July 25, 2014

REPORT ON

Colliery Dams, Nanaimo, BC Risk Assessment

Submitted to:
Toby Steward
City of Nanaimo
Nanaimo City Hall
455 Wallace Street
Nanaimo, BC
V9R 5J6

REPORT

Report Number: 1314470516-006-R-Rev0

Distribution:

2 copies – City of Nanaimo
2 copies – Golder Associates Ltd.

Executive Summary

Summary of Risk Assessment Process

Golder Associates, as the technical advisor to the Colliery Dams Technical Committee, has carried out a risk assessment for the Lower and Middle Colliery Dams. This approach was adopted as it provides a means to better understand dam safety risks and to comparatively evaluate various remediation options. The risk assessment provides a means to more thoroughly assess potential failure mode probabilities and consequences. Further, the risk assessment can be used to determine conformance with dam safety guidelines, based on the most recent revision of the Canadian Dam Safety Guidelines (CDA, 2013), which provides criteria to be used when carrying out a risk-informed dam safety assessment. While the CDA Guidelines do not form part of the BC Dam Safety Regulation, they are considered in the application of the Regulations. The adoption of the risk assessment approach was undertaken in collaboration with the Technical Committee and the Dam Safety Section for the Province of BC.

This risk assessment has been carried out based on the assumption that the Lower Dam is remediated to increase flood routing capacity, by either: 1) an enlarged spillway (Labyrinth Option); or 2) dam crest and downstream face hardened to resist overtopping (Hardened Option).

Central to the risk assessment was the identification of valid potential “failure modes” for the dams and subsequent definition of a number of specific “failure scenarios” that adequately represented all those failure modes. The risk assessment considered all potential failure modes that lead to downstream inundation and thus consequences; dam failure modes that result in a slow release of water from the reservoir and no downstream flooding (and thus no consequences) were not considered. The failure modes of interest were breaches caused by either storm events, seismic events, or a broad category of “other” events, and included the cascading effects of a Middle Dam failure on the Lower Dam. A limited number of representative failure scenarios were developed that covered a Middle Dam breach only or both Middle Dam and Lower Dam breaches for various storm flows (including no storm flow for seismic and “other” failure events) and for various breach development times. For each failure scenario for each Lower Dam remediation option:

- Downstream consequences have been determined assuming that the failure scenario occurs, based on hydraulic modeling to determine the extent/magnitude of flooding and then assessment of likely damages and fatalities as a function of the flooding depths and velocities as predicted within a number of zoned areas in the inundated area. These predictions took into account the potential effectiveness of evacuation warnings and considered “incremental” consequences (i.e., consequences that are in addition to those that would occur if the dams were not there). For several scenarios, flooding or incremental consequences have been interpolated/extrapolated from the results of other scenarios, due to the high cost and time required for hydraulic modeling.
- The annual probability of each representative failure scenario occurring has been determined by assessing the annual probability of the triggering event and the probability of the dam breach scenario (Middle and/or Lower Dam breach) occurring if that triggering event occurred.

The risks for each Lower Dam remediation option have then been determined by appropriately combining (among all the failure scenarios); a) the consequences if each failure scenario occurs; and b) the probability of each failure scenario occurring.

The key inputs to the risk assessment were developed with a combination of traditional deterministic analyses and, where necessary, subjective assessments based on input from specialists. To address uncertainty in these inputs, probability distributions were used for key input parameters (e.g., breach development durations).

Summary of Risk Assessment Findings

The risk assessment process (i.e., assessing the consequences and probabilities of specific failure scenarios) has led to increased understanding of the key risks related to the dams, as well as allowing a determination of those risks:

- Lower Dam breaching can have significant consequences.
- Remediation of the Lower Dam to increase flood routing capacity significantly decreases the probability of Lower Dam breaching due to overtopping related to storms and/or Middle Dam breaching for any reason.
- If the Lower Dam has been remediated to increase flood routing capacity:
  - the cascade effect of a Middle Dam breach due to a seismic event causing an overtopping breach of the Lower Dam has been mitigated; and
  - hence, the contribution of the seismic and other failure modes becomes less than that of storm failure modes.
- Due to the relatively small size of the reservoirs, the dam breach development duration (i.e., the time it takes for the dam to fail completely) is a key determinant of the extent of flooding and thus of consequences/risk. Simply stated, if the dam failure is relatively slow, it was found that there was insufficient storage in the reservoirs to cause downstream flooding. As a means to understand this relationship, a number of different dam breach durations were considered for various failure modes. In general, it was found that significant incremental flooding occurred only for the very fast breach scenarios (i.e., assuming the dams failed in 10 to 20 minutes – which represents the lower limit of the range of breach times considered possible for these dams). Probability distributions were assessed for breach duration development times for each dam, from which the expected values were determined and used in the analysis.

In addition to developing these insights, the risks have been determined (as discussed above) for each of the dam remediation options in the following terms (see Table ES-1):

- The "expected value" (i.e., probability-weighted average value) of financial damages per year, both to property improvements and to contents.
- The maximum probability of dying due to dam failures, per year, for any one individual.
- The expected number of fatalities among the population due to dam failures per year, as well as the annual probabilities of at least one fatality and at least two fatalities (see Figure ES-1).

As shown, there is little difference in these risks between the two dam remediation options.

Table ES-1: Set of Annual Incremental Consequences for each Lower Dam Remediation Option

Lower Dam Remediation Options	Expected Damages ($M)/yr]	Expected Fatalities/yr	Prob. [>1 Fatality/yr]	Prob. [>2 Fatalities/yr]	Max Annual Individual Risk
Hardening	$0.017	4.3E-04	3.8E-04	3.2E-05	5.4E-05
Labyrinth	$0.014	4.2E-04	3.6E-04	4.0E-05	5.1E-05

Note: No change to Middle Dam. Also see Figure ES-1.

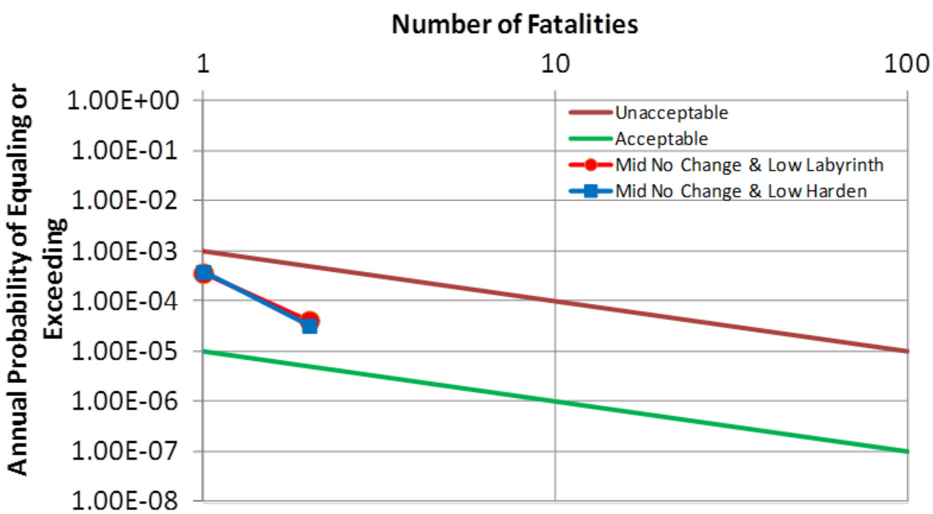


Figure ES-1. Incremental Societal Safety Risks for each Lower Dam Remediation Option (combined over all dam failure scenarios)

Note: No change to Middle Dam. The curves have not been extended beyond two fatalities.

The above results can be used to evaluate conformance of the remediation options to the criteria presented in the CDA Guidelines. The key findings are:

- ***Financial impacts*** – both dam remediation options have low damage costs (<$20,000 per year).
- ***Individual safety criteria*** - both dam remediation options meet CDA criteria (probability of less than 10^{-4} per year).
- ***Societal safety criteria*** - both dam remediation options have risk levels that are between the CDA “Acceptable” and “Unacceptable” regions, and are therefore in the “As Low As Reasonably Practicable” (ALARP) region of the criteria. The CDA Guidelines describe the ALARP principle as “… based on the duty to reduce risks to life to the point where further risk reduction is impracticable or requires action that is grossly disproportionate in time, trouble and effort to the reduction in risk achieved…”.

While the CDA Guidelines do not form part of the BC Dam Safety Regulation, they do inform current industry practice and therefore are considered as part of the evaluation of dam remediation options (see Section 1.1). The development of dam remediation options consistent with this is beyond the scope of this report.

Table of Contents

TABLES

FIGURES

APPENDICES

1.0 INTRODUCTION

Golder Associates Ltd. (Golder) has been retained by the City of Nanaimo (CON) to be part of the Colliery Dam Technical Committee (TC). The Colliery Dam Technical Committee's mandate is to identify an environmentally minimally invasive, cost- and time-effective remediation solution for the Colliery Dam system that meets safety standards and the respective objectives of the City of Nanaimo, Snuneymuxw First Nation (SFN), the Colliery Dam Park Preservation Society (CDPPS) and the community.

This report provides a summary of the risk assessment which has been undertaken by Golder. This study has been based on separate studies of dam stability, hydraulics and hydrology, which should be read in conjunction with this report for a more complete understanding of the project.

This report should be read in conjunction with the "Information and Limitations of This Report" which is included following the text of this report. The reader's attention is specifically drawn to this information, as it is essential that it is followed for the proper use and interpretation of this report.

1.1 Purpose and Objectives

The application of the risk assessment approach to the Colliery Dams Project was decided in consultation with the TC and the DSS, and has been used to inform the dam classification and the design of the dam remediation options. This approach has been developed, in part, based on the 2013 revision to the Canadian Dam Association (CDA) Dam Safety Guidelines (CDA, 2013), which provide further guidance on the application of the risk-informed approach. The risk informed approach has been identified by CDA as an alternative, or complementary, means to assess dam safety, which can provide a means to avoid the following potential limitations of traditional standards-based approaches to dam safety assessment, namely:

- *"Focus on extreme natural hazards in isolation, which can lead to preferentially implementing expensive solutions that may not necessarily improve the safety of the dam over that which could be achieved by other more economical means; and*
- *Inability to define standards for a number of dam failure modes, which may lead to inappropriate or misleading assessment of safety", (CDA, 2013).*

Hence, the risk assessment has been used to comparatively evaluate various dam remediation options, specifically by determining the risk of each option, in consultation with the CDA guidelines (CDA, 2013).

The DSS has provided guidance on the application of the risk-informed approach to the Colliery Dams, as follows:

> *The CDA Guidelines (Table 6-1A) give initial target frequency levels for flood and earthquake hazards for dams where a risk informed approach is being used. As stated in the Guidelines, these target levels are designed to form the basis for consideration and discussion between the Owner and Regulator. It may be appropriate to adjust some of these target levels up or down based on the principle of decreasing the risk to "As Low as Reasonably Practicable" (ALARP). This approach allows the Owner to take into consideration all of the uncertainties in their analyses and propose which hazard frequency levels they feel are appropriate for design. Therefore, the next steps from our perspective are for you to complete your analyses, conceptual design work and preliminary pricing, and then provide us with proposed design hazard frequency levels. At that point we can have a discussion and agree upon what will be acceptable design levels. (e-mail, S Morgan, 2014).*

Therefore, the results of this risk assessment will be used together with the traditional standards-based requirements, which are based on the dam classification, in order to determine the design hazard levels and consequential dam remediation requirements. The development of dam remediation options consistent with this is beyond the scope of this report.

The risk assessment has been supported by engineering analyses similar to those carried out for the traditional standards-based approach, as described in subsequent sections of this report.

1.2 Project Risk Assessment Background

The risk assessment has been developed and presented to the TC over a series of meetings and workshops, as outlined in further detail below. DSS representatives were present at these meetings.

- 13 Dec 2013 Meeting in Nanaimo. Contents of presentation
  - Objectives - *optimal* dam remediation option plan
  - Criteria – incremental *safety* risk, *financial, etc.*
  - Design Process – identify/evaluate dam remediation options
  - Risk assessment – model, uncertainties, assessments
- 21 Jan 2014 Meeting in Nanaimo. Contents of presentation
  - Risk model framework – elements/inputs/outputs/scenarios
  - Inputs – hypothetical / status / plans
- 04 Mar 2014 Meeting in Nanaimo. Contents of presentation
  - Phase 1 inputs / results
  - Phase 2 plans (remediation options, scenarios, inputs)

  Note: Phase 1 consisted of assessment of consequences of Middle Dam failure only, while Phase 2 considered assessment of consequences of failure of both dams, as well as the probability of failure for each dam remediation option.
- 04 Apr 2014 Risk Assessment Workshop at Golder (Burnaby)/ 24 Apr 2014 Meeting at DSS
  - Phase 2 preliminary inputs / results
  - Subsequent revisions in response to comments

1.3 Report Organization

The remainder of this report has been organized into the following sections:

- Approach (Section 2);
- Scenario inundation (Section 3);
- Scenario consequences (Section 4);

- Scenario probability (Section 5);
- Risks (Section 6);
- Detailed scenario inundation results (Appendix A); and
- Detailed downstream assets (Appendix B)

2.0 APPROACH

This risk assessment has been developed based on CDA Guidelines, relevant international dam safety guidelines and related risk-informed guidance documents. As indicated in CDA, 2013:

> *"Safety Management is ultimately concerned with management of risk and should provide answers to the following questions,*
>
> - What can go wrong?
> - What is the likelihood (probability) of it happening?
> - If it occurs, what are the possible consequences?" (CDA, 2013).

Further, CDA, 2013 states:

> "In view of the large uncertainties involved, a risk-informed approach is encouraged. Such an approach includes traditional deterministic standards-based analysis as one of many considerations, as shown in Figure 6-1" (Figure 2-1, below).

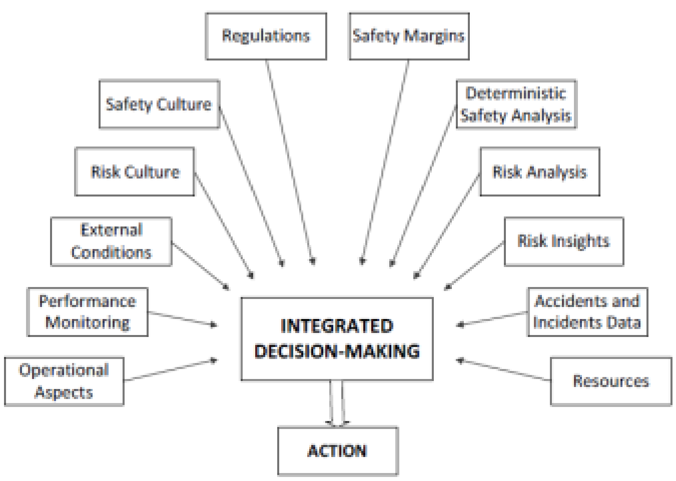


Figure 2-1. Risk- Informed decision making (CDA, 2013).

In this risk assessment, these items have been addressed as follows,

- What can go wrong - various dam failure modes have been considered, which have been captured by a set of representative “failure scenarios” in this report;
- Probability – the probability of the various failure scenarios have been assessed objectively (through the application of traditional standards-based analyses), or, where this is not possible, or practical, through subjective assessment; and
- Consequences - similarly, consequences have been assessed through a combination of objective and subjective assessment.

The risk-informed approach, as well as the traditional standards-based approach, is shown schematically in Figure 2-2. As shown, the hazard-rating approach consists of determining design criteria (e.g., design storm and seismic events) that are intended to achieve acceptable levels of risk, although that risk is not evaluated nor is acceptable risk defined, often resulting in overly conservative (and thus expensive) designs. The risk-based approach, on the other hand, involves an assessment of the risk associated with any particular design, and iterating that design to cost effectively achieve an acceptable level of risk, which must first be specified.

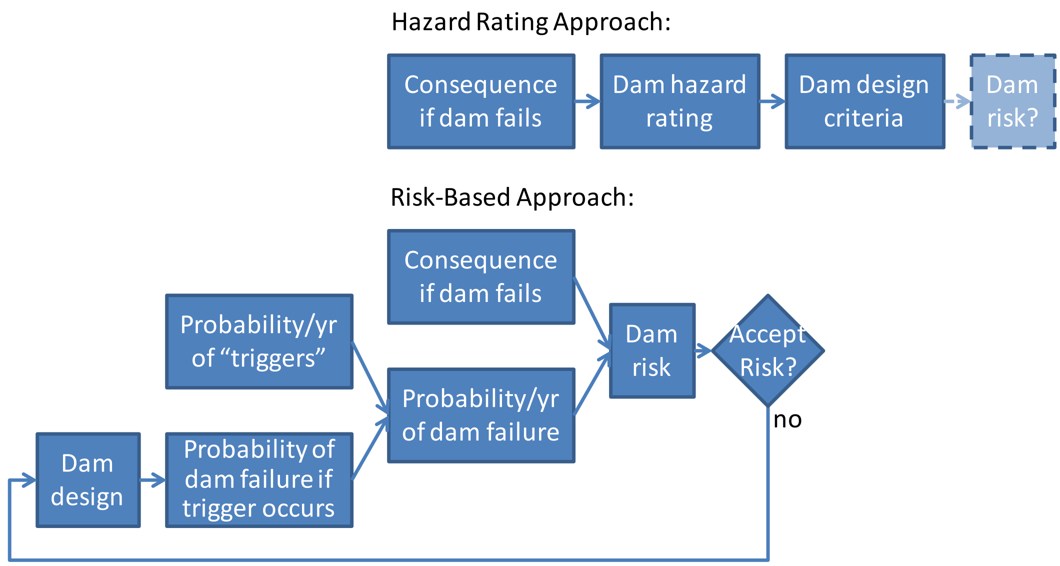


Figure 2-2. Risk-Based vs. Hazard Rating Approach for Dam Design

This section of the report presents several important components of the risk-based approach, as follows:

- Dam safety criteria (2.1);
- The Colliery Dam macro-system (2.2); and
- Dam failure modes/scenarios (2.3)

2.1 Dam Safety Criteria

Safety risk performance criteria are outlined in the CDA Guidelines (CDA, 2013) as follows:

- Incremental societal (population) safety-risk criteria require that the risk be below the “unacceptable” bound, as shown in Figure 2-3.
- Incremental individual safety risk criterion requires that everyone must have $<10^{-4}$ chance per year of fatality.

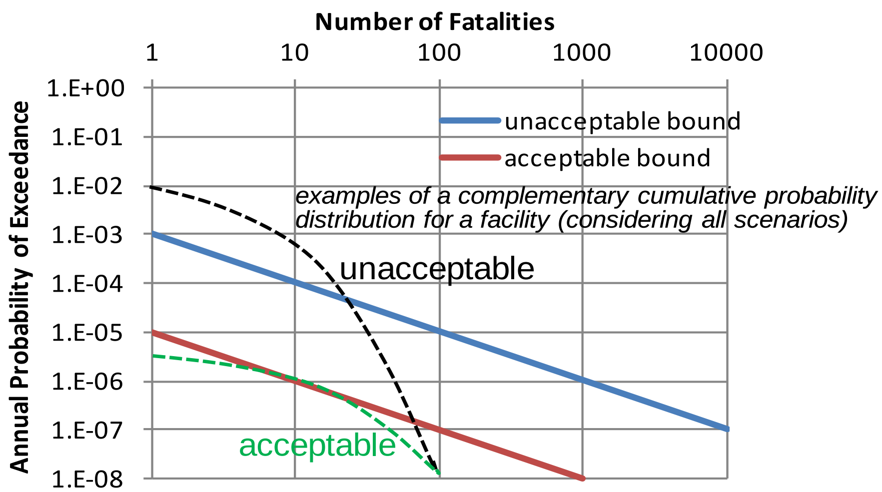


Figure 2-3. Incremental Societal Safety-Risk Criteria (CDA, 2013)

Note: “As Low As Reasonably Practical” (ALARP) between unacceptable and acceptable bounds. Bounds are assumed to extend to less than 1 fatality, for expected value of number of fatalities.

2.2 Dam System (Macro)

The current Middle and Lower Colliery Dam system is shown in Figure 2-4, with a brief description of each of the dams in their existing condition. A more detailed description of the dams is provided in various reports which have been prepared for the dams.

A schematic of the Middle and Lower Colliery Dam system is shown in Figure 2-5, showing potential dam failure “triggers” (seismic and storm events) and “vulnerable elements” (people and property which are located downstream of the Lower Dam, as well as people recreating in the Lower Dam reservoir (Colliery Dam Park)). This diagram is described as follows:

- Precipitation will drain through the various watersheds to the Middle Dam reservoir, the Lower Dam reservoir, or downstream.
- The Middle Dam reservoir will discharge into the Lower Dam reservoir, and the Lower Dam reservoir will discharge downstream.
- Normally, both reservoirs are full, so that the discharge from each reservoir simply equals the inflow into that reservoir.

- If a dam fails (breaches), it will release some of the impounded water, temporarily increasing the discharge rate.
- If the discharge rate exceeds the receiving channel (or reservoir) capacity, then flooding (inundation) outside the channel (or reservoir) will occur, possibly causing damage and/or casualties.

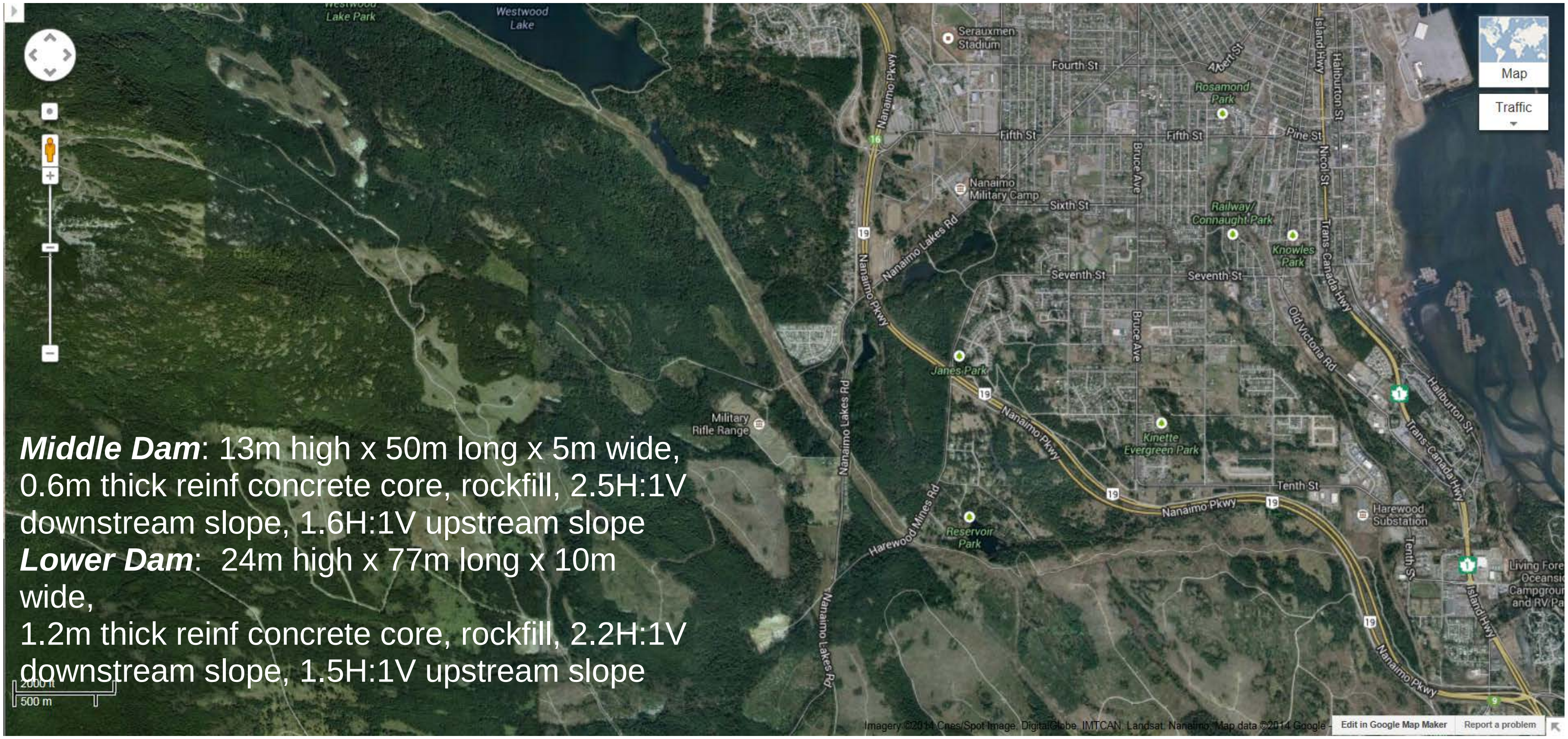


Figure 2-4. Existing Middle and Lower Colliery Dam System (including upstream and downstream areas)

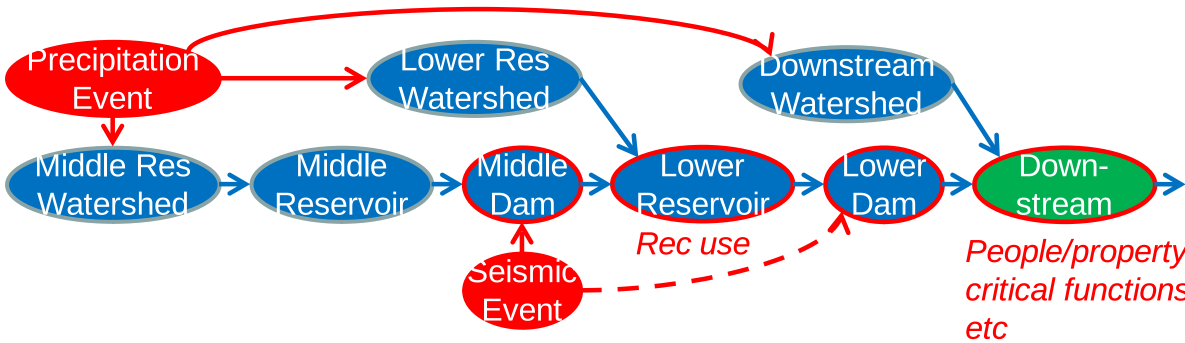


Figure 2-5. Schematic of the Middle and Lower Colliery Dam System (including potential dam failure "triggers" and "vulnerable elements")

2.3 Dam Remediation Options

As indicated above, the risk assessment process has been applied to various dam remediation options as a means to comparatively assess risk between the options, and as a means to evaluate risk for each option against the CDA criteria (Section 2.1). For the purposes of this risk assessment, the following dam remediation options have been defined for the Lower Dam (these options are defined in further detail in the relevant TC presentations).

- ***Labyrinth Spillway***. Enlarge the existing spillway, in its existing location, using a Labyrinth weir with a capacity of 144 cms.
- ***Dam Hardening***. This option considered the spillway at its current capacity (i.e. unaltered), but with the Lower Dam surface being strengthened in order to better withstand infrequent dam overtopping conditions. This option incorporates shaping and hardening (using soil cement) of the dam crest and downstream surface.

2.4 Dam Failure Scenarios

As a basis for the risk assessment, all reasonable potential dam failure modes were considered. In this assessment, failure modes of interest included those that resulted in a breach that releases significant impoundment relatively quickly, causing inundation and "incremental" damages/casualties (over and above what would happen if the dams weren't there). Failure modes that resulted in slow release of impounded water, with no consequential downstream flooding were not of interest to this risk assessment. The various failure modes included,

- ***Storm*** (or an upstream dam failure) causes enough dam "overtopping" to cause erosion that eventually leads to a breach.
- ***Seismic*** event damages the dam enough to initiate a breach (e.g., lowers the dam crest which causes overtopping from impounded water that causes erosion leading to a breach).
- ***"Other"*** processes (e.g., undetected piping / internal erosion / degradation) cause a breach to initiate, which is then similar to seismic-induced breach.

Based on the above failure modes, a number of “failure scenarios” were developed. As it was not possible or practical to objectively analyze all possible failure scenarios, a limited set of modeled scenarios was developed which covers a range of possibilities (as shown in Figure 2-5 and Tables 2-1 through 2-4). From this range of scenarios, additional failure scenarios can be interpolated or extrapolated, as summarized in Tables 2-2 through 2-4.

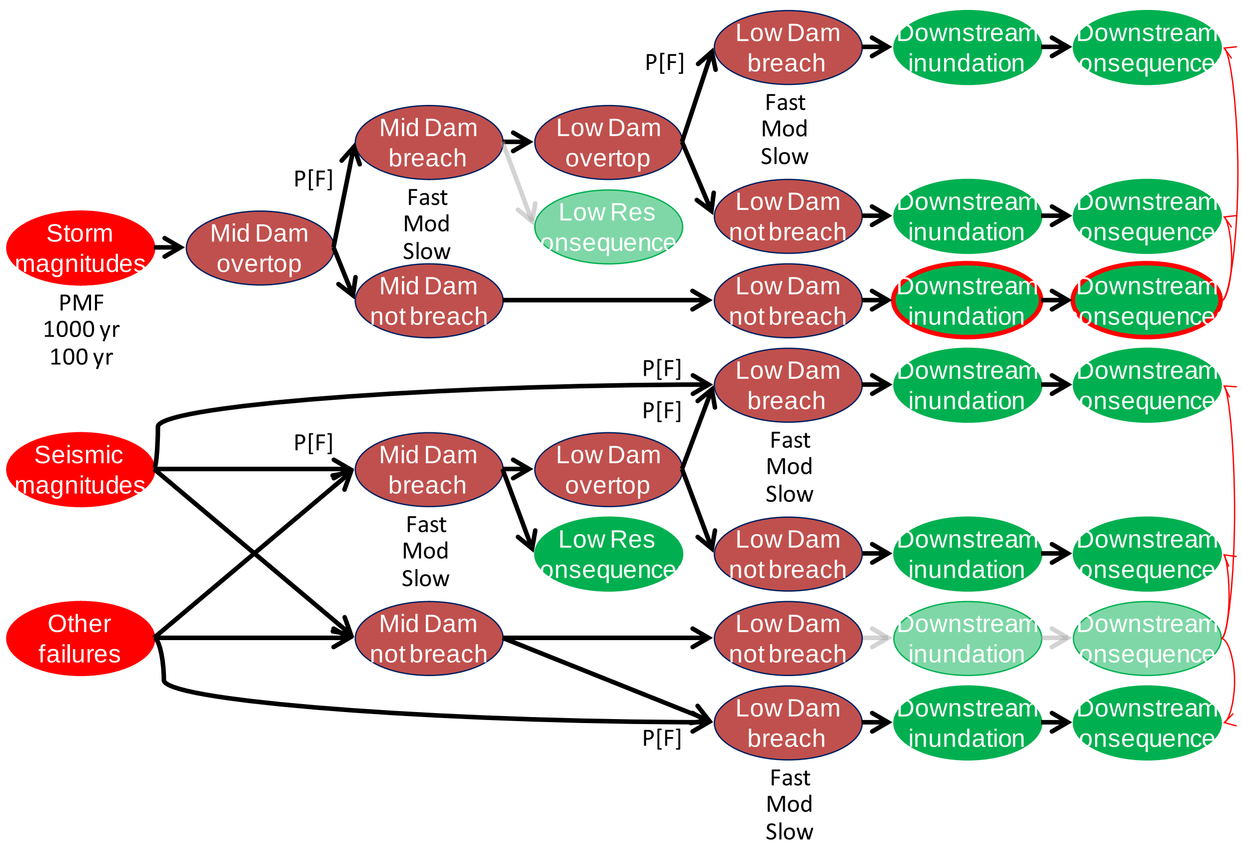


Figure 2-5. Set of Dam Failure Scenarios (including “No Dam Failures” as basis for incremental consequences)

Table 2-1. Set of Representative Dam Failure Scenarios (possible combinations of Middle Dam and various Lower Dam failure modes).

