Michigan's Innovative Approach to Risk Prioritization and Screening-Level Risk Assessments

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Introduction

Following the catastrophic failures of the Edenville and Sanford Dams on May 19, 2020, Governor Gretchen Whitmer directed the Department of Environment, Great Lakes, and Energy (EGLE) to perform a thorough review of Michigan's Dam Safety Program. This led to the establishment of the Michigan Dam Safety Task Force (MDSTF), which, in February 2022, published a report with 86 recommendations to strengthen the state's approach to dam safety. One critical recommendation was the development of a state-wide risk prioritization of Michigan's portfolio of dams, with the goal of supporting data-driven decisions for resource allocation, regulatory compliance, and dam safety enforcement.

To address the recommendation, EGLE's Dam Safety Unit (DSU) retained GEI Consultants, Inc. (GEI) to conduct an independent screening level risk prioritization for a portfolio of 219 high and significant hazard dams under state regulation. Each dam's risk to public safety was evaluated individually considering the likelihood and consequences of various types of hypothetical dam failures. The purpose of this work was to provide EGLE's DSU with a risk prioritization of the dam portfolio to inform programmatic decisions consistent with the MDSTF recommendation.

In development of the program, GEI created tools and workflows that could appropriately accommodate the large dam portfolio. The "Michigan Tool" (MI Tool) and program methodology was developed to be consistent with the following risk principles:

- Utilize the foundational pieces of the risk equation (Annual Exceedance Probability, System Response Probability, and consequences) to quantify risk for a large portfolio of dams in a consistent and repeatable way.
- Use streamlined traditional pieces of dam risk analysis workshops including:
  - well-rounded data review that considers all available documentation, not only the most recent dam inspection reports
  - consideration of common failure mechanisms and influence factors
  - documentation of confidence, data quality, and likelihood of failure justification
  - use of subject matter experts to develop SRP estimates
- Complete screening-level risk assessments consistently using available background data and limited time.
- Use freely available, industry accepted datasets and analysis tools to develop the AEP and consequences.
- The MI Tool can be used by the DSU to update/modify the risk of individual dams as the portfolio evolves over time.
- Be readily compatible with FEMA HHPD granting requirements.

GEI used these principles to develop the customized MI Tool and associated methodology created to meet DSU's objectives. The first part of the article summarizes the initial data inventory process and development of the MI Tool and risk workshop methods. The next section summarizes the development of the SRP, AEP, and consequences estimates. The final section summarizes the results of the risk assessment.

Data Inventory and Initial Categorization

Prior to developing a specialized risk prioritization tool for Michigan, the GEI team reviewed key background information provided by EGLE to develop an understanding of quantity, quality, and type of available information. In addition to dam report/records, EGLE provided their Dam Inventory Database, which they use to track key information for the dam portfolio. Data gaps critical to risk prioritization were identified, including a recent inspection report (within the last two inspection cycles), spillway capacity, reservoir storage capacity, and possible cascading failures.

Based on the data available, the 219 dams were divided into three categories. The categories are described here:

- Category 1 – Risk Prioritization Ready
  - Dams have sufficient information to proceed to risk prioritization without addi-tional effort.
- Category 2 – Missing Desktop Information/Studies
  - Dams have been recently inspected (within the last two inspection cycles) but one or more pieces of information critical to risk prioritization were missing. Missing information was divided into two subcategories: one requiring supple-mental calculations to be performed by GEI, and one requiring EGLE to coordi-nate with dam owners to obtain/complete missing documents.
- Category 3 – Field Inspection Required
  - Dams have not been recently inspected, or a recent inspection report is not avail-able, or spillway geometries are missing.

Dams that fell outside of the proposed process, such as breached or removed dams, were classified as Category 4 – Special Circumstances and excluded from the project.

A summary of the data categorization results is presented in the following table.

TABLE 1 SUMMARY OF DAM CATEGORIZATION

Category	1 – Risk Prioritization Ready	2 – Missing Desktop Information	3 – Field Inspection Required	4 – Special Circumstances	Total
Number of dams	44	162	7	6	219

Category 1 dams were taken directly into the risk prioritization process. For **Category 2** dams, GEI developed the missing information prior to completing risk prioritization. For **Category 3** dams, GEI developed missing information and conducted field inspections and field data collection efforts prior to completing risk prioritization.

Michigan Tool Development

Risk Calculations

The Michigan Tool includes several key features that are used to estimate the risk associated with specific potential failure mechanisms[1] (PFMs) and the aggregate risk associated with all failure mechanisms applicable to the dam. As a reminder, Equation 1 illustrates the standard, simplified equation for calculating risk:

$$Risk = P(Failure|Hazard) \times P(Hazard) \times Consequences|Failure \quad (1)$$

For this article, the probability of failure given the hazard, $P(Failure|Hazard)$, is referred to as the system response probability (SRP), and the probability of the hazard, *P(Hazard),* is often referred to as the likelihood of the load or the annual exceedance probability (AEP) of the load. Last, the consequences experienced as a result of the failure, $Consequences|Failure$, are referred to as "consequences" (or "incremental consequences," if appropriate). Using simplified nomenclature, Equation 1 can be rewritten as Equation 2:

$$Risk = SRP \times AEP \times Consequences \quad (2)$$

The MI Tool uses the term annual likelihood of failure (LOF) for the y-axis value on risk matrices. The LOF is generally synonymous with the annual probability of failure (APF) and was calculated using Equation 3:

$$LOF = SRP \times AEP \quad (3)$$

The MI Tool provides a structure for subject matter experts (SMEs) to estimate each term of the risk equation for typical PFMs. The following subsections walk through how each term is estimated and the various assumptions associated with the MI Tool development.

Load Cases

The loading conditions utilized in the MI Tool include normal, flood, and seismic loading. Normal loading is defined as having the water surface elevation at normal max pool (as determined by dam records) and with typical operating procedures. The AEP associated with normal loading conditions was assumed to be 1 for all dams.

For most PFMs, the flood loading considered is the flood at the dam crest (zero-freeboard). For overtopping PFMs, the definition of "flood loading" differs slightly. When SMEs assess the likelihood of failure associated with the overtopping mechanism for earthen embankments, they consider a flood with sufficient overtopping depth and duration to likely cause failure by erosion progressing to instability (0.5 ft to 1 ft depth is a reasonable assumption). This depth of overtopping is not correlated with the design storm, 200-year event, probable maximum flood, zero-freeboard, or any other specific flood. Refer to the section 'Flood Annual Exceedance Probability' for additional information related to the flood loading AEP calculations.

Michigan is in a seismically inactive region at the center of the North American tectonic plate, where ground shaking is minimal. After careful review of the seismic hazard curves using the USGS Unified Hazard Tool, the AEPs associated with seismic events large enough to cause dam failure were considered so remote as to be logically not a dam safety concern and extremely unlikely to be a risk-driving PFM for any dam in Michigan. As such, seismic loading failure mechanisms were not further addressed.

Potential Failure Mechanisms

The acronym PFM is commonly used to define potential failure *modes* in risk analyses. For this project, the more generic potential failure *mechanisms* (e.g., internal erosion) were utilized instead of specific potential failure *modes* (e.g., concentrated leak erosion along a conduit penetration) to broadly and quickly capture *mechanisms* of failure. After reviewing a subset of dams' background information, it was clear most dams were lacking sufficient information to meaningfully analyze specific potential failure *modes*. GEI elected to use potential failure *mechanisms* to ensure the tool can be widely and consistently applied across the portfolio with the available information. Selected PFMs were required to result in a catastrophic release of water (i.e., full height breach of a major water retaining structure).

GEI separated a dam into structures with the structure type categories of earthen embankment, concrete dams/non-overflow structures, and spillways. For each structure type, GEI developed a large list of typical failure mechanisms. Based on GEI's experience in performing potential failure

[1] The acronym PFM is commonly used to define potential failure mode. For this project, the more generic potential failure mechanisms (e.g., internal erosion) were utilized instead of specific potential failure modes (e.g., concentrated leak erosion along the low-level outlet conduit) to broadly and quickly capture mechanisms of failure.

modes analyses and documentation of the historic mechanisms leading to dam failures, the most common potential failure mechanisms were selected for use in the MI Tool. The failure mechanisms utilized in this project are listed in Table 2.

