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Condition Assessment Methodology for Spillways

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and Ralph Wittebolle

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Abstract: The U.S. Army Corps of Engineers (USACE) has primary responsibility for maintaining and operating U.S. navigable waterways and Federal flood control dams. Dam safety is a critical priority, but assessment and prioritization of dam safety concerns is difficult. This report describes a condition assessment and prioritization methodology for structural, mechanical, electrical, and operational aspects of spillways. The methodology was developed to help provide a firmer engineering basis for prioritization and decision making. The method described herein is less rigorous than conventional reliability-based risk assessment approaches. As a lower cost option it can be used as a preliminary method, a replacement, or an enhancement of conventional reliability-based assessment approaches, depending on the circumstances. Current Headquarters USACE policy for portfolio risk assessment for the dam and levee safety programs is to use the reliability-based risk assessment approach.

The methodology described herein uses visual inspection data in combination with spillway function and component importance criteria to develop priority rankings. The rankings reflect the condition ratings for the spillway and its subcomponents and also indicate the significance of any deficiencies. Although the rankings assist in budget prioritization, they are not intended for use as the sole criterion for maintenance and repair of spillways. This methodology is one of several that engineers and managers of spillways and other Civil Works infrastructure can use to help maintain their infrastructure.

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Preface

This work was supported by the Flood and Coastal Storm Damage Reduction R&D Program, O&M Management Tools Program, and Risk Analysis for Dam Safety R&D Program.

The work was performed by the Materials and Structures Branch (CF-M) of the Facilities Division (CF), U.S. Army Engineer Research and Development Center – Construction Engineering Research Laboratory (ERDC-CERL). The project manager was Stuart Foltz. At the time of publication, Vicki Van Blaricum was Chief, CF-M, L. Michael Golish was Chief, CF, and Martin J. Savoie was the Technical Director for Installations. The Deputy Director of ERDC-CERL was Dr. Kirankumar V. Topudurti and the Director was Dr. Ilker R. Adiguzel.

Portions of this work were conducted under a Cooperative Research and Development Agreement (CRADA) for Condition and Risk Evaluation of Spillways between ERDC-CERL and Hydro-Québec, Montréal Québec, dated 4 August 2000.

The participation of Hydro-Québec, Manitoba-Hydro, Ontario Power Generation, and the U.S. Bureau of Reclamation (USBR) is acknowledged in the development of the Condition Indexing Procedure for Spillways. The following individuals are acknowledged with gratitude:

Hydro-Québec: André Chouinard, Pierre Cormier, Claude Lemire, Joel Maniez, and Roland Ouellet; *Manitoba Hydro*: Terry Armstrong; *Ontario Power Generation*: Mona Bechai, Klaus Faisst, and Aldo Garro; *USACE*: Robert Fulton, Steve Graff, Tommy Papageorge, Robert Patev, Billy Randolph; *USBR*: Robert Todd; *Burns Cooley, and Dennis, Inc*: Glen R. Andersen; *McGill University*: Alejandro de la Puente and William Lim.

The Commander and Executive Director of ERDC was COL Richard B. Jenkins, and the Director was Dr. James R. Houston.

Unit Conversion Factors

Multiply	By	To Obtain
acres	4,046.873	square meters
cubic feet	0.02831685	cubic meters
cubic inches	1.6387064 E-05	cubic meters
degrees (angle)	0.01745329	radians
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
feet	0.3048	meters
gallons (U.S. liquid)	3.785412 E-03	cubic meters
horsepower (550 foot-pounds force per second)	745.6999	watts
inches	0.0254	meters
kips per square foot	47.88026	kilopascals
kips per square inch)	6.894757	megapascals
miles (U.S. statute)	1,609.347	meters
pounds (force)	4.448222	newtons
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.45359237	kilograms
square feet	0.09290304	square meters
square miles	2.589998 E+06	square meters
tons (force)	8,896.443	newtons
tons (2,000 pounds, mass)	907.1847	kilograms
tons (2,000 pounds, mass) per square foot	9,764.856	kilograms per square meter
yards	0.9144	meters

1 Introduction

Background

An analysis of embankment dam failure statistics worldwide by the International Commission on Large Dams (ICOLD) indicates that the most frequent mode of failure of dams is due to overtopping (ICOLD 1995). Failure to properly operate the spillway structure is due either to equipment or operational deficiencies. Spillway deficiencies may be associated either with poor original design or gradual deterioration.

Methodologies for objectively quantifying the condition of spillway components and evaluating their relative importance in terms of spillway safety or other operations are currently being developed. Such information is critical for effective prioritization and allocation of resources for spillway operations and maintenance budgets. Spillway component condition is also an important aspect of determining the probability of component failure within a risk analysis. Spillway failure rate information is very limited for most components and is highly dependent on condition. Developing a systematic process for quantifying component condition can be a first step toward understanding how component condition influences failure rates, and would offer the following benefits:

- provides a means to easily characterize each facility in its current state
- enables tracking the development of component condition as a function of time
- is readily integrated into existing periodic inspection cycles using the component condition tables to guide the inspection process
- can easily be interpreted or summarized in different ways to describe the nature of spillway deficiencies for various purposes
- describes conditions in a way that can be communicated easily to decision-makers who are non-specialists in civil engineering and operations
- provides insight into the inspection and evaluation process
- standardizes and facilitates inspection procedures and promotes consistency of inspection reports
- enables transfer of quantified measures of deterioration for purposes of failure rate estimation and risk analysis

- creates an orderly hierarchy for a structural system where the contributions of all subsystems and components are visible to the analyst
- allows an infrastructure manager to systematically add or delete variables that are relevant to the condition of the structure.

Objective

The objective of this project was to develop a methodology to evaluate the condition of spillway gate systems relative to dam safety functions and to assist in the prioritization of maintenance activities.

Approach

The procedure described in this report is based on the condition indexing methodology first developed by the United States Army Corps of Engineers (USACE) for pavements and adopted in the USACE Repair, Evaluation, Maintenance, and Rehabilitation (REMR) research program for Civil Works (i.e., water resource infrastructure). The USACE methodology was modified and adapted under a Cooperative Research and Development Agreement (CRADA) for Condition and Risk Evaluation of Spillways between U.S. Army Engineer Research and Development Center Construction Engineering Research Laboratory (ERDC-CERL) and Hydro-Québec, dated 4 August 2000. The purpose of the CRADA was to develop a condition indexing procedure for embankment dams (Robichaud et al. 2000; Chouinard et al. 1998; Andersen and Torrey 1995).

In the procedure documented here, priority rankings are established as a function of the relative importance and current condition of spillway components. Importance factors are obtained by identifying the main dam safety concerns relative to the operation of a given spillway and the criticality of each component to preventing failure. Redundant components are considered to increase the reliability of a system and should be properly identified. For example, a facility equipped with an emergency power supply is inherently more reliable than a facility without one. Similarly, components that can potentially be the common source for the same mode of failure for several gates (e.g., a non-dedicated hoist used to operate several gates) should be properly identified and weighted. Certain other types of components such as roads, monitoring systems, and telecommunication systems that are shared by several facilities in the same river basin also can be potential common modes of failure.

Condition assessment tables are developed for each component with the participation of an expert panel that has experience with the inspection and condition assessment of the component. The condition of a component is inferred through comparison with a list of qualitative or quantitative indicators with commentary that have meaningful diagnostic value relative to the component's level of performance. Observations pertaining to the indicators are obtained from detailed periodic inspections or from up-to-date evaluation reports. The component condition rating is based on a scale of 0 – 100, with 100 being excellent condition and 0 being failed condition.

The spillway condition indexing procedure is based on a systemic representation of the spillway (Figure 1.1). At each level, subordinate nodes are connected to a common parent node. Importance factors are assigned to the subordinate nodes as a function of the relative impact of the subordinate node on the performance of the parent node. At each level, a summation of the importance factors assigned to subordinate nodes must equal 1.

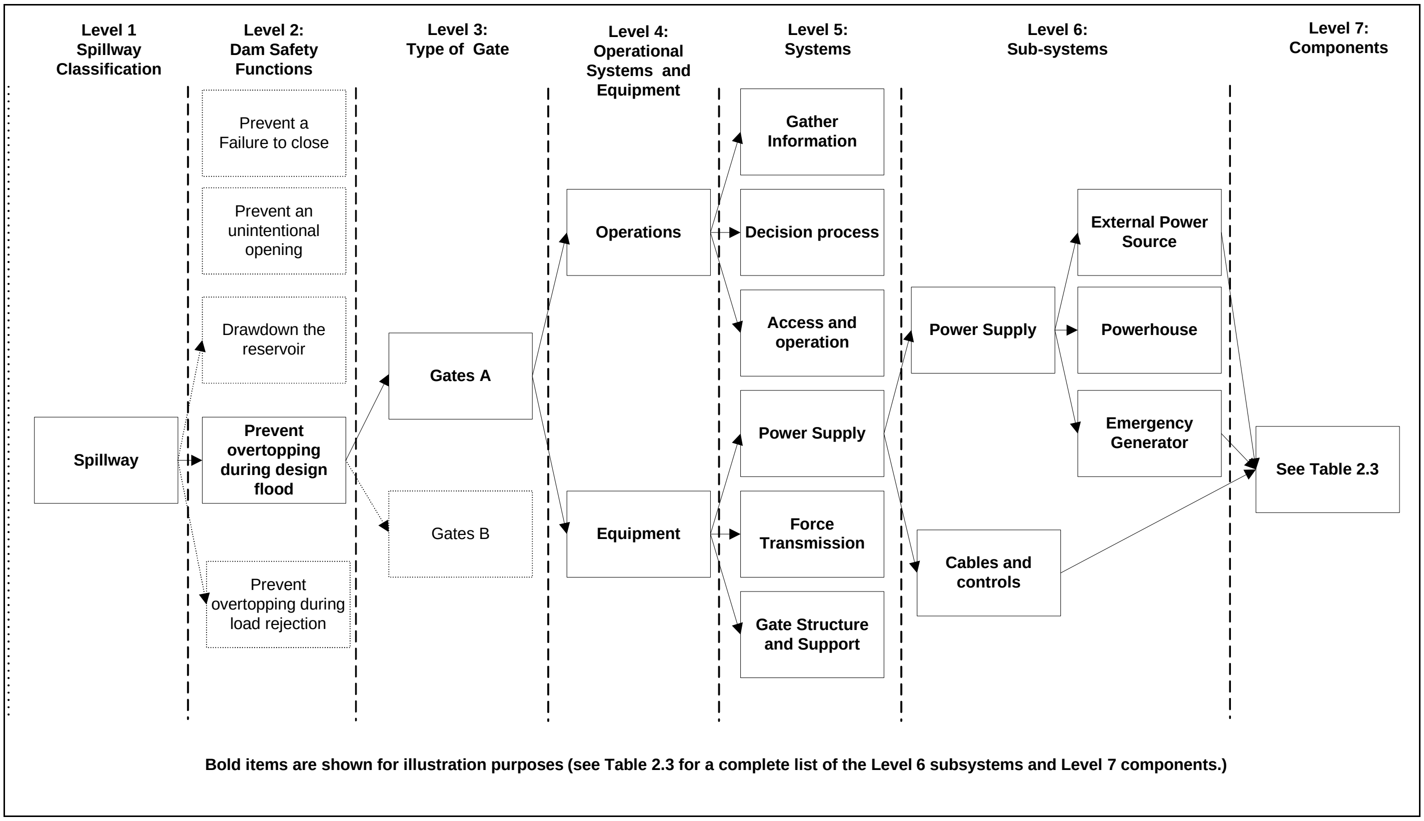


Figure 1.1. Systemic representation of a spillway.

The components at the lowest level of the system hierarchy correspond to the smallest units that are inspected and evaluated in a routine inspection of the facility. The rating of subsystems at higher levels in the overall system can be obtained through a weighted summation of the condition of subordinate elements at the immediately lower hierarchical level.

Scope

Spillways are defined as “structures over or through which flood flows are discharged” (ICOLD 1995). The procedure presented in this report was developed for spillways with vertical lift gates, stoplogs, and tainter (radial) gates since these are the most prevalent for the participants in this research. In the application of the condition indexing procedure, dam safety functions of the spillways were the main focus, but the procedure could be adapted to facilities where the economic functions (i.e., power generation, flood control, irrigation, navigation, recreation) of the spillway dominate. The spillway is evaluated relative to its current flow capacity and deficiencies are related to deterioration that can be addressed through maintenance and repair. Inadequate spilling capacity has not been addressed in the current project but could be included in future development of the procedure. Both equipment and operational deficiencies have been addressed. Rankings provided by the procedure assist in the identification of major deficiencies of the spillways. The final selection of remedial actions and maintenance activities should include this ranking within a comprehensive asset management program.

The methods described in this report represent the results of research by the authors. The methods herein are presented as a matter of record and made available to the dam safety community for their consideration. Publication does not imply endorsement by HQUSACE. Current HQUSACE policy for portfolio risk assessment for the dam and levee safety programs is to use the reliability-based risk assessment approach.

Mode of technology transfer

It is recommended that the inspection procedures developed in this study for operating equipment be incorporated into Engineer Regulation (ER) 1110-2-100, *Periodic Inspection and Continuing Evaluation of Completed Civil Works Structures*.

Participants

The participants in this research represent both electric utilities and government agencies. Hydro-Québec, Manitoba Hydro, and Ontario Power Generation are government-owned utilities in Canada that rely on hydroelectric facilities for power generation. USACE is a major command of the U.S. Army that manages water resource infrastructure used for navigation, irrigation, water supply, recreation, wildlife preservation, flood control, and production of electricity throughout the United States. The U.S. Bureau of Reclamation is a Federal agency that manages hydraulic facilities in the central and western United States for flood control, water supply, irrigation, and production of electricity.

The operational modes for dams and spillways differ among the participants. Hydroelectric facilities usually are operated close to their maximum levels in order to maximize power generation. Flood control and irrigation dams are not normally operated at high pool levels, and some spillways have never been operated under flow.

Definitions

Access and operation: Systems and equipment for accessing on-site or remotely controlled gates.

Condition index: A scoring system ranging from 0 (failed) and 100 (excellent) that rates the relative level of performance of a component or a system.

Decision process: Procedures and administrative responsibilities for the operation of spillway gates.

Design flood: Full spilling capacity of a spillway.

Drawdown of the reservoir: Ability to reduce the reservoir pool level to prevent a structural failure of the dam or foundation.

Failure to close a gate: Failure to close a gate due to equipment failure or failure to recognize the need to close a gate due to inaccurate information.

Force transmission: Mechanical systems for positioning and lifting the gates

Gates operated on site: Gates that can only be operated through on-site controls.

Gate structure and supports: Substructures and superstructures for supporting the gates and lifting apparatus. The gate structure includes supporting members as well as the plate.

Gate with dedicated lifting device: Gate that is operated with its own lifting system.

Gates with shared lifting device: Gates that are operated with a shared lifting device.

Gates with negative downstream impacts: Gates that, when operated, cause erosion, scouring, or damage to structures.

Gather information: Systems and devices used to forecast and measure inflows in the river basin.

Heated gates: Gates that need to be available during winter months.

Load rejection: Term for when a powerhouse goes offline.

Load rejection flow: Powerhouse flow during load rejection.

Opening time: Length of time measured from the start of the opening sequence to the full opening of a gate.

Power supply: Electrical equipment for the generation and transmission of electricity to the various components of the spillway.

Reaction time: Time required for the operation of a gate starting from the identification of the initiating event up to the start of the opening sequence for the gate.

Remotely controlled gate: Gate that does not require personnel on site for the gate to be operated.

Spillway: A structure over or through which flood flows are discharged.

Total operation time: The summation of the reaction and opening time.

Unheated gates: Gates that do not need to be available during winter months.

Unintentional opening: Structural failure of a gate (blowout) or unintended opening of gate due to inaccurate information or a failure of automatic controls.

2 Determination of Component Importance

A component importance factor between 0 and 100% is assigned to each item within a level. The sum of the importance factors at a given level of the system must be 100% and a precision of 5% is usually considered to be adequate. This assessment is spillway-specific and should be conducted in consultation with personnel familiar with the facility.

Spillway importance (Level 1)

A classification system is used to rank the importance of spillways relative to each other ***(I[Spillway])***. Most dam owners already have a classification system for their facilities, and that can be modified for the purposes of this procedure.

Dam safety functions importance (Level 2) (I[DSF])

Evaluation of the importance of deficiencies for a spillway is performed relative to its dam safety functions. Five dam safety functions have been identified in the project and are described in Table 2.1.

Table 2.1. Definitions of dam safety functions.

Dam Safety Functions	Definition
Prevent overtopping during a design flood	Ability to operate all gates to achieve full spilling capacity.
Prevent overtopping during load rejection	Ability to spill the powerhouse flow during load rejection
Prevent an unintentional opening of the gates	Structural failure of a gate (blowout) or unintended opening of gate due to inaccurate information or a failure of automatic controls.
Prevent failure to close a gate	Failure to close a gate due to equipment failure or failure to recognize the need to close a gate due to inaccurate information
Drawdown of the reservoir	Ability to draw down the reservoir to prevent a structural failure of the dam or foundation.

The relative importance of dam safety functions for a given spillway is obtained by answering the following question:

Question 1:

Given your understanding of the characteristics of the spillway, its performance history, hydrologic parameters and location, which spillway functions concern you the most in terms of dam safety?

In most applications, the main dam safety function for a spillway is to prevent overtopping. Overtopping can occur for a wide spectrum of inflows. Factors to consider from a dam safety point of view are the likelihood of the initiating event, the capacity of the spillway, the likelihood that it will be operated in a timely fashion, and the potential consequences of an improper operation of the spillway. The inflows that are considered for the purpose of evaluating the spillway are design flood and load rejection. The manner in which the spillway is operated, from the identification of the initiating event up to the start of the opening sequence for the gates, is defined as the *reaction time* for the operation of a gate. The time from the start of the opening sequence to the total opening of a gate is defined as the *opening time*. The summation of the reaction and opening time is defined as the *total operation time*. The various components of the spillway should be designed such that the total operation time for the gates is adequate for the response times of all possible initiating events.

The other three dam safety functions are generally not as important as those directly related to overtopping. The ability to draw down the reservoir can be a very important consideration in the case where a dam is known to have a structural or foundation deficiency. The failure to close a gate is a dam safety concern for downstream facilities or activities. Finally, the unintentional opening of a gate is a major concern for the safety of workers, personnel, and the public.

Gate importance (Level 3) (I[Gate|DSF])

In order to rate the performance of the spillway for each dam safety function, it is important to determine the role or impact of individual gates for each function. Factors that should be considered are the capacity and respective attributes of the gates, and the ability to operate the gates in the required time. For example, when load rejection requires a short response time, remotely operated heated gates with dedicated hoists will typically be the most important. In the case of the design flood, if the response time is long, the reaction time for the operation of the gates may not be relevant. If so, only the relative capacity of the gates can be considered.

Question 2:

Considering a given dam safety function, what is the relative importance of the gates of the spillway?

Gates are treated by type and attributes (Table 2.2) and need not be considered on an individual basis in answering the question. The various types of gates that have been considered in this project are vertical lift gates, tainter gates, and stoplogs. Note that flows through the power plant are not considered in the current evaluation procedure.

Table 2.2. Typical gate attributes.

Gate Attributes	Description
Heated gates	Gates need to be available during winter months
Unheated gates	Gates that do not need to be available during winter months
Remotely controlled gates	Gate that does not require personnel at the gate to be operated
Gates operated on site	Gates can only be operated through on-site controls
Gate with dedicated lifting device	Gate that is operated with its own lifting system
Gates with shared lifting device	Gates that are operated with a shared lifting device
Gates with negative downstream impacts	Examples of negative impacts are erosion, scouring, damage to structures
Elevation of gate on the dam	Crest of dam gates versus low-level gates

Importance of operational systems versus spillway equipment (Level 4) (I[operations|DSF], I[equipment|DSF])

The evaluation of the condition of spillways must consider both operational and equipment features because both are required for their operation. The current procedure was developed so that both factors can be considered and rated simultaneously, but both types of components can optionally be kept separate. In the latter case, it is not required to determine the relative importance factors of level 4 and the user can proceed directly to level 5.

Descriptions of operational systems and spillway equipment and their components are listed in Table 2.3. Operational systems include all the systems starting in sequence from *information gathering* to *gate operation*.

Table 2.3. Considerations in the evaluation of a spillway.

Level 4	Level 5	Level 6	Level 7
Operations	1. Gather information		Snow measuring stations Precipitation and temperature gauges network Weather forecasting Flow prediction model Ice and debris River flow measurement Reservoir level indicator Gate position indicator Third party data
	2. Decision process		Decision process Telecommunication system Public protection and warning system Operating procedures
	3. Access and operation		Availability and mobilization (design flood) Availability and mobilization (load rejection) Qualification and training of operator Portable equipment for lifting gates Roads Alternate means of access Local access Remote and on site controls Lighting system (normal and emergency)
Equipment	4. Power supply	4.1 Source - External Power	Medium voltage overhead lines Underground and encased cables
		4.2 Source - Powerhouse	Medium voltage overhead lines Underground and encased cables
		4.3 Source - Generator	Local emergency generator
		4.4 Cables and controls	Power feeder cables Motor control centre or individual control panel Limit switches Control panel (including breakers) External resistors Cam switches Transformers Distribution panels Power source transfer system Inverter control system

Table 2.3. Considerations in the evaluation of a spillway (concluded).

Level 4	Level 5	Level 6	Level 7
	5. Force transmission		Screw and nut thread Bearings Wire rope and connectors Split bushings or journal bearing Trunnion assembly Trunnion beam and anchorage Chain and sprocket assembly Hydraulic cylinder assembly Rotating shafts and support bearings including couplings Gear assembly Non-dedicated lifting connectors Wheel, axles and bearing for vertical lift gate Brakes Fan brakes Carriage wheels Dedicated lifting connectors Clutch and transmission Lifting and translation motor Drums and sheaves
	6. Gate structure and supports		Ice prevention system (heating) Ice prevention system (bubbler) Embedded parts Gate structure Lifting device structure (steel) Lifting device structure (concrete) Mobile structure to support shared lifting device Approach and exit channel Carrying tracks Gate wheel and bearing Bottom and side seals Closure structure

Question 3:

Considering a given dam safety function and the timely operation of a gate, what is the relative importance of operational systems and spillway equipment?

As noted above, the relative importance of operational systems versus spillway equipment may be difficult to determine. Recognizing this difficulty, one option is to rate operational and equipment deficiencies separately. This approach may be desirable since evaluation of the operations and equipment are usually performed by different groups of specialists and require specific remedial measures. In the first case, the rating indicates the ability to respond to dam safety events. In the second case, the rating indicates the condition of the equipment. Both options are explored in the two examples provided in Appendices A and B.

Importance of types of operational systems (Level 5) (I[type of operational systems|DSF]) and spillway equipment (I[type of equipment|DSF]

The next step is to identify the types of operations or equipment that are most critical to a gate's dam safety functions. Questions are posed separately for operations and for equipment.

Question 4a (*I[type of equipment|DSF]*):

Given a dam safety function and gate, what is the relative likelihood that a problem with (1) the power supply, (2) the force transmission, or (3) the gate structure and support would prevent the proper operation of the gate within the required time?

Question 4b (*I[type of operation|DSF]*):

Given a dam safety function and gate, what is the relative likelihood that a problem with (1) gather information, (2) the decision process, or (3) access and controls, would prevent the proper operation of the gate within the required time?

Importance of operational systems and spillway equipment subsystems (Level 6)

Power supply was further subdivided into Cables and Controls, External Power Source, Power House, and Local Emergency Generator.

Question 5a:

Given a dam safety function and gate, what is the relative likelihood that a power supply failure is due to a failure of (1) the power source, or (2) the cables and controls?

Question 5b:

Given a dam safety function and gate, what is the relative likelihood that a power source failure is due to a failure of (1) the external power source, (2) the powerhouse, or (3) the emergency generator?

Importance of components (Level 7)

The relative importance of components has not been considered in the project. For the present report, the importance factor for a type of operation or equipment is assigned to all of the components listed under it. Components that are considered secondary or irrelevant for a particular dam safety function are assigned a null importance.

3 Determination of Component Condition Index (CI)

Condition tables were developed for each spillway component by a panel of experts and fully field-tested through a series of inspections. Component condition is rated on a scale developed by USACE under the REMR program (Table 3.1). The component condition tables define both the function of a component and its excellent (100) and failed (0) conditions. Intermediate conditions are based on quantitative data or qualitative observations on indicators of condition. For each indicator, a range of condition ratings is suggested. Observations are obtained either from an onsite inspection or examination of existing records for the spillway. For each indicator, the inspector should assign a CI value within the appropriate intermediate condition, comparing what is seen with the description. Table 3.2 shows an example for transformers. Selection of a rating near the top, middle, or bottom of the rating category should be made according to the inspector's best judgment. The lowest CI is assigned to a component when several condition indicators are present. When a component is not relevant to a spillway's safety functions or cannot be observed, an appropriate comment should be entered in the inspection rating table. Estes (2005) presents an alternative method in which the mid-value of a rating category is used.

Table 3.1. REMR scale for condition (USACE)

Zone	Condition Index	Condition Description	Recommended action
1	85 to 100	**Excellent:** No noticeable defects. Some aging or wear may be visible.	Immediate action is not required
	70 to 84	**Good:** Only minor deterioration or defects are evident.	
2	55 to 69	**Fair:** Some deterioration or defects are evident, but function is not significantly affected.	Economic analysis of repair alternatives is recommended to determine appropriate action.
	40 to 54	**Marginal:** Moderate deterioration. Function is still adequate.	
3	25 to 39	**Poor:** Serious deterioration in at least some portions of the structure. Function is inadequate.	Detailed evaluation is required to determine the need for repair, rehabilitation, or reconstruction. Safety evaluation is recommended.
	10 to 24	**Very poor:** Extensive deterioration. Barely functional.	
	0 to 9	**Failed:** No longer functions. General failure or complete failure or a major structural component.	

Table 3.2. Sample transformer rating table.

Transformer									
Function	Supply power at correct voltage level								
Excellent	Built to current codes and standards, and maintained to provide continuous service at correct voltage level.								
Failed	Cannot supply correct voltage level.								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Dielectric (oil)									
Oil according to specifications							X		
Contaminated oil (presence of foreign matter, e.g.; moisture)		X	X	X	X				
Degraded oil (by arcing, aging, acidity)	X	X	X	X					
Dissolved gases	X	X	X	X					
Insulation									
Performs the function and/or passes the standard testing procedures (insulation resistance and power factor, etc.)						X	X		
Does not perform the function nor passes the standard testing procedures	X	X							
Windings									
Performs the function and/or passes the standard testing procedures (resistance and turns-ratio)						X	X		
Does not perform the function nor passes the standard testing procedures	X	X							
Cannot supply power	X								
Tank									
No leaks							X		
Inadequate oil level or oil leak	X	X	X	X	X				
Service life (based on utility standard practices)									

Transformer condition is evaluated by testing and visual inspection. The testing is performed to monitor the quality of the oil, the insulation, and the windings. The visual inspection determines the condition of the tank. Considering the wide variety of possible tests, outcomes are described qualitatively and must be evaluated by considering the recommendations of each specific manufacturer of testing devices.

The condition rating tables for spillway components are divided into four categories: (1) Civil/Structural, (2) Mechanical, (3) Electrical, and (4) Operational. This grouping of tables corresponds to typical fields of expertise for inspectors and was done to facilitate the on-site inspections. These rating tables are presented in Appendix C.

Specific components that are not common to all participants in this project have been identified, and those will be developed individually by each partner.

4 Calculations and Examples

Determination of priority ranking

The priority ranking **(PR)** of a component **(C_i)** or system is obtained as the complement of the condition index **(CI)** multiplied by its importance factor (I). This priority ranking is used to develop a prioritized list of maintenance activities on the spillway, the most important component in the worst condition being ranked first. Note that the importance factor used in the calculation is a function of the level at which the deficiency is considered. If the deficiency is evaluated at the same hierarchical level as the component, it is directly multiplied by its importance factor,

$$PR\left[C_{i,op}\right]=\left(100-CI\left[C_{i,op}\right]\right)\cdot I\left[C_{i,op}\right] \qquad [4.1]$$
$$PR\left[C_{i,eq}\right]=\left(100-CI\left[C_{i,eq}\right]\right)\cdot I\left[C_{i,eq}\right]$$

The importance factor of a component is obtained by summing the importance of the component for all the relevant dam safety functions **(DSF)**,

$$I\left[C_{i,op}\right]=\sum_{k=1}^{N_{DSF}} I\left[DSF_k\right]\cdot I\left[C_{i,op}\mid DSF_k\right] \qquad [4.2]$$
$$I\left[C_{i,eq}\right]=\sum_{k=1}^{N_{DSF}} I\left[DSF_k\right]\cdot I\left[C_{i,eq}\mid DSF_k\right]$$

If a component is irrelevant or secondary for a given dam safety function, its importance is set to equal zero, otherwise its importance is obtained by using the following equations for operations and equipment, respectively:

$$I\left[C_{j,op}\mid DSF_k\right]=\sum_{l=1}^{N_{gates}} I\left[gate_l\mid DSF_k\right]\cdot I\left[oper\mid DSF_k\cap gate_l\right]\cdot I\left[operational\ system\mid oper\cap DSF_k\cap gate_i\right] \qquad [4.3]$$
$$I\left[C_{j,op}\mid DSF_k\right]=0 \quad \text{if irrelevant or secondary component for } \mathrm{DSF_k}$$

$$I\left[C_{j,eq}\mid DSF_k\right]=\sum_{l=1}^{N_{gates}} I\left[gate_l\mid DSF_k\right]\cdot I\left[equip\mid DSF_k\cap gate_l\right]\cdot I\left[spillway\ equipment\mid equip\cap DSF_k\cap gate_i\right] \qquad [4.4]$$
$$I\left[C_{j,eq}\mid DSF_k\right]=0 \quad \text{if irrelevant or secondary component for } \mathrm{DSF_k}$$

These equations are used when a list of prioritized activities comprises both spillway equipment and operations. In the case where separate lists are made for the two types of components, the factors I[oper | DSF$_k$] and I[equip |DSF$_k$] are set to equal 1. Equations 4.3 and 4.4 indicate that the importance of a component is related to its impact on the operation of the gates for the various dam safety functions of the spillway. Components that affect all gates represent common modes of failure and have large importance factors while components that are redundant have lower importance factors because their failure does not necessarily imply a failure of the system.

Determination of aggregate condition

The condition of systems at higher hierarchical levels can be determined through aggregation from the condition of subordinate elements and their relative importance,

$$CI_{level_{i-1}} = \sum_{j=1}^{n} I_j \cdot CI_{j,level_i} \qquad [4.5]$$

Equation 4.5 assumes that the components at the hierarchical level *i* are in series. For redundant components, the equation is modified to the following form,

$$CI_{level_{i-1}} = \frac{\sqrt{\sum_{j=1}^{n} \left(CI_j \cdot I_{j,level_i}\right)^2}}{\sqrt{\sum_{j=1}^{n} \left(I_{j,level_i}^2\right)}} \qquad [4.6]$$

Equations 4.5 and 4.6 can be combined to calculate the condition of any type of system with a mixture of components in series and in parallel. Currently, importance factors have not been assigned at the level of system components. In order to compute a condition index for systems at higher levels, it is necessary to make assumptions about the importance of the components. The following options can be considered:

1. assign weight to each component equal to the importance of the system divided by the number of components
2. assign the weight of the system to each component
3. assign all the weight to the component in the worst condition
4. assign a weight based on the condition.

Calculations of aggregate condition have not been included in this report because the alternatives have not been fully validated through application of the methodology.

This report assesses the condition of components in a system and prioritizes the maintenance of components within a structure. Estes et al. (2005) use the same information and methodology to develop system condition indices that allow similar structures with differing distresses to be compared for maintenance prioritization, especially with respect to repair or rehabilitation of entire systems and subsystems. They used the same inspection data from the Dam B spillway as shown in Appendix B.

Reliability-based approach to aggregate condition

The methods described in this report, and this section in particular, represent the results of research by the authors. The methods herein are presented as a matter of record and made available to the dam safety community for their consideration. This method is not endorsed by HQUSACE.