Middle Dam Failure	Lower Dam Failure		
Overtopping (PMF)	None	Overtopping (PMF + Middle Dam failure)	
Overtopping (1000-yr)	None	Overtopping (1000-yr + Middle Dam failure)	
Overtopping (100-yr)	None	Overtopping (100-yr + Middle Dam failure)	
Seismic	None	Overtopping (Middle Dam failure)	Seismic
Other	None	Overtopping (Middle Dam failure)	

Table 2-2: Set of Dam Failure Scenarios (including "No Dam Failures" as basis for incremental consequences)

Trigger	Middle Dam Breach only				Middle and Lower Dam Breach		
	Fast	*Mod*	*Slow*	*None*	*Fast*	*Mod*	*Slow*
PMF	**SC3**	SC19*	**SC4**	**SC8**	SC14	SC13	
1000 yr storm	**SC5**	SC11	SC6**	**SC7**		SC12	
100 yr storm	SC9**	SC18*	SC10**	SC20*		SC17*	
Seismic	**SC1**	SC16*	SC2**	**NA**		SC15*	
Other	**SC1**	SC16*	SC2**	**NA**		SC15*,***	

Notes: "Other" behaves similarly to "Seismic" once breach occurs.
Phase 1 of Risk Assessment (modeled Middle Dam breach only, range of breach times) SC1, 3-5, 7-8
Phase 2 of Risk Assessment (modeled mostly Middle Dam and Lower Dam breaches, and moderate breach times) SC11-14
** SC15-20 not modeled but interpolated/extrapolated*
*** SC2, 6, 9-10 not modeled nor interpolated/extrapolated at this time*
**** Would be Lower Dam only breach, but assume that Middle and Lower Dam breach is not significantly higher.*

Table 2-3: Set of Dam Failure Scenarios (by scenario #)

Scenario ID	Event Type	Return Period	Breaches	Dam Breach Duration (min)
SC1	Seismic or Other	All	Middle Dam Only	Fast – 10
SC2**	Seismic or Other	All	Middle Dam Only	Slow – 150
SC3	PMF	~ 50,000 year	Middle Dam Only	Fast – 10
SC4	PMF	~ 50,000 year	Middle Dam Only	Slow – 150
SC5	1000-year Flood	1000 year	Middle Dam Only	Fast – 10
SC6**	1000-year Flood	1000 year	Middle Dam Only	Slow – 150
SC7	1000-year Flood	1000 year	No Breach	N/A
SC8	PMF	~ 50,000 year	No Breach	N/A
SC9**	100-year Flood	100 year	Middle Dam Only	Fast – 10
SC10**	100-year Flood	100 year	Middle Dam Only	Slow – 150
SC11	1000-year Flood	1000 year	Middle Dam Only	Mod – 60
SC12	1000-year Flood	1000 year	Middle&Lower Dams	Mod - 60&120
SC13	PMF	~ 50,000 year	Middle&Lower Dams	Mod - 60&120
SC14	PMF	~ 50,000 year	Middle&Lower Dams	Fast - 10&10
SC15*	Seismic or Other	All	Middle&Lower Dams	Mod - 60&120
SC16*	Seismic or Other	All	Middle Dam Only	Mod – 60
SC17*	100-year Flood	100 year	Middle&Lower Dams	Mod - 60&120
SC18*	100-year Flood	100 year	Middle Dam Only	Mod – 60
SC19*	PMF	~ 50,000 year	Middle Dam Only	Mod – 60
SC20*	100-year Flood	100 year	No Breach	N/A

** SC15-20 not modeled but interpolated/extrapolated (see Table 2-2)*
*** SC2, 6, 9-10 not modeled nor interpolated/extrapolated at this time*

Table 2-4. Set of Modeled Dam Failure Scenarios (by storm)

Scenario	Storm	Middle Dam Breach	Lower Dam Breach
SC3	PMF	10 min	None
SC14	PMF	10 min	10 min
SC19*	PMF	60 min	None
SC13	PMF	60 min	120 min
SC4	PMF	150 min	None
SC8	PMF	None	None
SC5	1000yr	10 min	None
SC11	1000yr	60 min	None
SC12	1000yr	60 min	120 min
SC7	1000yr	None	None
SC18*	100yr	60 min	None
SC17*	100yr	60 min	120 min
SC20*	100yr	None	None
SC1	0 (Seismic or Other)	10 min	None
SC16*	0 (Seismic or Other)	60 min	None
SC15*	0 (Seismic or Other)	60 min	120 min

* *interpolated/extrapolated SC15-20*

For each dam failure scenario, the consequences are determined as shown schematically in Figure 2-6.

Based on the above scenarios, risk can be determined by combining the failure scenarios probability and consequences, as shown in the equations below (also see Figure 2-6):

$$p[C] = \sum_{all\ S} p[C \mid S]\, P[S] \quad and \quad P_{>}[C] = \sum_{all\ C^* > C} p[C^*]$$

$$E[C] = \sum_{all\ S} E[C \mid S]\, P[S] \quad and \quad P_{>}[C] \approx \sum_{all\ S\ w\ E[C|S] > C} P[S]$$

where C is consequence and S is comprehensive mutually exclusive set of scenarios

$\mathrm{p[C]}$ is relative likelihood of C, $\mathrm{p[C \mid S]}$ is relative likelihood of C for S,

$\mathrm{P[S]}$ is probability of S, $\mathrm{C^*}$ is dummy variable for C,

$P_{>}[C]$ is probability of > C for comparison with societal safety risk criteria,

Consequence can be expressed as absolute or incremental, with incremental consequences being those that would be in addition to any consequences from the event (e.g. storm) that would occur if the dams were not there. For this report, incremental consequences (i.e. consequences arising due to the presence of the dams) are primarily addressed (for comparison with safety risk criteria).

It is noted that the dam remediation options considered herein primarily affect probability of failure (*P[S]*) of the various failure scenarios, as oppose to the consequences of those failure scenarios if they occur (*p[C|S]* or *E[C|S]*).

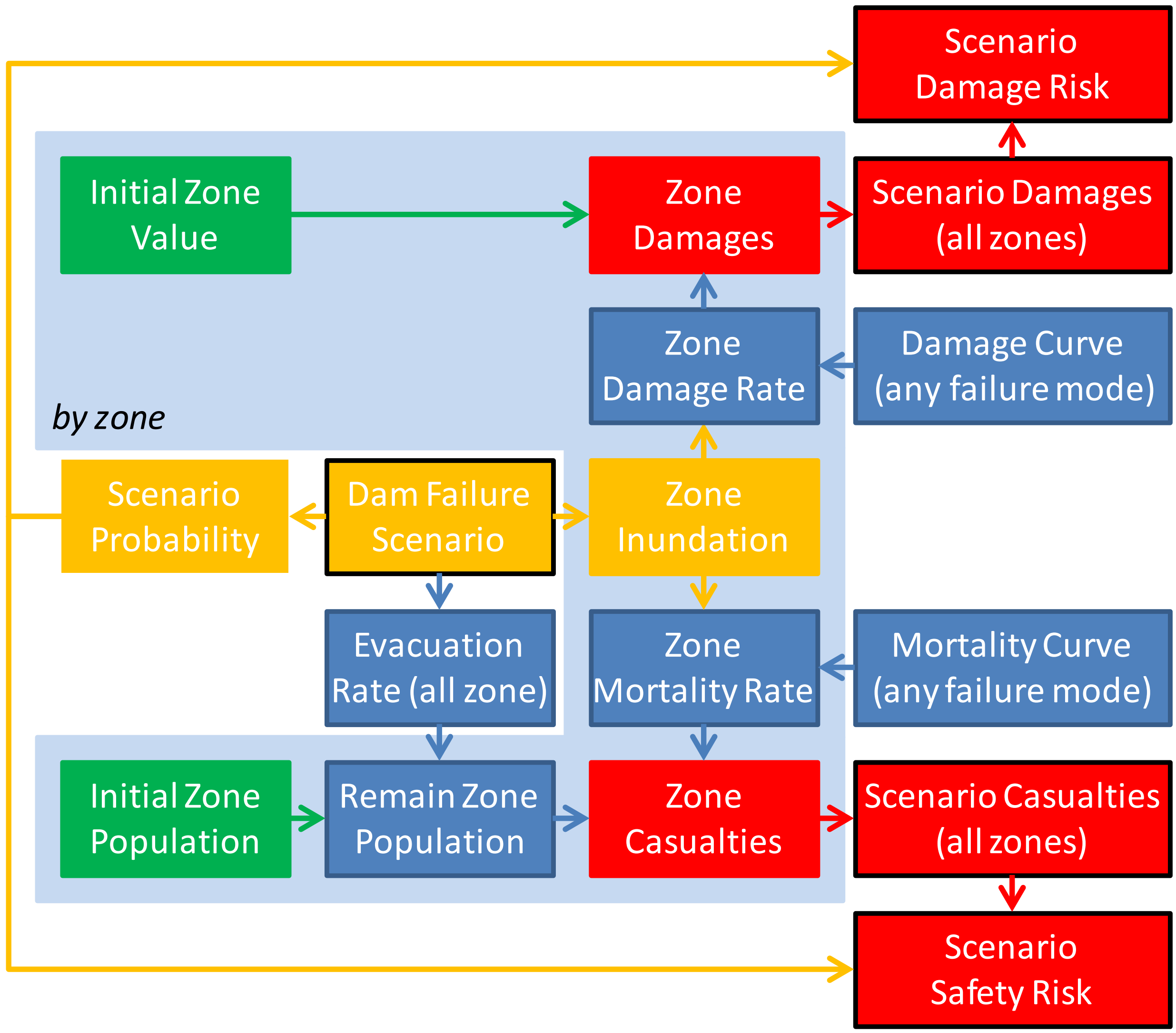


Figure 6-2. Schematic of Determination of Dam Failure Consequences and Risk

Note: Potentially inundated area is divided into spatial zones.

3.0 SCENARIO INUNDATION

This section of the report presents the methodology to determine the downstream inundation for each failure scenario, as follows:

- Scenario inundation models (3.1);
- Scenario inundation input parameters (3.2); and
- Scenario inundation outputs (3.3).

3.1 Scenario Inundation Models

Inundation of the area downstream of the Lower Dam has been modeled by Associated Engineering (AE, 2014), for each dam failure scenario as follows,

- Discharge from Lower Dam, for each failure scenario, is modeled as a hydrograph, which, in turn, is based on:
  - Flow into Middle Dam reservoir – which is a function of:
    - Precipitation;
    - Upstream watershed runoff; and
    - Non-precipitation inflow from upstream watershed.
  - Outflow from Middle Dam reservoir into Lower Dam reservoir – which is a function of:
    - Middle Dam Reservoir characteristics, if no breach occurs. Generally, the reservoir is full so that outflow equals inflow.
    - If Middle Dam breach occurs (e.g., due to overtopping), additional flow is function of Middle Dam Breach development time and geometry.
  - Other flow into Lower Dam reservoir – which is a function of:
    - Precipitation;
    - Upstream watershed (not including Middle Dam upstream watershed) runoff; and
    - Non-precipitation inflow from upstream watershed (not including Middle Dam upstream watershed).
  - Outflow from Lower Dam reservoir – which is a function of:
    - Lower Dam Reservoir characteristics, if no breach occurs. Generally, the reservoir is full so that outflow equals inflow.
    - If Lower Dam breach occurs (e.g., due to overtopping), additional flow is function of Lower Dam Breach development time and geometry.

- Downstream flow/inundation for each failure scenario is represented by flow depth and velocity as function of time for each cell (10m x 10m resolution =1 million cells) (AE, 2014).
- Reduced the number of downstream cells by abstracting the downstream inundation to reasonably practical number of “zones” (i.e. groups of similar cells), by:
  - Identified limits of potentially inundated downstream area based on previous analyses (AE 2012) – using same model with more extreme hydrograph than any of the current failure scenarios: PMF with higher runoff and very fast simultaneous breaches of both Middle and Lower Dams), as shown in Figure 3-1.
  - Subdivided potentially inundated area into 174 spatial “zones” within which: a) inundation is similar (and average depth and velocity can be used); and b) potentially affected properties / population can be combined.

Inundation of the Lower Reservoir area due to breach of the Middle Dam was modeled by Golder (Golder, 2014a), as follows:

- Discharge from Middle Dam (fast breach seismic with no base storm flow hydrograph, because it is very unlikely that there will be anybody in the reservoir area during a significant storm).
- Inundation was assessed based on numerical modeling (HEC-RAS), which calculates depth and velocity as function of time for each node in area.

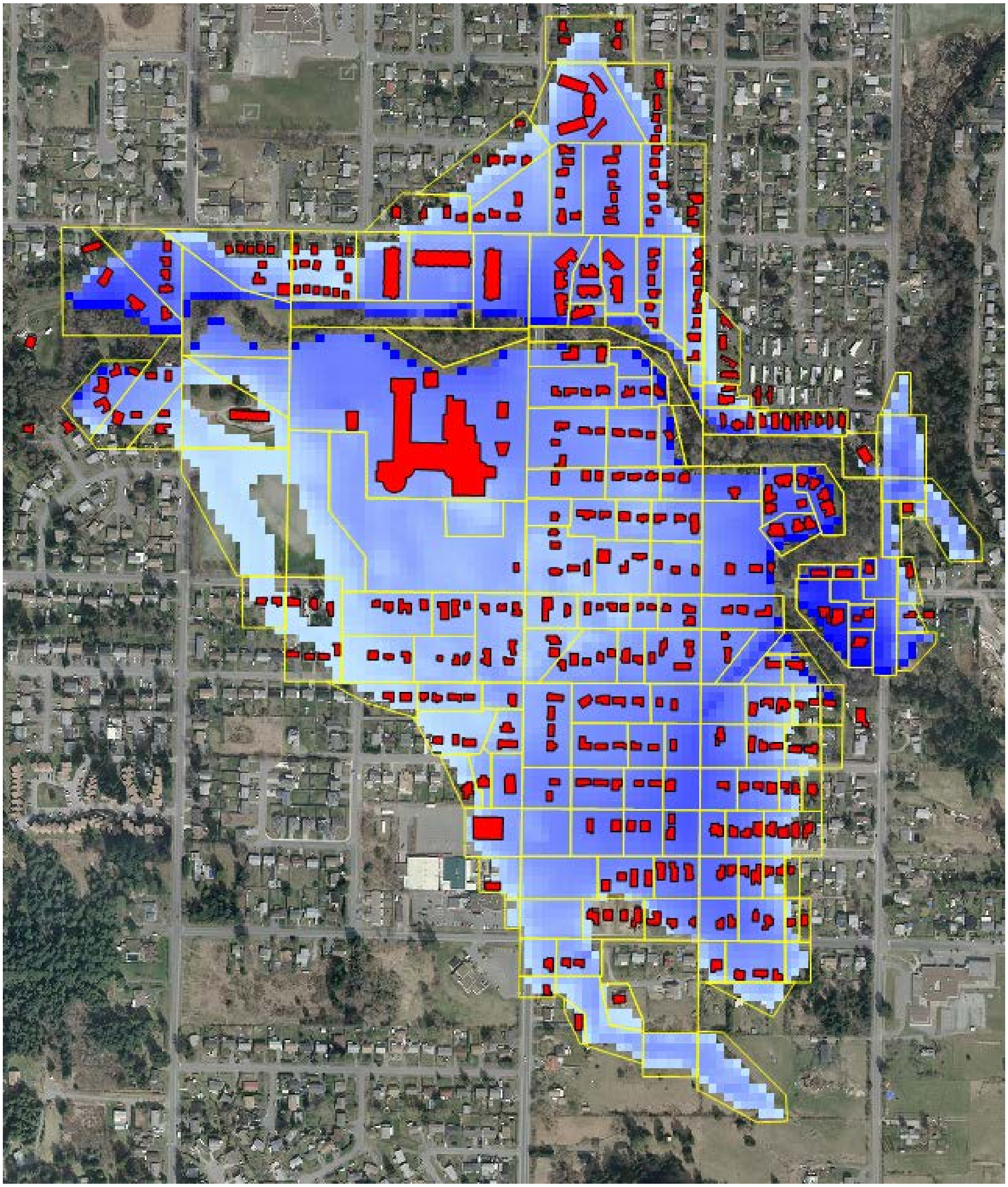


Figure 3-1. Limits of potentially inundated downstream area (based on previous analysis using same model with more extreme hydrograph than any of the current failure scenarios) and division into 174 "zones" (groups of cells – see Appendix A for zone identification) (AE, 2014)

Note: Blue indicates maximum depth downstream for PMF with high runoff in upstream watershed and simultaneous very fast (3 minute) breaches of both Middle and Lower Dams (AE, 2012)

3.2 Scenario Inundation Input Parameters

The primary input parameters that are used in the inundation modelling are as follows:

- Precipitation;
- Upstream runoff;
- Reservoir/spillway capacity;
- Breach duration/geometry;
- Lower Reservoir hydrology; and
- Downstream hydrology.

A detailed description of these inputs is provided in Golder 2014a), while a summary is provided below:

- ***Precipitation*** – frequency-magnitude relationship (by sub-basin), see Table 3-1 and Figure 3-2

Table 3-1. Frequency-Magnitude Relationship of Precipitation (by sub-basin) (Golder, 2014a)

Return Period (yrs)*, **	24-hr Rainfall (in mm) for each sub-basin			
	Upper Hw19	Lower Hw19	Middle chase	Lower chase
2	70.3	60.8	58.9	58.3
5	88.8	76.8	74.4	73.5
10	101	87.3	84.6	83.7
25	116.5	100.8	97.7	96.5
50	128	110.7	107.3	106.1
100	139.4	120.6	116.9	115.5
200	152.3	131.7	127.7	126.2
500	168.4	145.6	141.1	139.5
1,000	180.5	156.1	151.3	149.6
2,000	192.6	166.6	161.4	159.6
5,000	208.7	180.4	174.9	172.9
10,000	220.8	190.9	185	182.9
50,000	249	215.3	208.6	206.3

Note: PMF rainfall corresponds to about 50,000 year storm

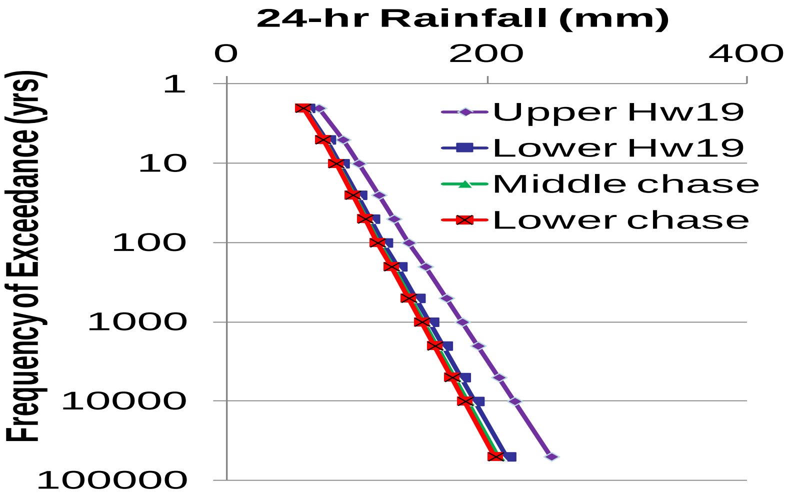
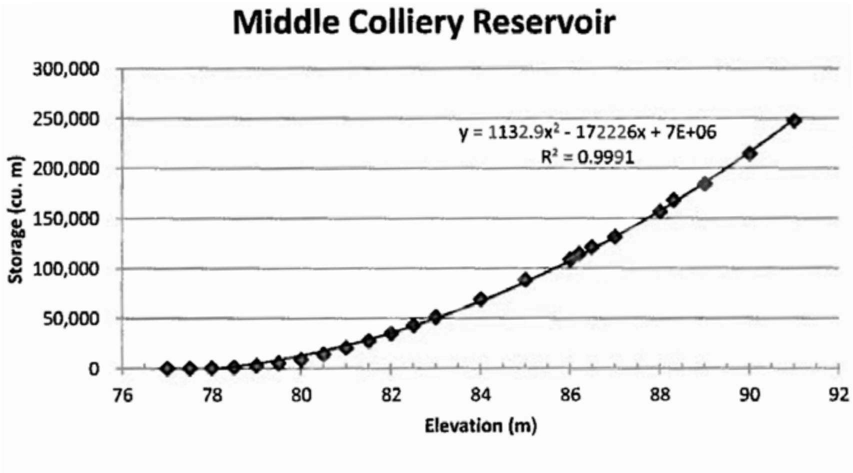


Figure 3-2. Frequency-Magnitude Relationship of Precipitation (by sub-basin) (Table 3-1)

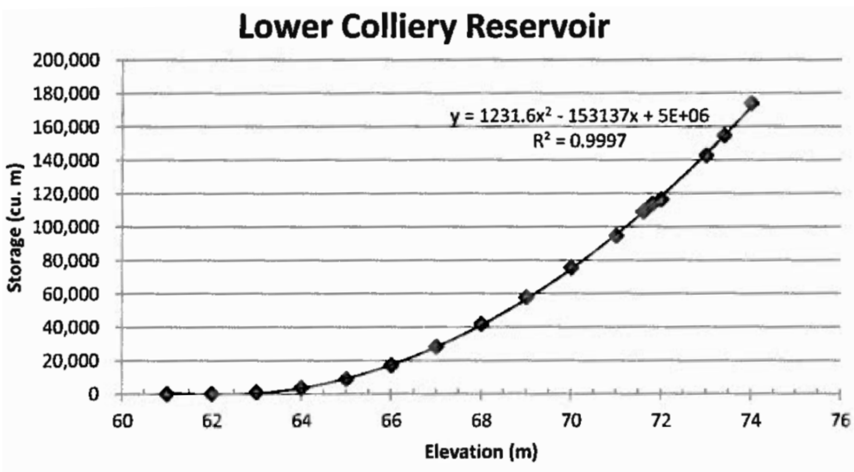
- ***Reservoir/spillway capacity*** – see Figure 3-3
  - Middle Dam
    - Dam crest at 88.3 m
    - Spillway (current)
      - crest at 86.2m
      - capacity 62 cms
  - Lower Dam
    - Dam crest at 73.4 m
    - Spillway (current or hardened / labyrinth)
      - crest at 71.6 / 71.6 m
      - capacity 55 / 144 cms

        where 144cms≈1000 year + 2/3(PMF-1000year)



Elevation-Storage Relationship for the Middle Colliery Reservoir

b) Middle Colliery Dam



Elevation-Storage Relationship for the Lower Colliery Reservoir

b) Lower Colliery Dam

Figure 3-3. Elevation-Storage Relationship for Colliery Dams (Golder, 2014a)

- Breach duration/geometry –
  - If dam breach occurs, the ultimate geometry of that breach (same regardless of mechanism), (Golder, 2014a):
    - **Final Breach Invert:** Full depth breach to the bottom of the reservoirs.
    - **Final Breach Bottom Width:** 10m (approximate width of natural valley invert)
    - **Final Breach Side Slopes:** 1h:1v

- Time for development of full breach (from the start of breach, which might occur, e.g., some time after overtopping starts, and proceed in steps over a period of time) is highly uncertain, a function primarily of dam conditions (erosion resistance) with the reservoir the primary driver of breach development once the breach has started. Based on expert judgement (supported primarily by anecdotal information of observed dam breaches), the uncertainty in dam breach development time has been assessed (Figure 3-4), regardless of how it was started (Golder, 2014a):
  - Middle Dam – "median" (50% chance of being less than and 50% chance of being more than) value of 60 minutes and reasonably extreme values of 15 minutes (with only 10% chance of being faster) and 120 minutes (only 10% chance of being slower).
  - Lower Dam – is believed to be more resistant to erosion, with a median value of 120 minutes and reasonably extreme values of 30 minutes (with only 10% chance of being faster) and 240 minutes (only 10% chance of being slower).

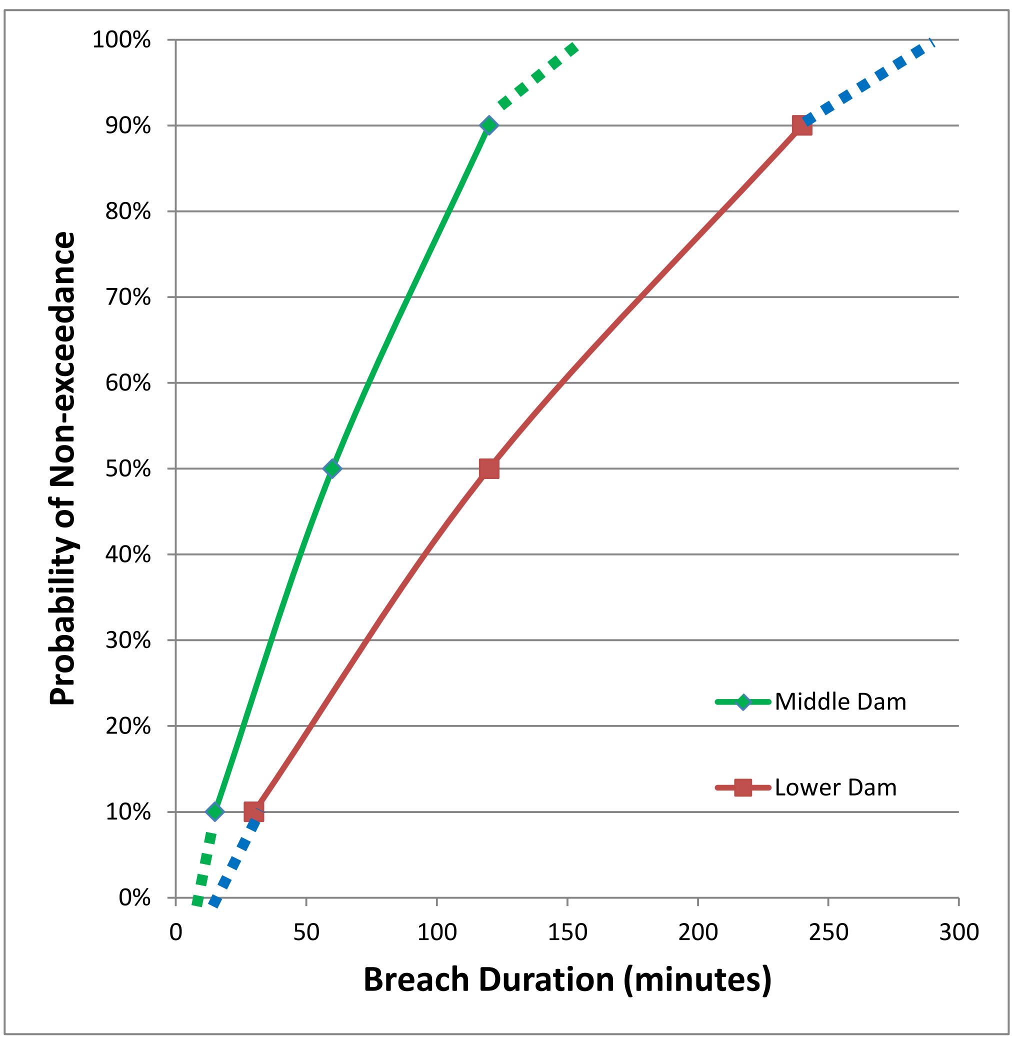


Figure 3-4. Uncertainty in breach development durations (Golder, 2014a)

3.3 Scenario Inundation Outputs

The main outputs from the modeling of each dam failure scenario are as follows:

- Peak Storm Inflows
- Middle Reservoir – (from upstream watershed) a summary of the inflows to the Middle Dam Reservoir is provided below (Golder 2014a).

Storm Event	Peak Inflow (m^3/sec)
2 year, 24 hour	23.4
5 year, 24 hour	35.7
10 year, 24 hour	44.3
25 year, 24 hour	55.5
50 year, 24 hour	64.1
100 year, 24 hour	72.6
1000 year, 24 hour	104.0

- Lower Reservoir – from Middle Reservoir (without breach) plus additional watershed – a summary of the inflows to the Lower Dam Reservoir is provided below (Golder 2014a).

Storm Event	Peak Inflow (m^3/sec)
2 year, 24 hour	23.4
5 year, 24 hour	36.1
10 year, 24 hour	44.9
25 year, 24 hour	56.2
50 year, 24 hour	64.9
100 year, 24 hour	74.5
1000 year, 24 hour	107.2

- Peak Dam Outflows
  - Without breach – same as inflows
  - With breach – inflows plus breach flow (which is function of breach geometry and duration)

- Overtopping
  - Depth and duration of overtopping for Middle Dam and for Lower Dam (for Labyrinth and for Hardening), combined either with no Middle Dam breach or with Middle Dam breach, see Table 3-2
  - Note: Lower Dam Labyrinth significantly reduces the amount of overtopping relative to Lower Dam Hardening

Table 3-2. Overtopping for Various Scenarios (Golder, 2014a)

Scenario	Middle Dam		Lower Dam Labyrinth		Lower Dam Hardening	
	Max Depth (m)	Duration (hr)	Max Depth (m)	Duration (hr)	Max Depth (m)	Duration (hr)
PMF storm	0.9	4.2	0.3/0.5*	1.2/1.5*	1.1/1.2*	6.0/6.0*
1000 yr storm	0.5	2.2	0.0/0.1*	0.0/0.4*	0.7/1.0*	3.0/3.0*
100 yr storm	0.1	1.0	0.0/0*	0.0/0.0*	0.3/0.8*	1.7/1.9*
Seismic/Other event	0.0	0.0	0.0/0.0*	0.0/0.0*	0.0/0.0*	0.0/0.0*

"Seismic" and "Other" behave similarly once breach initiates, and can only overtop Lower Dam.
**wo/w Middle Dam breach*

- Detailed downstream inundation results (spatially-averaged temporal-max depth and velocity for each zone) are presented in Appendix A for each failure scenario and summarized in Table 3-3:
  - Some inundation scenarios were modeled whereas others were interpolated/extrapolated:
    – Modeled – SC1, SC3, SC4, SC5, SC7, SC8, SC11, SC12, SC13, SC14 (AE, 2014)
    – Interpolated/extrapolated – SC17, SC19 and SC20
  - For example:
    – For SC-1 (fast breach of Middle Dam due to seismic event, with no Lower Dam failure) – see Figure 3-5:
      - 17 (of 174) zones were wet;
      - Spatially-averaged temporal-max depth (within worst zone) was 0.4m; and
      - Spatially-averaged temporal-max depth (within worst zone) was 0.3m/s.
    – For SC-3 (fast breach of Middle Dam due to PMF, with no Lower Dam failure), which was worst case of Phase 1 risk assessment – see Figure 3-6:
      - 83 (of 174) zones wet;

  - Spatially-averaged temporal-max depth (within worst zone) was 3.7m; and
  - Spatially-averaged temporal-max velocity (within worst zone) was 2.0m/s.

