine if Rip Rap or another slope protection is needed Evaluate channel velocities and geometry	Uncertainty about velocities in the channel due to lack of surveys and site-specific modeling Unsure about erosion resistance of streambank materials	

Failure Modes	**Evaluations/factors**	**Mitigation**	**Uncertainties**	**Other considerations**
PFM-9: Settlement due to groundwater extraction leads to breach (settlement/consolidation of aquifer due to groundwater extraction)	Depending on foundation information and the potential for high groundwater extraction, this settlement would need to be evaluated during design	Perform settlement analysis and ensure that groundwater extraction effects are considered	Unsure that groundwater extraction is leading to settlement in this area	
PFM-10: CLE between the floodwall highway embankment tie in leads to breach	Current wall highway embankment layout has a 10' perpendicular 25' along the profile of the levee. Compaction may be difficult between the highway embankment and the floodwall interface Depending on backfill material it may make this failure mode more or less likely	Needs to be evaluated during design to ensure embedment length is sufficient Specifications should address any special compaction at this interface and also specialized backfill material	Due to the lack of information on the highway embankment materials and backfill, unsure permeability parameters of the embankment materials or backfill	Coordination with the state MDOT. Consider 90 degree turn into roadway embankment past bridge abutment
PFM-11: Slope stability failure of the floodwall leads to breach	Need to evaluate slope stability of floodwall utilizing Properties of the foundation materials.	Evaluate during design to determine if any ground improvement may need to be performed	No specific site sub surface information has been obtained, unsure of the foundation conditions.	
PFM-12: Differential settlement of floodwall leads to breach	Depending upon foundation conditions may make this failure more or less likely These conditions may not be evident until actual excavation during construction	Needs to be evaluated during design Specifications should be written to remove unacceptable foundation material and replaced with select material	No specific site sub surface information has been obtained, unsure of the foundation conditions.	
PFM-13: CLE along a crack in the levee embankment leads to breach	Depending on the borrow source may make this failure mode more or less likely	Needs to be evaluated during design Site specific exploration program should be conducted to classify borrow material or identify off site borrow	No specific site sub surface information has been obtained, unsure of the borrow material.	

Failure Modes	Evaluations/factors	Mitigation	Uncertainties	Other considerations
PFM-14: BEP through the levee foundation leads to breach	Depending upon foundation conditions may make this failure more or less likely Anticipated short duration of loading will make this less likely Research into borings within the area indicates typically 20' of fine materials	Needs to be evaluated during design Site specific exploration program should be conducted to classify foundation materials.	No specific site sub surface information has been obtained, unsure of the foundation conditions.	PFM-14: BEP through the levee foundation leads to breach
PFM-15: BEP through the floodwall foundation leads to breach	Depending upon foundation conditions may make this failure more or less likely Anticipated short duration of loading will make this less likely Research into borings within the area indicates typically 20' of fine materials	Wall will be analyzed for seepage pressures to ensure that they fall within the proper factors of safety Site specific exploration program should be conducted to classify foundation materials. Due to the low head differential and short duration of the flood, seepage would likely not be an issue. However, a short seepage cutoff could be installed (i.e. sheet pile)	No specific site sub surface information has been obtained, unsure of the foundation conditions and need for a seepage cutoff.	PFM-15: BEP through the floodwall foundation leads to breach

Failure Modes	Evaluations/factors	Mitigation	Uncertainties	Other considerations
PFM-16: Slope stability failure of the levee leads to breach	Need to evaluate slope stability of levee utilizing Properties of the embankment and foundation materials.	Evaluate during design to determine if any ground improvement may need to be performed	No specific site sub surface information has been obtained, unsure of the embankment and foundation conditions.	
PFM-17: CLE through abandoned utility under levee leads to breach	This is an urban area and there is potential for abandoned utilities within the levee footprint. Main and utilities run on left of Hwy 51, investigate when topo data available. One service manhole runs on east side, need to investigate	Over excavate and remove abandoned utility Inspection or Cut off trench would be utilized to help identify any shallow abandoned utilities within the foundation	Likelihood of abandoned utilities in the foundation	Utilize geophysics (i.e. ground penetrating radar) to identify any abandoned utilities in the foundation. This could eliminate need for cut off trench
PFM-18: Streambank erosion at the levee leads to breach	Streambank is well vegetated, with steep slopes (maybe 1:1). Horn Lake Creek has reaches of instability Levee is set back 30' from edge of stream. The change in floodplain width at outside corner of the levee, and the interface between levee and floodwall where there is a change in direction warrant closer analysis of velocities and may require additional protection.	Evaluate during design to determine if Rip Rap or other slope protection is needed Evaluate channel velocities and geometry	Uncertainty about velocities in the channel due to lack of surveys and site-specific modeling Unsure about erosion resistance of streambank materials	

