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Navigation Systems Research Program

Risk-Based Prioritization of Operational Condition Assessments

Trinity River and Willamette River Case Studies

Willie H. Brown, John P. Richards, George E. Gallarno,
Christopher Morey, Titus L. Rice, and Jennifer M. Olszewski

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Abstract

The US Army Corps of Engineers (USACE) operates, maintains, and manages over 700 dams and 4,000 miles of levees, providing approximately \$257 billion worth of economic benefit to the Nation. USACE employs the Operational Condition Assessment (OCA) process to understand the condition of those assets and allocate resources to minimize risk associated with performance degradation. Understanding risk in flood risk management (FRM) assets requires an understanding of consequence of asset failure from a systemwide FRM watershed perspective and an understanding of likelihood of degradation based on the condition of the low-level components derived from OCA ratings. This research demonstrates a case-study application of a scalable methodology to model the likelihood of a dam performing as expected given the state of its gates and their components. The research team combines this likelihood of degradation with consequences generated by the application of designed simulation experiments with hydrological models to develop risk measures. These risk measures can be developed for all FRM gate assets in order to enable traceable, consistent resource allocation decisions. Two case study applications are provided.

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Preface

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The work was performed by the Institute for Systems Engineering Research (ISER), Computational Science and Engineering Division (CSED), ERDC Information Technology Laboratory (ITL), and the Water Quality and Contaminant Modeling Branch, Environmental Processes and Engineering Division, ERDC Environmental Laboratory (EL). At the time of publication of this report, Mr. Willie H. Brown was chief, ISER, and Dr. Jeffrey L. Hensley was chief, CSED. The deputy director of ERDC-ITL was Dr. Jacqueline S. Pettway, and the director was Dr. David A. Horner.

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The commander of ERDC was COL Christian Patterson, and the director was Dr. David W. Pittman.

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1 Introduction

The US Army Corps of Engineers (USACE) operates, maintains, and manages over 700 dams and 4,000 miles of levees, providing approximately \$257 billion worth of economic benefit to the Nation (IWR 2020). Ensuring the proper functioning of these assets is vital because those assets' functioning impacts the lives of people across the country on a daily basis. To track the condition of those assets in a way that maps to infrastructure investments, USACE developed the Operational Condition Assessment (OCA) system, where each component at every facility is assessed, at a minimum, every 5 years. A team from the Engineer Research and Development Center (ERDC) Institute for Systems Engineering (ISER) has been researching this system since 2020 to develop a modernized risk-based OCA system that is transparent, consistent, and traceable. The purpose of this document is to provide a methodology updated from 2021 research efforts and to describe its application to a case study on the Trinity River watershed.

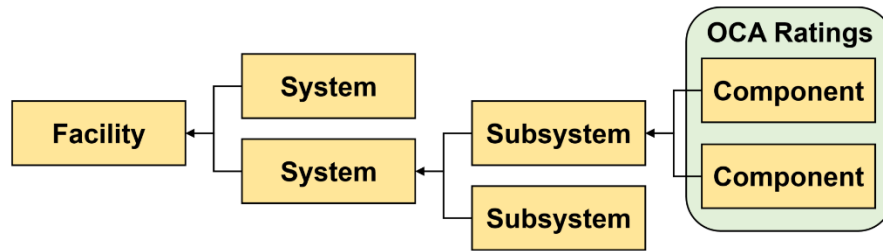
1.1 Background

Each year, USACE assigns OCA teams to conduct OCAs without using risk associated with an asset (e.g., a dam) to drive the assignment of OCA teams. This could have two unfortunate outcomes: (1) USACE could expend OCA resources on assets that pose minimal risk to the enterprise's ability to execute its mission, and (2) assets that pose great risk could fail, and that failure could be prevented via more frequent OCAs, preventive maintenance, or some other intervening action. A risk-based prioritization framework requires an understanding of the probability of failure of a system as a function of the state of its components—where the state of the components is defined by OCA ratings (see Table 1-1)—and the consequence of the system's failure given the associated FRM watershed. This framework must be robust enough to accommodate a range of facility types and system configurations, and it must be feasible to implement at scale given the large number of components and their interactions in a single facility (see Figure 1-1).

Table 1-1. Operational Condition Assessment (OCA) ratings.

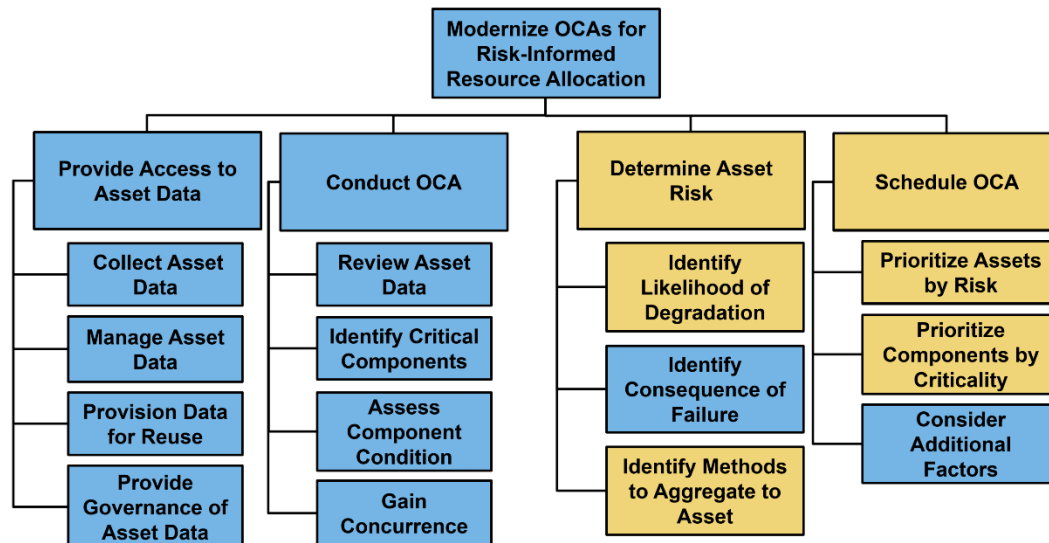
OCA Rating	Index Value	Descriptor	Physical Condition	Performance	Likelihood of Failure
A	9	Excellent	No signs of degradation and recently put into service	No performance issues and was recently put into service	Extremely unlikely to fail within the next 5 years
A–	8	Excellent	No signs of degradation and recently put into service	No performance issues and was recently put into service	Extremely unlikely to fail within the next 5 years
B	7	Good	Minor deficiencies	No performance issues	Low likelihood of failure within the next 5 years
B–	6	Good	Minor deficiencies	No performance issues	Low likelihood of failure within the next 5 years
C	5	Fair	Moderate deficiencies	Deficiency is beginning to affect component's performance, operational procedures, or maintenance requirements	Potential failure mode with a moderate likelihood of failure within the next 5 years
C–	4	Fair	Moderate deficiencies	Deficiency is beginning to affect component's performance, operational procedures, or maintenance requirements	Potential failure mode with a moderate likelihood of failure within the next 5 years
D	3	Poor	Significant deficiencies affecting a substantial portion or critical feature of the component	Deficiency increasingly affects component's performance, operational procedures, or maintenance requirements	Potential failure mode with a high likelihood of failure within the next 5 years
D–	2	Poor	Significant deficiencies affecting a substantial portion or critical feature of the component	Deficiency increasingly affects component's performance, operational procedures, or maintenance requirements	Potential failure mode with a high likelihood of failure within the next 5 years
F	1	Failing	Severe deficiencies affecting a substantial or critical feature of the component	Deficiency substantially affects component's performance, operational procedures, or maintenance requirements	Potential failure mode that could fail imminently
CF	0	Completely failed	Due to degradation, component is failed and does not perform its intended function	Component is failed or does not perform its intended function	Component is failed
U	n/a	Unratable	Unratable	Unratable	Unratable

Figure 1-1. Operational Condition Assessment (OCA) hierarchy.



In 2020, the USACE HQ Asset Management (AM) Program tasked the ERDC ISER team with (1) understanding the current state of the OCA system, (2) envisioning a modernized OCA system that informs risk, and (3) documenting a strategic roadmap to develop a transparent, consistent, and traceable risk-based OCA system. The team recommended four strategic objectives: provide access to asset data, conduct OCA, determine asset risk, and schedule OCA (Brown and Alt 2021) (see Figure 1-2).

Figure 1-2. OCA strategic objectives. Those addressed in this document are highlighted.



The USACE HQ AM Program has leveraged the strategic roadmap to initiate several research projects, including this one, as part of their effort to modernize OCAs. Begun in 2020, the objective of this 3-year effort is to develop an enterprise framework for risk-based prioritization of OCAs. This project will help decision-makers understand which FRM facility components to prioritize for assessment and maintenance based on their current condition and contribution to overall operational risk. The project focuses on gates at facilities associated with FRM, but the prioritization methodology developed can be generalized to critical infrastructure for other USACE business lines. The output of the project and framework will

be the set of FRM risk-driving components to prioritize for OCAs and maintenance, given limited resources; an understanding of risk based on modeled results of consequences given probabilities of failure; and an easily understandable presentation of potential trade-offs.

In fiscal year 2021 (FY21), the team developed a methodology to determine system and facility probability of failure based on the condition of components and applied that methodology to the Jennings Randolph facility and the Elm Fork of the Trinity River as proofs of principle. For the literature review associated with the FY21 effort and the results of the Jennings Randolph Lake Facility and Baltimore District staff interviews, see Alt et al. (2021). For the results from the Jennings Randolph and the Elm Fork Trinity River case studies, see Alt, Brown, Gallarno, et al. (2022) and Alt, Brown, Richards, et al. (2022).

1.2 Objectives

USACE plans to scale this methodology to all FRM facilities. Therefore, in FY22, the team applied the methodology to the entire Trinity River watershed. The objectives of this Trinity River case study are to apply the updated subject matter expert (SME) elicitation methodology, which may aid in scaling to implement at all USACE FRM facilities, and apply an alternate design of experiment approach (instead of a full-factorial design) to the consequence data development process, which should also aid in scaling to implement at all USACE FRM facilities.

1.3 Approach

The general approach for FY22 consisted of an expansion of the approach taken for the FY21 Jennings Randolph and the Elm Fork of the Trinity River studies. As stated in the Objectives, the primary changes from the previous case studies include the elicitation and use of SME input and the updated design of experiments for developing consequence data.

1.4 Report Organization

Section 3 of this report highlights the methodology changes from previous case studies. Section 4 details the updated methodology. Section 4 documents how this methodology was applied to a case study on the full Trinity River watershed and the case study results. Section 5 documents how this

methodology was applied to a case study on the full Willamette River watershed and the case study results. Lastly, Section 6 provides a summary and a discussion of potential future work.

2 Project Methodology Changes

To determine risk for FRM gates, the team had to determine both probability of failure and consequence of failure. In both cases, the team implemented changes in its methodology from the previous execution of the case studies

In developing probabilities of failure, the team's goal for the expert elicitation was to understand each component's relative influence on system functioning and to understand each system's relative influence on the facility's ability to carry out the FRM mission. The previous year's methodology asked experts to rate each system and component. For example, if component 1 received a rating of 100 and component 2 received a rating of 50, then component 1 was twice as influential to system functioning as component 2. In accordance with the Borda count system (De Borda 1781), the methodology captured in this report was to ask experts to rank each system and component from 1 to n . The team thought this new methodology would be more straightforward for the experts.

For developing consequences of failure, the team's goal was to understand each gate's contribution to economic damages in the watershed. To understand contributions to economic damages, the modelers ran a design of experiments that simulated the effects of various combinations of operational and nonoperational gates across the watershed. For each combination, the models* output economic damages. In the previous, simpler case studies, the design of experiments was full factorial. The current methodology employs a nearly orthogonal Latin hypercube design, which screens out some designs, making the problem computationally feasible while attempting to adequately represent the design space.

* "Models" refers to the series of models in Hydrologic Engineering Center Watershed Analysis Tool (HEC-WAT) that produce economic damages due to flooding. These models include ResSim, HMS, RAS, and FIA (HEC IWR USACE 2017).

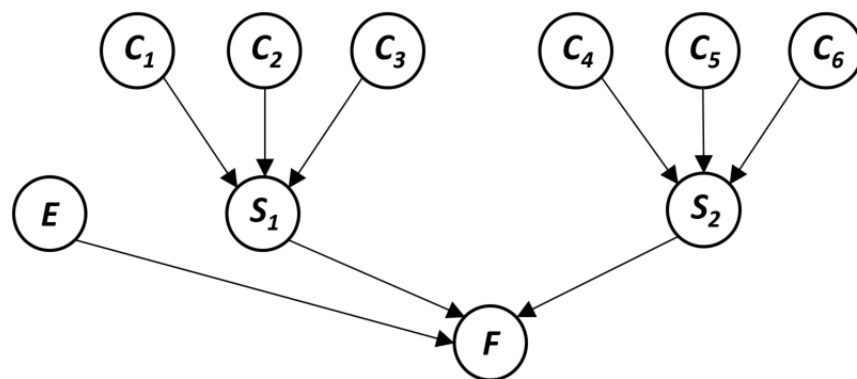
3 Methodology and Data Collection

To ascertain risk, probability of failure and consequence of failure data are required. This section will describe the methodology and data collection efforts employed to develop probability of failure and consequence of failure data.

3.1 Facility Performance Model

This research effort continued the use of Bayesian (Belief) Networks (BBN) as a means to assess facility performance and system probability of failure (see Alt et al. 2021). Per the established convention, there are component, system, and facility nodes within the BBN used to assess the operational capabilities of a watershed. It should also be noted that environmental conditions can be included in the calculation of probabilities associated with the operational status of facility-level nodes (Figure 3-1).

Figure 3-1. Example Bayesian network for facility operational status, where C represents components critical to the function of systems, S , that in turn determine the operational status of the facility, F , and E represents environmental factors.



To improve the facility performance model, researchers allow for components to be in one of many operational states (Table 3-1). The inclusion of multiple operational states increases the state space, improving model fidelity when compared to the previously leveraged binary rating schema (i.e., pass or fail).

In the absence of failure or downtime data, researchers still require information gathered through engagement with SMEs to initialize the conditional probability tables required to use this model for inference.

Table 3-1. Possible operational states of system components. (USACE 2019)

Operational State	Meaning
A	Component was recently put into service and shows no signs for wear.
B	Component performs its intended function. Any deficiencies are normal wear and not actively progressing at a greater rate than normal wear.
C	Component has a deficiency that is beginning to affect its performance, operational procedures, and/or maintenance requirements. AND/OR Component is beginning to show a greater rate of change in degradation that has the potential to cause a functional failure.
D	Component has deficiency that increasingly or moderately affects its performance, operational procedure, and/or maintenance requirements. AND/OR Component has a clear mode of failure due to an advanced state of degradation, likely with an accelerating trend.
F	Component has a deficiency that substantially affects its performance, operational procedures, or maintenance requirements and is approaching complete failure. AND/OR Component is clearly in the final stage of degradation trending toward complete failure (imminent failure).
CF	Component is completely failed and does not perform its intended function. AND/OR Component is red-tagged.

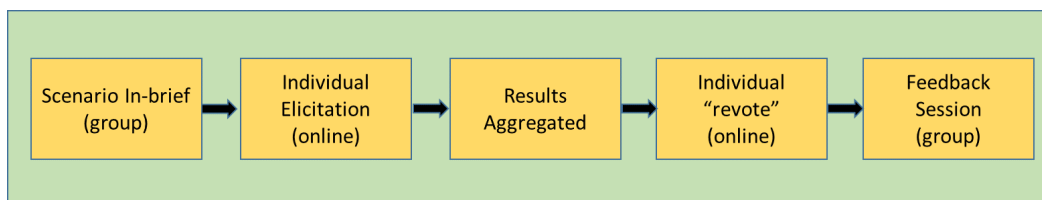
3.2 Subject Matter Expert Elicitation

For the collection of expert opinion of the relative influence of systems on the facility and components on the systems, the researchers used a modified Delphi method to elicit SME input through multiple rounds to build consensus (Richards et al. 2021). The elicitation approach established a specific scenario setting for the SMEs and then asked each SME to assign a numerical ranking for the specified gate systems and components as identified in the OCA hierarchy for each of the facilities. The intent was to generate relative comparisons of the components' relative influence on system functioning. These relative comparisons were used to calculate the conditional probabilities.

The team did case studies on the Trinity and Willamette River basins in FY22. For both case studies, the team conducted SME elicitation in five

stages, starting with the scenario in brief and ending with the feedback session (Figure 3-2).

Figure 3-2. FY22 case study subject matter expert elicitation process.



The first step of the elicitation process delivered an orientation to the elicitation methodology, provided a scenario overview of normal and flood scenarios, and included a brief tutorial on how to use this online data collection tool. For both FY22 case studies, the script found in Appendix B was followed, and the session was recorded and made available to the SMEs in the event they were not able to attend the session or wanted to review how to complete the online elicitation tool.

The second step of the elicitation process was data collection. To facilitate data collection, analysis, and visualization, the team developed a set of Common Access Card (CAC)–enabled, web-based applications hosted on ERDC’s Cloud Computing Environment (CCE) for both the first and second rounds of elicitation. SMEs were given a unique identification number (SME ID) to track their responses through the process and asked to provide information on their duty position and level of experience (both in their position and as it related to the facility being evaluated). The data collection tool presented the platform for each SME to rank each system or component according to its importance to the operations of its associated next higher level (facility or system). All of the facilities of interest for the specific case study watershed were listed on the CCE-hosted webpage, with each facility broken into two levels: (1) the gate systems and (2) their components. For the gate operations, the SMEs were asked to rank the systems under two scenarios: * operating under high-water / flood emergency operations (_Fld), which necessitates the operation of gates to control the output of water so as not to overtop the dam, and operating under normal operating conditions (_Norm), in which water release is to control water

* During the FY21 Trinity case study (Alt, Brown, Richards, et al. 2022), the SMEs indicated that water quality gates are very important under normal operating conditions but are not used in high water / flood operations. Therefore, the SMEs were asked to rank the influence of these gates on the operation of the facility, both under normal conditions and under high-water conditions.

flow, lake levels, and associated environmental conditions. SMEs were asked to rank components from most (1) to least important to normal operation of its associated gate. For both systems and components, SMEs were asked not to give more than one system or component the same rank.

A dynamic bar chart on the webpage showed the rankings, providing the SME a visual indicator of their rankings across the facility (or system). Additionally, a free text block allowed for any SME comments, and an additional block asked SMEs to indicate their level of confidence in assigning their rankings.

After completion of the initial individual data collection, the third step of the process involved a second round of individual data collection based on the aggregated values from the first round using another ERDC CCE–hosted application. A second instructional packet provided guidance on how to complete the second round of elicitation in the online tool. This round afforded the SMEs the opportunity to review and adjust, if desired, their initial individual rankings of the facility systems and their associated components as compared to the aggregated group rankings. SMEs were asked to review the numerical value reflecting their assessment of the ranking of the specified gate systems and components as identified in the OCA hierarchy for each of the facilities identified for elicitation in the watershed, and after considering their first-round rankings and the aggregated group rankings, they were free to adjust their rankings based on any additional insights they had. If their ranking for a system or component differed greatly from the aggregate ranking, they were asked to provide greater insight into their thought process in the “NewComments” field within the table. As it was for the first round, each SME was asked to complete an assessment for each of the facilities of interest in the watershed, even if they were not familiar with a specific facility. In that case, they were advised to use their best engineering/operational experience to assign rankings to the systems and components in that facility.

The final step after the second round of data collection was a group feedback session to discuss similarities and differences in rankings across the SMEs and to finalize those rankings. Additionally, a System Usability Survey (SUS) was conducted as part of this feedback session. Specifically, the meeting sought to accomplish three tasks:

1. Review the aggregated group rankings of the systems and components for the facilities of interest in the watershed based on the two rounds of data collection
2. Provide the SMEs the opportunity to express differences with the group ratings
3. Receive SME feedback on the usability of the online data collection process and tools

The SUS was developed by John Brooke at Digital Equipment Corporation and is used to take a quick measurement of how people perceive the usability of computer systems on which they are working. Each user is asked to provide their level of agreement (strongly agree, agree, neutral, disagree, and strongly disagree) on 10 statements (Table 3-2) (Lewis 2018).

Table 3-2. System Usability Survey questions. (Lewis 2018)

Question	Statement
1	I think that I would like to use this system frequently in conjunction with ranking systems and components.
2	I found the system unnecessarily complex.
3	I thought the system was easy to use.
4	I think that I would need the support of a technical person to be able to use this system.
5	I found the various functions in this system were well integrated.
6	I thought there was too much inconsistency in this system.
7	I would imagine that most people would learn to use this system very quickly.
8	I found the system very cumbersome to use.
9	I felt very confident using the system.
10	I needed to learn a lot of things before I could get going with this system.

Raw scores ranging from 0 (poorest rating) to 4 (best rating) are used to calculate a standard SUS score, which is on a scale of 0 to 100. The responses from each SME for their level of agreement on each of the 10 SUS questions were collected and converted from the qualitative level of agreement to a SUS score using Equation (1) (Lewis 2018).

$$SUS = 2.5[20 + \text{SUM}(SUS01, SUS03, SUS05, SUS07, SUS09) - \text{SUM}(SUS02, SUS04, SUS06, SUS08, SUS10)] \quad (1)$$

The average SUS can then be graded in comparison to other computer systems using the curved grading scale (Table 3-3) (Lewis and Sauro 2018).

Table 3-3. Curved grading scale for the System Usability Survey. (Lewis and Sauro 2018)

Grade	SUS	Percentile Range
A+	84.1–100	96–100
A	80.8–84.0	90–95
A-	78.9–80.7	85–89
B+	77.2–78.8	80–84
B	74.1–77.1	70–79
B-	72.6–74.0	65–69
C+	71.1–72.5	60–64
C	65.0–71.0	41–59
C-	62.7–64.9	35–40
D	51.7–62.6	15–34
F	0–51.6	0–14

After the data were collected, the results were aggregated according to the methodology outlined in this section, and those results are in Sections 4.4 and 5.3.1.

In the research team’s FY21 elicitation process, SMEs were asked to assess the relative influence of each system or component as compared to the others using the statement, “Since the least influential component was set at 1, indicate how much greater would you say the influence of this component is than the least influential (7, 37, 100...times)” (Alt et al. 2022b). Feedback from the SMEs was that this subjective rating process was a challenging undertaking, and each SME responded with a widely varying sense of relative influence. While the discussions with the SMEs implemented through the modified Delphi method facilitated eventually coming to a strong group consensus on the relative influence of the systems and components within a facility, the process was time- and resource-intensive.

