

Using maturity matrices to evaluate a dam safety programme and improve practices

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Dam owners manage many complex activities to maintain and operate their dams safely and resiliently. Identifying, and continually improving, the key elements of an effective dam safety program and associated practices can be challenging but are essential to support resilient dams and resilient communities; using the Dam Safety Maturity Matrices (DSMM) is an efficient and thorough way to do this. A maturity matrix is a tool to evaluate how well-developed and effective a process or program is. The matrices were developed within CEATI's Dam Safety Interest Group (DSIG) for owners to assess the effectiveness of their dam safety program against industry practice, and to assist with identifying improvement initiatives.

This paper will present the matrices and demonstrate how they are used to evaluate the effectiveness (or maturity) of a dam safety program. It will also highlight the benefits associated with using the matrices as an assessment tool, including the identification of improvements that can be made to a dam safety program, and the prioritization of efforts across multiple facets of a dam safety program.

User case studies from dam owners in both New Zealand and overseas will be presented to elaborate on the tool and the process.

1. Introduction

1.1 Dam Safety Management

Dam owners manage many complex activities to maintain and operate their dams safely and resiliently; typically, these activities are planned, organized and implemented in a dam safety program or dam safety management system. Dam safety programs and management systems provide a structured framework for the completion of dam safety activities, reaching appropriate dam safety decisions, and addressing identified dam safety issues and deficiencies.

Identifying, and continually improving, the key elements of an effective dam safety program, and their associated level of practice, allows the dam owner to demonstrate appropriate safe management of its dams; this is a fundamental step in achieving resilient dams and resilient communities. Using the Dam Safety Maturity Matrices (DSMM) is an efficient and thorough way to do this.

1.2 The Dam Safety Maturity Matrices uses and benefits

The DSMM have been developed for dam owners to assess the effectiveness of their dam safety program against industry practice. A maturity matrix is a tool to evaluate how well-developed and effective a process or program is.

The matrices can be used to review the effectiveness of an existing dam safety program, to identify program improvements, and to periodically re-evaluate the dam safety program to determine whether improvement initiatives have been successful.

The primary benefit from using the matrices is improved understanding of the dam safety program across the whole range of activities that influence its effectiveness. Use of the maturity matrices also provides a valuable means to communicate the effectiveness of a dam safety program to wider audiences and can therefore be used to support the case for targeted funding and resources to address program improvements.

1.3 The Dam Safety Maturity Matrices development

The matrices were originally developed in 2015 by CEATI International's Dam Safety Interest Group (DSIG), then updated in 2018 after many of the DSIG members had used the tool and suggested improvements. The current version of the matrices was developed collaboratively with the 65 members of the DSIG, including dam owners, regulators, government agencies and technical practitioners across multiple countries. Due to the international diversity of the development group the matrices are applicable to world-wide users.

The DSIG had recognized the dedicated and formalised maturation of dam safety programs over the past decade and envisioned an assessment and awareness tool that would support further dam safety program growth in the industry. The aims were to make existing dam safety programs better, and to provide guidance to owners who did not have a program in place.

1.4 CEATI International Dam Safety Interest Group

CEATI International is a user-driven organisation committed to providing technology solutions to its electrical utility participants, who are brought together to collaborate and act jointly to advance the industry. CEATI's participants represent 16 countries on 6 continents, a diversity that contributes to the strength of CEATI and brings value directly to the participants.

CEATI’s Dam Safety Interest Group (DSIG) was formed in 1998 with 6 dam owners, and over the last 20 years has grown to include 65 members from 7 countries. The DSIG provides a cost-effective technical resource tool for benchmarking and sharing best practices, as well as cost leveraging opportunities through project funding consortiums (such as that used to develop the DSMM).

2. How the Dam Safety Maturity Matrices Work

2.1 Dam Safety Maturity Matrices make-up

The Dam Safety Maturity Matrices are made up of twelve matrix charts – one for each of a typical dam safety program’s elements. An element is a component, or grouping of activities, of the dam safety program. Table 2 in Section 3 describes the dam safety program elements and sub-elements covered by the matrices.

The matrix charts have maturity level on the horizontal axis (Level 1 to 5) and dam safety program “sub-elements” (sub-components/sub-groupings) on the vertical axis. Each sub-element is divided into a number of “differentiators”, which are the aspects of that sub-element that are evaluated for maturity level. The cells within the body of the matrix contain maturity level descriptors, varying the degree to which the differentiator is achieved as the maturity levels progress from 1 to 5. The user selects the descriptor that best describes their level of maturity, for that differentiator. Figure 1 demonstrates these matrix features.