- Lower Reservoir inundation – see Figure 3-7 (Golder 2014a)
  - For fast Middle Dam breach due to seismic event:
    - Max Depth in area was <1.5m*; and
    - Max velocity in area was <0.5m/s*

    **Except thru upstream "neck" where people rarely are*

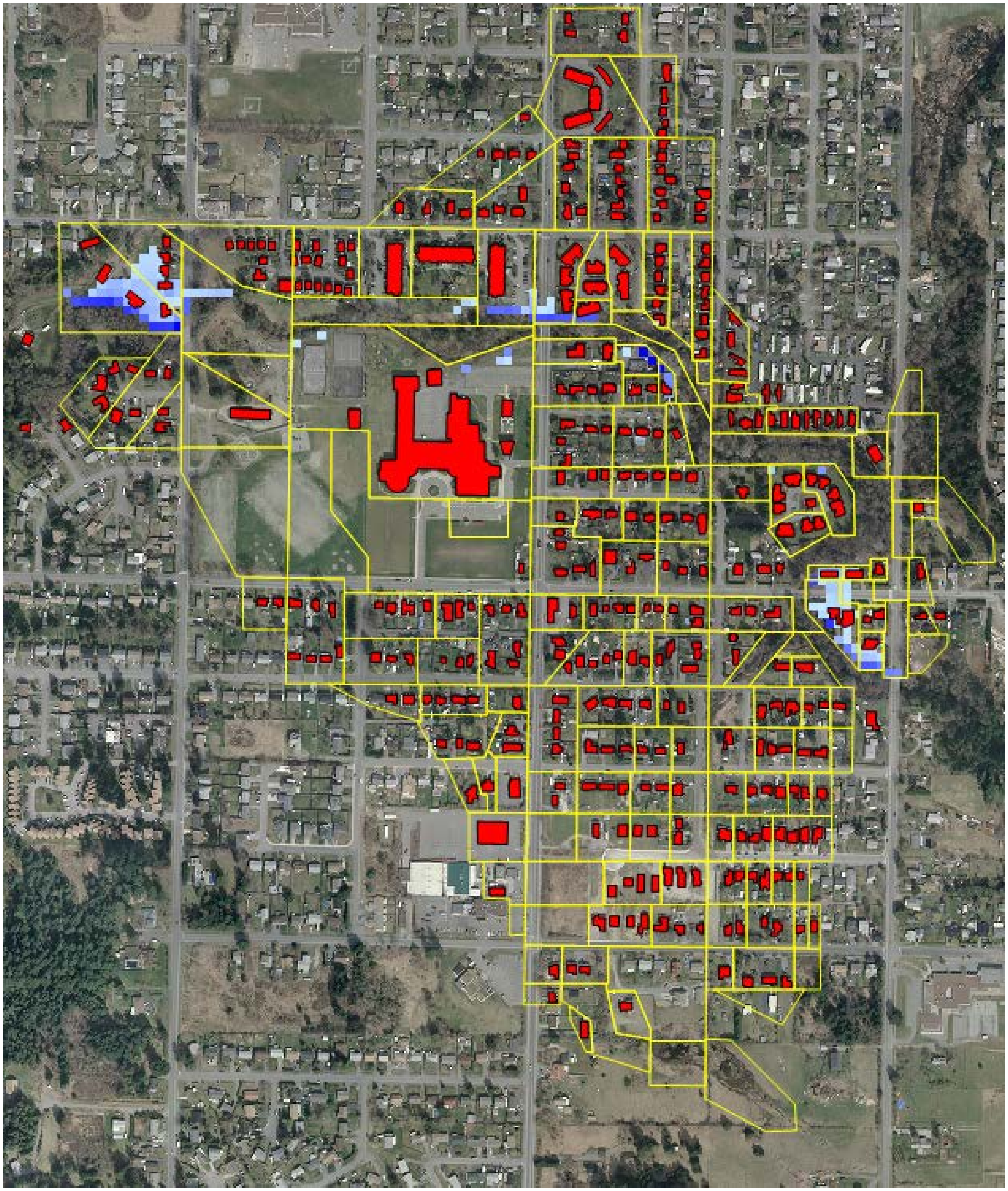


Figure 3-5. Downstream Inundation (max depth) for SC-1 (fast breach of Middle Dam due to seismic event, with no Lower Dam failure) (AE, 2014)

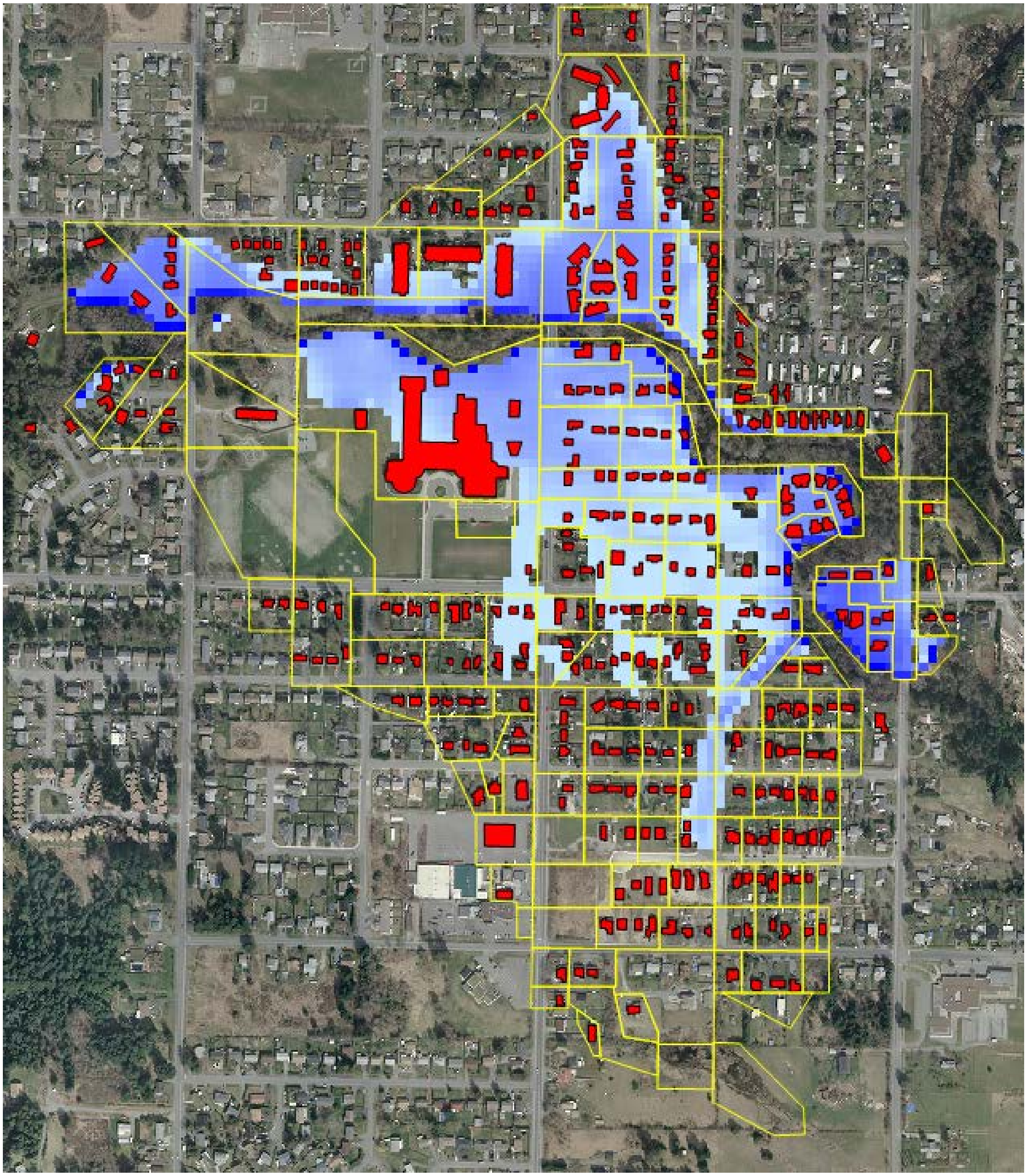


Figure 3-6. Downstream Inundation (max depth) for SC-3 (fast breach of Middle Dam due to PMF, with no Lower Dam failure) (AE, 2014)

Table 3-3. Summary of Downstream Inundation Results for each Failure Scenario

Scenario ID	# Zones Flooded	Max Depth (m)	Max Velocity (m/s)
SC1	17	0.42	0.25
SC2**	Not interpolated/extrapolated		
SC3	83	3.71	2.00
SC4	53	2.88	0.47
SC5	64	3.01	1.70
SC6**	Not interpolated/extrapolated		
SC7	38	1.80	1.70
SC8	52	2.75	1.70
SC9**	Not interpolated/extrapolated		
SC10**	Not interpolated/extrapolated		
SC11	47	2.42	0.42
SC12	55	2.89	0.49
SC13	86	3.60	4.60
SC14	123	4.39	5.00
SC15***	Incremental consequences interpolated/extrapolated		
SC16***	Incremental consequences interpolated/extrapolated		
SC17*	48	2.63	0.25
SC18***	Incremental consequences interpolated/extrapolated		
SC19*	54	3.16	0.25
SC20*	25	1.25	0.25

Notes: "Max depth" and "max velocity" are spatial averages of temporal max values within worst zone.
** Inundation not modeled but interpolated/extrapolated (approximate)*
For example, depths for each zone for SC19 were interpolated from SC3 and SC4, assuming log linear relationship with breach duration, but if SC4 was zero depth and the difference between SC3 and SC4 was less than 0.5m (based on plotting these values), SC19 was assumed to be zero (dry) – otherwise it would have hit all the same zones as SC3
*** Inundation not modeled nor interpolated/extrapolated*
**** Inundation not modeled nor interpolated/extrapolated, but consequences interpolated/extrapolated (approximate)*
For example, incremental consequences for SC15 were interpolated/extrapolated from SC17 (SC12 and SC13)

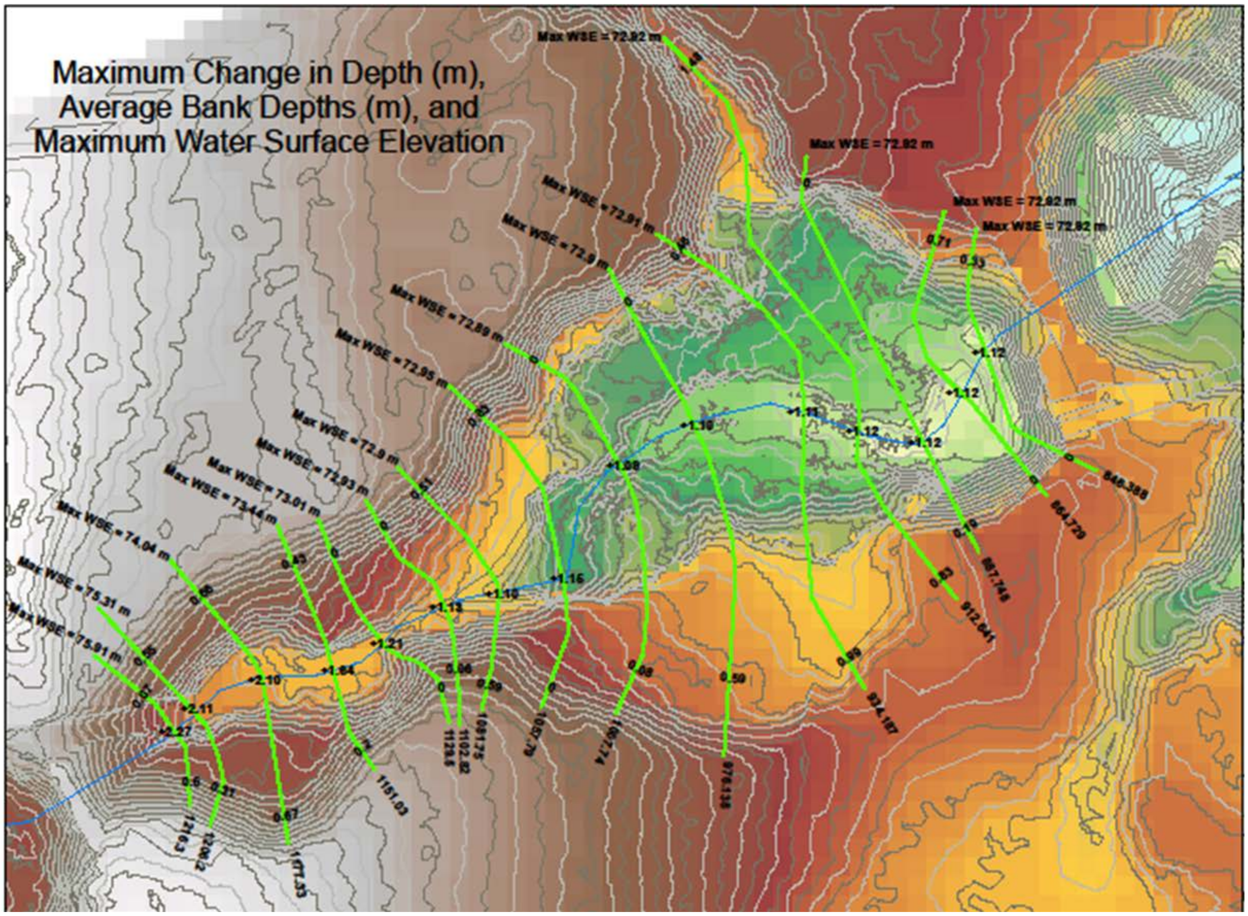


Figure 3-7. Inundation (max depth) for Lower Reservoir if Fast Middle Dam Breach due to Seismic Event (Golder, 2014a)

4.0 SCENARIO CONSEQUENCES

This section of the report presents the methodology to determine the downstream consequences for each failure scenario, as follows:

- Scenario consequence models (4.1);
- Scenario consequence input parameters (4.2); and
- Scenario consequence outputs (4.3)

4.1 Scenario Consequence Models

The downstream consequences for each scenario were modeled as follows:

- For each spatial zone (downstream and Lower Dam reservoir area):
  - expected value of damages in zone = approximate zone value x average damage % for zone:

  - separately for improvements and for contents; and
  - average damage % for zone is function of the spatial-average of the temporal-max depth and velocity of inundation within that zone.
- expected number of fatalities in zone = expected number of exposed population in zone x average individual probability of fatality for zone:
  - expected number of exposed population in zone depends on pre-inundation population, which in turn depends on when inundation happens (night/weekend vs weekday), and on how many of those people leave before inundation, which in turn depends on warning/evacuation procedures and the nature of inundation; and
  - average individual probability of fatality for zone is function of the spatial-average of the temporal-max depth and velocity of inundation within that zone.
- probability of at least one fatality in zone = binomial distribution with expected number of exposed population in that zone each with independent average individual probability of fatality for that zone.

- Combine over all spatial zones:
  - sum (over all zones) expected value of damages (both improvements and contents);
  - sum (over all zones) expected number of fatalities;
  - $P[\geq 1] = 1- p[=0] = 1 - \Pi_{\text{all } i} (1 – P_i)$ where P_i is probability of at least one fatality for each zone i ≈ sum (over all zones) $_{\text{proba}}$bility $_{\text{o}}$f at least one fatality, if sum is less than 10%;
  - $P[\geq 2] = 1 – (p[=0] + p[=1] = 1- [\Pi_{\text{all } i} (1 – P_i) + \Sigma_{\text{all } i} (p_i * \Pi_{\text{all } j \text{ except } i} (1 – P_j)]$ where p_i is probability of one fatality for each zone i; and
  - maximum (over all zones) probability of fatality per individual (conservatively assume 100% time in zone pre-warning), but reduce by chance of leaving prior to inundation.

4.2 Scenario Consequence Input Parameters

The primary input parameters (besides inundation) used in determining the consequences for each failure scenario are provided in the following subsections:

- Downstream assets (4.2.1);
- Lower reservoir assets (4.2.2);
- Warning/evacuation effectiveness (4.2.3);
- Mortality rates (4.2.4); and
- Property damage functions (4.2.5).

4.2.1 Downstream Assets

Downstream assets are summarized collectively (see Table 4-1) and by zone (see Appendix B)

- Property (improvements and contents):
  - Individual property improvement and content values were derived from CoN assessed valuations (AE, 2012);
  - Individual property values were aggregated by zone (AE, 2014); and
  - Aggregated property values by zone in the future (when inundation might occur) will not be significantly different considering controllable future growth.
- Population (weekday and weekend/nighttime) – pre-inundation (Table 4-2):
  - Mostly residential, plus school and some commercial;
  - Average per dwelling unit vs specific properties (AE 2012, higher than current, considering controllable future growth);
  - Different for work day (25%) vs nights/weekends (75%), but not significantly different among seasons;
  - Mix of population type (age and capability) and location (in structure, in vehicle, outside) – averaged; and
  - Inundation is random occurrence (workday vs night/weekend)

Table 4-1. Collective Assets in Potentially Affected Area (in 174 spatial zones, see Figure 3-1)
Note: CoN assessed values for individual properties, as of 2012 (AE, 2012).

Asset	Value
Adjusted gross improvements	$68.4M
Contents	$27.2M
Pre-evacuation day population	1070
Pre-evacuation night/weekend population	1713

Table 4-2. Average Population in Downstream Area at any Particular Time (by property type)

Property type	Weekday (25%)	Weekend/night (75%)
Residential (avg per Dwelling Unit) / Commercial	x1/3 (1/5 if >30)	3
Multifamily (avg per Dwelling Unit)	x1/4 (1/3 if <25)	3
School/daycare	533	12
Soccer field	31	3

Note: based on survey from 2012 (AE, 2012)

4.2.2 Lower Reservoir Assets

Lower reservoir assets include:

- Property (improvements and contents):
  - Insignificant – recreational facilities only.
- Population (pre-warning/evacuation) - see Table 4-3:
  - Only recreational use – everyone is outside;
  - Different for weekend day (10%), week day (25%) and night (65%), and different for summer (25%), spring/fall (50%), and winter (25%) – nobody during major storm;
  - Mix of population type (age and capability) – averaged;
  - Seismic only, for which inundation Is a random occurrence; and
  - Population varies significantly, but averages 3.9 at any time over a year.

Table 4-3. Average Population in Lower Reservoir Area at any Particular Time

Season | time of day/week	Weekend Day (10%)	Weekday (25%)	Night (65%)
Summer (25%)	25*	15	0
Spring/Fall (50%)	15	10	0
Winter (25%)	5	3	0

** If average summer weekend day increases to 50, average exposed population would only increase from 3.9 to 4.5.*

4.2.3 Population Reduction Due to Evacuation/Warning

Pre-inundation population reduction (evacuation) is summarized by breach type in Table 4-5 and thereby by scenario in Table 4-6, based on the following:

- Evacuation requires warning + mobilization + transit (if time is still available).
- Average downstream population reduction % due to evacuation.
  - ≈ Reduced probability of fatality per individual.
  - ≈ P[warning] x P[mob] x P[average evacuation time < average flood arrival time].
    - Probability of being warned is function of time from breach, which varies with type of breach – see Figure 4-1.
    - Probability of mobilizing once warned is function of time after warning – see Figure 4-2.
    - Probability that average evacuation time (ET) is less than flood arrival time (FAT).

$P[ET<FAT] = \Phi\{(FAT - m[ET])/s[ET]\}$

where Φ is standard cumulative distribution function, assuming ET is normally distributed, where (see Table 4-4)

- Average evacuation time (relative to dam breach initiation) is sum of following: - see Table 4-4.

  1) "Warning" (+/- time relative to breach initiation), which varies with type of breach*
  2) Mobilization (delay after warning to start evacuation)*
  3) Evacuation (transit time out of flood zone, for pedestrians and for vehicles, considering traffic): est. 0.2 to 0.5 hr

  ** conservatively do not consider CoN procedures*

- Flood arrival time (from the initiation of breaching) is assumed to be about the same as the duration of breach development (flood travel time is conservatively assumed to be relatively small).

■ For example, for SC-3 (fast breach of Middle Dam due to PMF, with no Lower Dam failure, which was worst case inundation of Phase 1 risk assessment, see Figure 3-6), is a case Of (fast breach due to storm/overtopping) so that average population reduction (evacuation) = 36%.

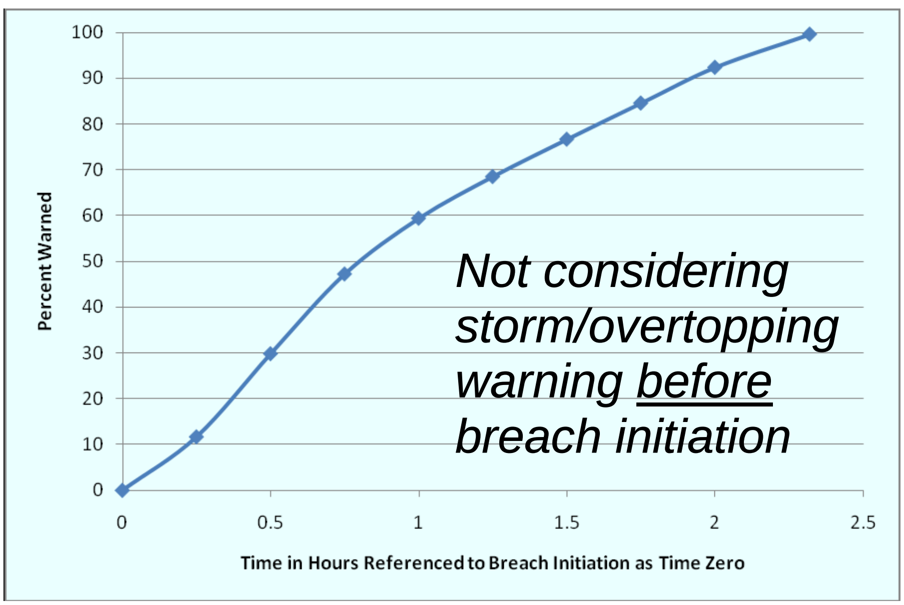


Figure 4-1. Average Probability of Being Warned of Inundation (ref. USACE in Feinberg et al)

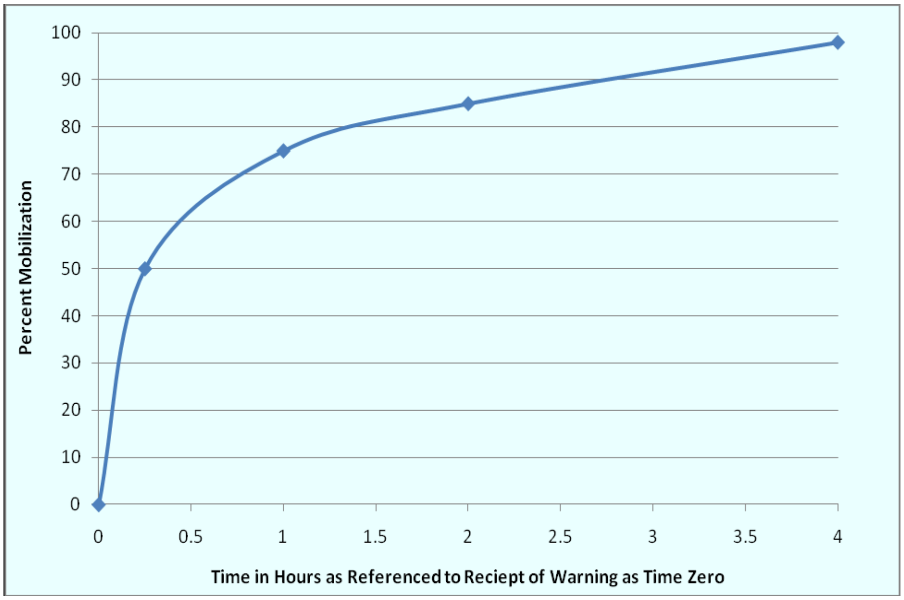


Figure 4-2. Average Probability of Mobilizing Once Warned (ref. USACE in Feinberg et al)

Table 4-4. Uncertainty in Average Evacuation Time (by Breach Type)

Breach type	P[Warning]	Warning (hr)*	P[Mob]	Mob (hr)*	Transit (hr)*	m[ET] (hr)*	s[ET] (hr)*
Storm/overtopping (O)	95%	-2 to 0.5	98%	0.1 to 2	0.2 to 0.5	0.65	1.23
Seismic/other (S)	80%	0 to 1.0	98%	0.1 to 2	0.2 to 0.5	1.90	0.85

*Note: * time ranges are assumed to be normally distributed and independent, subjectively assessed 10th to 90th percentiles (from which mean and standard deviations are derived)*

Evacuation Time (ET) = Warning Time + Mob Time + Transit Time
m[ET] ≈ m[Warn] + m[Mob] + m[Transit]
s[ET] ≈ (s2[Warn] + s2[Mob] + s2[Transit])1/2

Table 4-5. Average Population Reduction % due to Evacuation (by Breach Type)

Breach type	Slow breach (2.5hr) / no breach ("s")			Moderate breach (1hr) ("m")			Fast breach (0.3hr) ("f")		
	Case	P[ET< FAT]	Pop Reduct	Case	P[ET< FAT]	Pop Reduct	Case	P[ET< FAT]	Pop Reduct
Storm/overtopping ("O")	Os	93%	87%	Om	61%	57%	Of	39%	36%
Seismic/other ("S")	Ss	76%	60%	Sm	14%	11%	Sf	3%	2%

Note: P[ET<FAT] = □{(m[FAT] – m[ET])/s[ET]}
where flood arrival time (FAT) = breach development time + flood travel time (which is conservatively assumed to be minimal relative to breach development time, which is especially true for Lower Reservoir evacuation)
For example, for fast breach due to storm (Of):

P[Warning] = 95% (Table 4-5)
P[Mob] = 98% (Table 4-5)
P[ET<FAT] = □{(0.65)/1.23} = 39% (Table 4-6)
Population reduction % due to evacuation = 0.95 x 0.98 x 0.39 = 36%

Table 4-6. Average Population Reduction % due to Evacuation (by Scenario – see Table 2-2)

Scenario ID	Event Type	Return Period	Breaches	Dam Breach Duration (min)	Case	Population Reduction
SC1	Seismic/Other	All	Middle Dam Only	Fast – 10	Sf	2%
SC2**	Seismic/Other	All	Middle Dam Only	Slow – 150	Ss	60%
SC3	PMF	~ 50,000 year	Middle Dam Only	Fast – 10	Of	36%
SC4	PMF	~ 50,000 year	Middle Dam Only	Slow – 150	Os	87%
SC5	1000-year Flood	1000 year	Middle Dam Only	Fast – 10	Of	36%
SC6**	1000-year Flood	1000 year	Middle Dam Only	Slow – 150	Os	87%
SC7	1000-year Flood	1000 year	No Breach	N/A	Os	87%
SC8	PMF	~ 50,000 year	No Breach	N/A	Os	87%
SC9**	100-year Flood	100 year	Middle Dam Only	Fast – 10	Of	36%
SC10**	100-year Flood	100 year	Middle Dam Only	Slow – 150	Os	87%
SC11	1000-year Flood	1000 year	Middle Dam Only	Mod – 60	Om	57%
SC12	1000-year Flood	1000 year	Middle&Lower Dams	Mod - 60&120	Om	57%
SC13	PMF	~ 50,000 year	Middle&Lower Dams	Mod - 60&120	Om	57%
SC14	PMF	~ 50,000 year	Middle&Lower Dams	Fast - 10&10	Of	36%
SC15***	Seismic or Other	All	Middle&Lower Dams	Mod - 60&120	Sm	11%
SC16***	Seismic or Other	All	Middle Dam Only	Mod – 60	Sm	11%
SC17*	100-year Flood	100 year	Middle&Lower Dams	Mod - 60&120	Om	57%
SC18***	100-year Flood	100 year	Middle Dam Only	Mod – 60	Om	57%
SC19*	PMF	~ 50,000 year	Middle Dam Only	Mod – 60	Om	57%
SC20*	100-year Flood	100 year	No Breach	N/A	Om	57%

** Scenario inundation not modeled, but interpolated/extrapolated from other scenarios.*
*** Scenario inundation and consequences not modeled, nor interpolated /extrapolated.*
**** Scenario inundation not modeled nor interpolated /extrapolated, but scenario consequences interpolated /extrapolated*

4.2.4 Mortality Rates

The average mortality rate for remaining affected population is determined as follows,

- Assume remaining population in affected areas collectively is "average" re age, gender, capability, protection, etc.
- Mortality rate = % of affected population killed = average probability of fatality for each individual (P[F]).
- Mortality rate is function of flood depth (D) and velocity (V), as well as population characteristics.
- Primarily used recent (2010), empirically-derived Dutch mortality function as a lognormal function of depth (Figure 4-3).

  P[F] = Φ\{(ln(D) - 1.46)/0.28\} if DxV<7m^2/s or V<2 m/s

  = 1 if DxV>7m^2/s and V>2 m/s

  Where D=depth (m) & V=velocity (m/s)

- This relationship was adjusted at the extremes.

  P[F] > 0.0002 (USACE min) for D>0

  = 1.00 if structural collapse (Figure 4-6)

- Note: New USBR mortality rates from "USBR Consequence Estimating Methodology" (USBR, 2014) are lower than the mortality rates used herein (Table 4-7), albeit they are applied to total pre-warning population whereas the above rates are applied to remaining population.
  - For the higher depths (of which there were very few areas/population), the rates used herein were about mid USBR range for short warning and well above the USBR range for long warning (which would be closer to reality).
  - For lower depths (which were much more prevalent), the rates used herein are above USBR's rates.
  - Hence, the rates used herein, in conjunction with the reduced population due to evacuation, are somewhat conservative, relative to USBR's new rates.