A reliability approach developed by Estes et al. (2005) can be used to assign CI ratings for groups of components, systems, and projects. It is presented here and shown in a simple example, but it is not the method used for the dams discussed in Appendices A and B. The approach described here is deterministic, but in reality there is considerable uncertainty associated with the process, including:

- Uncertainty in the ability of different inspectors to reliably choose the correct condition state and to a greater degree, the appropriate score within a condition state
- Uncertainty associated with the condition state tables where a single numerical score is obtained from matching an inspector observation to a word description of the distress.
- Uncertainty in defining at which condition state a component will actually fail and need to be replaced.
- Uncertainty with how a component will deteriorate over time, although this uncertainty is gradually eliminated as inspections occur and the maintenance plan is updated.

Estes et al. (2005) address these uncertainties on the basis of a few reasonable assumptions. Using the CI value as the random variable, the reliability index and probability of failure for a component at a point in time can be computed. With some further assumptions about deterioration, a time-dependent reliability analysis can be conducted using hazard functions to facilitate a probabilistic cost-benefit analysis. The authors illustrate those concepts using a both a simple hypothetical structure and the Dam B spillway gate system.

For a system reliability analysis, Equations 4.5 and 4.6 were used to compute the mean values for series and parallel systems, respectively. Standard deviations were based on assumed distribution types and statistical independence of the system components. The use of these equations provided interesting system reliability implications, which are discussed fully in Estes et al. (2005).

Using the reliability approach developed by Estes et al. 2005 the standard deviation of CI ratings, the reliability index and a failure probability for a component can be estimated based on inspector determination of the condition state (CS) and assignment of the CI value at the mean of the condition state. These component failure probabilities can be used to calculate a system failure probability and standard deviation that correspond to a system reliability index and CI rating. The steps in this process are illustrated in the following example.

Step 1 – Determine CIs of system components

For each condition indicator for a component, descriptions are made for condition states. Some condition states include large ranges of CI value. In this methodology, the CI is assumed to be at the mean value of the range. As examples, components in parallel and series are chosen and assigned condition states. These condition states also have corresponding mean values as shown in Table 4.1.

Table 4.1. CI ratings used for the example.

Component	Identifier	CS range	CI (μ of CS)
Parallel			
Medium Voltage overhead lines (Grid power)	A	25-69	47
Generator	B	70-100	84
Series			
Gear assembly	C	55-84	69
Wire rope	D	40-69	54

Note: The procedures described in this section could also be applied to the indicators for a component. The indicators would be treated in series. It is reasonable to assume that components with distresses for multiple indicators would have a higher probability of failure.

Step 2 – Calculate σ for each component based on the condition state of the component

If the condition state range is from 25 – 69, as for example component A, the mean value would be CI=47. Assuming a 5% inspector error, the probability of obtaining a value of CI<69 when the structure is actually in this condition state is 97.5%, or 0.975. The standard deviation σ can be computed as:

$$P(CI_A \le 69) = 0.975 = \Phi(\frac{CI-\mu}{\sigma}) = \Phi(\frac{69-47}{\sigma_A})$$

$$\sigma_A = \frac{(69-47)}{\Phi^{-1}(0.975)} = \frac{(69-47)}{1.96} = 11.22$$

$$P(CI_B \le 84) = 0.975 = \Phi(\frac{100-84}{\sigma_B})$$

$$\sigma_B = \frac{(100-84)}{\Phi^{-1}(0.975)} = \frac{(100-84)}{1.96} = 8.16$$

$$P(CI_C \le 84) = 0.975 = \Phi(\frac{84-69}{\sigma_C})$$

$$\sigma_C = \frac{(84-69)}{\Phi^{-1}(0.975)} = \frac{(84-69)}{1.96} = 7.65$$

$$P(CI_D \le 69) = 0.975 = \Phi(\frac{69-54}{\sigma_D})$$

$$\sigma_D = \frac{(69-54)}{\Phi^{-1}(0.975)} = \frac{(69-54)}{1.96} = 7.65$$

where Φ is the standard normal variate whose value can be found in the standard normal distribution tables, and μ is the mean value of the condition state (Ang and Tang 1975).

Step 3 – Calculate β for each component

$$\beta_A = \frac{CI_{Actual} - CI_{Failure}}{\sqrt{\sigma^2_{Actual} + \sigma^2_{Failure}}} = \frac{47-25}{\sqrt{(11.22)^2 + (12.5)^2}} = 1.31$$

$$\beta_B = \frac{84-25}{\sqrt{(8.16)^2 + (12.5)^2}} = 3.95$$

$$\beta_C = \frac{69-25}{\sqrt{(7.65)^2 + (12.5)^2}} = 3.00$$

$$\beta_D = \frac{54-25}{\sqrt{(7.65)^2 + (12.5)^2}} = 1.98$$

Step 4 – Calculate p_f. for each component

$$p_{f,A} = \Phi(-\beta) = \Phi(-1.31) = 1 - \Phi(1.31) = 1 - 0.9049 = 9.51(10)^{-2}$$

$$p_{f,B} = \Phi(-\beta) = \Phi(-3.95) = 1 - \Phi(3.95) = 1 - 0.999961 = 3.9(10)^{-5}$$

$$p_{f,C} = \Phi(-\beta) = \Phi(-3.00) = 1 - \Phi(3.00) = 1 - 0.99865 = 1.35(10)^{-3}$$

$$p_{f,D} = \Phi(-\beta) = \Phi(-1.98) = 1 - \Phi(1.98) = 1 - 0.976148 = 2.3852(10)^{-2}$$

Step 5 – Calculate system CI using component p_f and σ.

For calculating the system failure probability for parallel components, multiply p_f for each component. Standard deviation is determined by the square root of the summed squares. System standard deviation is determined by the square root of the summed squares of the component standard deviation. Calculations are made for two power sources assuming equal importance of each power source.

$$p_{f,power} = p_{f,A} \bullet p_{f,B} = 9.51(10)^{-2} \bullet 3.9(10)^{-5} = 3.709(10)^{-6}$$

$$\sigma_{Power} = \sqrt{(I_A)^2(\sigma_A)^2 + (I_B)^2(\sigma_B)^2}$$

$$\sigma_{Power} = \sqrt{(0.5)^2(11.22)^2 + (0.5)^2(8.16)^2} = 6.94$$

For series components, use the probability summed over the components P(A, B, C, ...) System standard deviation is determined by the square root of the summed squares of the component standard deviation. Component standard deviations are multiplied by their importance.

$$p_{f,force} = p_{f,A} + p_{f,B} - p_{f,A} \bullet p_{f,B}$$
$$p_{f,force} = 1.35(10)^{-3} + 2.3852(10)^{-2} - 1.35(10)^{-3} \bullet 2.3852(10)^{-2} = 2.517(10)^{-2}$$

$$\sigma_{force} = \sqrt{(0.5)^2(7.65)^2 + (0.5)^2(7.65)^2} = 5.41$$

Note that for three components in series, the equation would be:

$$p_{f,power} = p_{f,A} + p_{f,B} + p_{f,C} - p_{f,A} \bullet p_{f,B} - p_{f,A} \bullet p_{f,C} - p_{f,B} \bullet p_{f,C} + p_{f,A} \bullet p_{f,B} \bullet p_{f,C}$$

The system failure probability can be approximated by:

$$P_{f\ system} = 1 - [(1 - p_{f,A})(1 - p_{f,B})]$$

Step 6 – Calculate the reliability index, β, based on the system probability of failure, p_f

$$\beta_{power} = \Phi^{-1}(p_f) = \Phi^{-1}(3.709(10)^{-6}) = \Phi(.99999629) = 4.95$$
$$\beta_{force} = \Phi^{-1}(p_f) = \Phi^{-1}(2.517(10)^{-2}) = \Phi(.9748302) = 1.96$$

Step 7 – Calculate the system CI using the reliability index and standard deviation.

$$CI_{power} = \beta\sqrt{\sigma^2_{Actual} + \sigma^2_{Failure}} + CI_{Failure} = 4.95\sqrt{(6.94)^2 + (12.5)^2} + 25 = 95.8$$
$$CI_{force} = \beta\sqrt{\sigma^2_{Actual} + \sigma^2_{Failure}} + CI_{Failure} = 1.96\sqrt{(5.41)^2 + (12.5)^2} + 25 = 52.7$$

In this example, the parallel system calculation results in a rating 95.8, indicating that the overall system condition is excellent. The force transmission components in series have a much lower rating or 52.7. Note that the high system rating for power does not imply that the overhead power lines don’t need repair but it does suggest that repairs of series components such as for force transmission may be a higher priority.

Examples

The spillway CI procedure has been applied to several spillways during development of the method and the tables. Fully developed examples are presented in Appendices A and B for two of the spillways inspected during the project. Appendix A presents the detailed results for Hydro-Québec Dam A, which has a spillway with six vertical lift gates operated with shared lifting devices. Appendix B presents the detailed results for Manitoba Hydro Dam B, which is a spillway with four vertical lift gates with dedicated hoists.

5 Conclusions and Recommendations

A condition rating and priority ranking methodology for spillways has been presented. A conceptual framework has been formulated that can account for the various dam safety functions that need to be addressed in the condition assessment of a spillway. In addition, a hierarchical model has been proposed that can account for the dependencies of various equipment and operations that interact during the operation of a spillway and to account for complex systems that comprise both redundant and shared components. The procedure is complemented by a series of condition tables for all major components of a spillway.

The condition rating and priority ranking procedure documented here offers the following benefits:

- It provides a means to easily characterize each facility in its current state.
- It permits a tracking of the evolution of the condition as a function of time.
- It is readily integrated into existing periodic inspection cycles using the rating tables to guide the inspection process.
- It can be easily interpreted or summarized in various ways in order to describe the nature of spillway deficiencies.
- It describes conditions in a way that can be communicated easily to decision-makers who are not specialists in civil works engineering or operations.
- It provides insight into the inspection and evaluation process.
- It facilitates and standardizes inspection procedures and promotes consistency of inspection reports.

The condition rating procedure provides a quantified measure of deterioration that can be applied to failure rate estimation and risk analysis.

Implementation of the methodology for managing a large number of spillways can be accomplished through a series of steps similar to those used for implementing a condition indexing and priority ranking procedure for embankment dams at Hydro-Québec (Robichaud et al. 2000) and Manitoba-Hydro (Halayko et al. 2003).

References

Andersen, G. R., and V. H. Torrey III. 1995. Function-based condition indexing for embankment dams. *J. Geotech. Engrg.* ASCE, 121(8):579–588.

Andersen, G.R., L. E. Chouinard, W. H. Hover, and C. W. Cox. 2001a. Risk indexing tool to assist in prioritizing improvements to embankment dams, *J. Geotech. and Geoenvir Engrg.*, ASCE, 127(4):325–334.

Andersen, G. R., C. W. Cox, L. E. Chouinard, and W. H. Hover. 2001b. Prioritization of 10 embankment dams according to physical deficiencies. *J. Geotech. and Geoenvir. Engrg.*, ASCE, 127(4):335–345.

Chouinard, L. E., J. G. Robichaud, G. Blanchette, and R. Gervais. 1998. Priority ranking for maintenance activities on embankment dams. Conf. Can. Dam Safety Assn., Canadian Dam Safety Association, Halifax, Canada, 252–265.

Chouinard, L. E. 2001. Condition Indexing for Spillways – Interim Report, July 2001. Department of Civil Engineering and Applied Mechanics, McGill University, Montréal (Québec), Canada.

Estes, A. C., S. D. Foltz, and D. T. McKay. 2005. *Estimating Risk from Spillway Gate Systems on Dams Using Condition Assessment Data.* ERDC/CERL TR-05-40. ADA466342. Champaign, IL: U.S. Army Engineer Research and Development Center.

Halayko, K., R. Gervais, and L. Chouinard. 2003. Condition Indexing of Embankment Dams – Case Studies for Manitoba Hydro and Hydro-Québec. Canadian Geotechnical Society Annual Conference, Winnipeg.

Hydro-Québec. 2000. *Indices de condition pour les barrages en remblai.* Montréal (Québec), Canada.

Hydro-Québec. 2000. *Classification des évacuateurs*. Montréal (Québec), Canada.

International Commission on Large Dams (ICOLD). 1995. Dam Failures Statistical Analysis, Bulletin 99. Paris, France.

Robichaud, J. G., L. E. Chouinard, G. Andersen, and V. Torrey III. 2000. Using Indexing Tools to Prioritize Work on Dams. *Hydro Review*, XIX(4):40–47.

Rondenay, A., N. Lévesque, and S. Robert. 1990. Rangement des ouvrages régulateurs et évacuateurs d'Hydro-Québec selon l'impact de la défaillance. Hydro-Québec, Montréal (Québec), Canada.

Appendix A: Dam A (Hydro-Québec)

Description of Dam A

The spillway of Dam A is located in Québec, Canada. It is part of a system of four spillways starting from the upper reservoir down to a city. It is the first spillway downstream from the upper reservoir located at the top of the watershed. The reservoir behind the spillway is small and its level can fluctuate rapidly. Only one gate is necessary to pass all the powerhouse flow (787 m^3/s). The principal features of the Dam A spillway are listed below:

- Number of gates — 6 vertical lift gates
- Capacity of each gate —800 m^3/s
- Number of heated gates — 2 (gate 4 and gate 5)
- Number of remotely controlled gates — 1 (gate 5)
- Emergency generator — 1
- Number of trolleys — 2 (hoist 1 for gates 1 to 5, and hoist 2 for gates 2 to 6)
- Road access — 1

Other physical and operational characteristics are as follows:

- Unhooked gates cannot be operated if overtopped.
- The maximum yield is four gates per day.
- Two gates are permanently attached to hoists. Personnel (mechanics and electricians) can be reached within 3 hours to lift a third gate or more).
- West access road is open during flood event.
- Impact loads from floating debris could fail a gate.
- The gates are not designed to pass winter flood.
- No embankment dams on the Dam A reservoir.
- The factor of safety for seismic performance is below the required minimum.
- The impoundment is relatively small and can be emptied rapidly.
- The response time in the event of a design flood (2 weeks) is such that operational errors are unlikely.
- The two shared lifting devices can only be operated simultaneously with the powerhouse as a source.

- Power supply from the powerhouse is reliable in a flood.
- The concrete structure is affected by Alkali Aggregate Reaction.
- Potential electric problem: Chariot can be stranded if it jumps the busbar.
- Gate 5 is the only gate that can be operated remotely.
- Gate 4 needs to be operated on site (two people are sent to operate the gate for safety reasons).
- Overhead line is not 100% secure; it is subject to atmospheric hazards and impacts with trucks, etc.
- When load rejection occurs, the first order of business is to reestablish the flow balance of the river. Auxiliary services are restored in priority since they are they are required to restart the powerhouse.
- During precarious conditions (e.g., harsh weather conditions) two operators are on duty.
- Gates 4 and 5 can be lowered and opened at any intermediate level. Gates 1, 2, 3, and 6 can only be opened or closed completely.
- The two trolleys are usually connected to gates 4 and 5. If a decision is made to open a gate, one of the two trolleys is disconnected and moved over one of the gates 1, 2, 3, or 6. The gate is then fully opened and the trolley is moved back to its original position.

Figures A.1 and A.2 show a block diagram for the operation of the spillway during a design flood and during load rejection, respectively. The blocks are grouped into operations and equipment. Blocks in series are considered as common failure modes, while blocks in parallel indicate redundancy. The block diagrams are identical for all dam safety functions except that some blocks may be inapplicable in some cases. As an example, considering load rejection (Figure A.2), gathering information, the decision process, as well as gates 1, 2, 3, and 6 are irrelevant. In this example, the powerhouse and the emergency generator are redundant sources of power, while hoist 1 and 2 are redundant lifting devices for gates 2, 3, 4, and 5 during the design flood (Figure A.1). All gates need to be fully opened during the design flood. During load rejection, only gates 4 and 5 are involved, and hoists 1 and 2 are considered dedicated lifting devices (Figure A.2). Only one of the two gates needs to be fully opened during a load rejection.

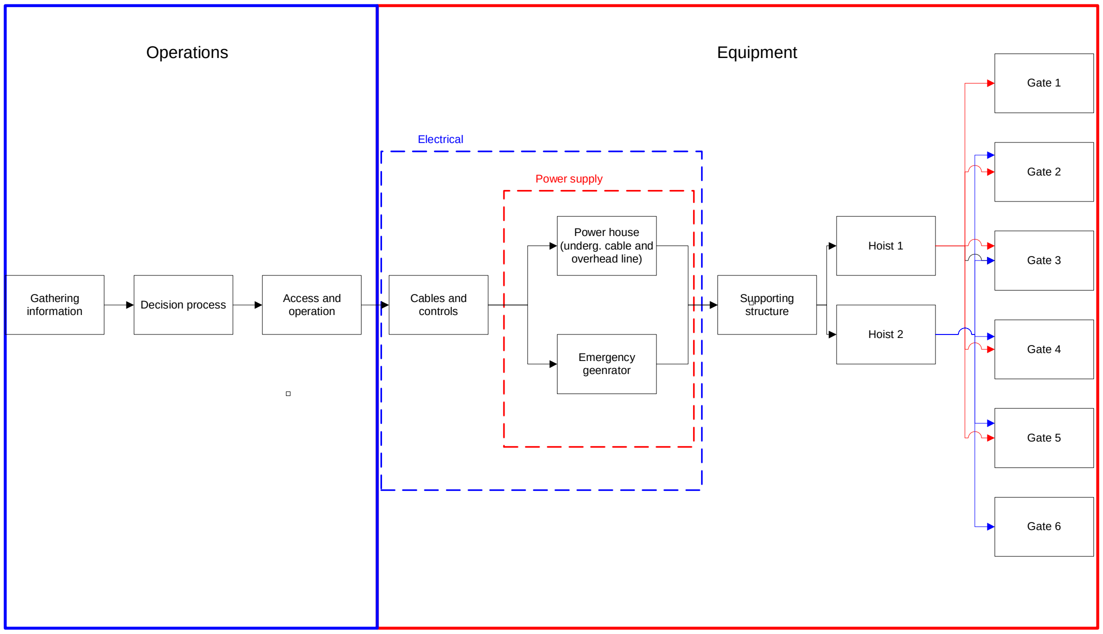


Figure A.1. Block diagram for design flood — Dam A.

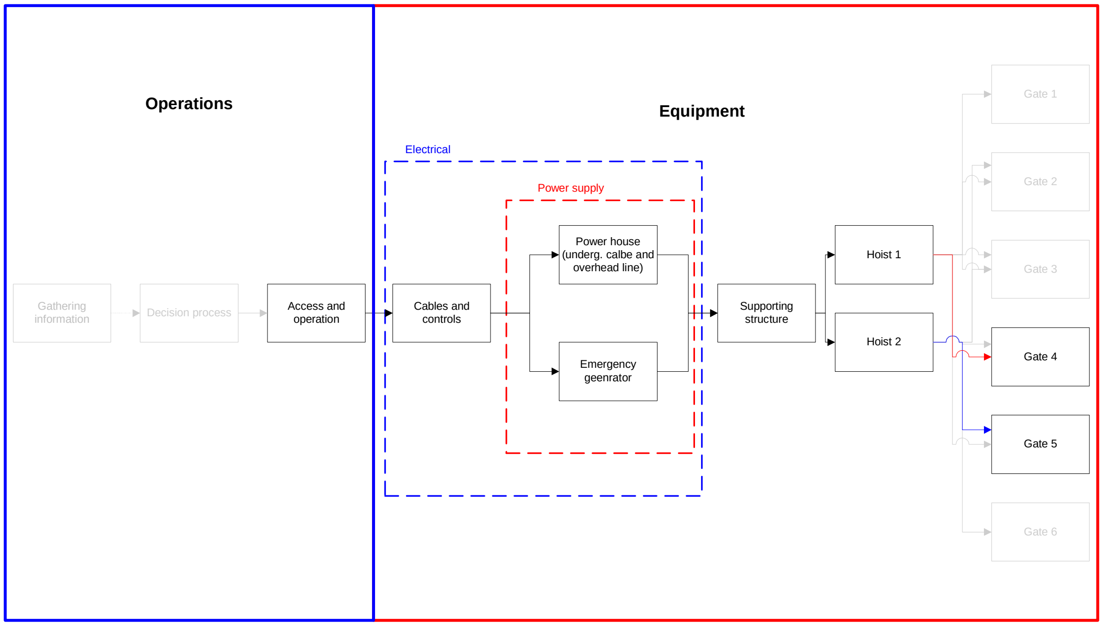


Figure A.2. Block diagram for load rejection — Dam A.

Importance factors

Step 1: Importance of the facility

The relative importance of the spillway at Dam A is determined by using a scoring procedure developed by Hydro-Québec.

Step 2: Importance of dam safety objectives

Question 1:

Given your understanding of the characteristics of the spillway, performance history, and setting, which spillway functions concern you the most in terms of dam safety?

Table A.1. Importance of dam safety functions — Dam A.

Level 2:	Dam Safety Functions	I_{DSF}
1)	Prevent overtopping due to a design flood	0.30
2)	Prevent overtopping due to a load rejection	0.50
3)	Prevent an unintentional opening	0.05
4)	Prevent a failure to close	0.05
5)	Drawdown to prevent a dam failure.	0.10

Justifications

Overtopping during a design flood is possible but is not perceived as the major concern. The response time at Dam A during a design flood is estimated to be 2 weeks. The head reservoir is quite large, and flows out of the reservoir are controlled during a design flood. In addition, flows from tributaries between the head reservoir and Dam A are relatively small even during a design flood. Operators have not had to open more than one gate during floods over the past 10 years. Since the design flood requires that all gates be opened, all gates have equal importance. The relative importance of the gates could be different in cases where a sequence of gate openings is required. Preventing overtopping during a load rejection is perceived as the major dam safety concern at Dam A. During load rejection, the response time has been estimated at a few hours since the reservoir upstream of the spillway is rather small. A single gate is sufficient for passing the entire flow of the powerhouse. During load rejection, there is a very high likelihood that the power supply from the powerhouse is disrupted. In the latter case, the emergency generator has to be used for operating the gates. The equipment at Dam A is old and not up to current standards. The generator has to be started and operated on site. Several incidents have been reported during which the operators could not get the generator started on their own and had to rely on specialized help from mechanics and electricians. The capacity of the generator is not sufficient for providing power simultaneously to the hoists and to heating elements. Preventing an unintentional opening is also a concern since the gates are known to be close to their structural capacity. In the event of a gate blowout, there is a potential for loss of life during the summer months due to the presence of swimmers downstream from the spillway. The ability to draw down the reservoir to prevent failure due to a structural or foundation problem is not a major concern at Dam A.

Step 3: Importance of the gates

Question 2:

Considering a given dam safety function, what is the relative importance of the gates of the spillway?

Table A.2. Importance of gates — Dam A.

	DSF				
	1) Prevent overtopping due to a design flood	2) Prevent overtopping due to a load rejection	3) Prevent an unintentional opening	4) Prevent a failure to close	5) Drawdown to prevent a dam failure.
I_{DSF}	0.30	0.50	0.05	0.05	0.10
Gate 1	0.167	0.000	0.140	0.167	0.000
Gate 2	0.167	0.000	0.140	0.167	0.000
Gate 3	0.167	0.000	0.140	0.167	0.000
Gate 4	0.167	0.325	0.140	0.167	0.500
Gate 5	0.167	0.675	0.300	0.167	0.500
Gate 6	0.167	0.000	0.140	0.167	0.000

Gate	I[gate]
1	0.07
2	0.07
3	0.07
4	0.28
5	0.46
6	0.07

Justifications

For the design flood, the full capacity of the spillway is required. Heated and unheated gates are equally important (the design flood does not occur in the winter). The relative importance of each gate is only a function of the total flow through each gate.

For load rejection, the two trolleys are attached to gates 4 and 5. Gate 5 is the only gate that can be operated remotely and for this reason receives a higher importance factor.

For drawing down the reservoir, only heated gates are considered important since they are the only ones that can be operated at all times. Each heated gate has equal importance: 0.5

The results from Table A.2 can be combined to obtain the importance of each individual gate for each dam safety function. These importance factors are provided in Table A.3 for each dam safety function, as well as for each gate overall. In this case, gate 5 has the highest score since load rejection is the most important dam safety concern and it is the only heated gate that can be remotely controlled.

Step 4: Importance of operational and equipment deficiencies

Question 3

Considering a given dam safety function and the timely operation of a gate, what is the relative importance of operational and equipment deficiencies?

Table A.3. Importance of operational and equipment deficiencies — Dam A.

DSF		Gates					
		1	2	3	4	5	6
1) Prevent overtopping due to a design flood	Oper	0.2	0.3	0.3	0.3	0.3	0.2
2) Prevent overtopping due to a load rejection	Oper	0	0	0	0.1	0.1	0
3) Prevent an unintentional opening	Oper	0.3	0.3	0.3	0.3	0.8	0.3
4) Prevent a failure to close	Oper	0.2	0.2	0.2	0.2	0.2	0.2
5) Drawdown to prevent a dam failure.	Oper	0	0	0	0.1	0.1	0
1) Prevent overtopping due to a design flood	Equip	0.8	0.7	0.7	0.7	0.7	0.8
2) Prevent overtopping due to a load rejection	Equip	0	0	0	0.9	0.9	0
3) Prevent an unintentional opening	Equip	0.7	0.7	0.7	0.7	0.2	0.7
4) Prevent a failure to close	Equip	0.8	0.8	0.8	0.8	0.8	0.8
5) Drawdown to prevent a dam failure.	Equip	0	0	0	0.9	0.9	0

Justifications

Equipment failure is the main concern for a timely operation of the gates and appears as the major concern except for an unintentional opening of gate 5, which can be remotely operated. In the latter case, an operational error is most likely. The configuration of the spillway is old and not up to current standards and is prone to equipment failures considering both the age and the large number of components that fail during operations.

Step 5: Importance of types of operations and equipment

Question 4b (*I[type of operations| DSF]*):

Given a dam safety function and gate, what is the relative likelihood that a problem with 1) gathering information, 2) the decision process, or 3) the access and controls, would prevent the proper operation of the gate within the required time?

Table A.4. Importance of operational systems — Dam A.

DSF		Gates					
		1	2	3	4	5	6
1) Prevent overtopping due to a design flood	Gathering Information	0.2	0.2	0.2	0.2	0.2	0.2
	Decision process	0.35	0.35	0.35	0.35	0.35	0.35
	Access and operation	0.45	0.45	0.45	0.45	0.45	0.45
2) Prevent overtopping due to a load rejection	Gathering Information	0	0	0	0	0	0
	Decision process	0	0	0	0.35	0.35	0
	Access and operation	0	0	0	0.65	0.65	0
3) Prevent an unintentional opening	Gathering Information	0.7	0.7	0.7	0.7	0.7	0.7
	Decision process	0.3	0.3	0.3	0.3	0.3	0.3
	Access and operation	0	0	0	0	0	0
4) Prevent a failure to close	Gathering Information	0.2	0.2	0.2	0.2	0.2	0.2
	Decision process	0.6	0.6	0.6	0.6	0.6	0.6
	Access and operation	0.2	0.2	0.2	0.2	0.2	0.2
5) Drawdown to prevent a dam failure.	Gathering Information	0	0	0	0	0	0
	Decision process	0	0	0	0	0	0
	Access and operation	0	0	0	1	1	0

Justifications

During a design flood, the most critical operational issue is access and operation, followed closely by the decision process and finally information gathering. Access and operation is the most important step because the operation of the spillway requires the intervention of several specialists (operators, mechanics, electricians, technical personnel) on site. In particular, electricians and mechanics are needed whenever the hoist has to be moved to open more than one gate. The next step in importance is the decision process. The decision process is slightly less important than access and operation at Dam A since the operators will operate the gates in the last resort; however, this time may not be optimal from a dam safety perspective. Finally, gathering information on flows is the least important given the long response time at Dam A.

Question 4a (I[type of equipment|DSF])**:**

Given a dam safety function and gate, what is the relative likelihood that a problem with 1) the power supply, 2) the force transmission, or 3) the gate structure and support, would prevent the proper operation of the gate within the required time?

Table A.5. Importance of equipment deficiencies — Dam A.

DSF		Gates					
		1	2	3	4	5	6
1) Prevent overtopping due to a design flood	Power Supply	0.1	0.2	0.2	0.2	0.2	0.1
	Force Transmission	0.6	0.35	0.35	0.35	0.35	0.6
	Gate structures and support	0.3	0.45	0.45	0.45	0.45	0.3
2) Prevent overtopping due to a load rejection	Power Supply	0	0	0	0.7	0.7	0
	Force Transmission	0	0	0	0.2	0.2	0
	Gate structures and support	0	0	0	0.1	0.1	0
3) Prevent an unintentional opening	Power Supply	0	0	0	0	0	0
	Force Transmission	0	0	0	0	0	0
	Gate structures and support	1	1	1	1	1	1
4) Prevent a failure to close	Power Supply	0.2	0.2	0.2	0.2	0.2	0.2
	Force Transmission	0.6	0.6	0.6	0.6	0.6	0.6
	Gate structures and support	0.2	0.2	0.2	0.2	0.2	0.2
5) Drawdown to prevent a dam failure.	Power Supply	0	0	0	0.1	0.1	0
	Force Transmission	0	0	0	0.6	0.6	0
	Gate structures and support	0	0	0	0.3	0.3	0

Justifications

Relative to equipment, the most likely failure is with the force transmission. The force transmission system is comprised of numerous parts that need to be well aligned and adjusted for attaching the gates. Parts for old hoists are difficult to obtain or repair in case of a failure. For the design flood, the importance of the force transmission is equal to 0.6 for gates 1 and 6. The importance factors are lower for gates 2, 3, 4, and 5 since both hoists 1 and 2 can be used to lift them.

The power supply is not perceived as a major problem for the design flood since the response time is 2 weeks. However, the power supply is crucial for load rejection since the response time is on the order of a few hours.

i) Given a dam safety function and gate, what is the relative likelihood that failure of the power supply is due to a failure of 1) the power source, or 2) the cables and controls?

Table A.6. Importance of power supply - Dam A.

DSF		Gates					
		1	2	3	4	5	6
1) Prevent overtopping due to a design flood	Cables and controls	0.75	0.75	0.75	0.75	0.75	0.75
	Power Source	0.25	0.25	0.25	0.25	0.25	0.25
2) Prevent overtopping due to a load rejection	Cables and controls	0	0	0	0.22	0.22	0
	Power Source	0	0	0	0.78	0.78	0
3) Prevent an unintentional opening	Cables and controls	0	0	0	0	0	0
	Power Source	0	0	0	0	0	0
4) Prevent a failure to close	Cables and controls	0.75	0.75	0.75	0.75	0.75	0.75
	Power Source	0.25	0.25	0.25	0.25	0.25	0.25
5) Drawdown to prevent a dam failure.	Cables and controls	0	0	0	0.75	0.75	0
	Power Source	0	0	0	0.25	0.25	0

Justifications

Cables and control are more critical components during design floods since all the gates are opened and the hoists have to be operated both for translation and lifting. In addition, there are two sources of power, while cables and controls lack redundancy. During load rejection, there is a higher likelihood that auxiliary services will fail and there is no need for translation of the hoists.

ii) Given a dam safety function and gate, what is the relative importance of the sources of power: 1) the external source, 2) the power plant, and 2) the emergency generator?

Table A.7. Importance of power source — Dam A.

DSF		Gates					
		1	2	3	4	5	6
1) Prevent overtopping due to a design flood	External Source	0	0	0	0	0	0
	Power House	0.65	0.65	0.65	0.65	0.65	0.65
	Generator	0.35	0.35	0.35	0.35	0.35	0.35
2) Prevent overtopping due to a load rejection	External Source	0	0	0	0	0	0
	Power House	0	0	0	0.5	0.5	0
	Generator	0	0	0	0.5	0.5	0
3) Prevent an unintentional opening	External Source	0	0	0	0	0	0
	Power House	0	0	0	0	0	0
	Generator	0	0	0	0	0	0
4) Prevent a failure to close	External Source	0	0	0	0	0	0
	Power House	0.65	0.65	0.65	0.65	0.65	0.65
	Generator	0.35	0.35	0.35	0.35	0.35	0.35
5) Drawdown to prevent a dam failure.	External Source	0	0	0	0	0	0
	Power House	0	0	0	0.65	0.65	0
	Generator	0	0	0	0.35	0.35	0

Justifications

For design floods, the main source of power is the power house since the emergency generator can be used to operate only one hoist at a time. During load rejection, both sources of power are equally important. Note that the emergency generator is not designed for heating and lifting the gates simultaneously.