Matrix 1: [Element]	Maturity Level Differentiators	Maturity Level Descriptors				
		1. Needing Development	2. Intermediate	3. Good Industry Practice	4. Best Industry Practice	5. Leading Edge
Sub-elements						
1-A. [Sub-element]	(a) [Differentiator]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]
	(b) [Differentiator]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]
	(c) [Differentiator]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]
	(d) [Differentiator]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]
1-B. [Sub-element]	(a) [Differentiator]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]
	(b) [Differentiator]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]
	(c) [Differentiator]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]
	(d) [Differentiator]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]
1-C. [Sub-element]	(a) [Differentiator]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]
	(b) [Differentiator]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]
	(c) [Differentiator]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]
	(d) [Differentiator]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]
1-D. [Sub-element]	(a) [Differentiator]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]
	(b) [Differentiator]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]
	(c) [Differentiator]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]
	(d) [Differentiator]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]

Figure 1: Maturity Matrix features.

2.2 Dam Safety Maturity Matrices principles

The maturity matrices have been developed to evaluate dam safety program effectiveness. The concept of dam safety program effectiveness is described in the report “Gauging the Effectiveness of Dam Safety Programs” (CEATI, 2008). The report states: “From a dam owner’s perspective, an ‘effective’ Dam Safety Program provides an understanding of the specific safety risks (including operational) to the dam facilities and has a management strategy for each risk integrated into the asset management for the company”.

The descriptions that define maturity levels have therefore been selected to assess both the understanding of dam safety risks and their integration into asset management. The expectation is firstly, that dam safety programs at the lower end of the maturity scale are typically less effective in achieving appropriate dam safety outcomes, and secondly, programs with a higher level of maturity are typically more effective and better integrated into asset management through organisational objectives, values and processes. The maturity level is therefore an indication of the effectiveness of a dam safety program to meet organisational goals and obligations for dam safety.

Another important principle is the application of the maturity matrices within the lifecycle of a dam as shown in Figure 2. The focus of the maturity matrices is on the operation and maintenance phase. The maturity matrices have not been developed to include life extension and upgrade activities, however, the important interface of life extension and upgrade with dam safety has been included.

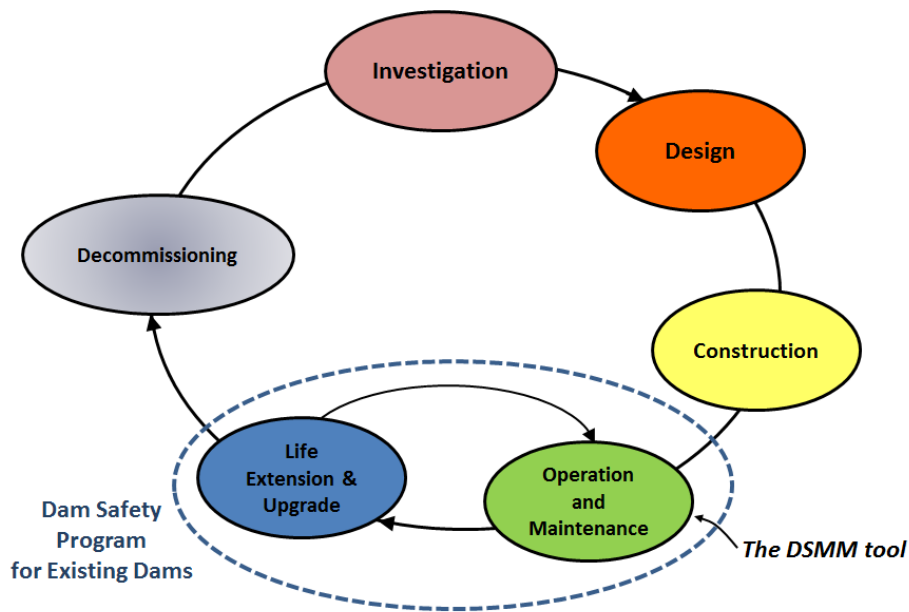


Figure 2: Dam Lifecycle and Focus of the Maturity Matrices.

2.3 Dam Safety Maturity Matrices boundaries

The maturity matrices describe varying levels of dam safety program effectiveness ranging from those that do not conform to applicable guidelines, standards and industry practice to those that have a high degree of understanding and conformance with applicable guidelines, standards and industry practice.

