Ministry of
Forests, Lands and
Natural Resource Operations

Downstream Consequence of Failure Classification Interpretation Guideline

Dam Safety Program

Ministry of Forests, Lands and Natural Resource Operations

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Introduction

The purpose of this guideline is to assist dam owners to determine the most appropriate consequence of failure classification for dams in their jurisdiction in a manner that is consistent across the province. This guideline is intended to be a companion document to "Estimating Dam Break Downstream Inundation". These two documents have been designed to update the document "Consequence of Failure Classification: A Guide for Initial Assessment" prepared by the BC Dam Safety Section in 2001.

This guideline is based on the Canadian Dam Association (CDA) Guidelines, the Dam Safety Regulation (the regulation) and the collected wisdom of Dam Safety Officers and hydrologists who have many years of experience determining the consequence classification of dams. The CDA Guidelines state that where there are inconsistencies between their guidelines and provincial regulations, "legal regulations take precedence over guidelines produced by non-governmental organizations" (CDA Guidelines, Preface). Therefore where there is a difference in interpretation, the regulation takes precedence over the CDA Guidelines. This guideline contains multiple references and direct quotes from the CDA guidelines and regulation where ever possible to assist the reader. The concept of this guideline is that the dam owners will be able to compare the two documents without flipping back and forth between them. American agencies at both the federal and state levels have also been referenced for their insight into the determination of consequence classification for dams.

In 2010, following the failure of the Testalinden Dam, the Solicitor General of British Columbia conducted a review of the provincial Dam Safety Program. In the report, "Review of the Testalinden Dam Failure, July 2010", the Solicitor General recognized the importance of the CDA Guidelines to the provincial Dam Safety Program. The report recommended a closer alignment with those guideline and in particular with "Table 2-1: Dam Consequence" from the CDA Guidelines, which has five consequence classifications instead of the four that were in the 2000 Dam Safety Regulation. The Dam Safety Regulation was amended in November 2011 and February 2016 and now has a Consequence Classification table in Schedule 1 which is similar to the CDA Table 2-1. The CDA Table 2-1 could not be adopted directly into the regulation due to some language that was not appropriate or specific enough for legislation. In general, the verbal descriptions in Schedule 1 are longer and clearer than the language in Table 2-1. A summary of the differences is listed below and discussed in more detail in the following sections.

- "Incremental consequences" are defined in the CDA Guidelines, but are only implied in the regulation.
- The term "sunny-day failure" is defined in the CDA Guidelines but not in the regulation.
- The term "flood-induced failure" is defined in the CDA Guidelines but not in the regulation.
- "Population at Risk" is subdivided into two categories: temporary and permanent. Both are defined in the CDA Guidelines and the regulation, but there are some differences in interpretation. As previously noted, the regulation takes precedence over the CDA Guidelines.

- The CDA Guidelines and regulation differ in their descriptions of the Loss of Life category for Significant Classification, but are not contradictory and so both can be used to help with interpretation.

Definitions

Consequences of Failure

The term "consequences of failure" is defined in the Dam Safety Regulation and the CDA Guidelines as follows:

> ***"Consequences of failure"*** *means losses or damages that are caused by a failure of a dam.* (Dam Safety Regulation, Schedule 1, Definitions)

> ***"Failure"*** *in relation to a dam, means an uncontrolled release of all or part of the water impounded by the dam, whether or not caused by a collapse of the dam.* (Dam Safety Regulation, Schedule 1, Definitions)

> ***"Consequences of failure"*** *Impacts on the downstream or upstream area of a dam as a result of failure of the dam or its appurtenances. In these guidelines, the term consequences refers to the damage above and beyond the damage that would have occurred in the same event or conditions had the dam not failed. These may also be called incremental consequences of failure.* (CDA Guidelines – Glossary)

The consequences of failure should be evaluated for all three categories in Schedule 1 of the Dam Safety Regulation: loss of life, environment and cultural values, and infrastructure and economics. The category with the worst potential consequences is the classification of the dam as per Section 2 of Schedule 1 of the Dam Safety Regulation. The CDA Guidelines suggest the same thing:

> *Environmental, cultural, and third-party economic losses should be estimated separately and taken into account in assigning a dam to a class. The class should be determined by the highest potential consequences, whether loss of life or environmental, cultural, or economic losses.* (CDA Guidelines, Section 2.5.4 Dam Classification)

The consequence classification of a dam is used to determine design criteria in the CDA Guidelines and the frequency of safety activities (surveillance, inspection etc.) in Schedule 2 of the regulation.

Total and Incremental Consequences

Incremental consequences of failure are defined as "the incremental losses or damage that a dam failure might inflict on upstream areas, on downstream areas, or at the dam itself, over and above any losses or damage that would have occurred in the same event or conditions had the dam not failed" (CDA Guidelines, Glossary).