Importance factors and priority rankings

Table A.8 provides the importance factors calculated for the components that are specific to each gate using the importance factors listed in Tables A.1 – A.7 and Equations 4.1 – 4.5. The last two columns indicate the condition and the priority ranking of the components. The conditions were obtained during site inspections and from interviews with facilities personnel.

The cells that are shaded in yellow indicate that the components are considered irrelevant or secondary for that dam safety function and their importance is set equal to zero. During the inspection, a separate condition was not assigned to the components of each gate. In this example, the same conditions are used for the components of each gate.

Table A.8. Importance of gate components — Dam A.

Individual Gate Components	1) Prevent overtopping due to a design flood	2) Prevent overtopping due to a load rejection	3) Prevent an unintentional opening	4) Prevent a failure to close	5) Draw down the reservoir to prevent a failure due to a structural of foundation problem	CI	PR (100-CI)*I
I(FSB)	0.30	0.50	0.05	0.05	0.10		
Gagte n° 1							
Gate Structure and Supports							
1. Approach and exit channel (Upstream and downstream apron including base of pier // stilling basin/exit channel)	0.04	0.08	0.10	0.03	0.00	40.00	1.09
2. Embedded Parts (including sill)	0.04	0.08	0.10	0.03	0.00	20.00	1.46
3. Gate Structure	0.04	0.08	0.10	0.03	0.00	35.00	1.10
4. Closure structure (stoplogs, bulkheads)	0.04	0.00	0.10	0.03	0.00	60.00	0.00
5. Roller trains	0.04	0.08	0.10	0.03	0.00	90.00	0.16
Access and Operation							
1. Remote and on site controls	0.02	0.08	0.00	0.01	0.00	30.00	0.34
Gate n° 2							
Gate Structure and Supports							
1. Approach and exit channel (Upstream and downstream apron	0.05	0.08	0.10	0.03	0.00	40.00	1.32
2. Embedded Parts (including sill)	0.05	0.08	0.10	0.03	0.00	20.00	1.76
3. Gate Structure	0.05	0.08	0.10	0.03	0.00	35.00	1.43
4. Closure structure (stoplogs, bulkheads)	0.05	0.00	0.10	0.03	0.00	60.00	0.00
5. Roller trains	0.05	0.08	0.10	0.03	0.00	90.00	0.22
Access and Operation							
1. Remote and on site controls	0.02	0.09	0.00	0.01	0.00	30.00	0.50
Gate n° 3							
Gate Structure and Supports							
1. Approach and exit channel (Upstream and downstream apron	0.05	0.08	0.10	0.03	0.00	40.00	1.32
2. Embedded Parts (including sill)	0.05	0.08	0.10	0.03	0.00	20.00	1.76
3. Gate Structure	0.05	0.08	0.10	0.03	0.00	35.00	1.43
4. Closure structure (stoplogs, bulkheads)	0.05	0.00	0.10	0.03	0.00	60.00	0.00
5. Roller trains	0.05	0.00	0.10	0.03	0.00	90.00	0.22
Access and Operation							
1. Remote and on site controls	0.02	0.00	0.00	0.01	0.00	30.00	0.60
Gate n° 4							
Gate Structure and Supports							
1. Approach and exit channel (Upstream and downstream apron	0.05	0.03	0.10	0.03	0.14	40.00	3.01
2. Embedded Parts (including sill)	0.05	0.03	0.10	0.03	0.14	20.00	4.01
3. Gate Structure	0.05	0.03	0.10	0.03	0.14	35.00	3.26
4. Closure structure (stoplogs, bulkheads)	0.05	0.03	0.10	0.03	0.14	60.00	0.00
5. Roller trains	0.05	0.03	0.10	0.03	0.14	90.00	0.60
6. Ice prevention system (heating elements, fans, thermostats, gain	0.05	0.03	0.10	0.03	0.14	90.00	0.33
Access and Operation							
1. Remote and on site controls	0.02	0.02	0.00	0.01	0.05	30.00	1.69
Gate n° 5							
Gate Structure and Supports							
1. Approach and exit channel (Upstream and downstream apron	0.05	0.06	0.06	0.03	0.14	40.00	3.84
2. Embedded Parts (including sill)	0.05	0.06	0.06	0.03	0.14	20.00	5.12
3. Gate Structure	0.05	0.06	0.06	0.03	0.14	35.00	4.16
4. Closure structure (stoplogs, bulkheads)	0.05	0.06	0.06	0.03	0.14	60.00	0.00
5. Roller trains	0.05	0.06	0.06	0.03	0.14	80.00	0.64
6. Ice prevention system (heating elements, fans, thermostats, gain	0.05	0.06	0.06	0.03	0.14	90.00	0.47
Access and Operation							
1. Remote and on site controls	0.02	0.04	0.00	0.01	0.05	30.00	2.36
Gate n° 6							
Gate Structure and Supports							
1. Approach and exit channel (Upstream and downstream apron	0.04	0.00	0.10	0.03	0.00	40.00	1.09
2. Embedded Parts (including sill)	0.04	0.00	0.10	0.03	0.00	20.00	1.46
3. Gate Structure	0.04	0.00	0.10	0.03	0.00	35.00	0.00
4. Closure structure (stoplogs, bulkheads)	0.04	0.00	0.10	0.03	0.00	60.00	0.91
5. Roller trains	0.04	0.00	0.10	0.03	0.00	80.00	0.00
Access and Operation							
1. Remote and on site controls	0.02	0.00	0.00	0.01	0.00	30.00	0.34

Example calculation : Gate 1, item 3 (Gate structure)

$$
\begin{aligned}
&\text{I}\left[\text{Gate structure} \mid \text{Gate 1} \cap \text{Prevent overtopping during design flood}\right] = 0.04 \\
&\qquad = \text{I}\left[\text{Prevent overtopping during design flood} \mid \text{Gate 1}\right] \cdot \\
&\qquad\quad \text{I}\left[\text{Equipment} \mid \text{Prevent overtopping during design flood} \cap \text{Gate 1}\right] \cdot \\
&\qquad\quad \text{I}\left[\text{Gate structure and supports} \mid \text{Equipment} \cap \text{Gate 1}\right] \\
&\text{where} \\
&\qquad\quad \text{I}\left[\text{Prevent overtopping during design flood} \mid \text{Gate 1}\right] = 0.167 \text{ (From Table A.2)} \\
&\qquad\quad \text{I}\left[\text{Equipment} \mid \text{Prevent overtopping during design flood} \cap \text{Gate 1}\right] = 0.8 \text{ (From Table A.3)} \\
&\qquad\quad \text{I}\left[\text{Gate structure and supports} \mid \text{Equipment} \cap \text{Gate 1}\right] = 0.3 \text{ (From Table A.5)}
\end{aligned}
$$

$$
\begin{aligned}
&\text{PR}[\text{Gate structure} \mid \text{Gate 1}] = 1.09 \\
&\qquad = (100 - \text{CI}) \cdot \\
&\qquad\quad \{\text{I}[\text{Prevent overtopping during design flood}] \cdot \text{I}\left[\text{Gate structure} \mid \text{Gate 1} \cap \text{Prevent overtopping during design flood}\right] + \\
&\qquad\quad \text{I}[\text{Prevent overtopping during load rejection}] \cdot \text{I}\left[\text{Gate structure} \mid \text{Gate 1} \cap \text{Prevent overtopping during load rejection}\right] + \\
&\qquad\quad \text{I}[\text{Prevent an unintentional opening}] \cdot \text{I}\left[\text{Gate structure} \mid \text{Gate 1} \cap \text{Prevent an unintentional opening}\right] + \\
&\qquad\quad \text{I}[\text{Prevent a failure to close}] \cdot \text{I}\left[\text{Gate structure} \mid \text{Gate 1} \cap \text{Prevent a failure to close}\right] + \\
&\qquad\quad \text{I}[\text{Drawdown to prevent failure}] \cdot \text{I}\left[\text{Gate structure} \mid \text{Gate 1} \cap \text{Drawsdown to prevent failure}\right]\} \\
&\text{where} \\
&\qquad\quad \text{CI} = 40 \\
&\qquad\quad \text{I}[\text{Prevent overtopping during design flood}] = 0.30 \\
&\qquad\quad \text{I}\left[\text{Gate structure} \mid \text{Gate 1} \cap \text{Prevent overtopping during design flood}\right] = 0.04 \\
&\qquad\quad \text{I}[\text{Prevent overtopping during load rejection}] = 0.50 \\
&\qquad\quad \text{I}\left[\text{Gate structure} \mid \text{Gate 1} \cap \text{Prevent overtopping during load rejection}\right] = 0 \\
&\qquad\quad \text{I}[\text{Prevent an unintentional opening}] = 0.05 \\
&\qquad\quad \text{I}\left[\text{Gate structure} \mid \text{Gate 1} \cap \text{Prevent an unintentional opening}\right] = 0.10 \\
&\qquad\quad \text{I}[\text{Prevent a failure to close}] = 0.05 \\
&\qquad\quad \text{I}\left[\text{Gate structure} \mid \text{Gate 1} \cap \text{Prevent a failure to close}\right] = 0.03 \\
&\qquad\quad \text{I}[\text{Drawdown to prevent failure}] = 0.10 \\
&\qquad\quad \text{I}\left[\text{Gate structure} \mid \text{Gate 1} \cap \text{Drawsdown to prevent failure}\right] = 0.0
\end{aligned}
$$

Table A.9 provides the importance factors calculated for the components that are specific to each hoist using the importance factors listed in Tables A.1 – A.7 and Equations 4.1 – 4.5. The last two columns indicate the condition and the priority ranking of the components. The cells that are shaded in yellow indicate that the components are considered irrelevant or secondary for that dam safety function and their importance is set equal to zero. During the inspection, a separate condition was not assigned to the components of each hoist. In this example, the same conditions are used for the components of each specific hoist. Hoist 1 is used for gates 1 through 5, and hoist 2 is used for gates 2 through 6.

Table A.9. Importance of hoist components — Dam A.

Individual Hoist Components	1) Prevent overtopping due to a design flood	2) Prevent overtopping due to a load rejection	3) Prevent an unintentional opening	4) Prevent a failure to close	5) Draw down the reservoir to prevent a failure due to a structural of foundation problem	CI	PR (100-CI)*I
	0.30	0.50	0.05	0.05	0.10		
Mobile structure to support a shared lifting device (including gantry crane)	0.25	0.09	0.00	0.13	0.27	80.00	3.53
Limit switches	0.08	0.14	0.00	0.10	0.07	0.00	10.51
Motor Control Center or Individual Control Panel	0.08	0.14	0.00	0.10	0.07	20.00	8.40
Distribution panel	0.08	0.14	0.00	0.10	0.07	40.00	6.30
Cam switches	0.08	0.14	0.00	0.10	0.07	30.00	2.50
External resistors	0.08	0.14	0.00	0.10	0.07	20.00	2.86
Screw and Nut (Screw-type hoist)	0.24	0.18	0.00	0.40	0.54	60.00	9.48
Bearings (Radial, thrust, power screw assembly)	0.24	0.18	0.00	0.40	0.54	90.00	2.37
Split Bushing or journal bearing	0.24	0.18	0.00	0.40	0.54	80.00	4.74
Rotating Shafts, Support Bearings and Couplings	0.24	0.18	0.00	0.40	0.54	75.00	5.93
Gear Assembly (hoist)	0.24	0.18	0.00	0.40	0.54	75.00	5.93
Gear Assembly (carriage)	0.24	0.18	0.00	0.40	0.54	75.00	5.93
Non-dedicated lifting connectors (Pins and dogging pins, lugs to the gate)	0.24	0.18	0.00	0.40	0.54	50.00	11.85
Carriage wheels (mobile lifting hoist)	0.24	0.18	0.00	0.40	0.54	60.00	5.88
Hoist Brake	0.24	0.18	0.00	0.40	0.54	85.00	3.56
Carriage Brake	0.24	0.18	0.00	0.40	0.54	95.00	1.19
Translation Motor (electric)	0.24	0.18	0.00	0.40	0.54	90.00	1.47
Lifting Motor (electric) new	0.24	0.18	0.00	0.40	0.54	75.00	5.93
Mobile structure to support a shared lifting device (including gantry	0.25	0.09	0.00	0.13	0.27	80.00	3.53
Limit switches	0.08	0.14	0.00	0.10	0.07	0.00	10.51
Motor Control Center or Individual Control Panel	0.08	0.14	0.00	0.10	0.07	20.00	8.40
Distribution panel	0.08	0.14	0.00	0.10	0.07	40.00	6.30
Cam switches	0.08	0.14	0.00	0.10	0.07	30.00	2.50
External resistors	0.08	0.14	0.00	0.10	0.07	20.00	2.86
Screw and Nut (Screw-type hoist)	0.24	0.18	0.00	0.40	0.54	60.00	9.48
Bearings (Radial, thrust, power screw assembly)	0.24	0.18	0.00	0.40	0.54	90.00	2.37
Split Bushing or journal bearing	0.24	0.18	0.00	0.40	0.54	80.00	4.74
Rotating Shafts, Support Bearings and Couplings	0.24	0.18	0.00	0.40	0.54	75.00	5.93
Gear assembly (exposed or encased) including associated bushing	0.24	0.18	0.00	0.40	0.54	75.00	5.93
Gear assembly (exposed or encased) including associated bushing	0.24	0.18	0.00	0.40	0.54	75.00	5.93
Non-dedicated lifting connectors (Pins and dogging pins, lugs to the	0.24	0.18	0.00	0.40	0.54	50.00	11.85
Carriage wheels (mobile lifting hoist)	0.24	0.18	0.00	0.40	0.54	60.00	5.88
Hoist Brake	0.24	0.18	0.00	0.40	0.54	85.00	3.56
Carriage Brake	0.24	0.18	0.00	0.40	0.54	95.00	1.19
Translation Motor (electric)	0.24	0.18	0.00	0.40	0.54	90.00	1.47
Lifting Motor (electric) new	0.24	0.18	0.00	0.40	0.54	75.00	5.93

Example calculation : Hoist 1, item 8 (Screw and nut)

$$
\begin{aligned}
&\mathrm{I}\left[\text{Screw and nut} \mid \text{Hoist } 1 \cap \text{Prevent overtopping during design flood}\right] = 0.24 \\
&\quad = \mathrm{I}\left[\text{Prevent overtopping during design flood} \mid \text{Gate } 1\right] \cdot \\
&\qquad \mathrm{I}\left[\text{Equipment} \mid \text{Prevent overtopping during design flood} \cap \text{Gate } 1\right] \cdot \\
&\qquad \mathrm{I}\left[\text{Force Transmission} \mid \text{Equipment} \cap \text{Gate } 1\right] + \\
&\qquad \mathrm{I}\left[\text{Prevent overtopping during design flood} \mid \text{Gate } 2\right] \cdot \\
&\qquad \mathrm{I}\left[\text{Equipment} \mid \text{Prevent overtopping during design flood} \cap \text{Gate } 2\right] \cdot \\
&\qquad \mathrm{I}\left[\text{Force Transmission} \mid \text{Equipment} \cap \text{Gate } 2\right] + \\
&\qquad \mathrm{I}\left[\text{Prevent overtopping during design flood} \mid \text{Gate } 3\right] \cdot \\
&\qquad \mathrm{I}\left[\text{Equipment} \mid \text{Prevent overtopping during design flood} \cap \text{Gate } 3\right] \cdot \\
&\qquad \mathrm{I}\left[\text{Force Transmission} \mid \text{Equipment} \cap \text{Gate } 3\right] + \\
&\qquad \mathrm{I}\left[\text{Prevent overtopping during design flood} \mid \text{Gate } 4\right] \cdot \\
&\qquad \mathrm{I}\left[\text{Equipment} \mid \text{Prevent overtopping during design flood} \cap \text{Gate } 4\right] \cdot \\
&\qquad \mathrm{I}\left[\text{Force Transmission} \mid \text{Equipment} \cap \text{Gate } 4\right] + \\
&\qquad \mathrm{I}\left[\text{Prevent overtopping during design flood} \mid \text{Gate } 5\right] \cdot \\
&\qquad \mathrm{I}\left[\text{Equipment} \mid \text{Prevent overtopping during design flood} \cap \text{Gate } 5\right] \cdot \\
&\qquad \mathrm{I}\left[\text{Force Transmission} \mid \text{Equipment} \cap \text{Gate } 5\right]
\end{aligned}
$$

where

$$
\begin{aligned}
&\mathrm{I}\left[\text{Prevent overtopping during design flood} \mid \text{Gate(i)}\right] = 0.167 \quad (i = 1,5) && \text{(Table A.2)} \\
&\mathrm{I}\left[\text{Equipment} \mid \text{Prevent overtopping during design flood} \cap \text{Gate } 1\right] = 0.8 && \text{(Table A.3)} \\
&\mathrm{I}\left[\text{Force Transmission} \mid \text{Equipment} \cap \text{Gate } 1\right] = 0.6 && \text{(Table A.5)} \\
&\mathrm{I}\left[\text{Equipment} \mid \text{Prev. overt. dur. design flood} \cap \text{Gate(i)}\right] = 0.7 \quad (i = 1,5) && \text{(Table A.3)} \\
&\mathrm{I}\left[\text{Force Transmission} \mid \text{Equipment} \cap \text{Gate(i)}\right] = 0.35 \quad (i = 2,5) && \text{(Table A.5)}
\end{aligned}
$$

$$\underline{\text{Example calculation : Hoist 1, item 8 }\left(\text{Screw and nut}\right)}$$

$$
\begin{aligned}
&\text{PR[Screw and nut | Hoist 1]} = 8.77\\
&\quad = (100 - \text{CI}) \cdot\\
&\qquad \{\text{I[Prevent overtopping during design flood]} \cdot \text{I}\left[\text{Screw and nut | Hoist 1} \cap \text{Prevent overtopping during design flood}\right] +\\
&\qquad \text{I[Prevent overtopping during load rejection]} \cdot \text{I}\left[\text{Screw and nut | Hoist 1} \cap \text{Prevent overtopping during load rejection}\right] +\\
&\qquad \text{I[Prevent an unintentional opening]} \cdot \text{I}\left[\text{Screw and nut | Hoist 1} \cap \text{Prevent an unintentional opening}\right] +\\
&\qquad \text{I[Prevent a failure to close]} \cdot \text{I}\left[\text{Screw and nut | Hoist 1} \cap \text{Prevent a failure to close}\right] +\\
&\qquad \text{I[Drawdown to prevent failure]} \cdot \text{I}\left[\text{Screw and nut | Hoist 1} \cap \text{Drawsdown to prevent failure}\right]\}\\
&\text{where}\\
&\qquad \text{CI} = 60\\
&\qquad \text{I[Prevent overtopping during design flood]} = 0.30\\
&\qquad \text{I}\left[\text{Screw and nut | Hoist 1} \cap \text{Prevent overtopping during design flood}\right] = 0.24\\
&\qquad \text{I[Prevent overtopping during load rejection]} = 0.50\\
&\qquad \text{I}\left[\text{Screw and nut | Hoist 1} \cap \text{Prevent overtopping during load rejection}\right] = 0.18\\
&\qquad \text{I[Prevent an unintentional opening]} = 0.05\\
&\qquad \text{I}\left[\text{Screw and nut | Hoist 1} \cap \text{Prevent an unintentional opening}\right] = 0.45\\
&\qquad \text{I[Prevent a failure to close]} = 0.05\\
&\qquad \text{I}\left[\text{Screw and nut | Hoist 1} \cap \text{Prevent a failure to close}\right] = 0.13\\
&\qquad \text{I[Drawdown to prevent failure]} = 0.10\\
&\qquad \text{I}\left[\text{Screw and nut | Hoist 1} \cap \text{Drawsdown to prevent failure}\right] = 0.27
\end{aligned}
$$

Table A.10 provides the importance factors calculated for the components that are shared by all gates using the importance factors listed in Tables A.1 – A.7 and Equations 4.1 – 4.5. The last two columns indicate the condition and the priority ranking of the components. The cells that are shaded in yellow indicate that the components are considered irrelevant or secondary for that dam safety function and their importance is set equal to zero.

Table A.10. Importance of shared components — Dam A.

Shared Components		1) Prevent overtopping due to a design flood	2) Prevent overtopping due to a load rejection	3) Prevent an unintentional opening	4) Prevent a failure to close	5) Draw down the reservoir to prevent a failure due to a structural of foundation problem	CI	PR (100-CI)*I
I(FSS)		0.30	0.30	0.05	0.05	0.10		
Gate Structure and Supports								
	Lifting device structure (steel)	0.29	0.08	0.55	0.16	0.27	75.00	4.66
	Lifting Device Structure (concrete)	0.29	0.08	0.55	0.16	0.27	80.00	3.69
	Carrying Tracks	0.29	0.08	0.55	0.16	0.27	80.00	3.69
Power Supply (Source - Power House)								
	Medium Voltage Overhead Lines	0.02	0.25	0.00	0.03	0.01	60.00	5.26
Power Supply (Source - Power House)								
	Underground and Encased Cables (medium voltage)	0.02	0.25	0.00	0.03	0.01	100.00	0.00
Power Supply (Source - Generator)								
	Local or Emergency Generator	0.01	0.25	0.00	0.01	0.01	0.00	12.75
Power Supply (Cables and Controls)								
	Power feeder cables (low voltage)	0.09	0.14	0.00	0.12	0.07	100.00	0.00
	Transformer	0.09	0.14	0.00	0.12	0.07	90.00	1.09
	Power source transfer system	0.09	0.14	0.00	0.12	0.07	90.00	1.09
Gathering Information								
	River Flow Measurement (manual or electronic)	0.05	0.00	0.32	0.04	0.00	45.00	1.88
	Reservoir level indicator	0.05	0.00	0.32	0.04	0.00	45.00	1.88
	Precipitation and Temperature Gauge Network	0.05	0.00	0.32	0.04	0.00	80.00	0.66
	Snow Measuring Stations	0.05	0.00	0.32	0.04	0.00	65.00	1.18
	Gate Position Indicator	0.05	0.00	0.32	0.04	0.00	0.00	3.36
Decision process								
	Decision process	0.09	0.04	0.14	0.12	0.00	75.00	1.49
	Telecommunication system	0.09	0.04	0.14	0.12	0.00	80.00	1.17
	Public Protection and Warning System	0.09	0.04	0.14	0.12	0.00	15.00	4.96
	Operating procedures	0.09	0.04	0.14	0.12	0.00	0.00	5.83
Access and Operation								
	Qualification and training of operator	0.12	0.07	0.00	0.04	0.10	70.00	2.42
	Availability and Mobilization (Design flood)	0.12	0.07	0.00	0.04	0.10	65.00	1.28
	Availability and Mobilization (Load rejection)	0.12	0.07	0.00	0.04	0.10	85.00	0.48
	Lighting system (normal and emergency)	0.12	0.07	0.00	0.04	0.10	20.00	6.44
	Road	0.12	0.07	0.00	0.04	0.10	35.00	5.23
	Alternate means of access	0.12	0.07	0.00	0.04	0.10	30.00	5.64
	Local access	0.12	0.07	0.00	0.04	0.10	10.00	7.25

The priority rankings and the conditions for each component of the spillway are illustrated in Figure A.3 in order of decreasing priority.

Example calculation : Emergency Generator (item 7 in the list)

$$
\begin{aligned}
&\text{I}\left[\text{Emergency Generator} \mid \text{Prevent overtopping during load rejection}\right] = 0.24\\
&\quad = \text{I}\left[\text{Prevent overtopping during load rejection} \mid \text{Gate 1}\right]\cdot\\
&\qquad \text{I}\left[\text{Equipment} \mid \text{Prevent overtopping during load rejection} \cap \text{Gate 1}\right]\cdot\\
&\qquad \text{I}\left[\text{Power supply} \mid \text{Equipment} \cap \text{Prev. overtop during load rejection} \cap \text{Gate 1}\right]\cdot\\
&\qquad \text{I}[\text{Power source} \mid \text{Power supply} \cap \text{Prev. overtop during load rejection} \cap \text{Gate 1}]\cdot\\
&\qquad \text{I}[\text{Emergency Generator} \mid \text{Power source} \cap \text{Prev. overtop during load rejection} \cap \text{Gate 1}] +\\
&\qquad \text{I}\left[\text{Prevent overtopping during load rejection} \mid \text{Gate 2}\right]\cdot\\
&\qquad \text{I}\left[\text{Equipment} \mid \text{Prevent overtopping during load rejection} \cap \text{Gate 2}\right]\cdot\\
&\qquad \text{I}\left[\text{Power supply} \mid \text{Equipment} \cap \text{Prev. overtop during load rejection} \cap \text{Gate 2}\right]\cdot\\
&\qquad \text{I}[\text{Power source} \mid \text{Power supply} \cap \text{Prev. overtop during load rejection} \cap \text{Gate 2}]\cdot\\
&\qquad \text{I}[\text{Emergency Generator} \mid \text{Power source} \cap \text{Prev. overtop during load rejection} \cap \text{Gate 2}] +\\
&\qquad \text{I}\left[\text{Prevent overtopping during load rejection} \mid \text{Gate 3}\right]\cdot\\
&\qquad \text{I}\left[\text{Equipment} \mid \text{Prevent overtopping during load rejection} \cap \text{Gate 3}\right]\cdot\\
&\qquad \text{I}\left[\text{Power supply} \mid \text{Equipment} \cap \text{Prev. overtop during load rejection} \cap \text{Gate 3}\right]\cdot\\
&\qquad \text{I}[\text{Power source} \mid \text{Power supply} \cap \text{Prev. overtop during load rejection} \cap \text{Gate 3}]\cdot\\
&\qquad \text{I}[\text{Emergency Generator} \mid \text{Power source} \cap \text{Prev. overtop during load rejection} \cap \text{Gate 3}] +\\
&\qquad \text{I}\left[\text{Prevent overtopping during load rejection} \mid \text{Gate 4}\right]\cdot\\
&\qquad \text{I}\left[\text{Equipment} \mid \text{Prevent overtopping during load rejection} \cap \text{Gate 4}\right]\cdot\\
&\qquad \text{I}\left[\text{Power supply} \mid \text{Equipment} \cap \text{Prev. overtop during load rejection} \cap \text{Gate 4}\right]\cdot\\
&\qquad \text{I}[\text{Power source} \mid \text{Power supply} \cap \text{Prev. overtop during load rejection} \cap \text{Gate 4}]\cdot\\
&\qquad \text{I}[\text{Emergency Generator} \mid \text{Power source} \cap \text{Prev. overtop during load rejection} \cap \text{Gate 4}] +\\
&\qquad \text{I}\left[\text{Prevent overtopping during load rejection} \mid \text{Gate 5}\right]\cdot\\
&\qquad \text{I}\left[\text{Equipment} \mid \text{Prevent overtopping during load rejection} \cap \text{Gate 5}\right]\cdot\\
&\qquad \text{I}\left[\text{Power supply} \mid \text{Equipment} \cap \text{Prev. overtop during load rejection} \cap \text{Gate 5}\right]\cdot\\
&\qquad \text{I}[\text{Power source} \mid \text{Power supply} \cap \text{Prev. overtop during load rejection} \cap \text{Gate 5}]\cdot\\
&\qquad \text{I}[\text{Emergency Generator} \mid \text{Power source} \cap \text{Prev. overtop during load rejection} \cap \text{Gate 5}] +\\
&\qquad \text{I}\left[\text{Prevent overtopping during load rejection} \mid \text{Gate 6}\right]\cdot\\
&\qquad \text{I}\left[\text{Equipment} \mid \text{Prevent overtopping during load rejection} \cap \text{Gate 6}\right]\cdot\\
&\qquad \text{I}\left[\text{Power supply} \mid \text{Equipment} \cap \text{Prev. overtop during load rejection} \cap \text{Gate 6}\right]\cdot\\
&\qquad \text{I}[\text{Power source} \mid \text{Power supply} \cap \text{Prev. overtop during load rejection} \cap \text{Gate 6}]\cdot\\
&\qquad \text{I}[\text{Emergency Generator} \mid \text{Power source} \cap \text{Prev. overtop during load rejection} \cap \text{Gate 6}]
\end{aligned}
$$

where

$$
\begin{aligned}
&\text{I}\left[\text{Prevent overtopping during load rejection} \mid \text{Gate(i)}\right] = 0.167 \quad (\text{i} = 1,6) && \text{(Table A.2)}\\
&\text{I}\left[\text{Equipment} \mid \text{Prevent overtopping during load rejection} \cap \text{Gate(i)}\right] = 0.0 \;\; (\text{i} = 1,2,3,6) && \text{(Table A.3)}\\
&\text{I}\left[\text{Equipment} \mid \text{Prevent overtopping during load rejection} \cap \text{Gate(i)}\right] = 0.9 \;\; (\text{i} = 4,5) && \text{(Table A.3)}\\
&\text{I}\left[\text{Power supply} \mid \text{Equipment} \cap \text{Prev. overtop during load rejection} \cap \text{Gate(i)}\right] = 0.0 \;\; (\text{i} = 1,2,3,6) && \text{(Table A.5)}\\
&\text{I}\left[\text{Power supply} \mid \text{Equipment} \cap \text{Prev. overtop during load rejection} \cap \text{Gate(i)}\right] = 0.7 \;\; (\text{i} = 4,5) && \text{(Table A.5)}\\
&\text{I}[\text{Power source} \mid \text{Power supply} \cap \text{Prev. overtop during load rejection} \cap \text{Gate(i)}] = 0.0 \;\; (\text{i} = 1,2,3,6) && \text{(Table A.6)}\\
&\text{I}[\text{Power source} \mid \text{Power supply} \cap \text{Prev. overtop during load rejection} \cap \text{Gate(i)}] = 0.78 \;\; (\text{i} = 4,5) && \text{(Table A.6)}\\
&\text{I}[\text{Emergency generator} \mid \text{Power source} \cap \text{Prev. overtop during load rejection} \cap \text{Gate(i)}] = 0.0\; (\text{i} = 1,2,3,6) && \text{(Table A.7)}\\
&\text{I}[\text{Emergency generator} \mid \text{Power source} \cap \text{Prev. overtop during load rejection} \cap \text{Gate(i)}] = 0.5\; (\text{i} = 4,5) && \text{(Table A.7)}
\end{aligned}
$$

Example calculation : Emergency Generator

$$
\begin{aligned}
&\mathrm{PR}[\text{Emergency Generator}] = 12.67\\
&\quad = (100 - \mathrm{CI}) \cdot\\
&\qquad \{\mathrm{I}[\text{Prevent overtopping during design flood}] \cdot \mathrm{I}\left[\text{Emergency Generator} \mid \text{Prevent overtopping during design flood}\right] +\\
&\qquad \mathrm{I}[\text{Prevent overtopping during load rejection}] \cdot \mathrm{I}\left[\text{Emergency Generator} \mid \text{Prevent overtopping during load rejection}\right] +\\
&\qquad \mathrm{I}[\text{Prevent an unintentional opening}] \cdot \mathrm{I}\left[\text{Emergency Generator} \mid \text{Prevent an unintentional opening}\right] +\\
&\qquad \mathrm{I}[\text{Prevent a failure to close}] \cdot \mathrm{I}\left[\text{Emergency Generator} \mid \text{Prevent a failure to close}\right] +\\
&\qquad \mathrm{I}[\text{Drawdown to prevent failure}] \cdot \mathrm{I}\left[\text{Emergency Generator} \mid \text{Drawsdown to prevent failure}\right]\}
\end{aligned}
$$

where

$$
\begin{aligned}
&\mathrm{CI} = 0\\
&\mathrm{I}[\text{Prevent overtopping during design flood}] = 0.30\\
&\mathrm{I}\left[\text{Emergency Generator} \mid \text{Prevent overtopping during design flood}\right] = 0.01\\
&\mathrm{I}[\text{Prevent overtopping during load rejection}] = 0.50\\
&\mathrm{I}\left[\text{Emergency Generator} \mid \text{Prevent overtopping during load rejection}\right] = 0.25\\
&\mathrm{I}[\text{Prevent an unintentional opening}] = 0.05\\
&\mathrm{I}\left[\text{Emergency Generator} \mid \text{Prevent an unintentional opening}\right] = 0.0\\
&\mathrm{I}[\text{Prevent a failure to close}] = 0.05\\
&\mathrm{I}\left[\text{Emergency Generator} \mid \text{Prevent a failure to close}\right] = 0.01\\
&\mathrm{I}[\text{Drawdown to prevent failure}] = 0.10\\
&\mathrm{I}\left[\text{Emergency Generator} \mid \text{PDrawdown to prevent failure}\right] = 0.01
\end{aligned}
$$

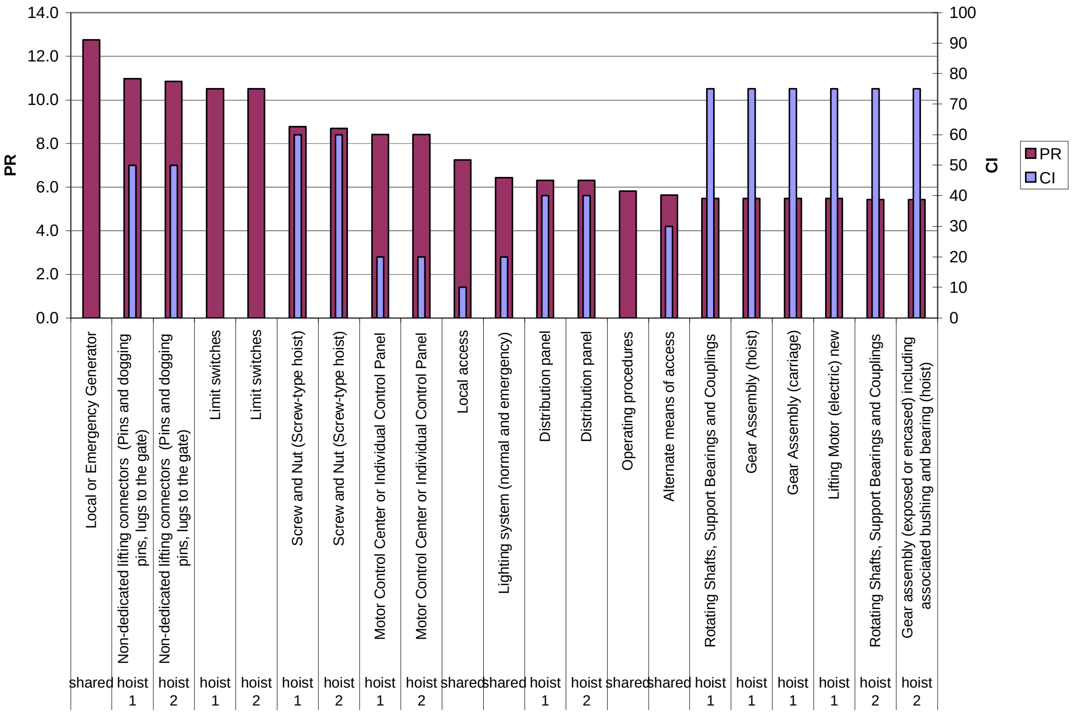


Figure A.3. Condition and priority rankings — Dam A.