To streamline this process and simplify the work requested of the SMEs, the team used the Borda voting method in the FY22 SME elicitation process. Lansdowne and Woodward (1996) succinctly summarize the Borda voting methodology and its benefits.

The Borda method is a relatively simple positional voting method that determines the ranking of the candidates by evaluating the total number of points assigned to each one. The method is easy to implement

and has the added feature of being able to assign weights to the alternative criteria.

The team leveraged two specific Borda voting method benefits identified by Lansdowne and Woodward: (1) “It minimizes the need for subjective assessments. In contrast, subjective assessments are generally needed to construct utility functions in multiple attribute utility theory and to make pairwise comparisons in the analytic hierarchy process”; and (2) “[t]he Borda method needs only enough precision in data to determine a rank order for each criterion. In contrast, cardinal methods require additional precision to determine the degree of preference of one alternative over another” (Lansdowne and Woodward 1996).

3.3 Initializing Conditional Probability Tables using the Borda Score Methodology

Researchers use a modified version of the technique presented by Hassall et al. (2019) to initialize conditional probability tables (CPT) used within the facility performance model. Hassall et al. use SME-elicited relative influences of BBN parent and child nodes to initial CPTs. Given the number of components and systems within each facility, and to ease the burden on SMEs during the elicitation process, SMEs are asked to assign a rank of 1 to n for the component and system levels. The rankings are then used to assign a normalized Borda score to each SME-ranked component or system. Given n systems/components and multiple SMEs, points of $n-1$, $n-2$, ... and 0 are assigned to the first-ranked, second-ranked, and last-ranked system/component. The points for each system/component are summed across all SMEs and normalized to establish relative influence values (Lansdowne and Woodward 1996).

A comparison of this methodology to the previously used relative influence methodology is provided in Appendix G.

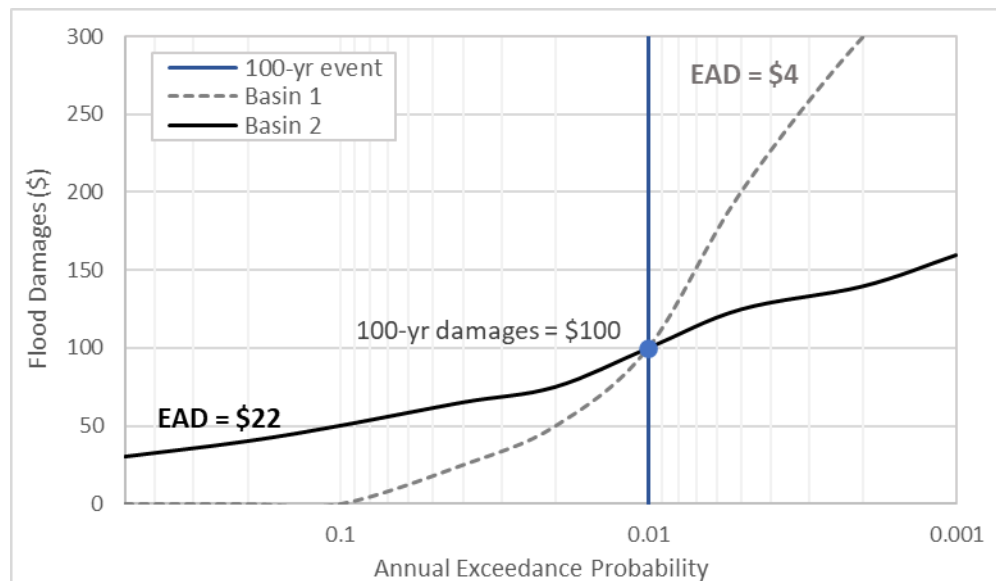
It should be noted that this CPT initialization methodology still allows the probability estimates to be refined using empirical data should they become available.

3.4 Consequence Development

The consequences effort leveraged existing Corps Water Management System (CWMS) models to compute expected annual damages (EAD) associated with individual gate outages. The team developed consequences through a series of activities. For ultimately generating consequences, the team converted the CWMS models to the Hydrologic Engineering Center-Watershed Analysis Tool (HEC-WAT), which is an analogous software that's better organized for scenario development and simulation (HEC IWR USACE 2017). The team also developed input precipitation intensity-duration curves for the basin, created gate outage scenarios in HEC-ResSIM (Reservoir Simulation), and ran all gate outage scenarios through a range of precipitation events (e.g., the 2- through 500-year events).

EAD represents the damages expected to occur in any given year without prior knowledge of if a flood will occur. EAD is computed as the area under the damages curve for a given gate outage scenario. The importance of using a risk-based metric like EAD is illustrated in Figure 3-3.

Figure 3-3. Example damages curves for fictional basin 1 (dashed gray) and basin 2 (black). Expected annual damages (EAD) summarizes the full range of event damages, demonstrating that basin 2 is the riskier basin despite the two basins having equal damages for the 100-year event.



The 100-year event damages are \$100 for both fictional basins 1 and 2. The basin damage curves, however, are very different. Basin 1 produces very few damages in the smaller, more frequent events, with most of its damages being produced by events larger and less frequent than the 100-

year. Conversely, basin 2 produces most of its damages in the more frequent small events, steadily increasing damages with event size. Because basin 2 produces more damages than basin 1 in the smaller, more frequent events, its EAD (\$22) is more than five times that of basin 1 (\$4). Damages are more likely to occur in any given year in basin 2 because it produces damages in smaller events with a higher likelihood of occurring. If we had just used the 100-year event to compare the basins, we would assume they have equal potential flood damages. However, when we use the EAD to summarize the full range of event damages, we see that basin 2 has much higher flood risk than basin 1.

Methods were developed using nationally available datasets including the NOAA Atlas but were also made flexible to allow for use of local data where available. The direct outputs of the resulting HEC-WAT models are flood damages and life loss estimates by frequency event (e.g., 2-year, 50-year, 500-year damages). These event-level values are then aggregated up to estimate overall expected annual damages and life loss. This study focuses on estimating consequences associated with different gate outages (e.g., “What is the EAD associated with a broken flood gate at Dam A?”). In addition to these applications, the HEC-WAT model and outputs developed as part of this effort could be used across a wide array of applications, including informing Operations and Maintenance (O&M) budgeting, the evaluation of alternatives in planning studies, and emergency repair work.

3.5 Determining Risk

Risk is often defined in terms of the likelihood of an event and the consequences associated with that event’s occurring (Garvey 2008). CPTs initialized through SME elicitation determine the likelihood of an event, and HEC-WAT model outputs assess the consequences of an event. This allows researchers to assess risk associated at the system and component levels. For further details on risk determination, refer to Alt et al. (2021).

3.6 Summary

This section provided an overview of the Borda Score methodology, including the rationale behind the change from the relative influence methodology. The methodology is intended to be robust to different data sources and provide a framework for developing risk measures for FRM facilities across the enterprise. The next sections provide application of this methodology to the Trinity River and Willamette River basins.

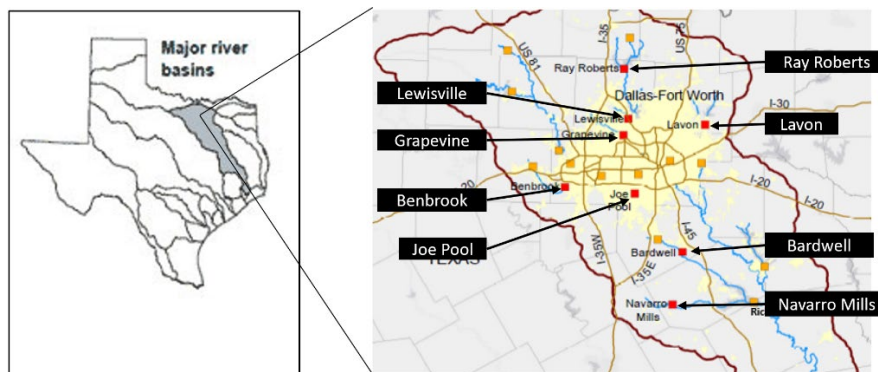
4 Case Study: Trinity River Results

This section provides an overview of the Trinity River watershed case study.

4.1 Overview

The Trinity River watershed provides a case study in the application of these methods. Figure 4-1 presents the eight USACE-owned facilities in the Trinity watershed: Bardwell Lake, Benbrook Lake, Grapevine Lake, Joe Pool Lake, Lavon Lake, Lewisville Lake, Navarro Mills Lake, and Ray Roberts Lake.

Figure 4-1. US Army Corps of Engineers (USACE)–owned OCA facilities in the Trinity River watershed.



Modeling eight facilities introduced more complexity and the need for more coordination than in the previous two case studies where the North Potomac sub-basin had one USACE-owned facility and the Elm Fork of the Trinity River had three USACE-owned facilities. The increase in complexity had an impact on the probability-of-failure and consequence-of-failure modeling. Both methodologies were refined to meet the need at hand and with an eye toward scaling those methodologies to the entire FRM enterprise.

4.2 Data Exploration

Each facility in this case study was represented in the OCA database. The facility decomposes into systems, which decompose into subsystems and components, which are the target for OCAs. Each facility has many major systems, but this research focused solely on FRM gates because they are so

critical to mitigating flood risk during a flood event. Table 4-1 shows the gate systems at each facility and the number of gates within each of those gate systems. The OCA gates were aligned with the CWMS models, so the team did not have to consult any additional data sources to reconcile the two.

Table 4-1. Gate types and associated number of gates across the Trinity River watershed.

Facility	Gate Type	Number of Gates
Bardwell	Service discharge gates	2
Benbrook	Service discharge gates	2
Benbrook	Water quality gate	1
Grapevine	Service discharge gates	2
Grapevine	Water quality gates	2
Joe Pool	Service discharge gates	2
Joe Pool	Water quality gate	1
Lavon	Spillway gates	12
Lewisville	Service discharge gates	3
Lewisville	Water quality gates	2
Navarro Mills	Spillway gates	6
Navarro Mills	Water quality gates	2
Ray Roberts	Service discharge gates	2
Ray Roberts	Water quality gate	1

SME input was required to understand the relative influence of each component and system on the functioning of the facility.

4.3 Developing Relative Influence and Probability of Failure

The team conducted SME elicitation for the Trinity River Basin per the methodology in Section 3.2. The USACE Fort Worth District identified 16 SMEs for this case study based on their knowledge and experience with the operation of the five facilities as well as FRM operations. Of those 16 SMEs, 7 serve at the district with an overarching view of the entire basin, 4 have a regional-level view over multiple facilities within a specific watershed in the basin (but not the entire basin), and 5 serve as staff at the actual facilities involved in their day-to-day operations (see Appendix E for names).

The first of two 1-hour group sessions that the team conducted provided the SMEs with an explanation of the circumstances under which to consider normal and flood scenarios and a brief tutorial on how to complete the online data collection tool. The session was recorded and provided to

the SMEs in the event they were not able to attend the session or wanted a refresher on how to complete the online elicitation tool.

Following the group session, each SME was provided the link to the online data collection tool and a unique identification number and asked to complete an assessment for each of the five facilities (Bardwell, Benbrook, Joe Pool, Lavon, and Navarro Mills) using the online data collection tool. If they were not familiar with a specific facility, the SMEs were asked to use their best engineering/operational experience to assign rankings to the systems and components in that facility. Additionally, the SMEs were asked to not give any system or component the same rank as another.

For the second round of individual data collection, SMEs were asked to review and consider the numerical value reflecting their individual assessment of the rankings of the specified gate systems and components for each of the five facilities with the aggregated group rankings. Based on this consideration, they were free to adjust their rankings based on any additional insights they had. If their ranking for a system or component differed greatly from the aggregate ranking, they were asked to provide greater insight into their thought process in the “NewComments” field within the table. Again, each SME was asked to complete an assessment for each of the five facilities even if they were not familiar with a specific facility. In that case, they were advised to use their best engineering/operational experience to assign rankings to the systems and components in that facility.

Finally, a second group session was held to discuss the results and conduct a usability survey. Eight SMEs were able to attend the session in person. To accomplish the three tasks outlined in Section 3.2 (review group rankings, discuss differences, and receive online data collection tool usability feedback), the session was divided into discussing the ratings first by facility and then by system type, then a WebEx poll conducted to collect feedback on the usability of the online data collection tool, and lastly a summary and discussion of future steps.

Overall, there was good consensus across the majority of facilities for the rankings of the systems and their associated components. The facility that caused the most discussion was the Spillway Gates at Lavon Lake concerning the hierarchy of the components. According to several SMEs, the components listed in the OCA hierarchy did not match the components

actually present in the gates. This highlights the importance of the feedback session to the elicitation process.

For this specific case study, since several of the SMEs had participated in the previous year's case study, the first SUS question (Table 3-2) was slightly modified to "FY22 Online Data Collection Tool was easier/better to utilize than the FY21 Online Data Collection Tool." The remaining standard SUS statements were utilized for the survey along with the free response opportunity. The responses from each SME for their level of agreement on each of the 10 SUS questions were collected and converted from the qualitative level of agreement to a SUS score using Equation (1). Eight of the SMEs completed the SUS. For Question 1, only three of the eight respondents indicated that they participated in both FY21 and FY22 data collection elicitations. The remaining five indicated they had not, so based on the SUS scoring methodology, the other respondents were given a raw score of 3 (neither agree nor disagree). The complete set of response data is in Appendix H. The average SUS score across all respondents was 58.44.

In comparison to other computer systems using the curved grading scale (Table 3-3), the Trinity River SMEs evaluated the current data collection tool as average. This indicates there is room for improvement in the online data collection tool. The following free response feedback (edited for clarity) also indicates areas for improvement.

- "Both tools were easy to use but I do like the 2022 better. The most challenging part was not good familiarity with the system, being evaluate {sic}."
- "It was better than last year, but I still believe definitions of the components need to be sent out; we all call things by different names. There are also some issues with the first just ranking and then change to 1–20 in order of importance scale. It was confusing."
- "Standard definitions for components, better explanation of how risk will be derived or associated with each component and system."

This feedback from the SMEs indicated that the changes made in the elicitation methodology and user interface of the online data collection tools were improvements on the previous methods.

The SME elicitation was successful in determining a consensus ranking of the systems and their associated components in the Trinity River Basin to support development of the conditional probability tables. The process also identified several areas for improvement when conducting future elicitations.

Tables 4-2, 4-3, and 4-4 provide examples of the data for a given facility using the Borda score methodology.

4.4 Consequence Modeling Results

The consequence modeling results are not available as of the writing of this report. The research team will develop a project summary report in collaboration with the consequence modeling team. The consequence modeling results for this case study will be presented in that summary report.

Table 4-2. Bardwell system relative influence in normal operating conditions.

System	SME 07	SME 08	SME 09	SME 10	SME 12	SME 13	SME 15	SME 16	SME 17	SME 19	SME 20	SME 21	SME 22	Rank	Borda Score	Normalized Borda Score
Service discharge gates	1	1	1	1	1	1	1	1	1	1	1	1	1	1	13	1

Table 4-3. Bardwell system relative influence in flood operating conditions.

System	SME 07	SME 08	SME 09	SME 10	SME 12	SME 13	SME 15	SME 16	SME 17	SME 19	SME 20	SME 21	SME 22	Rank	Borda Score	Normalized Borda Score
Service discharge gates	1	1	1	1	1	1	1	1	1	1	1	1	1	1	13	1

Table 4-4. Bardwell service discharge gate component relative influence on system operability.

Component	SME 07	SME 08	SME 09	SME 10	SME 12	SME 13	SME 15	SME 16	SME 17	SME 19	SME 20	SME 21	SME 22	Rank	Borda Score	Normalized Borda Score
Lifting stem and guides	3	1	1	3	1	1	1	2	2	5	1	4	1	1	260	0.083
Screw actuators	2	2	2	5	2	2	2	3	3	6	2	4	2	2	249	0.080
Basic structure	1	3	4	9	3	8	4	1	1	1	3	5	3	3	240	0.077
Operating equipment, electric components	4	4	6	1	4	4	3	18	4	8	4	2	4	4	220	0.071
Electric motors	5	5	9	7	5	3	5	4	5	7	5	2	5	5	219	0.070
Power cable, <= 480V	7	7	5	14	7	5	7	5	9	9	7	1	7	6	196	0.063
Anchorage	6	6	3	8	6	9	6	19	16	2	6	3	6	7	190	0.061
Limit switches	8	8	13	4	10	6	8	8	8	12	8	7	8	8	178	0.057
Enclosed gear boxes	9	9	7	6	9	10	9	9	7	13	9	8	9	9	172	0.055
Control cables, <= 480V	11	11	12	15	11	7	11	6	11	10	11	1	11	10	158	0.051

Table 4-4 (cont.). Bardwell service discharge gate component relative influence on system operability.

Component	SME 07	SME 08	SME 09	SME 10	SME 12	SME 13	SME 15	SME 16	SME 17	SME 19	SME 20	SME 21	SME 22	Rank	Borda Score	Normalized Borda Score
Embedded guides	10	10	8	16	8	11	10	13	10	4	10	11	10	11	155	0.050
Gate control panel	12	12	14	10	12	12	12	7	6	11	12	6	12	12	148	0.047
Couplings	13	13	10	11	13	13	13	11	20	18	13	10	13	13	115	0.037
Embedded bottom seal	14	15	11	19	15	15	15	14	13	3	15	12	15	14	110	0.035
Operator pushbutton	16	14	17	12	14	14	14	15	12	20	14	14	14	15	96	0.031
Seals	15	16	15	17	18	17	16	10	14	10	16	13	16	16	93	0.030
Position indicators	18	17	16	13	17	16	18	12	15	15	17	16	17	17	79	0.025
Programmable logic controller	17	21	19	2	16	19	19	17	21	19	16	9	16	18	75	0.024
Remote control equipment	21	18	18	0	21	0	20	21	17	21	18	18	18	19	75	0.024
Paint system	19	19	20	18	20	18	17	20	18	14	19	17	19	20	48	0.015
Cathodic protection	20	20	21	20	19	20	18	16	19	17	20	15	20	21	41	0.013

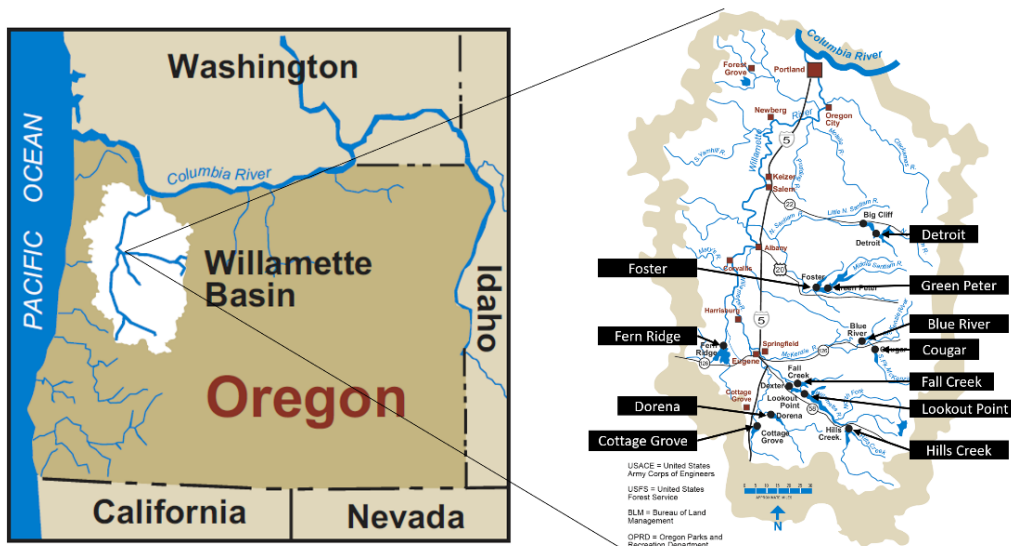
5 Case Study: Willamette River Results

This section provides an overview of the Willamette River watershed case study.

5.1 Overview

The Willamette River watershed provides a case study in the application of these methods in an even larger watershed in a different region of the country. Figure 5-1 presents the 11 USACE-owned facilities in the Willamette River watershed: Blue River Lake, Cottage Grove Lake, Cougar Lake, Detroit Lake, Dorena Lake, Fall Creek Lake, Fern Ridge Lake, Foster Lake, Green Peter Lake, Hills Creek Lake, and Lookout Point Lake.

Figure 5-1. USACE-owned OCA facilities in the Willamette watershed.



Similar to the Trinity River case study, the Willamette River case study introduced more complexity and the need for more coordination. The methodology for conducting the Willamette River case study was identical to that for the Trinity River case study as described in Section 3.

5.2 Data Exploration

Similar to the Trinity River case study, all of the facilities in the Willamette River case study are represented in the OCA database, and all the OCA

gates aligned with the CWMS models. Table 5-1 shows the gate systems at each facility and the number of gates within each of those gate systems.

Table 5-1. Gate types and associated number of gates across the Willamette River watershed.

Facility	Gate Type	Number of Gates
Blue River	Service discharge gates	2
Blue River	Spillway gates	2
Cottage Grove	Service discharge gates	3
Cougar	Service discharge gates	2
Cougar	Spillway gates	2
Detroit	Service discharge gates	4
Detroit	Spillway gates	6
Dorena	Service discharge gates	5
Fall Creek	Service discharge gates	2
Fall Creek	Spillway gates	2
Fern Ridge	Service discharge gates	4
Fern Ridge	Spillway gates	6
Foster	Spillway gates	4
Green Peter	Service discharge gates	2
Green Peter	Spillway gates	2
Hills Creek	Service discharge gates	2
Hills Creek	Spillway gates	3
Lookout Point	Service discharge gates	4
Lookout Point	Spillway gates	5

As in the Trinity River case study, SME input was required to understand the relative influence of each component and system to the functioning of the facility.