The CDA Technical Bulletin #1 discusses incremental and total consequences in more detail in Section 3.6:

> *It is traditionally assumed that the standard of care and due diligence expected of a dam owner relate to the potential damages above and beyond those that would occur due to a natural event when the dam does not fail. The "incremental losses" are defined as the total damages from an event with dam failure minus damages resulting from the same event if the dam had not failed*

Under the regulation, the consequence of failure is based on losses, damage, deterioration or destruction *"caused by the failure of the dam"*, (see Schedule 1, Definitions; "**consequences of failure",** clause (a)). The term "incremental" as related to consequences of failure is not defined or addressed in the regulation but is implied by that phrase *"caused by the failure of the dam".* Therefore, the dam owner should assume that the consequences of failure only include the damages that would have occurred over and above any losses or damage that would have occurred in the same event or conditions had the dam not failed, as defined by "incremental consequences of failure" in the CDA Guidelines.

Flood-induced failure and sunny-day failure

The initial hydrologic conditions for a dam breach are categorized as "flood induced failure" and "sunny day failure" in the CDA Guidelines. The definitions from the CDA Guidelines are as follows.

> ***flood-induced failure****—This is a dam failure resulting from a natural flood of a magnitude that is greater than what the dam can safely pass.* (CDA Guidelines, Section 2.5.2 Dam Breach Analysis and Inundation Mapping)

> ***Sunny-day failure****—This is a sudden dam failure that occurs during normal operations. It may be caused by internal erosion, piping, earthquakes, mis-operation leading to overtopping, or another event.* (CDA Guidelines, Section 2.5.2 Dam Breach Analysis and Inundation Mapping)

According to the CDA Guidelines, Principle 1b, the consequence classification used for the purposes of determining the design criteria of specific parts of the dam, e.g. spillway capacity and structural stability, may not necessarily be the same. Different failure modes will impact some elements of the dam differently. An example is described in a quote from the CDA Technical Bulletin #1 below. However, the overall classification of the dam would be equal to the highest classification level. The overall classification is used to determine compliance with Schedule 2 of the regulation, classification level in the dam registry, audit frequency and the dam owners' overall management of the dam.

> *The class should be based on the failure scenario that would result in the worse consequences: either sunny day failure or flood failure. This classification should be used for purposes of general management oversight, as well as inspection, maintenance, and* ***surveillance*** *programs. For*

determining design criteria for specific components at a site, the consequences of failure of the components may be evaluated separately. (CDA Guidelines, Principle 1b)

"For failure due to causes other than flood (sunny day failure), the incremental consequences may be the same as the total consequences. For example, if the dam failed after an earthquake, the incremental consequences (which are equal to total consequences) could be high. In this case, the dam should be designed to resist earthquake loadings, but it would not be required to resist a flood with a similar return frequency. For this reason the consequences of a dam failure should be analyzed for a random (i.e. sunny day) failure as well as for a flood scenario in order to define design requirements for each. A dam could have low consequences from a flood failure even though there would be high consequences under a sunny day failure; in this case the consequences of flood failure would be used to establish the appropriate design flood. The higher of the two consequence scenarios will generally dictate the overall level of care in management oversight, inspection, maintenance and safety assessment" (CDA Technical Bulletin #1, Section 3.6).

Population at Risk and Loss of Life

Definitions

The terms Loss of Life (LOL) and Population at Risk (PAR) are not specifically defined in the Dam Safety Regulation, but they are defined and explained in the CDA Guidelines, Section 2.5.3 Dam Failure Consequences, under the section titled "Loss of Life":

*The consequences of dam failure should be evaluated in terms of **life safety**. The population at risk (PAR) in the inundated area provides an indication of the number of people exposed to the hazard. It accounts for demographic and land-use factors for the inundated area. Some classifications rely on estimates of PAR, defined as the number of people who would be exposed to floodwaters and would experience consequences that could range from inconvenience and economic losses to loss of life.*

Consistent estimates of expected loss of life are very difficult to develop. The potential for loss of life depends on many highly uncertain and variable factors, such as depth of flow, velocity, time of day, advance warning, topography, distance from the dam, transportation routes, historical patterns of human activity, and mobility of the population.

No simple, reliable, or universally applicable methodology is available—different methods can produce very different estimates of loss of life. Estimates should take into consideration specific scenarios that account for a wide range of parameters. The assumptions, reasoning, and calculations should be clearly documented.