The dam safety program elements and sub-elements used in the maturity matrices are described in Section 3.

Regulatory regimes vary across different jurisdictions and for this reason, the maturity matrices do not specifically assess regulatory compliance. However, owners in a regulated jurisdiction may use the matrices to evaluate the level of understanding of regulatory dam safety requirements and the level of relationships with regulators within Matrix 12: Governance.

3. Maturity Matrices Detail

3.1 Maturity levels

Five maturity levels are used in the matrices, ranging from Level 1 “Needing Development” to Level 5 “Leading Edge”. Table 1 provides descriptions of each maturity level. Typical characteristics were also defined for each maturity level, such as completeness, structure, planning and level of understanding. These were used to guide the development of matrix descriptors.

Most dam owners will rate their dam safety program maturity in the Level 1 to 4 range. Level 5 will be less commonly used and is often driven by circumstances such as response to a dam safety incident or identified program shortcoming, or an owner striving to advance the state of practice.

Table 1: Maturity Level Descriptions

Maturity Level	Maturity Level Description
1. Needing Development	Does not conform to applicable guidelines, standards, and industry practice
2. Intermediate	Partially conforms to applicable guidelines, standards, and industry practice
3. Good Practice	Mostly conforms to applicable guidelines, standards, and industry practice
4. Best Practice	High degree of understanding and conformance with applicable guidelines, standards, and industry practice
5. Leading Edge	Achieving Level 4 Best Practice level, AND developing, trialing, and implementing new technology, methods or systems

3.2 Dam safety program elements and sub-elements

The twelve matrix charts in the dam safety maturity matrices represent a typical dam safety program’s elements. An element is a component, or grouping of activities, of the dam safety program. The elements range from dam safety practice in the field to support functions and governance required to provide assurance of dam safety. Each element is further broken down into sub-elements (sub-components/sub-groupings of the dam safety program).

Table 2 provides examples of some of the dam safety program elements and sub-elements represented in the maturity matrices.

Table 2: Example Dam Safety Program Elements and Sub-elements

Dam Safety Program Elements (one matrix for each element)	Sub-elements
Dam Surveillance	Dam Surveillance Program Inspections Instrumentation and Data Management Routine Dam Performance Evaluation
Dam and Water Conveyance Structure Maintenance	Maintenance Program Dam, Reservoir and Access Route Maintenance Water Conveyance Structure Maintenance
Public Safety and Security	Public Safety Management System Public Safety Plans and Control Measures Public Safety Monitoring and Evaluation <i>[and other Sub-elements]</i>
Governance	Regulation Policy, Goals, Values and Risk Management Delegated Roles and Responsibilities <i>[and other Sub-elements]</i>
<i>[and other Elements]</i>	

3.3 Dam Safety Maturity Matrices differentiators and descriptors

As described in Section 2, the sub-elements in a matrix are divided into “differentiators” that are evaluated for maturity level. The cells within the body of the matrix then contain maturity level “descriptors” that vary the degree to which the differentiator is achieved as the maturity levels progress from 1 to 5. The user selects the descriptor that best describes their level of maturity, for that differentiator. Figure 3 below demonstrates these features.

The descriptors are consistent and develop across the maturity levels. This allows the user to identify the current status and to identify the requirements for achieving a higher maturity rating.

Example (refer Figure 3): A differentiator in the “Dam Surveillance Program” sub-element is “(b) Documentation, including inventory of structures to inspect and monitor” and the descriptor at Maturity Level 1 is “None”. This progresses to “Some” at Maturity Level 2, “Complete” at Maturity Level 3 and “Thorough and reviewed regularly” at Maturity Level 4.

The differentiators and descriptors were developed in careful consultation with the 65 DSIG members, including dam owners, regulators, government agencies and technical practitioners across multiple countries.