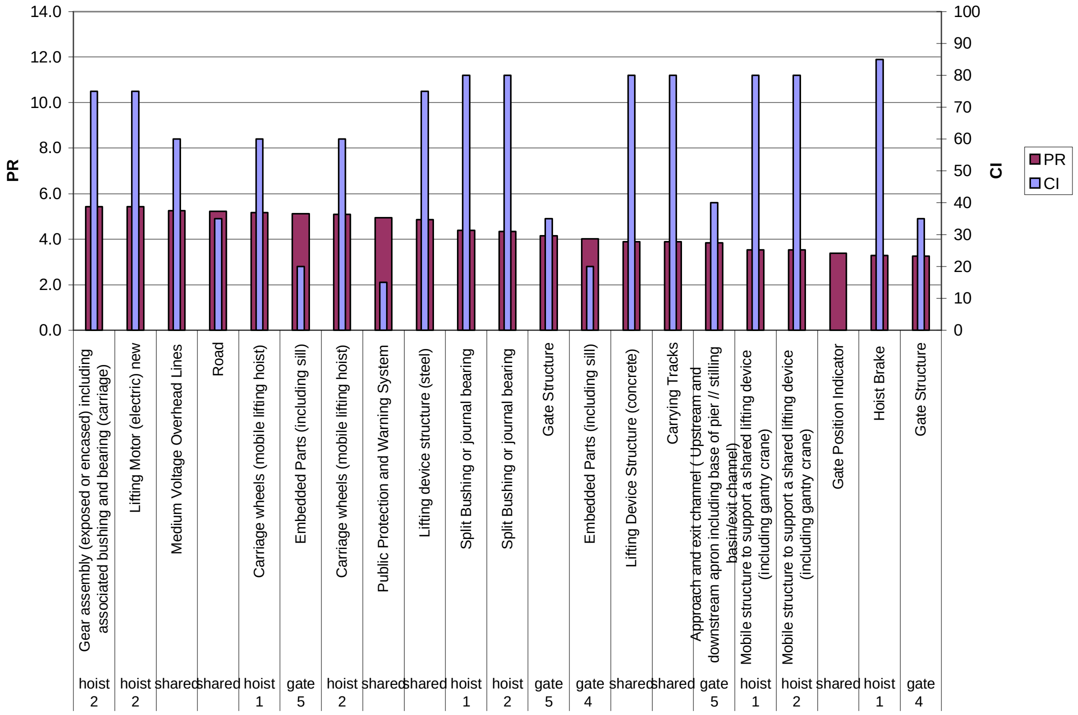


Figure A.3 (continued). Condition and priority rankings — Dam A.

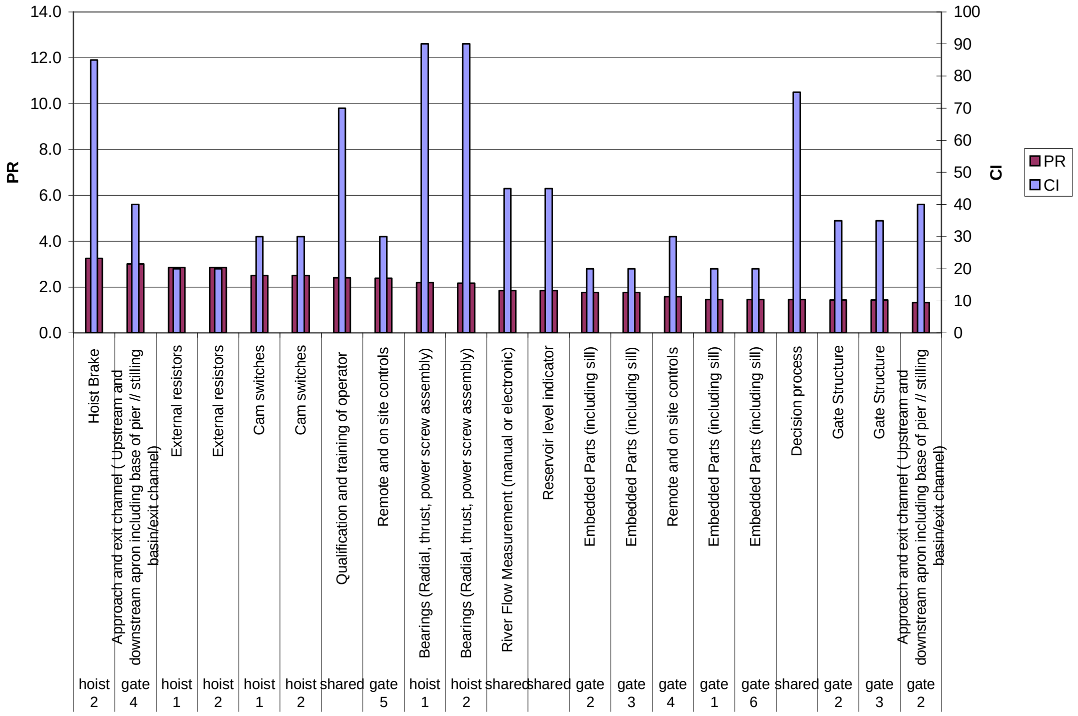


Figure A.3 (continued). Condition and priority rankings — Dam A.

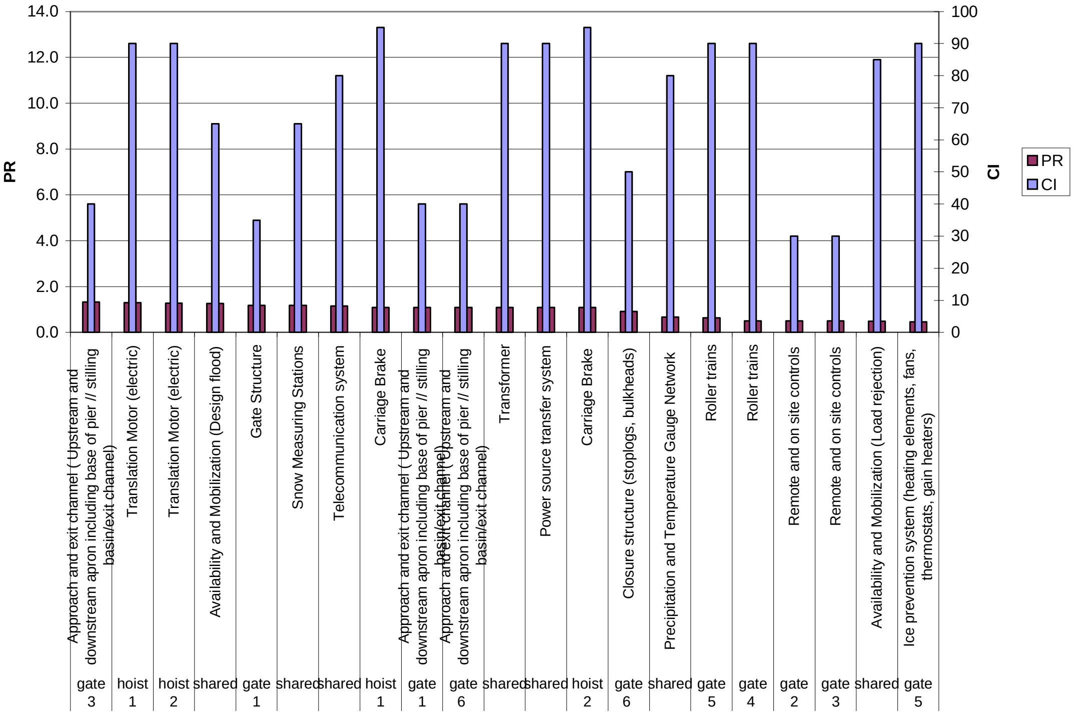


Figure A.3 (continued). Condition and priority rankings — Dam A.

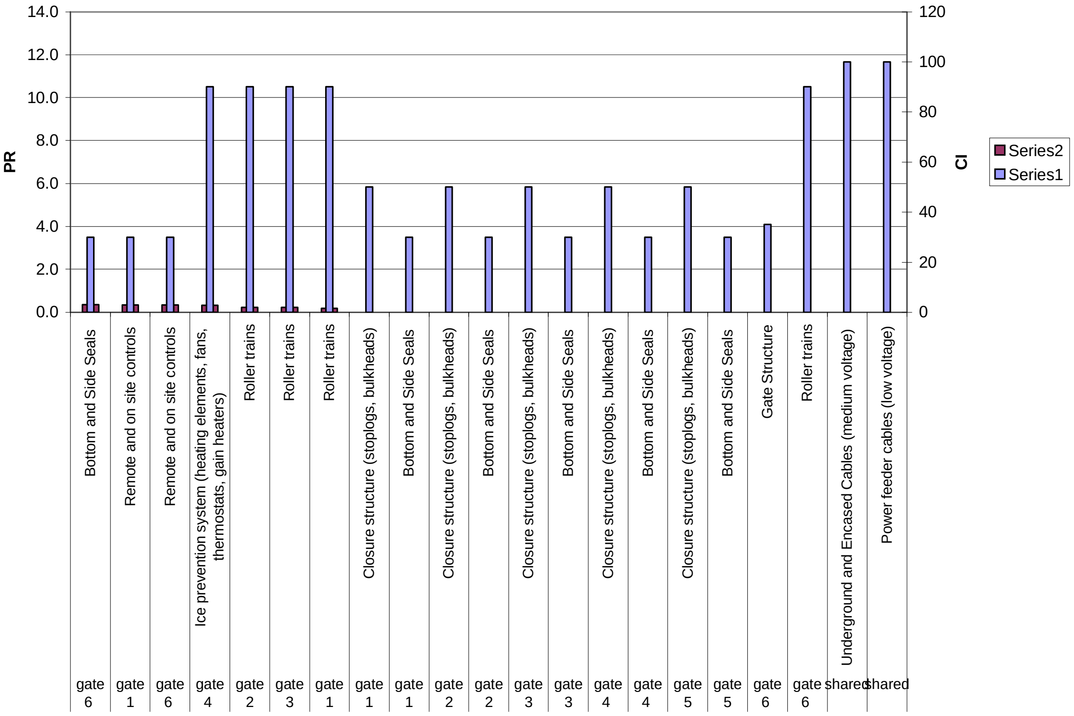


Figure A.3 (concluded). Condition and priority rankings — Dam A.

Summary of importance factors for Dam A

Questions (Answers to questions are recorded on Figure A.4.)

Level 2

Given your understanding of the characteristics of the spillway, its performance history, hydrologic parameters, and location, which spillway functions concern you the most in terms of dam safety?

Level 3

Considering a given dam safety function, what is the relative importance of the gates of the spillway?

Level 4

Considering a given dam safety function and the timely operation of a gate, what is the relative importance of operational and equipment deficiencies?

Level 5

Given a dam safety function and gate, what is the relative likelihood that a problem with 1) gathering information, 2) the decision process, or 3) the access and controls, would prevent the proper operation of the gate within the required time?

Given a dam safety function and gate, what is the relative likelihood that a problem with 1) the power supply, 2) the force transmission, or 3) the gate structure and support, would prevent the proper operation of the gate within the required time?

Level 6

i) Given a dam safety function and gate, what is the relative likelihood that failure of the power supply is due to a failure of 1) the power source, or 2) the cables and controls?

ii) Given a dam safety function and gate, what is the relative importance of the sources of power: 1) the power plant, and 2) the emergency generator?

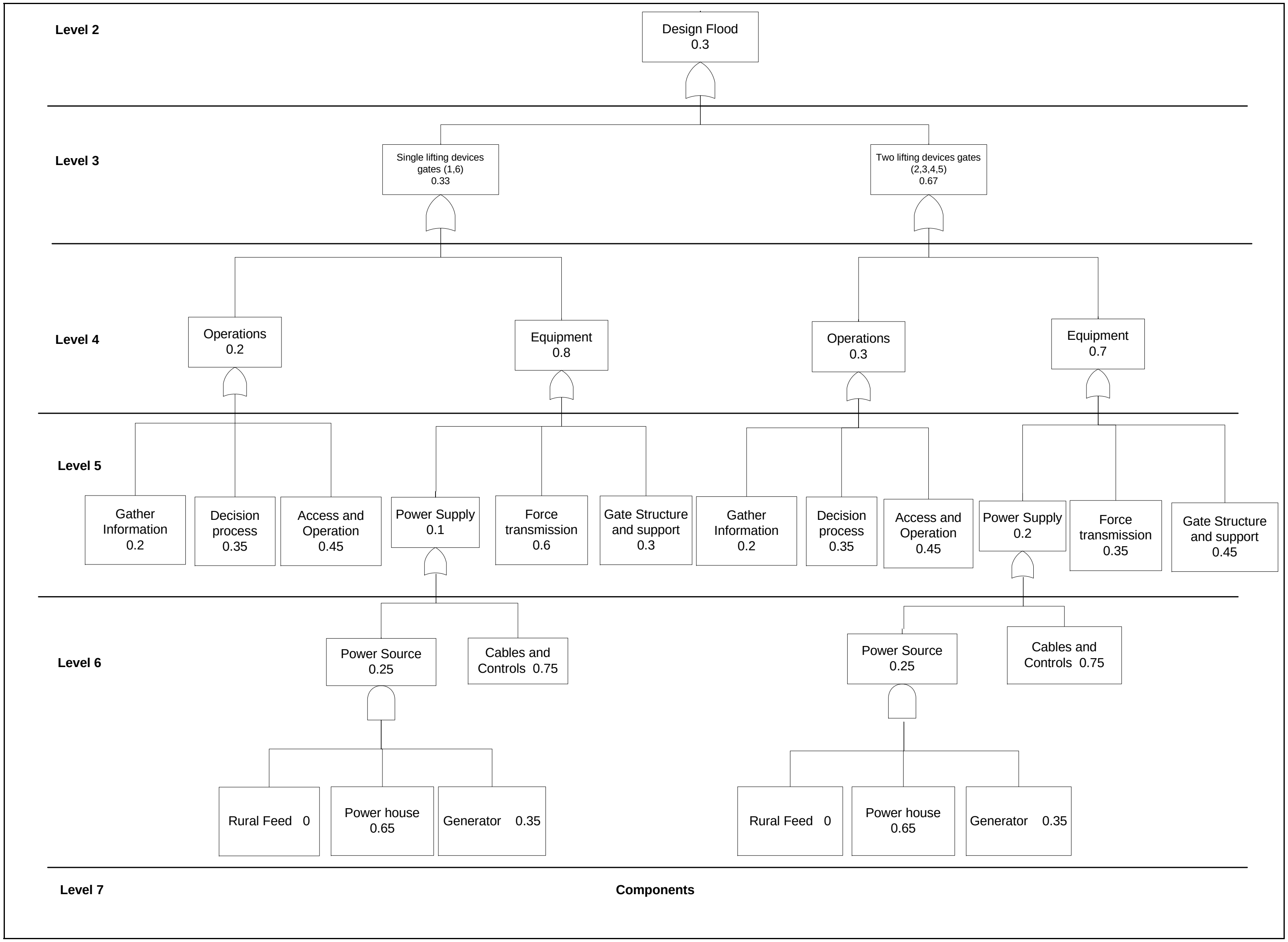


Figure A.4. Importance factors for Dam A (design flood).

Questions (Answers to questions are recorded on Figure A.5.)

Level 2

Given your understanding of the characteristics of the spillway, its performance history, hydrologic parameters, and location, which spillway functions concern you the most in terms of dam safety?

Level 3

Considering a given dam safety function, what is the relative importance of the gates of the spillway?

Level 4

Considering a given dam safety function and the timely operation of a gate, what is the relative importance of operational and equipment deficiencies?

Level 5

Given a dam safety function and gate, what is the relative likelihood that a problem with 1) gathering information, 2) the decision process, or 3) the access and controls, would prevent the proper operation of the gate within the required time?

Given a dam safety function and gate, what is the relative likelihood that a problem with 1) the power supply, 2) the force transmission, or 3) the gate structure and support, would prevent the proper operation of the gate within the required time?

Level 6

i) Given a dam safety function and gate, what is the relative likelihood that failure of the power supply is due to a failure of 1) the power source, or 2) the cables and controls?

ii) Given a dam safety function and gate, what is the relative importance of the sources of power: 1) the power plant, and 2) the emergency generator?

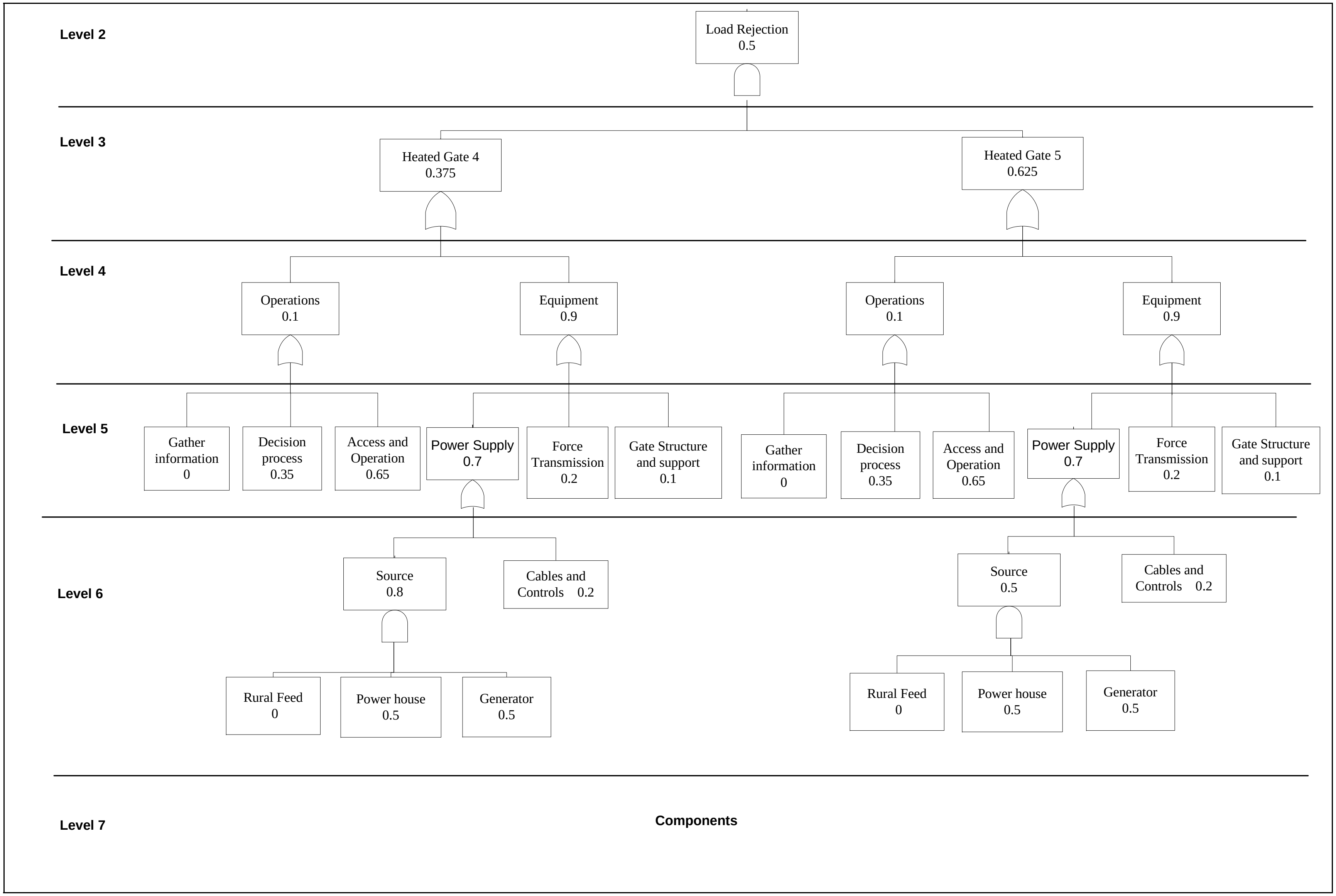


Figure A.5. Importance factors for Dam A (load rejection).

Questions (Answers to questions are recorded on Figure A.6.)

Level 2

Given your understanding of the characteristics of the spillway, its performance history, hydrologic parameters, and location, which spillway functions concern you the most in terms of dam safety?

Level 3

Considering a given dam safety function, what is the relative importance of the gates of the spillway?

Level 4

Considering a given dam safety function and the timely operation of a gate, what is the relative importance of operational and equipment deficiencies?

Level 5

Given a dam safety function and gate, what is the relative likelihood that a problem with 1) gathering information, 2) the decision process, or 3) the access and controls, would prevent the proper operation of the gate within the required time?

Given a dam safety function and gate, what is the relative likelihood that a problem with 1) the power supply, 2) the force transmission, or 3) the gate structure and support, would prevent the proper operation of the gate within the required time?

Level 6

i) Given a dam safety function and gate, what is the relative likelihood that failure of the power supply is due to a failure of 1) the power source, or 2) the cables and controls?

ii) Given a dam safety function and gate, what is the relative importance of the sources of power: 1) the power plant, and 2) the emergency generator?

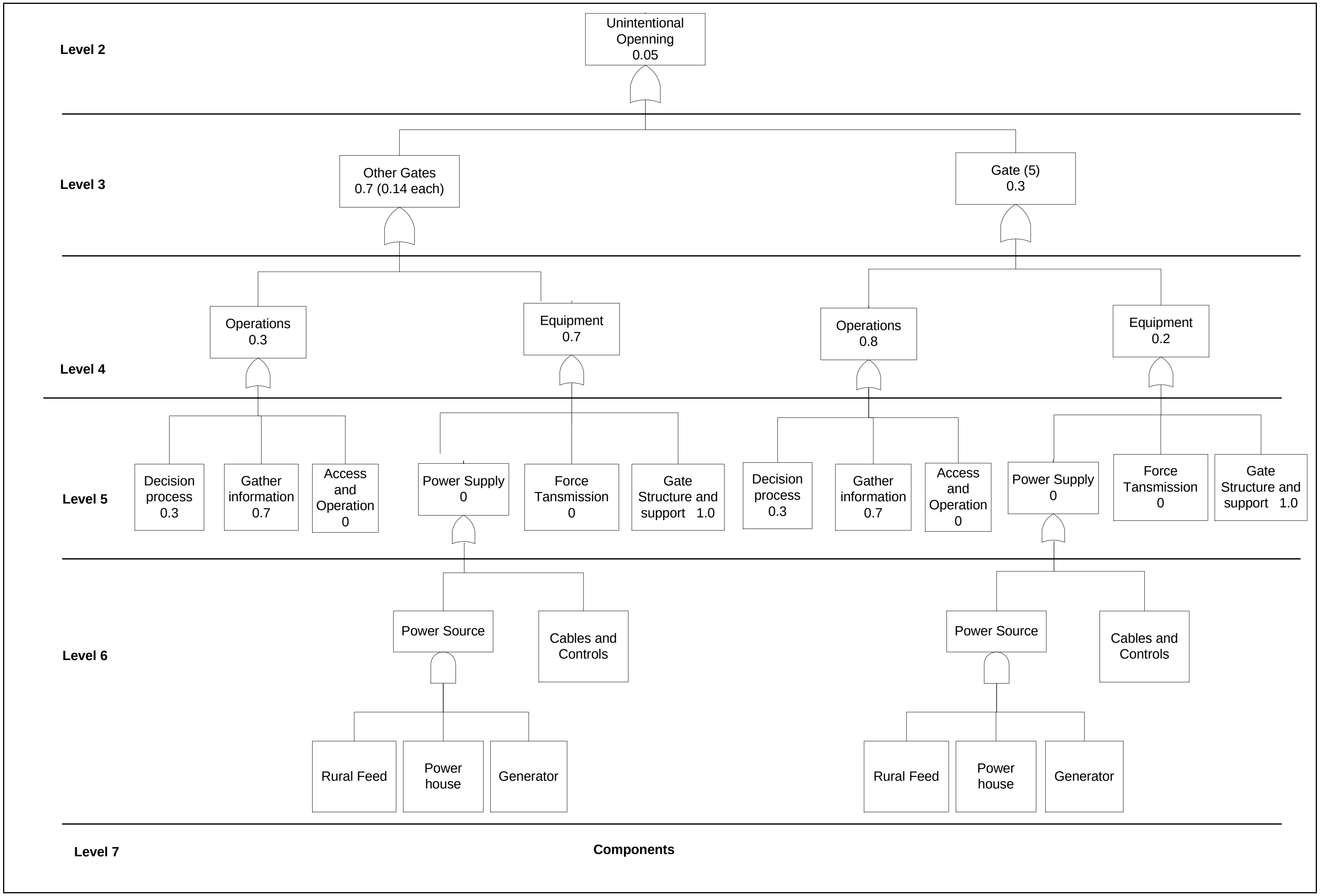


Figure A.6. Importance factors for Dam A (unintentional opening).

Questions (Answers to questions are recorded on Figure A.7.)

Level 2

Given your understanding of the characteristics of the spillway, its performance history, hydrologic parameters, and location, which spillway functions concern you the most in terms of dam safety?

Level 3

Considering a given dam safety function, what is the relative importance of the gates of the spillway?

Level 4

Considering a given dam safety function and the timely operation of a gate, what is the relative importance of operational and equipment deficiencies?

Level 5

Given a dam safety function and gate, what is the relative likelihood that a problem with 1) gathering information, 2) the decision process, or 3) the access and controls, would prevent the proper operation of the gate within the required time?

Given a dam safety function and gate, what is the relative likelihood that a problem with 1) the power supply, 2) the force transmission, or 3) the gate structure and support, would prevent the proper operation of the gate within the required time?

Level 6

i) Given a dam safety function and gate, what is the relative likelihood that failure of the power supply is due to a failure of 1) the power source, or 2) the cables and controls?

ii) Given a dam safety function and gate, what is the relative importance of the sources of power: 1) the power plant, and 2) the emergency generator?

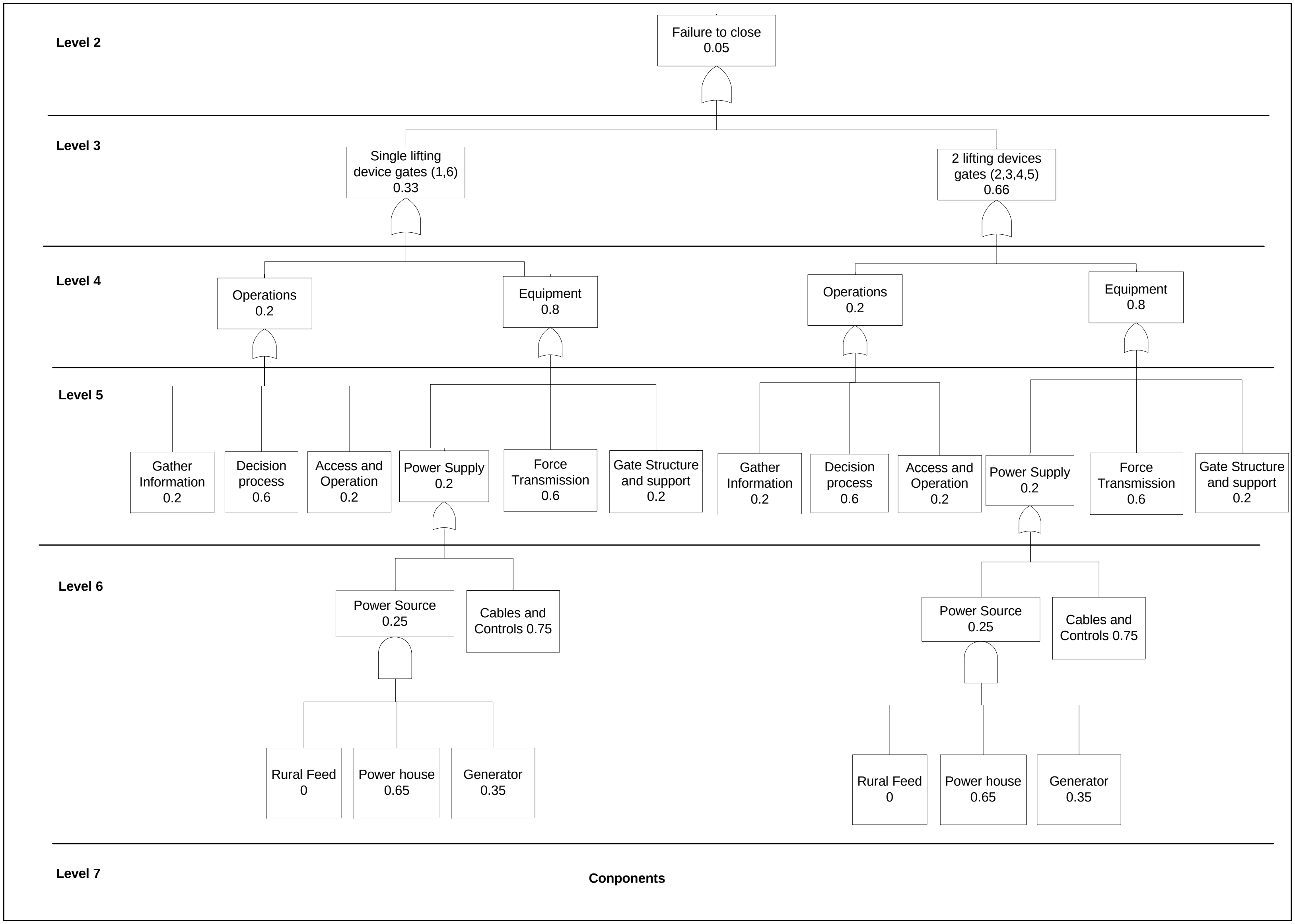


Figure A.7. Importance factors for Dam A (failure to close).