Further information on LOL and PAR can be found in the CDA Technical Bulletin #1, Section 3.0 Dam Failure Consequences. PAR is defined in that bulletin as a footnote:

All those persons who would be directly exposed to flood waters within the dam failure inundation zone if they took no action to evacuate

Different methods to estimate loss of life for dam failure scenarios are summarized in the following publications: "Dams Sector: Estimating Loss of Life for Dam Failure Scenarios" (Homeland Security, 2011) and "RCEM – Reclamation Consequence Estimating Methodology" (U.S. Department of the Interior, 2014).

Temporary and Permanent Population at Risk

The CDA Guidelines and the Dam Safety Regulation differ in their definitions of temporary and permanent population at risk. As previously noted, the regulation takes precedence over the CDA guidelines.

These terms are defined in the **CDA guidelines** (Table 2-1) as follows:

> **Temporary—***People are only temporarily in the dam-breach inundation zone [e.g., seasonal cottage use, passing through on transportation routes, participating in recreational activities]*.
>
> **Permanent—***The population at risk is ordinarily located in the dam-breach inundation zone [e.g., as permanent residents]; three consequence classes [high, very high, extreme] are proposed to allow for more detailed estimates of potential loss of life [to assist in decision-making if the appropriate analysis is carried out*.

These terms are defined in the **Dam Safety Regulation** (Schedule 1 table - footnotes 2 and 3) as follows:

> **Temporary only:** *People are only occasionally and irregularly in the dam-breach inundation zone, for example stopping temporarily, passing through on transportation routes or participating in recreational activities.*
>
> Interpretation: Includes informal camping areas with no facilities
>
> **Permanent** *The population at risk is ordinarily or regularly located in the dam breach inundation zone, whether to live, work or recreate*.
>
> Interpretation: Includes formal campgrounds with facilities that are advertised and regularly occupied e.g. forest recreation sites, private campgrounds, provincial parks etc. By the same definition, this would also include "seasonal cottages" which are noted in the CDA definition of temporary above. The term "seasonal cottage" is not defined in the CDA Guidelines. For the purpose of this guideline, the difference between a seasonal cottage and a permanent residence is that a seasonal cottage would be off the grid, i.e. no municipal sewer or water system, no permanent electrical grid connection, etc. Seasonal cottages would be viewed as similar to a formal campground.

The main difference between the regulation and CDA Guideline definitions for temporary and permanent population at risk is in regards to campgrounds and seasonal cottage use. The interpretation

is that the regulation is more conservative. The regulation implies that if formal campgrounds and seasonal cottages are found within the inundation area, the dam would be classified as high if loss of life is possible. In this case the dam owner would be required to operate, maintain and inspect the dam as a high consequence dam as per the Dam Safety Regulation.

In the cases where a permanent population may be exposed to floodwaters, but the potential for loss of life is low (i.e. shallow and low-velocity flooding), the impacts could be better captured under the other consequence of failure categories; environmental and cultural losses or infrastructure and economics.

Loss of Life - Estimating Fatality Rate using floodwater depth and velocity conditions

The 2014 report titled "RCEM – Reclamation Consequence Estimating Methodology: Guidelines for Estimating Life Loss for Dam Safety Risk Analysis" published by the U.S. Bureau of Reclamation provides the most recent depth vs. velocity (DV) charts. The RCEM introduces DV charts for "Little or No Warning" and "Adequate warning" to estimate the fatality rate for certain water depth and velocity conditions. The DV graphs were developed using empirical research following a comprehensive study of 60 dam failure case histories. This graphical approach needs to be used with caution; the following is an excerpt from the RCEM Guideline regarding the limits to the graphical approach:

> *Each chart includes dashed lines that represent "suggested" and "overall" limits for fatality rates over the full range of DV values. The suggested limits were selected visually based on the most representative case history data points for each warning time scenario, with no mathematical or statistical formulation of the curves. Cases with questionable data were given less influence on the suggested range. The overall limits, also established visually, are intended to represent the upper and lower bounds of fatality rates, between which nearly all case history data falls. The limits shown are not intended to be used by estimators directly, but rather they are intended to help the estimator interpret the data trends from the case histories. For example, the range of overall limits for little to no warning and a DV of 50 ft2/s covers over four orders of magnitude; however it is unlikely that the range of uncertainty in the fatality rate for a given project would span that full range.*

The report also provides a discussion of key considerations and recommendations regarding the use of this approach, tasks for application of the procedure and comparison with other life loss estimating approaches.

Determination of Loss of Life for Low Consequence dams

The table in Schedule 1 of the regulation states that for a low consequence dam "there is no possibility of loss of life other than through unforeseeable misadventure". Table 2-1 of the CDA Guidelines simply uses "0" as the potential loss of life for a low consequence dam. These consequences of failure are interpreted to be essentially the same.