Influence Factors

An influence factor is a positive or adverse attribute of a dam that as a group, or individually, could impact a failure mechanism. The MI Tool's influence factors were developed using industry best practices (ASDSO, 2025; FEMA, 2016; FERC, 2021; USACE & USBR, 2019). The influence factors were developed to largely be assessed using readily available field observations and photographs, limited or no engineering studies, and limited or no historic documentation related to construction.

Table 3 and Table 4 illustrate the load condition, structure type, failure mechanism, and influence factors used in the MI Tool. Each failure mechanism included an "Other" influence factor that is not reflected in these tables. The Other influence factor used by SMEs to document any additional relevant factors/conditions specific to the dam.

TABLE 2 POTENTIAL FAILURE MECHANISMS

Load Case	Structure Type	Failure Mechanism
Normal	Earth embankments	Slope stability
		Internal erosion
	Concrete dams / non-overflow structures	Global stability
		Structural failure
	Spillways	Operational / mechanical failure to open
		Scour
Flood	Earth embankments	Slope stability
		Internal erosion
		Overtopping erosion – full capacity
		Overtopping erosion – reduced capacity
	Concrete dams / non-overflow structures	Global stability
		Structural failure
	Spillways	Scour

Although the major failure mechanisms were considered in the MI Tool, some less typical PFMs specific to seismic mechanisms, rapid drawdown, pressure pipes, arch action, beaching/waves, seiches, floatation, and damage state failures were not considered.

TABLE 3 MICHIGAN TOOL NORMAL LOAD CONDITION DISCRETIZATION

Load Condition	Structure Type	Failure Mechanism	Influence factors
Flood	Earth embankments	Slope stability	Historic or Observed Instability
			Foundation Condition
			Embankment Condition
			Slope Stability Factor of Safety
			Evidence of High Phreatic Surface (Seepage, Sloughing)
		Internal erosion	Presence of Seepage
			Foundation and Embankment Condition
			Conduit Penetration
			Animal Burrows
			Woody Vegetation (Trees With Toppling Potential)
	Concrete dams / non-overflow structures	Global stability	Distortion/Movement
			Concrete Cracks
			Leakage Along Joints/Cracks
			Foundation Condition
			External Stability / Global Stability Factors of Safety
			Ice
		Structural failure	Distortion / Movement
			Concrete Cracking / Deterioration
			Gate Deterioration
			Ice
	Spillways	Operational / mechanical failure to open	Material Deterioration (of Gates or Hoist)
			Means of Operation (Electrical, Human, Remote vs. Local)
			Spillway / Debris Obstruction
		Scour	Channel / Foundation Material


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TABLE 4 MICHIGAN TOOL FLOOD LOAD CONDITION DISCRETIZATION

Load Condition	Structure Type	Failure Mechanism	Influence factors
Normal	Earth embankments	Slope stability	Historic or Observed Instability
			Foundation Condition
			Embankment Condition
			Slope Stability Factor of Safety
			Evidence of High Phreatic Surface (Seepage, Sloughing)
		Internal erosion	Presence of Seepage
			Foundation and Embankment Condition
			Conduit Penetration
			Animal Burrows
			Woody Vegetation (Trees With Toppling Potential)
		Overtopping erosion – full capacity	Embankment Resistance
		Overtopping erosion – reduced capacity	Embankment Resistance
			Material Deterioration (of Gates or Hoist)
			Means of Operation (Electrical, Human, Remote vs. Local)
			Spillway / Debris Obstruction
	Concrete dams / non-overflow structures	Global stability	Distortion / Movement
			Concrete Cracks
			Leakage Along Joints / Cracks
			Foundation Condition
			External Stability / Global Stability Factors of Safety
		Structural failure	Distortion / Movement
			Concrete Cracking/Deterioration
			Gate Deterioration
	Spillways	Scour	Channel / Foundation Material

Guidance Matrix

To help the SMEs consistently rank the presence and severity of each influence factor, a guidance matrix was prepared. The guidance matrix outlines the conditions or characteristics that contribute to the severity of each influence factor. The severity rankings were divided into four categories: "low," "moderate," "high," and "very high." Although not shown in the guidance matrix, two additional rating options of "insufficient data" and "not applicable" were available. Insufficient data is intended for situations where data were inadequate to rank the influence factor. Not applicable is provided to exclude influence factors that do not apply or are not physically possible (e.g., there is no gate; therefore, a gate failing to open and contributing to reduced capacity is not possible).

SRP Workshops

After developing all required information, all dams were advanced to the SRP workshops. The workshops had a consistent agenda consisting of a standardized summary presentation of the dam information followed by collaborative SME discussions of the PFMs, their influence factors, SRPs, confidence, and data quality, with documentation in the MI Tool. The presentations and documentation in the MI Tool were completed by recorders.

Through extensive scheduling and coordination efforts, all 219 workshops were completed. Each workshop team consisted of two recorders and a structural, geotechnical, and H&H SME, and two dams' SRPs were estimated per workshop. During the workshop, the recorder presented information about the dam, answered SME questions, and assisted with documenting justifications for the selected SRPs. Initially, a workshop for a single dam took about 3 hr to complete. As the team gained experience, workshop duration decreased to 2–2.5 hr.

GEI developed and tested the workshop process to gain confidence that the process would result in consistent outcomes. As a result, a training program was developed to ensure consistency of SRP estimation across the portfolio. The training program included a recorder-specific training and three training workshops attended by all recorders and SMEs. The four training sessions were recorded and used for training participants who were unable to attend original training. Where discrepancies or sources of confusion were identified during the training, the guidance matrices within the MI Tool were refined for clarity and consistency. Following the training sessions, the SMEs SRP categorizations were found to be appropriately consistent. The project was staffed with more than 30 SMEs and 30 recorders, and the procedures needed to be interpreted consistently.

System Response Probability Selection

SMEs participated in risk workshops and estimated the SRP for each dam. The SMEs were licensed professional engineers or geologists and had at least 5 years of experience in the dam industry. After assessing the severity of individual influence factors, the SMEs assigned an SRP using the SRP Guidance Matrix and their engineering judgement to weigh the criticality of the individual influence factors. The influence factors are intended to guide the SMEs in assessing the dam SRP under a given load. (Note, there is no mathematical relationship between the influence factors and the PFM SRP).

The SRP categories are "remote," "low," "moderate," "high," and "very high," and have the descriptors shown in Table 5. The verbal descriptors were modeled after FERC's Failure Likelihood Categories (FERC, 2021) but the SRP Guidance Matrix does not carry the same limitations or purpose as FERC's table, and SMEs were trained in its application.

TABLE 5 SYSTEM RESPONSE PROBABILITY GUIDANCE MATRIX

REMOTE	LOW	MODERATE	HIGH	VERY HIGH
The failure likelihood is so remote as to not be a dam safety concern (no additional studies are warranted, no risk reduction measures needed).	The possibility cannot be ruled out, but several events must occur concurrently or in a series to cause failure to occur.	The fundamental condition or defect is known to exist, key influence factors suggest the possibility of initiation, but redundancy indicates full progression to failure is "less likely" than "more likely."	The fundamental condition or defect is known to exist, key influence factors suggest the possibility of initiation, but a lack of redundancy indicates full progression to failure is "more likely" than "less likely."	The direct evidence or substantial indirect evidence to suggest that failure has initiated or is very likely to occur during life of the structure. Key influence factors suggest the possibility of initiation, but a lack of redundancy indicates full progression to failure is likely.

The SMEs documented their rationale for the selected SRP, assigned a confidence category ("low," "moderate," or "high") and a data quality category ("low," "moderate," or "high"), and provided justification for the data quality and confidence category.