Matrix 2: Dam Surveillance	Maturity Level Differentiators	Maturity Level Descriptors				
		1. Needing Development	2. Intermediate	3. Good Industry Practice	4. Best Industry Practice	5. Leading Edge
2-A. Dam Surveillance Program	(a) Program developed with consideration of failure modes, consequences of failure and risk	None	Consequences of failure considered only	Failure modes and consequences of failure considered only	Failure modes, consequences of failure and risk considered	New technology, methods or systems
	(b) Documentation, including inventory of structures to inspect	None	Some	Complete	Thorough and reviewed regularly	New technology, methods or systems
	(c) Quality assurance defined and completed	None	Rudimentary quality assurance for some activities	Considered quality assurance for most activities	High levels of quality assurance for all activities	New technology, methods or systems
	(d) Program delivery objectives stated and met	None	Some objectives stated and met	Most objectives stated and met - exceptions justified and documented	All objectives stated and met - high level of achievement	New technology, methods or systems
	(e) Process for escalation of issues identified during surveillance	None	Some process	Structured process	Well structured process and issues are tracked to resolution	New technology, methods or systems

Figure 3: Example of the Dam Surveillance Program sub-element (part of Matrix 2: Dam Surveillance) and its differentiators and descriptors.

4. Considerations for Preparing a Maturity Matrices Evaluation

4.1 Scope of a Dam Safety Maturity Matrices evaluation

Each dam owner’s organisational drivers and dam safety program are unique, however, there are common themes and objectives that owners may wish to achieve in evaluating their dam safety program using the matrices. The considerations in Table 3 will assist when developing the scope of an evaluation – i.e. what are the objectives and breadth, depth, coverage of the evaluation.

Table 3: Scoping Considerations for a Dam Safety Program Evaluation

Scoping Considerations	Comments
1. What are the objectives the dam owner wishes to achieve by completing a dam safety program evaluation?	Example objectives – improve organisational understanding of strengths and weaknesses, measure against an internationally credible reference, identify program improvements, communication and reporting to management, self-review and audit, benchmarking with other dam owner organisations, training.
2. Will the evaluation be facilitated internally or externally?	Use of a facilitator will maximize the value of the dam safety program evaluation. The facilitator’s role is to lead the owner’s staff through the maturity matrices, ask guiding questions, test the basis of their maturity level determinations, but not influence their determinations. Section 4.3 provides guidance on choosing a facilitator.
3. What is the organisational make-up of the dam safety program and which parts of the program will be included in the evaluation?	The 12 elements in the dam safety maturity matrices should be used as a guide to the full extent of the dam safety program that can be evaluated.
4. What will be the extent, or breadth and depth, of evaluation in each part of the dam safety program?	The sub-elements in each matrix should be used as a guide to the extent and detail of activities that can be evaluated.
5. What dam safety program groupings (e.g. hazard groups, other structure types, spillway gates, low level outlets) are being evaluated, and will this be achieved in one evaluation or separate evaluations?	Note that matrices, or individual sub-elements, can be replicated to separate the evaluation of one group of structures from another. E.g. Matrix 7: Dam and Water Conveyance Structure Maintenance as a whole, or any of its sub-elements, could be replicated to evaluate different structure types or consequences of failure separately.
6. What budget and personnel resources are available to complete the evaluation?	Section 4.2 provides guidance on who should be involved in the evaluation. The level of input required for internal staff and any external facilitation will vary depending on the size and complexity of the dam owner’s organisation and dam safety program.

4.2 Who should be involved in a Dam Safety Maturity Matrices evaluation

The activities that influence the effectiveness of a dam safety program commonly span many parts of a dam owner’s organisation. It is important that a maturity matrices evaluation receives broad input from the people responsible for oversight, planning and implementation of those activities. Some will have responsibilities that reach across all, or many, of the activities, while others will have fewer and more specific responsibilities. Each person’s input to the evaluation process should reflect the scope and level of their responsibility.

The evaluation should aim to receive input from operational levels, as well as strategic and managing levels in the organisation. Further, where owners operate dams in geographically separate or spread-out areas, it is important that the evaluation receives input from the range of areas.

The process of going through an evaluation with the matrices should involve as many people as is practical, as those utilities who have conducted this exercise have all emphasized the valuable collaboration, insights and training that the evaluation process provides.

The accompanying user manual provided with the matrices includes additional details on who should participate in the evaluation and how involved each internal role should be in the process.

4.3 Choosing a facilitator

The evaluation of dam safety program maturity is best conducted as a review workshop or series of workshops. The maturity levels descriptors are tested and checked against the owner’s documentation and established practice for all elements of the dam safety program.

A facilitator is necessary to direct the process and the workshops. This person could be internal and part of the dam safety program, internal but external to the dam safety program, or a dam safety engineer/expert external to the organisation that is familiar with the purpose and function of the maturity matrices.