5.3 Developing Relative Influence and Probability of Failure

5.3.1 Conducting Subject Matter Expert Elicitation

The team conducted SME elicitation for the Willamette River Basin per the methodology in Section 3.2. The USACE Portland District provided 10 SMEs for this case study based on their knowledge and experience with the operation of the 11 facilities as well as FRM operations. Due to some SMEs changing position or not feeling comfortable evaluating all facilities, 7 SMEs submitted data in six submissions. Five SMEs assessed all 11 facilities, though 2 combined their assessments into one submission, while 2 submitted for only 2 facilities each. Five of the 7 SMEs were at the District level, with the other 2 SMEs serving as staff at the actual facilities involved

in their day-to-day operations (see Appendix F for names). As described in Section 3.2, the team conducted two 1-hour group sessions, the first to orient the group to the expert elicitation and the second to review and discuss the results of the two rounds of individual data collection.

The SMEs were provided a link to complete their individual assessments, and each SME was asked to complete an assessment for each of the 11 facilities (Blue River Dam, Cottage Grove, Cougar, Detroit, Dorena, Fall Creek, Fern Ridge, Foster, Green Peter, Hills Creek, and Lookout Point). If they were not familiar with a specific facility, the SMEs were asked to use their best engineering/operational experience to assign rankings to the systems and components in that facility. Additionally, the SMEs were asked to not give any system or component the same rank as another.

For the second round of individual data collection, SMEs were asked to review and consider the numerical value reflecting their individual assessment of the rankings of the specified gate systems and components for each of the 11 facilities with the aggregated group rankings. Based on this consideration, they were free to adjust their rankings based on any additional insights they had. If their ranking for a system or component differed greatly from the aggregate ranking, they were asked to provide greater insight into their thought process in the “NewComments” field within the table. Again, each SME was asked to complete an assessment for each of the 11 facilities even if they were not familiar with a specific facility. In that case, they were advised to use their best engineering/operational experience to assign rankings to the systems and components in that facility.

Finally, a second group session was held to discuss the results and conduct a usability survey. Nine SMEs were able to attend the session in person. To accomplish the three tasks outlined in Section 3.2 (review group rankings, discuss differences, and receive online data collection tool usability feedback), the session was conducted in the following sequence: discussing the ratings first by facility and then discussing them by system type, conducting a WebEx poll to collect feedback on the usability of the online data collection tool, and concluding the session with a summary and discussing future steps.

The majority of the discussion centered on the evaluation process rather than consensus on the rankings. Several SMEs indicated that they would

have liked to have been provided more specificity on the components and systems and how they are defined in the database. Some also mentioned thinking about system complexity when ranking the components while others mentioned they did not consider redundancy, condition, likelihood of failure, immediacy of impact, proximity of maintenance/repair personnel, or response times and that changing any of those considerations would alter their ranking order. This brought up a concern that “each evaluator is using different assumptions in their ranking of criteria (each are understandable), which is sounding like an inconsistent approach overall—coupled with inaccurate or incomplete equipment configurations.” This highlights the importance of the feedback session to the elicitation process.

This iteration of SUS was conducted using a WebEx poll with the standard statements utilized for the survey (Table 3-2). The WebEx poll did not track responses by individual, so it was not possible to associate the survey data to each individual SME. Therefore, only the average score of each question was used to calculate the overall average SUS score, as shown in Table 5-2.

Table 5-2. Willamette River subject matter expert system usability scale scores.

Question	Statement	Average Score
1	I think that I would like to use this system frequently in conjunction with ranking systems and components.	2.0
2	I found the system unnecessarily complex.	1.8
3	I thought the system was easy to use.	2.6
4	I think that I would need the support of a technical person to be able to use this system.	1.0
5	I found the various functions in this system were well integrated.	1.8
6	I thought there was too much inconsistency in this system.	3.2
7	I would imagine that most people would learn to use this system very quickly.	2.6
8	I found the system very cumbersome to use.	1.8
9	I felt very confident using the system.	1.4
10	I needed to learn a lot of things before I could get going with this system.	1.6
Total	—	52.5

In comparison to other computer systems using the curved grading scale (Table 3-3), the Willamette SMEs evaluated the current data collection tool as well below average. This indicates there is room for improvement in the online data collection tool. The feedback indicated that some of the

Table 5-4. Blue River Dam system relative influence in flood operating conditions.

System	SME 01	SME 02	SME 03	SME 04	SME 05	Rank	Borda Score	Normalized Borda Score
Service discharge gates	1	1	1	1	1	2	6	0.375
Spillway gates	1	2	2	2	2	1	10	0.625

Table 5-5. Blue River Dam service discharge gate component relative influence on system operability.

Component	SME 01	SME 02	SME 03	SME 04	SME 05	Rank	Borda Score	Normalized Borda Score
Basic structure	1	1	1	1	1	1	75	0.122
Control valves	4	2	5	8	9	2	52	0.084
Gate control panel	13	3	8	3	5	3	48	0.078
Seals	1	13	7	12	2	4	45	0.073
Embedded guides	5	6	6	14	4	5	45	0.073
Hydraulic piping	8	4	3	10	11	6	44	0.071
Hydraulic cylinder	11	5	2	11	8	7	43	0.070
Hydraulic hoses	9	7	4	9	9	8	42	0.068
Operator pushbutton	3	9	10	7	12	9	39	0.063
Remote control equipment	7	8	12	2	13	10	38	0.062
Limit switches	12	10	9	6	7	11	36	0.058
Position indicators	10	11	13	5	6	12	35	0.057
Embedded bottom seal	6	13	14	13	3	13	31	0.050
Control cables, <=480V	14	12	11	4	15	14	24	0.039
Paint system	2	14	15	15	14	15	20	0.032

Table 5-6. Blue River Dam spillway gate component relative influence on system operability.

Component	SME 01	SME 02	SME 03	SME 04	SME 05	Rank	Borda Score	Normalized Borda Score
Basic structure	1	1	1	2	1	1	104	0.082
Anchorage	3	2	2	1	4	2	98	0.078
Lifting cables	4	3	3	9	3	3	88	0.070
Open gears	7	4	0	13	10	4	76	0.060
Couplings	10	6	5	11	5	5	73	0.058
Gate control panel	5	7	11	4	11	6	72	0.057
Brakes	12	5	8	10	6	7	69	0.055
Electric motors	17	11	7	7	2	8	66	0.052
Limit switches	6	10	6	14	9	9	65	0.052
Enclosed gear boxes	11	4	4	12	15	10	64	0.051
Operating equipment, electric components	14	8	9	8	8	11	63	0.050
Control cables, <=480V	18	12	0	5	17	12	58	0.046
Embedded guides	9	9	10	20	12	13	50	0.040

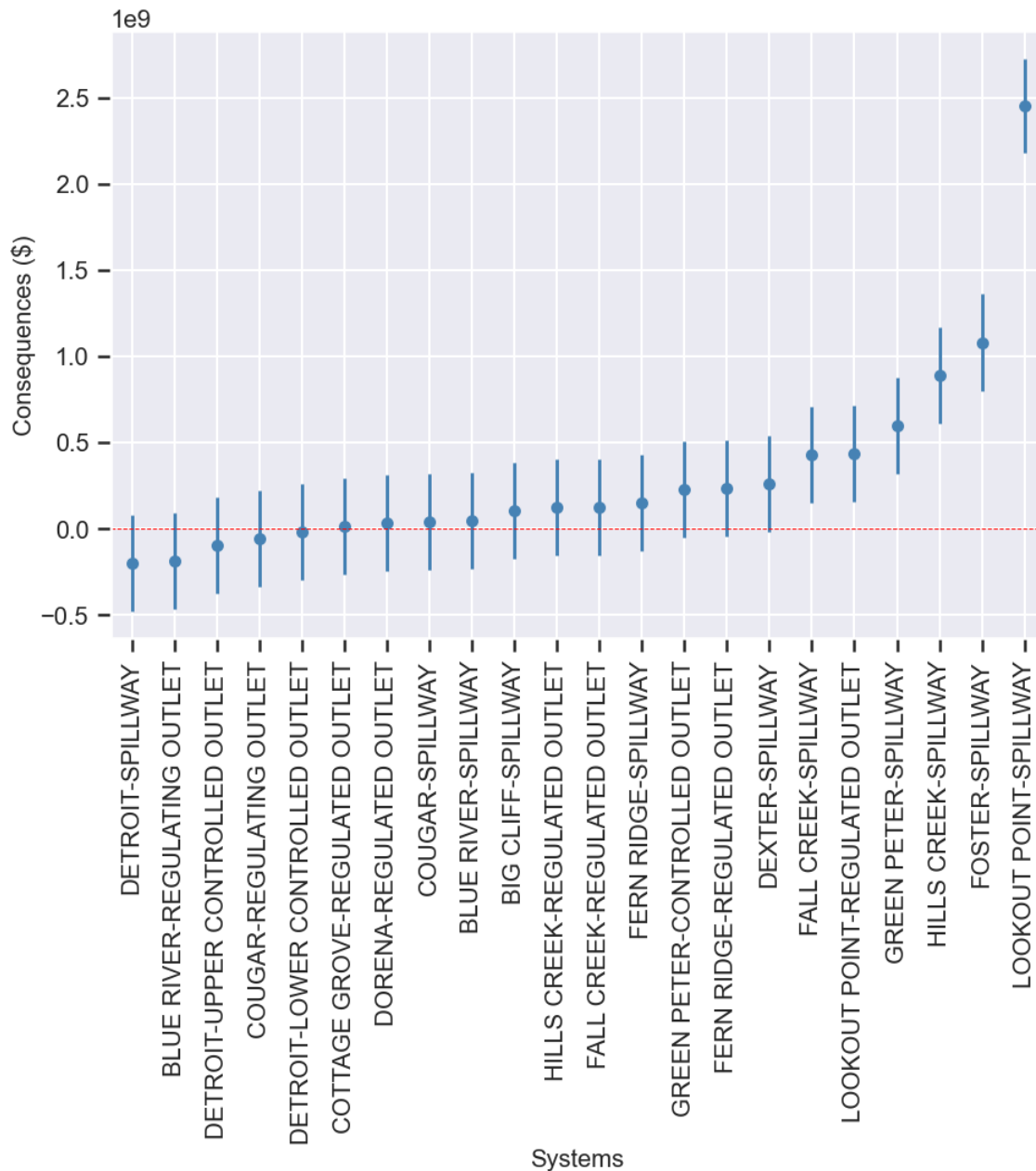
Table 5-6 (cont.). Blue River Dam spillway gate component relative influence on system operability.

Component	SME 01	SME 02	SME 03	SME 04	SME 05	Rank	Borda Score	Normalized Borda Score
Operator pushbutton	8	17	12	3	21	14	49	0.039
Embedded bottom seal	1	14	15	19	13	15	48	0.038
Seals	13	14	0	17	20	16	46	0.036
Position indicators	15	16	14	15	7	17	43	0.034
Power cable, <=480V	16	15	13	6	19	18	41	0.032
Paint system	2	19	16	21	18	19	34	0.027
Catwalks, ladders, and platforms	19	13	18	16	14	20	30	0.024
Greasing system	16	18	17	18	16	21	25	0.020

5.4 Consequence Modeling Results

The output of SME elicitation is used in conjunction with a system-level consequence model, generated via simulation by the Portland District Hydraulics and Hydrology staff in conjunction with the USACE Hydrologic Engineering Center, to develop a statistical model to estimate the expected system-level consequences for the Willamette basin. To explore the contribution of gates, IWR leveraged a nearly orthogonal Latin hypercube space-filling design to estimate system-level consequences and the interaction of systems within the watershed. Consistent with previous modeling efforts (Alt et al. 2022b), multiple regression was used to fit a linear model where the number of operable gate systems are treated as the explanatory variables and the expected consequences generated by each case is treated as the response variable (see Figure 5-2). The resulting model accounts for 81.2% of the variance in the dependent variable while meeting appropriate assumptions.

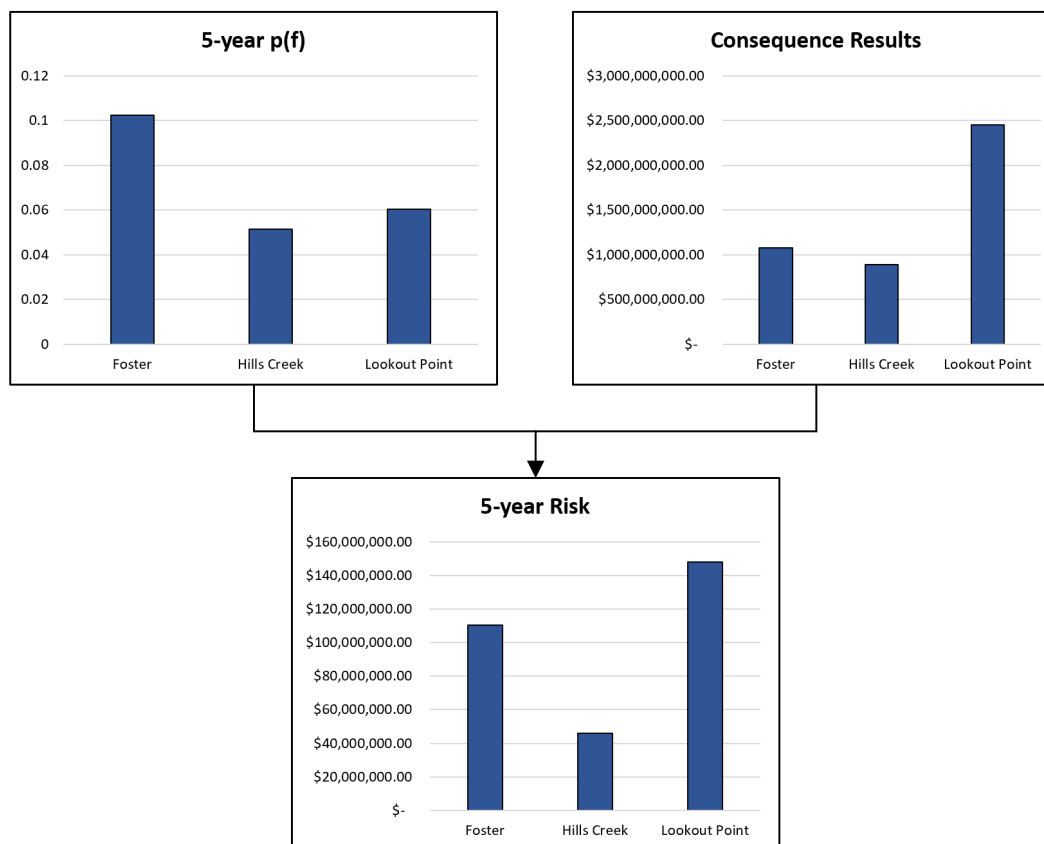
Figure 5-2. Coefficients of regression model with 95% confidence interval.



5.5 Risk Results

Consistent with previous case studies, the research team then used the OCA ratings in conjunction with relative risk values and the consequence modeling results to develop risk scores (Alt et al. 2022b). Figure 5-3 illustrates a probability of failure, consequence of failure, and risk comparison for the spillway gates at the Foster, Hills Creek, and Lookout Point facilities.

Figure 5-3. Probability of failure, consequence of failure, and risk comparison for Foster and Hills Creek spillway gates.



The results in Figure 5-3 demonstrate the potential differences among three bases for resource allocation: a probability-only approach, a consequence-only approach, and a risk-informed approach. In this illustrative example, if a decision-maker were to prioritize investments based solely on probability of failure, then the Foster spillway gates are the clear priority with little difference between the Hills Creek and Lookout Point spillway gates. If a decision-maker were to prioritize investment based solely on consequence of failure, then the Lookout Point spillway gates are the clear priority with little difference between the Foster and Hills Creek spillway gates. However, if a decision-maker were to take a more holistic risk-informed approach, then the Lookout Point spillway gates are the priority, followed closely by the Foster spillway gates, and the Hills Creek spillway gates are definitively the lowest priority.

6 Summary and Way Ahead

Understanding risk in complex engineered systems requires a flexible and scalable modeling approach. In this paper, that approach has been explained and demonstrated through two case studies.

6.1 Modeling Methodology

This research has developed a methodology and elicitation and analysis tools to determine system probability of degradation based on component condition through SME elicitation and BBNs. In both case studies, the team was able to successfully elicit relative influence information from the SMEs and populate conditional probability tables based on component condition and component relative influence. Also, the team successfully collaborated with the consequence modeling team to develop consequence-of-failure data for the Willamette River Basin case study. The research team is currently working with the Fort Worth District through the consequence modeling team to attain consequence-of-failure data for the Trinity River Basin case study.

6.2 Way Ahead

In FY23, the research team has two primary goals following the Trinity and Willamette River Basin case studies:

- Refine the elicitation methodology. The research team expected that the component-ranking methodology would improve the experience for the SMEs. However, the SMEs struggled with not being able to assign two components the same rank. Another drawback is that the SMEs were not able to express magnitude of difference between components. In addition to the drawbacks of the ranking methodology, the SMEs also asked a lot of clarifying questions regarding whether they should consider redundancy of components or operational downtime if a component fails or the cascading effects of component failure. These drawbacks and questions have prompted the research team to reconsider the ranking methodology and to provide clearer contextual framing for individual SME understanding and for consistency across SMEs.
- Improve elicitation tool user experience. Based on the SUS and user feedback, the research team recognizes that these tools require some improvement before data are collected for all FRM facilities. Most of

the changes will aim at improving the user experience and creating a database to store and analyze user input.

The team will implement the necessary changes to meet these goals and exercise them on another case study in FY23.

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Appendix A: Operational Condition Assessment Ratings

Table A-1. Operational Condition Assessment (OCA) ratings.

OCA Rating	Index Value	Descriptor	Physical Condition	Performance	Likelihood of Failure
A	9	Excellent	No signs of degradation and recently put into service	No performance issues and was recently put into service	Extremely unlikely to fail within the next 5 years
A–	8	Excellent	No signs of degradation and recently put into service	No performance issues and was recently put into service	Extremely unlikely to fail within the next 5 years
B	7	Good	Minor deficiencies	No performance issues	Low likelihood of failure within the next 5 years
B–	6	Good	Minor deficiencies	No performance issues	Low likelihood of failure within the next 5 years
C	5	Fair	Moderate deficiencies	Deficiency is beginning to affect component's performance, operational procedures, or maintenance requirements	Potential failure mode with a moderate likelihood of failure within the next 5 years
C–	4	Fair	Moderate deficiencies	Deficiency is beginning to affect component's performance, operational procedures, or maintenance requirements	Potential failure mode with a moderate likelihood of failure within the next 5 years
D	3	Poor	Significant deficiencies affecting a substantial portion or critical feature of the component	Deficiency increasingly affects component's performance, operational procedures, or maintenance requirements	Potential failure mode with a high likelihood of failure within the next 5 years
D–	2	Poor	Significant deficiencies affecting a substantial portion or critical feature of the component	Deficiency increasingly affects component's performance, operational procedures, or maintenance requirements	Potential failure mode with a high likelihood of failure within the next 5 years
F	1	Failing	Severe deficiencies affecting a substantial or critical feature of the component	Deficiency substantially affects component's performance, operational procedures, or maintenance requirements	Potential failure mode that could fail imminently
CF	0	Completely failed	Due to degradation, component is failed and does not perform its intended function	Component is failed or does not perform its intended function	Component is failed
U	n/a	Unratable	Unratable	Unratable	Unratable

Appendix B: Data Collection Round 1 Instructions

We thank you so much for your time in assisting us with this research project and appreciate the opportunity to receive your expert input on the rankings on the facility and components on the systems. Your input will be extremely helpful in our understanding of the US Army Corps of Engineers (USACE) facilities of the Trinity River Basin.

B.1 Setting the Stage on the Expert Elicitation

This will be a two-step process:

1. Individual collection of opinion on the rankings of specific systems and their components on the operations of the facility
2. Group meeting to discuss similarities and differences and to finalize those rankings

The first step in our structured elicitation is to ask you to assign a numerical value reflecting your assessment of the ranking of the specified gate systems and components as identified in the Operational Condition Assessment (OCA) hierarchy for each of the facilities (Bardwell, Benbrook, Joe Pool, Lavon, and Navarro Mills). To align with the Corps Water Management System (CWMS) consequence modeling effort being conducted with the Environmental Laboratory / Institute for Water Resources, we are going to look at each of the facilities at two levels: the ranking of specific gates on the operation of the entire facility and how the individual components identified in the OCA influence each of their associated systems.

Since the CWMS model takes into account both service discharge and water quality low-flow gates, we will ask for the rankings of these gates on the operation of the facility both under normal conditions and under high-water conditions. Additionally, the CWMS model provides life loss and monetary consequences due to damage to structures from water release at various lake levels. The model does not consider other factors at this time (such as loss of fish, etc.).

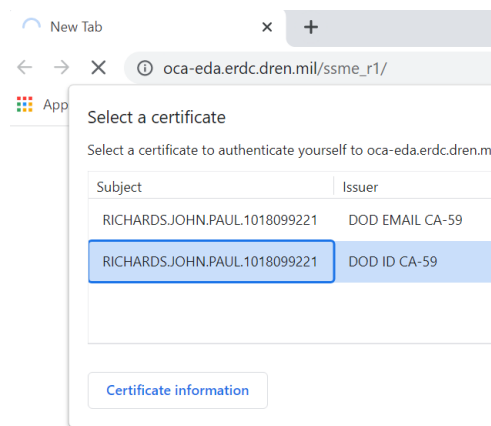
For everyone, we ask that you complete an assessment for each of the five facilities (Bardwell, Benbrook, Joe Pool, Lavon, and Navarro Mills). Even

if you are not familiar with a specific facility, please use your best engineering/operational experience to assign rankings to the systems and components in that facility.

B.2 Data Collection

Go to the link https://oca-eda.erdcdren.mil/ssme_r1/ (Chrome is the recommended browser) and log in using your CAC, choosing the non-email certificate when prompted.

Figure B-1. CAC authentication.



Please enter your first and last name and the SME ID provided to you. Enter your current duty position and your overall years of experience with USACE.

Figure B-2. Demographic information.

The screenshot shows a mobile-style form titled 'OCA Elicitation'. It contains the following fields:

- Name:** Bob Jones
- SME ID:** SME1
- Duty Position:** facility manager
- Years Experience:** 30

All five facilities of interest are listed on this webpage, with each facility broken into two levels: (1) the gate systems and (2) their components. The

rankings are prepopulated with the number of gates (or components) in the facility (or system).

For each facility, please indicate your level of experience with that facility.

Figure B-3. Collecting SME experience level.

Bardwell Systems

How much experience do you have with this facility?