Flood Annual Exceedance Probability

To perform the risk calculations simply and consistently across the 219 dams, the AEP for most PFMs was based on a flood associated with the zero-freeboard event. This flood was chosen because most existing rating and stage-storage curves extend up to the dam crest, and it is simpler to develop new rating and stage-storage curves that terminate at the dam crest. For overtopping PFMs, the defined flood differed slightly. SMEs were instructed to assess the overtopping SRPs for earthen embankments by considering a flood occurs with “sufficient overtopping depth and duration to reasonably initiate failure” (with 0.5- to 1-ft depth considered reasonable). Note, the flood needed for overtopping is not correlated with the 200-year flood, probable maximum flood, or any other specific flood.

It is understood that there is a discontinuity between the conceptual depth of flooding used to determine the SRP and the AEP flood load probability associated with the zero-freeboard event. Although the numerical difference in AEP under an overtopping flood could exceed an order of magnitude, the results will still be consistent across the portfolio and are appropriate for prioritization. Therefore, GEI used the zero-freeboard AEP for the overtopping PFMs.

The flood AEP was typically determined by extrapolating the flood frequency estimates from the EGLE Flood Frequency Database (EGLE, 2025), which provided estimates for the 10-, 50-, 100-, 200-, and 500-year flood events. Because Michigan Dam Safety regulations specify that the design flood for significant and high hazard dams less than 40 ft tall is the 200 year flood, many dams are sized around these more frequent discharges. The flood AEP was estimated based on a log-normal extrapolation of flood frequency data. A log-normal distribution was chosen due to the goodness of fit over the range of frequencies considered. Given that the largest flood in the EGLE discharge data is the 500 year event (AEP of 0.002), extrapolation to around the 1,000-year event (AEP of 0.001) was appropriate.

In some instances, extrapolation zero-freeboard discharge results greatly exceeded the 1,000-year event, so an alternate estimation method was used. The discharge frequencies for the zero-freeboard capacity were estimated using USACE’s RMC BestFit v.2.0 and utilized the best available streamflow data from the USGS. The gage data were scaled by watershed area, and the data were input into BestFit. The statistical distribution used in the BestFit analysis was Log-Pearson Type III, and the zero-freeboard discharge associated with the posterior predictive results was extracted. The Log-Pearson Type III was chosen for the streamflow dataset because trial datasets showed favorable goodness of fit, and the Log-Pearson Type III dataset is generally appropriate for streamflow data.

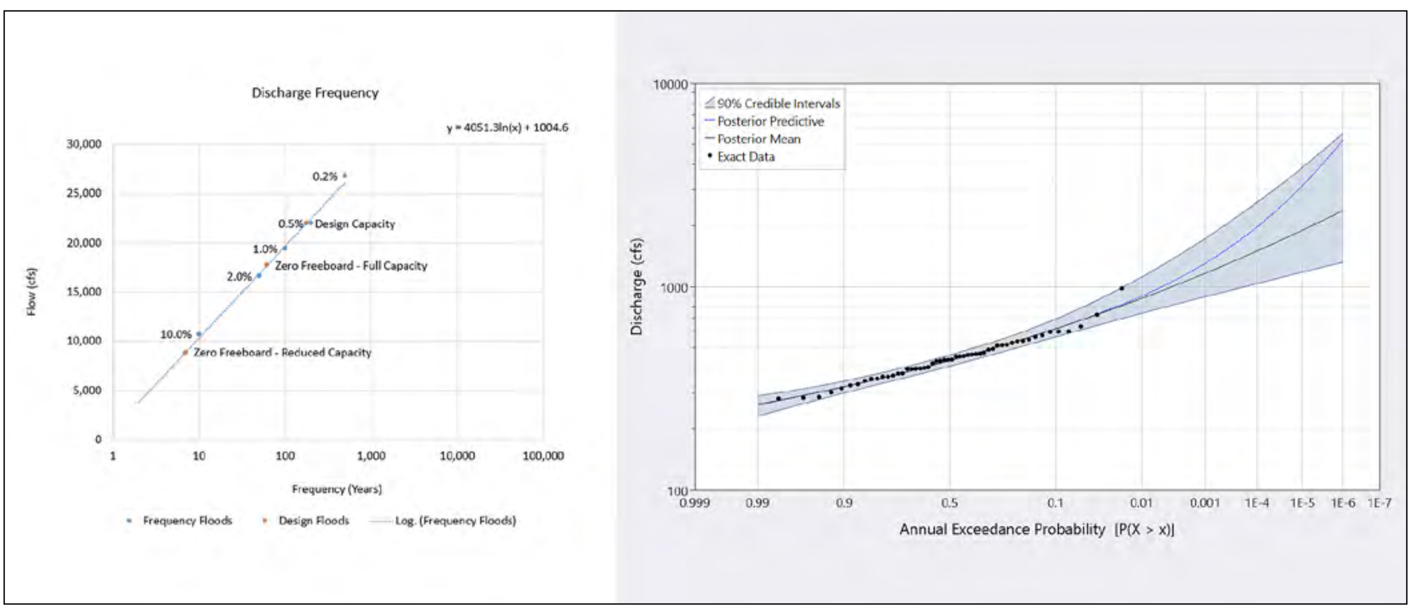

Figure 1 Example Discharge-Frequency Plots for the Log Linear Trendline *(Left)* and BestFit *(Right)*

Preliminary AEP Results

According to the dam safety regulations in Michigan, the required spillway capacity for most significant and high hazard dams is the 200-year event. Although many dams exceed this minimum spillway capacity,[2] others do not. Figure 2 illustrates the results of the flood frequency analysis for the zero-freeboard event for 196 dams. Based on the preliminary flood frequency results, 78 have a zero-freeboard spillway capacity of less than the 1,000-year event and 51 have a zero-freeboard spillway capacity of less than a 200-year event (i.e., do not meet the dam safety guidelines with no freeboard).

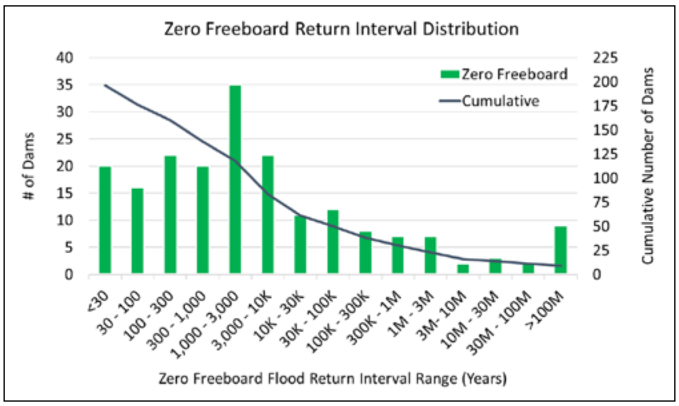

Figure 2 Zero-Freeboard Flood Recurrence Interval Range

Consequences

GEI used the USACE's Dam Screening Tool (DST) (FEMA 2024a, 2024b), for consequence analysis and to develop consequence estimates for potential life loss (PLL), the exposed population at risk (EPAR),[3] and financial damages. DST is a web-based tool that USACE developed for the FEMA High Hazard Potential Dam Grant Program and works in conjunction with their FEMA Risk Prioritization Tool. DST completes dam breach inundation mapping and estimates the likely population at risk (PAR) and PLL. This estimate is intended for a screening-level approach and should always be considered approximate. This software runs a simplified version of HEC-RAS for breach modeling and LifeSim for consequence analysis utilizing the National Structure Inventory.