An internal facilitator may have a deep understanding of the dam safety program but may be too close to the program to make objective assessments and may find some of the necessary questions confronting. An external facilitator would understand the industry practice that underpins the maturity levels and would provide objectivity and industry benchmarking examples to assist with maturity evaluation.

4.4 Adaption of the Dam Safety Maturity Matrices

The maturity matrices may be adapted to suit an owner’s dam portfolio and organisation. The following portfolio and organisation aspects may vary significantly:

- Size and complexity of owner’s dam portfolio – from a single dam to large numbers of dams of multiple types
- Consequences of failure – from very low to extreme or catastrophic
- Dam safety related asset types or components (e.g. water conveyance structures), and/or the dam safety practice applied to each
- The owner’s organisational structure, governance, and dam safety program, public safety and security information and communication requirements

Accordingly, when evaluating their dam safety program owners may wish to adapt the maturity matrices by replicating elements or sub-elements to allow additional evaluation granularity and/or separation. For example, the 'Governance' matrix as a whole, or its sub-elements, may be replicated to allow separate evaluation of dam safety governance and public safety and security governance.

5. Using the Dam Safety Maturity Matrices

5.1 How to use the Dam Safety Maturity Matrices

The matrices are an introspective tool for highlighting strengths and weaknesses, in a relative sense, not as absolute judgements. Users are encouraged to not over-analyse their determination of maturity – the words in the matrices and how they can be interpreted are inherently subjective. It is most beneficial to make an honest appraisal of maturity (not overly optimistic or pessimistic) and to follow a consistent approach through the entire evaluation.

The dam owner may choose to either define desired maturity levels for each element and sub-element prior to completing their evaluation, or to first complete the evaluation and then determine what levels are desired.

In the example evaluation shown in Figure 4 it could be concluded that there is further development required in the 'Inspections' and 'Routine Dam Performance Evaluation' sub-elements if the owner wished 'Dam Surveillance' element to achieve at least a 'Good Industry Practice' maturity level. Alternatively, the dam owner may find that the level achieved in a sub-element is acceptable or is a low priority, even if less than “Good Practice”.

Matrix 2: Dam Surveillance	Maturity Level Differentiators	Maturity Level Descriptors					Selected Maturity Level
		1. Needing Development	2. Intermediate	3. Good Industry Practice	4. Best Industry Practice	5. Leading Edge	
Sub-elements							
1-A. Dam Surveillance Program	(a) [Differentiator]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	3
	(b) [Differentiator]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	4
	(c) [Differentiator]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	3
	(d) [Differentiator]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	4
	(e) [Differentiator]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	3
1-B. Inspections	(a) [Differentiator]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	2
	(b) [Differentiator]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	2
	(c) [Differentiator]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	3
1-C. Instrumentation and Data Management	(a) [Differentiator]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	4
	(b) [Differentiator]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	3
	(c) [Differentiator]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	3
	(d) [Differentiator]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	3
	(e) [Differentiator]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	4
1-D. Routine Dam Performance Evaluation	(a) [Differentiator]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	2
	(b) [Differentiator]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	3
	(c) [Differentiator]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	2
	(d) [Differentiator]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	[Descriptor]	2

Figure 4: Example maturity level results selection for Matrix 2: Dam Surveillance.

5.2 Documenting the evaluation

Documenting the evaluation carefully will ensure that the user group’s thought processes are captured and can be clearly understood in the future, including when periodic re-evaluations are completed (an important tool to gauge the effectiveness of programme improvements). Supporting arguments for maturity level selections made during the evaluation should be documented, as well as the reasons why the next highest maturity level was not selected. This will help identify the improvement outcomes necessary to advance dam safety program maturity if that is desired.

The process of documenting the evaluation results is also an excellent training tool and can assist with informing and engaging the people participating in the exercise.

5.3 Presenting the evaluation results

The maturity matrices include a dashboard summary of results for each matrix, and for all matrices combined. The latter is termed a master matrix – it provides a snapshot of the maturity status of the overall dam safety program. An example audience for the master matrix is the owner’s managers and other key decision-makers, who may need to quickly identify

program strengths and weaknesses and any areas where they may wish to close the gap between the current status and the desired maturity levels. The dashboard summary for each individual matrix is more likely to be used by those managing and implementing the various elements of the dam safety program, for the purpose of progress reporting, team communication, identification of improvement initiatives and training.