☒ No experience ☐ Some experience ☐ Much experience

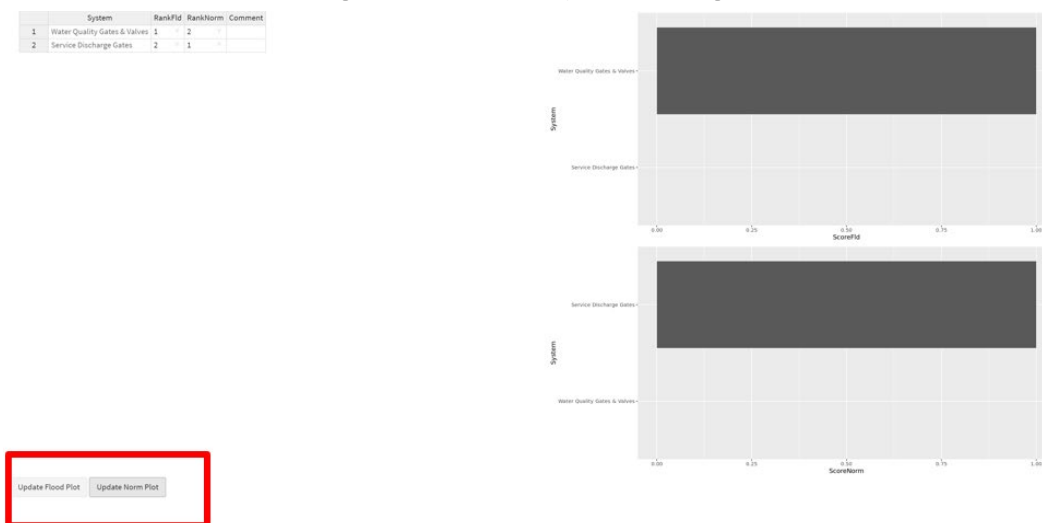
For the gate operations, please rank them as which is most important for operating under (1) high water/flood emergency operations that necessitates the operation of gates to control the output of water so as to not over-top the dam (RankFld) and (2) normal operating conditions under which water release is controlled by normal operation of the gates to control water flow, lake levels, and associated environmental conditions (Rank-Norm). A ranking of 1 is the most important.

- You may add optional comments regarding how you are assigning the ranking.
- If there is only one gate system, rank will be assigned “1” but can add a free text comment.
- Multiple systems may have the same rank.
- You may view a bar graph showing the rankings for each scenario (highest ranked system has the biggest bar) by clicking on the “Update Flood Plot” or “Update Norm Plot” buttons.

Figure B-4. Ranking facility systems.

	System	RankFld	RankNorm	Comment
1	Water Quality Gates & Valves	0	0	
2	Service Discharge Gates	1	0	
		2		

Figure B-5. Visualize system rankings.



For the components, please rank them from most (1) to least important to normal operation of the associated gate. You may rank more than one component as the same (e.g., you may decide that Basic Structure and Seals are both ranked 19 of 21 components). You can use “enter” key to drop down to the next gate or component.

Also, if you believe that a gate or component is not present at that facility, indicate this condition by typing in a 0, and please provide a comment.

Comments on gates and components are optional but are helpful to add if you have a specific reasoning for the ranking you indicated.

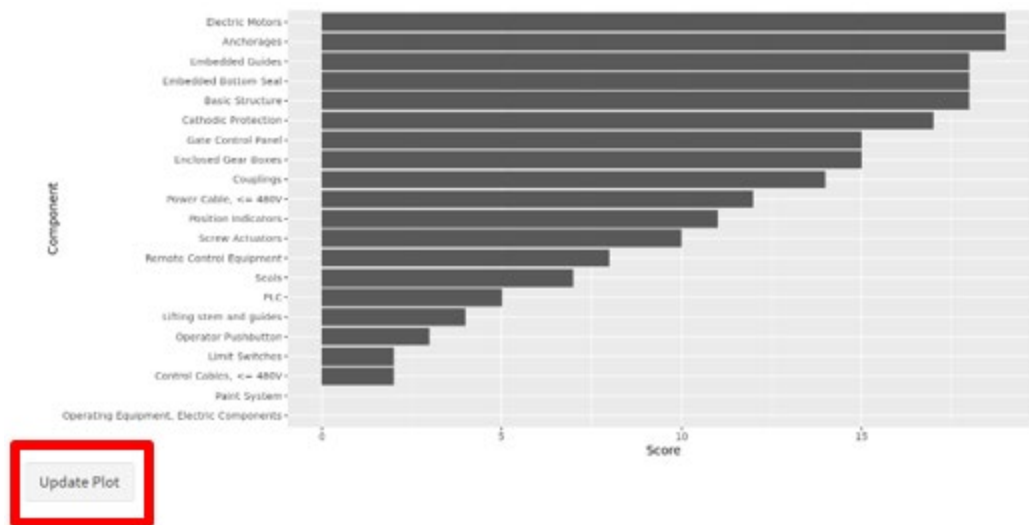
Figure B-6. Ranking components.

Bardwell Service Discharge Gates Components

	Component	Rank	Comment
1	Anchorage	1	
2	Basic Structure	7	
3	Cathodic Protection	8	
4	Control Cables, <= 480V	9	
5	Electric Motors	10	
6	Embedded Bottom Seal	11	
7	Embedded Guides	12	
8	Gate Control Panel	13	
9	Limit Switches	14	
10	Operating Equipment, Electric Components	15	
11	Paint System	16	

You may view a bar graph showing the rankings (highest ranked system has the biggest bar and will automatically be ordered most to least important) by clicking on the “Update Plot” button.

Figure B-7. Visualize component rankings.



When complete, please scroll back up to the admin portion and hit the “Save” button!

Figure B-8. Save input.

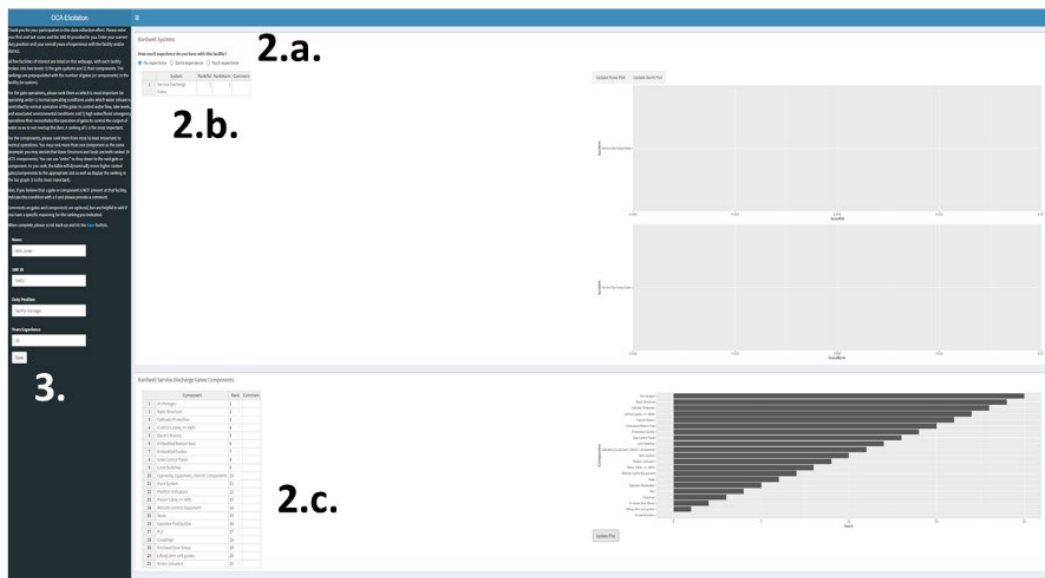
Name	Bob Jones
SME ID	SME1
Duty Position	facility manager
Years Experience	30
Save	

In summary, please complete the following:

1. Admin data
2. For each facility:
 - a. Experience identified
 - b. Systems (gates) ranked
 - (1) Flood operations
 - (2) Normal operations

- (3) Comments (optional)
 - c. Components ranked (with optional comments)
3. Data saved

Figure B-9. Summary of data collection.



Thank you for your time and effort! We greatly appreciate your input into this project and look forward to the upcoming group meeting to discuss the results.

If there are any questions or concerns, please contact John Richards at John.P.Richards@erdcdren.mil or Willie Brown at Willie.H.Brown@erdcdren.mil.

Appendix C: Data Collection Round 2 Instructions

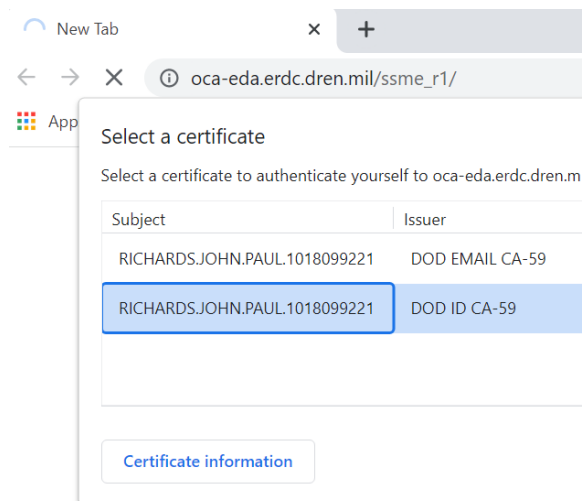
Welcome to the Trinity River OCA Project Round 2 Data Collection. We thank you so much for your time in assisting us with this research project and appreciate the opportunity to receive your expert input on the rankings of importance of systems in the facility and components in those systems. Your input will be extremely helpful in our understanding of the USACE facilities of the Trinity River Basin.

This is the second stage of the Delphi Method for Expert Elicitation, during which we seek to come to consensus across the subject matter experts (SMEs) on the rankings of specific systems and their components on the operations of the facility. This data collection round allows you the opportunity to review your initial individual rankings of the facility systems and their associated components, as compared to the aggregated group rankings. The final step after this round of data collection will be a group meeting to discuss similarities and differences and to finalize those rankings.

C.1 Data Collection

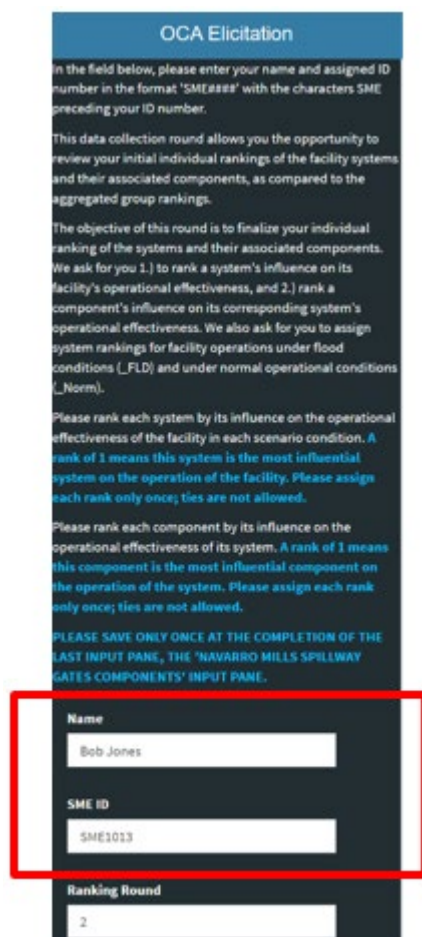
Go to the link https://oca-eda.erdcdren.mil/ssme_nr/ (Chrome is the recommended browser) and log in using your CAC, choosing the non-email certificate when prompted.

Figure C-1. CAC authentication.



Please enter your first and last name and the unique SME ID provided to you. If you get an error, please confirm that you correctly entered your assigned ID number in the format “SME###,” with the characters SME preceding your ID number.

Figure C-2. Demographic information.



The screenshot displays a mobile application interface titled "OCA Elicitation". The main text area contains instructions for entering name and ID, and details about the data collection round. At the bottom, there are three input fields: "Name" (containing "Bob Jones"), "SME ID" (containing "SME1013"), and "Ranking Round" (containing "2"). A red rectangular box highlights the "Name" and "SME ID" fields.

OCA Elicitation

In the field below, please enter your name and assigned ID number in the format 'SME###' with the characters SME preceding your ID number.

This data collection round allows you the opportunity to review your initial individual rankings of the facility systems and their associated components, as compared to the aggregated group rankings.

The objective of this round is to finalize your individual ranking of the systems and their associated components. We ask for you 1.) to rank a system's influence on its facility's operational effectiveness, and 2.) rank a component's influence on its corresponding system's operational effectiveness. We also ask for you to assign system rankings for facility operations under flood conditions (_FLD) and under normal operational conditions (_Norm).

Please rank each system by its influence on the operational effectiveness of the facility in each scenario condition. A rank of 1 means this system is the most influential system on the operation of the facility. Please assign each rank only once; ties are not allowed.

Please rank each component by its influence on the operational effectiveness of its system. A rank of 1 means this component is the most influential component on the operation of the system. Please assign each rank only once; ties are not allowed.

PLEASE SAVE ONLY ONCE AT THE COMPLETION OF THE LAST INPUT PANE, THE 'NAVARRO MILLS SPILLWAY GATES COMPONENTS' INPUT PANE.

Name
Bob Jones

SME ID
SME1013

Ranking Round
2

The application will bring up your data input from the first round along with the aggregated group ranking (GroupRanking) for each system and component and any comments (Comment) based on all SME data collected during the first round of data collection.

Note: If you see the same number for all the components under your SME ID, it indicates that your Round 1 data were collected as either blank or left at the default values. Please adjust to rank from 1 (most important) to the least important system or component.

C.2 Round 2 Instructions

The first step in this round is for you to review the numerical value reflecting your assessment of the ranking of the specified gate systems and components as identified in the OCA hierarchy for each of the facilities (Bardwell, Benbrook, Joe Pool, Lavon, and Navarro Mills). As a reminder, to align with the consequence modeling, we are going to look at each of the facilities at two levels: the ranking of specific gates on the operation of the entire facility, and how the individual components identified in the OCA influence each of their associated systems.

All five facilities of interest are listed on this webpage, with each facility broken into two levels: (1) the gate systems and (2) their components. For the gate operations, recall that the rankings are for two scenarios, (1) operating under high water / flood emergency operations that necessitate the operation of gates to control the output of water so as to not overtop the dam (_Fld) and (2) operating under normal operating conditions under which water release is controlled by normal operation of the gates to control water flow, lake levels, and associated environmental conditions (_Norm). A ranking of 1 is the most important. If there is only one type of gate system (regardless of the number of gates of that type), the rank assigned will be “1,” but you can add a free text comment.

For the components, please rank them from most (1) to least important to normal operation of its associated gate. You can use “enter” key to drop down to the next gate or component.

After considering your first-round rankings and the aggregated group rankings, feel free to adjust your rankings based on any additional insights you may have.

Note: If you didn’t submit a rank for a system or component in Round 1, the default value of 25000 will show. Please adjust to rank from 1 (most important) to the least important system or component.

Please do not give more than one system or component the same rank.

If you make changes to your rankings, you can see how that changes the overall group ranking by selecting the “Update Plot” tab. The highest

ranked system has the biggest bar and will automatically be ordered most to least important.

If your ranking for a system or component differs greatly from the aggregate ranking, please provide greater insight into your thought process in the “NewComments” field within the table.

For everyone, we ask that you complete an assessment for each of the five facilities (Bardwell, Benbrook, Joe Pool, Lavon, and Navarro Mills). Even if you are not familiar with a specific facility, please use your best engineering/operational experience to assign rankings to the systems and components in that facility.

Remember to save once after completion of ranking the components of the “Navarro Mills Spillway Gates Components” input pane.

Figure C-3. Entering and saving data.

Navarro Mills Spillway Gates Components

After considering your first-round rankings and the aggregated group rankings, feel free to adjust your rankings based on any additional insights you may have.

If you make changes to your rankings, you can see how that changes the overall group ranking by hitting the 'Update Plot' tab.

If your ranking for a system or component differs greatly from the aggregate ranking, please provide greater insight into your thought process in the 'NewComments' field within the table.

REMEMBER TO SAVE ONCE AFTER COMPLETION OF RANKING THE COMPONENTS OF THE 'NAVARRO MILLS SPILLWAY GATES COMPONENTS' INPUT PANE.

	Component	SME1013	GroupRanking	Comment
2	Basic Structure	2	1	
11	Lifting Cables	8	2	
6	Electric Motors	6	3	
13	Operating Equipment, Electric Components	9	4	
5	Control Cables, <= 480V	5	5	
1	Anchorage	1	6	
9	Gate Control Panel	7	7	
16	Power Cable, <= 480V	10	7	
12	Limit Switches	14	8	
8	Embedded Guides	4	9	guides for a tainter gate?
17	Remote Control Equipment	11	10	do they have that?
4	Catwalks, Ladders & Platforms	13	11	
7	Embedded Bottom Seal	3	12	
10	Greasing System	15	12	
18	Seals	12	13	
15	Position Indicators	18	14	
14	Paint System	16	15	
3	Cathodic Protection	17	16	

Update Plot

Save

Thank You!

our data has been saved successfully!

OK

In summary, please complete the following:

1. Name and SME ID number in the format “SME####”

2. For each facility:
 - a. Update systems (gates) ranking
 - (1) Flood operations
 - (2) Normal operations
 - (3) Comments (optional) in “NewComments” column
 - b. Update components ranking (with optional comments in “NewComments” column)
3. Data saved

Thank you for your time and effort! We greatly appreciate your input into this project and look forward to the upcoming group meeting to discuss the results.

We ask you to please complete Round 2 Data Entry by 15 April.

Any questions or concerns, please contact John Richards at john.p.richards@erdc.dren.mil or Willie Brown at Willie.H.Brown@erdc.dren.mil.

Appendix D: Trinity Delphi Feedback Discussion Script

Good afternoon. We thank you so much for your time in assisting us with this research project. We appreciated your individual assessment of the rankings of the influence of systems on the facilities and components on the systems of the Bardwell, Benbrook, Joe Pool, Lavon, and Navarro Mills facilities. Today we'll close out the data collection portion of the case study.

With your permission, I'd like to record this afternoon's session. [HIT RECORD]

Today's meeting, as the next step in our structured elicitation, seeks to accomplish three tasks:

1. Review the aggregated group rankings of the systems and components for Bardwell Lake, Benbrook Lake, Joe Pool Lake, Lavon Lake, and Navarro Mills Dam based on the two rounds of data collection
2. Provide the SMEs the opportunity to express differences with the group ratings
3. Receive SME feedback on the usability of the online data collection process and tools

I sent out read-ahead slides earlier today that display the results of the aggregation of the individual rankings by facility and by gate type.

D.1 Ratings by Facility

I would like to start with ratings by facility.

D.1.1 Bardwell Lake

For Bardwell Lake, which only has one type of gate, service discharge, the final aggregated ranking puts lifting stem and guides as the most important components to normal operations down to the programmable logic controller (PLC) as the lowest-ranked component.

As you look through the rankings, are there any opinions on rankings that should be moved up or down?

D.1.2 Benbrook Lake

Since there are two types of gates, service discharge and water quality, we asked you to rank their importance under two scenarios, flood and normal operations. The aggregated rankings result in the service discharge gates having a higher rank for flood operations and the water quality gates having a higher rank for normal operations. Are there any disagreements with these rankings?

You can also see the component ranks for both types of gates. Looking at the component rankings for the service discharge gate system, are there any opinions on rankings that should be moved up or down?

Looking at the component rankings for the water quality gate system, are there any opinions on rankings that should be moved up or down?

D.1.3 Joe Pool Lake

Since there are two types of gates, service discharge and water quality, we asked you to rank their importance under two scenarios, flood and normal operations. The aggregated rankings result in the service discharge gates having a higher rank for both flood operations and normal operations with the water quality gates having a lower rank for both scenarios. Are there any disagreements with these rankings?

You can also see the component ranks for both types of gates. Looking at the component rankings for the service discharge gate system, are there any opinions on rankings that should be moved up or down?

Looking at the component rankings for the water quality gate system, are there any opinions on rankings that should be moved up or down?

D.1.4 Navarro Mills Dam

Since there are two types of gates, spillway and water quality, we asked you to rank their importance under two scenarios, flood and normal operations. The aggregated rankings result in the spillway gates having a higher rank for both flood operations and normal operations with the water quality gates having a lower rank for both scenarios. Are there any disagreements with these rankings?

You can also see the component ranks for both types of gates. Looking at the component rankings for the spillway gate system, are there any opinions on rankings that should be moved up or down?

Looking at the component rankings for the Water Quality Gate system, are there any opinions on rankings that should be moved up or down?

D.1.5 Lavon Lake

For Lavon Lake, which only has one type of gate, spillway, the final aggregated ranking puts basic structure as the most important components to normal operations down to the seals as the lowest-ranked component.

As you look through the rankings, are there any opinions on rankings that should be moved up or down?

D.2 Ratings by System

Another way we would like to discuss the results is to view the rankings of all the systems across the facilities.

Does looking across the systems generate any opinions on the rankings between the two types of gates under flood or normal operations?

Digging down into the components of each of the service discharge gates at the facilities, the first thing that jumped out to us was that the same type of gate had a different number of components at different facilities. We assume that's due to each facility being a bit different but wanted to confirm this with you SMEs.

Also, does looking across the systems generate any opinions on the rankings of the components at any of these facilities?

We have the same questions looking across the components of each of the water quality gates at the facilities—again, the same type of gate had a different number of components at different facilities.

Also, does looking across the systems generate any opinions on the rankings of the components at any of these facilities?

Finally, the same questions for the spillway gates.

Does looking across the systems generate any opinions on the rankings of the components at any of these facilities?

D.3 Usability Discussion

We are also interested in how easily you felt it was to use the online data collection application tool. As we go through these questions, which are a standard software usability survey, please think back to your use of the application and answer the questions in the poll from Strongly Agree to Strongly Disagree.

Additionally, for those of you who participated in the Elm Fork FY21 Case Study, we'd like you to provide feedback on if the process was improved.

- I found the system unnecessarily complex.
- I thought the system was easy to use.
- I think that I would need the support of a technical person to be able to use this system.
- I found the various functions in this system were well integrated.
- I thought there was too much inconsistency in this system.
- I would imagine that most people would learn to use this system very quickly.
- I found the system very cumbersome to use.
- I felt very confident using the system.
- I needed to learn a lot of things before I could get going with this system.

Free response comments: the online application tool could be improved by (better instructions, better interface, etc.).

The FY22 Online Data Collection Tool was easier/better to utilize than the FY21 Online Data Collection Tool.