Questions (Answers to questions are recorded on Figure A.8.)

Level 2

Given your understanding of the characteristics of the spillway, its performance history, hydrologic parameters, and location, which spillway functions concern you the most in terms of dam safety?

Level 3

Considering a given dam safety function, what is the relative importance of the gates of the spillway?

Level 4

Considering a given dam safety function and the timely operation of a gate, what is the relative importance of operational and equipment deficiencies?

Level 5

Given a dam safety function and gate, what is the relative likelihood that a problem with 1) gathering information, 2) the decision process, or 3) the access and controls, would prevent the proper operation of the gate within the required time?

Given a dam safety function and gate, what is the relative likelihood that a problem with 1) the power supply, 2) the force transmission, or 3) the gate structure and support, would prevent the proper operation of the gate within the required time?

Level 6

i) Given a dam safety function and gate, what is the relative likelihood that failure of the power supply is due to a failure of 1) the power source, or 2) the cables and controls?

ii) Given a dam safety function and gate, what is the relative importance of the sources of power: 1) the power plant, and 2) the emergency generator?

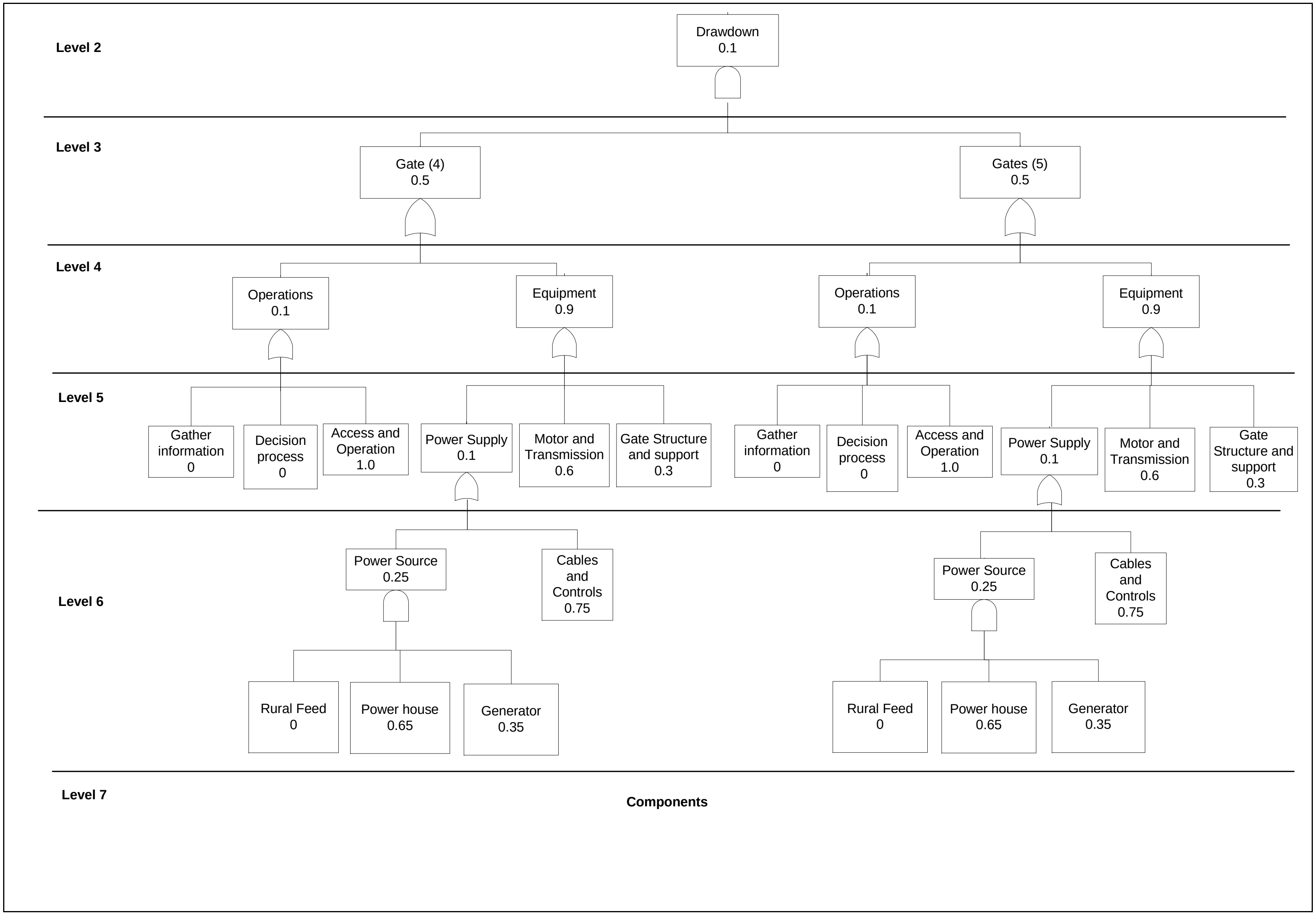


Figure A.8. Importance factors for Dam A (drawdown).

Appendix B: Dam B (Manitoba Hydro)

Features of Dam B

The spillway of Dam B is located on the Winnipeg River and consists of four vertical lift gates with dedicated lifting systems. All four gates are heated. The location and features of the power plant and spillway are summarized in Figures B.1 through B.4.

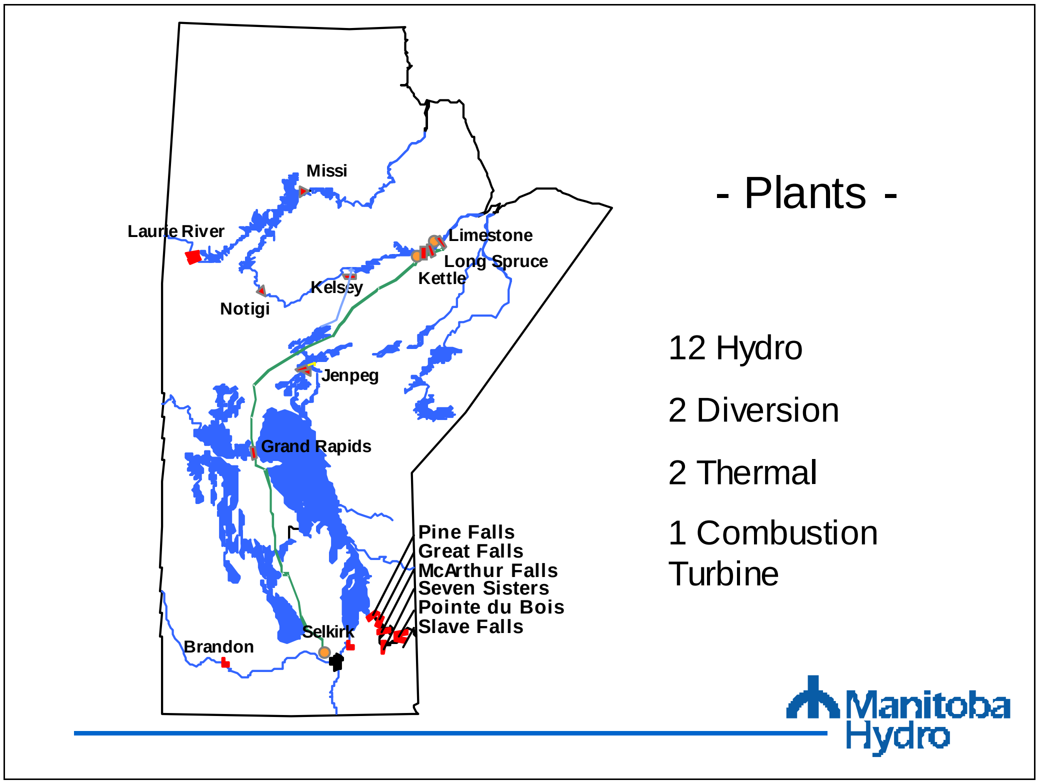
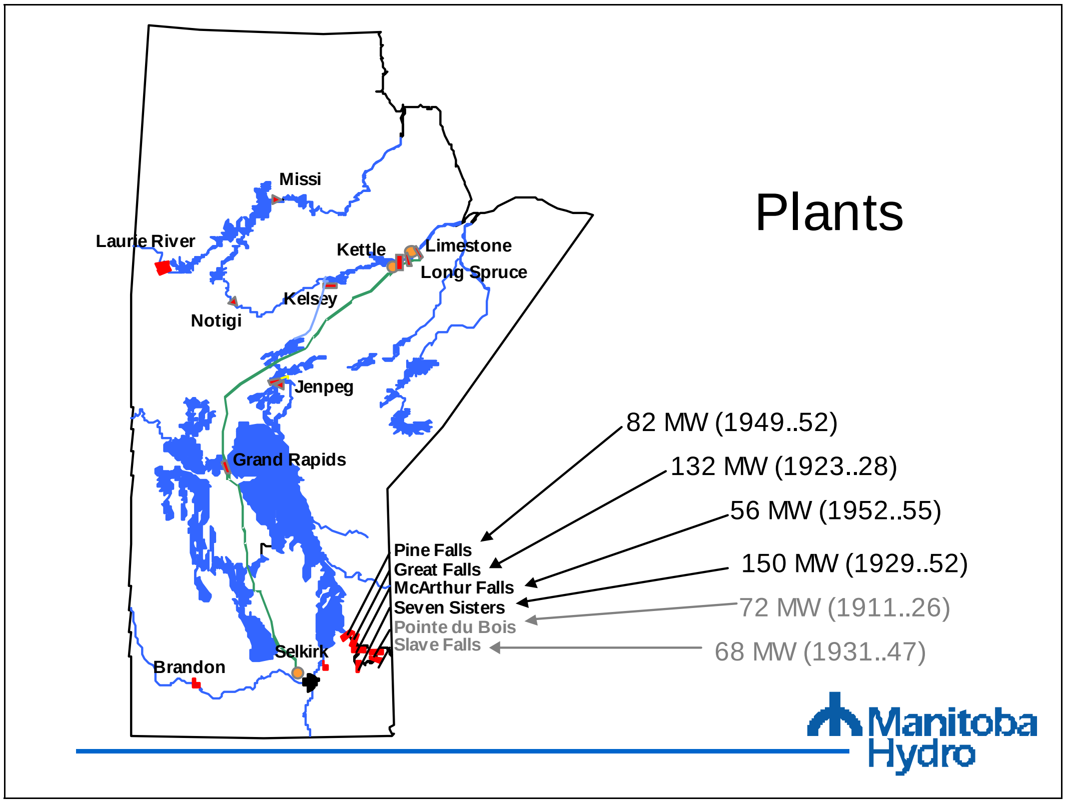


Figure B.1. Manitoba Hydro power plants.



Plants

82 MW (1949..52)

132 MW (1923..28)

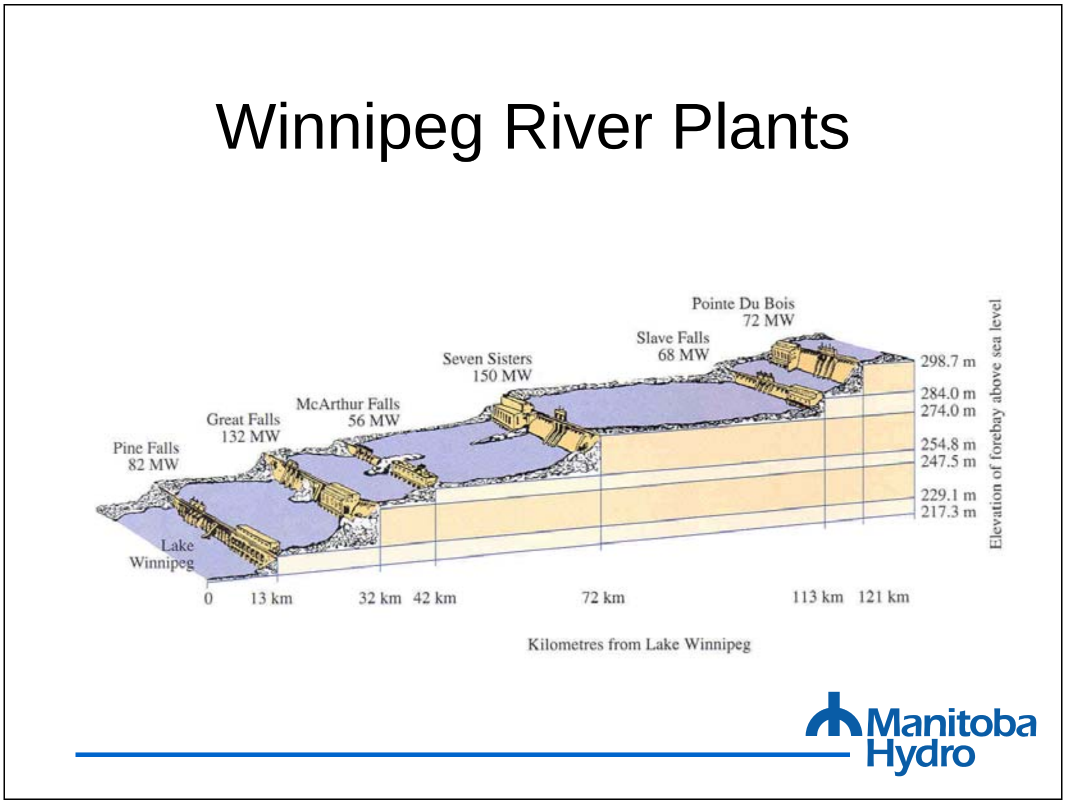
56 MW (1952..55)

150 MW (1929..52)

72 MW (1911..26)

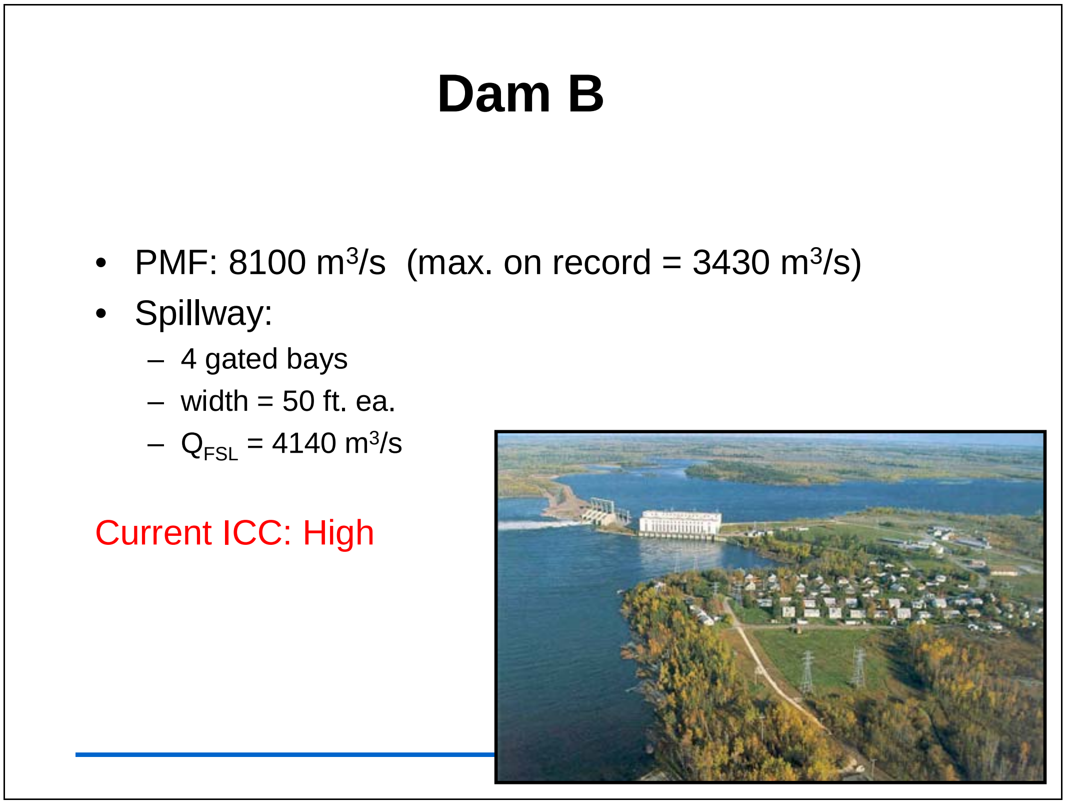
68 MW (1931..47)

Figure B.2. Manitoba Hydro power plants, capacity, and year of construction.



Winnipeg River Plants

Figure B.3. Winnipeg River plants.



Dam B

- PMF: 8100 m^3/s (max. on record = 3430 m^3/s)
- Spillway:
  - – 4 gated bays
  - – width = 50 ft. ea.
  - – Q_{FSL} = 4140 m^3/s

Current ICC: High

Figure B.4. Features of the Dam B spillway.

The four gates are heated and have dedicated hoists. The block diagram of Figure B.5 is a representation of the spillway that is common for all dam safety functions.

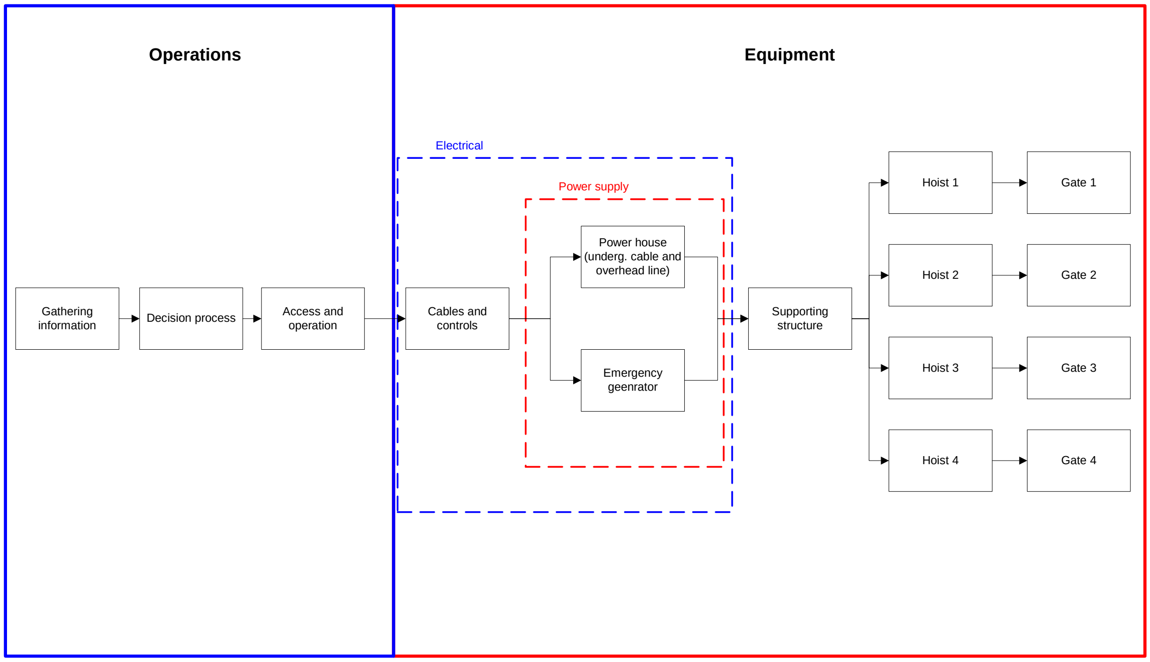


Figure B.5. Block diagram of Dam B spillway.

Importance factors

Step 1: Importance of the facility

The relative importance of the spillway at Dam B is determined by using a scoring procedure developed by Manitoba Hydro.

Step 2: Importance of dam safety functions

Question 1

Given your understanding of the characteristics of the spillway, performance history, and setting, which spillway functions concern you the most in terms of dam safety?

Table B.1. Importance of dam safety functions.

	Dam Safety Functions	I_{DSF}
1)	Prevent overtopping due to a design flood	0.80
2)	Prevent overtopping due to a load rejection	0.10
3)	Prevent an uncontrolled release	0.05
4)	Prevent a failure to close	0.05
5)	Draw down the reservoir to prevent a failure due to a structural or foundation problem	0.00

Justifications: Overtopping due to the design flood is the main dam safety concern. Drawdown the reservoir was not considered important but could be required in the case of severe windstorms.

Step 3: Importance of the gates

Question 2

Considering a given dam safety function, what is the relative importance of the gates of the spillway?

Table B.2. Importance of gates (*I[Gate|DSF]*).

	DSF				
	1) Prevent overtopping due to a design flood	2) Prevent overtopping due to a load rejection	3) Prevent an unintentional opening	4) Prevent a failure to close	5) Drawdown to prevent a dam failure.
I_{DSF}	0.80	0.10	0.05	0.05	0.00
Gate 1	0.25	0.25	0.25	0.25	0
Gate 2	0.25	0.25	0.25	0.25	0
Gate 3	0.25	0.25	0.25	0.25	0
Gate 4	0.25	0.25	0.25	0.25	0

Justifications: All gates have the same importance because they are all heated, all have dedicated hoists, and there is no difference in “operability” from one gate to another

Step 4: Importance of operational and equipment deficiencies

Question 3

Considering a given dam safety function and the timely operation of a gate, what is the relative importance of operational and equipment deficiencies?

Table B.3. Importance of operational and equipment deficiencies (*I[Oper|DSF], I[Equip|DSF]*).

DSF	Operations	Equipment
1) Prevent overtopping due to a design flood	0.3	0.7
2) Prevent overtopping due to a load rejection	0.2	0.8
3) Prevent an unintentional opening	0.9	0.1
4) Prevent a failure to close	0.1	0.9
5) Draw down the reservoir to prevent a dam failure	0.8	0.2

Step 5: Importance of types of operations and equipment

Question 4b (*I[type of operations| DSF]*)

Given a dam safety function and gate, what is the relative likelihood that a problem with 1) gathering information, 2) the decision process, or 3) the access and controls, would prevent the proper operation of the gate within the required time?

Table B.4. Importance of operations (*I[type of operations* | *DSF]*).

DSF		
1) Prevent overtopping due to a design flood	Gathering Information	0.35
	Decision process	0.55
	Access and operation	0.1
2) Prevent overtopping due to a load rejection	Gathering Information	0.25
	Decision process	0.7
	Access and operation	0.05
3) Prevent an unintentional opening	Gathering Information	0.2
	Decision process	0.8
	Access and operation	0
4) Prevent a failure to close	Gathering Information	0.7
	Decision process	0.25
	Access and operation	0.05
5) Drawdown to prevent a dam failure.	Gathering Information	0
	Decision process	0
	Access and operation	0

Question 4a (*I[type of equipment|DSF]*)

Given a dam safety function and gate, what is the relative likelihood that a problem with 1) the power supply, 2) the force transmission, or 3) the gate structure and support, would prevent the proper operation of the gate within the required time?

Table B.5. Importance of equipment (*I[type of equipment|DSF]*).

DSF		
1) Prevent overtopping due to a design flood	Power Supply	0.4
	Force Transmission	0.5
	Gate structures and support	0.1
2) Prevent overtopping due to a load rejection	Power Supply	0.8
	Force Transmission	0.1
	Gate structures and support	0.1
3) Prevent an unintentional opening	Power Supply	0.9
	Force Transmission	0
	Gate structures and support	0.1
4) Prevent a failure to close	Power Supply	0.2
	Force Transmission	0.2
	Gate structures and support	0.6
5) Drawdown to prevent a dam failure.	Power Supply	0
	Force Transmission	0
	Gate structures and support	0

i) Given a dam safety function and gate, what is the relative likelihood that failure of the power supply is due to a failure of 1) the power source, or 2) the cables and controls?

Table B.6. Importance of power supply (*I[PS|DSF]*).

DSF		
1) Prevent overtopping due to a design flood	Cables and controls	0.6
	Power Source	0.4
2) Prevent overtopping due to a load rejection	Cables and controls	0.8
	Power Source	0.2
3) Prevent an unintentional opening	Cables and controls	1
	Power Source	0
4) Prevent a failure to close	Cables and controls	0.5
	Power Source	0.5
5) Drawdown to prevent a dam failure.	Cables and controls	0
	Power Source	0

ii) Given a dam safety function and gate, what is the relative likelihood that a power source failure is due to a failure of 1) the external power source, 2) the powerhouse, or 3) the emergency generator?

Table B.7. Importance of power source.

DSF		
1) Prevent overtopping due to a design flood	Rural Feed	0
	Power House	0.8
	Emergency Generator	0.2
2) Prevent overtopping due to a load rejection	Rural Feed	0
	Power House	0.9
	Emergency Generator	0.1
3) Prevent an unintentional opening	Rural Feed	0
	Power House	0
	Emergency Generator	0
4) Prevent a failure to close	Rural Feed	0
	Power House	0.8
	Emergency Generator	0.2
5) Drawdown to prevent a dam failure.	Rural Feed	0
	Power House	0
	Emergency Generator	0

Table B.8 provides the importance factors calculated for the components that are specific to each gate using the importance factors listed in Table B.1 – B.7 and Equations 4.1 – 4.5. The last two columns indicate the condition and the priority ranking of the components. The conditions were obtained during site inspections and from interviews with facilities personnel.

Cells that are shaded in yellow indicate the components considered irrelevant or secondary for that dam safety function, and their importance is set equal to zero. During the inspection, a separate condition was not assigned to the components of each gate. In this example, the same conditions are used for the components of each gate.

Table B.8. Importance of gate components and priority rankings.

	Component	1) Prevent overtopping due to a design flood	2) Prevent overtopping due to a load rejection	3) Prevent an unintentional opening	4) Prevent a failure to close	5) Drawdown to prevent a dam failure.	CI	PR (100-CI)*I
I[DSF]		0.80	0.10	0.05	0.05	0.00		
Gate Structure and Supports								
	Embedded parts	0.018	0.020	0.003	0.135	0.000	84.00	0.37
	Gate Structure	0.018	0.020	0.003	0.135	0.000	85.00	0.34
	Mobile Structure to support a shared lifting device	0.018	0.020	0.003	0.135	0.000	NA	NA
	Approach and Exit Channel	0.018	0.020	0.003	0.135	0.000	95.00	0.11
	Carrying tracks	0.018	0.020	0.003	0.135	0.000	NA	NA
	Closure Structure	0.018	0.020	0.003	0.135	0.000	95.00	0.00
	Bottom and side seals	0.018	0.020	0.003	0.135	0.000	90.00	0.00
	Ice Prevention System (heating element, fans, thermostats, gain heaters)	0.018	0.020	0.003	0.135	0.000	100.00	0.00
Force Transmission								
	Trunnin assembly (radial gates)	0.088	0.020	0.000	0.045	0.000	NA	NA
	Trunnion beam and anchorage	0.088	0.020	0.000	0.045	0.000	NA	NA
Access and control								0.00
	Remote and on site controls	0.008	0.003	0.000	0.001	0.000	95.00	0.03

$$\underline{\text{Example calculation : Gate 1, item 2 (Gate structure and supports)}}$$

$$
\begin{aligned}
&\mathrm{I}\left[\text{Gate structure and supports} \cap \text{Prevent overtopping during design flood} \mid \text{Gate 1}\right] = 0.018\\
&\quad = \mathrm{I}\left[\text{Prevent overtopping during design flood} \mid \text{Gate 1}\right] \cdot\\
&\qquad \mathrm{I}\left[\text{Equipment} \mid \text{Prevent overtopping during design flood} \cap \text{Gate 1}\right] \cdot\\
&\qquad \mathrm{I}\left[\text{Gate structure and supports} \mid \text{Equipment} \cap \text{Gate 1}\right]\\
&\text{where}\\
&\qquad \mathrm{I}\left[\text{Prevent overtopping during design flood} \mid \text{Gate 1}\right] = 0.25 \text{ (From Table B.2)}\\
&\qquad \mathrm{I}\left[\text{Equipment} \mid \text{Prevent overtopping during design flood} \cap \text{Gate 1}\right] = 0.7 \text{ (From Table B.3)}\\
&\qquad \mathrm{I}\left[\text{Gate structure and supports} \mid \text{Equipment} \cap \text{Gate 1}\right] = 0.1 \text{ (From Table B.5)}
\end{aligned}
$$

$$
\begin{aligned}
&\mathrm{PR}[\text{Gate structure} \mid \text{Gate 1}] = 0.37\\
&\quad = (100 - \mathrm{CI}) \cdot\\
&\qquad \{\mathrm{I}[\text{Prevent overtopping during design flood}] \cdot \mathrm{I}\left[\text{Gate structure} \mid \text{Gate 1} \cap \text{Prevent overtopping during design flood}\right] +\\
&\qquad \mathrm{I}[\text{Prevent overtopping during load rejection}] \cdot \mathrm{I}\left[\text{Gate structure} \mid \text{Gate 1} \cap \text{Prevent overtopping during load rejection}\right] +\\
&\qquad \mathrm{I}[\text{Prevent an unintentional opening}] \cdot \mathrm{I}\left[\text{Gate structure} \mid \text{Gate 1} \cap \text{Prevent an unintentional opening}\right] +\\
&\qquad \mathrm{I}[\text{Prevent a failure to close}] \cdot \mathrm{I}\left[\text{Gate structure} \mid \text{Gate 1} \cap \text{Prevent a failure to close}\right] +\\
&\qquad \mathrm{I}[\text{Drawdown to prevent failure}] \cdot \mathrm{I}\left[\text{Gate structure} \mid \text{Gate 1} \cap \text{Drawsdown to prevent failure}\right]\}\\
&\text{where}\\
&\qquad \mathrm{CI} = 85\\
&\qquad \mathrm{I}[\text{Prevent overtopping during design flood}] = 0.80\\
&\qquad \mathrm{I}\left[\text{Gate structure} \mid \text{Gate 1} \cap \text{Prevent overtopping during design flood}\right] = 0.018\\
&\qquad \mathrm{I}[\text{Prevent overtopping during load rejection}] = 0.10\\
&\qquad \mathrm{I}\left[\text{Gate structure} \mid \text{Gate 1} \cap \text{Prevent overtopping during load rejection}\right] = 0.020\\
&\qquad \mathrm{I}[\text{Prevent an unintentional opening}] = 0.02\\
&\qquad \mathrm{I}\left[\text{Gate structure} \mid \text{Gate 1} \cap \text{Prevent an unintentional opening}\right] = 0.003\\
&\qquad \mathrm{I}[\text{Prevent a failure to close}] = 0.05\\
&\qquad \mathrm{I}\left[\text{Gate structure} \mid \text{Gate 1} \cap \text{Prevent a failure to close}\right] = 0.135\\
&\qquad \mathrm{I}[\text{Drawdown to prevent failure}] = 0.0\\
&\qquad \mathrm{I}\left[\text{Gate structure} \mid \text{Gate 1} \cap \text{Drawsdown to prevent failure}\right] = 0.0
\end{aligned}
$$

Table B.9 provides the importance factors calculated for the components that are specific to each hoist using the importance factors listed in Table B.1 – B.7 and Equations 4.1 – 4.5. The last two columns indicate the condition and the priority ranking of the components. Cells shaded in yellow indicate the components are considered irrelevant or secondary for that dam safety function, and their importance is set equal to zero. During the inspection, a separate condition was not assigned to the components of each hoist. In this example, the same conditions are used for the components of each specific hoist.

Table B.9. Importance of hoist components.