Table 4-7. Comparison with New USBR Mortality Rates (USBR Feb 2014)

Depth (m)	Velocity (m/s)	DxV (m2/s)	DxV (ft2/s)	New USBR Mortality Rates (% of pre-warn population)		Mortality Rates Used Herein (% of remaining population)
				Short warning	Long warning	
4	4	16	175	0.2 to 0.6	0.0004 to 0.01	39.62
3	2	9	100	0.04 to 0.3	0.0002 to 0.006	9.84
2	2	4	44	0.001 to 0.05	0.00002 to 0.002	0.31
2	1	2	22	0 to 0.001	0 to 0.0007	0.31
1	1	1	11	0	0 to 0.0002	0.02
1	0.5	0.5	5.5	0	0 to 0.0001	0.02

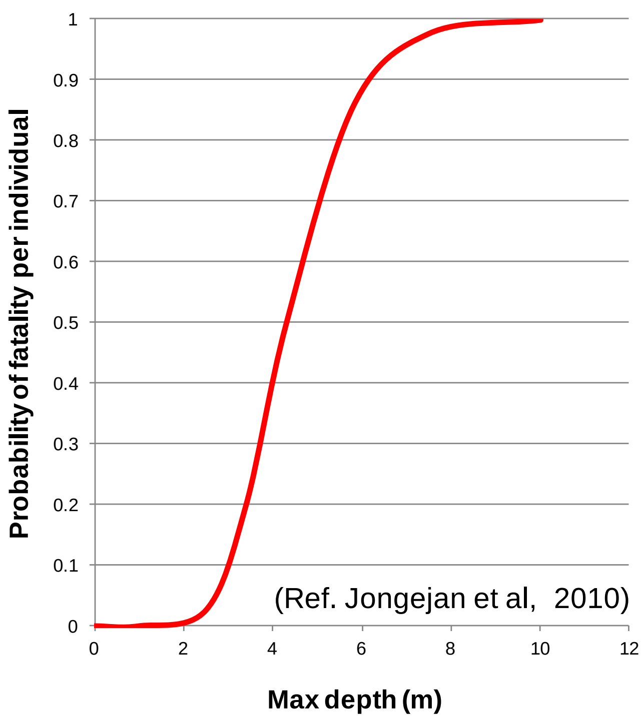


Figure 4-3. Average Flood Mortality Rate (subject to lower and upper limits – see Subsection 4.2.5)

4.2.5 Property Damage Functions

Property damage is calculated as a % of value which is as function of inundation (typically in terms of max depth). These damage functions assume that affected properties are primarily residential 2+ story (timber) with basement.

- Residential contents damage function (Figure 4-4).
- Structure (improvements) damage function (Figure 4-5).
- Structural collapse function (Figure 4-6). Note: Collapse for different types of structures is presented in Table 4.8.

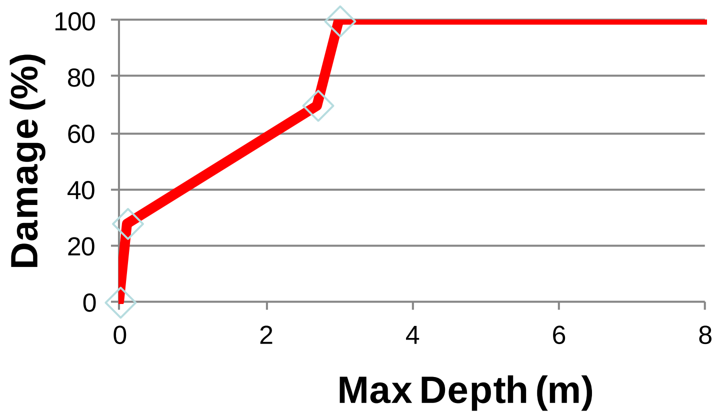


Figure 4-4. Residential Contents Average Damage Function (ref. AE, 2012)

Note: For residential 2+ story (timber) with basement.

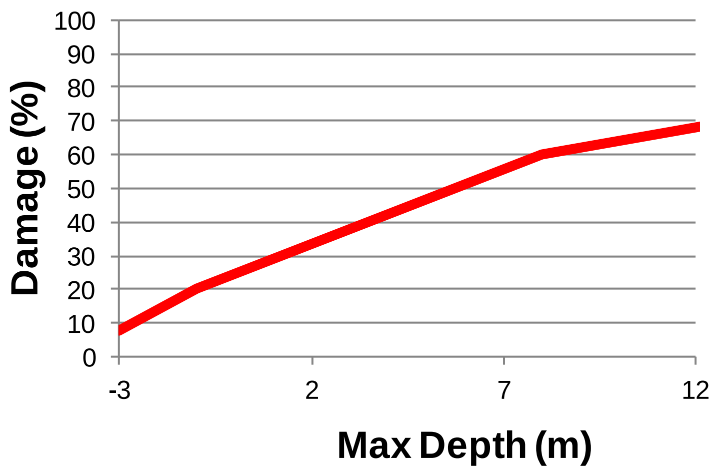


Figure 4-5. Structure Average Damage Function (ref. AE, 2012)

Note: For residential 2+ story (timber) with basement. Structural damage becomes 100% if collapse (see Figure 4-6)

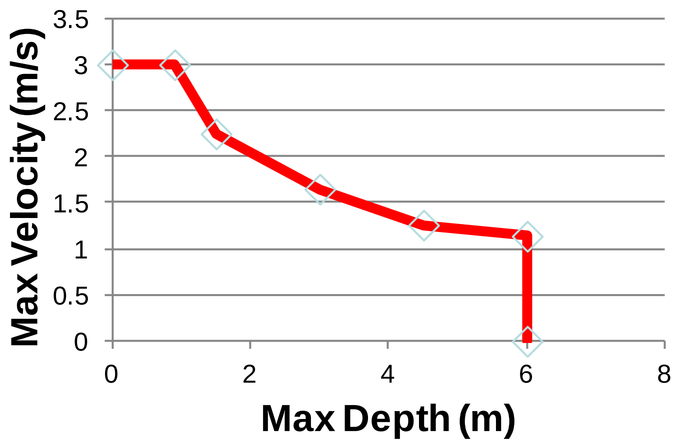


Figure 4-6. Structural Average Collapse Function (ref. AE, 2012)

Note: For residential 2+ story (timber) with basement. Assumed to collapse (which in turn affects mortality and structural damage) if above curve, and not collapse if below curve, although in reality it's not that definitive with the probability of collapse varying from 0.0 to 1.0 with max depth and velocity.

Table 4-8. Structural Average Collapse Function for Different Structure Types

Structure type	Collapse if D*V (m2/s) >
Poorly constructed	5
Well built timber	10
Well built masonry	15
Concrete	20
Large concrete	35

Note: As noted in Figure 4-6, in reality collapse is not this definitive, with the probability of collapse varying from 0.0 to 1.0 with max depth x velocity.

4.3 Scenario Consequence Outputs

The outputs from the modeling of the downstream consequences are as follows,

- For each scenario, inundation (max depth and velocity by zone, see Section 3) for that scenario was used in conjunction with assets (property values and pre-warning population) by zone to first determine the potentially affected assets. Potentially affected assets for each scenario are identified from the list of assets (by zone) and the inundation (by zone), and then summed over all zones. This is summarized for each scenario in Table 4-9. For example, for SC-3 (fast breach of Middle Dam due to PMF, with no Lower Dam failure, which was worst case of Phase 1 risk assessment – see Figure 3-6)
  - Affected property (sum of values in downstream wet zones; nothing significant in Lower Reservoir area)
    - Improvements $44.2M

- Contents $16.2M

- Affected pre-inundation population (sum of populations in downstream wet zones; nobody in Lower reservoir area during PMF)
  - Day 917
  - Night 1254

- Then for each scenario, the affected population was reduced due to evacuation for that scenario, and mortality/damage functions (rates as function of inundation) were used to determine damages and fatalities by zone and collectively over all zones for that scenario, first absolute and then incremental consequences (relative to same storm with no dam failures).
  - For example, for SC-3 (fast breach of Middle Dam due to PMF, with no Lower Dam failure),
    - Downstream
      - “Absolute”
        - Damages
          - Expected improvements/structural damages $7.6M
          - Expected value of contents damages $4.4M
          - Expected value of total damages $12.1M
        - Safety
          - Expected number of Fatalities 2.0
          - Probability of at least 1 fatality 0.90
          - Maximum probability of Individual fatality 0.19
      - “Incremental” (relative to scenario with same storm but no dam breaches)
        - Damages
          - Expected value of total damages $5.3M
        - Safety
          - Expected number of Fatalities 1.9
          - Probability of at least 1 fatality 0.87
          - Maximum probability of Individual fatality 0.18
  - For another example, Lower Reservoir area consequences (moderate breach of Middle Dam due to seismic event or other cause)
      - “Incremental” is the same as absolute

- Damages
  - Expected value of total damages $0.0M
- Safety
  - Expected number of Fatalities 7.6E-04
  - Probability of at least 1 fatality 2.4E-07
  - Maximum probability of Individual fatality 2.0E-05

- Consequences for each representative dam failure scenario (if it happens) are presented by zone in Appendix C and summarized in Table 4-10 and for each failure mode (if it happens) in Table 4-11. For example, one particular failure mode consists of both dams breaching (with expected value breach development times) during a PMF storm, which is represented by Scenario 13.

Table 4-9. Potentially Affected Assets (Collectively by Scenario)

Scen ID	# Zones Flooded	Max D Depth (m)	Max V Velocity (m/s)	Max DV (m^2/s)	Adj Gross Impr Value $	Contents Value $	Total Prop Value $	Day Pop.	Night Pop.
SC1	17	0.42	0.25	0.06	5,545,000	2,753,500	8,298,500	606	306
SC2**	Not interpolated/extrapolated								
SC3	83	3.71	2.00	0.98	44,231,000	16,169,500	60,400,500	917	1254
SC4	53	2.88	0.47	0.58	22,906,000	11,433,500	34,339,500	813	1032
SC5	64	3.01	1.70	0.83	37,773,000	13,008,500	50,781,500	866	1101
SC6**	Not interpolated/extrapolated								
SC7	38	1.80	1.70	0.34	14,607,000	7,284,500	21,891,500	708	652
SC8	52	2.75	1.70	0.51	22,686,000	11,323,500	34,009,500	811	1026
SC9**	Not interpolated/extrapolated								
SC10**	Not interpolated/extrapolated								
SC11	47	2.42	0.42	0.51	20,363,000	10,162,000	30,525,000	792	969
SC12	55	2.89	0.49	0.68	23,006,000	11,483,500	34,489,500	814	1035
SC13	86	3.60	4.60	0.83	44,692,000	16,368,500	61,060,500	919	1260
SC14	123	4.39	5.00	5.00	55,588,000	21,785,500	77,373,500	1001	1506
SC15***	Incremental consequences extrapolated from SC17 (SC12 and SC13)								
SC16***	Incremental consequences extrapolated from SC17 (SC12 and SC13)								
SC17*	48	2.63	0.25	0.26	20,727,000	10,344,000	31,071,000	782	919
SC18***	Incremental consequences extrapolated from SC17 (SC12 and SC13)								
SC19*	54	3.16	0.25	0.32	22,906,000	11,433,500	34,339,500	813	1032
SC20*	25	1.25	0.25	0.17	9,022,000	4,492,000	13,514,000	635	393

Based on downstream zones and their assets that become “wet”, as determined by inundation analysis.
**Inundation not modeled but interpolated/extrapolated (approximate) (Table 3-4)*
*** Inundation and consequences not modeled nor interpolated/extrapolated*
**** Inundation not modeled nor interpolated/extrapolated, but consequences interpolated/extrapolated (approximate)*

Table 4-10. Expected Value of Conditional Scenario Consequences (Absolute vs. Incremental)

Scen ID	Absolute Scenario Consequences							Incremental Scenario Consequences				
	Building Dmg ($M)	Contents Dmg ($M)	Total Dmg ($M)	Number Fatalities	P[≥1 fatal]	P[≥2 fatal]	Max Ind P[F]	Total Dmg ($M)	Number Fatalities	P[≥1 fatal]	P[≥2 fatal]	Max Ind P[F]
SC1	$0.8	$0.5	$1.3	7.5E-02	7.2E-02	2.6E-03	2.0E-04	$1.3	7.5E-02	7.2E-02	2.6E-03	2.0E-04
SC3	$7.6	$4.4	$12.1	2.0E+00	9.0E-01	6.5E-01	1.9E-01	$5.3	1.9E+00	8.7E-01	6.5E-01	1.8E-01
SC4	$5.2	$3.1	$8.3	7.2E-02	4.8E-02	9.9E-04	9.8E-03	$1.6	1.7E-02	1.1E-02	3.5E-04	2.7E-03
SC5	$5.8	$3.5	$9.3	4.9E-01	4.2E-01	9.8E-02	6.4E-02	$5.5	4.8E-01	4.1E-01	9.8E-02	6.4E-02
SC7	$2.4	$1.4	$3.8	1.8E-02	1.7E-02	1.4E-04	1.2E-04	Used as base for 1000-yr incremental consequences				
SC8	$4.2	$2.5	$6.7	5.4E-02	3.7E-02	6.4E-04	7.2E-03	Used as base for PMF incremental consequences				
SC11	$2.9	$1.7	$4.7	1.1E-01	9.8E-02	4.81E-03	8.4E-03	$0.9	8.8E-02	8.2E-02	4.7E-03	8.3E-03
SC12	$4.0	$2.4	$6.4	2.4E-01	2.1E-01	2.07E-02	3.3E-02	$2.7	2.3E-01	1.9E-01	2.1E-02	3.3E-02
SC13	$5.8	$3.4	$9.2	1.1E+00	6.6E-01	2.59E-01	1.1E-01	$2.5	1.0E+00	6.2E-01	2.6E-01	1.0E-01
SC14	$9.5	$5.5	$15.0	1.1E+01	1.0E+00	1.0E+00	6.4E-01	$8.2	1.1E+01	9.6E-01	NA	6.3E-01
SC15**	Incremental consequences ≈ (30% of SC17) Need to add LowRes							$1.5	2.1E-02	1.9E-02	1.3E-03	3.0E-03
SC16**	Incremental consequences ≈ (10% of SC1) Need to add LowRes							$0.1	7.5E-03	7.2E-03	2.6E-04	2.0E-05
SC17*	$5.5	$3.2	$8.7	1.1E-01	4.3E-03	5.02E-03	1.0E-02	$4.9	7.0E-02	6.3E-02	4.3E-03	1.0E-02
SC18**	Incremental consequences ≈ (35% of SC17)							$1.7	2.5E-02	2.2E-02	1.5E-03	3.5E-03
SC19*	$6.2	$3.9	$10.1	4.4E-01	5.8E-02	5.89E-02	5.8E-02	$3.4	3.8E-01	3.1E-01	5.8E-02	5.0E-02
SC20*	$2.4	$1.4	$3.8	3.9E-02	3.8E-02	7.23E-04	8.6E-05	Used as base for 100-yr incremental consequences				
SC1+ SC15+ SC16+	Add Lower Res (no sig property, 3.9 people avg pre-warn, max individ is 10% occ, P[evac]=2%, maxD➔P[F]=0.0002							$0.0	7.6E-04	7.6E-04	2.4E-07	2.0E-05

*Note: *Inundation was interpolated/extrapolated, but then used in the same way as for those where inundation was modeled.*
***Inundation was not modeled nor interpolated /extrapolated for SC15, SC16, and SC18, but the incremental consequences were interpolated/extrapolated.*

Table 4-11. Conditional Incremental Consequences (by Failure Mode)

Storm	Breach	Rep Scenario(s)	Dmg ($M)	Fatalities	P[≥1 Fatal]	P[≥2 Fatal]	Ind Risk
PMF	Mid Dam only	SC19	$3.4	3.8E-01	3.1E-01	3.1E-03	5.0E-02
"	Mid & Low Dam	SC13	$2.5	1.0E+00	6.2E-01	2.6E-02	1.0E-01
1000 yr	Mid Dam only	SC11	$0.9	8.8E-02	8.2E-02	1.8E-04	8.3E-03
"	Mid & Low Dam	SC12	$2.7	2.3E-01	1.9E-01	6.3E-04	3.3E-02
100 yr	Mid Dam only	SC18*	$1.7	2.5E-02	2.2E-02	2.4E-05	3.6E-03
"	Mid & Low Dam	SC17	$4.9	7.0E-02	6.3E-02	6.8E-05	1.0E-02
Seismic	Mid Dam only	SC16*+Low Res	$0.1	8.2E-03	7.9E-03	5.7E-05	4.0E-05
"	Mid & Low Dam	SC15*+Low Res	$1.5	2.2E-02	2.0E-02	2.1E-05	3.1E-03
Other	Mid Dam only	SC16*+Low Res	$0.1	8.2E-03	7.9E-03	5.7E-05	4.0E-05
"	Mid & Low Dam	SC15*+Low Res	$1.5	2.2E-02	2.0E-02	2.1E-05	3.1E-03

** Conditional incremental consequences are interpolated/extrapolated*

5.0 SCENARIO PROBABILITIES

This section of the report presents the methodology to determine the probabilities of the various failure modes, as follows:

- Seismically-induced dam failures;
- Storm-induced dam failures; and
- "Other" dam failure modes.

5.1 Seismically-Induced Failure Probabilities

The annual probability of seismically-induced failure of the dam(s) has been based primarily on stability analyses undertaken for this project (Golder, 2014b; EBA, 2010), considering the following:

- Annual probability of seismically induced dam failure is a function of the uncertainty in the maximum seismic event that will occur in any one year (nature) and the probability that such an event will cause dam failure (dam response).
- Seismic frequency-magnitude relationship for the site (Table 5-1 and Figure 5-1) (EBA, 2010).
- Probability of seismic dam failure (leading to breach) is function of seismic magnitude and dam conditions – Figure 5-2. Based on seismic stability studies undertaken (2475 and 10,000 year return periods) for this project (Golder, 2014b, and EBA, 2010), and informed by opinion from specialists, the probability of dam failure due to different earthquake magnitudes has been determined. In this context, "failure" refers to a rapid failure with breach durations given by Figure 3-4, and does not include failure modes which would develop slowly and result in a more gradual release of water from the reservoir. The stability studies have found that there is an extremely low probability of overtopping during an earthquake due to loss of freeboard (ie toppling of the core wall, or settlement of the crest). Post-earthquake stability analyses which considered the most severe and conservative assumptions for soil properties, stratigraphy and damage of

the core wall, have shown that the downstream slope of the survival dam section is marginally stable from a post-earthquake static shear failure and that severe surface sloughing and piping erosion of downstream rockfill due to reservoir flow through the residual dam section is limited. The Middle Dam has been assigned a relatively higher probability of failure for the following reasons,

- There is less information available for this dam in comparison to the Lower Dam – ie there is greater uncertainty related to the conditions of the concrete, presence and condition of re-bar, and the potential presence of an undetected low level outlet.
- The Middle Dam has a thinner concrete core, and is composed primarily of sand and gravel in the downstream shell, and is therefore more likely to erode and pipe if the core is severely cracked during an earthquake.

- Annual probability of dam failure (P[F]) can be approximately determined by discretizing these relationships, as shown schematically in Figure 5-3,

  $P[F]=\Sigma_{\text{all }\alpha}P[F|\alpha]\ p[\alpha]$ where

  - A set of different representative values of seismic peak ground acceleration (α) that cover the range of interest are identified;
  - The probability of dam failure if that peak ground acceleration occurs ($P[F|\alpha]$) is derived for each value of α from the appropriate dam failure relationship (Figure 5-2); and
  - The probability of each α being the largest value during a random year is derived from the frequency-magnitude relationship (Figure 5-1).

- Annual probability of seismically induced dam failure is presented in Table 5-2 for each dam remediation option, considering the assessed high correlation between Middle and Lower Dam failures.

Table 5-1. Seismic Frequency-Magnitude (ref. EBA 2010)

Return Period (yrs)	Peak Ground Acceleration, α (g)
98	0.125
475	0.267
975	0.36
2475	0.499
MCE (10k)	0.8

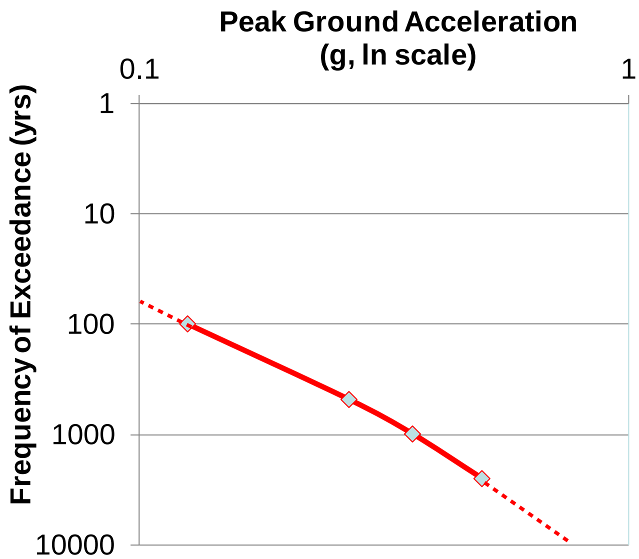


Figure 5-1. Seismic Frequency-Magnitude (see Table 5-1)

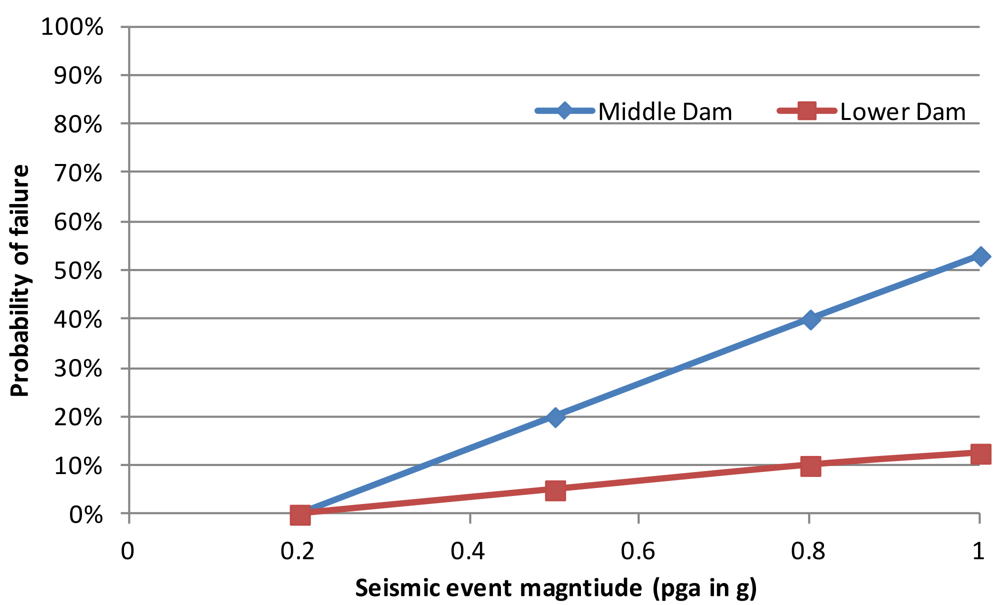


Figure 5-2. Probability of Dam Failure as Function of Seismic Magnitude for Middle Dam and for each Lower Dam Remediation Option

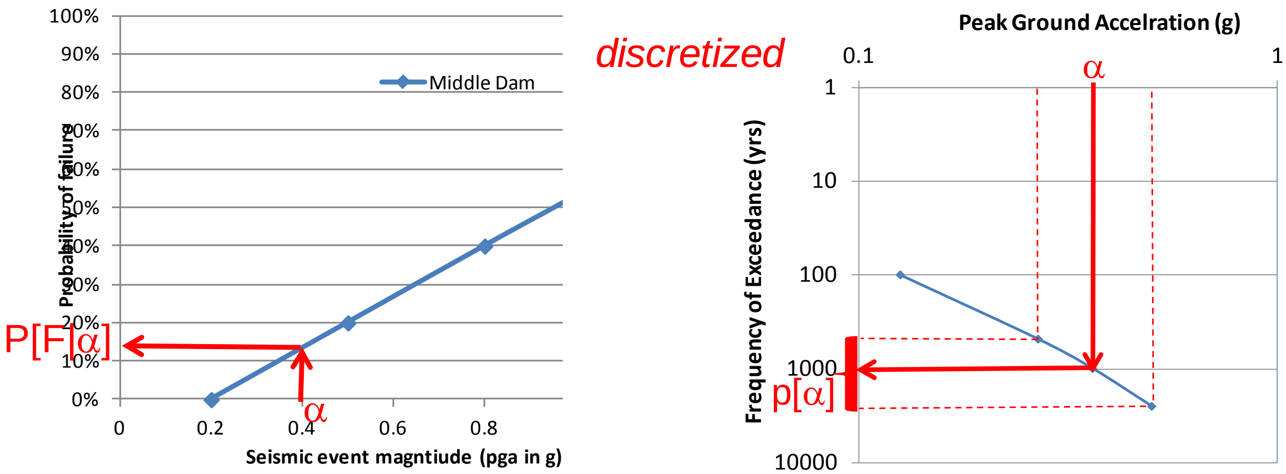


Figure 5-3. Schematic of Derivation of Probability of Seismic Dam Failure

Table 5-2. Annual Probability of Seismically Induced Dam Failure(s)

Dam Remediation Option	Middle Dam	Lower Dam
Unconditional annual P[F]	$2.4x10^{-4}$	$6.0x10^{-5}$
P[Lower Dam Failure|Middle Dam Failure]		0.25
P[Middle Dam only fails]		$1.8x10^{-4}$
P[Middle and Lower Dam both fail]		$6.0x10^{-5}$

Note: Lower and Middle Dam failures are highly correlated, so that the chance of the Lower Dam failing in a seismic event if the Middle Dam does not fail in that event is essentially zero, i.e., if the Lower Dam fails in a seismic event it is very likely that the Middle Dam will fail also.

5.2 Storm-Induced / Overtopping Failure Probabilities

The annual probability of storm-induced failure of the dam(s) considers the following;

- Annual probability of storm induced dam failure is a function of the probability of each of the representative storms being the maximum storm in a random year, combined with the probability of dam failure if that storm occurs.
- Annual probability of each storm scenario (PMF, 1000-yr and 100-yr) being the maximum can be approximated by discretizing the continuous frequency of exceedance – magnitude relationship (Table 5-3), similar to the way the probability of various seismic magnitudes was determined (Figure 5-3).

Table 5-3. Annual Probability of Maximum Storm Scenarios

	Return (yr)		Annual	Annual
Rep Storm	Rep Storm	Limits*	P>[Limits]	p[Rep Storm]
		NA	0	
PMF	50000			1.00E-04
		10000	1.00E-04	
1000-yr	1000			1.90E-03
		500	2.00E-03	
100-yr	100			1.80E-02
		50	2.00E-02	

*Note: *Ranges are shifted up to account for non-linearity*

- The probability of dam failure due to overtopping for each storm is a function of the over-topping depth / duration associated with that storm and dam conditions. Further discussion of this is provided in (Golder 2014a).
  - The magnitude of overtopping (depth and duration) was previously presented for each scenario (Table 3-3).
  - The relationship between the probability of breach as a function of overtopping was assessed subjectively for each dam remediation option, based on expert judgment considering available info on conditions of each dam remediation option and case histories (Figure 5-4).

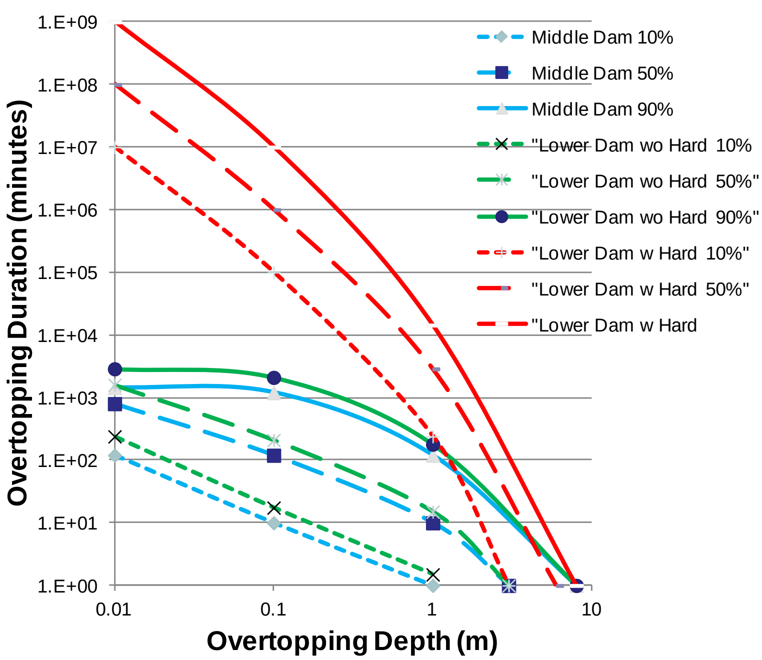


Figure 5-4. Conditional Probability of Dam Breaching as Function of Overtopping Magnitude for each Dam Remediation Option

- For example, for Middle Dam (Figure 5-5):
  - For the PMF, overtopping was 1.5 m deep for 4.4 hrs (Table 3-3), which is the green dot in Figure 5-5, and interpolates to about 95% probability.
  - For 1000 yr storm, overtopping was 0.8 m deep for 2.4 hrs (Table 3-3), which is the blue dot in Figure 5-5, and interpolates to about 85% probability.
  - For 100 yr storm, overtopping was 0.1 m deep for 1.0 hrs (Table 3-3), which is the red dot in Figure 5-5, and interpolates to about 35% probability.
- The other dam remediation options were evaluated in the same way, as summarized in Table 5-4.

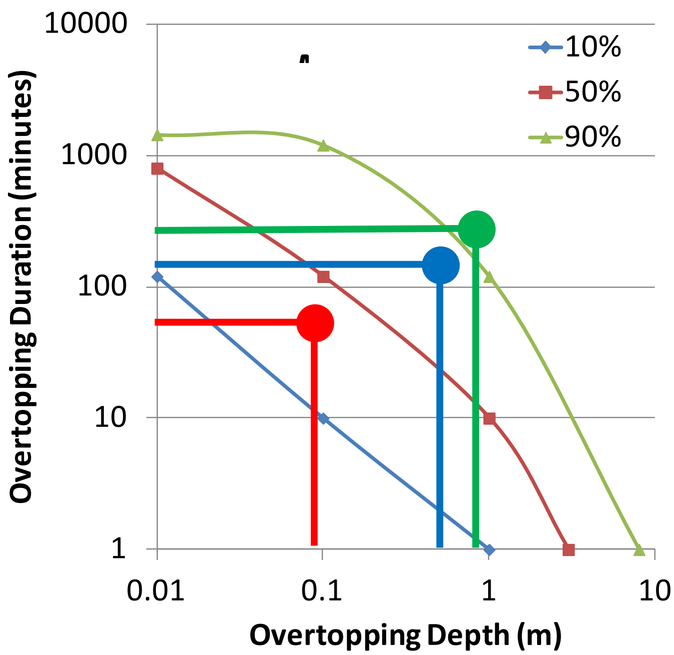


Figure 5-5. Derivation of Conditional Probability of Breaching from Overtopping for Middle Dam

Note: Relationship from Figure 5-4, overtopping from Table 3-3.