Consistent with the standard of practice, the potential loss of human life is the foremost metric for classifying a dam's risk. However, because the Michigan portfolio included both significant and high hazard dams, it was important to use additional metrics to enable comparison between dams with and without PLL. For all dams, GEI used potential financial damages and potential EPAR risks as additional risk prioritization metrics. The results reflect incremental consequences and exclude those consequences that could have been anticipated from the flood itself without a dam breach. To determine the incremental consequences, a non-breach flood scenario (steady state with zero-freeboard discharge) was run in DST to identify the consequences attributable to the flood alone. These consequences were subtracted from the breach flood consequences. This calculation informed what additional (incremental) consequences the breach of the dam generated. Five breach scenarios were run for each dam, including:

- nonbreach under the zero-freeboard flood
- embankment breach under the zero-freeboard flood
- concrete dam (or spillway) breach under the zero-freeboard flood
- embankment sunny day breach under normal pool[4]
- concrete dam (or spillway) sunny day breach under normal pool

Additional potential consequences, including impacts on transportation, natural resources, contaminated lands, trout and salmon streams, historically or culturally important infrastructure, and critical infrastructure, were analyzed in GIS and provided to EGLE to support future decision-making.

Individual Risk Calculations and Preliminary Results

Individual Dam Risk Calculations and Results

The final PLL risk matrix used in the MI Tool is shown in Figure 8 with the Tolerable Risk and APF Guidelines with axis values labeled. Throughout the reporting and the rest of this article, these guidelines and the numerical y-axis probabilities

[2] Because the Michigan dam safety guidelines do not contain minimum freeboard requirements, quantifying how many dams meet the 200-year requirement with adequate freeboard is not possible. The zero-freeboard event provides an upper bound for this assessment.

[3] EPAR is the people, or groups of people, who do not reach safety, or who remain in their structure and do not evacuate before the flood arrives. Final shelter locations include vehicles, structures, or on foot (USACE, 2020).

[4] Normal pool and typical operating conditions were based on the available background information. If the typical reservoir conditions were not specified, normal pool was set to the spillway crest.

are not shown to emphasize the screening-level nature of this study and to help focus the results on relative ranking versus numerical risk. To group dams with equivalent risk, the diagonals of the risk matrix were labeled sequentially from Category A through Category K. However, to attempt to be aligned with more thorough risk assessments and assist with risk calculations within the MI Tool, GEI set the upper limit of the SRP moderate category, which is considered representative of an "average" condition dam, at 1E-04 based. Consideration was given to anchoring around the individual potential failure mode APF guideline of 1E-04; although, it was recognized that this guideline was developed specifically for the APF related to individual potential failure *modes* and is not directly comparable to the SRP for individual potential failure *mechanisms*. The APF guideline is anchored to the historic failure rate of dams under all loading conditions and inherently includes the AEP of the normal, flood, and seismic events that led to failure. It would follow that the average SRP should have a higher probability than the average AFP, given that the AEP of the load lowers the AFP. GEI anchored the upper limit of moderate to 1E-04, recognizing that the SRP of potential failure mechanisms would have a higher probability than that of an individual potential failure mode.

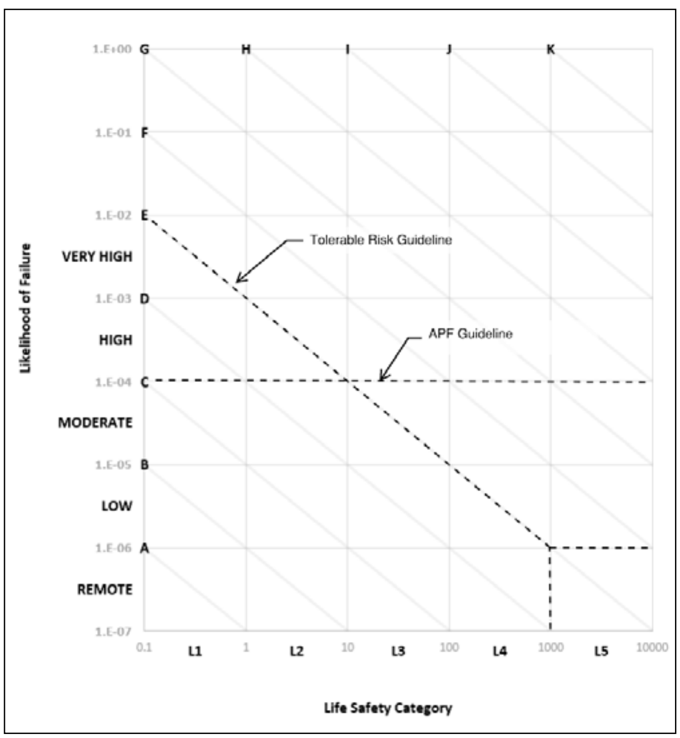

Figure 3 Life Safety Matrix with Tolerable Risk and APF Guidelines Shown

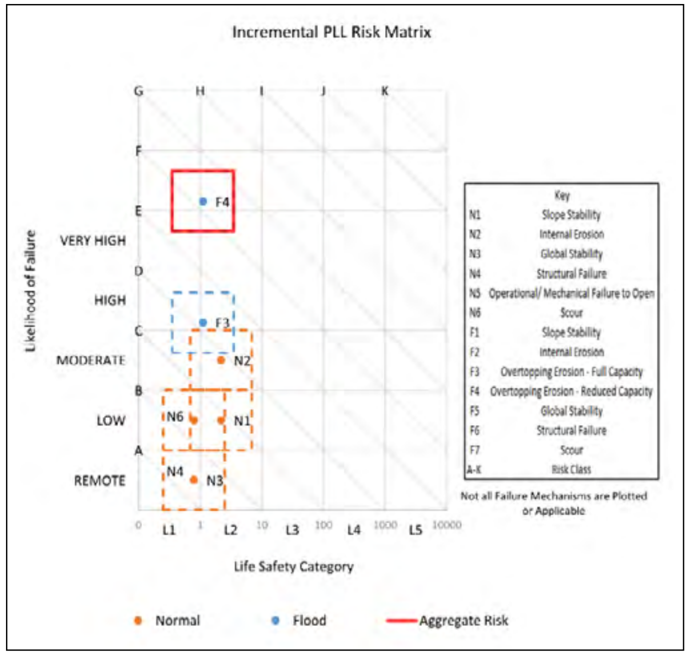

Figure 4 Example Risk Matrix Showing Preliminary Results for Potential Life Loss Consequences for an Individual Dam

Results for a single dam for incremental PLL, financial, and EPAR consequences are shown respectively in Figure 4 and Figure 5. Individual PFMs have an associated LOF category determined by multiplying the PFM's SRP by the AEP of the load and a consequence category determined using DST. The dashed box surrounding each PFM indicates that the point could reasonably plot anywhere within this one order of magnitude range. The PFM that plots on the highest diagonal line is the risk-driving failure mode (PFM F4 in the following example). The aggregate dam risk is shown as a red box, also indicating a potential one order of magnitude range. The aggregate risk was calculated in general accordance with recommendations by O'Leary (2018). The boxes reflect the relatively coarse review and limited analysis that is inherent in screening-level risk assessment.

Aggregate risk for each dam was calculated as the sum of the LOF of each PFM multiplied by the incremental consequence of each PFM:

$$Risk = Sum\,(LOF_{PFM}\,x\,Incremental\,Consequences_{PFM}) \qquad (4)$$

To plot the aggregate risk for each dam, the y-coordinate of risk is the sum of the LOFs for all PFMS with nonzero consequences. The x-coordinate of risk is the quotient of the aggregate risk and y-coordinate.