Thank you for your assistance with this project. This concludes the data-collection portion for the FY22 Trinity Case Study, but we'll circle back with the SMEs toward the end of the FY to provide a summary of the overall results with the consequence modeling.

Appendix E: List of Trinity River Subject Matter Experts

Table E-1. Trinity River subject matter experts.

Name	Position	Level
Mark Sissom	Operations Division	District
Joshua Pickering	Geotechnical Engineer	District
James (Jim) McClain	Water Management	District
Terry Bachim	Chief, Maintenance Section	District
Marie Loftin	Assess Management Program Manager	District
Christopher Bryan	Asset and Maintenance Management	District
Todd Stowe	Flood Risk Management	District
Dee Pienaar	Trinity Region Operations Lead	Region
James Murphy	Operations Project Manager	Region
J. Harvey	Flood Risk Management Business Line Manager	Region
Tim Horn	OPM Operations Project Manager	Region
Justin Berndt	Benbrook	Facility
Jeremy Spencer	Joe Pool	Facility
Dylan Mayfield	Bardwell	Facility
Michael Kinard	Lavon	Facility
Steven Ridlehuber	Navarro Mills	Facility

Appendix F: List of Willamette River Subject Matter Experts

Table F-1. Willamette River subject matter experts.

Name	Position	Level
Ross Hiner	Dam Safety	District
David Tucker	Asset Management Program Manager	District
Benjamin Filan	Mechanical Design	District
Daniel Jensen	Mechanical Section Chief	District
Marc Whitehead	Mechanical Design	District
Ryan Cahill	Hydraulics / Dam Safety	District
Matt Chase	Dam Safety Program Manager	District
Camden Fernald	Power Plant Shift Operator	Facility
Tim Peirce	Power Plant Operator	Facility
Jim Williams	Operations	Facility

Appendix G: Relative Influence Methodology Comparison

The conditional probability table (CPT) initialization methodology for FY 22 diverges from FY21 by replacing the relative influence scores with Borda scores. That is, in FY21, SMEs assessed the relative influence of child nodes to the parent node within the Bayesian Belief Network (BBN) for the facility-to-system and system-to-component levels. In FY22, the SMEs ranked child nodes from 1 to n , where n is the number of child nodes with a directed edge from a parent node within the BBN. This appendix overviews the FY21 and FY22 CPT initialization methodologies, compares percentage effect at the system and component levels, and compares the results of the mixed integer program for component selection (based on notional consequence data).

G.1 CPT Initialization Methodology Overview

In FY21, to determine the relative influence ratings, SMEs identified the child nodes with the least influence to the parent node as well as the child nodes with the greatest influence to the parent node. If multiple child nodes are selected for the least/greatest relative influence rating, all of those selected child nodes are given the same relative influence rating. The child nodes with the least influence are assigned a relative influence rating of 1. The child nodes with the greatest relative influence are given a rating based on the order of magnitude difference in influence between these child nodes and the child nodes with the least relative influence. SMEs then assign the other child nodes relative influence values using the aforementioned relative influence ratings as upper and lower bounds for the assigned values. After each SME completes their assessment of the relative influence at the facility-to-systems level and system-to-components level, all SME relative influence ratings are averaged for each child node. To initialize the BBN CPTs, the relative influence ratings at a specific level are normalized between 0 and 1 and multiplied by the Operational Condition Assessment (OCA) condition ratings at the component level to initialize the component-level CPTs. The component level is then aggregated to initialize system-level CPTs.

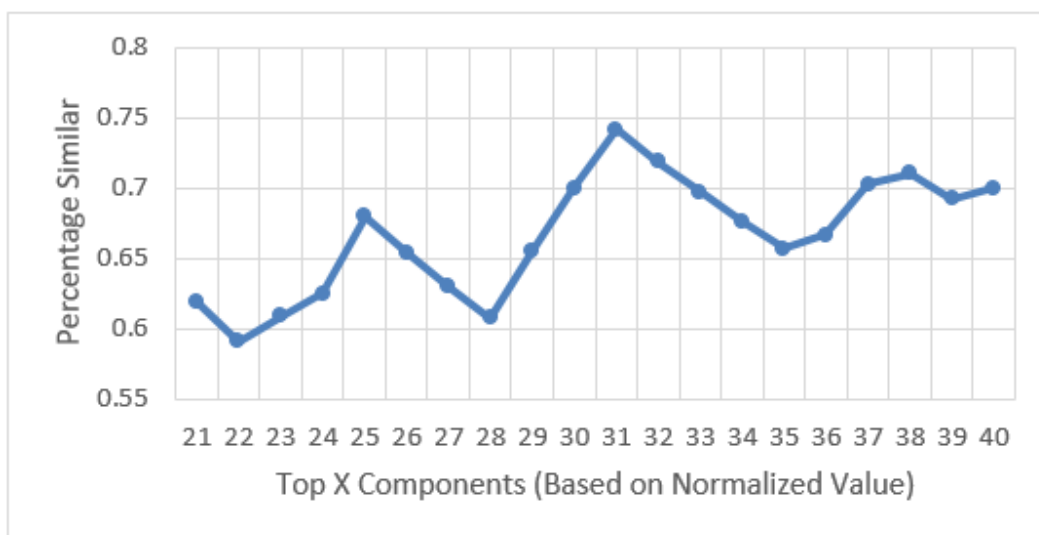
In FY22, to approximate the relative influence ratings, SMEs were asked to rank the system level and component levels from 1 to n , where n is the number of systems or components at the facility-to-system or system-to-

component levels, respectively. The rankings from all SMEs are used to generate a Borda score. These Borda scores at the facility-to-system and system-to-component levels are then normalized and used as a proxy for the system- and component-level relative influence. Then, consistent with the FY21 methodology, the relative influence ratings at a specific level are normalized between 0 and 1 and multiplied by the OCA condition ratings at the component level to initialize the component-level CPTs. The component level is then aggregated to initialize system-level CPTs.

G.2 Comparison: System- and Component-Level Relative Influence

In order to facilitate comparison data from three Trinity facilities (Grapevine, Lewisville, and Ray Roberts), researchers convert the SME-elicited relative influence at the system and component levels to rankings. In the event that child nodes at the facility-to-system or system-to-component level was assigned the same relative influence value, the nodes are assigned adjacent ranking values (e.g., if two components were assigned the highest relative influence value, then they would randomly be assigned the ranks 1 and 2). See the similarity between methodology results in Figure G-1.

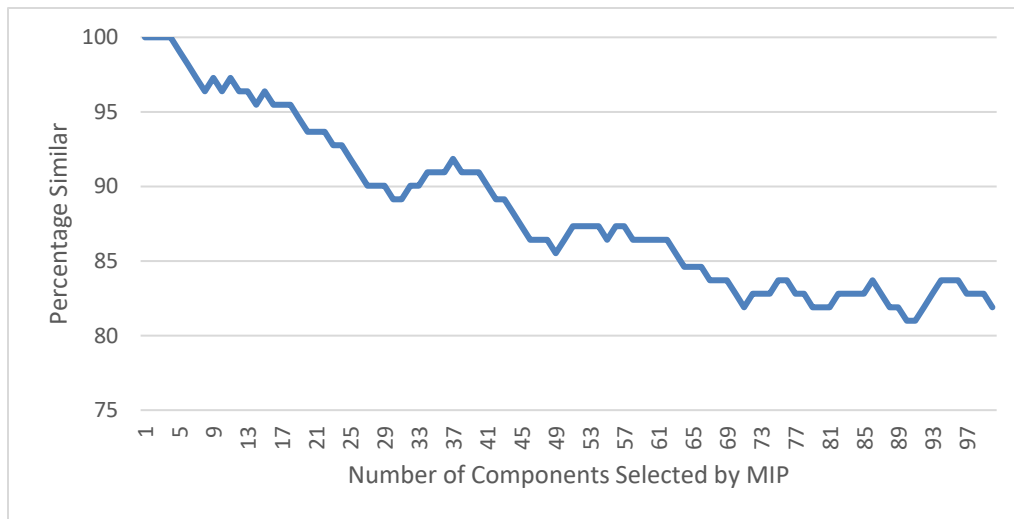
Figure G-1. Similarity between top X components based on selection by normalized relative influence value vs. normalized Borda score.



G.3 Comparison: Mixed Integer Program Component Selection

The similarity between component lists increasing as more components are considered implies that there should be some similarity between results when subjecting components to the mixed integer program for selection. Specifically, assuming 8 million dollars of consequences for Grapevine, 6 million dollars of consequences for Lewisville, and 3 million dollars of consequences for Ray Roberts, the results of the mixed integer program (MIP) observed for similarity between the two methodologies indicate a strong similarity ($> 80\%$) in resulting component selection (see illustrative component selection comparison in Figure G-2). Some of these differences can be attributed to SME relative influence similarities being identical for a number of components (e.g., there are only 25 unique relative influence scores for the first 100 components).

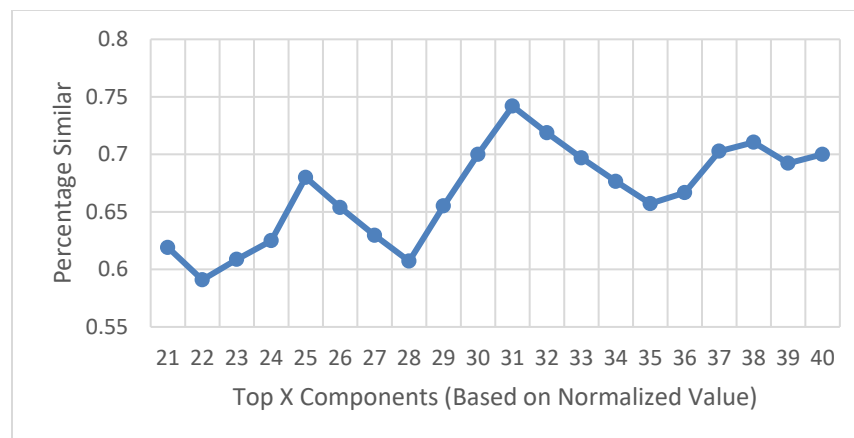
Figure G-2. Similarity between mixed integer program results between the two methodologies.



See Table G-1 for comparison of the following normalized relative influence and normalized Borda score “relative influence approximation” at the facility-to-system level. See Table G-2 for exemplar comparison of top 20 components (across Grapevine, Lewisville, and Ray Roberts) identified using normalized relative influence values and the normalized Borda score “relative influence approximation” values. See Table G-3 for similar comparison of normalized Borda score “relative influence approximation” values to normalized relative influence values.

As seen in Table G-1, the relative influence varies greatly between SME-assessed vs. Borda score approximation. The downside of the Borda score approximation is that some systems may be under- or overvalued in comparison to the relative influences elicited during a more intensive SME engagement. A comparison of the top 20 components listed based on the two methodologies shows a 60% similarity between the two lists. If the number of components is increased, the similarity between the listed components tends to increase as well (see Figure G-3).

Figure G-3. Similarity between top X components based on selection by normalized relative influence value vs. normalized Borda score.



G.4 Comparison: Mixed Integer Program Component Selection

The similarity between component lists increasing as more components are considered implies that there should be some similarity between results when subjecting components to the mixed integer program for selection. Specifically, assuming 8 million dollars of consequences for Grapevine, 6 million dollars of consequences for Lewisville, and 3 million dollars of consequences for Ray Roberts, the results of the MIP observed for similarity between the two methodologies indicate a strong similarity

(> 80%) in resulting component selection (see illustrative component selection comparison in Figure G-4). Some of these differences can be attributed to SME relative influence similarities being identical for a number of components (e.g., there are only 25 unique relative influence scores for the first 100 components).

Figure G-4. Similarity between mixed integer program results between the two methodologies.

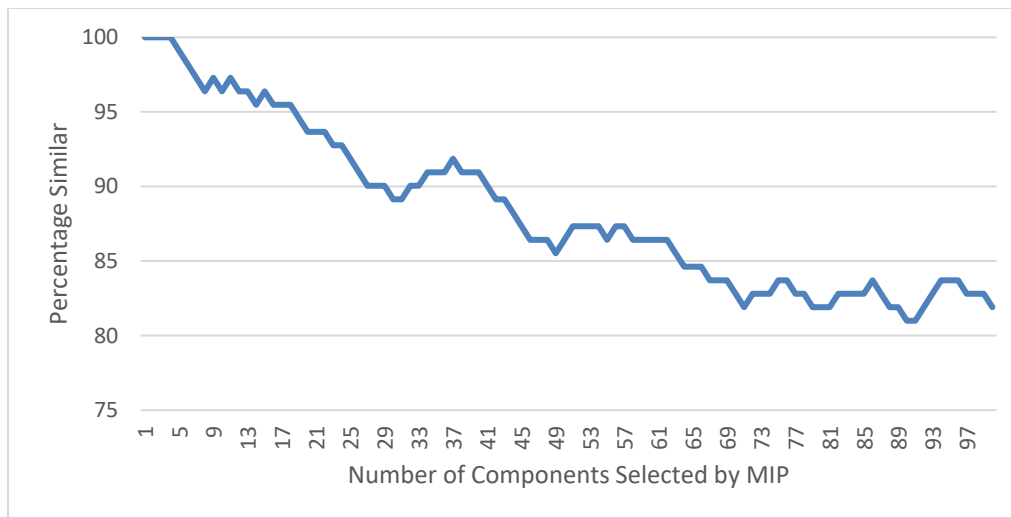


Table G-1. Comparison of normalized SME-elicited Relative Influence ratings and normalized Borda score ratings at the facility-to-systems level.

Location	System	Normalized Relative Influence	Normalized Borda Score
Grapevine	Service discharge gate—slide gate 1	0.495	0.4
Grapevine	Service discharge gate—slide gate 2	0.495	0.3
Grapevine	Water quality gate—low flow gate 1	0.005	0.2
Grapevine	Water quality gate—low flow gate 2	0.005	0.1
Lewisville	Service discharge gate—slide gate 1	0.331	0.333
Lewisville	Service discharge gate—slide gate 2	0.331	0.266
Lewisville	Service discharge gate—slide gate 3	0.331	0.2
Lewisville	Water quality gate—low flow gate 1	0.003	0.133
Lewisville	Water quality gate—low flow gate 2	0.003	0.066
Ray Roberts	Service discharge gate—slide gate 1	0.488	0.5
Ray Roberts	Service discharge gate—slide gate 2	0.488	0.333
Ray Roberts	Water quality gate—low flow gate 1	0.024	0.166

Table G-2. Comparison of top 20 components across Grapevine, Lewisville, and Ray Roberts based on normalized SME-elicited relative influence ratings to components across Grapevine, Lewisville, and Ray Roberts based on normalized Borda score ratings.

Component	Normalized Relative Influence	Normalized Relative Influence Ranking (tie ranking)	Normalized Borda Score	Normalized Borda Score Ranking
Ray Roberts, service discharge gate 1, basic structure	0.0375	1 (1)	0.0435	1
Ray Roberts, service discharge gate 2, basic structure	0.0375	2 (1)	0.029	15
Ray Roberts, service discharge gate 1, electric motors	0.0356	3 (2)	0.0415	2
Ray Roberts, service discharge gate 1, hydraulic cylinder	0.0356	4 (2)	0.0395	3
Ray Roberts, service discharge gate 1, lifting stem and guides	0.0356	5 (2)	0.0375	4
Ray Roberts, service discharge gate 2, electric motors	0.0356	6 (2)	0.0277	20
Ray Roberts, service discharge gate 2, hydraulic cylinder	0.0356	7 (2)	0.0264	24
Ray Roberts, service discharge gate 2, lifting stem and guides	0.0356	8 (2)	0.0250	30
Grapevine, service discharge gate 1, basic structure	0.0353	9 (3)	0.0348	6
Grapevine, service discharge gate 1, electric motors	0.0353	10 (3)	0.0332	8
Grapevine, service discharge gate 1, lifting cables	0.0353	11 (3)	0.0316	10
Grapevine, service discharge gate 1, brakes	0.0353	12 (3)	0.0300	13
Grapevine, service discharge gate 2, basic structure	0.0353	13 (3)	0.0261	25
Grapevine, service discharge gate 2, electric motors	0.0353	14 (3)	0.0249	31
Grapevine, service discharge gate 2, lifting cables	0.0353	15 (3)	0.0237	37
Grapevine, service discharge gate 2, brakes	0.0353	16 (3)	0.0225	40
Ray Roberts, service discharge gate 1, hydraulic piping	0.0336	17 (4)	0.0356	5
Ray Roberts, service discharge gate 2, hydraulic piping	0.0336	18 (4)	0.0237	36
Ray Roberts, service discharge gate 1, gate control panel	0.0326	19 (5)	0.0336	7
Ray Roberts, service discharge gate 2, gate control panel	0.0326	20 (5)	0.0224	41

Table G-3. Comparison of top 20 components across Grapevine, Lewisville, and Ray Roberts based on normalized Borda score ratings to components across Grapevine, Lewisville, and Ray Roberts based on normalized SME-elicited relative influence ratings.

Component	Normalized Borda Score	Normalized Borda Score Ranking	Normalized Relative Influence	Normalized Relative Influence Ranking (tie ranking)
Ray Roberts, service discharge gate 1, basic structure	0.0435	1	0.0375	1 (1)
Ray Roberts, service discharge gate 1, electric motors	0.0415	2	0.0356	3 (2)
Ray Roberts, service discharge gate 1, hydraulic cylinder	0.0395	3	0.0356	4 (2)
Ray Roberts, service discharge gate 1, lifting stem and guides	0.0375	4	0.0356	5 (2)
Ray Roberts, service discharge gate 1, hydraulic piping	0.0356	5	0.0336	17 (4)
Grapevine, service discharge gate 1, basic structure	0.0348	6	0.0353	9 (3)
Ray Roberts, service discharge gate 1, gate control panel	0.0336	7	0.0326	19 (5)
Grapevine, service discharge gate 1, electric motors	0.0332	8	0.0353	10 (3)
Lewisville, service discharge gate 1, basic structure	0.0317	9	0.0251	51 (14)
Grapevine, service discharge gate 1, lifting cables	0.0316	10	0.0353	11 (3)
Ray Roberts, service discharge gate 1, anchorages	0.0316	11	0.0316	23 (7)
Lewisville, service discharge gate 1, electric motors	0.0302	12	0.0251	52 (14)
Grapevine, service discharge gate 1, brakes	0.0300	13	0.0353	12 (3)
Ray Roberts, service discharge gate 1, control cables ≤ 480 V	0.0296	14	0.0296	29 (10)
Ray Roberts, service discharge gate 2, basic structure	0.029	15	0.0375	2 (1)
Grapevine, water quality gate 1, anchorages	0.0286	16	0.0006	143 (39)
Lewisville, service discharge gate 1, lifting cables	0.0286	17	0.0251	53 (14)
Grapevine, service discharge gate 1, enclosed gear box	0.0285	18	0.0318	21 (6)
Ray Roberts, service discharge gate 1, operating equipment, electric components	0.0277	19	0.0296	30 (10)
Ray Roberts, service discharge gate 2, electric motors	0.0277	20	0.0356	6 (2)

Appendix H: System Usability Survey Results

Table H-1. Trinity River SME system usability survey responses.

Number	Statement	Response	Count
1	The FY22 Online Data Collection Tool was easier/better to utilize than the FY21 Online Data Collection Tool.	Strongly Agree	0
		Agree	3
		Neither Agree nor Disagree	0
		Disagree	0
		Strongly Disagree	0
		N/A I did not participate in the FY21 Case Study data collection	5
2	I found the system unnecessarily complex.	Strongly Agree	0
		Agree	1
		Neither Agree nor Disagree	5
		Disagree	2
		Strongly Disagree	0
3	I thought the system was easy to use.	Strongly Agree	1
		Agree	3
		Neither Agree nor Disagree	3
		Disagree	1
		Strongly Disagree	0
4	I think that I would need the support of a technical person to be able to use this system.	Strongly Agree	1
		Agree	0
		Neither Agree nor Disagree	1
		Disagree	5
		Strongly Disagree	1
5	I found the various functions in this system were well integrated.	Strongly Agree	0
		Agree	3
		Neither Agree nor Disagree	4
		Disagree	1
		Strongly Disagree	0
6	I thought there was too much inconsistency in this system.	Strongly Agree	0
		Agree	2
		Neither Agree nor Disagree	3
		Disagree	3
		Strongly Disagree	0

Table H-1 (cont.). Trinity River SME system usability survey responses.

Number	Statement	Response	Count
7	I would imagine that most people would learn to use this system very quickly.	Strongly Agree	1
		Agree	4
		Neither Agree nor Disagree	2
		Disagree	1
		Strongly Disagree	0
8	I found the system very cumbersome to use.	Strongly Agree	0
		Agree	2
		Neither Agree nor Disagree	3
		Disagree	2
		Strongly Disagree	1
9	I felt very confident using the system.	Strongly Agree	0
		Agree	2
		Neither Agree nor Disagree	3
		Disagree	3
		Strongly Disagree	0
10	I needed to learn a lot of things before I could get going with this system.	Strongly Agree	0
		Agree	2
		Neither Agree nor Disagree	0
		Disagree	5
		Strongly Disagree	1

Table H-2. Willamette River SME system usability survey responses.

Number	Statement	Response	Count
1	I think that I would like to use this system frequently in conjunction with ranking systems and components	Strongly Agree	0
		Agree	2
		Neither Agree nor Disagree	1
		Disagree	2
		Strongly Disagree	0
2	I found the system unnecessarily complex.	Strongly Agree	0
		Agree	1
		Neither Agree nor Disagree	2
		Disagree	2
		Strongly Disagree	0
3	I thought the system was easy to use.	Strongly Agree	1
		Agree	2
		Neither Agree nor Disagree	1
		Disagree	1
		Strongly Disagree	0
4	I think that I would need the support of a technical person to be able to use this system.	Strongly Agree	0
		Agree	0
		Neither Agree nor Disagree	1
		Disagree	3
		Strongly Disagree	1

Table H-2 (cont.). Willamette River SME system usability survey responses.