Table 5-4. Conditional Probability of Breach from Overtopping for each Dam Remediation Option

Storm	Middle Dam	Lower Dam** Labyrinth	Lower Dam**Hardened
PMF	95%	60/70%	10/15%
1000 yr	75%	0/10%	5/10%
100 yr	35%	0/0%	2/5%
Seismic***	NA	NA/0%	NA/0%

***Overtopping wo/w Middle Dam breach*
**** Overtopping of Lower Dam due to seismically-induced Middle Dam breach*

- The annual probability of each storm scenario occurring can then be determined by multiplying the probability of the storm being the maximum storm (Table 5-3) by the probability of dam failure if that storm occurs (Table 5-4), as summarized in Table 5-5.

Table 5-5. Annual Probability of Breach from Overtopping for each Dam Remediation Option

Storm	Middle Dam	Lower Dam** Labyrinth	Lower Dam**Hardened
PMF	9.5E-05	6.0 E-05/7.0E-05	1.0E-05/1.5E-05
1000 yr	1.4E-03	0.0/1.9E-04	9.4E-05/1.9E-04
100 yr	6.3E-03	0.0/0.0	3.6E-04/9.0E-04
Seismic***	NA	NA/0.0	NA/0.0

***Overtopping wo/w Middle Dam breach*
**** Overtopping of Lower Dam due to seismically-induced Middle Dam breach*

5.3 "Other" Dam Failure Probabilities

The annual probability of other types of dam failures considers the following:

- Other dam failures (e.g., piping/internal erosion, etc.) are typically conservatively estimated at about 1.0E-03 per year for each dam, based on historical evidence worldwide. However, these dams have performed well for a very long time, with no indication of other causes of failure, and are being regularly monitored for signs of distress.
- Failures of the Middle and Lower Dams due to other causes would be independent (unlike seismically-induced or storm-induced failures) and extremely unlikely to occur together.
- Hence, the probability of one or the other dam failing, with consequences similar to seismic failure of the middle dam, is assessed to be 1.0E-03.

5.4 Scenario Probabilities

Annual probability of each representative dam failure scenario for each Lower Dam remediation option was determined from seismic- induced (Section 5-1), storm-induced (Section 5-2) and other-induced (Section 5-3) dam failure probabilities for each dam remediation option. It is noted that non dam failure scenarios have no consequences and thus are not of interest. For each combination of dam remediation options:

- For each storm:
  - the probability of Middle Dam breach from overtopping (Table 5-5) becomes P[Mid Dam];
  - the probability of Lower Dam breach from overtopping for the appropriate Lower Dam remediation option if Middle Dam breaches from overtopping (Table 5-4) is divided by the probability of Middle Dam breaching from overtopping (Table 5-4) and becomes P[Low|Mid] for Mid&Low Dam breach; and
  - 100% - P[Low|Mid] for Mid&Low Dam breach becomes P[Low|Mid] for Mid Dam only breach

- For seismic:
  - the probability of Middle Dam seismic failure for the appropriate Middle Dam remediation option (Table 5-2) becomes P[Mid Dam];
  - the probability of Lower Dam seismic failure for the appropriate Lower Dam remediation option (Table 5-2) is divided by the probability of Middle Dam seismic failure (Table 5-2) and becomes P[Low|Mid] for Mid&Low Dam breach; and
  - 100% - P[Low|Mid] for Mid&Low Dam breach becomes P[Low|Mid] for Mid Dam only breach.
- For "other":
  - the probability of Middle or Lower Dam breach from other causes for the appropriate Lower Dam remediation option (Section 5-3) becomes P[Mid Dam];
  - P[Low|Mid] for Mid Dam only breach becomes 100%; and
  - P[Low|Mid] for Mid&Low Dam breach becomes 0%.
- The probability for each scenario is then simply P[Mid Dam] x P[Low|Mid].

Table 5-6. Annual Probability of each Failure Scenario for Lower Dam Hardening

Storm	Breach	P[Mid Dam]	P[Low|Mid]	P[Scenario]
PMF	Mid Dam only	9.50E-05	0.84	7.98E-05
"	Mid & Low Dam		0.16	1.52E-05
1000 yr	Mid Dam only	1.40E-03	0.86	1.20E-03
"	Mid & Low Dam		0.14	1.96E-04
100 yr	Mid Dam only	6.30E-03	0.86	5.42E-03
"	Mid & Low Dam		0.14	8.82E-04
Seismic	Mid Dam only	2.40E-04	0.75	1.80E-04
"	Mid & Low Dam*		0.25	6.00E-05
Other	Mid Dam only	1.00E-03	1.00	1.00E-03
"	Mid & Low Dam**		1.00	1.00E-03

*Notes: *Lower Dam fails either directly by seismic event or from overtopping from Middle Dam failure*
***Lower Dam fails either from overtopping from Middle Dam failure or directly without Middle Dam failure (although conservatively assume incremental consequences are the same).*

Table 5-7. Annual Probability of each Failure Scenario for Lower Dam Labyrinth

Storm	Breach	P[Middle Dam]	P[Low|Mid]	P[Scenario]
PMF	Mid Dam only	9.50E-05	0.26	2.47E-05
"	Mid & Low Dam		0.74	7.03E-05
1000 yr	Mid Dam only	1.40E-03	0.86	1.20E-03
"	Mid & Low Dam		0.14	1.96E-04
100 yr	Mid Dam only	6.30E-03	1.00	6.30E-03
"	Mid & Low Dam		0.00	0.00E+00
Seismic	Mid Dam only	2.40E-04	0.75	1.80E-04
"	Mid & Low Dam*		0.25	6.00E-05
Other*	Mid Dam only	1.00E-03	1.00	1.00E-03
"	Mid & Low Dam**		1.00	1.00E-03

*Notes: *Lower Dam fails either directly by seismic event or from overtopping from Middle Dam failure*
***Lower Dam fails either from overtopping from Middle Dam failure or directly without Middle Dam failure (although conservatively assume incremental consequences are the same).*

6.0 RISK

This section of the report presents the risk that has been determined for each dam remediation option by combining each option's set of failure scenario conditional consequences (Section 4) with the corresponding failure scenario annual probability of occurrence (Section 5). As shown in Table 6-1 for each dam remediation option:

- The expected value of the amount of damages per year is determined as follows:

  $E[\$/yr] = \Sigma_{all\ S}\ E[\$|S]\ P[S/yr]$

  where E[x] is expected value of x, P[x] is probability of x, $ is damages, S is scenario, x|y is x if y occurs

- The maximum annual individual risk (for comparison with safety criteria) is determined as follows:

  $P[F/yr] = \Sigma_{all\ S}\ P[F|S]\ P[S/yr]$

  where F is particular individual fatality

- The societal safety risk is determined in various ways as follows:
  - The expected value of the number of fatalities per year is determined as follows:

    $E[N/yr] = \Sigma_{all\ S}\ E[N|S]\ P[S/yr]$

    where N is number of fatalities

  - The probability of at least various specific numbers of fatalities per year is determined as follows:

    $P[\geq N/yr] = \Sigma_{all\ S}\ P[\geq N|S]\ P[S/yr]$

    These results are also presented for comparison with the CDA criteria in Figure 6-1.

As shown in Table 6-1 and Figure 6-1, there is little difference between the dam remediation options:

- ***Financial impacts*** – both dam remediation options have low damage costs (<$20,000 per year).
- ***Individual safety criteria*** - both dam remediation options meet CDA criteria (<10^{-4} per year).
- ***Societal safety criteria*** - both dam remediation options have risk levels that are between the CDA "Acceptable" and "Unacceptable" regions, and are therefore in the "As Low As Reasonably Practicable" (ALARP) region of the criteria.
  - To help better understand the safety risks, the conditional expected value of the number of fatalities (Table 4-11) and the annual probability of occurrence (Tables 5-6 and 5-7) have been summarized for each failure mode for each of the dam remediation options in Tables 6-2 and 6-3, and Figure 6-2.The conditional expected number of fatalities for each dam break scenario is the same for each of the dam remediation options, but the probability of each scenario occurring is different (because the probability of the Lower Dam failing is different between the options)
  - As shown, relative to hardening, the labyrinth reduces the risk for smaller floods, but increases the risk for larger floods, with no difference for moderate floods, seismic and other events.

Table 6-1. Set of Annual Incremental Consequences for each Dam Remediation Option (combined over all dam failure scenarios)

Dam Remediation Option	E[Damages ($M)/yr]	E[Fatalities/ yr]	Max Ann Ind Risk	P[≥1 Fatal/ yr]	P[≥2 Fatal/ yr]
Lower Dam Hardening	$0.017	4.3E-04	5.4E-05	3.8E-04	3.2E-05
Lower Dam Labyrinth	$0.014	4.2E-04	5.1E-05	3.6E-04	4.0E-05

Note: No change to Middle Dam.

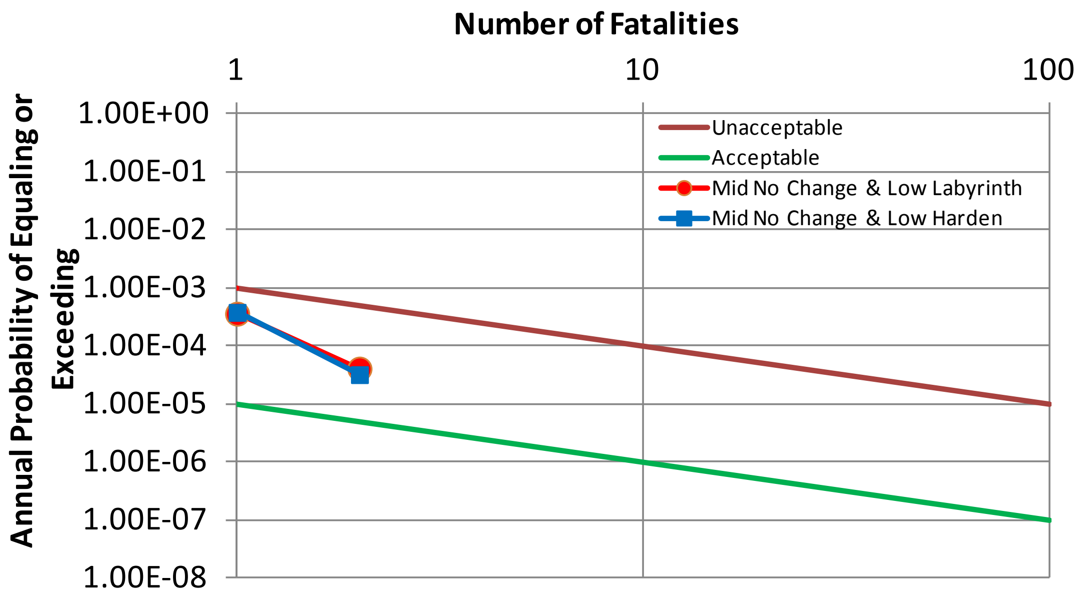


Figure 6-1. Incremental Societal Safety Risks for each Lower Dam Remediation Option (combined over all dam failure scenarios)

Note: See Table 6-1. No change to Middle Dam.

Table 6-2. Incremental Societal Safety Risks for each Lower Dam Remediation Option (by dam failure scenario)

Trigger	Breach Scenario	E[Fatalities] if Scenario	P[Trigger & Middle Dam Breach]	P[Scenario] if Lower Dam Hardened	P[Scenario] if Lower Dam Labyrinth
PMF	Middle Dam only	3.8E-01	9.50E-05	7.98E-05	2.47E-05
	Middle Dam & Lower Dam	1.0E+00		1.52E-05	7.03E-05
1000 yr	Middle Dam only	8.8E-02	1.40E-03	1.20E-03	1.20E-03
	Middle Dam & Lower Dam	2.3E-01		1.96E-04	1.96E-04
100 yr	Middle Dam only	2.5E-02	6.30E-03	5.42E-03	6.30E-03
	Middle Dam & Lower Dam	7.0E-02		8.82E-04	0.00E+00
Seismic	Middle Dam only	8.2E-03	2.40E-04	1.80E-04	1.80E-04
	Middle Dam & Lower Dam	2.2E-02		3.00E-05	6.00E-05
Other*	Middle Dam only	8.2E-03	1.00E-03	1.00E-03	1.00E-03
	Middle Dam & Lower Dam	2.2E-02		1.00E-03	1.00E-03
	*Note: * see below*		E[Fatalities]	4.3E-04	4.2E-04

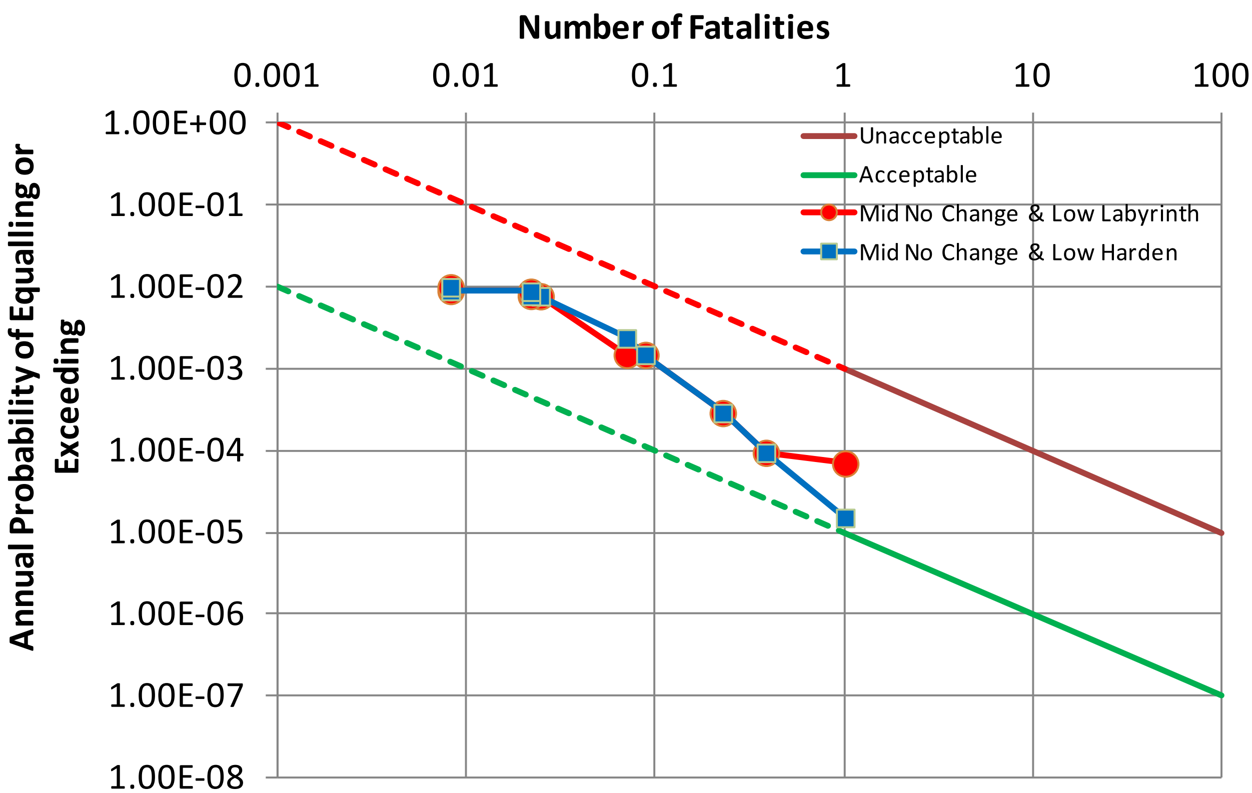


Figure 6-2. Incremental Societal Safety Risks for each Lower Dam Remediation Option (by dam failure scenario)

Note: See Table 6-2. No change to Middle Dam. Expected number of fatalities and annual probability of exceedance are shown for each failure scenario; expected number of fatalities of <1 are shown, even though the criteria (CDA, 2013) do not extend below one fatality.

Table 6-3. Expected Number of Fatalities (by Failure Mode) for each Dam Remediation Option

Dam Remediation Option	Conditional Expected Number of Fatalities				
	PMF	**1000 yr**	**100 yr**	**Seismic**	**Other**
Lower Dam Hardening	4.83E-01	1.08E-01	3.10E-02	1.16E-02	3.01E-05
Lower Dam Labyrinth	8.45E-01	1.08E-01	2.46E-02	1.160E-02	3.01E-05

Note: No change to Middle Dam.

7.0 CLOSURE

We trust that the contents of the report meet with your current requirements. Should you have questions or need clarification of contents, please do not hesitate to contact the undersigned.

GOLDER ASSOCIATES LTD.

Reviewed by:

ORIGINAL SIGNED

ORIGINAL SIGNED

Bill Roberds, Sc.D, MS
Principal, Decision and Risk Analysis

Bruce Downing, P.Eng
Principal, Senior Geotechnical Engineer

BR/BRD/do

Golder, Golder Associates and the GA globe design are trademarks of Golder Associates Corporation.

o:\final\2013\1447\13-1447-0516\1314470516-006-r-rev0\1314470516-006-r-rev0 con colliery dams risk assessment 25jul_14.docx

8.0 REFERENCES

Associated Engineering Ltd, 2012. Chase River Dam Breach Flood Inundation Study, September, 2012.

Associated Engineering Ltd, 2014. Design memo on Dam Breach Modelling – Chase River, July, 2014.

CDA, 2013. Dam Safety Guidelines.

EBA, Engineering Consultants, Ltd. 2010. “Seismic Hazard Assessment Middle and lower Chase Dams”

Feinberg, B., T. Heinzer, and D. Williams. Using the Life Safety Model to Estimate Life Loss from Dam Failure in Urbanized Areas, US Bureau of Reclamation.

Golder Associates Ltd. 2014a. Report on “Colliery Dams – Hydraulics, Hydrology and Dam Breach Analysis”, July 2014.

Golder Associates Ltd. 2014b. Report on “Colliery Dams– Dam Stability”, July 2014.

Jongejan et al, 2010.

USBR, 2014. “USBR Consequence Estimating Methodology”.

IMPORTANT INFORMATION AND LIMITATIONS OF THIS REPORT

Standard of Care: Golder Associates Ltd. (Golder) has prepared this report in a manner consistent with that level of care and skill ordinarily exercised by members of the engineering and science professions currently practising under similar conditions in the jurisdiction in which the services are provided, subject to the time limits and physical constraints applicable to this report. No other warranty, expressed or implied is made.

Basis and Use of the Report: This report has been prepared for the specific site, design objective, development and purpose described to Golder by the Client. The factual data, interpretations and recommendations pertain to a specific project as described in this report and are not applicable to any other project or site location. Any change of site conditions, purpose, development plans or if the project is not initiated within eighteen months of the date of the report may alter the validity of the report. Golder cannot be responsible for use of this report, or portions thereof, unless Golder is requested to review and, if necessary, revise the report.

The information, recommendations and opinions expressed in this report are for the sole benefit of the Client. No other party may use or rely on this report or any portion thereof without Golder's express written consent. If the report was prepared to be included for a specific permit application process, then upon the reasonable request of the client, Golder may authorize in writing the use of this report by the regulatory agency as an Approved User for the specific and identified purpose of the applicable permit review process. Any other use of this report by others is prohibited and is without responsibility to Golder. The report, all plans, data, drawings and other documents as well as all electronic media prepared by Golder are considered its professional work product and shall remain the copyright property of Golder, who authorizes only the Client and Approved Users to make copies of the report, but only in such quantities as are reasonably necessary for the use of the report by those parties. The Client and Approved Users may not give, lend, sell, or otherwise make available the report or any portion thereof to any other party without the express written permission of Golder. The Client acknowledges that electronic media is susceptible to unauthorized modification, deterioration and incompatibility and therefore the Client cannot rely upon the electronic media versions of Golder's report or other work products.

The report is of a summary nature and is not intended to stand alone without reference to the instructions given to Golder by the Client, communications between Golder and the Client, and to any other reports prepared by Golder for the Client relative to the specific site described in the report. In order to properly understand the suggestions, recommendations and opinions expressed in this report, reference must be made to the whole of the report. Golder cannot be responsible for use of portions of the report without reference to the entire report.

Unless otherwise stated, the suggestions, recommendations and opinions given in this report are intended only for the guidance of the Client in the design of the specific project. The extent and detail of investigations, including the number of test holes, necessary to determine all of the relevant conditions which may affect construction costs would normally be greater than has been carried out for design purposes. Contractors bidding on, or undertaking the work, should rely on their own investigations, as well as their own interpretations of the factual data presented in the report, as to how subsurface conditions may affect their work, including but not limited to proposed construction techniques, schedule, safety and equipment capabilities.

Soil, Rock and Groundwater Conditions: Classification and identification of soils, rocks, and geologic units have been based on commonly accepted methods employed in the practice of geotechnical engineering and related disciplines. Classification and identification of the type and condition of these materials or units involves judgment, and boundaries between different soil, rock or geologic types or units may be transitional rather than abrupt. Accordingly, Golder does not warrant or guarantee the exactness of the descriptions.

Special risks occur whenever engineering or related disciplines are applied to identify subsurface conditions and even a comprehensive investigation, sampling and testing program may fail to detect all or certain subsurface conditions. The environmental, geologic, geotechnical, geochemical and hydrogeologic conditions that Golder interprets to exist between and beyond sampling points may differ from those that actually exist. In addition to soil variability, fill of variable physical and chemical composition can be present over portions of the site or on adjacent properties. **The professional services retained for this project include only the geotechnical aspects of the subsurface conditions at the site, unless otherwise specifically stated and identified in the report.** The presence or implication(s) of possible surface and/or subsurface contamination resulting from previous activities or uses of the site and/or resulting from the introduction onto the site of materials from off-site sources are outside the terms of reference for this project and have not been investigated or addressed.

Soil and groundwater conditions shown in the factual data and described in the report are the observed conditions at the time of their determination or measurement. Unless otherwise noted, those conditions form the basis of the recommendations in the report. Groundwater conditions may vary between and beyond reported locations and can be affected by annual, seasonal and meteorological conditions. The condition of the soil, rock and groundwater may be significantly altered by construction activities (traffic, excavation, groundwater level lowering, pile driving, blasting, etc.) on the site or on adjacent sites. Excavation may expose the soils to changes due to wetting, drying or frost. Unless otherwise indicated the soil must be protected from these changes during construction.

Sample Disposal: Golder will dispose of all uncontaminated soil and/or rock samples 90 days following issue of this report or, upon written request of the Client, will store uncontaminated samples and materials at the Client's expense. In the event that actual contaminated soils, fills or groundwater are encountered or are inferred to be present, all contaminated samples shall remain the property and responsibility of the Client for proper disposal.

Follow-Up and Construction Services: All details of the design were not known at the time of submission of Golder's report. Golder should be retained to review the final design, project plans and documents prior to construction, to confirm that they are consistent with the intent of Golder's report.

During construction, Golder should be retained to perform sufficient and timely observations of encountered conditions to confirm and document that the subsurface conditions do not materially differ from those interpreted conditions considered in the preparation of Golder's report and to confirm and document that construction activities do not adversely affect the suggestions, recommendations and opinions contained in Golder's report. Adequate field review, observation and testing during construction are necessary for Golder to be able to provide letters of assurance, in accordance with the requirements of many regulatory authorities. In cases where this recommendation is not followed, Golder's responsibility is limited to interpreting accurately the information encountered at the borehole locations, at the time of their initial determination or measurement during the preparation of the Report.

Changed Conditions and Drainage: Where conditions encountered at the site differ significantly from those anticipated in this report, either due to natural variability of subsurface conditions or construction activities, it is a condition of this report that Golder be notified of any changes and be provided with an opportunity to review or revise the recommendations within this report. Recognition of changed soil and rock conditions requires experience and it is recommended that Golder be employed to visit the site with sufficient frequency to detect if conditions have changed significantly.

Drainage of subsurface water is commonly required either for temporary or permanent installations for the project. Improper design or construction of drainage or dewatering can have serious consequences. Golder takes no responsibility for the effects of drainage unless specifically involved in the detailed design and construction monitoring of the systems.

APPENDIX A

Scenario Inundation Results

Appendix A – Scenario Inundation Results

For each scenario:

- Hydrograph(s) at key places (see AE 2014)
- Downstream zone map (see AE 2014, Figure 11)
- Downstream inundation map(s) (see AE 2014, Figures 1 to 10)
- Downstream inundation table – Tables A-1 – A-13 (below)

Table A-1. Inundation for Dam Failure Scenario 1
Note: Spatial average of temporal max depth and velocity within each zone (AE, 2014)

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
0	0.00	0.00	0.00
1	0.42	0.15	0.06
2	0.30	0.12	0.04
3	0.27	0.10	0.03
4	0.00	0.00	0.00
5	0.07	0.10	0.01
6	0.13	0.10	0.01
7	0.00	0.00	0.00
8	0.00	0.00	0.00
9	0.00	0.00	0.00
10	0.00	0.00	0.00
11	0.00	0.00	0.00
12	0.00	0.00	0.00
13	0.00	0.00	0.00
14	0.00	0.00	0.00
15	0.00	0.10	0.00
16	0.00	0.00	0.00
17	0.29	0.10	0.03
18	0.13	0.10	0.01
19	0.00	0.00	0.00
20	0.00	0.00	0.00
21	0.00	0.00	0.00
22	0.00	0.00	0.00
23	0.00	0.00	0.00
24	0.00	0.00	0.00
25	0.00	0.00	0.00
26	0.00	0.00	0.00
27	0.03	0.10	0.00
28	0.00	0.10	0.00
29	0.00	0.00	0.00
30	0.00	0.00	0.00
31	0.00	0.00	0.00
32	0.00	0.25	0.00
33	0.21	0.10	0.02
34	0.00	0.00	0.00

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
35	0.00	0.00	0.00
36	0.00	0.00	0.00
37	0.00	0.00	0.00
38	0.00	0.00	0.00
39	0.00	0.00	0.00
40	0.00	0.00	0.00
41	0.00	0.00	0.00
42	0.00	0.00	0.00
43	0.00	0.00	0.00
44	0.00	0.00	0.00
45	0.00	0.00	0.00
46	0.00	0.00	0.00
47	0.00	0.00	0.00
48	0.00	0.00	0.00
49	0.00	0.00	0.00
50	0.00	0.00	0.00
51	0.00	0.00	0.00
52	0.00	0.00	0.00
53	0.00	0.00	0.00
54	0.00	0.00	0.00
55	0.00	0.00	0.00
56	0.00	0.00	0.00
57	0.00	0.00	0.00
58	0.29	0.10	0.03
59	0.00	0.10	0.00
60	0.00	0.00	0.00
61	0.00	0.00	0.00
62	0.00	0.00	0.00
63	0.13	0.10	0.01
64	0.31	0.10	0.03
65	0.26	0.10	0.03
66	0.00	0.00	0.00
67	0.15	0.10	0.02
68	0.10	0.10	0.01
69	0.00	0.00	0.00
70	0.00	0.00	0.00
71	0.00	0.00	0.00

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
72	0.00	0.00	0.00
73	0.00	0.00	0.00
74	0.00	0.00	0.00
75	0.00	0.00	0.00
76	0.00	0.00	0.00
77	0.00	0.00	0.00
78	0.00	0.00	0.00
79	0.00	0.00	0.00
80	0.00	0.00	0.00
81	0.00	0.00	0.00
82	0.20	0.10	0.02
83	0.02	0.10	0.00
84	0.00	0.00	0.00
85	0.00	0.00	0.00
86	0.00	0.00	0.00
87	0.00	0.00	0.00
88	0.00	0.00	0.00
89	0.00	0.00	0.00
90	0.00	0.00	0.00
91	0.00	0.00	0.00
92	0.00	0.00	0.00
93	0.00	0.00	0.00
94	0.00	0.00	0.00
1001	0.00	0.00	0.00
1002	0.00	0.00	0.00
1003	0.00	0.00	0.00
1004	0.00	0.00	0.00
1005	0.00	0.00	0.00
1006	0.00	0.00	0.00
1007	0.00	0.00	0.00
1008	0.00	0.00	0.00
1009	0.00	0.00	0.00
1010	0.00	0.00	0.00
1011	0.00	0.00	0.00
1012	0.00	0.00	0.00
1013	0.00	0.00	0.00
1014	0.00	0.00	0.00

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
1015	0.00	0.00	0.00
1016	0.00	0.00	0.00
1017	0.00	0.00	0.00
1018	0.00	0.00	0.00
1019	0.00	0.00	0.00
1020	0.00	0.00	0.00
1021	0.00	0.00	0.00
1022	0.00	0.00	0.00
1023	0.00	0.00	0.00
1024	0.00	0.00	0.00
1025	0.00	0.00	0.00
1026	0.00	0.00	0.00
1027	0.00	0.00	0.00
1028	0.00	0.00	0.00
1029	0.00	0.00	0.00
1030	0.00	0.00	0.00
1031	0.00	0.00	0.00
1032	0.00	0.00	0.00
1033	0.00	0.00	0.00
1034	0.00	0.00	0.00
1035	0.00	0.00	0.00
1036	0.00	0.00	0.00
1037	0.00	0.00	0.00
1038	0.00	0.00	0.00
1039	0.00	0.00	0.00
1040	0.00	0.00	0.00
1041	0.00	0.00	0.00
1042	0.00	0.00	0.00
1043	0.00	0.00	0.00
1044	0.00	0.00	0.00
1045	0.00	0.00	0.00
1046	0.00	0.00	0.00
1047	0.00	0.00	0.00
1048	0.00	0.00	0.00
1049	0.00	0.00	0.00
1050	0.00	0.00	0.00
1051	0.00	0.00	0.00

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
1052	0.00	0.00	0.00
1053	0.00	0.00	0.00
1054	0.00	0.00	0.00
1055	0.00	0.00	0.00
1056	0.00	0.00	0.00
1057	0.00	0.00	0.00
1058	0.00	0.00	0.00
1059	0.00	0.00	0.00
1060	0.00	0.00	0.00
1061	0.00	0.00	0.00
1062	0.00	0.00	0.00
1063	0.00	0.00	0.00
1064	0.00	0.00	0.00
1065	0.00	0.00	0.00
1066	0.00	0.00	0.00
1067	0.00	0.00	0.00
1068	0.00	0.00	0.00
1069	0.00	0.00	0.00
1070	0.00	0.00	0.00
1071	0.00	0.00	0.00
1072	0.00	0.00	0.00
1073	0.00	0.00	0.00
1074	0.00	0.00	0.00
1075	0.00	0.00	0.00
1076	0.00	0.00	0.00
1077	0.00	0.00	0.00
1078	0.00	0.00	0.00
1079	0.00	0.00	0.00
1080	0.00	0.00	0.00
	0.42	**0.25**	**0.06**
	Max D	Max V	Max DxV