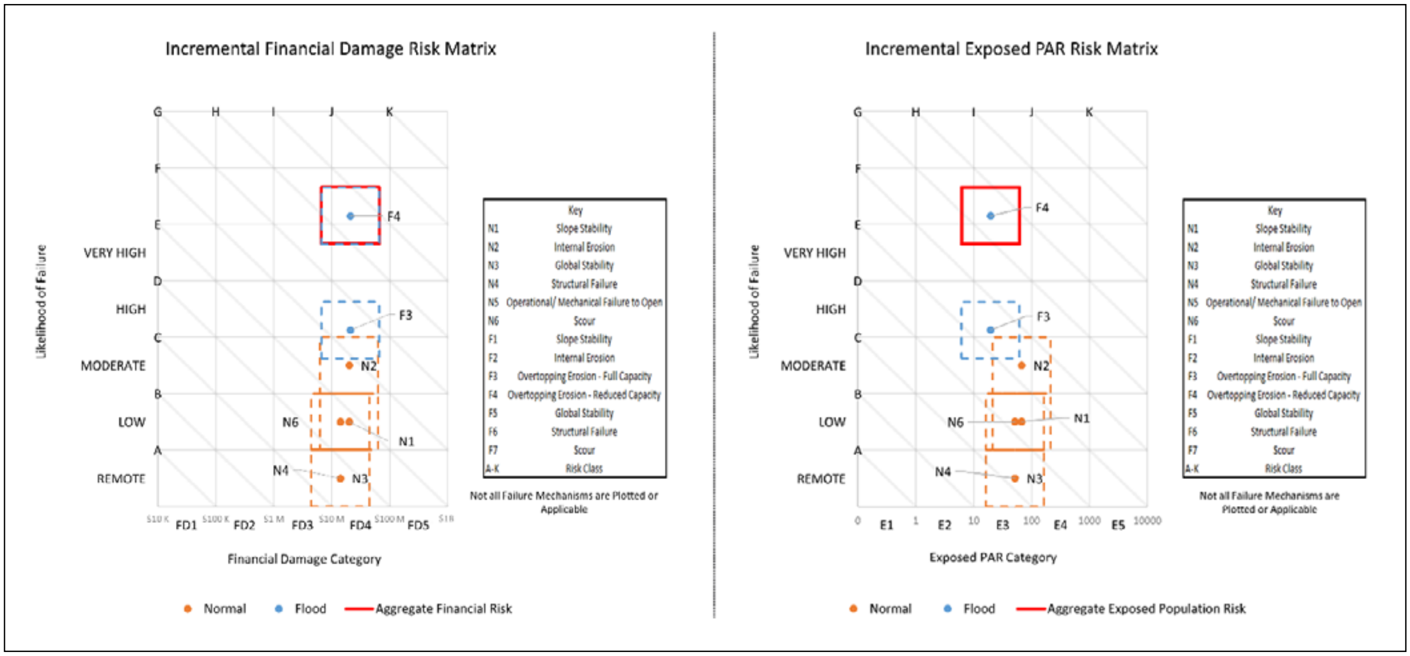

Figure 5 Example Risk Matrices Showing Preliminary Results for Incremental Financial Damages *(left)* and Incremental EPAR *(right)* for an Individual Dam

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TABLE 6 LOF CATEGORY NUMERICAL RANGES

Categories	Minimum Value	Maximum Value
Remote	1E-07	1E-06
Low	1E-06	1E-05
Moderate	1E-05	1E-04
High	1E-04	1E-03
Very high	1E-03	1

TABLE 7 CONSEQUENCE CATEGORIES NUMERICAL RANGES

Applicable Matrix	Consequence	Minimum Value	Maximum Value
PLL/EPAR	L1/E1	0 people	1 PERSON
	L2/E2	1 person	10 PEOPLE
	L3/E3	10 people	100 PEOPLE
	L4/E4	1,00 people	1,000 PEOPLE
	L5/E5	1,000 people	10,000 PEOPLE
Financial damage	FD1	$10,000	$100,000
	FD2	$100,000	$1,000,000
	FD3	$1,000,000	$10,000,000
	FD4	$10,000,000	$100,000,000
	FD5	$100,000,000	$1,000,000,000

LOF (*SRP x AEP*) is plotted along the y-axis, and consequences are plotted along the x-axis. For all three risk plots (PLL, EPAR, Financial), LOF has been broken into five categories: “remote,” “low,” “moderate,” “high,” and “very high.” Their numerical ranges are given in Table 6.

Consequences have also been broken into five categories, with the prefixes “L,” “FD,” and “E” for life loss, financial damages, and exposed population, respectively, and numbered from 1 to 5. The numerical ranges for these categories are given in Table 7.

SRP Results by PFM

Preliminary SRPs results for the 13 PFMs for 199 dams were studied to analyze trends across the portfolio. Figure 6 illustrates the SRP categories selected for 2,587 distinct PFMs (13 PFMs per dam for 199 dams). Figure 6 displays the number of dams on the y axis and the PFMs considered on the x-axis. The numbers on the bar chart depict the number of times each SRP category was selected by the SMEs for each PFM. The SRP results illustrate the general dam condition