Determination of Loss of Life for Significant Consequence dams

The table in Schedule 1 of the regulation states that for a significant consequence dam there is "low potential for multiple loss of life". Additional text from the 2000 BC Dam Safety Regulation (Appendix B) may provide clarification on the meaning of this phrase, as quoted below:

> *Low potential for multiple loss of life. Inundation area is typically undeveloped except for minor roads, temporarily inhabited or non-residential farms and rural activities. There must be reliable element of natural warning if larger development exists. (2000 BC Dam Safety Regulation, Schedule 1)*

Table 2-1 of the CDA Guidelines uses "unspecified" as the potential for loss of life for a significant consequence dam. The definition for unspecified is as follows:

> ***Unspecified**—The appropriate level of safety required at a dam where people are temporarily at risk depends on the number of people, the exposure time, the nature of their activity, and other conditions. A higher class could be appropriate, depending on the requirements. However, the design flood requirement, for example, might not be higher if the temporary population is not likely to be present during the flood season.* (CDA Guidelines, Table 2-1, Note 2)

The regulation and the CDA Guidelines can both be used to interpret the loss of life consequences of failure for the significant classification. The regulation and CDA Guidelines definitions outlined above do not conflict with each other. Furthermore, the definition of "unspecified" can help to inform the dam owner when considering PAR in the significant classification.

Number of persons per dwelling

It is common practice to use a value of 3 persons per inhabited dwelling (Department of the Interior, 1988).

Loss of Life on Roads and Railways

Well-travelled highways are more likely to have loss of life because the travelling speed is faster (i.e. less warning time) and there are lots of cars, whereas rural roads are unlikely to have loss of life because of slower travelling speeds (i.e. greater warning time) and fewer cars (Department of the Interior, 1988).

Consideration should be given to those rail lines that carry passenger traffic and the frequency that those trains pass through. The population at risk on trains would be categorized as "temporary" (see footnote 2 in Schedule 1 of the Dam Safety Regulation). Consideration should also be given to the type of dangerous goods and the frequency and that they are carried on a rail line.

In cases where there is some potential for loss of life to a population temporarily at risk as a result of road or railway failure, the classification is significant based on Schedule 1. In this case, the design criteria selected should be at the high end of the range within this classification.

Environment and Cultural Values

Evaluation of environmental values may require discussion with regional biologists regarding the relative importance of the fisheries and wildlife habitat as well as the impacts of a dam breach on the ecosystem. As a general guideline, if there is a significant loss or deterioration of habitat for blue-listed species, then the consequence of failure would be at high consequence. If there is a significant loss or deterioration of habitat for red-listed species, then the consequence of failure would be at very high consequence.

Various habitat and fisheries mapping programs are available for reference through the Community Mapping Network (http://www.cmnbc.ca/) . The B.C. Conservation Data Centre (http://www.env.gov.bc.ca/cdc/) also provides information on species and ecological communities at risk in British Columbia.

The Archaeology Branch of the Provincial Government (http://www.for.gov.bc.ca/archaeology/) can be consulted to determine if any important historical or archaeological sites are found in the inundation area. The Remote Access to Archaeological Data (RAAD) mapping program accessed through this site offers a spatial perspective. The regional First Nations Branch with the Ministry of Forests, Lands and Natural Resource Operations may have additional information on archaeological sites or sites of cultural importance that could potentially be located within the inundation zone.

Infrastructure and Economics

"The estimate of economic losses should include damage to third-party property facilities, other utilities and infrastructure. In most cases, the damage to the dam owner's property may be excluded from the estimate and left to the owner to consider separately. However, it should be recognized that in many cases the owner's losses would have significant impacts on society. Where appropriate, costs or values can be assigned to social and cultural impacts and included as economic consequences" (CDA Guidelines, Section 2.5.3).

Dam Owner Property

For a dam to be classified as low, economic losses from a dam breach must be mostly limited to the dam owner's property (Schedule 1 of the Dam Safety Regulation). As a general guideline, a dam breach should not damage another property owner's dwelling and or impede access to their property for more than a day for a dam to be classified as low.

Roads and Railways

Table 1 should be used as only a general guideline. For the purposes of this section, a washout of a road is enough significant damage for a complete closure and an extended disruption of access. Lesser damage would likely result in the choice of a lower classification.

Forest Service Roads (FSRs) are maintained to two different levels: wilderness and industrial (as described under Section 79-81 of the Forest Planning and Practices Regulation). Within each category, FSRs can have varying social and economic values. The best way to determine the relative value of FSRs is to contact a MFLNRO forest engineering officer. There are a number of FSRs that function as the sole access to private property, recreation areas, or Indian Reserves. The direct cost to repair a washout could be as high as $50,000, but in most cases the cost would be significantly less than this amount (personal communication with MFLNRO). Indirect economic losses may also occur in the form of impacts to logging activity, for example. If a FSR is washed out, the consequence in most cases would be either low or significant.