Figures 5 and 6 provide examples of the dashboard summary for each matrix and the master matrix. The dashboards are editable so the user can customise them to suit their organisational reporting needs, e.g. columns may be added to the right with explanatory comments/justifications/opportunities.

In the dashboard summaries a basic numerical system is used to represent:

- average sub-element maturity level (the sum of maturity level scores divided by the number of differentiators in the sub-element)
- average element maturity level (the sum of average sub-element maturity levels divided by the number of sub-elements)

The numerical system recognizes partial maturity level achievement for a given sub-element and element. E.g. in Figure 5, sub-element 2-A, where ‘Best Practice’ is achieved for 2 out of the 5 differentiators, and ‘Good Practice’ for the rest, the average sub-element maturity level is 3.4.

Matrix 2: Dam Surveillance (Dashboard Summary)		Maturity Level					Average Sub-Element Maturity Level
Sub-elements		1. Needing Development	2. Intermediate	3. Good Industry Practice	4. Best Industry Practice	5. Leading Edge	
2-A. Dam Surveillance Program	(a)						3.4
	(b)						
	(c)						
	(d)						
	(e)						
2-B. Inspections	(a)						2.3
	(b)						
	(c)						
2-C. Instrumentation and Data Management	(a)						3.4
	(b)						
	(c)						
	(d)						
	(e)						
2-D. Routine Dam Performance Evaluation	(a)						2.3
	(b)						
	(c)						
	(d)						
Average Element Maturity Level:							2.8

Figure 5: Example of Dashboard Summary for Matrix 2: Dam Surveillance.

Dam Safety Program Master Matrix Dashboard		Maturity Level				
Elements		1. Needing Development	2. Intermediate	3. Good Industry Practice	4. Best Industry Practice	5. Leading Edge
1. [not shown]			2.8			
2. Dam Surveillance				3.4		
3. [not shown]				3.2		
4. [not shown]					4.2	
5. Public Safety and Security			2.2			
6. [not shown]				3.8		
7. Dam and Water Conveyance Structure Maintenance					4.0	
8. [not shown]				3.0		
9. [not shown]				3.4		
10. [not shown]			2.8			
11. [not shown]				3.8		
12. Governance				3.6		

Figure 6: Example of Master Matrix Dashboard.

6. Applying Evaluation Outcomes to Improve the Dam Safety Program

6.1 Advancing dam safety program maturity

Advancing dam safety program maturity is a key goal and benefit of the DSMM tool – the DSMM were designed with this as an objective. The matrices were developed in a collaborative and internationally diverse process, with a range of owner, regulator, government and practitioner inputs – as a result, they are a credible reference, and an effective tool, for the assessment and advancement of program maturity.

Once a maturity evaluation has been completed for the dam safety program, the owner may choose to set higher maturity goals for specific elements and sub-elements and then identify the gap between these goals and the current maturity status. Alternatively, maturity level goal setting may be completed prior to an evaluation. The differentiator descriptors above the evaluated maturity levels can be used as a guide to develop activities and plans to reach the desired levels.

The owner may then consider how program maturity advancements are best prioritised and staged to achieve the most appropriate path to improve their organisational goals and risk management practices.

6.2 How the evaluation results can be used to drive dam safety program improvement

Section 5 describes the importance of documenting the program evaluation results carefully, including identification of improvement activities that would achieve the next or desired level. Action owners can then be assigned and specific actions identified. It is important that planned actions are well integrated into the evaluation documentation, so that improvements can be tracked and communicated, and future program re-evaluations can be completed efficiently, using the matrices as the central tool.

Program improvements may be staged over time, where there is a significant gap between the achieved and desired maturity levels, or simply where a large effort is required to make the desired maturity change. The owner may choose to advance in successive steps or actions, e.g. one maturity level at a time, or part of a maturity level at a time. It may also be useful to identify quick-win improvements, where little effort is required to make a tangible maturity change.

6.3 Communication of dam safety program improvements

The completed matrices, with integrated evaluation documentation and planned actions, are a powerful tool for communicating with a range of internal stakeholders, including managers and executives responsible for oversight and resourcing of the dam safety program. As discussed previously, any program improvements identified can be promoted for budget and implementation in the context of the gap between the achieved and desired maturity levels. Progress can be tracked and “gap closure” can be demonstrated at subsequent program re-evaluations.

The matrices are editable so that users can tailor the graphical results presentation and documentation/action headings to their organisational needs.