Number	Statement	Response	Count
5	I found the various functions in this system were well integrated.	Strongly Agree	0
		Agree	2
		Neither Agree nor Disagree	1
		Disagree	1
		Strongly Disagree	1
6	I thought there was too much inconsistency in this system.	Strongly Agree	2
		Agree	2
		Neither Agree nor Disagree	1
		Disagree	0
		Strongly Disagree	0
7	I would imagine that most people would learn to use this system very quickly.	Strongly Agree	1
		Agree	1
		Neither Agree nor Disagree	3
		Disagree	0
		Strongly Disagree	0
8	I found the system very cumbersome to use.	Strongly Agree	0
		Agree	1
		Neither Agree nor Disagree	2
		Disagree	2
		Strongly Disagree	0
9	I felt very confident using the system.	Strongly Agree	0
		Agree	1
		Neither Agree nor Disagree	0
		Disagree	4
		Strongly Disagree	0
10	I needed to learn a lot of things before I could get going with this system.	Strongly Agree	0
		Agree	1
		Neither Agree nor Disagree	2
		Disagree	1
		Strongly Disagree	1

Appendix I: Trinity Case Study Results

Table I-1. Bardwell system relative influence in normal operating conditions.

System	SME 07	SME 08	SME 09	SME 10	SME 12	SME 13	SME 15	SME 16	SME 17	SME 19	SME 20	SME 21	SME 22	Rank	Borda Score	Normalized Borda Score
Service Discharge Gates	1	1	1	1	1	1	1	1	1	1	1	1	1	1	13	1

Table I-2. Bardwell system relative influence in flood operating conditions.

System	SME 07	SME 08	SME 09	SME 10	SME 12	SME 13	SME 15	SME 16	SME 17	SME 19	SME 20	SME 21	SME 22	Rank	Borda Score	Normalized Borda Score
Service Discharge Gates	1	1	1	1	1	1	1	1	1	1	1	1	1	1	13	1

Table I-3. Bardwell service discharge gate component relative influence on system operability.

Component	SME 07	SME 08	SME 09	SME 10	SME 12	SME 13	SME 15	SME 16	SME 17	SME 19	SME 20	SME 21	SME 22	Rank	Borda Score	Normalized Borda Score
Lifting stem and guides	3	1	1	3	1	1	1	2	2	5	1	4	1	1	260	0.083413539
Screw actuators	2	2	2	5	2	2	2	3	3	6	2	4	2	2	249	0.079884504

Table I-3 (cont.). Bardwell service discharge gate component relative influence on system operability.

Component	SME 07	SME 08	SME 09	SME 10	SME 12	SME 13	SME 15	SME 16	SME 17	SME 19	SME 20	SME 21	SME 22	Rank	Borda Score	Normalized Borda Score
Basic structure	1	3	4	9	3	8	4	1	1	1	3	5	3	3	240	0.076997113
Operating equipment, electric components	4	4	6	1	4	4	3	18	4	8	4	2	4	4	220	0.070580687
Electric motors	5	5	9	7	5	3	5	4	5	7	5	2	5	5	219	0.070259865
Power cable, <= 480V	7	7	5	14	7	5	7	5	9	9	7	1	7	6	196	0.062880975
Anchorage	6	6	3	8	6	9	6	19	16	2	6	3	6	7	190	0.060956047
Limit switches	8	8	13	4	10	6	8	8	8	12	8	7	8	8	178	0.057106192
Enclosed gear boxes	9	9	7	6	9	10	9	9	7	13	9	8	9	9	172	0.055181264
Control cables, <= 480V	11	11	12	15	11	7	11	6	11	10	11	1	11	10	158	0.050689766
Embedded guides	10	10	8	16	8	11	10	13	10	4	10	11	10	11	155	0.049727302
Gate control panel	12	12	14	10	12	12	12	7	6	11	12	6	12	12	148	0.047481553

Table I-3 (cont.). Bardwell service discharge gate component relative influence on system operability.

Component	SME 07	SME 08	SME 09	SME 10	SME 12	SME 13	SME 15	SME 16	SME 17	SME 19	SME 20	SME 21	SME 22	Rank	Borda Score	Normalized Borda Score
Couplings	13	13	10	11	13	13	13	11	20	18	13	10	13	13	115	0.036894450
Embedded bottom seal	14	15	11	19	15	15	15	14	13	3	15	12	15	14	110	0.035290343
Operator pushbutton	16	14	17	12	14	14	14	15	12	20	14	14	14	15	96	0.030798845
Seals	15	16	15	17	18	17	16	10	14	10	16	13	16	16	93	0.029836381
Position indicators	18	17	16	13	17	16	18	12	15	15	17	16	17	17	79	0.025344883
PLC	17	21	19	2	16	19	19	17	21	19	16	9	16	18	75	0.024061598
Remote control equipment	21	18	18	0	21	0	20	21	17	21	18	18	18	19	75	0.024061598
Paint system	19	19	20	18	20	18	17	20	18	14	19	17	19	20	48	0.015399423
Cathodic protection	20	20	21	20	19	20	18	16	19	17	20	15	20	21	41	0.013153673

Table I-4. Benbrook system relative influence in normal operating conditions.

System	SME 07	SME 08	SME 09	SME 10	SME 12	SME 13	SME 15	SME 16	SME 17	SME 19	SME 20	SME 21	SME 22	Rank	Borda Score	Normalized Borda Score
Service discharge gates	1	1	1	1	1	1	2	1	1	1	2	1	1	1	24	0.631579
Water quality gates and valves	2	2	2	2	2	1	2	2	2	2	2	2	2	2	14	0.368421

Table I-5. Benbrook system relative influence in flood operating conditions.

System	SME 07	SME 08	SME 09	SME 10	SME 12	SME 13	SME 15	SME 16	SME 17	SME 19	SME 20	SME 21	SME 22	Rank	Borda Score	Normalized Borda Score
Water quality gates and valves	1	2	1	1	1	1	2	2	0	2	2	2	2	1	20	0.512821
Service discharge gates	2	1	2	2	2	2	2	1	1	1	2	1	1	2	19	0.487179

Table I-6. Benbrook service discharge gate component relative influence on system operability.

Component	SME 07	SME 08	SME 09	SME 10	SME 12	SME 13	SME 15	SME 16	SME 17	SME 19	SME 20	SME 21	SME 22	Rank	Borda Score	Normalized Borda Score
Lifting stem and guides	3	1	1	2	1	1	1	2	2	4	1	2	1	1	225	0.099513490
Screw actuators	2	2	2	3	2	2	2	3	3	5	2	1	2	2	216	0.095532950
Basic structure	1	3	3	8	3	9	4	1	1	2	3	9	3	3	197	0.087129589

Table I-6 (cont.). Benbrook service discharge gate component relative influence on system operability.

Component	SME 07	SME 08	SME 09	SME 10	SME 12	SME 13	SME 15	SME 16	SME 17	SME 19	SME 20	SME 21	SME 22	Rank	Borda Score	Normalized Borda Score
Operating equipment, electric components	4	4	5	1	4	5	3	9	4	8	4	8	4	4	184	0.081379920
Electric motors	5	5	7	9	5	3	5	4	5	7	5	6	5	5	176	0.077841663
Gate control panel	6	10	10	4	6	4	6	7	6	11	6	13	6	6	152	0.067226891
Limit switches	8	8	8	5	8	6	8	8	7	12	8	7	8	7	146	0.064573198
Anchorage	7	6	4	7	7	18	7	15	13	1	7	3	7	8	145	0.064130916
Control cables, <= 480 V	9	9	9	12	9	7	9	6	9	6	9	4	9	9	140	0.061919505
Power cable, <= 480 V	10	7	6	11	10	8	10	5	8	9	10	5	10	10	138	0.061034940
Operator pushbutton	13	11	13	6	11	0	11	11	10	17	11	12	11	11	110	0.048651039
Seals	11	12	11	10	12	13	12	10	14	10	12	11	12	12	97	0.042901371
Embedded bottom seal	12	13	12	15	13	14	13	13	11	3	13	10	13	13	92	0.040689960
Position indicators	14	14	14	13	14	10	17	12	12	14	14	14	14	14	71	0.031402034
Greasing system	15	15	15	14	15	11	14	16	14	13	15	16	15	15	59	0.026094648
Remote control equipment	18	16	16	0	18	15	18	18	15	18	16	18	16	16	45	0.019902698
Cathodic protection	17	17	17	17	16	17	15	14	16	15	17	15	18	17	36	0.015922158
Paint system	16	18	18	16	17	12	16	17	17	16	18	17	17	18	32	0.014153030

Table I-7. Bardwell system relative influence in normal operating conditions.

System	SME 07	SME 08	SME 09	SME 10	SME 12	SME 13	SME 15	SME 16	SME 17	SME 19	SME 20	SME 21	SME 22	Rank	Borda Score	Normalized Borda Score
Service discharge gates	1	1	1	1	1	1	1	1	1	1	1	1	1	1	13	1

Table I-8. Bardwell system relative influence in flood operating conditions.

System	SME 07	SME 08	SME 09	SME 10	SME 12	SME 13	SME 15	SME 16	SME 17	SME 19	SME 20	SME 21	SME 22	Rank	Borda Score	Normalized Borda Score
Service discharge gates	1	1	1	1	1	1	1	1	1	1	1	1	1	1	13	1

Table I-9. Bardwell service discharge gate component relative influence on system operability.

Component	SME 07	SME 08	SME 09	SME 10	SME 12	SME 13	SME 15	SME 16	SME 17	SME 19	SME 20	SME 21	SME 22	Rank	Borda Score	Normalized Borda Score
Lifting stem and guides	3	1	1	3	1	1	1	2	2	5	1	4	1	1	260	0.083413539
Screw actuators	2	2	2	5	2	2	2	3	3	6	2	4	2	2	249	0.079884504
Basic structure	1	3	4	9	3	8	4	1	1	1	3	5	3	3	240	0.076997113
Operating equipment, electric components	4	4	6	1	4	4	3	18	4	8	4	2	4	4	220	0.070580687
Electric motors	5	5	9	7	5	3	5	4	5	7	5	2	5	5	219	0.070259865
Power cable, <= 480 V	7	7	5	14	7	5	7	5	9	9	7	1	7	6	196	0.062880975

Table I-9 (cont.). Bardwell service discharge gate component relative influence on system operability.

Component	SME 07	SME 08	SME 09	SME 10	SME 12	SME 13	SME 15	SME 16	SME 17	SME 19	SME 20	SME 21	SME 22	Rank	Borda Score	Normalized Borda Score
Anchorage	6	6	3	8	6	9	6	19	16	2	6	3	6	7	190	0.060956047
Limit switches	8	8	13	4	10	6	8	8	8	12	8	7	8	8	178	0.057106192
Enclosed gear boxes	9	9	7	6	9	10	9	9	7	13	9	8	9	9	172	0.055181264
Control cables, <= 480 V	11	11	12	15	11	7	11	6	11	10	11	1	11	10	158	0.050689766
Embedded guides	10	10	8	16	8	11	10	13	10	4	10	11	10	11	155	0.049727302
Gate control panel	12	12	14	10	12	12	12	7	6	11	12	6	12	12	148	0.047481553
Couplings	13	13	10	11	13	13	13	11	20	18	13	10	13	13	115	0.036894450
Embedded bottom seal	14	15	11	19	15	15	15	14	13	3	15	12	15	14	110	0.035290343
Operator pushbutton	16	14	17	12	14	14	14	15	12	20	14	14	14	15	96	0.030798845
Seals	15	16	15	17	18	17	16	10	14	10	16	13	16	16	93	0.029836381
Position indicators	18	17	16	13	17	16	18	12	15	15	17	16	17	17	79	0.025344883
PLC	17	21	19	2	16	19	19	17	21	19	16	9	16	18	75	0.024061598
Remote control equipment	21	18	18	0	21	0	20	21	17	21	18	18	18	19	75	0.024061598
Paint system	19	19	20	18	20	18	17	20	18	14	19	17	19	20	48	0.015399423
Cathodic protection	20	20	21	20	19	20	18	16	19	17	20	15	20	21	41	0.013153673

Table I-10. Benbrook system relative influence in normal operating conditions.

System	SME 07	SME 08	SME 09	SME 10	SME 12	SME 13	SME 15	SME 16	SME 17	SME 19	SME 20	SME 21	SME 22	Rank	Borda Score	Normalized Borda Score
Service discharge gates	1	1	1	1	1	1	2	1	1	1	2	1	1	1	24	0.631579
Water quality gates and valves	2	2	2	2	2	1	2	2	2	2	2	2	2	2	14	0.368421

Table I-11. Benbrook system relative influence in flood operating conditions.

System	SME 07	SME 08	SME 09	SME 10	SME 12	SME 13	SME 15	SME 16	SME 17	SME 19	SME 20	SME 21	SME 22	Rank	Borda Score	Normalized Borda Score
Water quality gates and valves	1	2	1	1	1	1	2	2	0	2	2	2	2	1	20	0.512821
Service discharge gates	2	1	2	2	2	2	2	1	1	1	2	1	1	2	19	0.487179

Table I-12. Benbrook service discharge gate component relative influence on system operability.

Component	SME 07	SME 08	SME 09	SME 10	SME 12	SME 13	SME 15	SME 16	SME 17	SME 19	SME 20	SME 21	SME 22	Rank	Borda Score	Normalized Borda Score
Lifting stem and guides	3	1	1	2	1	1	1	2	2	4	1	2	1	1	225	0.09951349
Screw actuators	2	2	2	3	2	2	2	3	3	5	2	1	2	2	216	0.09553295
Basic structure	1	3	3	8	3	9	4	1	1	2	3	9	3	3	197	0.087129589
Operating equipment, electric components	4	4	5	1	4	5	3	9	4	8	4	8	4	4	184	0.08137992
Electric motors	5	5	7	9	5	3	5	4	5	7	5	6	5	5	176	0.077841663
Gate control panel	6	10	10	4	6	4	6	7	6	11	6	13	6	6	152	0.067226891

Table I-12 (cont.). Benbrook service discharge gate component relative influence on system operability.

Component	SME 07	SME 08	SME 09	SME 10	SME 12	SME 13	SME 15	SME 16	SME 17	SME 19	SME 20	SME 21	SME 22	Rank	Borda Score	Normalized Borda Score
Limit switches	8	8	8	5	8	6	8	8	7	12	8	7	8	7	146	0.064573198
Anchorage	7	6	4	7	7	18	7	15	13	1	7	3	7	8	145	0.064130916
Control cables, <= 480 V	9	9	9	12	9	7	9	6	9	6	9	4	9	9	140	0.061919505
Power cable, <= 480 V	10	7	6	11	10	8	10	5	8	9	10	5	10	10	138	0.061034940
Operator pushbutton	13	11	13	6	11	0	11	11	10	17	11	12	11	11	110	0.048651039
Seals	11	12	11	10	12	13	12	10	14	10	12	11	12	12	97	0.042901371
Embedded bottom seal	12	13	12	15	13	14	13	13	11	3	13	10	13	13	92	0.040689960
Position indicators	14	14	14	13	14	10	17	12	12	14	14	14	14	14	71	0.031402034
Greasing system	15	15	15	14	15	11	14	16	14	13	15	16	15	15	59	0.026094648
Remote control equipment	18	16	16	0	18	15	18	18	15	18	16	18	16	16	45	0.019902698
Cathodic protection	17	17	17	17	16	17	15	14	16	15	17	15	18	17	36	0.015922158
Paint system	16	18	18	16	17	12	16	17	17	16	18	17	17	18	32	0.014153030

Table I-13. Benbrook water quality gate component relative influence on system operability.

Component	SME 07	SME 08	SME 09	SME 10	SME 12	SME 13	SME 15	SME 16	SME 17	SME 19	SME 20	SME 21	SME 22	Rank	Borda Score	Normalized Borda Score
Lifting cables	1	1	1	2	1	1	1	3	2	5	1	4	1	1	288	0.075989
Electric motors	2	2	4	4	2	2	2	4	3	6	2	2	2	2	275	0.072559
Basic Structure	3	3	2	14	3	16	3	1	1	2	3	5	3	3	253	0.066755
Power cable, <= 480 V	5	5	3	12	5	8	5	5	5	10	4	1	4	4	240	0.063325
Gate control panel	4	4	14	5	4	7	4	7	4	8	3	6	3	5	239	0.063061
Brakes	6	7	5	8	7	5	7	2	6	12	6	14	6	6	221	0.058311
Limit switches	6	6	13	3	6	6	6	8	7	15	5	7	5	7	219	0.057784
Control cables,<= 480 V	7	8	6	15	8	9	8	6	8	7	6	1	6	8	217	0.057256
Operating equipment, electric components	8	9	7	1	9	3	9	18	9	9	7	2	7	9	214	0.056464
Enclosed gear boxes	9	10	9	9	10	4	10	21	10	11	8	9	8	10	184	0.048549
Embedded guides	10	11	8	16	11	10	11	13	11	4	9	11	9	11	178	0.046966
Roller train	11	12	10	11	12	11	12	22	12	13	10	8	10	12	158	0.041689
Anchorage	13	14	11	13	14	19	14	17	19	1	12	3	12	13	150	0.039578
Couplings	12	13	12	10	13	15	13	10	23	17	11	16	11	14	136	0.035884
PLC	17	15	23	7	15	11	21	11	20	18	13	10	13	15	118	0.031135
Embedded bottom seal	14	18	16	21	18	18	17	14	15	3	16	9	16	16	117	0.030871
Seals	15	17	15	19	17	13	16	11	14	16	15	12	15	17	117	0.030871

Table I-13 (cont.). Benbrook water quality gate component relative influence on system operability.

Component	SME 07	SME 08	SME 09	SME 10	SME 12	SME 13	SME 15	SME 16	SME 17	SME 19	SME 20	SME 21	SME 22	Rank	Borda Score	Normalized Borda Score
Operator pushbutton	16	16	20	6	16	12	15	16	13	22	14	17	14	18	115	0.030343
Position indicators	18	19	18	17	19	14	20	12	16	19	17	13	17	19	93	0.024538
Remote control equipment	23	23	19	0	23	0	21	23	18	23	19	20	21	20	79	0.020844
Greasing system	19	20	17	18	20	13	18	19	17	14	23	18	18	21	78	0.020580
Cathodic protection	21	21	21	22	21	17	19	15	21	20	20	15	20	22	59	0.015567
Paint system	20	22	22	20	22	20	20	20	22	21	23	19	19	23	42	0.011082

Table I-14. Grapevine system relative influence in normal operating conditions.

Systems	Weights	Normalized Weights
Service discharge gate—slide gate	78	0.987341772
Water quality gate—low flow gate	1	0.012658228

Table I-15. Grapevine system relative influence in flood operating conditions.

Systems	Weights	Normalized Weights
Service discharge gate—slide gate	100	0.9901
Water quality gate—low flow gate	1	0.0099

Table I-16. Grapevine service discharge gate component relative influence on system operability.

Components	Weights	Normalized Weights
Anchorage	57.5	0.041013
Basic structure	100	0.071327
Cathodic protection	1	0.000713
Control cables, <=480 V	60	0.042796
Electric motors	100	0.071327
Embedded bottom seal	40	0.028531
Embedded guides	87.5	0.062411
Gate control panel	75	0.053495
Greasing system	50	0.035663
Lifting cables	100	0.071327
Limit switches	75	0.053495
Operating equipment, electric components	75	0.053495
Paint system	1	0.000713
Position indicators	50	0.035663
Power cable, <= 480V	60	0.042796
Seals	40	0.028531
Operator pushbutton	75	0.053495
PLC	1	0.000713
Brakes	100	0.071327
Couplings	85	0.060628
Enclosed gear boxes	90	0.064194
Roller train	79	0.056348

Table I-17. Grapevine water quality gate component relative influence on system operability.

Components	Weights	Normalized Weights
Anchorage	80	0.125589
Basic structure	80	0.125589
Cathodic protection	1	0.001570
Electric motors	70	0.109890
Embedded bottom seal	25	0.039246
Operating equipment, electric components	70	0.109890
Paint system	1	0.001570
Position indicators	15	0.023548
Power cable, <= 480 V	70	0.109890
Seals	25	0.039246
Operator pushbutton	40	0.062794
Lifting stem and guides	80	0.125589
Screw actuators	80	0.125589

Table I-18. Joe Pool system relative influence in normal operating conditions.

System	SME 07	SME 08	SME 09	SME 10	SME 12	SME 13	SME 15	SME 16	SME 17	SME 19	SME 20	SME 21	SME 22	Rank	Borda Score	Normalized Borda Score
Service discharge gates	1	1	2	1	1	1	2	1	1	1	2	1	1	1	23	0.638889
Water quality gates and valves	2	2	2	2	2	2	2	2	2	2	2	2	2	2	13	0.361111

Table I-19. Joe Pool system relative influence in flood operating conditions.

System	SME 07	SME 08	SME 09	SME 10	SME 12	SME 13	SME 15	SME 16	SME 17	SME 19	SME 20	SME 21	SME 22	Rank	Borda Score	Normalized Borda Score
Service discharge gates	2	1	2	2	2	1	2	1	1	1	2	1	1	1	20	0.555556
Water quality gates and valves	1	2	2	1	1	2	2	2	2	2	2	2	2	2	16	0.444444

Table I-20. Joe Pool service discharge gate component relative influence on system operability.

Component	SME 07	SME 08	SME 09	SME 10	SME 12	SME 13	SME 15	SME 16	SME 17	SME 19	SME 20	SME 21	SME 22	Rank	Borda Score	Normalized Borda Score
Lifting stem and guides	3	1	20	2	1	1	1	2	2	3	1	2	1	1	147	0.087792
Screw actuators	2	2	20	4	2	2	2	3	3	4	2	1	2	2	201	0.084401
Electric motors	4	5	20	3	4	3	4	4	4	7	3	6	3	3	35	0.076488
Basic structure	1	3	20	11	3	12	3	1	1	2	3	9	3	4	147	0.075735
Gate control panel	5	11	20	5	5	0	5	7	5	9	4	10	4	5	96	0.068953
Operating equipment, electric components	6	4	20	1	6	5	6	16	6	10	4	8	4	6	203	0.066692

Table I-20. (cont.). Joe Pool service discharge gate component relative influence on system operability.