Ministry of Transportation and Infrastructure (MOTI) roads are classified into five groups (primary highways, secondary highways, major roads, minor roads and local roads). The five classes are:

- **Primary Highways:** A continuous, integrated highway network for long distance international trips and inter/intra provincial trips between major population centres (population typically in excess of 50,000) and other major activity nodes. Carry substantial heavy truck volumes over long distances. Expected to provide for high overall travel speeds, with minimum interference to through movements. Typically are freeways, expressways arterials Highway Planning Section expressways, and/or arterials.
- **Secondary Highways:** A network which serves inter/intra provincial travel having a trip length of regional significance. They integrate with primary highways to provide a balanced highway network. Connect urban areas with population typically from 5,000 to 50,000, and significant activity centres not served by the primary system. May be freeways or expressways, but are usually arterials.
- **Major Roads:** Major roads serve intra provincial travel with trip lengths and traffic volumes of regional or sub-regional importance. Connect significant settlement areas and activity centres not already served by primary or secondary highways. May service resource areas. Typically are arterials; may be collectors.
- **Minor Roads:** Also serve intra provincial travel, with trip lengths and traffic volumes of sub-regional importance. Connect all remaining settlement areas and other areas of equal activity level not already served by higher function roads, where it is reasonable to do so. May service resource areas. Typically are collectors; may be arterials.
- **Local Roads:** Serve to provide direct access to individual land uses. They integrate with the higher classes to provide a balanced highway network. Note that the lowest functional class and the lowest service class have the same term: local road.

The **"National Highway System" (NHS)** is a subset of primary highways which have been deemed to be of national importance, and therefore have higher expectations placed on them regarding mobility, reliability, geometric standards and condition.

The classifications of specific roads can be found in the following document: http://www.th.gov.bc.ca/publications/planning/Provincial%20Highways/BC_Numbered_Hwy_Functional_Classes.pdf.

Table 1 shows the resultant dam consequence classification if the failure of that dam would wash out a particular class of FSR or MOTI road. The washout of primary and secondary highways are considered to

be a very high consequence, because in addition the direct cost of replacing the road, there are additional indirect economic implications (e.g. commercial transportation, food distribution) and social impacts such as impaired emergency services and public mobility.

Table 1. Dam failure consequence classification and washout of various road classifications.

Dam Failure Consequence Classification	**Washout of FSR**	**Washout of MOTI road**
Low	FSR of limited use	
Significant	FSR that serves as access to private property, recreation areas, and industrial use	Local or minor road
High	FSR that serves as sole access to a community	Major road or a Local or minor road that serves as sole access to a community
Very High		Secondary or Primary Highway
Extreme		

The dam consequence classification may be lower if the road would only be damaged or temporarily blocked instead of being washed out. The classification may be increased if the road washout would be significant enough to warrant a lengthy closure.

Some dams are classified as high consequence only because they are upstream of a major highway. In many cases it is not clear whether the paved embankment would be washed out and there may be a "low potential for multiple loss of life", i.e. the dam would be low consequence under loss of life. But, the consequence classification may be higher if the economic damage to the highway would warrant it.

Highway crossings are often designed for the 1:100 year event, or for a high-value crossing they are designed for the 1:200 year event. As noted above, dams located above these highways are usually classified as high consequence, because of their proximity to the high asset highway. However, consideration can be given to lowering the spillway design requirements to a size that can pass a 1:1000 year flood, if there is a high probability that the highway would wash out at a flood much below that return period regardless of whether the dam fails or not.

The five main railway lines in BC are a) CP mainline from Banff to Vancouver; b) CN mainline from Jasper to Vancouver; c) CN line Jasper to Prince Rupert; d) CN line from North Vancouver to Tumbler Ridge; and e) from Sparwood to Golden. As a general guideline, if a main railway is washed out the consequence classification is very high. More minor rail lines would have a lower consequence.

As shown in Table 2, factors to consider when evaluating the potential for a road or railway to washout include flood wave characteristics, debris, channel morphology, and road characteristics.