7. User Case Studies

Three user case studies from dam owners in Canada (BC Hydro), New Zealand (Trustpower), and the United States (Example X) are presented to elaborate on what their drivers were for using the matrices, how they used the matrices and how the results were used to drive dam safety program improvement. BC Hydro has completed an initial evaluation. Trustpower has completed an initial evaluation and one subsequent re-evaluation to measure program improvement with time. Example X has completed an initial evaluation and two subsequent re-evaluations to measure program improvement with time.

7.1 BC Hydro (Canadian dam owner)

An external audit of BC Hydro’s (BCH) Dam Safety Program recommended that its Dam Safety department perform a self-assessment. As a starting point, BCH decided to evaluate the Dam Safety Program using the CEATI Dam Safety Maturity Matrices. An external facilitator familiar with the matrices was engaged to carry this out.

Means of performing the evaluation were discussed with the external facilitator and it was determined that the most efficient method would be for BCH to carry out a pre-evaluation of each sub-matrix with key staff responsible for implementing those elements of the dam safety program. For instance, a Regional General Manager of Operations was involved in evaluating the Flow Control Equipment and Reservoir Operations sub-matrices as that person is responsible for elements of each matrix. Meetings were held with each of the key staff, initial maturity levels were assessed for each element and documented as colour-coded cells in the matrices, and the supporting evidence was gathered. This information was then provided to the external facilitator prior to the facilitated evaluation.

The facilitated evaluation took place over five days, involving the same key staff who performed the pre-evaluation. Meetings were one to three hours long and were documented in the matrices. Where the pre-evaluation and facilitated evaluation levels differed, differences were discussed, reconciled and documented to provide the justification for a chosen level. At the end of the five days, the final maturity matrix evaluations were presented to the Director of Dam Safety.

The facilitator prepared a final report with key findings, a write-up for each sub-matrix with suggested improvements to raise some elements to the next maturity level, and a variety of plots illustrating the maturity levels for each sub-matrix and the overall Dam Safety Program. Some of these plots and narratives have subsequently been used to communicate the results to BCH's Dam Safety Department, senior management and the Board of Directors.

Most importantly, the documented findings have been used to provide direction for ongoing initiatives to improve BCH's Dam Safety Program. The finalized maturity matrices identified two main elements of the dam safety program that were lagging in maturity level. As a result, for the first element, the dam safety program has expanded its responsibility to have more direct involvement and to establish higher expectations. For the second element, a new process was established to ensure better action and reporting. Both of these changes will improve the dam safety program and have subsequently been supported by the most recent external audit.

7.2 Trustpower (New Zealand dam owner)

Trustpower completed an evaluation of its Dam Safety Management System (DSMS) using the CEATI Dam Safety Maturity Matrices in late 2017. The evaluation was completed as part of a broader independent review of the DSMS, and the evaluation results were compared with the results of other dam owners who had completed evaluations using the CEATI matrices. The CEATI matrices were chosen because Trustpower was familiar with the use of maturity matrices and they were seen as a valuable tool that could easily be repeated periodically to measure progress of improvement initiatives.

The evaluation was completed as a two day workshop with the following participants:

- Three external reviewers (including a facilitator)
- Three Trustpower personnel
 - Engineering Manager
 - Lead Dam Safety and Water Resources Engineer
 - Dam Safety Engineer
- Previous Trustpower Hydro Development Manager responsible for Trustpower's DSMS for 15 years (now external)

The facilitated workshop used a large screen and print-outs to work through the matrix evaluations. The group had good and thorough discussions on various individual sub-element questions and descriptors, and generally had no problem agreeing on the appropriate maturity level.

Trustpower dam safety staff conducted a dam safety workshop with the Board and used the MM results to educate senior management and Board on the maturity of Trustpower's DSMS. As part of the workshop staff and Board agreed on an overall maturity target profile that should be targeted for 2023.

The initial matrix evaluation showed distinctive clusters of low performing areas. The general understanding within the wider Trustpower Generation team was that in especially two of those clusters (flow control equipment and training/education/stakeholder management) very little progress would be made without dedicated resource. As a result Trustpower created two additional roles in the dam safety team that will specifically address those two clusters.