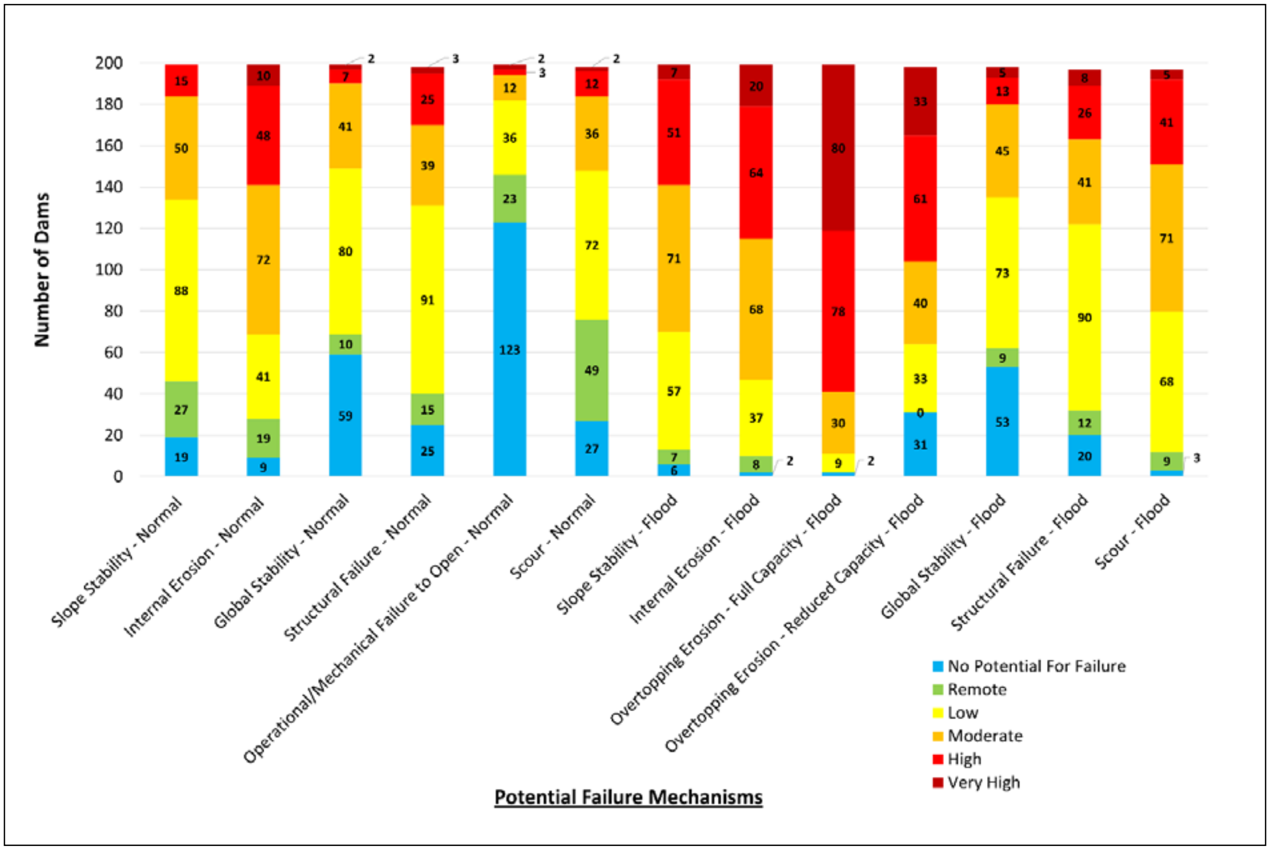

Figure 6 PFM Scoring by System Response Probability

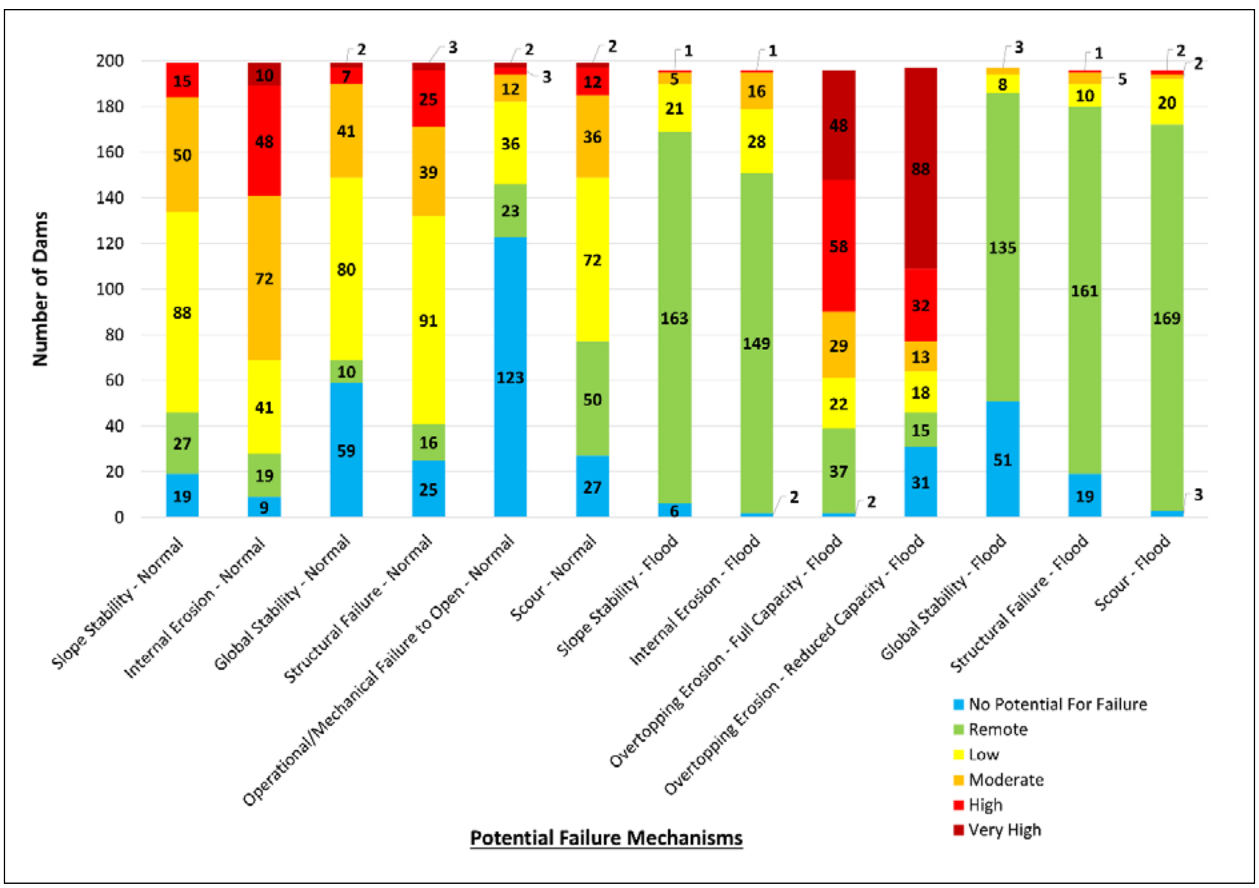

Figure 7 PFM Scoring by Likelihood of Failure

independent of the frequency of the flood. As an example, refer to the operational/mechanical failure to open-normal PFM. The SRP data show this PFM is not applicable for 123 dams (dams without gates), and for the other 76 dams, the SRPs vary from remote to very high. This indicates that almost all dams in the portfolio are not heavily reliant on gate operation, but operability of gates for a few dams is critical under normal condition.

Recalling that the SRP is independent of the AEP (i.e., the SRP is the likelihood the dam will progress to failure assuming the load occurs), the SRP results illustrate that the Michigan dam portfolio is most susceptible to overtopping failures and internal erosion. This is consistent with the expected result because (a) overtopping is the largest cause of historic dam failures, and (b) most of Michigan's portfolio are embankment dams without overtopping protection.

LOF Results by PFM

The SRPs results (Figure 6) were multiplied by the AEP of the load (refer to Figure 2 for flood AEP results) to obtain a likelihood of failure for each PFM. A comparison between Figure 6 and Figure 7 shows the normal PFM bars remain unchanged (AEP of 1), whereas the flood PFMs bar colors changed significantly.[5] The PFMs that are most likely to develop were overtopping erosion under flood loading assuming a loss of spillway capacity, overtopping erosion under flood loading assuming no loss of spillway capacity, and internal erosion under normal conditions. Note that Figure 7 does not illustrate the dam risk-driving failure mechanisms, rather this plot represents the LOF for all 2,587 possible PFMs and a single dam can have several very high PFMs, for example. Dam risk-driving PFMs are illustrated in Table 8.

Michigan Dam Portfolio Risk Results

The aggregate risk for 199 of the 219 dams was plotted on portfolio-wide risk plots, where each dot represents a dam's order of magnitude aggregate risk (Figure 8 and Figure 9). For clarity, the one order of magnitude risk range boxes were omitted. Each dam was assigned a confidence value, which corresponds confidence level with the dam's risk-driving PFM.

By reviewing the confidence level, EGLE can identify dams that might benefit from additional study.

The PLL risk matrix in Figure 8 illustrates the 33 dams with risk of PLL consequences. Three dams had low confidence, 15 dams had moderate confidence, and 15 dams had high confidence.

The potential financial damages and potential EPAR were used to develop a method for comparing significant and high hazard dams against each other. Of the 199 dams evaluated to date, 165 have potential financial damages exceeding $10,000 (Figure 9, right). Most of Michigan's dams had potential EPAR consequences, with 125 dams plotting with EPAR > 0.1 person (Figure 9, left). Similar to the findings on the PLL plot, these screening-level results provide a relative comparison of risk across the portfolio, and the matrices provide valuable portfolio-wide perspective on the relative risk by dam.

The risk-driving PFMs for the portfolio are summarized in Table 8.

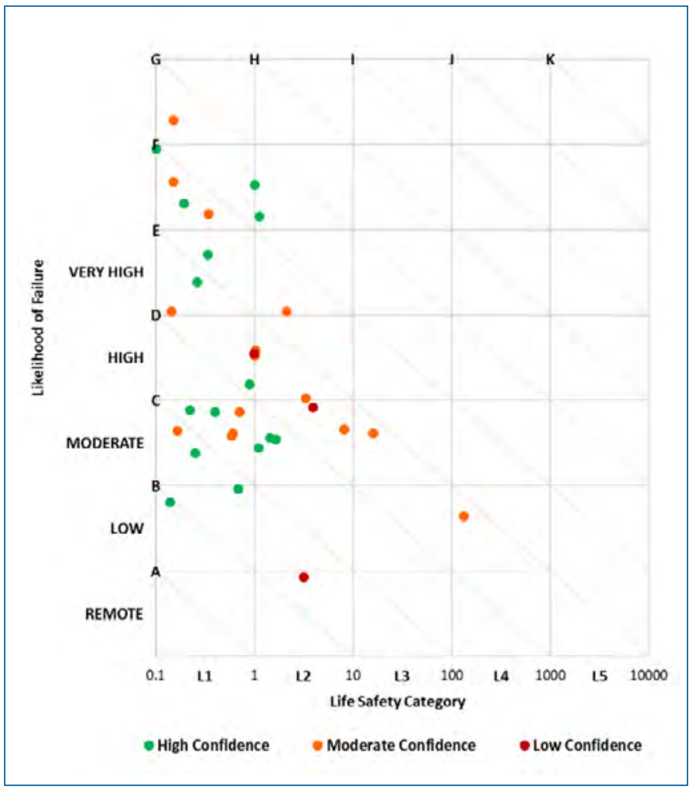

Figure 8 Risk Matrix Showing Preliminary Results for Dams with Incremental Potential Life Loss Consequences

[5] The height of the bars representing flood loading are shorter because not all flood frequency estimations have been completed.