Table 2. Factors to consider when evaluating the possibility of a washout to a roadway or railway

Flood wave characteristics
• Flow velocity • Depth of water • Duration of flood wave (related to reservoir volume and breach characteristics)
Debris impacts
• Culvert or bridge blockage   ○ Culverts will almost always be blocked with debris as a result of a dam failure. • Increased destructive capacity of the flood wave • Increased potential for creek avulsion
Channel morphology
• A steep slope mobilizes more debris • The angle of approach of the creek channel in relation to the roadway   ○ An oblique angle of approach increases the potential for the road to divert the flow downhill along the ditch or the roadway. In this case, the road may overtop at an unexpected location and cause flooding well away from the original creek channel • Alluvial fan increases the likelihood of avulsion and a road washout at an unexpected location without a culvert or bridge • A well-incised creek has a lower risk of avulsion and the roadway damage is more likely to be localized at the expected stream crossing
Road and railway characteristics
• Culvert or bridge conveyance capacity • Shoulder material as it relates to the potential for undermining the road fill • Height of road or rail fill (lower height has a lower potential for washout) • Road surface material - pavement or gravel road • Road fill material

Loss of a Community Water Supply

The failure of a community water supply dam could leave the community with a water shortage with little or no warning. If the reservoir is the sole source of water for a community and the water supply system is down for an extended period of time, the consequence classification of the dam should be high or greater depending on the number of residents, businesses and the other critical infrastructure that would be affected.

Other infrastructure, commercial facilities, public transportation or services

Other infrastructure and facilities to consider when evaluating consequence classification include hospitals, airports, pipelines, public utilities, and power lines. If access to high-value infrastructure such as hospitals or airports would be affected, the consequence classification of the dam should be high or greater depending on the severity of the expected impacts. If a dam failure would result in disruption of power to more than 10 dwellings, then the consequence classification should be high or greater.

Residential Areas

As a guideline, the term “scattered residential buildings” from Schedule 1 of the Dam Safety Regulation may be considered to be in areas with lots averaging greater than 0.5 hectare or residential buildings 50 m apart. Residential areas would have a higher population density.

Economic Losses

The 2000 BC Dam Safety Regulation downstream consequence classification guide included estimates of direct and indirect economic losses and can be used as an additional tool in deciding consequence classification (Appendix B). The dollar values in this table are from the year 2000, therefore, they would need to be amended to account for the increases to cost of living and housing prices.

Loss of Recreational and Social Value

The 2016 Dam Safety Regulation Dam Classification Schedule 1 does not include direct reference to recreational losses or social values. The 2000 BC Dam Safety Regulation downstream consequence classification guide included estimates of social losses and can be used as an additional tool in deciding consequence classification (Appendix B).

The public reaction to the possible loss of recreational and aesthetic aspects of reservoirs has clearly shown that these can have a high value to the community. This aspect of a dam is not well captured in Schedule 1, but can be closely compared to the loss or deterioration of unique landscapes or sites of cultural significance. A dam breach would obviously cause a significant loss of the recreational and aesthetic aspects of a reservoir and restoration is highly possible only if a dam was re-built. In that case it would fit into the High consequence classification because of the cost of reconstruction. It could be argued that it would be impractical to re-build the dam though, either from a purely financial perspective, or possibly due to resistance from the community below that would have already experienced one dam break. If it is considered impractical to re-build the dam after a failure this would lead to the possibility that the dam should perhaps be considered a Very High consequence dam instead of just a High consequence one.

Future Development

The downstream consequence classification should reflect the current downstream development. However, it should be recognized that the future downstream development might increase the classification. Subdivision applications downstream of a dam can be an indication that the consequence classification needs to be re-evaluated.

When using the classification to determine design criteria, it is advisable to investigate the effect that potential future downstream development may have in increasing the classification and thus the design criteria.

Multiple Dams (Cascade Projects)

"In the case of cascade projects, the safety of a particular dam is affected by any dams located upstream, so dam safety must be analyzed globally. The evaluation of failure consequences of a dam in a cascade must include the failure consequences of dams located downstream if such failure would be caused by the dam under study and if that failure would not otherwise have occurred in the scenario under study. The consequences also include the cost of rebuilding the downstream failed dams and the loss of production at those dams.

For dams in a cascade, the Inflow Design Flood (IDF) for a particular dam may be lower than the IDF of an upstream dam. In this case, if a flood with a frequency between the two IDFs occurs, flood releases at the upstream dam may cause the failure of the downstream dam. When the inflow flood exceeds the capacity of the flood control structures at the upstream dam, the failure consequences of the downstream dam are the responsibility of the downstream dam owner." (CDA Technical Bulletin #1, Section 3.5).

In other words, if the failure of the upstream dam would cause the failure of the downstream dam, then the classification for the upstream dam must be as high as, or higher than, the downstream dam.