In February 2019 Trustpower carried out a second evaluation. Participants were:

- One external reviewer who acted as a facilitator (part of the original three)
- Four Trustpower personnel
 - New Engineering Manager
 - Lead Dam Safety and Water Resources Engineer
 - Dam Safety Engineer
 - Dam Safety Engineer – Flow Control Equipment
- Previous Trustpower Hydro Development Manager

This assessment showed some substantial improvements in some areas like governance and audits (largely as a result of the Board workshop), some minor improvements in other areas, but also areas with little to no improvement. The latter has especially been the case for element areas where knowledge or processes across a larger number of structures or schemes needed to be improved in order for the marker to slide from 'needing development' to 'intermediate' or even 'good industry practice'.

The changes in the matrix evaluations have been reported to the Board as an annual update report.

Trustpower will repeat this facilitated internal scoring in 2020 followed by a full external review and facilitated scoring in 2021 similar to the one in late 2017, continuing on this three-yearly external review cycle with internal assessments in the years in-between.

7.3 Example X (US dam owner)

As a component of Example X's Dam Safety Program, as prescribed by the Regulator, the company is committed to carrying out an annual internal assessment of the corporate dam safety program. The Chief Dam Safety Engineer

(CDSE) is responsible for performing internal assessments of the implementation and effectiveness of the company's dam safety program.

In early 2015, CEATI International published "Using Maturity Matrices to Evaluate Dam Safety Programs". Being one of the sponsors and monitors involved in this project afforded Example X the unique opportunity to be part of the evolution of the matrices. Example X began using the matrices in 2016 to conduct an internal assessment of its dam safety program. Using the matrices provided Example X with a formalized, detailed and systematic process to evaluate its program that, up until this time, had not existed.

The format for carrying out the initial assessment in 2016 using the Maturity Matrices was as follows:

- Schedule a full 8-hour meeting to carry out the assessment using the Maturity Matrices.
- A week prior to the meeting, all three dam safety engineers and the CDSE went through the 10 sub-matrices (the first version of the matrices had 10 elements not 12) and independently assigned a Maturity Level as to where they believed the maturity level was for the program.
- On the meeting day, the meeting convener (CDSE) was responsible for keeping the meeting on schedule.
- As a group, Example X went through each sub-element within each matrix. The matrices were projected onto a large screen so that the status of the program for each sub-element could be easily viewed and discussed and then color-coded for each agreed upon Maturity Level.
- Filling in the Maturity Level for each sub-element was based on a detailed discussion, including each engineer's pre-meeting assessment of the program, until a consensus was reached.
- The Master Matrix was compiled by the CDSE following the 8-hour meeting. In addition, a summary report documenting the internal assessment was issued to senior company personnel following the meeting.

The initial meeting took the full 8 hours but subsequent yearly assessments in 2017 and 2018 took about 4-5 hours to complete. Reducing the time to complete the subsequent 2017 and 2018 assessments was largely the result of increased understanding of how to use the matrices, a better understanding of the elements of the dam safety program and an increase in efficiency in modifying or editing the Maturity Level that had already been established.

The initial 2016 internal assessment of Example X's Dam Safety Program using the Maturity Matrices established a baseline for the maturity level of their program. From this initial assessment, they were able identify the strengths and any weaknesses in the program for each sub-elements within each matrix. The baseline provided them with the ability to identify and establish priorities where more emphasis/effort and resource re-allocation was required to take appropriate action to move to a higher maturity level within specific target sub-elements. Noticeable improvements in the program were identified during the 2017 and 2018 assessments.

8. Conclusions

Identifying, and continually improving, the key elements of an effective dam safety program, and their associated level of practice, allows the dam owner to demonstrate appropriate safe management of its dams; this is a fundamental step in achieving resilient dams and resilient communities.

The CEATI Dam Safety Maturity Matrices are a powerful tool to:

- evaluate the effectiveness of an owner's dam safety program against industry practice
- identify program strengths and areas for improvement
- communicate program strengths and areas for improvement to managers and other key stakeholders

The matrices can be used to evaluate dam safety programs; initially to identify areas for improvement and periodically to track subsequent improvements.

The primary benefit from using the maturity matrices is expected to be the improved understanding of a dam safety program, across the whole range of activities that influence its effectiveness. The matrices are a useful platform for communication of the program to wider audiences and a useful training tool for new team members.

The value of an evaluation will be maximized by using a facilitator familiar with the purpose and function of the matrices, including early involvement at the planning stage.

Moving forward, the goal of the CEATI DSIG is for its members to use the matrices as a benchmarking tool, to assist with identifying best practices and knowledge gaps across the membership and to identify future areas for collaboration and further development.

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