Table A-2. Inundation for Dam Failure Scenario 3
Note: Spatial average of temporal max depth and velocity within each zone (AE, 2014)

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
0	0.00	2.00	0.00
1	2.15	0.46	0.98
2	1.37	0.48	0.66
3	1.86	0.43	0.80
4	0.30	0.10	0.03
5	0.55	0.12	0.07
6	0.00	0.24	0.00
7	0.63	0.19	0.12
8	0.05	0.10	0.01
9	0.00	0.00	0.00
10	0.12	0.10	0.01
11	0.26	0.10	0.03
12	0.51	0.22	0.11
13	0.68	0.31	0.21
14	0.83	0.28	0.23
15	0.90	0.10	0.09
16	0.00	0.00	0.00
17	0.96	0.17	0.16
18	0.34	0.10	0.03
19	0.34	0.10	0.03
20	0.04	0.10	0.00
21	0.02	0.10	0.00
22	0.03	0.10	0.00
23	0.18	0.10	0.02
24	0.19	0.12	0.02
25	0.33	0.20	0.07
26	0.77	0.26	0.20
27	1.08	0.27	0.29
28	0.85	0.18	0.15
29	0.33	0.16	0.06
30	0.00	0.10	0.00
31	0.00	0.10	0.00
32	1.20	0.65	0.78
33	1.33	0.37	0.49
34	0.11	0.10	0.01

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
35	0.02	0.10	0.00
36	0.01	0.10	0.00
37	0.04	0.10	0.00
38	0.04	0.10	0.00
39	0.15	0.10	0.01
40	0.11	0.10	0.01
41	0.19	0.11	0.02
42	0.33	0.10	0.03
43	0.21	0.10	0.02
44	0.24	0.10	0.02
45	0.00	0.10	0.00
46	0.17	0.10	0.02
47	0.38	0.10	0.04
48	0.51	0.10	0.05
49	0.83	0.24	0.20
50	0.99	0.35	0.35
51	0.61	0.12	0.07
52	0.30	0.10	0.03
53	0.02	0.10	0.00
54	0.03	0.10	0.00
55	0.01	0.10	0.00
56	0.06	0.10	0.01
57	0.76	0.10	0.08
58	0.95	0.10	0.09
59	1.55	0.10	0.15
60	1.43	0.10	0.14
61	0.15	0.10	0.01
62	0.00	0.10	0.00
63	3.34	0.17	0.57
64	3.30	0.13	0.42
65	2.95	0.10	0.29
66	1.79	0.10	0.18
67	2.62	0.12	0.31
68	2.08	0.10	0.21
69	0.00	0.00	0.00
70	0.00	0.00	0.00
71	0.73	0.10	0.07

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
72	0.00	0.00	0.00
73	0.37	0.10	0.04
74	0.77	0.10	0.08
75	0.31	0.10	0.03
76	0.03	0.10	0.00
77	0.02	0.10	0.00
78	0.04	0.10	0.00
79	0.11	0.10	0.01
80	0.99	0.10	0.10
81	0.00	0.10	0.00
82	3.71	0.10	0.39
83	2.96	0.19	0.55
84	0.63	0.12	0.08
85	0.15	0.10	0.02
86	0.07	0.10	0.01
87	0.16	0.10	0.02
88	0.44	0.10	0.04
89	0.24	0.10	0.02
90	0.33	0.10	0.03
91	0.34	0.10	0.03
92	0.18	0.10	0.02
93	0.28	0.10	0.03
94	0.15	0.10	0.01
1001	0.00	0.00	0.00
1002	0.00	0.00	0.00
1003	0.00	0.00	0.00
1004	0.00	0.00	0.00
1005	0.00	0.00	0.00
1006	0.00	0.00	0.00
1007	0.00	0.00	0.00
1008	0.00	0.00	0.00
1009	0.00	0.00	0.00
1010	0.00	0.00	0.00
1011	0.00	0.00	0.00
1012	0.00	0.00	0.00
1013	0.00	0.00	0.00
1014	0.00	0.00	0.00

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
1015	0.00	0.00	0.00
1016	0.00	0.00	0.00
1017	0.00	0.00	0.00
1018	0.00	0.00	0.00
1019	0.00	0.00	0.00
1020	0.00	0.00	0.00
1021	0.00	0.00	0.00
1022	0.00	0.00	0.00
1023	0.00	0.00	0.00
1024	0.00	0.00	0.00
1025	0.00	0.00	0.00
1026	0.00	0.00	0.00
1027	0.00	0.00	0.00
1028	0.00	0.00	0.00
1029	0.00	0.00	0.00
1030	0.00	0.00	0.00
1031	0.00	0.00	0.00
1032	0.00	0.00	0.00
1033	0.00	0.00	0.00
1034	0.00	0.00	0.00
1035	0.00	0.00	0.00
1036	0.00	0.00	0.00
1037	0.00	0.00	0.00
1038	0.00	0.00	0.00
1039	0.00	0.00	0.00
1040	0.00	0.00	0.00
1041	0.00	0.00	0.00
1042	0.00	0.00	0.00
1043	0.00	0.00	0.00
1044	0.00	0.00	0.00
1045	0.00	0.00	0.00
1046	0.00	0.00	0.00
1047	0.00	0.00	0.00
1048	0.00	0.00	0.00
1049	0.00	0.00	0.00
1050	0.00	0.00	0.00
1051	0.00	0.00	0.00

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
1052	0.00	0.00	0.00
1053	0.00	0.00	0.00
1054	0.00	0.00	0.00
1055	0.00	0.00	0.00
1056	0.00	0.00	0.00
1057	0.00	0.00	0.00
1058	0.00	0.00	0.00
1059	0.00	0.00	0.00
1060	0.00	0.00	0.00
1061	0.00	0.00	0.00
1062	0.00	0.00	0.00
1063	0.00	0.00	0.00
1064	0.00	0.00	0.00
1065	0.00	0.00	0.00
1066	0.00	0.00	0.00
1067	0.00	0.00	0.00
1068	0.00	0.00	0.00
1069	0.00	0.00	0.00
1070	0.00	0.00	0.00
1071	0.00	0.00	0.00
1072	0.00	0.00	0.00
1073	0.00	0.00	0.00
1074	0.00	0.00	0.00
1075	0.00	0.00	0.00
1076	0.00	0.00	0.00
1077	0.00	0.00	0.00
1078	0.00	0.00	0.00
1079	0.00	0.00	0.00
1080	0.00	0.00	0.00
	3.71	**2.00**	**0.98**
	Max D	Max V	Max DxV

Table A-3. Inundation for Dam Failure Scenario 4
Note: Spatial average of temporal max depth and velocity within each zone (AE, 2014)

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
0	0.00	0.00	0.00
1	1.69	0.34	0.58
2	1.18	0.44	0.52
3	1.50	0.33	0.49
4	0.89	0.10	0.09
5	0.26	0.10	0.03
6	0.00	0.20	0.00
7	0.65	0.17	0.11
8	0.00	0.00	0.00
9	0.00	0.00	0.00
10	0.00	0.00	0.00
11	0.04	0.10	0.00
12	0.20	0.10	0.02
13	0.33	0.19	0.06
14	0.43	0.17	0.08
15	0.51	0.10	0.05
16	0.00	0.00	0.00
17	0.75	0.12	0.09
18	0.27	0.10	0.03
19	0.18	0.10	0.02
20	0.03	0.10	0.00
21	0.00	0.00	0.00
22	0.00	0.00	0.00
23	0.03	0.10	0.00
24	0.05	0.10	0.00
25	0.14	0.11	0.01
26	0.35	0.14	0.05
27	0.65	0.18	0.12
28	0.45	0.11	0.05
29	0.16	0.10	0.02
30	0.00	0.10	0.00
31	0.00	0.10	0.00
32	0.84	0.47	0.39
33	0.88	0.23	0.21
34	0.00	0.00	0.00

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
35	0.00	0.00	0.00
36	0.00	0.00	0.00
37	0.00	0.00	0.00
38	0.00	0.00	0.00
39	0.03	0.10	0.00
40	0.03	0.10	0.00
41	0.02	0.10	0.00
42	0.17	0.10	0.02
43	0.00	0.10	0.00
44	0.01	0.10	0.00
45	0.00	0.10	0.00
46	0.10	0.10	0.01
47	0.20	0.10	0.02
48	0.27	0.10	0.03
49	0.51	0.15	0.08
50	0.60	0.22	0.13
51	0.36	0.10	0.04
52	0.18	0.10	0.02
53	0.00	0.00	0.00
54	0.00	0.00	0.00
55	0.00	0.00	0.00
56	0.00	0.00	0.00
57	0.33	0.10	0.03
58	0.30	0.10	0.03
59	0.74	0.10	0.07
60	0.60	0.10	0.06
61	0.00	0.00	0.00
62	0.00	0.00	0.00
63	2.42	0.11	0.27
64	2.34	0.10	0.23
65	2.01	0.10	0.20
66	0.88	0.10	0.09
67	1.70	0.10	0.17
68	1.49	0.10	0.15
69	0.00	0.00	0.00
70	0.00	0.00	0.00
71	0.73	0.10	0.07

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
72	0.00	0.00	0.00
73	0.30	0.10	0.03
74	0.48	0.10	0.05
75	0.23	0.10	0.02
76	0.00	0.00	0.00
77	0.00	0.00	0.00
78	0.00	0.00	0.00
79	0.00	0.00	0.00
80	0.00	0.00	0.00
81	0.00	0.00	0.00
82	2.88	0.10	0.29
83	2.07	0.14	0.28
84	0.55	0.10	0.05
85	0.00	0.00	0.00
86	0.00	0.00	0.00
87	0.00	0.00	0.00
88	0.00	0.00	0.00
89	0.00	0.00	0.00
90	0.00	0.00	0.00
91	0.00	0.00	0.00
92	0.00	0.00	0.00
93	0.00	0.00	0.00
94	0.00	0.00	0.00
1001	0.00	0.00	0.00
1002	0.00	0.00	0.00
1003	0.00	0.00	0.00
1004	0.00	0.00	0.00
1005	0.00	0.00	0.00
1006	0.00	0.00	0.00
1007	0.00	0.00	0.00
1008	0.00	0.00	0.00
1009	0.00	0.00	0.00
1010	0.00	0.00	0.00
1011	0.00	0.00	0.00
1012	0.00	0.00	0.00
1013	0.00	0.00	0.00
1014	0.00	0.00	0.00

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
1015	0.00	0.00	0.00
1016	0.00	0.00	0.00
1017	0.00	0.00	0.00
1018	0.00	0.00	0.00
1019	0.00	0.00	0.00
1020	0.00	0.00	0.00
1021	0.00	0.00	0.00
1022	0.00	0.00	0.00
1023	0.00	0.00	0.00
1024	0.00	0.00	0.00
1025	0.00	0.00	0.00
1026	0.00	0.00	0.00
1027	0.00	0.00	0.00
1028	0.00	0.00	0.00
1029	0.00	0.00	0.00
1030	0.00	0.00	0.00
1031	0.00	0.00	0.00
1032	0.00	0.00	0.00
1033	0.00	0.00	0.00
1034	0.00	0.00	0.00
1035	0.00	0.00	0.00
1036	0.00	0.00	0.00
1037	0.00	0.00	0.00
1038	0.00	0.00	0.00
1039	0.00	0.00	0.00
1040	0.00	0.00	0.00
1041	0.00	0.00	0.00
1042	0.00	0.00	0.00
1043	0.00	0.00	0.00
1044	0.00	0.00	0.00
1045	0.00	0.00	0.00
1046	0.00	0.00	0.00
1047	0.00	0.00	0.00
1048	0.00	0.00	0.00
1049	0.00	0.00	0.00
1050	0.00	0.00	0.00
1051	0.00	0.00	0.00

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
1052	0.00	0.00	0.00
1053	0.00	0.00	0.00
1054	0.00	0.00	0.00
1055	0.00	0.00	0.00
1056	0.00	0.00	0.00
1057	0.00	0.00	0.00
1058	0.00	0.00	0.00
1059	0.00	0.00	0.00
1060	0.00	0.00	0.00
1061	0.00	0.00	0.00
1062	0.00	0.00	0.00
1063	0.00	0.00	0.00
1064	0.00	0.00	0.00
1065	0.00	0.00	0.00
1066	0.00	0.00	0.00
1067	0.00	0.00	0.00
1068	0.00	0.00	0.00
1069	0.00	0.00	0.00
1070	0.00	0.00	0.00
1071	0.00	0.00	0.00
1072	0.00	0.00	0.00
1073	0.00	0.00	0.00
1074	0.00	0.00	0.00
1075	0.00	0.00	0.00
1076	0.00	0.00	0.00
1077	0.00	0.00	0.00
1078	0.00	0.00	0.00
1079	0.00	0.00	0.00
1080	0.00	0.00	0.00
	2.88	**0.47**	**0.58**
	Max D	Max V	Max DxV

Table A-4. Inundation for Dam Failure Scenario 5

Note: Spatial average of temporal max depth and velocity within each zone (AE, 2014)

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
0	0.00	1.70	0.00
1	1.99	0.42	0.83
2	1.25	0.45	0.56
3	1.73	0.39	0.68
4	0.42	0.10	0.04
5	0.42	0.12	0.05
6	0.00	0.22	0.00
7	0.61	0.20	0.12
8	0.02	0.10	0.00
9	0.00	0.00	0.00
10	0.03	0.10	0.00
11	0.11	0.10	0.01
12	0.33	0.16	0.05
13	0.49	0.26	0.13
14	0.61	0.24	0.15
15	0.63	0.10	0.06
16	0.00	0.00	0.00
17	0.78	0.14	0.11
18	0.13	0.10	0.01
19	0.25	0.10	0.02
20	0.04	0.10	0.00
21	0.00	0.00	0.00
22	0.01	0.10	0.00
23	0.07	0.10	0.01
24	0.08	0.10	0.01
25	0.18	0.14	0.03
26	0.49	0.19	0.09
27	0.81	0.22	0.18
28	0.58	0.13	0.08
29	0.19	0.11	0.02
30	0.00	0.10	0.00
31	0.00	0.10	0.00
32	1.03	0.57	0.59
33	1.12	0.32	0.36
34	0.12	0.10	0.01

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
35	0.00	0.00	0.00
36	0.00	0.00	0.00
37	0.00	0.00	0.00
38	0.03	0.10	0.00
39	0.06	0.10	0.01
40	0.05	0.10	0.01
41	0.05	0.10	0.00
42	0.18	0.10	0.02
43	0.96	0.10	0.10
44	0.94	0.10	0.09
45	1.77	0.10	0.18
46	0.14	0.10	0.01
47	0.24	0.10	0.02
48	0.34	0.10	0.03
49	0.61	0.23	0.14
50	0.79	0.31	0.25
51	0.41	0.11	0.04
52	0.24	0.10	0.02
53	0.00	0.00	0.00
54	0.00	0.00	0.00
55	0.00	0.00	0.00
56	0.04	0.10	0.00
57	0.39	0.10	0.04
58	0.37	0.10	0.04
59	0.72	0.10	0.07
60	0.59	0.10	0.06
61	0.02	0.10	0.00
62	0.01	0.10	0.00
63	2.57	0.12	0.31
64	2.49	0.10	0.25
65	2.16	0.10	0.22
66	1.03	0.10	0.10
67	1.84	0.10	0.18
68	1.56	0.10	0.16
69	0.00	0.00	0.00
70	0.00	0.00	0.00
71	0.85	0.10	0.08

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
72	0.00	0.00	0.00
73	0.30	0.10	0.03
74	0.55	0.11	0.06
75	0.25	0.10	0.02
76	0.00	0.00	0.00
77	0.00	0.00	0.00
78	0.00	0.00	0.00
79	0.00	0.00	0.00
80	0.01	0.10	0.00
81	0.00	0.00	0.00
82	3.01	0.10	0.30
83	2.21	0.15	0.33
84	0.67	0.10	0.07
85	0.00	0.00	0.00
86	0.00	0.00	0.00
87	0.00	0.00	0.00
88	0.00	0.00	0.00
89	0.00	0.00	0.00
90	0.00	0.00	0.00
91	0.00	0.00	0.00
92	0.00	0.00	0.00
93	0.00	0.00	0.00
94	0.00	0.00	0.00
1001	0.00	0.00	0.00
1002	0.00	0.00	0.00
1003	0.00	0.00	0.00
1004	0.00	0.00	0.00
1005	0.00	0.00	0.00
1006	0.00	0.00	0.00
1007	0.00	0.00	0.00
1008	0.00	0.00	0.00
1009	0.00	0.00	0.00
1010	0.00	0.00	0.00
1011	0.00	0.00	0.00
1012	0.00	0.00	0.00
1013	0.00	0.00	0.00
1014	0.00	0.00	0.00

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
1015	0.00	0.00	0.00
1016	0.00	0.00	0.00
1017	0.00	0.00	0.00
1018	0.00	0.00	0.00
1019	0.00	0.00	0.00
1020	0.00	0.00	0.00
1021	0.00	0.00	0.00
1022	0.00	0.00	0.00
1023	0.00	0.00	0.00
1024	0.00	0.00	0.00
1025	0.00	0.00	0.00
1026	0.00	0.00	0.00
1027	0.00	0.00	0.00
1028	0.00	0.00	0.00
1029	0.00	0.00	0.00
1030	0.00	0.00	0.00
1031	0.00	0.00	0.00
1032	0.00	0.00	0.00
1033	0.00	0.00	0.00
1034	0.00	0.00	0.00
1035	0.00	0.00	0.00
1036	0.00	0.00	0.00
1037	0.00	0.00	0.00
1038	0.00	0.00	0.00
1039	0.00	0.00	0.00
1040	0.00	0.00	0.00
1041	0.00	0.00	0.00
1042	0.00	0.00	0.00
1043	0.00	0.00	0.00
1044	0.00	0.00	0.00
1045	0.00	0.00	0.00
1046	0.00	0.00	0.00
1047	0.00	0.00	0.00
1048	0.00	0.00	0.00
1049	0.00	0.00	0.00
1050	0.00	0.00	0.00
1051	0.00	0.00	0.00

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
1052	0.00	0.00	0.00
1053	0.00	0.00	0.00
1054	0.00	0.00	0.00
1055	0.00	0.00	0.00
1056	0.00	0.00	0.00
1057	0.00	0.00	0.00
1058	0.00	0.00	0.00
1059	0.00	0.00	0.00
1060	0.00	0.00	0.00
1061	0.00	0.00	0.00
1062	0.00	0.00	0.00
1063	0.00	0.00	0.00
1064	0.00	0.00	0.00
1065	0.00	0.00	0.00
1066	0.00	0.00	0.00
1067	0.00	0.00	0.00
1068	0.00	0.00	0.00
1069	0.00	0.00	0.00
1070	0.00	0.00	0.00
1071	0.00	0.00	0.00
1072	0.00	0.00	0.00
1073	0.00	0.00	0.00
1074	0.00	0.00	0.00
1075	0.00	0.00	0.00
1076	0.00	0.00	0.00
1077	0.00	0.00	0.00
1078	0.00	0.00	0.00
1079	0.00	0.00	0.00
1080	0.00	0.00	0.00
	3.01	**1.70**	**0.83**
	Max D	Max V	Max DxV

Table A-5. Inundation for Dam Failure Scenario 7
Note: Spatial average of temporal max depth and velocity within each zone (AE, 2014)

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
0	0.00	1.70	0.00
1	1.31	0.26	0.34
2	0.95	0.36	0.34
3	1.15	0.24	0.28
4	0.00	0.00	0.00
5	0.18	0.10	0.02
6	0.00	0.18	0.00
7	0.61	0.18	0.11
8	0.00	0.00	0.00
9	0.00	0.00	0.00
10	0.00	0.00	0.00
11	0.00	0.00	0.00
12	0.02	0.10	0.00
13	0.07	0.10	0.01
14	0.10	0.10	0.01
15	0.15	0.10	0.02
16	0.00	0.00	0.00
17	0.68	0.10	0.07
18	0.00	0.10	0.00
19	0.14	0.10	0.01
20	0.06	0.10	0.01
21	0.00	0.00	0.00
22	0.00	0.00	0.00
23	0.00	0.00	0.00
24	0.00	0.00	0.00
25	0.00	0.00	0.00
26	0.11	0.10	0.01
27	0.24	0.10	0.02
28	0.19	0.10	0.02
29	0.19	0.10	0.02
30	0.00	0.10	0.00
31	0.01	0.10	0.00
32	0.45	0.26	0.12
33	0.42	0.11	0.05
34	0.00	0.00	0.00

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
35	0.00	0.00	0.00
36	0.00	0.00	0.00
37	0.00	0.00	0.00
38	0.00	0.00	0.00
39	0.00	0.00	0.00
40	0.00	0.00	0.00
41	0.00	0.00	0.00
42	0.07	0.10	0.01
43	0.00	0.10	0.00
44	0.00	0.10	0.00
45	0.00	0.00	0.00
46	0.00	0.00	0.00
47	0.04	0.10	0.00
48	0.04	0.10	0.00
49	0.11	0.10	0.01
50	0.18	0.10	0.02
51	0.06	0.10	0.01
52	0.01	0.10	0.00
53	0.00	0.00	0.00
54	0.00	0.00	0.00
55	0.00	0.00	0.00
56	0.00	0.00	0.00
57	0.16	0.10	0.02
58	0.00	0.10	0.00
59	0.13	0.10	0.01
60	0.48	0.10	0.05
61	0.00	0.00	0.00
62	0.00	0.00	0.00
63	1.38	0.10	0.14
64	1.40	0.10	0.14
65	1.09	0.10	0.11
66	0.64	0.10	0.06
67	0.77	0.10	0.08
68	0.81	0.10	0.08
69	0.00	0.00	0.00
70	0.00	0.00	0.00
71	0.00	0.00	0.00

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
72	0.00	0.00	0.00
73	0.00	0.00	0.00
74	0.11	0.10	0.01
75	0.00	0.00	0.00
76	0.00	0.00	0.00
77	0.00	0.00	0.00
78	0.00	0.00	0.00
79	0.00	0.00	0.00
80	0.00	0.00	0.00
81	0.00	0.00	0.00
82	1.80	0.10	0.18
83	0.99	0.10	0.10
84	0.00	0.10	0.00
85	0.00	0.00	0.00
86	0.00	0.00	0.00
87	0.00	0.00	0.00
88	0.00	0.00	0.00
89	0.00	0.00	0.00
90	0.00	0.00	0.00
91	0.00	0.00	0.00
92	0.00	0.00	0.00
93	0.00	0.00	0.00
94	0.00	0.00	0.00
1001	0.00	0.00	0.00
1002	0.00	0.00	0.00
1003	0.00	0.00	0.00
1004	0.00	0.00	0.00
1005	0.00	0.00	0.00
1006	0.00	0.00	0.00
1007	0.00	0.00	0.00
1008	0.00	0.00	0.00
1009	0.00	0.00	0.00
1010	0.00	0.00	0.00
1011	0.00	0.00	0.00
1012	0.00	0.00	0.00
1013	0.00	0.00	0.00
1014	0.00	0.00	0.00

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
1015	0.00	0.00	0.00
1016	0.00	0.00	0.00
1017	0.00	0.00	0.00
1018	0.00	0.00	0.00
1019	0.00	0.00	0.00
1020	0.00	0.00	0.00
1021	0.00	0.00	0.00
1022	0.00	0.00	0.00
1023	0.00	0.00	0.00
1024	0.00	0.00	0.00
1025	0.00	0.00	0.00
1026	0.00	0.00	0.00
1027	0.00	0.00	0.00
1028	0.00	0.00	0.00
1029	0.00	0.00	0.00
1030	0.00	0.00	0.00
1031	0.00	0.00	0.00
1032	0.00	0.00	0.00
1033	0.00	0.00	0.00
1034	0.00	0.00	0.00
1035	0.00	0.00	0.00
1036	0.00	0.00	0.00
1037	0.00	0.00	0.00
1038	0.00	0.00	0.00
1039	0.00	0.00	0.00
1040	0.00	0.00	0.00
1041	0.00	0.00	0.00
1042	0.00	0.00	0.00
1043	0.00	0.00	0.00
1044	0.00	0.00	0.00
1045	0.00	0.00	0.00
1046	0.00	0.00	0.00
1047	0.00	0.00	0.00
1048	0.00	0.00	0.00
1049	0.00	0.00	0.00
1050	0.00	0.00	0.00
1051	0.00	0.00	0.00

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
1052	0.00	0.00	0.00
1053	0.00	0.00	0.00
1054	0.00	0.00	0.00
1055	0.00	0.00	0.00
1056	0.00	0.00	0.00
1057	0.00	0.00	0.00
1058	0.00	0.00	0.00
1059	0.00	0.00	0.00
1060	0.00	0.00	0.00
1061	0.00	0.00	0.00
1062	0.00	0.00	0.00
1063	0.00	0.00	0.00
1064	0.00	0.00	0.00
1065	0.00	0.00	0.00
1066	0.00	0.00	0.00
1067	0.00	0.00	0.00
1068	0.00	0.00	0.00
1069	0.00	0.00	0.00
1070	0.00	0.00	0.00
1071	0.00	0.00	0.00
1072	0.00	0.00	0.00
1073	0.00	0.00	0.00
1074	0.00	0.00	0.00
1075	0.00	0.00	0.00
1076	0.00	0.00	0.00
1077	0.00	0.00	0.00
1078	0.00	0.00	0.00
1079	0.00	0.00	0.00
1080	0.00	0.00	0.00
	1.80	**1.70**	**0.34**
	Max D	Max V	Max DxV

Table A-6. Inundation for Dam Failure Scenario 8

Note: Spatial average of temporal max depth and velocity within each zone (AE, 2014)

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
0	0.00	1.70	0.00
1	1.61	0.32	0.51
2	1.13	0.42	0.47
3	1.43	0.31	0.44
4	0.13	0.10	0.01
5	0.23	0.10	0.02
6	0.00	0.19	0.00
7	0.66	0.20	0.13
8	0.00	0.00	0.00
9	0.00	0.00	0.00
10	0.00	0.00	0.00
11	0.03	0.10	0.00
12	0.16	0.10	0.02
13	0.29	0.17	0.05
14	0.37	0.16	0.06
15	0.44	0.10	0.04
16	0.00	0.00	0.00
17	0.71	0.11	0.08
18	0.26	0.10	0.03
19	0.18	0.10	0.02
20	0.03	0.10	0.00
21	0.00	0.00	0.00
22	0.00	0.00	0.00
23	0.02	0.10	0.00
24	0.04	0.10	0.00
25	0.11	0.10	0.01
26	0.29	0.12	0.04
27	0.58	0.16	0.09
28	0.39	0.10	0.04
29	0.13	0.10	0.01
30	0.00	0.10	0.00
31	0.00	0.10	0.00
32	0.79	0.44	0.35
33	0.80	0.21	0.17
34	0.00	0.00	0.00

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
35	0.00	0.00	0.00
36	0.00	0.00	0.00
37	0.00	0.00	0.00
38	0.00	0.00	0.00
39	0.02	0.10	0.00
40	0.02	0.10	0.00
41	0.02	0.10	0.00
42	0.30	0.10	0.03
43	0.00	0.10	0.00
44	0.00	0.10	0.00
45	0.00	0.10	0.00
46	0.09	0.10	0.01
47	0.19	0.10	0.02
48	0.24	0.10	0.02
49	0.45	0.15	0.07
50	0.53	0.21	0.11
51	0.33	0.10	0.03
52	0.19	0.10	0.02
53	0.00	0.00	0.00
54	0.00	0.00	0.00
55	0.00	0.00	0.00
56	0.00	0.00	0.00
57	0.28	0.10	0.03
58	0.31	0.10	0.03
59	0.60	0.10	0.06
60	0.68	0.10	0.07
61	0.00	0.00	0.00
62	0.00	0.00	0.00
63	2.27	0.10	0.23
64	2.19	0.10	0.22
65	1.86	0.10	0.19
66	0.73	0.10	0.07
67	1.55	0.10	0.15
68	1.36	0.10	0.14
69	0.00	0.00	0.00
70	0.00	0.00	0.00
71	0.59	0.10	0.06

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
72	0.00	0.00	0.00
73	0.30	0.10	0.03
74	0.44	0.10	0.04
75	0.20	0.10	0.02
76	0.00	0.00	0.00
77	0.00	0.00	0.00
78	0.00	0.00	0.00
79	0.00	0.00	0.00
80	0.00	0.00	0.00
81	0.00	0.00	0.00
82	2.75	0.10	0.28
83	1.93	0.13	0.25
84	0.42	0.10	0.04
85	0.00	0.00	0.00
86	0.00	0.00	0.00
87	0.00	0.00	0.00
88	0.00	0.00	0.00
89	0.00	0.00	0.00
90	0.00	0.00	0.00
91	0.00	0.00	0.00
92	0.00	0.00	0.00
93	0.00	0.00	0.00
94	0.00	0.00	0.00
1001	0.00	0.00	0.00
1002	0.00	0.00	0.00
1003	0.00	0.00	0.00
1004	0.00	0.00	0.00
1005	0.00	0.00	0.00
1006	0.00	0.00	0.00
1007	0.00	0.00	0.00
1008	0.00	0.00	0.00
1009	0.00	0.00	0.00
1010	0.00	0.00	0.00
1011	0.00	0.00	0.00
1012	0.00	0.00	0.00
1013	0.00	0.00	0.00
1014	0.00	0.00	0.00

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
1015	0.00	0.00	0.00
1016	0.00	0.00	0.00
1017	0.00	0.00	0.00
1018	0.00	0.00	0.00
1019	0.00	0.00	0.00
1020	0.00	0.00	0.00
1021	0.00	0.00	0.00
1022	0.00	0.00	0.00
1023	0.00	0.00	0.00
1024	0.00	0.00	0.00
1025	0.00	0.00	0.00
1026	0.00	0.00	0.00
1027	0.00	0.00	0.00
1028	0.00	0.00	0.00
1029	0.00	0.00	0.00
1030	0.00	0.00	0.00
1031	0.00	0.00	0.00
1032	0.00	0.00	0.00
1033	0.00	0.00	0.00
1034	0.00	0.00	0.00
1035	0.00	0.00	0.00
1036	0.00	0.00	0.00
1037	0.00	0.00	0.00
1038	0.00	0.00	0.00
1039	0.00	0.00	0.00
1040	0.00	0.00	0.00
1041	0.00	0.00	0.00
1042	0.00	0.00	0.00
1043	0.00	0.00	0.00
1044	0.00	0.00	0.00
1045	0.00	0.00	0.00
1046	0.00	0.00	0.00
1047	0.00	0.00	0.00
1048	0.00	0.00	0.00
1049	0.00	0.00	0.00
1050	0.00	0.00	0.00
1051	0.00	0.00	0.00