Component		1) Prevent overtopping due to a design flood	2) Prevent overtopping due to a load rejection	3) Prevent an uncontrolled release	4) Prevent a failure to close	5) Drawdown to prevent a dam failure.	CI	PR (100-CI)*I
I[DSF]		0.80	0.10	0.05	0.05	0.00		
Power supply and controls								
	Limit Switches	0.042	0.128	0.023	0.023	0.000	100.00	0.00
	Motor Control Centre or Individual Control Panel	0.042	0.128	0.023	0.023	0.000	100.00	0.00
	Distribution Panel	0.042	0.128	0.023	0.023	0.000	100.00	0.00
	Cam Switches	0.042	0.128	0.023	0.023	0.000	100.00	0.00
	External resistors	0.042	0.128	0.023	0.023	0.000	NA	NA
	Inverter Control system (includes the rectifier system)	0.042	0.128	0.023	0.023	0.000	NA	NA
Force Transmission								
	Screw and nut thread (server type hoist)	0.088	0.020	0.000	0.045	0.000	NA	NA
	Bearings (Radial, thrust, power screw assembly)	0.088	0.020	0.000	0.045	0.000	NA	NA
	Trunnion assembly	0.088	0.020	0.000	0.045	0.000	NA	NA
	Split bushing or journal bearing	0.088	0.020	0.000	0.045	0.000	100.00	0.00
	Rotating shafts, support bearings and coupling	0.088	0.020	0.000	0.045	0.000	100.00	0.00
	Gear assembly (exposed or encased) including associated bushing and bearing	0.088	0.020	0.000	0.045	0.000	90.00	0.74
	Wheel, axles and bearings for vertical lift gates	0.088	0.020	0.000	0.045	0.000	90.00	0.74
	Non-dedicated lifting connectors (pins and dogging pins, lugs to the gate)	0.088	0.020	0.000	0.045	0.000	100.00	0.00
	Dedicated lifting connectors (pins, lugs, clevises and chain connectors)	0.088	0.020	0.000	0.045	0.000	95.00	0.37
	Carriage wheel (mobile lifting hoist)	0.088	0.020	0.000	0.045	0.000	NA	NA
	Clutch and transmission	0.088	0.020	0.000	0.045	0.000	NA	NA
	Drum, sheaves and pulleys	0.088	0.020	0.000	0.045	0.000	90.00	0.74
	Brake (hoist)	0.088	0.020	0.000	0.045	0.000	95.00	0.37
	Fan Brake	0.088	0.020	0.000	0.045	0.000	100.00	0.00
	Wire rope and connectors	0.088	0.020	0.000	0.045	0.000	90.00	0.74
	Chain and sprocket assembly	0.088	0.020	0.000	0.045	0.000	NA	NA
	Hydraulic Cylinder assembly	0.088	0.020	0.000	0.045	0.000	NA	NA
	Translation motor (electric)	0.088	0.020	0.000	0.045	0.000	NA	NA
	Lifting motor (electric)	0.088	0.020	0.000	0.045	0.000	100.00	0.00

$$\underline{\text{Example calculation : Hoist 1 (Gate 1), item 12 (Gear Assembly)}}$$

$$\begin{aligned}
&I[\text{Gear Assembly} \mid \text{Hoist 1} \cap \text{Prevent overtopping during design flood}] = 0.088\\
&\quad = I[\text{Prevent overtopping during design flood} \mid \text{Gate 1}]\cdot\\
&\qquad I[\text{Equipment} \mid \text{Prevent overtopping during design flood} \cap \text{Gate 1}]\cdot\\
&\qquad I[\text{Force Transmission} \mid \text{Equipment} \cap \text{Gate 1}]\\
&\text{where}\\
&\qquad I[\text{Prevent overtopping during design flood} \mid \text{Gate1}] = 0.25 \qquad \text{(Table B.2)}\\
&\qquad I[\text{Equipment} \mid \text{Prevent overtopping during design flood} \cap \text{Gate 1}] = 0.7 \quad \text{(Table B.3)}\\
&\qquad I[\text{Force Transmission} \mid \text{Equipment} \cap \text{Gate 1}] = 0.5 \qquad \text{(Table B.5)}
\end{aligned}$$

$$\underline{\text{Example calculation : Hoist 1 (Gate 1), item 12 (Gear Assembly)}}$$

$$\begin{aligned}
&PR[\text{Gear Assembly} \mid \text{Hoist 1}] = 0.74\\
&\quad = (100 - CI)\cdot\\
&\qquad \{I[\text{Prevent overtopping during design flood}]\cdot I[\text{Gear Assembly} \mid \text{Hoist 1} \cap \text{Prevent overtopping during design flood}] +\\
&\qquad I[\text{Prevent overtopping during load rejection}]\cdot I[\text{Gear Assembly} \mid \text{Hoist 1} \cap \text{Prevent overtopping during load rejection}] +\\
&\qquad I[\text{Prevent an unintentional opening}]\cdot I[\text{Gear Assembly} \mid \text{Hoist 1} \cap \text{Prevent an unintentional opening}] +\\
&\qquad I[\text{Prevent a failure to close}]\cdot I[\text{Gear Assembly} \mid \text{Hoist 1} \cap \text{Prevent a failure to close}] +\\
&\qquad I[\text{Drawdown to prevent failure}]\cdot I[\text{Gear Assembly} \mid \text{Hoist 1} \cap \text{Drawsdown to prevent failure}]\}\\
&\text{where}\\
&\qquad CI = 90\\
&\qquad I[\text{Prevent overtopping during design flood}] = 0.80\\
&\qquad I[\text{Gear Assembly} \mid \text{Hoist 1} \cap \text{Prevent overtopping during design flood}] = 0.088\\
&\qquad I[\text{Prevent overtopping during load rejection}] = 0.10\\
&\qquad I[\text{Gear Assembly} \mid \text{Hoist 1} \cap \text{Prevent overtopping during load rejection}] = 0.020\\
&\qquad I[\text{Prevent an unintentional opening}] = 0.05\\
&\qquad I[\text{Gear Assemblyt} \mid \text{Hoist 1} \cap \text{Prevent an unintentional opening}] = 0.0\\
&\qquad I[\text{Prevent a failure to close}] = 0.05\\
&\qquad I[\text{Gear Assemblyt} \mid \text{Hoist 1} \cap \text{Prevent a failure to close}] = 0.045\\
&\qquad I[\text{Drawdown to prevent failure}] = 0.0\\
&\qquad I[\text{Gear Assembly} \mid \text{Hoist 1} \cap \text{Drawsdown to prevent failure}] = 0.0
\end{aligned}$$

Table B.10 provides the importance factors calculated for the components that are shared by all gates using the importance factors listed in Table B.1 – B.7 and Equations 4.1 – 4.5. The last two columns indicate the condition and the priority ranking of the components. Cells shaded in yellow indicate the components are considered irrelevant or secondary for that dam safety function, and their importance is set equal to zero.

Table B.10. Importance of shared components.

	Component	1) Prevent overtopping due to a design flood	2) Prevent overtopping due to a load rejection	3) Prevent an uncontrolled release	4) Prevent a failure to close	5) Drawdown to prevent a dam failure.	CI	PR (100-CI) . I
DSF		0.80	0.10	0.05	0.05	0.00		
Gate structure and supports								
	Lifting device structure (Steel)	0.070	0.080	0.010	0.540	0.000	95.00	0.4575
	Lifting device structure (Concrete)	0.070	0.080	0.010	0.540	0.000	95.00	0.4575
	Ice Prevention System (air bubbler)	0.070	0.080	0.010	0.540	0.000	NA	NA
Power supply (source)						0.000		
	Medium Voltage overhead lines	0.090	0.230	0.000	0.072	0.000	NA	NA
	Local or Emergency Generators	0.090	0.230	0.000	0.072	0.000	100.00	0
Power supply (cables and controls)								
	Underground and Encased Cables (medium voltage)	0.168	0.512	0.090	0.090	0.000	100.00	0
	Power Feeder Cables (low voltage)	0.168	0.512	0.090	0.090	0.000	100.00	0
	Transformer	0.168	0.512	0.090	0.090	0.000	85.00	2.919
	Power Source Transfer System	0.168	0.512	0.090	0.090	0.000	100.00	0
Gathering information								
	River flow measurement (manual or electronic)	0.105	0.050	0.180	0.070	0.000	84.00	0.28
	Reservoir level indicator (manual or electronic)	0.105	0.050	0.180	0.070	0.000	65.00	3.5525
	Precipitation and temperature gauge network	0.105	0.050	0.180	0.070	0.000	50.00	0.875
	Snow measuring stations	0.105	0.050	0.180	0.070	0.000	50.00	0.875
	Flow Prediction model	0.105	0.050	0.180	0.070	0.000	50.00	0.875
	Weather forecasting	0.105	0.050	0.180	0.070	0.000	75.00	0.4375
	Data transmission (Microwave, telephone, satellite, radio, manual download)	0.105	0.050	0.180	0.070	0.000	NA	NA
	Ice and debris management	0.105	0.050	0.180	0.070	0.000	95.00	0.0875
	Gate position indicator	0.105	0.050	0.180	0.070	0.000	99.00	0.1015
	Third party flow data	0.105	0.050	0.180	0.070	0.000	100.00	0
Decision process								
	Data Processing	0.165	0.140	0.720	0.025	0.000	100.00	0
	Analysis (water management systems)	0.165	0.140	0.720	0.025	0.000	69.00	5.68075
	Decision process	0.165	0.140	0.720	0.025	0.000	50.00	9.1625
	Telecommunication system	0.165	0.140	0.720	0.025	0.000	NA	NA
	Public Protection and Warning System	0.165	0.140	0.720	0.025	0.000	95.00	0.91625
	Automated Data Acquisition Systems	0.165	0.140	0.720	0.025	0.000	NA	NA
	Operating Procedures	0.165	0.140	0.720	0.025	0.000	84.00	2.932
Access and operations								
	Availability and mobilization (Load rejection)	0.030	0.010	0.000	0.005	0.000	100.00	0
	Availability and Mobilization (Design flood)	0.030	0.010	0.000	0.005	0.000	100.00	0
	Qualification and training of operator	0.030	0.010	0.000	0.005	0.000	100.00	0
	Portable equipment for lifting gates	0.030	0.010	0.000	0.005	0.000	NA	NA
	Road	0.030	0.010	0.000	0.005	0.000	NA	NA
	Alternate means of access	0.030	0.010	0.000	0.005	0.000	NA	NA
	Local access	0.030	0.010	0.000	0.005	0.000	90.00	0.2525
	Lighting system (normal and emergency)	0.030	0.010	0.000	0.005	0.000	100.00	0

Example calculation : Emergency Generator (item 6 in the list)

$$
\begin{aligned}
&\text{I}\left[\text{Emergency Generator} \mid \text{Prevent overtopping during design flood}\right] = 0.090\\
&\quad = \text{I}\left[\text{Prevent overtopping during design flood} \mid \text{Gate 1}\right]\cdot\\
&\qquad \text{I}\left[\text{Equipment} \mid \text{Prevent overtopping during design flood} \cap \text{Gate 1}\right]\cdot\\
&\qquad \text{I}\left[\text{Power supply} \mid \text{Equipment} \cap \text{Prev. overtop during design flood} \cap \text{Gate 1}\right]\cdot\\
&\qquad \text{I}[\text{Power source} \mid \text{Power supply} \cap \text{Prev. overtop during design flood} \cap \text{Gate 1}]\cdot\\
&\qquad \text{I}[\text{Emergency Generator} \mid \text{Power source} \cap \text{Prev. overtop during design flood} \cap \text{Gate 1}] +\\
&\qquad \text{I}\left[\text{Prevent overtopping during design flood} \mid \text{Gate 2}\right]\cdot\\
&\qquad \text{I}\left[\text{Equipment} \mid \text{Prevent overtopping during design flood} \cap \text{Gate 2}\right]\cdot\\
&\qquad \text{I}\left[\text{Power supply} \mid \text{Equipment} \cap \text{Prev. overtop during design flood} \cap \text{Gate 2}\right]\cdot\\
&\qquad \text{I}[\text{Power source} \mid \text{Power supply} \cap \text{Prev. overtop during design flood} \cap \text{Gate 2}]\cdot\\
&\qquad \text{I}[\text{Emergency Generator} \mid \text{Power source} \cap \text{Prev. overtop during design flood} \cap \text{Gate 2}] +\\
&\qquad \text{I}\left[\text{Prevent overtopping during design flood} \mid \text{Gate 3}\right]\cdot\\
&\qquad \text{I}\left[\text{Equipment} \mid \text{Prevent overtopping during design flood} \cap \text{Gate 3}\right]\cdot\\
&\qquad \text{I}\left[\text{Power supply} \mid \text{Equipment} \cap \text{Prev. overtop during design flood} \cap \text{Gate 3}\right]\cdot\\
&\qquad \text{I}[\text{Power source} \mid \text{Power supply} \cap \text{Prev. overtop during design flood} \cap \text{Gate 3}]\cdot\\
&\qquad \text{I}[\text{Emergency Generator} \mid \text{Power source} \cap \text{Prev. overtop during design flood} \cap \text{Gate 3}] +\\
&\qquad \text{I}\left[\text{Prevent overtopping during design flood} \mid \text{Gate 4}\right]\cdot\\
&\qquad \text{I}\left[\text{Equipment} \mid \text{Prevent overtopping during design flood} \cap \text{Gate 4}\right]\cdot\\
&\qquad \text{I}\left[\text{Power supply} \mid \text{Equipment} \cap \text{Prev. overtop during design flood} \cap \text{Gate 4}\right]\cdot\\
&\qquad \text{I}[\text{Power source} \mid \text{Power supply} \cap \text{Prev. overtop during design flood} \cap \text{Gate 4}]\cdot\\
&\qquad \text{I}[\text{Emergency Generator} \mid \text{Power source} \cap \text{Prev. overtop during design flood} \cap \text{Gate 4}]
\end{aligned}
$$

where

$$
\begin{aligned}
&\text{I}\left[\text{Prevent overtopping during design flood} \mid \text{Gate(i)}\right] = 0.25 \quad (\text{i} = 1{,}4) && \text{(Table B.2)}\\
&\text{I}\left[\text{Equipment} \mid \text{Prevent overtopping during design flood} \cap \text{Gate(i)}\right] = 0.70\ (\text{i} = 1{,}4) && \text{(Table B.3)}\\
&\text{I}\left[\text{Power supply} \mid \text{Equipment} \cap \text{Prev. overtop during design flood} \cap \text{Gate(i)}\right] = 0.40\ (\text{i} = 1{,}4) && \text{(Table B.5)}\\
&\text{I}[\text{Power source} \mid \text{Power supply} \cap \text{Prev. overtop during design flood} \cap \text{Gate(i)}] = 0.40\ (\text{i} = 1{,}4) && \text{(Table B.6)}\\
&\text{I}[\text{Emergency Generator} \mid \text{Power source} \cap \text{Prev. overtop during design flood} \cap \text{Gate(i)}] = 0.2\ (\text{i} = 1{,}4) && \text{(Table B.7)}
\end{aligned}
$$

$\underline{\text{Example calculation : Emergency Generator}}$

$$
\begin{aligned}
&\text{PR[Emergency Generator]} = 0. \\
&\quad = (100 - \text{CI}) \cdot \\
&\qquad \{\text{I[Prevent overtopping during design flood]} \cdot \text{I}\big[\text{Emergency Generator} \mid \text{Prevent overtopping during design flood}\big] + \\
&\qquad \text{I[Prevent overtopping during load rejection]} \cdot \text{I}\big[\text{Emergency Generator} \mid \text{Prevent overtopping during load rejection}\big] + \\
&\qquad \text{I[Prevent an unintentional opening]} \cdot \text{I}\big[\text{Emergency Generator} \mid \text{Prevent an unintentional opening}\big] + \\
&\qquad \text{I[Prevent a failure to close]} \cdot \text{I}\big[\text{Emergency Generator} \mid \text{Prevent a failure to close}\big] + \\
&\qquad \text{I[Drawdown to prevent failure]} \cdot \text{I}\big[\text{Emergency Generator} \mid \text{Drawsdown to prevent failure}\big]\}
\end{aligned}
$$

where

$$
\begin{aligned}
&\text{CI} = 100 \\
&\text{I[Prevent overtopping during design flood]} = 0.80 \\
&\text{I}\big[\text{Emergency Generator} \mid \text{Prevent overtopping during design flood}\big] = 0.09 \\
&\text{I[Prevent overtopping during load rejection]} = 0.10 \\
&\text{I}\big[\text{Emergency Generator} \mid \text{Prevent overtopping during load rejection}\big] = 0.23 \\
&\text{I[Prevent an unintentional opening]} = 0.05 \\
&\text{I}\big[\text{Emergency Generator} \mid \text{Prevent an unintentional opening}\big] = 0.0 \\
&\text{I[Prevent a failure to close]} = 0.05 \\
&\text{I}\big[\text{Emergency Generator} \mid \text{Prevent a failure to close}\big] = 0.072 \\
&\text{I[Drawdown to prevent failure]} = 0.0 \\
&\text{I}\big[\text{Emergency Generator} \mid \text{PDrawdown to prevent failure}\big] = 0.0
\end{aligned}
$$

The priority rankings and the conditions for each component of the spillway are illustrated in Figure B.6 in order of decreasing priority.

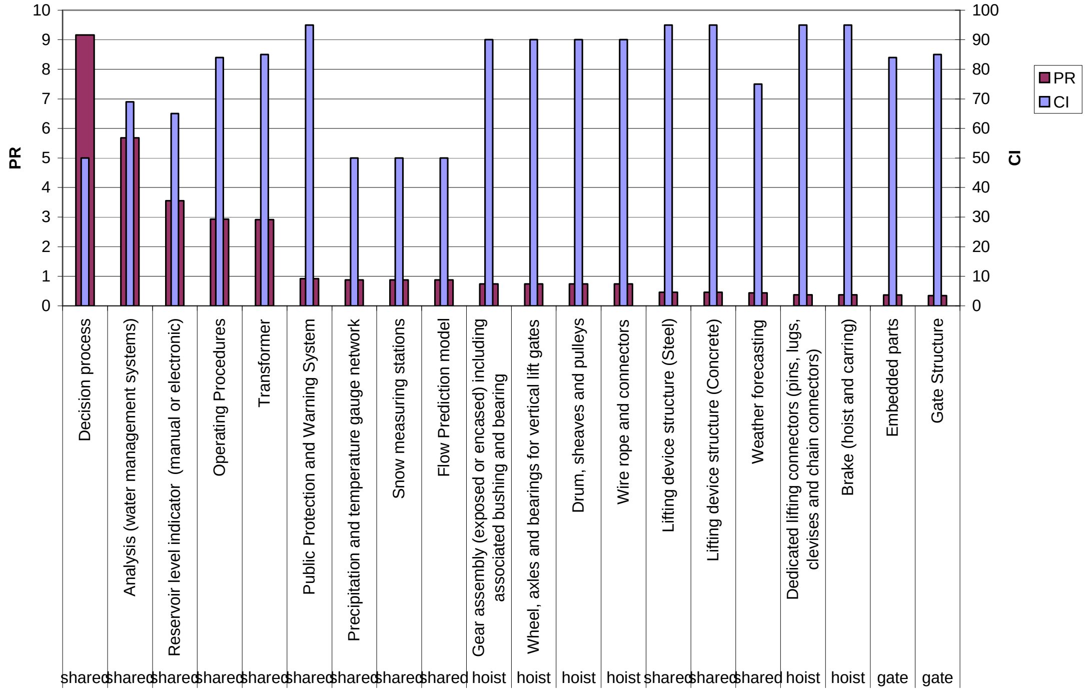


Figure B.6. Condition and priority ranking of components – Dam B.

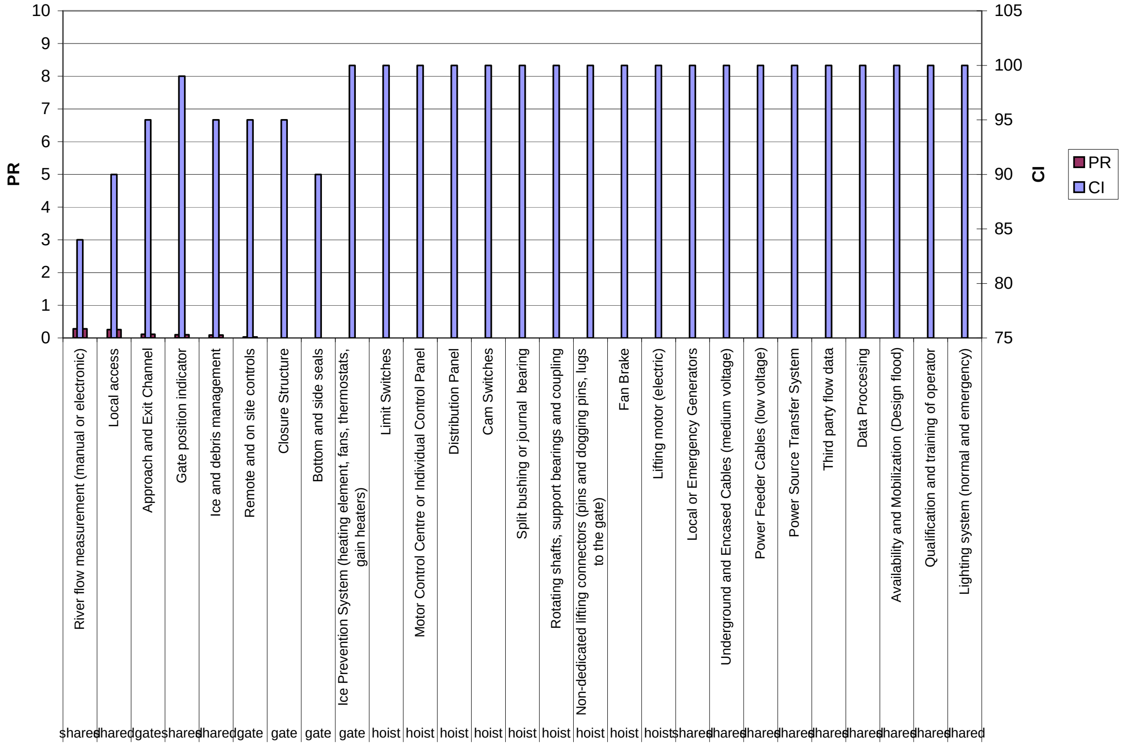


Figure B.6 (continued). Condition and priority ranking of components – Dam B.

Appendix C: Condition Rating Tables

Operational components

Table C.1. River flow measurement (manual or electronic).

River Flow Measurement									
Function	Provide measurement of flow upstream from the spillway.								
Excellent	Providing data accurately and reliably including under extreme conditions and at required frequency. Adequate number (for flow monitoring) for dam safety purposes. Instrument regularly checked and calibrated.								
Failed	Not providing accurate data, not functioning.								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Water Level Indicator and other measurement devices									
Providing data accurately, and reliably under extreme conditions and at required frequency. Adequate number (for flow monitoring) for dam safety. Instrument regularly checked and calibrated.							X		
Inadequate frequency of measurement				X	X				
Poorly located or calibrated and/or inadequate number for dam safety purposes. Cannot be checked manually or visually.		X	X						
Not functioning.	X								
Data acquisition device									
Recording data at required frequency, accurately and reliably.							X		
Low recording frequency but still adequate				X	X	X			
Unreliable with frequent breakdowns reported.		X	X						
Not accurate, not functioning	X								
Data transmission									
Transmitting data at required frequency, accurately and reliably.							X		
Transmitting data at less than required frequency					X	X			
Unreliable with frequent breakdowns reported.		X	X	X					
Not accurate, not functioning	X								

Comments:

River flow measurements are obtained from water level measurements in rivers upstream from the reservoir. Three aspects are evaluated: 1) Accuracy of river flow measurements, 2) Record keeping of data, and 3) Data transmission to operation centers. Accuracy is defined in terms of the precision, quality, frequency of readings, and number of locations for measurements of river flows. The frequency and the number of locations for measurements are to be determined for dam safety objectives (as opposed to power generation objectives) and should be determined for each facility in consultation with personnel involved in flow forecasting. The accuracy of the measurements depends on the accuracy of the stage-discharge curves and the stability of the river cross-section. An accurate stage-flow relation has to be determined from an adequate amount of data and over the full range of expected flows. Specific inspection tables may be developed by each partner for the types of devices that they use.

Table C.2. Reservoir level indicator.

Reservoir level indicator									
Function	Measure reservoir level								
Excellent	Providing accurate data, redundancy and no evidence of malfunction (water level in the reservoir) for dam safety purposes. Instrument regularly checked and calibrated.								
Failed	Not providing accurate data, not functioning.								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Water level indicators									
Measuring level accurately and continuously and adequate number for dam safety purposes							X		
Inadequate water level indicators to determine the influence of wind on pool level				X	X	X			
Poorly located (influenced by gate opening or difficult to read)			X	X	X				
Inadequate frequency of measurement			X	X					
No redundancy (only one gauge near the dam or spillway). Cannot be checked visually or manually.		X	X	X					
Not providing accurate data, not functioning	X								
Data acquisition device									
Recording data continuously accurately and reliably.							X		
Low recording frequency but still adequate				X	X	X			
Unreliable with frequent breakdowns reported.		X	X						
Not accurate, not functioning	X								
Data transmission									
Transmitting data at required frequency, accurately and reliably.							X		
Transmitting data at less than required frequency				X	X	X			
Unreliable with frequent breakdowns reported.		X	X						
Not accurate, not functioning	X								

Comments:

The purpose of this system is to provide accurate measurements of the water level in the reservoir to the operators. The data should also be properly stored and transmitted to operation centers. The adequate number of measuring devices at a given facility is to be determined for dam safety objectives in consultation with personnel involved in decision-making relative to the operation of the spillway.

Table C.3. Precipitation and temperature gauge network.

	Precipitation and Temperature Gauge Network **(For a watershed, including data acquisition and storage)**								
Function	Measure rainfall on watershed								
Excellent	Providing data accurately, continuously and reliably. Adequate number according to the size of the watershed for dam safety purposes. Instrument regularly checked and calibrated.								
Failed	Not providing accurate data, not functioning, no gauge in the entire watershed								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Precipitation and Temperature gauges									
Measuring rainfall accurately continuously and reliably. Adequate number according to the size of the watershed for dam safety purposes.							X		
Not accurate data or inadequate number of rain gauges			X	X	X				
Not providing accurate data, not functioning, no gauge in service in the entire watershed	X								
Data acquisition device									
Recording data continuously accurately and reliably.							X		
Low recording frequency but still adequate				X	X	X			
Unreliable with frequent breakdowns reported.		X	X						
Not accurate, not functioning	X								
Data transmission									
Transmitting data at required frequency, accurately and reliably.							X		
Transmitting data at less than required frequency				X	X	X			
Unreliable with frequent breakdowns reported.		X	X						
Not accurate, not functioning	X								

Comments:
The adequate number of rain gauges is to be determined by considering all other means of measuring the amount of precipitation (e.g., using Radarsat). Several items can be checked when evaluating the condition of a rain gauge (or precipitation gauge). For the purposes of the current project, it was agreed that only a generic description of potential problems would be used since there exists a wide variety of devices that can be used by the various partners. Examples of possible inspection items for rain gauges are the level and quality of the fluid used in the rain gauge and the location of the rain gauge in the field relative to accepted standards.

Table C.4. Snow measuring stations.

Snow Measuring Stations									
Function	Measure snow cover on watershed								
Excellent	Measurement of snow cover depth at an adequate number of locations with sufficient frequency for dam safety purposes.								
Failed	Not measuring snow depth cover in the watershed where applicable.								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Measurement of snow cover depth at an adequate number of locations with sufficient frequency for dam safety purposes							X		
Inadequate number of snow measurement locations and/or insufficient frequency of readings			X	X	X				
Not measuring snow depth cover in the watershed where applicable	X								

Comments:
The adequate number and frequency of snow depth cover measurements is determined by considering all means of estimating snow cover depth (aerial surveys, etc.).

Table C.5. Weather forecasting.

Weather Forecasting									
Function	Forecsat precipitation in the watershed								
Excellent	Weather forecasting system can predict major precipitation events for dam safety purposes.								
Failed	Unavailability of weather forecasting data.								
Inidcator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Weather forecasting system can predict major precipitation. Accurate for dam safety purposes							X		
Unavailability of weather forecasting data	X								

Comments:
Weather forecasting can be performed by the utility or obtained from a third party. The adequacy of forecasts for a given reservoir is a function of the response and reaction times for the project. Factors that may be considered are: frequency, availability and accuracy of forecasts. Intermediate conditions were not defined for lack of expertise in this field.

Table C.6. Ice and debris management.

Ice and debris									
Function	Provide information to the operator on debris and ice conditions upstream from the spillway and manage ice and debris accumulation								
Excellent	Ice and debris monitoring and management in place.								
Failed	No ice and debris monitoring and management in place.								
Inidcaotr	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Ice and debris monitoring									
Ice and debris monitoring in place							X		
No ice and debris monitoring in place	X								
Ice and debris management									
Ice and debris management procedures are detailed, up-to-date, available to operators, used, and effective.							X		
Ice and debris management procedures are documented but have not been used				X	X	X			
Outdated or difficult to implement IDM		X	X						
No IDM	X								
Ice and debris control equipment									
Ice and debris control is effective							X		
Ice and debris control in place but partially effective				X	X				
Ice and debris control not effective	X								

Comments:

Ice and debris monitoring is performed upstream from the spillway. Excessive debris or ice accumulation can block the spillway. Another unfavorable condition can occur when an ice jam is formed upstream from the spillway. A sudden increase in flow may occur when the ice jam is dislodged.

Table C.7. Third party data.

Third Party Data									
Function	Obtain data from other river users.								
Excellent	Provide reliable data on schedule								
Failed	Unreliable data and/or with unacceptable delays. Data not provided.								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Provide reliable data on schedule							X		
Unreliable data and/or with unacceptable delays	X	X	X						
Data not provided	X								

Comments:

Third party data must be adequate for dam safety purposes. The table rates the accuracy of predicted flow *magnitudes*, as well as accuracy of predicted *timing* of flows received in data from 3rd parties under normal and extreme conditions. The type of information provided by third parties may include flow data and meteorological data.

Table C.8. Gate position indicator.

Gate Position Indicator									
Function	Indicate the position of a spillway gate								
Excellent	Provides a true reading relative to the opened or closed position of the gate. Device regularly checked and calibrated.								
Failed	Not providing accurate data, not functioning. Gate position indicator provides a false reading (relative to the opened or closed position of the gate).								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Gate position indicator									
Provides a true reading relative to the opened or closed position of the gate Device regularly checked and calibrated.							X		
Gate position indicator out of adjustment					X	X			
Not providing accurate data, not functioning Gate position indicator provides a false reading (relative to the opened or closed position of the gate)	X								
Data acquisition device									
Recording data continuously accurately and reliably.							X		
Recording data intermittently but still adequate				X	X	X			
Unreliable with frequent breakdowns reported.		X	X						
Not accurate, not functioning	X								
Data transmission									
Transmitting data continuously accurately and reliably.							X		
Transmitting data at less than required frequency				X	X	X			
Unreliable with frequent breakdowns reported.		X	X						
Not accurate, not functioning	X								

Comments:

Gate position indicators are mainly for gates that are remotely operated. A visual gate position indicator should also be installed at a location visible from on-site controls. The gate position indicator is important both for dam safety purposes and for monitoring water flows.

Table C.9. Flow prediction model.

Flow prediction model									
Function	Models the inflows and outflows of the watershed								
Excellent	Properly utilizes input data to generate accurate and timely flow predictions under normal and extreme events.								
Failed	Inaccurate non dependable or untimely predictions								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Properly utilizes input data to generate accurate and timely flow predictions under normal and extreme events						X	X		
Dependable under normal conditions, untested under extreme events			X	X	X				
Dependable under normal conditions, undependable or untimely under extreme events		X	X						
Inaccurate, undependable or untimely under normal conditions	X								

Comments:

The flow prediction model describes the process by which data from rain gauges, snow measuring stations, river flow measurements, and weather forecasting are integrated in order to make inflow predictions.

Table C.10. Decision process.

Decision process									
Function	Clearly defined roles, responsibilities in determining the need to open a gate.								
Excellent	Clear and current decision process that promotes appropriate and timely decisions as events warrant. Process is documented and is tested on a regular basis.								
Failed	Not clearly defined process								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Clear and current decision process that promotes appropriate and timely decisions as events warrant. Process is documented and is tested on a regular basis.							X		
Clear and current decision process. Process is documented; however it has not been tested on a regular basis				X	X	X			
Decision process in place but is not documented.		X	X						
Roles and responsabilities not defined in decision process	X								

Comments:

The decision process describes the chain of command in case of emergencies as well as the flow of information from the prediction group and ultimately to operators.

Table C.11. Telecommunication system.

Telecommunication system									
Function	Provide communication between decision makers and local operators								
Excellent	Dedicated system designed to operate under extreme conditions, has been tested recently. Available at all times.								
Failed	No communication								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Dedicated system designed to operate under extreme conditions, has been tested recently. Available at all times							X		
Expected to be reliable under . extreme conditions, has not been tested recently. Available at all times					X	X			
Expected to be reliable under extreme conditions. System has not been tested recently.				X	X				
Vulnerable under extreme conditions.		X	X						
No Communication	X								

Comments:

Telecommunication systems should be reliable. Reliability can be improved with redundancy.