Component	SME 07	SME 08	SME 09	SME 10	SME 12	SME 13	SME 15	SME 16	SME 17	SME 19	SME 20	SME 21	SME 22	Rank	Borda Score	Normalized Borda Score
Power cable, <= 480 V	7	7	20	9	7	10	7	5	7	11	5	5	5	7	85	0.063301
Enclosed gear boxes	9	9	20	3	9	9	9	9	8	12	7	12	7	8	116	0.056518
Anchorage	8	6	20	10	8	14	8	18	18	1	6	3	6	9	150	0.055388
Control cables, <= 480 V	10	10	20	12	10	11	10	6	9	8	8	4	8	10	183	0.055388
Limit switches	11	8	20	6	11	6	11	8	14	13	9	7	9	11	59	0.052751
Embedded guides	12	12	20	13	12	13	12	13	13	6	10	11	10	12	233	0.043708
Couplings	13	13	20	7	13	15	13	11	17	16	11	17	11	13	140	0.036172
Operator pushbutton	16	14	20	8	14	7	14	17	10	20	12	15	12	14	177	0.035418
Position indicators	15	15	20	14	15	4	20	12	12	18	12	16	13	15	94	0.032781
Embedded bottom seal	14	16	20	17	16	16	15	14	15	5	13	13	14	16	31	0.032027
Seals	14	17	20	15	17	17	16	10	11	15	14	14	15	17	87	0.029390
Greasing system	19	18	20	16	18	8	17	19	16	14	15	18	16	18	168	0.022231
Cathodic protection	18	19	20	19	19	19	18	15	19	19	16	19	18	19	224	0.013188
Paint system	17	20	20	18	20	18	19	20	20	17	17	19	17	20	78	0.011680

Table I-21. Joe Pool water quality gate component relative influence on system operability.

Component	SME 07	SME 08	SME 09	SME 10	SME 12	SME 13	SME 15	SME 16	SME 17	SME 19	SME 20	SME 21	SME 22	Rank	Borda Score	Normalized Borda Score
Lifting stem and guides	3	1	16	3	1	1	1	2	2	3	1	2	1	1	184	0.106358
Screw actuators	1	2	16	4	2	2	2	3	3	4	2	1	2	2	177	0.102312
Basic structure	2	3	16	7	3	11	3	1	1	2	3	8	3	3	158	0.091329
Electric motors	4	5	16	2	4	3	4	4	4	5	3	6	3	4	158	0.091329
Operating equipment, electric components	5	4	16	1	5	5	5	11	5	7	4	7	4	5	142	0.082081
Gate control panel	7	9	16	9	7	0	6	7	6	10	6	11	6	6	121	0.069942
Anchorage	6	6	16	6	6	12	5	16	14	1	5	3	5	7	120	0.069364
Power cable, <= 480 V	8	7	16	11	8	10	7	5	7	8	6	5	6	8	117	0.067630
Control cables, <= 480 V	9	8	16	8	9	9	8	6	8	6	7	5	7	9	115	0.066474
Limit switches	10	10	16	5	10	7	9	8	10	12	8	4	8	10	104	0.060116
Seals	11	11	16	13	11	13	10	9	9	9	9	9	9	11	82	0.047399
Greasing system	12	12	16	10	12	4	11	13	13	11	10	13	10	12	74	0.042775
Position indicators	13	13	16	14	13	6	12	10	12	14	11	12	11	13	64	0.036994
Operator pushbutton	16	14	16	12	14	8	13	12	11	15	12	10	12	14	56	0.032370
Paint system	14	15	16	15	16	14	14	15	15	13	13	15	13	15	33	0.019075
Cathodic protection	15	16	16	16	15	15	15	14	16	16	14	14	14	16	25	0.014451

Table I-22. Lavon Spillway gate component relative influence on system operability.

Component	SME 07	SME 08	SME 09	SME 10	SME 12	SME 13	SME 15	SME 16	SME 17	SME 19	SME 20	SME 21	SME 22	Rank	Borda Score	Normalized Borda Score
Basic structure	11	1	11	11	1	11	11	11	11	1	1	11	1	1	193	0.063781
Lifting cables	11	2	11	11	2	11	11	11	11	2	2	11	2	2	188	0.062128
Control cables, <= 480 V	11	5	11	11	4	11	11	11	11	3	3	11	3	3	180	0.059484
Gate control panel	11	6	11	11	5	11	11	11	11	9	5	11	5	4	168	0.055519
Operating equipment, electric components	11	7	11	11	6	11	11	11	11	5	6	11	6	5	168	0.055519
Power cable, <= 480 V	11	11	11	11	3	11	11	11	11	4	7	11	7	6	166	0.054858
Electric motors	11	4	11	11	15	11	11	11	11	8	4	11	4	7	163	0.053866
Anchorage	11	8	11	11	7	11	11	11	11	7	8	11	11	8	157	0.051884
Brakes	11	3	11	11	8	11	11	11	11	10	15	11	8	9	154	0.050892
Limit switches	11	9	11	11	9	11	11	11	11	6	10	11	12	10	152	0.050231
Enclosed gear boxes	11	10	11	11	16	11	11	11	11	12	9	11	9	11	142	0.046927
Embedded guides	11	13	11	11	10	11	11	11	11	11	12	11	14	12	138	0.045605
Embedded bottom seal	11	15	11	11	11	11	11	11	11	15	11	11	13	13	133	0.043952
Catwalks, ladders, and platforms	11	16	11	11	12	11	11	11	11	13	13	11	15	14	129	0.042631
Operator pushbutton	11	17	11	11	17	11	11	11	11	20	6	11	10	15	128	0.042300
Position indicators	11	18	11	11	13	11	11	11	11	19	14	11	17	16	117	0.038665
Greasing system	11	12	11	11	19	11	11	11	11	18	15	11	18	17	116	0.038334

Table I-22 (cont.). Lavon Spillway gate component relative influence on system operability.

Component	SME 07	SME 08	SME 09	SME 10	SME 12	SME 13	SME 15	SME 16	SME 17	SME 19	SME 20	SME 21	SME 22	Rank	Borda Score	Normalized Borda Score
Seals	11	19	11	11	14	11	11	11	11	14	16	11	19	18	116	0.038334
Couplings	11	14	11	11	18	11	11	11	11	21	18	11	16	19	111	0.036682
Paint system	11	20	11	11	20	11	11	11	11	16	17	11	20	20	105	0.034699
Cathodic protection	11	21	11	11	21	11	11	11	11	17	16	11	21	21	102	0.033708

Table I-23. Lewisville system relative influence in normal operating conditions.

Systems	Weights	Norm_Weights
Service discharge gate—slide gate (3)	5	0.882354
Water quality gate—low flow gate (2)	1	0.117648

Table I-24. Lewisville system relative influence in flood operating conditions.

Systems	Weights	Norm_Weights
Service discharge gate—slide gate (3)	100	0.993378
Water quality gate—low flow gate (2)	1	0.006622

Table I-25. Lewisville service discharge gate component relative influence on system operability.

Components	Weights	Norm_Weights
Anchorage	58	0.044039
Basic structure	100	0.075930
Cathodic protection	1	0.000759
Control cables, <=480 V	60	0.045558
Electric motors	100	0.075930
Embedded bottom Seal	40	0.030372
Embedded guides	88	0.066819
Gate control panel	75	0.056948
Greasing system	50	0.037965
Lifting cables	100	0.075930
Limit switches	75	0.056948
Operating equipment, electric components	75	0.056948
Paint system	1	0.000759
Position indicators	50	0.037965
Power cable, <= 480V	60	0.045558
Seals	40	0.030372
Operator pushbutton	75	0.056948
Brakes	100	0.075930
Enclosed gear boxes	90	0.068337
Roller train	79	0.059985

Table I-26. Lewisville water quality gate component relative influence on system operability.

Components	Weights	Norm_Weights
Anchorage	80	0.094007
Basic structure	80	0.094007
Control cables, <=480 V	75	0.088132
Electric motors	70	0.082256
Embedded bottom seal	25	0.029377
Gate control panel	80	0.094007
Limit switches	60	0.070505
Operating equipment, electric components	70	0.082256
Paint system	1	0.001175
Position indicators	15	0.017626
Power cable, <= 480 V	70	0.082256
Seals	25	0.029377
Operator pushbutton	40	0.047004
Lifting stem and guides	80	0.094007
Screw actuators	80	0.094007

Table I-27. Navarro Mills system relative influence in normal operating conditions.

System	SME 07	SME 08	SME 09	SME 10	SME 12	SME 13	SME 15	SME 16	SME 17	SME 19	SME 20	SME 21	SME 22	Rank	Borda Score	Normalized Borda Score
Spillway gates	1	1	2	1	1	1	2	1	1	1	1	1	1	24	1	0.64865
Water quality gates and valves	2	2	2	2	2	2	2	2	2	2	2	2	2	13	0	0.35135

Table I-28. Navarro Mills system relative influence in flood operating conditions.

System	SME 07	SME 08	SME 09	SME 10	SME 12	SME 13	SME 15	SME 16	SME 17	SME 19	SME 20	SME 21	SME 22	Rank	Borda Score	Normalized Borda Score
Spillway gates	1	1	2	1	2	1	2	1	1	1	1	1	1	23	1	0.575
Water quality gates and valves	2	2	2	2	1	1	2	2	0	2	2	2	2	17	0	0.425

Table I-29. Navarro Mills spillway gate component relative influence on system operability.

Component	SME 07	SME 08	SME 09	SME 10	SME 12	SME 13	SME 15	SME 16	SME 17	SME 19	SME 20	SME 21	SME 22	Rank	Borda Score	Normalized Borda Score
Anchorage	6	6	14	6	6	11	6	13	12	1	6	3	6	99	0.571429	0.077103
Basic structure	1	3	14	7	3	10	3	1	1	2	3	8	3	136	0.835714	0.105919
Electric motors	4	4	14	8	4	3	4	4	4	6	4	6	4	126	0.764286	0.098131
Embedded bottom seal	11	11	14	10	11	13	11	10	12	5	11	9	11	56	0.264286	0.043614
Gate control panel	7	7	14	2	7	4	7	6	5	7	7	12	7	103	0.600000	0.080218

Table I-29 (cont.). Navarro Mills spillway gate component relative influence on system operability.

Component	SME 07	SME 08	SME 09	SME 10	SME 12	SME 13	SME 15	SME 16	SME 17	SME 19	SME 20	SME 21	SME 22	Rank	Borda Score	Normalized Borda Score
Lifting stem and guides	3	1	14	4	1	1	1	2	2	3	1	2	1	159	1.000000	0.123832
Limit switches	9	9	14	3	9	7	9	7	8	11	9	4	9	87	0.485714	0.067757
Operating equipment, electric components	5	5	14	1	5	6	5	12	9	8	5	7	5	108	0.635714	0.084112
Operator pushbutton	10	10	14	9	10	5	10	11	7	14	10	11	10	64	0.321429	0.049844
Paint system	14	14	14	12	14	14	13	14	13	12	14	14	14	19	0	0.014798
Position indicators	12	12	14	11	12	12	14	9	10	13	12	13	12	39	0.142857	0.030374
Power cable, <= 480 V	8	8	14	9	8	9	8	5	6	9	8	5	8	90	0.507143	0.070093
Screw actuators	2	2	14	5	2	2	2	3	3	4	2	1	2	151	0.942857	0.117601
Seals	13	13	14	10	13	8	12	8	11	10	13	10	13	47	0.200000	0.036604

Table I-30. Navarro Mills water quality gate component relative influence on system operability.

Component	SME 07	SME 08	SME 09	SME 10	SME 12	SME 13	SME 15	SME 16	SME 17	SME 19	SME 20	SME 21	SME 22	Rank	Borda Score	Normalized Borda Score
Anchorage	6	6	18	5	6	8	6	17	16	1	6	3	6	143	0.650888	0.065237
Basic structure	1	1	18	6	1	6	1	1	1	2	1	5	1	202	1.000000	0.092153
Cathodic protection	16	18	18	17	16	15	16	16	18	17	16	13	18	33	0	0.015055
Catwalks, ladders, and platforms	10	12	18	15	11	11	11	15	12	13	11	11	12	85	0.307692	0.038777
Control cables, <= 480V	5	5	18	7	5	5	5	6	5	5	5	1	5	170	0.810651	0.077555
Electric motors	3	3	18	2	3	2	3	3	3	6	3	2	3	193	0.946746	0.088047
Embedded bottom seal	11	13	18	14	12	14	12	14	9	3	12	9	13	93	0.355030	0.042427
Embedded guides	9	10	18	12	10	0	10	13	11	4	9	8	10	123	0.532544	0.056113
Gate control panel	7	7	18	8	7	3	7	7	6	7	7	6	7	150	0.692308	0.068431
Greasing system	12	14	18	13	13	9	13	12	13	15	12	14	14	75	0.248521	0.034215
Lifting cables	2	2	18	4	2	1	2	4	2	8	2	4	2	194	0.952663	0.088504
Limit switches	8	9	18	3	9	7	9	8	8	14	8	7	9	130	0.573964	0.059307
Operating equipment, electric components	4	4	18	1	4	6	4	11	4	9	4	2	4	172	0.822485	0.078467
Paint system	15	17	18	16	17	10	15	18	17	16	15	15	17	41	0.047337	0.018704
Position indicators	14	16	18	10	15	13	17	9	10	18	14	12	16	65	0.189349	0.029653
Power cable, <= 480 V	7	8	18	9	8	4	8	5	7	10	7	1	8	147	0.674556	0.067062
Remote control equipment	17	11	18	0	18	0	18	2	15	11	10	16	11	100	0.396450	0.045620
Seals	13	15	18	11	14	12	14	10	14	12	13	10	15	76	0.254438	0.034672

Table I-31. Ray Roberts system relative influence in normal operating conditions.

Systems (Quantity)	Weights	Norm_Weights
Service discharge gate—slide gate (2)	1	0.5
Water quality gate—low flow gate (1)	2	0.5

Table I-32. Ray Roberts system relative influence in flood operating conditions.

Systems (Quantity)	Weights	Norm_Weights
Service discharge gate—slide gate (2)	20	0.97561
Water Quality Gate—low flow gate (1)	1	0.02439

Table I-33. Ray Roberts service discharge gate component relative influence on system operability.

Components	Weights	Norm_Weights
Anchorage	80	0.064804
Basic structure	95	0.076954
Cathodic protection	1	0.000810
Control cables, <=480 V	75	0.060753
Electric motors	90	0.072904
Embedded bottom seal	25	0.020251
Embedded guides	40	0.032402
Gate control panel	82.5	0.066829
Greasing system	40	0.032402
Limit switches	0	0
Operating equipment, electric components	75	0.060753
Paint system	1	0.000810
Position indicators	50	0.040502
Power cable, <= 480V	75	0.060753
Seals	25	0.020251
Control valves	70	0.056703
Operator pushbutton	70	0.056703
Hydraulic cylinder	90	0.072904
Hydraulic hoses	0	0
Hydraulic piping	85	0.068854
Couplings	75	0.060753
Lifting stem and guides	90	0.072904

Table I-34. Ray Roberts water quality gate component relative influence on system operability.

Components	Weights	Norm_Weights
Anchorage	80	0.089686
Basic structure	80	0.089686
Cathodic protection	1	0.001121
Control cables, <=480 V	65	0.072870
Electric motors	70	0.078475
Embedded bottom seal	25	0.028027
Gate control panel	95	0.106502
Greasing system	40	0.044843
Limit switches	45	0.050448
Operating equipment, electric components	70	0.078475
Paint system	1	0.001121
Position indicators	15	0.016816
Power cable, <= 480V	70	0.078475
Seals	25	0.028027
Operator pushbutton	50	0.056054
Lifting stem and guides	80	0.089686
Screw actuators	80	0.089686

Appendix J: Willamette Case Study Results

Table J-1. Blue River Dam system relative influence in normal operating conditions.

System	SME 01	SME 02	SME 03	SME 04	SME 05	Rank	Borda Score	Normalized Borda Score
Service discharge gates	2	1	1	1	1	1	9	0.642857143
Spillway gates	2	2	2	2	2	2	5	0.357142857

Table J-2. Blue River Dam system relative influence in flood operating conditions.

System	SME 01	SME 02	SME 03	SME 04	SME 05	Rank	Borda Score	Normalized Borda Score
Service discharge gates	1	1	1	1	1	2	6	0.375
Spillway gates	1	2	2	2	2	1	10	0.625

Table J-3. Blue River Dam service discharge gate component relative influence on system operability.

Component	SME 01	SME 02	SME 03	SME 04	SME 05	Rank	Borda Score	Normalized Borda Score
Basic structure	1	1	1	1	1	1	75	0.121555916
Control valves	4	2	5	8	9	2	52	0.084278768
Gate control panel	13	3	8	3	5	3	48	0.077795786
Seals	1	13	7	12	2	4	45	0.072933549
Embedded guides	5	6	6	14	4	5	45	0.072933549
Hydraulic piping	8	4	3	10	11	6	44	0.071312804
Hydraulic cylinder	11	5	2	11	8	7	43	0.069692058
Hydraulic hoses	9	7	4	9	9	8	42	0.068071313
Operator pushbutton	3	9	10	7	12	9	39	0.063209076
Remote control equipment	7	8	12	2	13	10	38	0.061588331
Limit switches	12	10	9	6	7	11	36	0.058346840
Position indicators	10	11	13	5	6	12	35	0.056726094
Embedded bottom seal	6	13	14	13	3	13	31	0.050243112
Control cables, <= 480V	14	12	11	4	15	14	24	0.038897893
Paint system	2	14	15	15	14	15	20	0.032414911

Table J-4. Blue River Dam spillway gate component relative influence on system operability.

Component	SME 01	SME 02	SME 03	SME 04	SME 05	Rank	Borda Score	Normalized Borda Score
Basic structure	1	1	1	2	1	1	104	0.082409
Anchorage	3	2	2	1	4	2	98	0.077655
Lifting cables	4	3	3	9	3	3	88	0.069731
Open gears	7	4	0	13	10	4	76	0.060222
Couplings	10	6	5	11	5	5	73	0.057845
Gate control panel	5	7	11	4	11	6	72	0.057052
Brakes	12	5	8	10	6	7	69	0.054675
Electric motors	17	11	7	7	2	8	66	0.052298
Limit switches	6	10	6	14	9	9	65	0.051506
Enclosed gear boxes	11	4	4	12	15	10	64	0.050713
Operating equipment, electric components	14	8	9	8	8	11	63	0.049921
Control cables, <= 480 V	18	12	0	5	17	12	58	0.045959
Embedded guides	9	9	10	20	12	13	50	0.039620
Operator pushbutton	8	17	12	3	21	14	49	0.038827
Embedded bottom seal	1	14	15	19	13	15	48	0.038035
Seals	13	14	0	17	20	16	46	0.036450
Position indicators	15	16	14	15	7	17	43	0.034073
Power cable, <= 480 V	16	15	13	6	19	18	41	0.032488
Paint system	2	19	16	21	18	19	34	0.026941
Catwalks, ladders, and platforms	19	13	18	16	14	20	30	0.023772
Greasing system	16	18	17	18	16	21	25	0.019810

Table J-5. Cottage Grove system relative influence in normal operating conditions.

[illegible]

Table J-6. Cottage Grove system relative influence in flood operating conditions.

[illegible]

Table J-7. Cottage Grove service discharge gate component relative influence on system operability.

Component	SME 01	SME 02	SME 03	SME 04	SME 05	Rank	Borda Score	Normalize Borda Score
Basic structure	1	1	1	1	1	1	75	0.115920
Anchorage	15	1	0	2	2	2	60	0.092736
Hydraulic cylinder	7	3	2	8	4	3	56	0.086553
Electric motors	2	9	8	4	3	4	54	0.083462
Hydraulic piping	6	2	3	9	6	5	54	0.083462
Hydraulic hoses	8	6	4	7	5	6	50	0.077280
Gate control panel	9	7	5	5	10	7	44	0.068006
Seals	11	9	0	13	7	8	40	0.061824
Remote control equipment	3	11	10	6	15	9	35	0.054096
Limit switches	4	13	7	12	11	10	33	0.051005
Power cable, <= 480 V	12	10	9	3	13	11	33	0.051005
Embedded guides	10	8	6	15	9	12	32	0.049459
Control cables, <= 480 V	14	10	0	10	14	13	32	0.049459
Position indicators	5	12	11	11	12	14	29	0.044822
Embedded bottom seal	13	13	12	14	8	15	20	0.030912

Table J-8. Cougar System relative influence in normal operating conditions.

System	SME 02	SME 03	SME 04	SME 05	Rank	Borda Score	Normalized Borda Score
Service discharge gates	1	1	1	1	1	8	0.666667
Spillway gates	2	2	2	2	2	4	0.333333

Table J-9. Cougar system relative influence in normal operating conditions.

System	SME 02	SME 03	SME 04	SME 05	Rank	Borda Score	Normalized Borda Score
Service discharge gates	2	2	2	2	2	4	0.333333
Spillway gates	1	1	1	1	1	8	0.666667

Table J-10. Cougar service discharge gate component relative influence on system operability.

Component	SME 01	SME 02	SME 03	SME 04	SME 05	Rank	Borda Score	Normalized Borda Score
Anchorage	0	1	0	2	2	1	80	0.093786635
Basic structure	2	1	1	1	1	2	79	0.092614302
Hydraulic piping	0	2	3	7	6	3	67	0.078546307
Hydraulic hoses	0	4	4	6	5	4	66	0.077373974
Hydraulic cylinder	6	3	2	8	4	5	62	0.072684642
Lifting stem and guides	0	5	0	16	3	6	61	0.071512309

Table J-10 (cont.). Cougar service discharge gate component relative influence on system operability.

Component	SME 01	SME 02	SME 03	SME 04	SME 05	Rank	Borda Score	Normalized Borda Score
Gate control panel	0	6	5	4	15	7	55	0.064478312
Embedded guides	0	7	6	11	7	8	54	0.063305979
Seals	0	14	0	9	9	9	53	0.062133646
Remote control equipment	1	10	11	3	13	10	47	0.055099648
Couplings	0	5	7	15	14	11	44	0.051582649
Operator pushbutton	0	13	10	5	16	12	41	0.048065651
Position indicators	4	11	9	10	12	13	39	0.045720985
Limit switches	3	12	8	13	10	14	39	0.045720985
Embedded bottom seal	0	14	12	12	8	15	39	0.045720985
Paint system	5	15	13	14	11	16	27	0.031652989

Table J-11. Cougar spillway gate component relative influence on system operability.