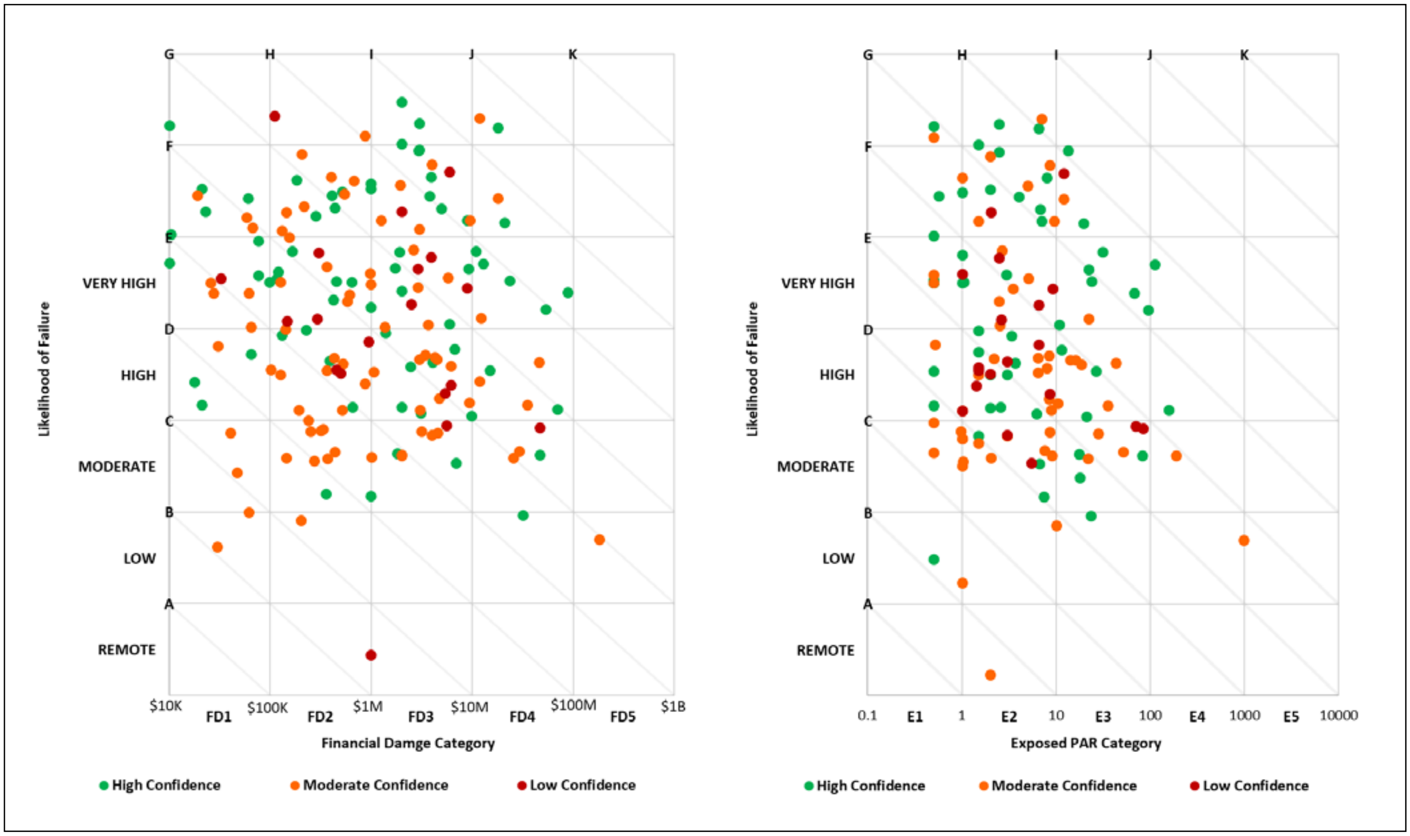

Figure 9 Risk Matrices Showing Preliminary Results for Dams with Potential Incremental Financial Damage and EPAR Consequences

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The portfolio-wide results show that most dams trend toward high and very high LOF values. This result is not unexpected, because in Michigan, state legislation requires spillway capacities to accommodate the 200-year flood for dams less than 40 ft, which corresponds to a smaller AEP than typically required by other states and federal agencies. Additionally, Michigan's dam portfolio is aging: 37 of the 199 dams plotted being built before 1900; 82 are more than 100 years old; and 180 are more than 50 years old. The combination of generally undersized spillways and an aging portfolio tends to skew Michigan's portfolio risk results higher.

Based on the DST analyses, most dams plot within Life Safety Category 1 (0.1 to 1 life), with a smaller subset plotting within Life Safety Category 2 (1 to 10 lives). The limited PLL consequences are consistent with the overall characteristics of Michigan dams and topography, but they may also be skewed lower by the lack of transient population considerations in the DST analyses. Michigan's portfolio consists of fairly low head dams, with only two dams exceeding 100 ft tall and average dam height of about 25 ft, and Michigan stream topography generally consists of wide, flat floodplains that allow for significant attenuation.

TABLE 8 MICHIGAN PORTFOLIO RISK-DRIVING PFMS

Potential Failure Mechanism	PLL Risk Driver	EPAR Risk Driver	Financial Risk Driver
Slope stability – normal	2	10	8
Internal erosion – normal	6	21	18
Global stability – normal	1	2	5
Structural failure – normal	2	6	10
Operational / mechanical failure to open – normal	0	1	1
Scour – normal	0	4	5
Slope stability – flood	0	0	0
Internal erosion – flood	0	0	0
Overtopping erosion – full capacity – flood	4	21	27
Overtopping erosion – reduced capacity – flood	17	59	90
Global stability – flood	0	0	1
Structural failure – flood	1	0	0
Scour – flood	0	1	0
Total dams appearing on the risk matrices	**33**	**125**	**165**
N/A (no consequences or LOF plots below x-axis)	166	74	34
TOTAL DAMS	**199**	**199**	**199**