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
1052	0.00	0.00	0.00
1053	0.00	0.00	0.00
1054	0.00	0.00	0.00
1055	0.00	0.00	0.00
1056	0.00	0.00	0.00
1057	0.00	0.00	0.00
1058	0.00	0.00	0.00
1059	0.00	0.00	0.00
1060	0.00	0.00	0.00
1061	0.00	0.00	0.00
1062	0.00	0.00	0.00
1063	0.00	0.00	0.00
1064	0.00	0.00	0.00
1065	0.00	0.00	0.00
1066	0.00	0.00	0.00
1067	0.00	0.00	0.00
1068	0.00	0.00	0.00
1069	0.00	0.00	0.00
1070	0.00	0.00	0.00
1071	0.00	0.00	0.00
1072	0.00	0.00	0.00
1073	0.00	0.00	0.00
1074	0.00	0.00	0.00
1075	0.00	0.00	0.00
1076	0.00	0.00	0.00
1077	0.00	0.00	0.00
1078	0.00	0.00	0.00
1079	0.00	0.00	0.00
1080	0.00	0.00	0.00
	2.75	**1.70**	**0.51**
	Max D	Max V	Max DxV

Table A-7. Inundation for Dam Failure Scenario 11

Note: Spatial average of temporal max depth and velocity within each zone (AE, 2014)

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
0	0.00	0.00	0.00
1	1.56	0.33	0.51
2	1.09	0.42	0.46
3	1.39	0.30	0.41
4	0.00	0.00	0.00
5	0.20	0.08	0.01
6	0.00	0.19	0.00
7	0.63	0.19	0.12
8	0.00	0.00	0.00
9	0.00	0.00	0.00
10	0.00	0.00	0.00
11	0.02	0.00	0.00
12	0.12	0.07	0.01
13	0.23	0.15	0.03
14	0.30	0.13	0.04
15	0.36	0.03	0.01
16	0.00	0.00	0.00
17	0.68	0.11	0.07
18	0.11	0.02	0.00
19	0.17	0.03	0.01
20	0.03	0.01	0.00
21	0.00	0.00	0.00
22	0.00	0.00	0.00
23	0.00	0.00	0.00
24	0.03	0.01	0.00
25	0.07	0.07	0.00
26	0.21	0.10	0.02
27	0.48	0.14	0.07
28	0.30	0.08	0.02
29	0.09	0.07	0.01
30	0.00	0.05	0.00
31	0.00	0.02	0.00
32	0.73	0.41	0.30
33	0.73	0.20	0.14
34	0.00	0.00	0.00

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
35	0.00	0.00	0.00
36	0.00	0.00	0.00
37	0.00	0.00	0.00
38	0.00	0.00	0.00
39	0.00	0.00	0.00
40	0.00	0.00	0.00
41	0.02	0.00	0.00
42	0.36	0.01	0.01
43	0.00	0.01	0.00
44	0.00	0.00	0.00
45	0.00	0.00	0.00
46	0.06	0.01	0.00
47	0.14	0.01	0.00
48	0.18	0.01	0.00
49	0.37	0.14	0.05
50	0.47	0.19	0.09
51	0.27	0.06	0.01
52	0.22	0.08	0.02
53	0.00	0.00	0.00
54	0.00	0.00	0.00
55	0.00	0.00	0.00
56	0.00	0.00	0.00
57	0.24	0.01	0.00
58	0.22	0.01	0.00
59	0.27	0.04	0.01
60	0.43	0.02	0.01
61	0.00	0.00	0.00
62	0.00	0.00	0.00
63	1.94	0.09	0.17
64	1.86	0.01	0.01
65	1.54	0.01	0.01
66	0.71	0.00	0.00
67	1.22	0.05	0.06
68	1.15	0.04	0.05
69	0.00	0.00	0.00
70	0.00	0.00	0.00
71	0.00	0.00	0.00

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
72	0.00	0.00	0.00
73	0.29	0.05	0.01
74	0.36	0.05	0.02
75	0.09	0.01	0.00
76	0.00	0.00	0.00
77	0.00	0.00	0.00
78	0.00	0.00	0.00
79	0.00	0.00	0.00
80	0.00	0.00	0.00
81	0.00	0.00	0.00
82	2.42	0.07	0.18
83	1.59	0.11	0.18
84	0.24	0.03	0.01
85	0.00	0.00	0.00
86	0.00	0.00	0.00
87	0.00	0.00	0.00
88	0.00	0.00	0.00
89	0.00	0.00	0.00
90	0.00	0.00	0.00
91	0.00	0.00	0.00
92	0.00	0.00	0.00
93	0.00	0.00	0.00
94	0.00	0.00	0.00
1001	0.00	0.00	0.00
1002	0.00	0.00	0.00
1003	0.00	0.00	0.00
1004	0.00	0.00	0.00
1005	0.00	0.00	0.00
1006	0.00	0.00	0.00
1007	0.00	0.00	0.00
1008	0.00	0.00	0.00
1009	0.00	0.00	0.00
1010	0.00	0.00	0.00
1011	0.00	0.00	0.00
1012	0.00	0.00	0.00
1013	0.00	0.00	0.00
1014	0.00	0.00	0.00

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
1015	0.00	0.00	0.00
1016	0.00	0.00	0.00
1017	0.00	0.00	0.00
1018	0.00	0.00	0.00
1019	0.00	0.00	0.00
1020	0.00	0.00	0.00
1021	0.00	0.00	0.00
1022	0.00	0.00	0.00
1023	0.00	0.00	0.00
1024	0.00	0.00	0.00
1025	0.00	0.00	0.00
1026	0.00	0.00	0.00
1027	0.00	0.00	0.00
1028	0.00	0.00	0.00
1029	0.00	0.00	0.00
1030	0.00	0.00	0.00
1031	0.00	0.00	0.00
1032	0.00	0.00	0.00
1033	0.00	0.00	0.00
1034	0.00	0.00	0.00
1035	0.00	0.00	0.00
1036	0.00	0.00	0.00
1037	0.00	0.00	0.00
1038	0.00	0.00	0.00
1039	0.00	0.00	0.00
1040	0.00	0.00	0.00
1041	0.00	0.00	0.00
1042	0.00	0.00	0.00
1043	0.00	0.00	0.00
1044	0.00	0.00	0.00
1045	0.00	0.00	0.00
1046	0.00	0.00	0.00
1047	0.00	0.00	0.00
1048	0.00	0.00	0.00
1049	0.00	0.00	0.00
1050	0.00	0.00	0.00
1051	0.00	0.00	0.00

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
1052	0.00	0.00	0.00
1053	0.00	0.00	0.00
1054	0.00	0.00	0.00
1055	0.00	0.00	0.00
1056	0.00	0.00	0.00
1057	0.00	0.00	0.00
1058	0.00	0.00	0.00
1059	0.00	0.00	0.00
1060	0.00	0.00	0.00
1061	0.00	0.00	0.00
1062	0.00	0.00	0.00
1063	0.00	0.00	0.00
1064	0.00	0.00	0.00
1065	0.00	0.00	0.00
1066	0.00	0.00	0.00
1067	0.00	0.00	0.00
1068	0.00	0.00	0.00
1069	0.00	0.00	0.00
1070	0.00	0.00	0.00
1071	0.00	0.00	0.00
1072	0.00	0.00	0.00
1073	0.00	0.00	0.00
1074	0.00	0.00	0.00
1075	0.00	0.00	0.00
1076	0.00	0.00	0.00
1077	0.00	0.00	0.00
1078	0.00	0.00	0.00
1079	0.00	0.00	0.00
1080	0.00	0.00	0.00
	2.42	**0.42**	**0.51**
	Max D	Max V	Max DxV

Table A-8. Inundation for Dam Failure Scenario 12
Note: Spatial average of temporal max depth and velocity within each zone (AE, 2014)

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
0	0.00	0.00	0.00
1	1.77	0.38	0.68
2	1.23	0.47	0.57
3	1.56	0.35	0.54
4	0.26	0.04	0.01
5	0.29	0.10	0.03
6	2.69	0.20	0.54
7	0.57	0.17	0.10
8	0.00	0.00	0.00
9	0.00	0.00	0.00
10	0.01	0.00	0.00
11	0.06	0.03	0.00
12	0.23	0.12	0.03
13	0.37	0.21	0.08
14	0.48	0.19	0.09
15	0.54	0.04	0.02
16	0.00	0.00	0.00
17	0.80	0.13	0.10
18	0.10	0.02	0.00
19	0.19	0.03	0.01
20	0.03	0.01	0.00
21	0.00	0.00	0.00
22	0.00	0.00	0.00
23	0.04	0.01	0.00
24	0.06	0.05	0.00
25	0.15	0.10	0.02
26	0.40	0.16	0.06
27	0.70	0.19	0.13
28	0.49	0.12	0.06
29	0.18	0.09	0.02
30	0.00	0.05	0.00
31	0.00	0.03	0.00
32	0.89	0.49	0.44
33	0.90	0.25	0.22
34	0.00	0.00	0.00

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
35	0.00	0.00	0.00
36	0.00	0.00	0.00
37	0.00	0.00	0.00
38	0.00	0.00	0.00
39	0.04	0.02	0.00
40	0.04	0.02	0.00
41	0.03	0.04	0.00
42	0.15	0.02	0.00
43	0.00	0.01	0.00
44	0.04	0.00	0.00
45	0.00	0.00	0.00
46	0.11	0.01	0.00
47	0.21	0.02	0.00
48	0.29	0.01	0.00
49	0.54	0.18	0.09
50	0.64	0.24	0.16
51	0.39	0.08	0.03
52	0.19	0.05	0.01
53	0.00	0.00	0.00
54	0.00	0.00	0.00
55	0.00	0.00	0.00
56	0.00	0.00	0.00
57	0.33	0.02	0.01
58	0.29	0.02	0.01
59	0.61	0.04	0.03
60	0.52	0.03	0.02
61	0.00	0.00	0.00
62	0.00	0.00	0.00
63	2.43	0.11	0.27
64	2.36	0.03	0.08
65	2.03	0.02	0.05
66	0.89	0.01	0.01
67	1.71	0.07	0.13
68	1.44	0.06	0.09
69	0.00	0.00	0.00
70	0.00	0.00	0.00
71	0.28	0.01	0.00

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
72	0.00	0.00	0.00
73	0.31	0.04	0.01
74	0.51	0.07	0.04
75	0.25	0.02	0.01
76	0.00	0.00	0.00
77	0.00	0.00	0.00
78	0.00	0.00	0.00
79	0.00	0.00	0.00
80	0.00	0.00	0.00
81	0.00	0.00	0.00
82	2.89	0.09	0.25
83	2.08	0.14	0.28
84	0.56	0.05	0.03
85	0.00	0.00	0.00
86	0.00	0.00	0.00
87	0.00	0.00	0.00
88	0.00	0.00	0.00
89	0.00	0.00	0.00
90	0.00	0.00	0.00
91	0.00	0.00	0.00
92	0.00	0.00	0.00
93	0.00	0.00	0.00
94	0.00	0.00	0.00
1001	0.00	0.00	0.00
1002	0.00	0.00	0.00
1003	0.00	0.00	0.00
1004	0.00	0.00	0.00
1005	0.00	0.00	0.00
1006	0.00	0.00	0.00
1007	0.00	0.00	0.00
1008	0.00	0.00	0.00
1009	0.00	0.00	0.00
1010	0.00	0.00	0.00
1011	0.00	0.00	0.00
1012	0.00	0.00	0.00
1013	0.00	0.00	0.00
1014	0.00	0.00	0.00

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
1015	0.00	0.00	0.00
1016	0.00	0.00	0.00
1017	0.00	0.00	0.00
1018	0.00	0.00	0.00
1019	0.00	0.00	0.00
1020	0.00	0.00	0.00
1021	0.00	0.00	0.00
1022	0.00	0.00	0.00
1023	0.00	0.00	0.00
1024	0.00	0.00	0.00
1025	0.00	0.00	0.00
1026	0.00	0.00	0.00
1027	0.00	0.00	0.00
1028	0.00	0.00	0.00
1029	0.00	0.00	0.00
1030	0.00	0.00	0.00
1031	0.00	0.00	0.00
1032	0.00	0.00	0.00
1033	0.00	0.00	0.00
1034	0.00	0.00	0.00
1035	0.00	0.00	0.00
1036	0.00	0.00	0.00
1037	0.00	0.00	0.00
1038	0.00	0.00	0.00
1039	0.00	0.00	0.00
1040	0.00	0.00	0.00
1041	0.00	0.00	0.00
1042	0.00	0.00	0.00
1043	0.00	0.00	0.00
1044	0.00	0.00	0.00
1045	0.00	0.00	0.00
1046	0.00	0.00	0.00
1047	0.00	0.00	0.00
1048	0.00	0.00	0.00
1049	0.00	0.00	0.00
1050	0.00	0.00	0.00
1051	0.00	0.00	0.00

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
1052	0.00	0.00	0.00
1053	0.00	0.00	0.00
1054	0.00	0.00	0.00
1055	0.00	0.00	0.00
1056	0.00	0.00	0.00
1057	0.00	0.00	0.00
1058	0.00	0.00	0.00
1059	0.00	0.00	0.00
1060	0.00	0.00	0.00
1061	0.00	0.00	0.00
1062	0.00	0.00	0.00
1063	0.00	0.00	0.00
1064	0.00	0.00	0.00
1065	0.00	0.00	0.00
1066	0.00	0.00	0.00
1067	0.00	0.00	0.00
1068	0.00	0.00	0.00
1069	0.00	0.00	0.00
1070	0.00	0.00	0.00
1071	0.00	0.00	0.00
1072	0.00	0.00	0.00
1073	0.00	0.00	0.00
1074	0.00	0.00	0.00
1075	0.00	0.00	0.00
1076	0.00	0.00	0.00
1077	0.00	0.00	0.00
1078	0.00	0.00	0.00
1079	0.00	0.00	0.00
1080	0.00	0.00	0.00
	2.89	**0.49**	**0.68**
	Max D	Max V	Max DxV

Table A-9. Inundation for Dam Failure Scenario 13
Note: Spatial average of temporal max depth and velocity within each zone (AE, 2014)

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
0	0.10	4.60	0.46
1	1.98	0.42	0.83
2	1.27	0.45	0.58
3	1.73	0.39	0.68
4	0.46	0.04	0.02
5	0.44	0.12	0.05
6	2.80	0.21	0.60
7	0.63	0.20	0.12
8	0.03	0.00	0.00
9	0.00	0.00	0.00
10	0.07	0.03	0.00
11	0.17	0.07	0.01
12	0.39	0.18	0.07
13	0.55	0.27	0.15
14	0.69	0.24	0.17
15	0.78	0.06	0.04
16	0.00	0.00	0.00
17	0.83	0.14	0.12
18	0.17	0.04	0.01
19	0.25	0.04	0.01
20	0.03	0.01	0.00
21	0.02	0.00	0.00
22	0.02	0.00	0.00
23	0.14	0.04	0.01
24	0.14	0.10	0.01
25	0.25	0.17	0.04
26	0.64	0.23	0.14
27	0.94	0.24	0.23
28	0.72	0.16	0.11
29	0.27	0.14	0.04
30	0.00	0.05	0.00
31	0.00	0.04	0.00
32	1.07	0.58	0.62
33	1.16	0.32	0.37
34	0.10	0.04	0.00

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
35	0.03	0.00	0.00
36	0.01	0.00	0.00
37	0.03	0.00	0.00
38	0.03	0.01	0.00
39	0.11	0.07	0.01
40	0.09	0.06	0.01
41	0.14	0.09	0.01
42	0.27	0.03	0.01
43	0.18	0.03	0.01
44	0.24	0.00	0.00
45	0.00	0.00	0.00
46	0.14	0.01	0.00
47	0.33	0.02	0.01
48	0.44	0.02	0.01
49	0.73	0.19	0.14
50	0.85	0.30	0.25
51	0.57	0.08	0.05
52	0.28	0.07	0.02
53	0.02	0.00	0.00
54	0.02	0.00	0.00
55	0.00	0.00	0.00
56	0.05	0.02	0.00
57	0.67	0.07	0.05
58	0.81	0.04	0.03
59	1.30	0.05	0.06
60	1.20	0.06	0.07
61	0.11	0.01	0.00
62	1.28	0.09	0.11
63	3.20	0.16	0.52
64	3.15	0.11	0.34
65	2.80	0.06	0.16
66	1.65	0.01	0.02
67	2.49	0.11	0.27
68	1.94	0.09	0.17
69	0.00	0.00	0.00
70	0.00	0.00	0.00
71	0.61	0.01	0.01

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
72	0.00	0.00	0.00
73	0.36	0.03	0.01
74	0.70	0.07	0.05
75	0.31	0.03	0.01
76	0.00	0.00	0.00
77	0.02	0.00	0.00
78	0.03	0.00	0.00
79	0.10	0.00	0.00
80	1.15	0.03	0.04
81	0.00	0.00	0.00
82	3.60	0.10	0.36
83	2.83	0.18	0.50
84	0.99	0.11	0.10
85	0.04	0.00	0.00
86	0.08	0.01	0.00
87	0.29	0.00	0.00
88	0.50	0.00	0.00
89	0.32	0.00	0.00
90	0.36	0.00	0.00
91	0.42	0.00	0.00
92	0.24	0.00	0.00
93	0.36	0.00	0.00
94	0.30	0.01	0.00
1001	0.00	0.00	0.00
1002	0.00	0.00	0.00
1003	0.00	0.00	0.00
1004	0.00	0.00	0.00
1005	0.00	0.00	0.00
1006	0.00	0.00	0.00
1007	0.00	0.00	0.00
1008	0.00	0.00	0.00
1009	0.00	0.00	0.00
1010	0.00	0.00	0.00
1011	0.00	0.00	0.00
1012	0.00	0.00	0.00
1013	0.00	0.00	0.00
1014	0.00	0.00	0.00

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
1015	0.00	0.00	0.00
1016	0.00	0.00	0.00
1017	0.00	0.00	0.00
1018	0.00	0.00	0.00
1019	0.00	0.00	0.00
1020	0.00	0.00	0.00
1021	0.00	0.00	0.00
1022	0.00	0.00	0.00
1023	0.00	0.00	0.00
1024	0.00	0.00	0.00
1025	0.00	0.00	0.00
1026	0.00	0.00	0.00
1027	0.00	0.00	0.00
1028	0.00	0.00	0.00
1029	0.00	0.00	0.00
1030	0.00	0.00	0.00
1031	0.00	0.00	0.00
1032	0.00	0.00	0.00
1033	0.00	0.00	0.00
1034	0.00	0.00	0.00
1035	0.00	0.00	0.00
1036	0.00	0.00	0.00
1037	0.06	0.00	0.00
1038	0.00	0.00	0.00
1039	0.00	0.00	0.00
1040	0.00	0.00	0.00
1041	0.00	0.00	0.00
1042	0.00	0.00	0.00
1043	0.00	0.00	0.00
1044	0.00	0.00	0.00
1045	0.07	0.00	0.00
1046	0.00	0.00	0.00
1047	0.00	0.00	0.00
1048	0.00	0.00	0.00
1049	0.00	0.00	0.00
1050	0.00	0.00	0.00
1051	0.00	0.00	0.00

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
1052	0.00	0.00	0.00
1053	0.00	0.00	0.00
1054	0.00	0.00	0.00
1055	0.00	0.00	0.00
1056	0.00	0.00	0.00
1057	0.00	0.00	0.00
1058	0.00	0.00	0.00
1059	0.00	0.00	0.00
1060	0.00	0.00	0.00
1061	0.00	0.00	0.00
1062	0.00	0.00	0.00
1063	0.00	0.00	0.00
1064	0.00	0.00	0.00
1065	0.00	0.00	0.00
1066	0.00	0.00	0.00
1067	0.00	0.00	0.00
1068	0.00	0.00	0.00
1069	0.00	0.00	0.00
1070	0.00	0.00	0.00
1071	0.00	0.00	0.00
1072	0.00	0.00	0.00
1073	0.00	0.00	0.00
1074	0.00	0.00	0.00
1075	0.00	0.00	0.00
1076	0.00	0.00	0.00
1077	0.00	0.00	0.00
1078	0.00	0.00	0.00
1079	0.00	0.00	0.00
1080	0.00	0.00	0.00
	3.60	**4.60**	**0.83**
	Max D	Max V	Max DxV

Table A-10. Inundation for Dam Failure Scenario 14
Note: Spatial average of temporal max depth and velocity within each zone (AE, 2014)

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
0	1.00	5.00	5.00
1	2.52	0.55	1.39
2	1.06	0.40	0.42
3	2.08	0.50	1.04
4	0.46	0.14	0.07
5	0.72	0.16	0.11
6	3.52	0.33	1.15
7	0.77	0.27	0.20
8	0.09	0.02	0.00
9	0.06	0.04	0.00
10	0.28	0.09	0.02
11	0.48	0.15	0.07
12	0.75	0.30	0.22
13	0.98	0.40	0.39
14	1.16	0.35	0.41
15	1.27	0.09	0.11
16	0.00	0.00	0.00
17	1.30	0.25	0.32
18	0.48	0.11	0.05
19	0.53	0.11	0.06
20	0.06	0.03	0.00
21	0.07	0.02	0.00
22	0.07	0.02	0.00
23	0.34	0.11	0.04
24	0.33	0.19	0.06
25	0.53	0.27	0.14
26	1.13	0.35	0.39
27	1.44	0.33	0.48
28	1.21	0.23	0.28
29	0.64	0.20	0.13
30	0.00	0.07	0.00
31	0.00	0.06	0.00
32	1.46	0.78	1.15
33	1.69	0.48	0.80
34	0.19	0.09	0.02

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
35	0.05	0.02	0.00
36	0.05	0.02	0.00
37	0.09	0.02	0.00
38	0.15	0.05	0.01
39	0.27	0.14	0.04
40	0.20	0.12	0.02
41	0.44	0.16	0.07
42	0.67	0.07	0.05
43	0.41	0.10	0.04
44	0.35	0.02	0.01
45	0.06	0.00	0.00
46	0.25	0.02	0.01
47	0.56	0.05	0.03
48	0.70	0.03	0.02
49	1.08	0.31	0.33
50	1.28	0.45	0.57
51	0.88	0.18	0.16
52	0.40	0.14	0.06
53	0.07	0.02	0.00
54	0.09	0.04	0.00
55	0.06	0.02	0.00
56	0.14	0.07	0.01
57	1.28	0.12	0.16
58	1.61	0.09	0.14
59	2.10	0.07	0.14
60	2.01	0.13	0.27
61	0.47	0.06	0.03
62	1.68	0.10	0.17
63	4.01	0.22	0.87
64	3.97	0.21	0.84
65	3.62	0.09	0.33
66	2.45	0.03	0.07
67	3.29	0.15	0.49
68	2.35	0.15	0.35
69	0.42	0.01	0.01
70	0.34	0.02	0.01
71	1.04	0.10	0.10

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
72	0.06	0.00	0.00
73	0.50	0.07	0.03
74	1.00	0.14	0.14
75	0.44	0.07	0.03
76	0.07	0.04	0.00
77	0.09	0.03	0.00
78	0.06	0.02	0.00
79	0.29	0.02	0.01
80	1.53	0.05	0.08
81	0.67	0.00	0.00
82	4.39	0.15	0.64
83	3.63	0.21	0.77
84	1.27	0.20	0.26
85	0.35	0.02	0.01
86	0.20	0.04	0.01
87	0.21	0.03	0.01
88	0.79	0.01	0.01
89	0.93	0.00	0.00
90	0.63	0.01	0.01
91	0.69	0.02	0.01
92	0.68	0.01	0.01
93	0.59	0.02	0.01
94	0.42	0.04	0.02
1001	0.11	0.10	0.01
1002	0.03	0.01	0.00
1003	0.05	0.03	0.00
1004	0.04	0.02	0.00
1005	0.00	0.00	0.00
1006	0.04	0.01	0.00
1007	0.00	0.00	0.00
1008	0.00	0.00	0.00
1009	0.05	0.02	0.00
1010	0.06	0.03	0.00
1011	0.00	0.00	0.00
1012	0.01	0.00	0.00
1013	0.03	0.00	0.00
1014	0.04	0.02	0.00

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
1015	0.05	0.01	0.00
1016	0.13	0.03	0.00
1017	0.04	0.03	0.00
1018	0.00	0.00	0.00
1019	0.02	0.00	0.00
1020	0.05	0.02	0.00
1021	0.00	0.00	0.00
1022	0.00	0.00	0.00
1023	0.00	0.00	0.00
1024	0.00	0.00	0.00
1025	0.00	0.00	0.00
1026	0.00	0.00	0.00
1027	0.06	0.00	0.00
1028	0.04	0.02	0.00
1029	0.00	0.00	0.00
1030	0.00	0.00	0.00
1031	0.00	0.00	0.00
1032	0.00	0.00	0.00
1033	0.00	0.00	0.00
1034	0.00	0.00	0.00
1035	0.01	0.00	0.00
1036	0.05	0.00	0.00
1037	0.38	0.00	0.00
1038	0.06	0.02	0.00
1039	0.00	0.00	0.00
1040	0.00	0.00	0.00
1041	0.00	0.00	0.00
1042	0.00	0.00	0.00
1043	0.00	0.00	0.00
1044	0.11	0.00	0.00
1045	0.36	0.00	0.00
1046	0.00	0.00	0.00
1047	0.00	0.00	0.00
1048	0.00	0.00	0.00
1049	0.00	0.00	0.00
1050	0.00	0.00	0.00
1051	0.00	0.00	0.00

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
1052	0.00	0.00	0.00
1053	0.19	0.01	0.00
1054	0.20	0.02	0.00
1055	0.00	0.00	0.00
1056	0.00	0.00	0.00
1057	0.00	0.00	0.00
1058	0.00	0.00	0.00
1059	0.00	0.00	0.00
1060	0.17	0.00	0.00
1061	0.27	0.02	0.01
1062	0.20	0.01	0.00
1063	0.00	0.00	0.00
1064	0.00	0.00	0.00
1065	0.00	0.00	0.00
1066	0.00	0.00	0.00
1067	0.00	0.00	0.00
1068	0.00	0.00	0.00
1069	0.00	0.00	0.00
1070	0.19	0.02	0.00
1071	0.06	0.01	0.00
1072	0.00	0.00	0.00
1073	0.00	0.00	0.00
1074	0.00	0.00	0.00
1075	0.00	0.00	0.00
1076	0.00	0.00	0.00
1077	0.18	0.02	0.00
1078	0.00	0.00	0.00
1079	0.00	0.00	0.00
1080	0.00	0.00	0.00
	4.39	**5.00**	**5.00**
	Max D	Max V	Max DxV

Table A-11. Inundation for Dam Failure Scenario 17

Note: Spatial average of temporal max depth and velocity within each zone, interpolated/extrapolated from inundation for other dam failure scenarios (depth from SC12 and SC13, and velocity, which does not have significant effect, from SC1).

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
0	0.00	0.00	0.00
1	1.65	0.15	0.24
2	1.20	0.12	0.14
3	1.46	0.10	0.15
4	0.14	0.00	0.00
5	0.21	0.10	0.02
6	2.63	0.10	0.26
7	0.53	0.00	0.00
8	0.00	0.00	0.00
9	0.00	0.00	0.00
10	0.00	0.00	0.00
11	0.00	0.00	0.00
12	0.13	0.00	0.00
13	0.26	0.00	0.00
14	0.35	0.00	0.00
15	0.41	0.10	0.04
16	0.00	0.00	0.00
17	0.78	0.10	0.08
18	0.06	0.10	0.01
19	0.15	0.00	0.00
20	0.03	0.00	0.00
21	0.00	0.00	0.00
22	0.00	0.00	0.00
23	0.00	0.00	0.00
24	0.01	0.00	0.00
25	0.09	0.00	0.00
26	0.25	0.00	0.00
27	0.55	0.10	0.06
28	0.35	0.10	0.03
29	0.13	0.00	0.00
30	0.00	0.00	0.00
31	0.00	0.00	0.00
32	0.78	0.25	0.19
33	0.75	0.10	0.08
34	0.00	0.00	0.00

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
35	0.00	0.00	0.00
36	0.00	0.00	0.00
37	0.00	0.00	0.00
38	0.00	0.00	0.00
39	0.00	0.00	0.00
40	0.02	0.00	0.00
41	0.00	0.00	0.00
42	0.07	0.00	0.00
43	0.00	0.00	0.00
44	0.00	0.00	0.00
45	0.00	0.00	0.00
46	0.10	0.00	0.00
47	0.14	0.00	0.00
48	0.21	0.00	0.00
49	0.42	0.00	0.00
50	0.52	0.00	0.00
51	0.28	0.00	0.00
52	0.14	0.00	0.00
53	0.00	0.00	0.00
54	0.00	0.00	0.00
55	0.00	0.00	0.00
56	0.00	0.00	0.00
57	0.13	0.00	0.00
58	0.00	0.10	0.00
59	0.21	0.10	0.02
60	0.11	0.00	0.00
61	0.00	0.00	0.00
62	0.00	0.00	0.00
63	1.98	0.10	0.20
64	1.89	0.10	0.19
65	1.57	0.10	0.16
66	0.44	0.00	0.00
67	1.25	0.10	0.13
68	1.14	0.10	0.11
69	0.00	0.00	0.00
70	0.00	0.00	0.00
71	0.08	0.00	0.00

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
72	0.00	0.00	0.00
73	0.28	0.00	0.00
74	0.39	0.00	0.00
75	0.22	0.00	0.00
76	0.00	0.00	0.00
77	0.00	0.00	0.00
78	0.00	0.00	0.00
79	0.00	0.00	0.00
80	0.00	0.00	0.00
81	0.00	0.00	0.00
82	2.48	0.10	0.25
83	1.64	0.10	0.16
84	0.31	0.00	0.00
85	0.00	0.00	0.00
86	0.00	0.00	0.00
87	0.00	0.00	0.00
88	0.00	0.00	0.00
89	0.00	0.00	0.00
90	0.00	0.00	0.00
91	0.00	0.00	0.00
92	0.00	0.00	0.00
93	0.00	0.00	0.00
94	0.00	0.00	0.00
1001	0.00	0.00	0.00
1002	0.00	0.00	0.00
1003	0.00	0.00	0.00
1004	0.00	0.00	0.00
1005	0.00	0.00	0.00
1006	0.00	0.00	0.00
1007	0.00	0.00	0.00
1008	0.00	0.00	0.00
1009	0.00	0.00	0.00
1010	0.00	0.00	0.00
1011	0.00	0.00	0.00
1012	0.00	0.00	0.00
1013	0.00	0.00	0.00
1014	0.00	0.00	0.00

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
1015	0.00	0.00	0.00
1016	0.00	0.00	0.00
1017	0.00	0.00	0.00
1018	0.00	0.00	0.00
1019	0.00	0.00	0.00
1020	0.00	0.00	0.00
1021	0.00	0.00	0.00
1022	0.00	0.00	0.00
1023	0.00	0.00	0.00
1024	0.00	0.00	0.00
1025	0.00	0.00	0.00
1026	0.00	0.00	0.00
1027	0.00	0.00	0.00
1028	0.00	0.00	0.00
1029	0.00	0.00	0.00
1030	0.00	0.00	0.00
1031	0.00	0.00	0.00
1032	0.00	0.00	0.00
1033	0.00	0.00	0.00
1034	0.00	0.00	0.00
1035	0.00	0.00	0.00
1036	0.00	0.00	0.00
1037	0.00	0.00	0.00
1038	0.00	0.00	0.00
1039	0.00	0.00	0.00
1040	0.00	0.00	0.00
1041	0.00	0.00	0.00
1042	0.00	0.00	0.00
1043	0.00	0.00	0.00
1044	0.00	0.00	0.00
1045	0.00	0.00	0.00
1046	0.00	0.00	0.00
1047	0.00	0.00	0.00
1048	0.00	0.00	0.00
1049	0.00	0.00	0.00
1050	0.00	0.00	0.00
1051	0.00	0.00	0.00

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
1052	0.00	0.00	0.00
1053	0.00	0.00	0.00
1054	0.00	0.00	0.00
1055	0.00	0.00	0.00
1056	0.00	0.00	0.00
1057	0.00	0.00	0.00
1058	0.00	0.00	0.00
1059	0.00	0.00	0.00
1060	0.00	0.00	0.00
1061	0.00	0.00	0.00
1062	0.00	0.00	0.00
1063	0.00	0.00	0.00
1064	0.00	0.00	0.00
1065	0.00	0.00	0.00
1066	0.00	0.00	0.00
1067	0.00	0.00	0.00
1068	0.00	0.00	0.00
1069	0.00	0.00	0.00
1070	0.00	0.00	0.00
1071	0.00	0.00	0.00
1072	0.00	0.00	0.00
1073	0.00	0.00	0.00
1074	0.00	0.00	0.00
1075	0.00	0.00	0.00
1076	0.00	0.00	0.00
1077	0.00	0.00	0.00
1078	0.00	0.00	0.00
1079	0.00	0.00	0.00
1080	0.00	0.00	0.00
	2.63	**0.25**	**0.26**
	Max D	Max V	Max DxV

Table A-12. Inundation for Dam Failure Scenario 19

Note: Spatial average of temporal max depth and velocity within each zone, interpolated/extrapolated from inundation for other dam failure scenarios (depth from SC3 and SC4, and velocity, which does not have significant effect, from SC1).