Additional Resources and Reference Material

The following sections of the Canadian Dam Association Dam Safety Guidelines and Technical Bulletins may provide additional useful context on consequences of failure and classification:

- CDA Dam Safety Guidelines, Section 1.1 under Principle 1b
- CDA Dam Safety Guidelines, Section 2.5.3 Dam Failure Consequences
- CDA Dam Safety Guidelines, Section 2.5.4 Dam Classification
- CDA Dam Safety Guidelines, Table 2-1: Dam Classification
- CDA Technical Bulletin #1: Inundation, Consequences, and Classification for Dam Safety
- CDA Technical Bulletin #5: Dam Safety Analysis and Assessment.

The Washington State Dam Safety Office website is a good source of information on Dam Safety for dams in a similar geographic setting (http://www.ecy.wa.gov/programs/wr/dams/dss.html).

References

BC Ministry of Transportation and Infrastructure. “Supplement to TAC Geometric Design Guide.” June 2007.

Canadian Dam Association. “Dam Safety Guidelines” and “Technical Bulletins”, 2007 and 2013 update.

U.S. Department of Homeland Security, “Dams Sector: Estimating Loss of Life for Dam Failure Scenarios.” September 2011.

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U.S. Department of the Interior (Bureau of Reclamation). “Downstream Hazard Classification Guidelines.” ACER Technical Memorandum No. 11. December 1988.

U.S. Department of the Interior (Bureau of Reclamation). “RCEM – Reclamation Consequence Estimating Methodology: Guidelines for Estimating Life Loss for Dam Safety Risk Analysis.” February 2014.

U.S. Department of the Interior (Bureau of Reclamation). “Reclamation’s New Life Loss Estimating Methodology”, an on-Line PowerPoint presentation, by Bruce Feinberg, February 2015

Washington State Department of Ecology. “Dam Safety Guidelines, Technical Note 1: Dam Breach Inundation Analysis and Downstream Hazard Classification”2007.

Appendix A – Schedule 1 (Current Dam Safety Regulation)

Dam Safety Regulation ~~(B.C. Reg. 44/2000), November 30, 2011~~[1]

Downstream Consequence Classification Guide

Dam failure consequences classification	Population at risk	Consequences of failure		
		Loss of life	Environment and cultural values	Infrastructure and economics
low	none[1]	no possibility of loss of life other than through unforeseeable misadventure	minimal short-term loss or deterioration and no long-term loss or deterioration of (a) fisheries habitat or wildlife habitat, (b) rare or endangered species, (c) unique landscapes, or (d) sites having significant cultural value	minimal economic losses mostly limited to the dam owner's property, with virtually no pre-existing potential for development within the dam inundation zone
significant	temporary only[2]	low potential for multiple loss of life	no significant loss or deterioration of (a) important fisheries habitat or important wildlife habitat, (b) rare or endangered species, (c) unique landscapes, or (d) sites having significant cultural value, and restoration or compensation in kind is highly possible	low economic losses affecting limited infrastructure and residential buildings, public transportation or services or commercial facilities, or some destruction of or damage to locations used occasionally and irregularly for temporary purposes
high	permanent[3]	10 or fewer	significant loss or deterioration of (a) important fisheries habitat or important wildlife habitat, (b) rare or endangered species, (c) unique landscapes or (d) sites having significant cultural value, and restoration or compensation in kind is highly possible	high economic losses affecting infrastructure, public transportation or services or commercial facilities, or some destruction of or some severe damage to scattered residential buildings
very high	permanent[3]	100 or fewer	significant loss or deterioration of (a) critical fisheries habitat or critical wildlife habitat, (b) rare or endangered species, (c) unique landscapes, or (d) sites having significant cultural value, and restoration or compensation in kind is possible but impractical	very high economic losses affecting important infrastructure, public transportation or services or commercial facilities, or some destruction of or some severe damage to residential areas
extreme	permanent[3]	more than 100	major loss or deterioration of (a) critical fisheries habitat or critical wildlife habitat, (b) rare or endangered species, (c) unique landscapes, or (d) sites having significant cultural value, and restoration or compensation in kind is impossible	extremely high economic losses affecting critical infrastructure, public transportation or services or commercial facilities, or some destruction of or some severe damage to residential areas

[1] There is no identifiable population at risk.
[2] People are only occasionally and irregularly in the dam-breach inundation zone, for example stopping temporarily, passing through on transportation routes or participating in recreational activities.
[3] The population at risk is ordinarily or regularly located in the dam-breach inundation zone, whether to live, work or recreate.

[1]This table is a copy of Schedule 1 of the Dam Safety Regulation . In case of discrepancy between this table and the approved Regulation, the Regulation takes precedence.