Table C.12. Public protection and warning system.

Public Protection and Warning System									
Function	System to warn and protect the public against consequences of gate opening and spillway hazards (includes horns, strobe lights, warning signs, fencing, safety booms, video cameras, site checks, etc.).								
Excellent	Warning system including opening sequence protocol is effective and comprehensive.								
Failed	No public protection and warning system								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Warning system including opening sequence protocol is effective and comprehensive.							X		
System is effective but public response is doubtful				X	X	X			
System is inadequate to warn and protect against spillway hazards and rapid water rise.		X	X						
No public protection and warning system	X								

Comments:

Public warning systems comprise signs and horns that are sounded before the operation of the gates. The signs should be located in areas that are in full view of people that may access the zone affected during spilling operations. Horns should be loud enough to be heard at locations that will be affected during spilling operations even when spillway gates are partially open.

Table C.13. Availability and mobilization (design flood).

Availability and Mobilization **(Design flood)**									
Function	Provide key personnel and resources required for operation of the spillway during the design flood.								
Excellent	Key personnel and resources can always be reached and can get to gate controls in a timely fashion.								
Failed	Key personnel or resources cannot reach gate in required time.								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Availability									
Key personnel always available at the site or at the gate controls							X		
Key personnel available on call continuously						X			
On-call plan activated as needed					X	X			
Extensive up-to-date list of key personnel				X	X				
Short list of key personnel		X	X						
No or outdated list of available key personnel	X								
Mobilization (Time required to contact personnel, get the required equipement and reach gate controls)									
Mobilization not required (Personnel and resources always available at the site or at the gate remote controls)							X		
Mobilization can be achieved before reaching the critical pool level						X			
Mobilization can be achieved before reaching the maximum pool level (above the critical pool level)			X	X	X				
Mobilization cannot be achieved before reaching the maximum pool level	X	X							

Comments:

The mobilization of personnel and resources describes the plan that has been put in place to respond to an emergency during a design flood event. Various levels of mobilization plans have been identified. The most complete plan requires that key personnel be always on site during design flood events. At the very least, an up-to-date list of key personnel should be made available to operators. At many sites several operators are required during periods of emergencies, especially for on-site operation of gates. Technical support personnel should be always ready to respond to emergencies relative to faulty equipment (civil, mechanical, and electrical). Ideally, key personnel should be on call during emergency periods. Key personnel are those required for gate operation and troubleshooting.

Table C.14. Availability and mobilization (load rejection).

Availability and Mobilization **(Load rejection)**									
Function	Provide key personnel and resources required for operation of the spillway during load rejection.								
Excellent	Key personnel and resources can always be reached and can get to gate controls in a timely fashion.								
Failed	Key personnel or resources cannot reach gate in required time.								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Availability									
Key personnel always available at the site or at the gate controls							X		
Key personnel available on call continuously						X			
On-call plan activated as needed					X	X			
Extensive up-to-date list of key personnel				X	X				
Short list of key personnel		X	X						
No or outdated list of available key personnel	X								
Mobilization (Time required to contact personnel, get the required equipement and reach gate controls)									
Mobilization not required (Personnel and resources always available at the site or at the gate remote controls)							X		
Mobilization can be achieved before reaching the critical pool level						X			
Mobilization can be achieved before reaching the maximum pool level (above the critical pool level)		X	X						
Mobilization cannot be achieved before reaching the maximum pool level	X								

Comments:

The mobilization of personnel and resources describes the plan that has been put in place to respond to an emergency during load rejection. Various levels of mobilization plans have been identified. The most complete plan requires that key personnel be always on site. At the very least, an up-to-date list of key personnel should be made available to operators. At many sites several operators are required during periods of emergencies, especially for on-site operation of gates. Technical support personnel should be always ready to respond to emergencies relative to faulty equipment (civil, mechanical, and electrical). Ideally, key personnel should be on call during emergency periods. Key personnel are those required for gate operation and troubleshooting.

Table C.15. Operating procedures.

Operating procedures									
Function	Provide detailed instructions for the proper operation of the gates.								
Excellent	Operating procedures are detailed, up-to-date and available to operators								
Failed	No operating procedures								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Standard operating procedures (covers normal and emergency situations) (SOP)									
Standard operating procedures are detailed, up-to-date, available to operators and tested.							X		
Standard operating procedures have not been fully tested.				X	X	X			
Outdated or difficult to implement standard operating procedures		X	X						
SOP do not cover emergency situations (fire, dam break, earthquake, flood exceeding spillway capacity)		X	X						
No standard operating procedures	X								
Autonomous operating procedures (covers normal and emergency situations) (AOP)									
AOP are detailed, up-to-date and available to operators and tested.							X		
AOP have not been fully tested				X	X	X			
Outdated or difficult to implement AOP		X	X						
AOP do not cover emergency situations (fire, dam break, earthquake, flood exceeding spillway capacity)		X	X						
No AOP	X								

Comments:
The operating procedures describe the procedures followed by the operator that cover all aspects of the normal operation of the spillway (including opening sequences where applicable). Extreme event operating procedures provide guidance to operators during extreme events even if they are not able to communicate with the outside world. Extreme events include flood events, earthquakes, ice storms, etc

SOP: Provide detailed instructions for spillway operation, including:

Communication protocols

Gate opening protocols (public warning, operational sequence, etc.)

AOP: Provide detailed instructions for autonomous spillway operation.

They allow operators to act independently in the event of communication breakdown and include specific local decision protocols.

Table C.16. Qualification and training of operator.

Qualification and training of operator									
Function	To insure that operators are qualified to operate the gates								
Excellent	Personnel are trained and practiced in the operation of the gates and are familiar with the site and standard operating procedures.								
Failed	Personnel are untrained, unpracticed and unfamiliar with the site and the standard operating procedures.								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Personnel are trained and practiced in the operation of the gates and are familiar with the site and the standard operating procedures.							X		
Personnel are trained but unpracticed with the operation of the gates.					X	X			
Personnel are unfamiliar with standard operating procedures.				X	X				
Personnel are unfamiliar with the site			X	X					
Personnel are untrained and unpracticed with the operation of the gates.		X	X						
Personnel are untrained, unpracticed and unfamiliar with site and the standard operating procedures.	X								

Comments:
Operators should be trained in every aspect of the operation of the spillway and should perform simulated operations on a regular basis. The latter includes operation of the gates with the emergency generator.

Table C.17. Portable equipment for lifting gates.

Portable equipment for lifting gates									
Function	Portable equipment that is required for operating the gates								
Excellent	Portable equipment is kept in good working order and is readily available								
Failed	Portable equipment can not be provided within the required time for operating the gate								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Portable equipment is kept in good working order and is readily available							X		
Portable equipment is readily available but condition is unknown				X	X				
Portable equipment must be rented		X	X						
Portable equipment can not be provided within the required time for operating the gate	X								

Comments:
Some spillways can be operated on site only and require that specialized equipment be available for opening or closing operations. The ideal situation is that the equipment is always available on site.

Table C.18. Road.

Road									
Function	To provide access to the site.								
Excellent	Travel by road is possible under adverse conditions without significant delay								
Failed	Road not available under adverse conditions or seasonally.								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Travel by road is possible under adverse conditions without significant delays							X		
Travel by road is possible under adverse conditions but distance to site is a hindrance				X	X	X			
Roadways or bridges known to be vulnerable to slides, erosion, flooding, etc. but alternate road available			X	X	X				
Roadways or bridges known to be vulnerable to slides, erosion, flooding, etc. with no alternate road		X	X						
Road not available under adverse conditions or seasonally	X								

Comments:

Roads are the main means of access for personnel and equipment. Road access to the spillway should be possible during extreme conditions. Accessibility to the site by road should be assessed by considering the vulnerability of the road to flooding and landslides under extreme conditions during all seasons (snow removal may be an important consideration for northern isolated sites).

Table C.19. Alternate means of access.

Alternate means of access									
Function	To provide access to the site in lieu of road access if required.								
Excellent	Alternate means of travel allowing access within required time under adverse conditions and recently tested								
Failed	Alternate means of access frequently not available								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Alternate means of travel allowing access within required time under adverse conditions and recently tested							X		
Helicopter or plane									
Company owned/leased helicopter or plane dedicated to operational staff and adequate landing area at site				X	X				
Helicopter or plane on call or shared and adequate landing area at site			X						
Landing site for helicopter or plane but no current use agreement		X							
No landing site	X								
Boat access									
Accessible by company boat on the waterway and dedicated to operational staff					X				
Accessible with boats available locally				X					
Accessible by company owned boat not near site			X						
No safe docking area available under flood conditions	X								
Ground access by specialized vehicles (ATV, snowmobile, etc.)									
Ground route accessible with specialized company vehicles and dedicated to operational staff				X	X				
Ground route accessible with specialized vehicles available locally			X	X					
Alternate means of access frequently not available.	X								

Comments:

Alternate means of access includes all means other than roads. Examples of alternate means of access are access by boat from upstream launching points, helipads and landing strips.

Table C.20. Local access.

Local access									
Function	Provide access to gate controls								
Excellent	Access is possible during adverse conditions.								
Failed	Access impracticable during adverse conditions. Access is not structurally sound.								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Pedestrian access									
Access is possible during adverse conditions							X		
Access is possible during adverse conditions but minor repairs are required. Excessive debris present.				X	X	X			
Access is possible during adverse conditions but is hazardous		X	X						
Access impracticable during adverse conditions.Access is not structurally sound	X								
Keys and locks									
Operators have the required keys to access all secured areas and equipment and locks are well maintained and identified							X		
Locks are not well maintained				X	X				
Operator does not have access to a full set of well-identified keys.	X								

Comments:
Pedestrian access includes all the walkways, catwalks, and ladders that are used to reach the controls of the spillway gates once onsite. Operators should have access to a full set of keys at all times. On most projects, critical components and controls are locked to prevent vandalism or unauthorized operation of the spillway.

Table C.21. Remote and onsite controls.

Remote and on site controls									
Function	Operate gate and equipment								
Excellent	Clearly labeled and properly maintained. Properly located and lighted.								
Failed	Improperly labeled controls. Improperly located or lighted.								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Clearly labeled and properly maintained. Properly located and lighted.							X		
Correctly labeled but improperly located controls				X	X				
Controls or devices require excessive effort to be activated			X	X					
Gate or gate position indicatornot located in the line of sight of the operator (visual or remote camera)		X	X	X					
Improperly labeled controls. Improperly located or lighted	X								

Comments:
Controls should be properly labeled, located, and maintained. Ideally, controls should be located such that the operator is always in full view of the gates and gate position indicators as they are being operated.

Other systems

Specific items that are not common to all participants in the project have been identified and will be developed by each partner separately.

Electrical components

Table C.22. Overhead lines.

Medium Voltage Overhead Lines									
Function	Supply power to the spillway.								
Excellent	Built to current codes and standards, and maintained to provide continuous service and assure that proper clearances are maintained.								
Failed	Loss of power.								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Vegetation control									
Line is free of vegetation						X	X		
Some vegetation encroachment (< 10 feet)			X	X	X				
Poor vegetation control (< 3 feet)	X	X							
Lightning protection									
Protection according to codes and standards						X	X		
Inadequate lightning protection but not exposed			X	X	X				
Damaged or inadequate lightning protection and exposed	X	X							
Poles, supports and accessories (insulators, conductors)									
No visual damage						X	X		
Damaged poles, supports, and accessories	X	X	X						

Comments:

Medium overhead lines that are used as a power source for the spillway may be lines that connect the powerhouse to the spillway and can also be External Power Source lines. Overhead lines are vulnerable to climatic loads such as wind and ice loads. Overhead lines may also be exposed to lighting strikes. An examination of repair records can be very useful in establishing the condition and vulnerability of a line.

Table C.23. Local or emergency generator.

Local or Emergency Generator									
Function	Supply power directly to the spillway								
Excellent	Provides nominal power at the correct frequency and voltage. Able to assume required load within specified time parameters and provide continuous service.								
Failed	Will not start. Rejects load. Unable to obtain nominal frequency and/or voltage to lift the gate. Unable to heat gate if required								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Functional tests for alternator and engine (Tests performed periodically under load conditions and to be verified during inspections)									
Frequency and voltage									
Frequency and voltage within nominal values						X	X		
Frequency or voltage do not meet nominal values but can still operate the gates		X	X	X					
Frequency or voltage do not permit gate operation	X								
Eng. Temp. and oil pressure									
Engine temperature and oil pressure within nominal values						X	X		
Engine temperature or oil pressure outside nominal values		X	X	X					
Extreme temperature (low or high) or no pressure	X								
Starting sequence									
Starting sequence successful at first trial						X	X		
Starting sequence successful within three trials			X	X					
Does not start within three trials	X								
Noise and vibration									
Engine runs without excessive vibrations or noise						X	X		
Engine runs with increasing vibrations or noise over time				X	X				
Functional test									
Functional test performed according to standards							X		
No periodic functional test		X							
Fuel									
Fuel according to specifications							X		
No fuel registry on site			X	X	X				
Contaminated or old fuel		X	X	X					
No fuel	X								
Batteries									
Sized and maintained for specified load						X	X		
Battery in service longer than its rated service life				X	X				
Improper electrolyte		X	X						
Battery discharged or faulty cells	X								
Battery charger									
Maintains battery charge at specified level						X	X		
Does not maintain battery charge at specified level	X	X							

Table C.23 (continued).

Alternator									
Insulation resistance within specifications						X	X		
Decreasing trend in insulation resistance with time but still within specifications			X	X	X				
Insulation resistance outside specifications	X	X							
Lubrication system									
Oil is within specifications (quality and level)						X	X		
Contaminated or oil outside of specifications but at correct level			X	X	X				
Clogged filter			X	X					
Low oil level due to leaks or excessive consumption		X							
No oil or excessive viscosity	X								
Cooling system									
Fluid is within specifications (quality and level)						X	X		
Contaminated fluid or significant leak			X	X	X				
No fluid, or no fluid (or air) circulation	X								
Intake and exhaust system									
Unobstructed air intake and exhaust system with filter in place						X	X		
Inadequate filter or no filter				X	X				
Partly clogged air filter or reduced circulation or exhaust defect		X	X						
Blocked air intake or exhaust system	X								

Comments:

The emergency generator is a critical component of the spillway. The evaluation of the generator is made relative to all the major components of the generator as well as from a series of functional tests.

Table C.24. Underground and encased cables (medium voltage).

Underground and Encased Cables (medium voltage)									
Function	Supply power to the spillway								
Excellent	Built to current codes and standards, and maintained to provide continuous service.								
Failed	Loss of power								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Insulation									
Performs the function and/or passes the standard testing procedures						X	X		
Does not perform the function nor passes the Standard Testing Procedures	X	X							
Terminations									
Adequate connection						X	X		
Loose connection		X	X	X					
Discoloration		X	X						
Cannot supply power	X								

Comments:

The condition of underground or encased cables is performed by tests on the insulation and by a visual inspection of the terminations. The results from the tests on the insulation are described only in a qualitative way since there are numerous alternative procedures for performing insulation tests. The rating in any particular case has to be done by considering guidelines from the manufacturers of each testing device. The visual inspection of the cables is usually limited to the state of the termination and for signs of overheating.

Table C.25. Power feeder cables (low voltage).

Power feeder cables (low voltage)									
Function	Supply power to gate operating equipment								
Excellent	Built to current codes and standards, and maintained to provide continuous service.								
Failed	Loss of power.								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Insulation									
Performs the function and/or passes the Standard Testing Procedures						X	X		
Does not perform the function nor passes the Standard Testing Procedures	X	X							
Terminations									
Adequate connection						X	X		
Loose connection		X	X	X					
Discoloration		X	X						
Cannot supply power	X								

Comments:

The condition of power feeder cables is performed by tests on the insulation and by a visual inspection of the terminations. The results from the tests on the insulation are only described in a qualitative way since there are numerous alternative procedures for performing insulation tests. The rating in any particular case has to be done by considering guidelines from the manufacturers of each testing device. The visual inspection of the cables is usually limited to the state of the termination and for signs of overheating.

Table C.26. Transformer.

Transformer									
Function	Supply power at correct voltage level								
Excellent	Built to current codes and standards, and maintained to provide continuous service at correct voltage level.								
Failed	Cannot supply correct voltage level.								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Dielectric (oil)									
Oil according to specifications							X		
Contaminated oil (presence of foreign matter, e.g.; moisture)		X	X	X	X				
Degraded oil (by arcing, aging, acidity)	X	X	X	X					
Dissolved gases	X	X	X	X					
Insulation									
Performs the function and/or passes the standard testing procedures (insulation resistance and power factor, etc.)						X	X		
Does not perform the function nor passes the standard testing procedures	X	X							
Windings									
Performs the function and/or passes the standard testing procedures (resistance and turns-ratio)						X	X		
Does not perform the function nor passes the standard testing procedures	X	X							
Cannot supply power	X								
Tank									
No leaks							X		
Inadequate oil level or oil leak	X	X	X	X	X				
Service life (based on utility standard practices)									

Comments:

The evaluation of the condition of a transformer is done by performing tests and by performing a visual inspection. The visual inspection is performed to determine the condition of the tank while tests are performed to control the quality of the oil, the state of the insulation and of the windings. Considering the wide variety of possible tests, outcomes are described qualitatively and must be evaluated by considering the recommendations of each specific manufacturer of testing devices.

Table C.27. Power source transfer system.

Power source transfer system									
Function	To transfer from normal source to alternate source and return								
Excellent	Built to applicable codes and standards, and maintained to provide the expected service.								
Failed	Cannot provide expected service.								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Functional test (transfer switch)									
Successful							X		
Failed	X								
Functional test (Manual transfer device)									
Successful							X		
Failed	X								

Comments:
A functional test is performed for evaluating the condition of the power source transfer system. The system is considered to be in either an excellent condition or failed condition. No intermediate state has been defined.

Table C.28. Ice prevention system (air bubbler).

Ice prevention system (air bubbler)									
Function	To keep gates ice free								
Excellent	Built to applicable codes and standards, and maintained to provide the expected service.								
Failed	Cannot provide expected service.								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Functional test									
Upstream gate surfaces maintained ice free							X		
Upstream ice accumulation prevents operation of the gate	X								

Comments:
Air bubblers can be used to prevent the formation of ice on the upstream face of the gates. A functional test is performed for evaluating the condition of the air bubbler. The system is considered to be either in an excellent condition or failed condition. No intermediate state has been defined.

Table C.29. Lighting system (normal and emergency).

Lighting system (normal and emergency)									
Function	Provide appropriate illumination to assure safe spillway operation								
Excellent	Built to applicable codes and standards, and maintained to provide the expected service.								
Failed	Cannot provide expected service.								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Functional test									
Safe level of lighting is provided							X		
Insufficient or impaired lighting (dirty, burned out or missing bulbs)		X	X	X	X				
Lighting system inoperable	X								

Comments:
The lighting system is to allow for the safe access and operation of the spillway under any conditions.

Table C.30. Limit switches.

Limit switches									
Function	To permit operation only within specified range								
Excellent	Built to applicable codes and standards, and maintained to provide the expected service.								
Failed	Cannot provide expected service.								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Functional test									
Operated successfully or passed simulated test							X		
Failed	X								

Comments:
A functional test is performed for evaluating the condition of limit switches. The system is considered to be in either an excellent condition or failed condition. No intermediate state has been defined.

Table C.31. Ice prevention system (heating).

Ice prevention system (heating elements, fans, thermostats, gain heaters)									
Function	To keep gates and gains ice free and/or prevent corrosion								
Excellent	Built to applicable codes and standards, and maintained to provide the expected service.								
Failed	Cannot provide expected service.								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Functional test									
Heat is maintained within specifications							X		
Some heating system components do not function but gate can still be operated in winter conditions		X							
Does not prevent ice accumulation or gate cannot be operated	X								

Comments:
A functional test is performed for evaluating the condition of the ice prevention system. The system is considered to be in either an excellent condition or failed condition. No intermediate state has been defined.

Table C.32. Distribution panel.

Distribution panel									
Function	To provide power to lighting, heaters, fans, monitoring instrumentation, etc.								
Excellent	Built to applicable codes and standards, and maintained to provide the expected service.								
Failed	Cannot provide expected service.								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Functional test									
Successful							X		
Failed	X								
Visual inspection									
No visible problems							X		
General condition		X	X	X	X	X			
Damaged or missing locks			X	X	X				
Loose connections			X	X					
Presence of moisture or corrosion		X	X	X					
Damaged seals		X	X	X					
Carbinet heating									
Operational							X		
Non operational		X	X	X					

Comments:
The main method for the evaluation of the condition of a distribution panel is a functional test. The functional test is complemented by a visual inspection to determine if there is some undesirable conditions such as the presence of moisture, loose connections, damaged seals, and damaged or missing locks. A statement relative to the general condition has been included to capture conditions that are not covered in the table. Cabinet

heating is an important element in distribution panels to eliminate moisture that can penetrate inside the panel.

Table C.33. Translation motor (electric).

Translation Motor (electric)									
Function	Transforms electric power into mechanical power								
Excellent	Built to applicable codes and standards, and maintained to provide the expected service.								
Failed	Cannot provide expected service								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Insulation									
Performs the function and/or passes the standard testing Procedures (insulation resistance)						X	X		
Does not perform the function nor passes the standard testing procedures	X	X							
Apparent Temperature									
Normal temperature range						X	X		
Overheating			X	X					
Overloading									
Current and voltage within name plate specifications						X	X		
Excessive current at rated voltage		X	X	X					
Fault trip	X								
Impaired ventilation (open motor)									
Impaired ventilation (open motor)		X	X	X					
Bearings and bushings									
Adequate, and appropriate lubrication						X	X		
Inadequate lubrication		X	X	X					
No rotation due to seizing	X								
Noise and vibrations									
Motor runs without excessive noise or vibrations						X	X		
Motor runs with increasing noise or vibrations over time				X	X				

Comments:

The translation motor is used to move a shared lifting device. The motor is evaluated by a combination of functional tests, measurement, and visual inspections.

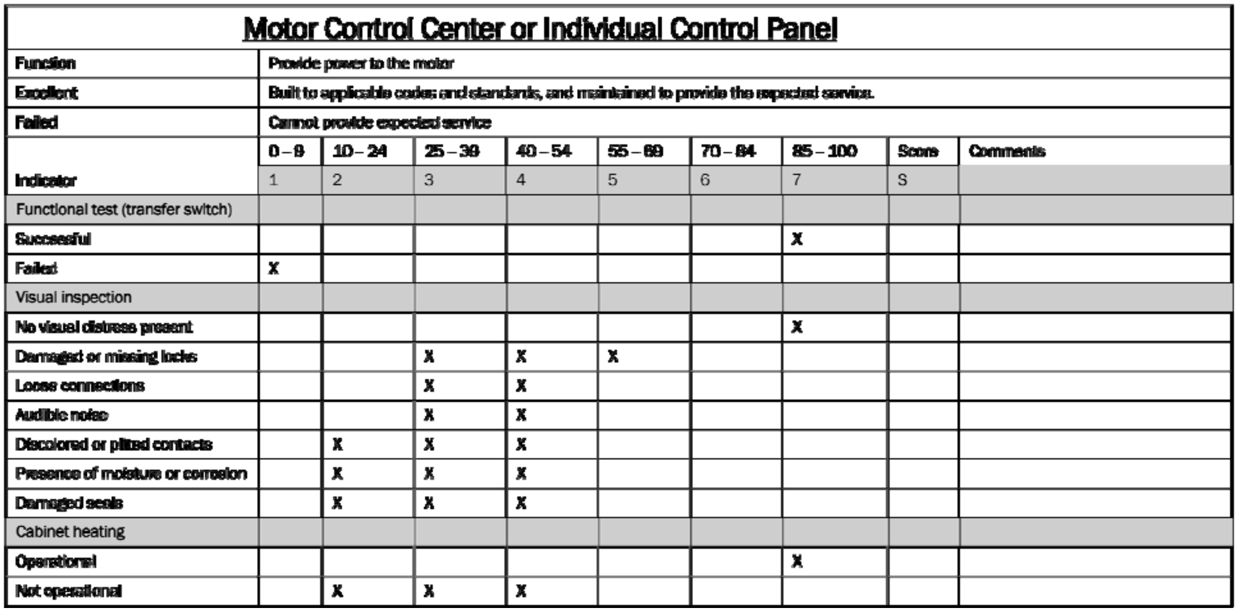
Table C.34. Lifting motor (electric).

Lifting Motor (electric)									
Function	Transforms electric power into mechanical power								
Excellent	Built to applicable codes and standards, and maintained to provide the expected service.								
Failed	Cannot provide expected service								
	0 – 9	10 – 24	25 – 39	40 – 54	55 – 69	70 – 84	85 – 100	Score	Comments
Indicator	1	2	3	4	5	6	7	S	
Insulation									
Performs the function and/or passes the standard testing procedures (insulation resistance)						X	X		
Does not perform the function nor passes the standard testing procedures	X	X							
Apparent Temperature									
Normal temperature range						X	X		
Overheating			X	X					
Overloading									
Current and voltage within name plate specifications						X	X		
Excessive current at rated voltage		X	X	X					
Fault trip	X								
Impaired ventilation (open motor)									
Normal ventilation							X		
Impaired ventilation(open motor)		X	X	X					
Bearings and bushings									
Adequate, appropriate lubrication						X	X		
Inadequate lubrication		X	X	X					
No rotation due to seizing	X								
Noise and vibrations									
Motor runs without excessive noise or vibrations						X	X		
Motor runs with increasing noise or vibrations over time				X	X				

Comments:

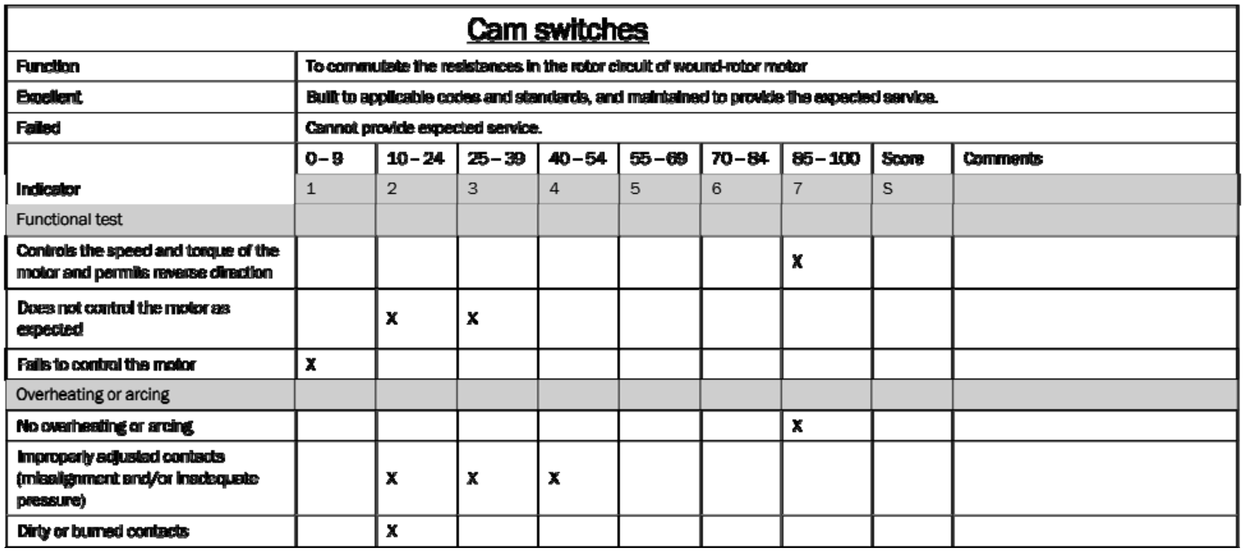
The lifting motor is used to lift the gate into position. The lifting motor is evaluated by a combination of functional tests, measurement, and visual inspections. Tests and measurements are performed to evaluate the condition of the insulation and to determine if the motor is overloaded. Overloading cannot always be considered as an adequate indicator of the state of the motor since overloading can occur due to excessive friction. When testing is done under load, the inspector should observe the gate for noise and vibrations that could be indicative of excessive friction. The visual inspection of the motor is done to determine qualitatively if the motor overheats under load (which could be indicative of overloading). The visual inspection also includes a determination relative to the level of noise and vibration and the lubrication of bearings.

Table C.35. Motor control center or individual control panel.



Motor Control Center or Individual Control Panel									
Function	Provide power to the motor								
Excellent	Built to applicable codes and standards, and maintained to provide the expected service.								
Failed	Cannot provide expected service								
	0 – 9	10 – 24	25 – 39	40 – 54	55 – 69	70 – 84	85 – 100	Score	Comments
Indicator	1	2	3	4	5	6	7	S	
Functional test (transfer switch)									
Successful							X		
Failed	X								
Visual inspection									
No visual distress present							X		
Damaged or missing locks			X	X	X				
Loose connections			X	X					
Audible noise			X	X					
Discolored or pitted contacts		X	X	X					
Presence of moisture or corrosion		X	X	X					
Damaged seals		X	X	X					
Cabinet heating									
Operational							X		
Not operational		X	X	X					

Table C.36. Cam switches.



Cam switches									
Function	To commutate the resistances in the rotor circuit of wound-rotor motor								
Excellent	Built to applicable codes and standards, and maintained to provide the expected service.								
Failed	Cannot provide expected service.								
	0 – 9	10 – 24	25 – 39	40 – 54	55 – 69	70 – 84	85 – 100	Score	Comments
Indicator	1	2	3	4	5	6	7	S	
Functional test									
Controls the speed and torque of the motor and permits reverse direction							X		
Does not control the motor as expected		X	X						
Fails to control the motor	X								
Overheating or arcing									
No overheating or arcing							X		
Improperly adjusted contacts (misalignment and/or inadequate pressure)		X	X	X					
Dirty or burned contacts		X							

Comments:
Cam switches are evaluated through a functional test. A visual inspection can be performed to determine if the contacts are well aligned, if the pressure is adequate, and if the contacts are dirty or burned.

Table C.37. External resistors.

External resistors									
Function	Add or remove resistance in the circuit of the rotor (wound-rotor motor)								
Excellent	Built to applicable codes and standards, and maintained to provide the expected service.								
Failed	Cannot provide expected service.								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Functional test									
Permits full control of the speed and torque of the motor							X		
Fail to adequately control the motor (missing or faulty resistor)		X							
No response from the motor	X								

Comments:
External resistors are evaluated through a functional test.

Table C.38. Inverter control system.

Inverter control system (includes the rectifier system)									
Function	Permits variable frequency control of the translation or lifting motor								
Excellent	Built to applicable codes and standards, and maintained to provide the expected service.								
Failed	Cannot provide expected service.								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Functional test									
Provide controlled variable speed and torque of the motor							X		
Fails to operate the motor	X								

Comments:
The condition of the inverter control system is determined from a functional test.

Mechanical components

Table C.39. Screw and nut (screw-type hoist).

Screw and Nut (Screw-type hoist)									
Function	Transfer shaft rotation into gate movement								
Excellent	No warping, no wear, geometry according to specifications, uncontaminated grease .								
Failed	Warped enough to jam the mechanism, broken, split, missing threads, enough surface damage/corrosion to cause excessive friction								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
No warping, no wear, geometry according to specifications, uncontaminated grease .							X		
Surface Contaminants on grease or slight warping on screw with some damage or wear to threads of nut					X	X			
Inappropriate lubrication			X	X	X				
Excessive friction/noise, vibration and jumping, presence of metal shavings		X	X						
Warped enough to jam the mechanism; broken, split, missing threads; enough surface damage/corrosion to cause excessive friction	X								

Table C.40. Bearings.

Bearings (Radial, thrust, power screw assembly)									
Function	Provide low friction support to rotating parts								
Excellent	Well lubricated and without abnormal noise or vibration, no excessive play								
Failed	Does not provide support to the moving parts and accessories (wheels or gears). Does not allow free movement.								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Normal noise or vibration, runs well							X		
Abnormal noise or vibration but still runs					X	X			
Abnormal noise or vibration with no lubrication or blockage of grease lines but still runs			X	X					
Abnormal noise or vibration with no lubrication or blockage of grease lines and cracked housing but still runs		X	X						
Seizing between pin/shaft and bushing. Rotation of pin in yoke/lug.	X	X							

Table C.41. Split bushing or journal bearing.