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
0	0.00	0.00	0.00
1	1.84	0.15	0.27
2	1.24	0.12	0.14
3	1.62	0.10	0.16
4	0.89	0.00	0.00
5	0.36	0.10	0.04
6	0.00	0.10	0.00
7	0.65	0.00	0.00
8	0.00	0.00	0.00
9	0.00	0.00	0.00
10	0.00	0.00	0.00
11	0.11	0.00	0.00
12	0.30	0.00	0.00
13	0.45	0.00	0.00
14	0.56	0.00	0.00
15	0.64	0.10	0.06
16	0.00	0.00	0.00
17	0.82	0.10	0.08
18	0.29	0.10	0.03
19	0.23	0.00	0.00
20	0.04	0.00	0.00
21	0.00	0.00	0.00
22	0.00	0.00	0.00
23	0.08	0.00	0.00
24	0.09	0.00	0.00
25	0.20	0.00	0.00
26	0.49	0.00	0.00
27	0.79	0.10	0.08
28	0.58	0.10	0.06
29	0.22	0.00	0.00
30	0.00	0.00	0.00
31	0.00	0.00	0.00
32	0.96	0.25	0.24
33	1.03	0.10	0.10
34	0.00	0.00	0.00

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
35	0.00	0.00	0.00
36	0.00	0.00	0.00
37	0.00	0.00	0.00
38	0.00	0.00	0.00
39	0.07	0.00	0.00
40	0.06	0.00	0.00
41	0.08	0.00	0.00
42	0.22	0.00	0.00
43	0.00	0.00	0.00
44	0.09	0.00	0.00
45	0.00	0.00	0.00
46	0.12	0.00	0.00
47	0.26	0.00	0.00
48	0.35	0.00	0.00
49	0.61	0.00	0.00
50	0.73	0.00	0.00
51	0.45	0.00	0.00
52	0.22	0.00	0.00
53	0.00	0.00	0.00
54	0.00	0.00	0.00
55	0.00	0.00	0.00
56	0.00	0.00	0.00
57	0.47	0.00	0.00
58	0.51	0.10	0.05
59	1.01	0.10	0.10
60	0.87	0.00	0.00
61	0.00	0.00	0.00
62	0.00	0.00	0.00
63	2.73	0.10	0.27
64	2.66	0.10	0.27
65	2.32	0.10	0.23
66	1.18	0.00	0.00
67	2.01	0.10	0.20
68	1.69	0.10	0.17
69	0.00	0.00	0.00
70	0.00	0.00	0.00
71	0.73	0.00	0.00

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
72	0.00	0.00	0.00
73	0.33	0.00	0.00
74	0.58	0.00	0.00
75	0.25	0.00	0.00
76	0.00	0.00	0.00
77	0.00	0.00	0.00
78	0.00	0.00	0.00
79	0.00	0.00	0.00
80	0.33	0.00	0.00
81	0.00	0.00	0.00
82	3.16	0.10	0.32
83	2.37	0.10	0.24
84	0.57	0.00	0.00
85	0.00	0.00	0.00
86	0.00	0.00	0.00
87	0.00	0.00	0.00
88	0.00	0.00	0.00
89	0.00	0.00	0.00
90	0.00	0.00	0.00
91	0.00	0.00	0.00
92	0.00	0.00	0.00
93	0.00	0.00	0.00
94	0.00	0.00	0.00
1001	0.00	0.00	0.00
1002	0.00	0.00	0.00
1003	0.00	0.00	0.00
1004	0.00	0.00	0.00
1005	0.00	0.00	0.00
1006	0.00	0.00	0.00
1007	0.00	0.00	0.00
1008	0.00	0.00	0.00
1009	0.00	0.00	0.00
1010	0.00	0.00	0.00
1011	0.00	0.00	0.00
1012	0.00	0.00	0.00
1013	0.00	0.00	0.00
1014	0.00	0.00	0.00

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
1015	0.00	0.00	0.00
1016	0.00	0.00	0.00
1017	0.00	0.00	0.00
1018	0.00	0.00	0.00
1019	0.00	0.00	0.00
1020	0.00	0.00	0.00
1021	0.00	0.00	0.00
1022	0.00	0.00	0.00
1023	0.00	0.00	0.00
1024	0.00	0.00	0.00
1025	0.00	0.00	0.00
1026	0.00	0.00	0.00
1027	0.00	0.00	0.00
1028	0.00	0.00	0.00
1029	0.00	0.00	0.00
1030	0.00	0.00	0.00
1031	0.00	0.00	0.00
1032	0.00	0.00	0.00
1033	0.00	0.00	0.00
1034	0.00	0.00	0.00
1035	0.00	0.00	0.00
1036	0.00	0.00	0.00
1037	0.00	0.00	0.00
1038	0.00	0.00	0.00
1039	0.00	0.00	0.00
1040	0.00	0.00	0.00
1041	0.00	0.00	0.00
1042	0.00	0.00	0.00
1043	0.00	0.00	0.00
1044	0.00	0.00	0.00
1045	0.00	0.00	0.00
1046	0.00	0.00	0.00
1047	0.00	0.00	0.00
1048	0.00	0.00	0.00
1049	0.00	0.00	0.00
1050	0.00	0.00	0.00
1051	0.00	0.00	0.00

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
1052	0.00	0.00	0.00
1053	0.00	0.00	0.00
1054	0.00	0.00	0.00
1055	0.00	0.00	0.00
1056	0.00	0.00	0.00
1057	0.00	0.00	0.00
1058	0.00	0.00	0.00
1059	0.00	0.00	0.00
1060	0.00	0.00	0.00
1061	0.00	0.00	0.00
1062	0.00	0.00	0.00
1063	0.00	0.00	0.00
1064	0.00	0.00	0.00
1065	0.00	0.00	0.00
1066	0.00	0.00	0.00
1067	0.00	0.00	0.00
1068	0.00	0.00	0.00
1069	0.00	0.00	0.00
1070	0.00	0.00	0.00
1071	0.00	0.00	0.00
1072	0.00	0.00	0.00
1073	0.00	0.00	0.00
1074	0.00	0.00	0.00
1075	0.00	0.00	0.00
1076	0.00	0.00	0.00
1077	0.00	0.00	0.00
1078	0.00	0.00	0.00
1079	0.00	0.00	0.00
1080	0.00	0.00	0.00
	3.16	**0.25**	**0.32**
	Max D	Max V	Max DxV

Table A-13. Inundation for Dam Failure Scenario 20

Note: Spatial average of temporal max depth and velocity within each zone, interpolated/extrapolated from inundation for other dam failure scenarios (depth from SC7 and SC8, and velocity, which does not have significant effect, from SC1).

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
0	0.00	0.00	0.00
1	1.14	0.15	0.17
2	0.85	0.12	0.10
3	0.98	0.10	0.10
4	0.00	0.00	0.00
5	0.15	0.10	0.01
6	0.00	0.10	0.00
7	0.58	0.00	0.00
8	0.00	0.00	0.00
9	0.00	0.00	0.00
10	0.00	0.00	0.00
11	0.00	0.00	0.00
12	0.00	0.00	0.00
13	0.00	0.00	0.00
14	0.00	0.00	0.00
15	0.00	0.10	0.00
16	0.00	0.00	0.00
17	0.66	0.10	0.07
18	0.00	0.10	0.00
19	0.13	0.00	0.00
20	0.08	0.00	0.00
21	0.00	0.00	0.00
22	0.00	0.00	0.00
23	0.00	0.00	0.00
24	0.00	0.00	0.00
25	0.00	0.00	0.00
26	0.00	0.00	0.00
27	0.04	0.10	0.00
28	0.08	0.10	0.01
29	0.23	0.00	0.00
30	0.00	0.00	0.00
31	0.02	0.00	0.00
32	0.25	0.25	0.06
33	0.20	0.10	0.02
34	0.00	0.00	0.00

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
35	0.00	0.00	0.00
36	0.00	0.00	0.00
37	0.00	0.00	0.00
38	0.00	0.00	0.00
39	0.00	0.00	0.00
40	0.00	0.00	0.00
41	0.00	0.00	0.00
42	0.00	0.00	0.00
43	0.00	0.00	0.00
44	0.00	0.00	0.00
45	0.00	0.00	0.00
46	0.00	0.00	0.00
47	0.00	0.00	0.00
48	0.00	0.00	0.00
49	0.00	0.00	0.00
50	0.00	0.00	0.00
51	0.00	0.00	0.00
52	0.00	0.00	0.00
53	0.00	0.00	0.00
54	0.00	0.00	0.00
55	0.00	0.00	0.00
56	0.00	0.00	0.00
57	0.09	0.00	0.00
58	0.00	0.10	0.00
59	0.00	0.10	0.00
60	0.36	0.00	0.00
61	0.00	0.00	0.00
62	0.00	0.00	0.00
63	0.86	0.10	0.09
64	0.93	0.10	0.09
65	0.64	0.10	0.06
66	0.59	0.00	0.00
67	0.31	0.10	0.03
68	0.49	0.10	0.05
69	0.00	0.00	0.00
70	0.00	0.00	0.00
71	0.00	0.00	0.00

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
72	0.00	0.00	0.00
73	0.00	0.00	0.00
74	0.00	0.00	0.00
75	0.00	0.00	0.00
76	0.00	0.00	0.00
77	0.00	0.00	0.00
78	0.00	0.00	0.00
79	0.00	0.00	0.00
80	0.00	0.00	0.00
81	0.00	0.00	0.00
82	1.25	0.10	0.12
83	0.43	0.10	0.04
84	0.00	0.00	0.00
85	0.00	0.00	0.00
86	0.00	0.00	0.00
87	0.00	0.00	0.00
88	0.00	0.00	0.00
89	0.00	0.00	0.00
90	0.00	0.00	0.00
91	0.00	0.00	0.00
92	0.00	0.00	0.00
93	0.00	0.00	0.00
94	0.00	0.00	0.00
1001	0.00	0.00	0.00
1002	0.00	0.00	0.00
1003	0.00	0.00	0.00
1004	0.00	0.00	0.00
1005	0.00	0.00	0.00
1006	0.00	0.00	0.00
1007	0.00	0.00	0.00
1008	0.00	0.00	0.00
1009	0.00	0.00	0.00
1010	0.00	0.00	0.00
1011	0.00	0.00	0.00
1012	0.00	0.00	0.00
1013	0.00	0.00	0.00
1014	0.00	0.00	0.00

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
1015	0.00	0.00	0.00
1016	0.00	0.00	0.00
1017	0.00	0.00	0.00
1018	0.00	0.00	0.00
1019	0.00	0.00	0.00
1020	0.00	0.00	0.00
1021	0.00	0.00	0.00
1022	0.00	0.00	0.00
1023	0.00	0.00	0.00
1024	0.00	0.00	0.00
1025	0.00	0.00	0.00
1026	0.00	0.00	0.00
1027	0.00	0.00	0.00
1028	0.00	0.00	0.00
1029	0.00	0.00	0.00
1030	0.00	0.00	0.00
1031	0.00	0.00	0.00
1032	0.00	0.00	0.00
1033	0.00	0.00	0.00
1034	0.00	0.00	0.00
1035	0.00	0.00	0.00
1036	0.00	0.00	0.00
1037	0.00	0.00	0.00
1038	0.00	0.00	0.00
1039	0.00	0.00	0.00
1040	0.00	0.00	0.00
1041	0.00	0.00	0.00
1042	0.00	0.00	0.00
1043	0.00	0.00	0.00
1044	0.00	0.00	0.00
1045	0.00	0.00	0.00
1046	0.00	0.00	0.00
1047	0.00	0.00	0.00
1048	0.00	0.00	0.00
1049	0.00	0.00	0.00
1050	0.00	0.00	0.00
1051	0.00	0.00	0.00

Zone_ID	Depth, m	Velocity, m/s	DxV, m^2/s
1052	0.00	0.00	0.00
1053	0.00	0.00	0.00
1054	0.00	0.00	0.00
1055	0.00	0.00	0.00
1056	0.00	0.00	0.00
1057	0.00	0.00	0.00
1058	0.00	0.00	0.00
1059	0.00	0.00	0.00
1060	0.00	0.00	0.00
1061	0.00	0.00	0.00
1062	0.00	0.00	0.00
1063	0.00	0.00	0.00
1064	0.00	0.00	0.00
1065	0.00	0.00	0.00
1066	0.00	0.00	0.00
1067	0.00	0.00	0.00
1068	0.00	0.00	0.00
1069	0.00	0.00	0.00
1070	0.00	0.00	0.00
1071	0.00	0.00	0.00
1072	0.00	0.00	0.00
1073	0.00	0.00	0.00
1074	0.00	0.00	0.00
1075	0.00	0.00	0.00
1076	0.00	0.00	0.00
1077	0.00	0.00	0.00
1078	0.00	0.00	0.00
1079	0.00	0.00	0.00
1080	0.00	0.00	0.00
	1.25	**0.25**	**0.17**
	Max D	Max V	Max DxV

APPENDIX B

Downstream Assets

Appendix B – Downstream Assets

List of individual downstream properties and their relevant characteristics (type, day and night populations, improvements and contents values) from AE 2012, combined by “spatial zone” (see Figure 3-1):

Zone_ID	Predominant Land Use	Land Use Comment	Population Day	Population Night	Adjusted Gross Impr.	Contents
0	RESIDENTIAL		4	12	$417,000.00	$208,500.00
1	RESIDENTIAL		4	12	$530,000.00	$265,000.00
2	RESIDENTIAL		0	0	$-	$-
3	RESIDENTIAL		5	15	$632,000.00	$316,000.00
4	RESIDENTIAL		4	12	$524,000.00	$262,000.00
5	School	School and Daycare	533	12	$1,440,000.00	$720,000.00
6	RESIDENTIAL		0	0	$-	$-
7	RESIDENTIAL		8	24	$960,000.00	$480,000.00
8	School soccer field	School soccer field	31	3	$12,396,000.00	$350,000.00
9	School soccer field		0	0	$-	$-
10	RESIDENTIAL		1	3	$100,000.00	$50,000.00
11	RESIDENTIAL		3	9	$415,000.00	$207,500.00
12	RESIDENTIAL		5	15	$575,000.00	$287,500.00
13	RESIDENTIAL		4	12	$530,000.00	$265,000.00
14	RESIDENTIAL		2	6	$243,000.00	$121,500.00
15	RESIDENTIAL		0	0	$-	$-
16	RESIDENTIAL		0	0	$-	$-
17	RESIDENTIAL		10	50	$270,000.00	$135,000.00
18	RESIDENTIAL		10	50	$270,000.00	$135,000.00
19	RESIDENTIAL		10	50	$270,000.00	$135,000.00
20	RESIDENTIAL		15	45	$1,800,000.00	$900,000.00
21	RESIDENTIAL		6	18	$676,000.00	$338,000.00
22	RESIDENTIAL		5	15	$500,000.00	$250,000.00

Zone_ID	Predominant Land Use	Land Use Comment	Population Day	Population Night	Adjusted Gross Impr.	Contents
23	RESIDENTIAL		2	6	$292,000.00	$146,000.00
24	RESIDENTIAL		3	9	$421,000.00	$210,500.00
25	RESIDENTIAL		3	9	$401,000.00	$200,500.00
26	RESIDENTIAL		2	6	$227,000.00	$113,500.00
27	RESIDENTIAL		2	6	$200,000.00	$100,000.00
28	RESIDENTIAL		1	3	$136,000.00	$68,000.00
29	RESIDENTIAL		1	3	$119,000.00	$59,500.00
30	RESIDENTIAL		0	0	$-	$-
31	RESIDENTIAL		0	0	$-	$-
32	RESIDENTIAL	Multifamily	5	20	$200,000.00	$100,000.00
33	RESIDENTIAL	Multifamily	15	60	$600,000.00	$300,000.00
34	RESIDENTIAL		4	12	$602,000.00	$290,500.00
35	RESIDENTIAL		2	6	$200,000.00	$100,000.00
36	RESIDENTIAL	Shared With Commercial Bldg	2	6	$200,000.00	$100,000.00
37	RESIDENTIAL		4	12	$450,000.00	$225,000.00
38	RESIDENTIAL		3	9	$314,000.00	$157,000.00
39	RESIDENTIAL		2	6	$274,000.00	$137,000.00
40	RESIDENTIAL		3	9	$433,000.00	$216,500.00
41	RESIDENTIAL		2	6	$318,000.00	$159,000.00
42	RESIDENTIAL		3	9	$375,000.00	$187,500.00
43	RESIDENTIAL	Mobile Home	3	9	$300,000.00	$150,000.00
44	RESIDENTIAL	Mobile Home	2	6	$220,000.00	$110,000.00
45	RESIDENTIAL		0	0	$-	$-
46	RESIDENTIAL		8	24	$973,000.00	$486,500.00
47	RESIDENTIAL		0	0	$-	$-
48	RESIDENTIAL		2	6	$279,000.00	$139,500.00

Zone_ID	Predominant Land Use	Land Use Comment	Population Day	Population Night	Adjusted Gross Impr.	Contents
49	RESIDENTIAL	Multifamily	10	40	$400,000.00	$200,000.00
50	RESIDENTIAL	Multifamily	10	40	$400,000.00	$200,000.00
51	RESIDENTIAL		7	21	$886,000.00	$443,000.00
52	RESIDENTIAL		6	18	$757,000.00	$378,500.00
53	RESIDENTIAL		5	15	$572,000.00	$286,000.00
54	RESIDENTIAL		2	6	$250,000.00	$125,000.00
55	RESIDENTIAL		2	6	$200,000.00	$100,000.00
56	RESIDENTIAL		3	9	$316,000.00	$158,000.00
57	RESIDENTIAL		1	3	$100,000.00	$50,000.00
58	RESIDENTIAL	Multifamily	20	80	$660,000.00	$330,000.00
59	RESIDENTIAL	Multifamily	20	80	$660,000.00	$330,000.00
60	RESIDENTIAL	Multifamily	15	60	$495,000.00	$247,500.00
61	RESIDENTIAL		3	9	$339,000.00	$169,500.00
62	RESIDENTIAL		0	0	$-	$-
63	RESIDENTIAL		2	6	$215,000.00	$107,500.00
64	RESIDENTIAL		1	3	$128,000.00	$64,000.00
65	RESIDENTIAL		1	3	$238,000.00	$100,000.00
66	RESIDENTIAL		1	3	$100,000.00	$50,000.00
67	RESIDENTIAL		0	0	$-	$-
68	RESIDENTIAL		0	0	$-	$-
69	RESIDENTIAL		1	3	$151,000.00	$75,500.00
70	RESIDENTIAL		0	0	$-	$-
71	RESIDENTIAL	Mobile Home	8	24	$800,000.00	$400,000.00
72	RESIDENTIAL	Mobile Home	4	12	$400,000.00	$200,000.00
73	RESIDENTIAL		10	30	$1,248,000.00	$623,500.00
74	RESIDENTIAL		4	12	$480,000.00	$240,000.00

Zone_ID	Predominant Land Use	Land Use Comment	Population Day	Population Night	Adjusted Gross Impr.	Contents
75	RESIDENTIAL	Multifamily	25	100	$1,050,000.00	$525,000.00
76	RESIDENTIAL		4	12	$507,000.00	$253,500.00
77	RESIDENTIAL		4	12	$557,000.00	$278,500.00
78	RESIDENTIAL		3	9	$381,000.00	$190,500.00
79	RESIDENTIAL		2	6	$200,000.00	$100,000.00
80	RESIDENTIAL		0	0	$-	$-
81	RESIDENTIAL		1	3	$160,000.00	$80,000.00
82	RESIDENTIAL		1	3	$162,000.00	$81,000.00
83	RESIDENTIAL		2	6	$200,000.00	$100,000.00
84	RESIDENTIAL		0	0	$-	$-
85	RESIDENTIAL		1	3	$100,000.00	$50,000.00
86	RESIDENTIAL		5	15	$771,000.00	$355,000.00
87	RESIDENTIAL		2	6	$233,000.00	$116,500.00
88	RESIDENTIAL		0	0	$-	$-
89	RESIDENTIAL		1	3	$133,000.00	$66,500.00
90	RESIDENTIAL		1	3	$126,000.00	$63,000.00
91	RESIDENTIAL		1	3	$199,000.00	$99,500.00
92	RESIDENTIAL		2	6	$276,000.00	$138,000.00
93	RESIDENTIAL		1	3	$152,000.00	$76,000.00
94	RESIDENTIAL		1	3	$275,000.00	$100,000.00
1001	RESIDENTIAL		4	12	$427,000.00	$213,500.00
1002	RESIDENTIAL		2	6	$225,000.00	$112,500.00
1003	Maintenance shed	Maintenance shed	1	3	$100,000.00	$50,000.00
1004	RESIDENTIAL		0	0	$-	$-
1005	RESIDENTIAL		0	0	$-	$-
1006	RESIDENTIAL		0	0	$-	$-

Zone_ID	Predominant Land Use	Land Use Comment	Population Day	Population Night	Adjusted Gross Impr.	Contents
1007	RESIDENTIAL		2	6	$263,000.00	$131,500.00
1008	RESIDENTIAL		7	21	$890,000.00	$445,000.00
1009	RESIDENTIAL		4	12	$471,000.00	$235,500.00
1010	RESIDENTIAL		3	9	$400,000.00	$200,000.00
1011	RESIDENTIAL		4	12	$438,000.00	$219,000.00
1012	RESIDENTIAL		2	6	$291,000.00	$145,500.00
1013	RESIDENTIAL		3	9	$315,000.00	$157,500.00
1014	RESIDENTIAL		3	9	$300,000.00	$150,000.00
1015	RESIDENTIAL		4	12	$562,000.00	$281,000.00
1016	RESIDENTIAL		1	3	$102,000.00	$51,000.00
1017	RESIDENTIAL		5	15	$682,000.00	$341,000.00
1018	RESIDENTIAL		3	9	$389,000.00	$194,500.00
1019	RESIDENTIAL		2	6	$311,000.00	$155,500.00
1020	RESIDENTIAL		4	12	$500,000.00	$250,000.00
1021	RESIDENTIAL		0	0	$-	$-
1022	RESIDENTIAL		0	0	$-	$-
1023	RESIDENTIAL		1	3	$100,000.00	$50,000.00
1024	RESIDENTIAL		1	3	$125,000.00	$62,500.00
1025	RESIDENTIAL	Multifamily	1	3	$320,000.00	$160,000.00
1026	OFFICE	OFFICE	1	3	$454,000.00	$227,000.00
1027	RESIDENTIAL		2	6	$301,000.00	$150,500.00
1028	RESIDENTIAL		3	9	$435,000.00	$217,500.00
1029	RESIDENTIAL		1	3	$164,000.00	$82,000.00
1030	RESIDENTIAL		1	3	$131,000.00	$65,500.00
1031	RESIDENTIAL		0	0	$-	$-
1032	RESIDENTIAL		0	0	$-	$-

Zone_ID	Predominant Land Use	Land Use Comment	Population Day	Population Night	Adjusted Gross Impr.	Contents
1033	RESIDENTIAL		4	12	$584,000.00	$292,000.00
1034	Parking Lot	Parking Lot	1	3	$2,058,000.00	$200,000.00
1035	RESIDENTIAL		0	0	$-	$-
1036	RESIDENTIAL		3	9	$456,000.00	$223,500.00
1037	RESIDENTIAL		2	6	$288,000.00	$144,000.00
1038	RESIDENTIAL		2	6	$260,000.00	$130,000.00
1039	RESIDENTIAL		3	9	$381,000.00	$190,500.00
1040	RESIDENTIAL		2	6	$284,000.00	$142,000.00
1041	RESIDENTIAL		1	3	$137,000.00	$68,500.00
1042	COMMERCIAL	COMMERCIAL	1	3	$280,000.00	$140,000.00
1043	RESIDENTIAL		0	0	$-	$-
1044	RESIDENTIAL		2	6	$318,000.00	$153,000.00
1045	RESIDENTIAL		2	6	$463,000.00	$200,000.00
1046	RESIDENTIAL		3	9	$487,000.00	$243,500.00
1047	RESIDENTIAL		2	6	$303,000.00	$151,500.00
1048	RESIDENTIAL		0	0	$-	$-
1049	RESIDENTIAL		0	0	$-	$-
1050	RESIDENTIAL		0	0	$-	$-
1051	RESIDENTIAL		4	12	$878,000.00	$361,500.00
1052	RESIDENTIAL		4	12	$884,000.00	$361,000.00
1053	RESIDENTIAL		3	9	$483,000.00	$241,500.00
1054	RESIDENTIAL		3	9	$522,000.00	$254,500.00
1055	RESIDENTIAL		2	6	$300,000.00	$150,000.00
1056	RESIDENTIAL		1	3	$100,000.00	$50,000.00
1057	RESIDENTIAL		1	3	$169,000.00	$84,500.00
1058	RESIDENTIAL		2	6	$286,000.00	$143,000.00

Zone_ID	Predominant Land Use	Land Use Comment	Population Day	Population Night	Adjusted Gross Impr.	Contents
1059	RESIDENTIAL		0	0	$-	$-
1060	RESIDENTIAL		3	9	$332,000.00	$166,000.00
1061	RESIDENTIAL		2	6	$271,000.00	$135,500.00
1062	RESIDENTIAL		3	9	$537,000.00	$254,500.00
1063	RESIDENTIAL		4	12	$688,000.00	$333,000.00
1064	RESIDENTIAL		1	3	$164,000.00	$82,000.00
1065	RESIDENTIAL		0	0	$-	$-
1066	RESIDENTIAL		1	3	$173,000.00	$86,500.00
1067	RESIDENTIAL		0	0	$-	$-
1068	RESIDENTIAL		0	0	$-	$-
1069	RESIDENTIAL		1	3	$175,000.00	$87,500.00
1070	RESIDENTIAL		2	6	$307,000.00	$153,500.00
1071	RESIDENTIAL		2	6	$333,000.00	$166,500.00
1072	RESIDENTIAL		2	6	$275,000.00	$137,500.00
1073	RESIDENTIAL		1	3	$100,000.00	$50,000.00
1074	RESIDENTIAL		1	3	$150,000.00	$75,000.00
1075	RESIDENTIAL		0	0	$-	$-
1076	RESIDENTIAL		3	9	$442,000.00	$221,000.00
1077	RESIDENTIAL		2	6	$237,000.00	$118,500.00
1078	RESIDENTIAL		1	3	$110,000.00	$55,000.00
1079	RESIDENTIAL		0	0	$-	$-
1080	RESIDENTIAL		1	3	$152,000.00	$76,000.00
	Total		**1070**	**1713**	**$68,422,000.00**	**$27,204,000.00**

APPENDIX C

Downstream Consequences

Appendix C – Downstream Consequences

For each dam failure scenario for which inundation was either modeled or interpolated/extrapolated, for each spatial zone as well as total over all zones:

- potentially affected initial and remaining population (day or night) and property (improvements and contents) values
- damages (improvements and contents)
- average (by zone) and max (over all zones) probability of fatality per individual
- expected number of fatalities
- probability of at least one fatality
- probability of at least two fatalities.

The incremental downstream consequences were simply interpolated/extrapolated for several dam failure scenarios, which are not shown in this appendix.

(See AE 2014, Table 2)

As a global, employee-owned organisation with over 50 years of experience, Golder Associates is driven by our purpose to engineer earth's development while preserving earth's integrity. We deliver solutions that help our clients achieve their sustainable development goals by providing a wide range of independent consulting, design and construction services in our specialist areas of earth, environment and energy.

For more information, visit golder.com

Africa	+ 27 11 254 4800
Asia	+ 86 21 6258 5522
Australasia	+ 61 3 8862 3500
Europe	+ 44 1628 851851
North America	+ 1 800 275 3281
South America	+ 56 2 2616 2000

solutions@golder.com
www.golder.com

Golder Associates Ltd.
500 - 4260 Still Creek Drive
Burnaby, British Columbia, V5C 6C6
Canada
T: +1 (604) 296 4200