Component	SME 02	SME 03	SME 04	SME 05	Rank	Borda Score	Normalized Borda Score
Basic structure	1	1	2	1	1	79	0.086338798
Anchorage	2	2	1	2	2	77	0.084153005
Lifting cables	3	3	8	4	3	66	0.072131148
Operating equipment, electric components	8	0	7	5	4	64	0.069945355
Gate control panel	7	9	4	6	5	58	0.063387978
Electric motors	9	8	6	3	6	58	0.063387978
Brakes	5	7	9	10	7	53	0.057923497
Enclosed gear boxes	4	4	11	12	8	53	0.057923497
Couplings	6	6	10	11	9	51	0.055737705
Open gears	4	5	12	13	10	50	0.054644809
Seals	14	0	17	9	11	44	0.048087432
Operator pushbutton	17	0	3	20	12	44	0.048087432
Limit switches	11	10	14	7	13	42	0.045901639
Power cable, <= 480 V	10	13	5	19	14	37	0.040437158
Control cables, <= 480 V	12	11	13	15	15	33	0.036065574
Position indicators	15	15	16	8	16	30	0.032786885
Catwalks, ladders, and platforms	13	16	15	14	17	26	0.028415301
Embedded guides	14	12	19	16	18	23	0.025136612
Greasing system	18	14	18	17	19	17	0.018579235
Paint system	19	17	20	18	20	10	0.010928962

Table J-12. Detroit system relative influence in normal operating conditions.

System	SME 02	SME 03	SME 04	SME 05	Rank	Borda Score	Normalized Borda Score
Service Discharge Gates	1	1	1	1	1	8	0.666666667
Spillway Gates	2	2	2	2	2	4	0.333333333

Table J-13. Detroit system relative influence in flood operating conditions.

System	SME 02	SME 03	SME 04	SME 05	Rank	Borda Score	Normalized Borda Score
Spillway Gates	1	1	1	1	1	8	0.666666667
Service Discharge Gates	2	2	2	2	2	4	0.333333333

Table J-14. Detroit service discharge gate component relative influence on system operability.

Component	SME 02	SME 03	SME 04	SME 05	Rank	Borda Score	Normalized Borda Score
Basic structure	1	1	1	1	1	88	0.082940622
Operating equipment, hydraulic components	2	4	6	4	2	76	0.071630537
Hydraulic piping	3	3	9	7	3	70	0.065975495
Hydraulic cylinder	4	2	10	6	4	70	0.065975495
Anchorage	7	12	2	2	5	69	0.065032988
Electric motors	12	10	5	3	6	62	0.058435438
Operating equipment, electric Components	14	8	8	5	7	57	0.053722903
Embedded guides	8	7	19	8	8	50	0.047125353
Local operating controls	16	9	7	10	9	50	0.047125353
Control cables, <= 480 V	3	13	11	17	10	48	0.045240339
Couplings	6	5	21	14	11	46	0.043355325
Lifting stem and guides	5	6	22	15	12	44	0.041470311
Cathodic protection	0	21	15	16	13	40	0.037700283
Limit switches	11	11	18	12	14	40	0.037700283
Power cable, <= 480 V	13	15	4	20	15	40	0.037700283
Greasing system	0	20	14	19	16	39	0.036757776
Operator pushbutton	15	14	3	22	17	38	0.035815269
Gaskets	10	19	12	18	18	33	0.031102733
Seals	19	17	16	9	19	31	0.029217719
Position indicators	18	16	17	11	20	30	0.028275212
Remote control equipment	17	18	13	21	21	23	0.021677663
Paint system	20	22	20	13	22	17	0.016022620

Table J-15. Detroit spillway gate component relative influence on system operability.

Component	SME 02	SME 03	SME 04	SME 05	Rank	Borda Score	Normalized Borda Score
Basic structure	1	1	2	1	1	83	0.085655315
Anchorage	2	2	1	2	2	81	0.083591331
Lifting cables	3	3	8	3	3	71	0.073271414
Electric motors	11	8	6	4	4	59	0.060887513
Operating equipment, electric components	8	9	7	5	5	59	0.060887513
Brakes	5	7	9	13	6	54	0.055727554
Enclosed gear boxes	4	4	11	15	7	54	0.055727554
Power cable, <= 480 V	10	13	5	7	8	53	0.054695562
Seals	13	0	13	9	9	53	0.054695562
Couplings	6	6	10	14	10	52	0.053663571
Open gears	4	5	12	16	11	51	0.052631579
Gate control panel	7	10	4	20	12	47	0.048503612
Limit switches	14	11	14	8	13	41	0.042311662
Operator pushbutton	17	12	3	19	14	37	0.038183695
Embedded guides	9	14	20	11	15	34	0.035087719
Position indicators	15	17	16	6	16	34	0.035087719
Embedded bottom seal	13	16	19	10	17	30	0.030959752
Catwalks, ladders, and platforms	12	18	17	17	18	24	0.024767802
Greasing system	18	19	18	12	19	21	0.021671827
Remote control equipment	16	15	15	21	20	21	0.021671827
Paint system	19	20	21	18	21	10	0.010319917

Table J-16. Dorena system relative influence in normal operating conditions.

[illegible]

Table J-17. Dorena system relative influence in flood operating conditions.

[illegible]

Table J-18. Dorena service discharge gate component relative influence on system operability.

Component	SME 02	SME 03	SME 04	SME 05	Rank	Borda Score	Normalized Borda Score
Basic structure	1	1	1	1	1	60	0.109289617
Anchorage	1	0	2	2	2	59	0.107468124
Hydraulic piping	2	3	9	4	3	46	0.083788707
Control valves	3	4	8	5	4	44	0.080145719
Hydraulic cylinder	5	2	10	3	5	44	0.080145719
Control cables, <= 480 V	4	0	11	12	6	37	0.067395264
Gate control panel	7	6	7	10	7	34	0.061930783
Operating equipment, electric components	8	5	6	11	8	34	0.061930783
Operator pushbutton	12	0	3	15	9	34	0.061930783
Seals	13	0	12	6	10	33	0.060109290
Embedded guides	6	7	15	7	11	29	0.052823315
Power cable, <= 480 V	9	8	5	13	12	29	0.052823315
Remote control equipment	10	9	4	14	13	27	0.049180328
Position indicators	11	10	13	9	14	21	0.038251366
Embedded bottom seal	13	11	14	8	15	18	0.032786885

Table J-19. Fall Creek system relative influence in normal operating conditions.

System	SME 01	SME 02	SME 03	SME 04	SME 05	Rank	Borda Score	Normalized Borda Score
Service discharge gates	1	1	1	1	1	1	10	0.666666667
Spillway gates	2	2	2	2	2	2	5	0.333333333

Table J-20. Fall Creek system relative influence in flood operating conditions.

System	SME 01	SME 02	SME 03	SME 04	SME 05	Rank	Borda Score	Normalized Borda Score
Service discharge gates	2	2	2	2	2	2	5	0.333333333
Spillway gates	1	1	1	1	1	1	10	0.666666667

Table J-21. Fall Creek service discharge gate component relative influence on system operability.

Component	SME 02	SME 03	SME 04	SME 05	Rank	Borda Score	Normalized Borda Score
Basic structure	1	1	1	1	1	44	0.160000000
Hydraulic cylinder	3	2	7	2	2	34	0.123636364
Hydraulic piping	2	3	6	4	3	33	0.120000000
Hydraulic hoses	7	4	5	3	4	29	0.105454545
Gate control panel	4	5	4	7	5	28	0.101818182
Control cables, <= 480 V	5	0	8	8	6	27	0.098181818

Table J-12 (cont.). Fall Creek service discharge gate component relative influence on system operability.

Component	SME 02	SME 03	SME 04	SME 05	Rank	Borda Score	Normalized Borda Score
Embedded guides	6	6	10	6	7	20	0.072727273
Power cable, <= 480 V	8	7	3	10	8	20	0.072727273
Remote control equipment	9	8	2	11	9	18	0.065454545
Embedded bottom seal	11	10	9	5	10	13	0.047272727
Position indicators	10	9	11	9	11	9	0.032727273

Table J-22. Fall Creek spillway gate component relative influence on system operability.

Component	SME 02	SME 03	SME 04	SME 05	Rank	Borda Score	Normalized Borda Score
Basic structure	1	1	2	1	1	63	0.106779661
Anchorage	2	2	1	2	2	61	0.103389831
Lifting cables	3	3	4	4	3	54	0.091525424
Enclosed gear boxes	4	4	10	7	4	43	0.072881356
Brakes	5	7	9	5	5	42	0.071186441
Electric motors	11	8	6	3	6	40	0.067796610
Open gears	4	5	11	8	7	40	0.067796610
Couplings	6	6	12	6	8	38	0.064406780
Operating equipment, electric components	8	9	3	11	9	37	0.062711864
Seals	12	0	15	9	10	32	0.054237288
Operator pushbutton	14	0	7	16	11	31	0.052542373
Power cable, <= 480 V	10	12	5	12	12	29	0.049152542
Control cables, <= 480 V	7	10	8	15	13	28	0.047457627
Embedded guides	9	11	14	13	14	21	0.035593220
Position indicators	13	13	16	10	15	16	0.027118644
Embedded bottom seal	12	14	13	14	16	15	0.025423729

Table J-23. Fern Ridge system relative influence in normal operating conditions.

System	SME 01	SME 02	SME 03	SME 04	SME 05	Rank	Borda Score	Normalized Borda Score
Service discharge gates	1	1	1	1	1	1	10	0.666666667
Spillway gates	2	2	2	2	2	2	5	0.333333333

Table J-24. Fern Ridge system relative influence in flood operating conditions.

System	SME 01	SME 02	SME 03	SME 04	SME 05	Rank	Borda Score	Normalized Borda Score
Service discharge gates	2	2	2	2	2	2	5	0.333333333
Spillway gates	1	1	1	1	1	1	10	0.666666667

Table J-25. Fern Ridge service discharge gate component relative influence on system operability.

Component	SME 02	SME 03	SME 04	SME 05	Rank	Borda Score	Normalized Borda Score
Basic structure	1	1	1	1	1	56	0.125000000
Anchorage	2	0	2	2	2	54	0.120535714
Hydraulic cylinder	5	2	7	3	3	43	0.095982143
Hydraulic piping	3	3	9	5	4	40	0.089285714
Hydraulic hoses	7	4	8	4	5	37	0.082589286
Control cables, <= 480 V	4	5	6	12	6	33	0.073660714
Power Cable, <= 480V	8	8	4	10	7	30	0.066964286
Embedded Guides	6	6	11	8	8	29	0.064732143
Seals	13	0	14	6	9	27	0.060267857
Remote Control Equipment	9	10	3	13	10	25	0.055803571
Limit Switches	11	7	12	9	11	21	0.046875000
Operator Pushbutton	12	9	5	14	12	20	0.044642857
Embedded Bottom Seal	13	12	10	7	13	18	0.040178571
Position Indicators	10	11	13	11	14	15	0.033482143

Table J-26. Fern Ridge spillway gate component relative influence on system operability.

Component	SME 02	SME 03	SME 04	SME 05	Rank	Borda Score	Normalized Borda Score
Basic structure	1	1	1	1	1	48	0.147692308
Lifting cables	2	2	7	3	2	38	0.116923077
Electric motors	7	3	5	2	3	35	0.107692308
Enclosed gear boxes	3	4	6	5	4	34	0.104615385
Operating equipment, Electric components	5	5	4	4	5	34	0.104615385
Power cable, <= 480 V	6	9	2	10	6	25	0.076923077
Embedded guides	4	8	9	7	7	24	0.073846154
Operator pushbutton	8	6	3	12	8	23	0.070769231
Seals	11	0	10	11	9	20	0.061538462
Embedded bottom seal	11	10	8	8	10	15	0.046153846
Position indicators	9	11	11	6	11	15	0.046153846
Limit switches	10	7	12	9	12	14	0.043076923

Table J-31. Green Peter system relative influence in flood operating conditions.

System	SME 01	SME 02	SME 03	SME 04	SME 05	SME 06	Rank	Borda Score	Normalized Borda Score
Service discharge gates	2	2	2	2	2	2	2	6	0.3333333333
Spillway gates	1	1	1	1	1	1	1	12	0.6666666667

Table J-32. Green Peter service discharge gate component relative influence on system operability.

Component	SME 02	SME 03	SME 04	SME 05	SME 06	Rank	Borda Score	Normalized Borda Score
Basic structure	1	1	1	1	11	1	60	0.112149533
Anchorage	1	2	2	2	10	2	58	0.108411215
Hydraulic cylinder	3	3	6	3	5	3	55	0.102803738
Gate control panel	2	7	4	9	1	4	52	0.097196262
Hydraulic piping	1	4	8	5	6	5	51	0.095327103
Hydraulic hoses	7	5	7	4	7	6	45	0.084112150
Operating equipment, electric components	8	6	3	11	2	7	45	0.084112150
Operator pushbutton	9	8	5	14	8	8	31	0.057943925
Embedded guides	5	9	12	7	12	9	30	0.056074766
Limit switches	11	10	10	10	4	10	30	0.056074766
Position indicators	10	11	9	12	3	11	30	0.056074766
Seals	12	14	13	6	9	12	21	0.039252336
Embedded bottom seal	12	12	11	8	13	13	19	0.035514019
Paint system	13	13	14	13	14	14	8	0.014953271

Table J-33. Green Peter spillway gate component relative influence on system operability.

Component	SME 02	SME 03	SME 04	SME 05	SME 06	Rank	Borda Score	Normalized Borda Score
Basic structure	1	1	2	1	15	1	80	0.082644628
Anchorage	2	2	1	2	14	2	79	0.081611570
Electric motors	10	8	8	3	3	3	68	0.070247934
Operating equipment, electric components	11	9	4	5	4	4	67	0.069214876
Lifting cables	3	3	13	4	12	5	65	0.067148760
Brakes	5	7	9	7	8	6	64	0.066115702
Gate control panel	7	10	6	12	1	7	64	0.066115702
Enclosed gear boxes	4	5	11	9	9	8	62	0.064049587
Open gears	4	4	12	10	10	9	60	0.061983471
Couplings	6	6	10	8	11	10	59	0.060950413
Control cables, <= 480 V	8	11	5	18	2	11	56	0.057851240
Power cable, <= 480 V	9	13	3	17	6	12	52	0.053719008

Table J-33 (cont.). Green Peter spillway gate component relative influence on system operability.

Component	SME 02	SME 03	SME 04	SME 05	SME 06	Rank	Borda Score	Normalized Borda Score
Position indicators	13	14	7	15	7	13	44	0.045454545
Limit switches	14	12	16	14	5	14	39	0.040289256
Seals	15	19	15	6	13	15	32	0.033057851
Embedded bottom seal	15	15	17	11	18	16	24	0.024793388
Catwalks, ladders, and platforms	12	16	14	19	16	17	23	0.023760331
Greasing system	16	17	18	13	17	18	19	0.019628099
Paint system	17	18	19	16	19	19	11	0.011363636

Table J-34. Hills Creek system relative influence in normal operating conditions.

System	SME 01	SME 02	SME 03	SME 04	SME 05	Rank	Borda Score	Normalized Borda Score
Service discharge gates	1	1	1	1	1	1	10	0.666666667
Spillway gates	2	2	2	2	2	2	5	0.333333333

Table J-35. Hills Creek system relative influence in flood operating conditions.

System	SME 01	SME 02	SME 03	SME 04	SME 05	Rank	Borda Score	Normalized Borda Score
Service discharge gates	2	2	2	2	2	2	5	0.333333333
Spillway gates	1	1	1	1	1	1	10	0.666666667

Table J-36. Hills Creek service discharge gate component relative influence on system operability.

Component	SME 01	SME 02	SME 03	SME 04	SME 05	Rank	Borda Score	Normalized Borda Score
Basic structure	3	1	1	1	1	1	98	0.074866310
Anchorage	0	1	2	2	2	2	98	0.074866310
Hydraulic hoses	7	0	0	8	4	3	86	0.065699007
Hydraulic cylinder	5	3	2	10	3	4	82	0.062643239
Hydraulic piping	6	2	3	9	5	5	80	0.061115355
Gate control panel	2	4	5	5	12	6	77	0.058823529
Operating equipment, electric components	8	5	4	4	11	7	73	0.055767762
Remote control equipment	1	7	10	3	19	8	65	0.049656226
Brakes	20	0	0	17	6	9	62	0.047364400
Couplings	19	0	0	18	7	10	61	0.046600458
Enclosed gear boxes	18	0	0	19	8	11	60	0.045836516
Open gears	17	0	0	20	9	12	59	0.045072574
Embedded guides	10	6	6	11	13	13	59	0.045072574

Table J-36 (cont.). Hills Creek service discharge gate component relative influence on system operability.

Component	SME 01	SME 02	SME 03	SME 04	SME 05	Rank	Borda Score	Normalized Borda Score
Seals	11	11	0	15	10	14	58	0.044308633
Position indicators	8	8	9	6	18	15	56	0.042780749
Limit switches	9	9	7	13	16	16	51	0.038961039
Operator pushbutton	12	10	8	7	20	17	48	0.036669213
Greasing system	16	12	0	16	15	18	46	0.035141329
Paint system	3	13	12	14	17	19	46	0.035141329
Embedded bottom seal	13	11	11	12	14	20	44	0.033613445

Table J-37. Hills Creek spillway gate component relative influence on system operability.

Component	SME 02	SME 03	SME 04	SME 05	Rank	Borda Score	Normalized Borda Score
Basic structure	1	1	2	1	1	79	0.085869565
Anchorage	2	2	1	2	2	77	0.083695652
Lifting cables	3	3	12	4	3	62	0.067391304
Brakes	5	6	9	6	4	58	0.063043478
Enclosed gear boxes	4	4	10	8	5	58	0.063043478
Electric motors	10	7	7	3	6	57	0.061956522
Couplings	6	5	11	7	7	55	0.059782609
Seals	12	0	14	5	8	53	0.057608696
Open gears	4	0	20	9	9	51	0.055434783
Gate control panel	8	9	6	12	10	49	0.053260870
Operating equipment, electric components	11	8	3	15	11	47	0.051086957
Power cable, <= 480 V	9	12	4	18	12	41	0.044565217
Greasing system	17	0	16	13	13	38	0.041304348
Embedded guides	7	13	17	11	14	36	0.039130435
Position indicators	13	14	5	17	15	35	0.038043478
Operator pushbutton	14	10	8	20	16	32	0.034782609
Limit switches	15	11	15	14	17	29	0.031521739
Embedded bottom seal	12	15	18	10	18	29	0.031521739
Catwalks, ladders, and platforms	16	16	13	19	19	20	0.02173913
Paint system	18	17	19	16	20	14	0.015217391

Table J-38. Lookout Point system relative influence in normal operating conditions.

System	SME 01	SME 02	SME 03	SME 04	Rank	Borda Score	Normalized Borda Score
Service discharge gates	2	1	1	1	1	7	0.583333333
Spillway gates	1	2	2	2	2	5	0.416666667

Table J-39. Lookout Point system relative influence in flood operating conditions.

System	SME 01	SME 02	SME 03	SME 04	Rank	Borda Score	Normalized Borda Score
Spillway gates	1	1	1	1	1	8	0.666666667
Service discharge gates	2	2	2	2	2	4	0.333333333

Table J-40. Lookout Point service discharge gate component relative influence on system operability.

Component	SME 02	SME 03	SME 04	SME 05	Rank	Borda Score	Normalized Borda Score
Basic structure	1	1	1	1	1	64	0.109965636
Anchorage	2	2	2	2	2	60	0.103092784
Hydraulic cylinder	3	3	8	3	3	51	0.087628866
Hydraulic piping	4	4	7	5	4	48	0.082474227
Hydraulic hoses	8	5	6	4	5	45	0.077319588
Gate control panel	5	7	5	8	6	43	0.073883162
Operating equipment, electric components	6	6	3	10	7	43	0.073883162
Operator pushbutton	12	0	4	14	8	38	0.065292096
Embedded guides	7	9	12	7	9	33	0.056701031
Limit switches	11	8	10	9	10	30	0.051546392
Seals	13	0	15	13	11	27	0.046391753
Embedded bottom seal	13	12	11	6	12	26	0.044673540
Position indicators	10	11	9	12	13	26	0.044673540
Remote control equipment	9	10	14	11	14	24	0.041237113
Greasing system	14	10	13	16	15	15	0.025773196
Paint system	15	13	16	15	16	9	0.015463918

Table J-41. Lookout Point spillway gate component relative influence on system operability.

Component	SME 02	SME 03	SME 04	SME 05	Rank	Borda Score	Normalized Borda Score
Basic structure	1	1	2	1	1	83	0.083669355
Anchorage	2	2	1	2	2	81	0.081653226
Lifting cables	3	3	11	3	3	68	0.068548387
Enclosed gear boxes	4	4	9	8	4	63	0.063508065
Brakes	5	7	8	6	5	62	0.062500000

Table J-41 (cont.). Lookout Point spillway gate component relative influence on system operability.

Component	SME 02	SME 03	SME 04	SME 05	Rank	Borda Score	Normalized Borda Score
Open gears	4	5	10	9	6	60	0.060483871
Electric motors	11	8	7	4	7	58	0.058467742
Couplings	6	6	13	7	8	56	0.056451613
Operating equipment, electric components	10	9	4	10	9	55	0.055443548
Seals	12	0	20	5	10	51	0.051411290
Gate control panel	8	10	6	13	11	51	0.051411290
Operator pushbutton	14	0	5	20	12	49	0.049395161
Power cable, <= 480 V	10	13	3	19	13	43	0.043346774
Control cables, <= 480 V	9	11	12	15	14	41	0.041330645
Embedded guides	7	14	18	12	15	37	0.037298387
Limit switches	16	12	15	17	16	28	0.028225806
Embedded bottom seal	17	17	17	11	17	26	0.026209677
Position indicators	15	15	14	18	18	26	0.026209677
Catwalks, ladders, and platforms	13	18	16	16	19	25	0.025201613
Greasing system	18	16	19	14	20	21	0.021169355
Paint system	19	19	21	21	21	8	0.008064516

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14. ABSTRACT The US Army Corps of Engineers (USACE) operates, maintains, and man-ages over 700 dams and 4,000 miles of levees, providing approximately \$257 billion worth of economic benefit to the Nation. USACE employs the Operational Condition Assessment (OCA) process to understand the condition of those assets and allocate resources to minimize risk associated with performance degradation. Understanding risk in flood risk management (FRM) assets requires an understanding of consequence of asset failure from a system-wide FRM watershed perspective and an understanding of likelihood of degradation based on the condition of the low-level components derived from OCA ratings. This research demonstrates a case-study application of a scalable methodology to model the likelihood of a dam performing as expected given the state of its gates and their components. The research team combines this likelihood of degradation with consequences generated by the application of designed simulation experiments with hydrological models to develop risk measures. These risk measures can be developed for all FRM gate assets in order to enable traceable, consistent resource allocation decisions. Two case study applications are provided.					
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