Split Bushing or journal bearing									
Function	Provide low friction support to rotating parts								
Excellent	Well lubricated and runs without noise, no excessive play								
Failed	Moving parts seized or excessive friction.								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Well lubricated and runs without noise, no excessive play							X		
Noise with lubrication with some wear				X	X	X			
Noise without lubrication, vibration or cracked housing, but still running		X	X						
Moving parts seized or excessive friction.	X								

Table C.42. Rotating shafts, supports, bearings, and couplings.

Rotating Shafts, Support Bearings and Couplings									
Function	Transfer torque								
Excellent	No corrosion, minor surface rust, no dent, straight, no crack								
Failed	Broken or severely bent or misaligned so that it cannot rotate								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Corrosion									
No corrosion							X		
Corrosion but no section loss						X			
Measurable section loss			X	X	X				
Severe pitting		X	X						
Warping or Misalignment									
No warping						X	X		
Slight warping or misalignment that does not affect the motor load				X	X				
Warping or misalignment that increases the motor load / lockout order		X	X						
Warping or misalignment that prevents movement	X								
Cracking									
No cracks							X		
Crack known to be non critical (after evaluation)				X	X				
New crack or growth in existing crack		X	X						
Split or broken shaft/couplings	X								
Missing bolts or components									
No missing bolts, distortion, or gap							X		
Missing bolts or distortion or gap	X	X	X						

Table C.43. Gear assembly (hoist).

Gear assembly (exposed or encased) including associated bushing and bearing (hoist)									
Function	Provide speed reduction for hoist mechanism								
Excellent	Shafts and Gears well aligned, well lubricated (no contamination, correct type of lubricant, stable level), no parts missing, no surface defects, no pitting. No excessive noise, jump or vibration.								
Failed	Gear can not transmit torque or motion								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Noise, jump and vibration									
No excessive noise, jump, or vibration						X	X		
Any one of excessive noise, jump, or vibration		X	X	X	X				
Tooth wear, contact, and breakage									
No wear with full contact and properly meshed							X		
Minor wear					X	X			
Significant part of contact surface of teeth missing due to breakage or wear, or misalignment		X	X	X					
Teeth missing preventing rotation	X								
Anchor (fastener to shaft, key or pin) movement or deterioration									
Fastener in place and undamaged							X		
Key or pin is cracked		X	X						
Gear slipping on shaft	X								
Bearing or bushing wear									
Normal noise, runs smoothly						X	X		
Excessive noise or cracked housing, but still running		X	X						
Jammed	X								
Lubricant									
Well lubricated, no contamination, correct type of lubricant, correct level or complete coverage of grease							X		
Presence of contaminants, low level of oil, or change in oil condition or color (encased)				X	X	X			
Inadequate coverage of lubricant		X	X	X					
Presence of contaminants that could jam the gear (includes ice formation)		X	X						
Presence of contaminants that jams the gear	X								

Table C.44. Gear assembly (carriage).

Gear assembly (exposed or encased) including associated bushing and bearing (carriage)									
Function	Provide gear reduction for translation mechanism								
Excellent	Shafts and Gears well aligned, well lubricated (no contamination, correct type of lubricant, stable level),								
	no parts missing, no surface defects, no pitting. No excessive noise, jump or vibration.								
Failed	Gear can not transmit torque or motion								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Noise, jump and vibration									
No excessive noise, jump, or vibration							X		
Any one of excessive noise, jump, or vibration		X	X	X	X				
Tooth wear, contact, and breakage									
No wear with full contact and properly meshed							X		
Minor wear					X	X			
Significant part of contact surface of teeth missing due to breakage or wear, or misalignment		X	X	X					
Teeth missing preventing rotation	X								
Anchor (fastener to shaft, key or pin) movement or deterioration									
Fastener in place and undamaged							X		
Key or pin is cracked		X	X						
Gear slipping on shaft	X								
Bearing or bushing wear									
Normal noise, runs smoothly						X	X		
Excessive noise or cracked housing, but still running		X	X						
Jammed	X								
Lubricant									
Well lubricated, no contamination, correct type of lubricant, correct level or complete coverage of grease							X		
Presence of contaminants, low level of oil, or change in oil condition or color (encased)				X	X	X			
Inadequate coverage of lubricant		X	X	X					
Presence of contaminants that could jam the gear (includes ice formation)		X	X						
Presence of contaminants that jams the gear	X								

Table C.45. Dedicated lifting connectors.

Dedicated lifting connectors (Pins, lugs, clevises, and chain connectors)									
Function	Connect gate to lifting mechanism								
Excellent	No cracks, no deformation, no corrosion, pin in place								
Failed	Cracked or cannot sustain load								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
No cracks, no deformation, no corrosion							X		
Bent, distorted or severely corroded elements				X	X				
Cracked elements	X	X	X						
Missing parts	X								

Table C.46. Non-dedicated lifting connectors.

Non-dedicated lifting connectors (Pins and dogging pins, lugs to the gate)									
Function	Connect gate to lifting mechanism								
Excellent	No cracks, no irregularity, no bending, pin well set with uniform bearing								
Failed	Broken or not in place or unable to insert								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Undamaged and correctly aligned							X		
Misalignment, damaged, bent, or severely corroded but pin can be inserted		X	X	X	X				
Misalignment, cracked, damaged, bent, or severely corroded and pin cannot be inserted or missing pin	X								

Table C.47. Carriage wheels.

Carriage wheels (mobile lifting hoist)									
Function	Allow travel of mobile lifting hoist								
Excellent	Roundness within tolerances, minimal rusting, freely rotating, no cracks, well aligned, correctly lubricated								
Failed	At least one wheel not rolling or cracked or damage preventing translation								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Roundness within tolerances, well aligned, minimal rusting, no cracks, correctly lubricated.							X		
Out of round or misalignment or damage on wheel not preventing translation. Vibrations, jerkiness or uneven speed			X	X	X				
At least one wheel not rolling or cracked or damage preventing translation	X								

Table C.48. Clutch.

Clutch									
Function	To engage or disengage shaft at will								
Excellent	No slipping while engaged and can be disengaged at will								
Failed	Impossible to transmit torque, cannot be engaged or disengaged.								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
No slipping while engaged and can be disengaged at will							X		
Minor slippage that still permits the power to be transmitted				X	X	X			
Major slippage that still permits the power to be transmitted but speed is reduced or overheating of plates		X	X						
Impossible to transmit torque, cannot be engaged or disengaged.	X								

Table C.49. Drum, sheaves, and pulleys

Drum, sheaves and pulleys									
Function	To transfer load to wire ropes								
Excellent	No visible wear, no abnormal noise, freely rotating								
Failed	Broken flange that cannot retain wire rope. Seized pulley								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Visible or measurable wear									
No visible wear, no abnormal noise, freely rotating							X		
Localized indentations, scratches				X	X	X			
Damage or wear that may cause a slip or misalignment, or abnormal noise, or vibration of wire rope		X	X	X	X				
Broken flange that cannot retain wire rope, or seized pulley	X								
Corrosion									
Failure of paint system, spots of surface rust, no section loss						X	X		
Surface scale present, no significant or measurable section loss				X	X				
Significant or measurable section loss		X	X						
Holes, complete section loss	X								
Groove wear (sheaves and drums)									
No wear							X		
Uneven groove				X	X				
Metal missing at the bottom of the groove		X	X						
Wire rope clamps or anchors									
Proper contact and solidly fastened							X		
Loose connection or damaged clamp		X	X						
Missing clamp or anchor	X								

Table C.50. Hoist brake.

Hoist Brake									
Function	To arrest motion of gate and hold gate in any position								
Excellent	Can arrest motion at any position, not seized								
Failed	Cannot arrest motion at any position, seizing of brake								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Can arrest motion at any position, not seized							X		
Limited slippage without impacting operation; no slip but vibration				X	X	X			
Limited slippage that impacts operation		X	X						
Continuous slippage, seizing of brake	X								

Table C.51. Carriage brake.

Carriage Brake									
Function	To arrest motion of carriage at will								
Excellent	Can arrest motion at any position, not seized								
Failed	Cannot arrest motion at any position, seizing of brake								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Can arrest motion at any position, not seized							X		
Limited slippage without impacting operation; no slip but vibration				X	X	X			
Limited slippage that impacts operation		X	X						
Continuous slippage, seizing of brake	X								

Table C.52. Fan brake.

Fan Brake									
Function	To limit the speed of descent of a gate in absence of power supply								
Excellent	Clean, unobstructed airways, louvers well-aligned and secured, gate closes at the specified speed.								
Failed	Exceeds the specified closing speed of the gate								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Clean, unobstructed airways, . louvers well-aligned and secured, gate closes at the specified speed							X		
Obstructed airways, unsecured louvers or damaged impeller		X	X	X	X	X			
Gate closes too fast	X								

Table C.53. Wire rope and connectors.

Wire rope and connectors									
Function	Transmit lifting force to the gate								
Excellent	No broken wires, can bend easily on a sheave or drum, well lubricated, no corrosion								
Failed	Six or more broken wires, bird caging, or reduction in wire diameter > 10%								
	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Indicator	1	2	3	4	5	6	7	S	
Kinking									
No kinking							X		
Minor, kinking of a wire				X	X				
Major, kinking of one or more strand	X	X	X						
Corrosion									
No corrosion, well lubricated							X		
No surface grease			X	X					
Carbon steel wire rope or connectors below the water line, and not inspected, or corrosion		X	X						
Reduction in wire diameter>10%	X								
Outer wire wear, or breakage									
No outer wire wear, or breakage							X		
Nicks or surface gouges (round ropes)		X	X						
Nicks or surface gouges (flat ropes)		X	X						
Six or more broken wires within a lay	X								
Bird caging	X								
Corrosion									
Even tension							X		
Uneven tension not preventing opening			X	X	X				
Uneven tension preventing opening	X								

Table C.54. Trunnion assembly.

Trunnion Assembly									
Function	Allow rotation of the radial gate								
Excellent	Well lubricated and without abnormal noise or vibration, no excessive play or friction								
Failed	Does not rotate or excessive friction during gate operation								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Functional Test									
Runs well with head. Frequently and uniformly lubricated, free rotation between pin and journal and/or thrust bearing. Well-aligned pins.							X		
Normal noise or vibration, Runs well in dry conditions without head. Free rotation between pin and journal and/or thrust bearing. Well-aligned pins						X			
Abnormal noise or vibration or no lubrication or blockage of grease lines or cracked housing but still running		X	X	X					
Seizing between pin/shaft and bushing.Rotation of pin in yoke/lug.	X	X	X						
Pin lateral displacement in trunnion	X	X							
Lubrication									
Well lubricated							X		
No lubrication or lubrication condition unknown			X	X	X				
Corrosion									
External corrosion on the assembly						X			
Corrosion preventing the removal of the cover plate				X	X				

Table C.55. Trunnion beam and anchorage.

Trunnion beam and anchorage									
Function	To provide structural support of trunnion assembly								
Excellent	No cracks, no discoloring, no corrosion, no displacement, no deformation, no loose or missing anchor bolts, no concrete spalling								
Failed	Loss of support								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
No cracks, no discoloring, no corrosion, no displacement, no deformation, no loose or missing anchor bolts, no concrete spalling							X		
Corrosion of the anchorage and bolts				X	X				
Excessive displacement of the anchorage (if data is available)			X	X	X				
Excessive deflection of anchor beam (if data is available)			X	X	X				
External post-tension rods corrosion			X	X	X				
Diagonal shear cracks in concrete trunnion beam		X	X	X					
Loss of support	X								

Table C.56. Chain and sprocket assembly.

Chain and sprocket assembly									
Function	To transmit lifting force to gate								
Excellent	No wear/play, well aligned, no corrosion, free movement of the pins, well lubricated, no deformations of the links or sprocket, no missing retention clips, no missing chain guides								
Failed	Missing pin, link, or cracked link or severely damaged sprocket								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
No wear/play, well aligned, no corrosion, free movement of the pins, well lubricated, no deformations of the links or sprocket, no missing retention clips, no missing chain guides							X		
Corrosion visible on surface of chain				X	X	X			
Operates but not well lubricated				X	X	X			
Noise, jumping, or vibration		X	X	X	X				
Kinking, not impacting operation			X	X					
Links do not lay flat on the chain rack under self-weight				X					
Links must be forced to rotate over the sprocket		X	X						
Corrosion limiting rotation of links		X	X						
Kinking limiting operation	X	X							
Improper meshing of chain and sprocket	X	X							
Missing pin, link, or cracked link or severely damaged sprocket.	X								

Table C.57. Hydraulic cylinder assembly.

Hydraulic cylinder assembly									
Function	To provide lifting force to gate								
Excellent	No leak in the hydraulic system. Operates properly along full stroke within specifications.								
Failed	No pressure buildup or no movement at release pressure								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
No leak in the hydraulic system. Operates properly along full stroke within specifications.							X		
Loss of pressure controllable by motor			X	X	X				
Corrosion/pitting of rod			X	X					
Oil leakage		X	X	X					
Insufficient pressure buildup or no movement at release pressure	X								

Table C.58. Fixed wheels for vertical lift gates.

Fixed wheels for vertical lift gates									
Function	Reduce friction when operating gates								
Excellent	Roundness within tolerances, minimal rusting, freely rotating, no cracks, well aligned, correctly lubricated.								
Failed	Enough wheels do not rotate preventing lifting of gate. Enough friction to prevent lifting or closing								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Roundness within tolerances, minimal rusting and pitting, freely rotating, no cracks, well aligned, correctly lubricated.							X		
Vibrations, jerkiness, uneven motion not preventing lifting or closing of gate			X	X	X				
Seized or damaged wheel or bearing not preventing lifting or closing of gate		X	X	X					
Enough friction to prevent lifting or closing of the gate.	X								

Table C.59. Roller trains.

Roller trains									
Function	Reduce friction when operating gates								
Excellent	Roundness within tolerances, minimal rusting, freely rotating, no cracks, well aligned. Casings undamaged and follow gate movement.								
Failed	Jammed rollers prevent lifting of gate. Broken cable. Debris block rollers. Casing severely damaged or missing rollers.								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Roundness within tolerances, minimal rusting, freely rotating, no cracks, well aligned. Casings undamaged and follow gate movement.							X		
Vibrations, jerkiness.				X	X	X			
Uneven motion not preventing lifting or closing of gate			X	X	X				
Jammed or damaged roller not preventing lifting or closing of gate		X	X						
Jammed rollers prevent lifting of gate. Broken cable. Debris block rollers. Casing severely damaged or missing rollers.	X								

Civil/structural components

Table C.60. Carrying tracks.

Carrying Tracks									
Function	Provides support for, and the means to displace the lifting structure to access all the gates of the spillway.								
Excellent	Alignment according to specsification, no missing parts or sections.								
Failed	Visible or measured misalignment, section missing that prevents the carriage from moving or lifting.								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Alignment, elevation, spacing (gauge)									
According to specifications							X		
Out of specification but no noticeable wear of track, crane can still lift gate and travel (without noise and vibration)					X	X			
Out of specification but no noticeable wear of track, crane can still lift gate and travel (with noise and vibration)				X					
Out of specification with noticeable wear of track can still lift gate and move freely			X						
Enough misalignment, so that crane may not/cannot lift gate or move freely	X	X							
Anchor									
Present							X		
1 - 2 consecutive missing, damaged or loose anchor			X	X	X				
More than 2 missing, damaged, or loose consecutive anchor	X	X	X						
Missing sections									
None							X		
At least one gate cannot be opened	X	X	X						

Table C.61. Lifting device structure.

Lifting Device Structure (concrete)									
Function	To provide support for hoisting device (and carrying tracks for mobile hoisting device)								
Excellent	Comprehensive structural inspection has been performed. All critical structural members fully accessible for inspection. No member deformations, no cracks, no exposed rebars, no concrete spalling or erosion. No loss of bearing support. No misalignment according to specifications.								
Failed	Inability to correctly position or operate the lifting device or the lifting structure. Extensive deterioration, visible member deformations. Loss of concrete section.								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Support for lifting structure or hoisting mechanism									
No misalignment in a dedicated hoisting mechanism							X		
Displacement and deterioration of the structure causing misalignment in a hoisting mechanism with no effect on lifting						X			
Displacement and deterioration of the structure causing misalignment in a hoisting mechanism with abnormal noise and vibration				X	X				
Displacement and deterioration of the structure causing misalignment in a hoisting mechanism with motor overload		X	X						
Displacement and deterioration of the structure causing misalignment in a hoisting mechanism that cannot be lifted	X								

Table C.62. Mobile structure to support a shared lifting device.

Mobile structure to support a shared lifting device (including gantry crane)									
Function	Provide structural support for the hoisting device								
Excellent	Comprehensive structural inspection has been performed. All critical structural members fully accessible for inspection. No visible cracks, no visible member deformation, no corrosion, no missing bolts or members, no visible misalignment.								
Failed	Visible deformations, missing parts, or cracks of a load-carrying member. Corrosion resulting in the loss of more than 20% of the cross-section of critical structural member. Missing bolts or cracked welds on a fracture-critical member or connection (a non-redundant tensile member or connection whose loss would result in the collapse of the structure)								
	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Indicator	1	2	3	4	5	6	7	S	
Displacement and deterioration									
No misalignment in the hoisting mechanism							X		
Displacement and deterioration of the structure causing visible or measurable misalignment in a shared lifting device with no effect on lifting						X			
Displacement and deterioration of the structure causing visible or measurable misalignment in a shared lifting device with excessive noise and vibration				X	X				
Displacement and deterioration of the structure causing visible or measurable misalignment in a shared lifting device with motor overload		X	X						
Displacement and deterioration of the structure causing visible or measurable misalignment in a dedicated hoisting mechanism that cannot be lifted	X								
Anchor bolts									
Corrosion on nuts and bolts				X	X	X			
Cracks in the concrete around the bolt and or missing concrete around the bolt		X	X						
At least one missing bolt or nut	X								
Cracks									
No cracks							X		
Crack in compression member	X	X	X	X					
Crack in tension members, web plate, or tension or compression connections (missing or cracked weld, splices, bolts and rivet heads)	X	X							
Crack in a fracture critical member	X								
Distortion									
No distorsion							X		
Distorion in tension members and braces				X	X				
Compression members and braces, web, and bolts	X	X	X						
Corrosion (Compression and tension members and flanges)									
Intact coating							X		
Loss of coating, surface scaling					X	X			
Visible loss of section (< 20%)			X	X					
Loss of section > 20%	X	X							
Missing or loose parts									
No missing of loose parts									
Missing bolts or rivet heads in a connection < 10%			X	X					
Missing bolt or rivet head in a stiffener or a brace of main	X	X	X	X					
Missing bolts or rivet heads in a connection > 10%	X	X							
Missing welds	X								

Table C.63. Approach and exit channel.

<table>
<tr><th colspan="10"><u>Approach and exit channel</u>
(Upstream and downstream apron including base of pier / stilling basin/exit channel)</th></tr>
<tr><td>Function</td><td colspan="9">Protect the downstream and upstream portion of the spillway channel from erosion associated with the flow of water during discharge. Provide unobstructed passage to the flow of water.</td></tr>
<tr><td>Excellent</td><td colspan="9">No cavitation damage or erosion. No sedimentation upstream. No obstructions downstream.</td></tr>
<tr><td>Failed</td><td colspan="9">Major erosion at foot of spillway at the foundation level compromising the stability of the dam.
Obstructions to the flow of water from sedimentation or downstream blockage.</td></tr>
<tr><td>Indicator</td><td>0 -- 9</td><td>10 -- 24</td><td>25 -- 39</td><td>40 -- 54</td><td>55 -- 69</td><td>70 -- 84</td><td>85 -- 100</td><td>Score</td><td>Comments</td></tr>
<tr><td>Loss of concrete due to cracking, erosion, cavitation (Apron and stilling basin)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>No loss</td><td></td><td></td><td></td><td></td><td></td><td></td><td>X</td><td></td><td></td></tr>
<tr><td>Depth < 4"</td><td></td><td></td><td></td><td></td><td>X</td><td>X</td><td></td><td></td><td></td></tr>
<tr><td>4" to 6" or exposure of rebar</td><td></td><td></td><td></td><td>X</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>> 6" up to 30% of as-built cross-section</td><td></td><td>X</td><td>X</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>> 30% of as-built cross-section design load and no structural evaluation</td><td>X</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Loss of concrete due to cracking, erosion, cavitation (in pier and/or base)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>No loss</td><td></td><td></td><td></td><td></td><td></td><td></td><td>X</td><td></td><td></td></tr>
<tr><td>Minor (<2")</td><td></td><td></td><td></td><td></td><td>X</td><td>X</td><td></td><td></td><td></td></tr>
<tr><td>Exposure of rebar</td><td></td><td></td><td>X</td><td>X</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Undermine rebar</td><td>X</td><td>X</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Scour of foundation material (caused by full opening of gates), scours and potential scour of sidewalls and bottom of spillway channel</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>No loss of foundation material</td><td></td><td></td><td></td><td></td><td></td><td></td><td>X</td><td></td><td></td></tr>
<tr><td>Loss or potential loss of material without undermining of dam (including never used)</td><td></td><td></td><td></td><td>X</td><td>X</td><td>X</td><td></td><td></td><td></td></tr>
<tr><td>Loss or potential loss of material with undermining of dam (including never used)</td><td>X</td><td>X</td><td>X</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Upstream sedimentation</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>None</td><td></td><td></td><td></td><td></td><td></td><td></td><td>X</td><td></td><td></td></tr>
<tr><td>Minor</td><td></td><td></td><td></td><td></td><td></td><td>X</td><td></td><td></td><td></td></tr>
<tr><td>Important</td><td>X</td><td>X</td><td>X</td><td>X</td><td>X</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Downstream blockage</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>None</td><td></td><td></td><td></td><td></td><td></td><td></td><td>X</td><td></td><td></td></tr>
<tr><td>Minor</td><td></td><td></td><td></td><td></td><td></td><td>X</td><td></td><td></td><td></td></tr>
<tr><td>Important</td><td>X</td><td>X</td><td>X</td><td>X</td><td>X</td><td></td><td></td><td></td><td></td></tr>
</table>

Table C.64. Lifting device structure (steel).

Lifting device structure (steel)									
Function	Provide structural support for the hoisting device (and carrying tracks for mobile hoisting device)								
Excellent	Comprehensive structural inspection has been performed. All critical structural members fully accessible for inspection. No visible cracks, no visible member deformation, no corrosion, no missing bolts or members, no visible misalignment.								
Failed	Visible deformations, missing parts, or cracks of a load-carrying member. Corrosion resulting in the loss of more than 20% of the cross-section of critical structural member. Missing bolts or cracked welds on a facture critical member or connection (a non-redundant tensile member or connection whose loss would result in the collapse of the structure).								
	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Indicator	1	2	3	4	5	6	7	S	
Displacement and deterioration									
No misalignment in a dedicated hoisting mechanism							X		
Displacement and deterioration of the structure causing visible or measurable misalignment in a hoisting mechanism with no effect on lifting						X			
Displacement and deterioration of the structure causing visible or measurable misalignment in a hoisting mechanism with excessive noise and vibration				X	X				
Displacement and deterioration of the structure causing visible or measurable misalignment in a hoisting mechanism with motor overload		X	X						
Displacement and deterioration of the structure causing visible or measurable misalignment in a hoisting mechanism that cannot be lifted	X								
Anchor bolts									
No corrosion							X		
Corrosion on nuts and bolts				X	X	X			
Cracks in the concrete around the bolt and or missing concrete around the bolt		X	X						
At least one missing bolt or nut	X								
Cracks									
No cracks							X		
Crack in compression member	X	X	X	X					
Crack in tension members, web plate, or tension or compression connections (missing or cracked weld, splices, bolts and rivet heads)	X	X							
Crack in a fracture critical member	X								
Distortion									
No distortion							X		
Distortion in tension members and braces				X	X				
Distortion in compression members and braces, web, and bolts	X	X	X						
Corrosion (Compression and tension members and flanges)									
Intact coating							X		
Loss of coating, surface scaling					X	X			
Visible loss of section (< 20%)			X	X					
Loss of section > 20%	X	X							
Missing or loose parts									
No missing or loose parts							X		
Missing bolts or rivet heads in a connection < 10%			X	X					
Stiffener of brace of main member	X	X	X	X					
Missing bolts or rivet heads in a connection > 10%	X	X							
Missing welds	X								

Table C.65. Embedded parts.

Embedded Parts (including sill)									
Function	To provide external support and bearing surfaces to the gate and seals. i. Embedded sill plate ii. Roller path and sealing surfaces iii. Lateral guides								
Excellent **Failed**	Gate has been dewatered for inspection or observations in accordance with specified schedule. - No misalignment, warping or distortion - Working heating elements - No visible surface defects (pitting, cracking, wearing, punctures, dents, missing sections) - Full structural support - No surface contaminants (crustaceans) - Gate has been tested under load and lifts with appropriate load and velocity - Warping that could bind the gate in place								
	- Heating elements not working - Loss of structural support under the roller pads - Enough displacement of the structural support that could bind the gate in place - Enough displacement of the structural support under seismic loading that could damage the gate - Localized pitting or puncturing under the roller path (1/8" or greater) - Puncturing of the embedded part outside of the roller path								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Gate lifting effort									
Gate lifts under load without overloading hoist at rated speed							X		
Gate lifts under load with hoist overload		X	X	X					
Gate does not lift	X								
Geometrical alignment of roller path									
With measurement meeting specifications							X		
No Visual warping or no known displacement of supports in the absence of measurements				X	X	X			
Measurements that do not meet specifications	X	X	X	X	X				
Visual warping or known displacement of supports in absence of measurements	X	X	X						
Corrosion (confined to roller track path)									
Light surface scaling					X	X			
Pitting < 1/8" deep			X	X					
Pitting > 1/8" deep	X	X							
Roller track wear									
No wear							X		
< 10% of thickness				X	X	X			
> 10% of thickness	X	X	X						
Corrosion (Rest of embedded part - excluding roller track)									
Failure of paint system, spots of surface rust, no section loss						X	X		
< 30% loss of cross-section [locally]					X	X			
> 30% loss of cross-section [locally]		X	X	X					
Puncture or holes	X	X							

Table C.66. Gate structure.

Gate Structure	
Function	Supporting structure To hold the skinplate in place and transfer water load to wheels or trunnion. Skin plate Provide lateral support to girders, retain water, water tightness
Excellent	Gate has been dewatered for inspection or observations in accordance with specified schedule. Gate has been tested under design load and lifts and closes according to specifications. - No visual warping or member deformation - No loss of paint - No visible surface defects on members or - connections (pitting, cracking, wearing, puncture, missing sections) - No fractured or missing welds - No missing bolts or members
Failed	Warping or member deformation that could bind or overload the gate. Corrosion resulting in the loss of more than 20% of the cross-section. Missing bolts or cracked welds on a facture critical member or connection (a non-redundant tensile member or connection whose loss would result in the collapse of the structure).

Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Loading history									
Operated under design load and positive structural evaluation							X		
Operated under design load but no structural evaluation			X	X	X	X			
Operated under design load but negative structural evaluation	X	X	X						
Never been operated under design load but positive structural evaluation					X	X			
Never been operated under design load and no structural evaluation		X	X	X					
Never been operated under design load and negative structural evaluation	X	X							
Cracks									
No Cracks							X		
Cracks in skin plate if due to impact (tear)				X	X				
Cracks in compression member o fatigue crack in skin plate	X	X	X	X					
Cracks in tension members, web plate, or tension or compression connections (missing or cracked weld, splices, bolts and rivet heads)	X	X							
Crack in a fracture critical member	X								
Distortion									
No Distortion							X		
Distortion in tension members and braces, skin plate				X	X				
Distortion in compression members and braces, web, bolts, and pins	X	X	X						
Corrosion (skin plate)									
Failure of coating and/or surface scaling present						X	X		
Visible loss of section (< 30%)			X	X					
Holes, > 30% section loss	X	X							
Corrosion (Compression and tension members and flanges)									
Intact coating							X		
Loss of coating, surface scaling					X	X			
Visible loss of section (< 20%)			X	X					
Loss of section > 20%	X	X							
Missing or loose parts									
No missing or loose parts							X		
Missing bolts or rivet heads in a connection < 10%			X	X					
Missing or lose part in a plate stiffener (bracing behind skin plate, skin plate stiffeners)			X	X					
Stiffener or brace of main member	X	X	X	X					
Missing bolts or rivet heads in a connection > 10%	X	X							
Missing welds	X								

Table C.67. Stoplogs, bulkheads (steel).

Stoplogs, bulkheads (steel)									
Function	Provide closure for dewatering inspection, maintenance, and rehabilitation of gates and possible emergency closure. Used as a gate.								
Excellent	Comprehensive structural inspection has been performed. All critical structural members fully accessible for inspection. No visible cracks, no visible member deformation, no corrosion, no missing bolts or members, no visible misalignment.No loss of paint. Adequate sealing for safe working conditions downstream								
Failed	Visible deformations, missing part, or crack of a load-carrying member. Warping/member deformation that could bind the bulkhead in place. Corrosion resulting in the loss of more than 20% of the cross-section. Missing bolts or cracked weld on a fracture critical member or connection (a non-redundant tensile member or connection whose loss would result in the collapse of the structure). Cannot be lowered or raised into position. Does not provide sufficient water tightness.								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Previously installed successfully and a positive structural evaluation							X		
Previously installed successfully and no structural evaluation			X	X	X	X			
Cracks									
No cracks							X		
Crack in skin plate if due to impact (tear)				X	X				
Crack in compression member or fatigue crack in skin plate	X	X	X	X					
Crack in tension members, web plate, or tension or compression connections (missing or cracked weld , splices, bolts and rivet heads)	X	X							
Crack in a fracture critical member	X								
Distortion									
No distortion							X		
Distortion in tension members and braces, skin plate				X	X	X			
Distortion in compression members and braces, web, bolts, and pins	X	X	X						
Corrosion (skin plate)									
No corrosion							X		
Failure of coating and/or surface scaling present					X	X			
Visible loss of section (< 30%)			X	X					
Holes, > 30% section loss	X	X							
Corrosion (Compression and tension members and flanges)									
Intact coating							X		
Loss of coating, surface scaling					X	X			
Visible loss of section (< 20%)			X	X					
Loss of section > 20%	X	X							
Missing or loose parts									
No missing or loose parts							X		
Missing bolts or rivet heads in a connection < 10%			X	X					
Plate stiffener (bracing behind skin plate, skin plate stiffeners)			X	X					
Stiffener or brace of main member	X	X	X	X					
Missing bolts or rivet heads in a connection > 10%	X	X							
Missing welds	X								

Table C.68. Bottom and side seals.

Bottom and Side Seals									
Function	Prevent leaks on the sides and at the bottom of the gate.								
Excellent	No leak								
Failed	Blowout of seal								
Indicator	0 -- 9	10 -- 24	25 -- 39	40 -- 54	55 -- 69	70 -- 84	85 -- 100	Score	Comments
Leaks									
No leaks							X		
Leak not causing ice buildup, nor deterring maintenance or inspection, nor causing erosion.				X	X	X			
Leak deterring maintenance or inspection, or causing erosion, or causes ice buildup	X	X	X	X					

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14. ABSTRACT

The U.S. Army Corps of Engineers (USACE) has primary responsibility for maintaining and operating U.S. navigable waterways and Federal flood control dams. Dam safety is a critical priority, but assessment and prioritization of dam safety concerns is difficult. This report describes a condition assessment and prioritization methodology for structural, mechanical, electrical, and operational aspects of spillways. The methodology was developed to help provide a firmer engineering basis for prioritization and decision making. The method described herein is less rigorous than conventional reliability-based risk assessment approaches. As a lower cost option it can be used as a preliminary method, a replacement, or an enhancement of conventional reliability-based assessment approaches, depending on the circumstances. Current Headquarters USACE policy for portfolio risk assessment for the dam and levee safety programs is to use the reliability-based risk assessment approach.

The methodology described herein uses visual inspection data in combination with spillway function and component importance criteria to develop priority rankings. The rankings reflect the condition ratings for the spill-way and its subcomponents and also indicate the significance of any deficiencies. Although the rankings assist in budget prioritization, they are not intended for use as the sole criterion for maintenance and repair of spill-ways. This methodology is one of several that engineers and managers of spillways and other Civil Works infrastructure can use to help maintain their infrastructure.

15. SUBJECT TERMS
Dams, hydraulic structures, condition rating, maintenance and repair, safety

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