Appendix B – Schedule 1 (2000 Dam Safety Regulation)

Dam Safety Regulation (B.C. Reg. 44/2000), March 10, 2000

Downstream Consequence Classification Guide

Rating	Loss of Life	Economic and Social Loss	Environmental and Cultural Losses
VERY HIGH	Large potential for multiple loss of life involving residents and working, travelling and/or recreating public. Development within inundation area (the area that could be flooded if the dam fails) typically includes communities, extensive commercial and work areas, main highways, railways, and locations of concentrated recreational activity. Estimated fatalities could exceed 100.	Very high economic losses affecting infrastructure, public and commercial facilities in and beyond inundation area. Typically includes destruction of or extensive damage to large residential areas, concentrated commercial land uses, highways, railways, power lines, pipelines and other utilities. Estimated direct and indirect (interruption of service) costs could exceed $100 million.	Loss or significant deterioration of nationally or provincially important fisheries habitat (including water quality), wildlife habitat, rare and/or endangered species, unique landscapes or sites of cultural significance. Feasibility and/or practicality of restoration and/or compensation is low.
HIGH	Some potential for multiple loss of life involving residents, and working, travelling and or recreating public. Development within inundation area typically includes highways and railways, commercial and work areas, locations of concentrated recreational activity and scattered residences. Estimated fatalities less than 100.	Substantial economic losses affecting infrastructure, public and commercial facilities in and beyond inundation area. Typically includes destruction of or extensive damage to concentrated commercial land uses. highways, railways, power lines, pipelines and other utilities. Scattered residences may be destroyed or severely damaged. Estimated direct and indirect (interruption of service) costs could exceed $1 million.	Loss or significant deterioration of nationally or provincially important fisheries habitat (including water quality), wildlife habitat, rare and/or endangered species, unique landscapes or sites of cultural significance. Feasibility and practicality of restoration and/or compensation is high.
LOW	Low potential for multiple loss of life. Inundation area is typically undeveloped except for minor roads, temporarily inhabited or non-residential farms and rural activities. There must be a reliable element of natural warning if larger development exists.	Low economic losses to limited infrastructure, public and commercial activities. Estimated direct and indirect(interruption of service) costs could exceed $100,000.	Loss or significant deterioration of regional important fisheries habitat (including water quality), wildlife habitat, rare and endangered species, unique landscapes or sites of cultural significance. Feasibility and practicality of restoration and/or compensation is high. Includes situations where recovery would occur with time without restoration.
VERY LOW	Minimal potential for any loss of life. The inundation area is typically undeveloped	Minimal economic losses typically limited to owners property and do not exceed $100,000. Virtually no potential for future development of other land uses within the foreseeable future.	No significant loss or deterioration of fisheries habitat, wildlife habitat, rare or endangered species, unique landscapes or sites of cultural significance.

Appendix C – Canadian Dam Association Guidelines, 2007

Table 2-1: Dam Classification

Dam class	Population at risk [note 1]	Incremental losses		
		Loss of life [note 2]	Environmental and cultural values	Infrastructure and economics
Low	None	0	Minimal short-term loss No long-term loss	Low economic losses; area contains limited infrastructure or services
Significant	Temporary only	Unspecified	No significant loss or deterioration of fish or wildlife habitat Loss of marginal habitat only Restoration or compensation in kind highly possible	Losses to recreational facilities, seasonal workplaces, and infrequently used transportation routes
High	Permanent	10 or fewer	Significant loss or deterioration of *important* fish or wildlife habitat Restoration or compensation in kind highly possible	High economic losses affecting infrastructure, public transportation, and commercial facilities
Very high	Permanent	100 or fewer	Significant loss or deterioration of *critical* fish or wildlife habitat Restoration or compensation in kind possible but impractical	Very high economic losses affecting important infrastructure or services (e.g., highway, industrial facility, storage facilities for dangerous substances)
Extreme	Permanent	More than 100	Major loss of *critical* fish or wildlife habitat Restoration or compensation in kind impossible	Extreme losses affecting critical infrastructure or services (e.g., hospital, major industrial complex, major storage facilities for dangerous substances)

Note 1. Definitions for population at risk:

None—There is no identifiable population at risk, so there is no possibility of loss of life other than through unforeseeable misadventure.

Temporary—People are only temporarily in the dam-breach inundation zone (e.g., seasonal cottage use, passing through on transportation routes, participating in recreational activities).

Permanent—The population at risk is ordinarily located in the dam-breach inundation zone (e.g., as permanent residents); three consequence classes (high, very high, extreme) are proposed to allow for more detailed estimates of potential loss of life (to assist in decision-making if the appropriate analysis is carried out).

Note 2. Implications for loss of life:

Unspecified—The appropriate level of safety required at a dam where people are temporarily at risk depends on the number of people, the exposure time, the nature of their activity, and other conditions. A higher class could be appropriate, depending on the requirements. However, the design flood requirement, for example, might not be higher if the temporary population is not likely to be present during the flood season.