Failure Modes	Evaluations/factors	Mitigation	Uncertainties	Other considerations
PFM-19: Erosion of levee embankment during a flood leads to breach	Initial modeling indicates that velocities are low along the levee during floods. A vulnerable area may be between the floodwall interface and the first 90 degree turn in the levee. Levee is set back 30' from edge of streambank and may experience higher velocities along the levee. The change in floodplain width at outside corner of the levee, and the interface between levee and floodwall where there is a change in direction warrant closer analysis of velocities and may require additional protection.	Evaluate during design to determine if Rip Rap or other embankment slope protection is needed	Uncertainty about velocities along the levee due to lack of surveys and site-specific modeling Unsure about erosion resistance of the embankment materials since borrow material has not been classified	
PFM-20: Debris build up at goodman road causing premature overtopping of the levee and floodwall	Where Goodman Rd. crosses horn lake creek there is a potential for woody debris to be trapped under the bridge and restrict flow. This flow restriction may cause the levee or floodwall to be overtopped sooner.	Outline in O&M manual that the sponsor should clear debris on a regular basis from the bridge opening Goodman Rd. If warranted, consider analyzing flow under the bridge with some blockage	Amount of constriction needed to actually increase the frequency of overtopping How much debris blockage is collecting under the bridge	Potential for the waterline to catch debris, may need provisions in the O&M manual that the sponsor should clear debris on a regular basis.

Failure Modes	Evaluations/factors	Mitigation	Uncertainties	Other considerations
PFM-21: CLE through an animal burrow leads to breach	If animal control is not performed, burrows could lead to pathways for CLE to develop.	Ensure that the O&M manual accounts for animal control plan and the treatment of animal burrows if they are observed.	Unsure about burrowing animal activity in the area	
PFM-22: CLE through the embankment due to tree roots leads to breach	If trees are allowed to grow in embankment, tree roots may serve as pathways for CLE to develop.	Ensure that the O&M manual accounts for vegetation control plan. Ensure that vegetation is not allowed to be within the 15' vegetation free zone		
PFM-23: Tree collapse or excessive vegetation causes turbulence and erosion of streambank leading to breach	If a tree collapses or vegetation is allowed to grow in the embankment, then it could create turbulence that would erode the embankment.	Ensure that the O&M manual accounts for vegetation control plan.		
PFM-24: CLE along waterline under floodwall leads to breach	Waterline is ~5-6' below top bank, would not expect to encounter it within the floodwall excavation of ~3-4'. If a cutoff wall or other seepage improvements are needed, then we would encounter the waterline With the waterline being ~5-6' below ground and also under the parking lot, probably less likely that you would have CLE along the line and a seepage exit at the surface	Determine depth of the waterline and see if it will be encountered in the excavation. Special treatment may be needed to prevent CLE along the waterline. Ensure that the floodwall will not negatively impact the waterline	Unsure of exact depth of and backfill around the waterline	Expand on how we address the waterline within engineering appendix of the final report

While none of the failure modes evaluated stood out as particularly "risk driving", these failure modes should and will be considered during design of the project and will be re-evaluated once the design is more substantial.

5. Typical Risks

A more rigorous risk assessment (e.g., Semi-Quantitative Risk Assessment, Quantitative Risk Assessment) will be completed during the Pre-Construction, Engineering and design phase of the study and has not been performed at this point. Having subsurface data and design at least at the 35-65% level would reduce the uncertainties to the point that the risk assessment may further inform what measures will be needed to ensure compliance with USACE Levee Safety guidelines, so that incremental risks are properly mitigated and managed as low as practicable.

6. Key Limitations

The limitation of the PFMA session and any risk analysis methodology is primarily driven by the availability and the completeness of the information used to assess the risk. With due regards for uncertainty at this point it is recommended that further design is conducted and that at least an SQRA session is completed between the 35-65% design level.

The methodology for the scaled down PFMA seems appropriate for this level of study. It identifies the potential for risks but cannot fully quantify the risk until more information is available on the design and existing conditions.

7. Conclusions

At the feasibility phase of the project, the screening level risk assessment did not identify any potential failure modes that would favor one alternative significantly over the other or that would lead to elimination of the PLAN 8 alternative. Additional information, including modeled life loss evaluations, subsurface investigations, and advancing design will allow for a more thorough and quantitative evaluation.