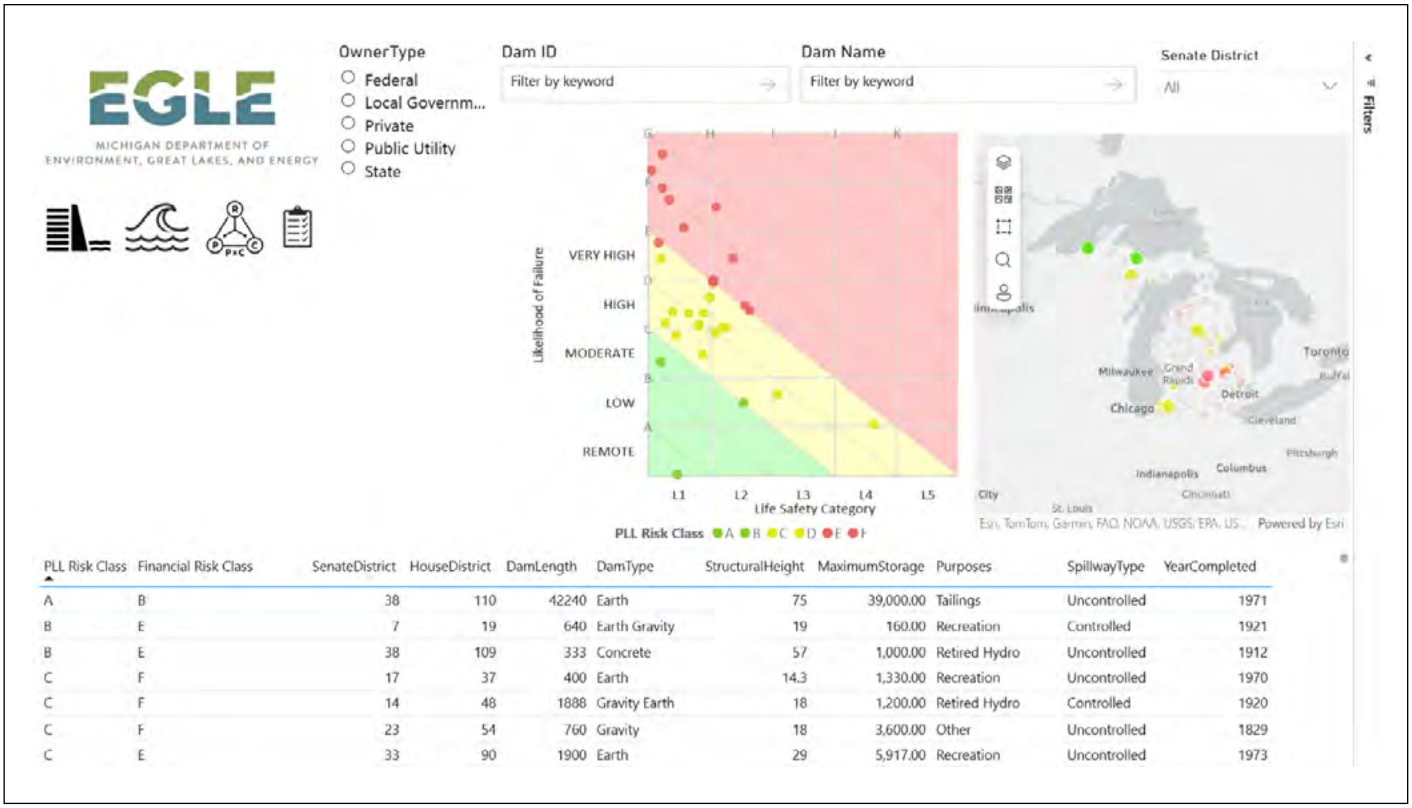


Figure 10 Draft Dashboard Developed for EGLE Dam Portfolio

CONCLUSIONS

a) Next Steps for Michigan

Risk prioritization studies lay a strong foundation for implementing a risk-informed decision-making (RIDM) approach for managing a portfolio of dams; however, this study only provides a static starting point. As of this writing, GEI is working with EGLE to assess the screening-level risk analysis results, identify areas of uncertainty/low confidence and evaluate cost-effective ways to reduce uncertainty, and define the practical next steps for managing/updating the risk portfolio.

One area already identified for improvement is within consequence analysis. Currently, DST does not support evaluation of cascading failures. This analysis would need to be performed separately, likely using HEC-RAS and LifeSim. Additionally, DST does not capture transient populations or other consequence considerations. As such, a GIS analysis is proposed to identify additional potential consequences such as impacts to public recreational spaces, critical infrastructure, transportation, and environmental and historically significant sites to inform future studies.

Ultimately, the goal for Michigan's DSU is to convert risk insights gained from the project into actionable investment and preparedness, and strategize plans for a dam safety risk management program. To move this piece forward for Michigan, GEI is currently developing a dashboard that aggregates the findings of the prioritization study and provides data visualizations, maps, risk estimates, consequences estimates, dam risk classification, and more on a single platform. The dashboard will allow EGLE to prioritize actions for dams driving risk; and produce graphics and materials for communicating funding needs to stakeholders, executives, and political representatives, or for building risk awareness with the public. This dashboard will be a dynamic platform that EGLE can update to reflect changed conditions or additional data at each dam.

Some dam owners and regulators may be interested in a full-service data management system that expands upon the dashboard concept and creates a more comprehensive and customized solution for managing the dam portfolio. A dam safety management system can include a wide variety of data sources beyond risk results, including instrumentation and monitoring data, asset management, and O&M procedures, among others. This allows for real-time monitoring of a portfolio of dams.

b) Applicability of the Michigan Tool to Other States

Recently, state dam safety officials have shown interest in integrating RIDM into their programs. Few states have fully adopted a risk-informed approach, but several states, like Michigan, have applied different methods for dam risk prioritization. The methodology behind the MI Tool provides dam owners and state regulators with a clear, practical pathway for beginning to implement a modern, risk-informed dam safety program. This SLRA approach offers an effective starting point for owners who may be unsure where to begin or who have limited documentation and constrained funding. The MI Tool's modular structure further enables customization and scalability to meet a portfolio's specific needs or to integrate with alternative analytical tools.

This framework delivers a structured method for transforming available information, whether extensive or minimal, into a consistent and comparable method for screening-level dam risk assessments. The methodology identifies primary risk drivers, highlights where additional studies or investigations would most effectively reduce uncertainty, and supports strategic capital planning. Because the MI Tool functions effectively across a wide range of data quality and dam types, it is equally well suited to owners managing a handful of structures as it is to those overseeing large, complex statewide portfolios.

For legislators and policymakers, the framework offers a practical mechanism for understanding statewide or regional risk. The MI Tool was designed with dashboard integration in mind, supporting clearer communication of system wide conditions, funding needs, and policy priorities. As new data sources, analytical tools, or regulatory requirements emerge, the dataset can be readily updated so that decisions continue to be grounded in consistent and defensible information. ■

References

Association of State Dam Safety Officials. (2025). Dam safety toolbox resources (including dam ownership fact sheets). https://damtoolbox.org.

Federal Emergency Management Agency. (2016). *Pocket safety guide for dams and impoundments (FEMA P 911).* https://damsafety.org/sites/default/files/files/FEMA%20Pocket%20Safety%20Guide%20911.pdf

Federal Emergency Management Agency. (2024a, July). Project prioritization tool template (Version 1.2).

Federal Emergency Management Agency. (2024b, July). USACE dam screening tool (DST) breach simulation job aid.

Federal Energy Regulatory Commission. (2021). *Engineering guidelines for the evaluation of hydropower projects, chapter 17 – potential failure modes analysis.* https://elibrary.ferc.gov/eLibrary/filelist?accession_number=20211216-3086&optimized=false

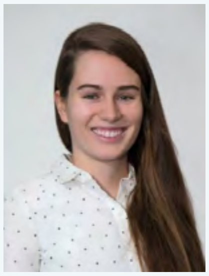
Federal Energy Regulatory Commission. (2021, December). Engineering guidelines for the evaluation of hydropower projects: Chapter 18 – level 2 risk analysis. https://hydro.org/wp-content/uploads/2021/12/Final-Engineering-Guidelines-for-the-Evaluation-of-Hydropower-Projects-Chapter-18-Level-2-Risk-Analysis-under-AD20-23-000.pdf

Michigan Department of Environment, Great Lakes, and Energy. (EGLE, 2025). Flow discharge database query (Hflowqry). https://www.egle.state.mi.us/flow/hflowqry.asp.

O'Leary, T. M. (2018). *SQRA calculation methodology.* (RMC-TN-2018-01). U.S. Army Corps of Engineers, Institute for Water Resources, Risk Management Center. https://www.scribd.com/document/754151032/SQRA-Calculation-Methodology-USACE

U.S. Army Corps of Engineers, Hydrologic Engineering Center. (2020, July). HEC-LifeSim life loss estimation: Technical reference manual (Version 2.0).

U.S. Army Corps of Engineers and U.S. Bureau of Reclamation. (2019). Best practices in dam and levee safety risk analysis. https://usbr.gov/ssle/damsafety/risk/BestPractices/Chapters/1-BestPracticesCover.pdf



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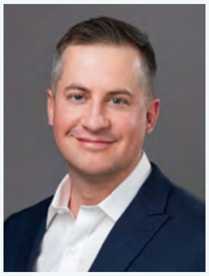

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ASDSO Peer

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