Patching the Gaps:
Improving the Regulatory Capacity of British Columbia's Water Dam Safety Program

by

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Abstract

Aging infrastructure, watershed development, and the emergence of a risk-informed society has led to the need to re-examine dam safety through a societal lens. The incorporation of risk tolerance criteria and systems thinking into dam safety management necessitates a knowledgeable regulator. Lack of qualified personnel, discouragement from participating in learning opportunities, and overreliance on legislation and individual dam owners leaves British Columbia's water dam regulator falling short of achieving regulatory excellence in many areas. Regulatory frameworks in other jurisdictions are examined to identify best practices for water dam safety regulation. Policy options that aim to improve the regulator's capacity to understand the risks associated with dams and effectively manage them are evaluated.

Keywords: water dams; dam safety; regulation; water governance; public safety

To my mother, Carolyn.

Thank you for your endless support and unconditional love.

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Table of Contents

List of Tables

List of Figures

List of Acronyms

ALARP As Low as Reasonably Practicable

ANCOLD Australian National Committee on Large Dams

APEGBC Association of Professional Engineers and Geoscientists of British Columbia

BCDSP British Columbia Dam Safety Program

CDA Canadian Dam Association

DSC Dams Safety Committee *(New South Wales)*

EA Environment Agency *(England)*

FLNRO Ministry of Forests, Lands, and Natural Resource Operations *(British Columbia)*

ICE Institution of Civil Engineers

ICOLD International Committee on Large Dams

IPENZ Institution of Professional Engineers New Zealand

MEM Ministry of Energy and Mines *(British Columbia)*

NSW New South Wales

NZSOLD New Zealand Society on Large Dams

QCE Qualified Civil Engineer

UK United Kingdom

Glossary

ALARP	A fundamental principle of risk management in common law societies that refers to a level of risk that is tolerable and cannot be reduced further without expenditure that is grossly disproportionate to the benefit gained or due to technical unfeasibility[1]
Dam	A barrier constructed for the purpose of enabling the storage or diversion of water
Dam Failure	An uncontrolled release of all or part of the water impounded by the dam, whether or not caused by a collapse of the dam[2]
Dam Owner	The person or legal entity, including a company, organization, government department, public utility, or corporation, that is responsible for the safety of the dam
Failure Mode	The way(s) by which a dam can fail. Failure modes for dams include overtopping, seepage, erosion, and structural
Hazard	The potential of a machine, equipment, process, material or physical factor in the working environment to cause harm to people, environment, assets or production[3]
Inundation Zone	The geographical area that will be impacted in the event of a dam failure

[1] From (Talbot, 2016)
[2] Definition from *Water Sustainability Act, 2016*
[3] From (Wilson, Buchanan, & McCutcheon, 2003)

Maximum Credible Earthquake	The largest earthquake that could conceivably occur under the known tectonic framework for a specific fault or seismic source, as based on geologic and seismologic data
Meta Regulation	A form of regulation where the regulator is involved in a procedural capacity, by setting the terms on which the objectives of regulation may be met by the parties' own strategies[4]
Probable Maximum Flood	The most severe flood that could conceivably occur at a particular location, usually based on the probable maximum precipitation
Regulation	A specific set of commands that yields a binding set of rules to be applied by an entity or agency
Regulator	A government ministry, department, office, or other unit of the national or provincial government entrusted by law or administrative Act with the responsibility for the general supervision of the safe design, construction, and operation of dams and reservoirs
Reservoir	The body of water that is impounded by a dam, including its shores and banks and any facility or installation necessary for its operation
Risk Analysis	A quantitative calculation or qualitative expression of risk[5]
Risk Assessment	The process of deciding whether existing risks are tolerable and present risk control measures are adequate and if not, whether alternative risk control

[4] Frazer 2016 p. 239
[5] From (Scott, 2010)

measures are justified and should be implemented.[6] It is the decision-making process that considers both risk analysis and risk criteria

Risk Criteria — Criteria used in the risk assessment process to determine whether the risk level calculated through risk analysis is tolerable

Risk Management — The complete process of identifying risks, understanding them, assessing them, and then making decisions to ensure that effective risk controls are in place and implemented. Risk management begins with actively identifying possible hazards leading to the ongoing management of those risks deemed to be acceptable[7]

Standards-Based Approach — The traditional approach to dam engineering, where risks are managed by pre-established rules (‘standards’) for defining design events and loads, structural capacity, safety coefficients, and defensive design measures

Undertaker — In UK legislation, refers to the person(s) bearing ultimate responsibility for the safety of a reservoir. The undertaker is usually the owner or operator of the reservoir

[6] Ibid.

[7] (Wilson, Buchanan, & McCutcheon, 2003)

Executive Summary

In common law societies, dam safety is ultimately the owner's responsibility under strict liability. Dam safety regulation serves to address the inherent conflict of interest a dam owner faces, between their duty to protect the public interest and their own financial self-interest. It is the regulator's role to make sure this balance does not move too much to the end of the owner's self-interest. Regulation also addresses information asymmetries that exist between the dam owner and the downstream population, who are often unaware of the risks they face.

Historically, dam safety was left to the engineers tasked with designing the structure, and the probable maximum flood was the de-facto standard. Whether or not a dam was safe enough was judged by its ability to pass the prescribed standard. More recently, the drawbacks of the standards-based approach to dam safety have begun to be considered. Standards are rigid and often result in over-engineering and over-investment in dam safety. Additionally, the standards-based approach considers one failure mode only. In response to these limitations, a risk-informed approach to dam safety emerged in the mid 1990s. This approach looks at a dam as a system that is vulnerable to multiple failure modes, and can look at combinations of events to determine a dam's overall risk level. This comprehensive perspective changes the way the safety level of a dam is determined. It necessitates the development of societal and individual risk criteria to determine what levels of risk are tolerable. This process is highly complex and political.

Expert interviews were conducted to understand the implications this has for both dam owners and regulators. A risk-based approach to dam safety provides dam owners with increased flexibility with respect to how they manage the safety of their dams. For regulators, they can establish high-level goals for safety they require of their regulatees, but monitoring compliance is much more difficult than the standards system. Such a risk-based system requires a knowledgeable regulator with experience in dam-specific engineering.

Considering this, British Columbia's regulator of water dam safety is evaluated based on its ability to ensure compliance under such a system. The British Columbia

water dam safety regulation is administered under the Ministry of Forests, Lands, and Natural Resources, and compliance is handled through a small program known as the British Columbia Dam Safety Program (BCDSP). Upon further investigation, significant regulatory capacity deficiencies were identified. The BCDSP is a small departmental program with limited resources and experience. Currently, only two out of its twelve dam safety officers possess a professional engineering designation. Due to public spending concerns, participation of staff in interjurisdictional learning opportunities is not at an adequate level. The policy problem can be summarized as "The British Columbia Dam Safety Program lacks sufficient regulatory capacity to innovatively manage water dam safety."

To identify policy options that will remediate this problem, a jurisdictional scan of the dam safety regulatory frameworks in place in other jurisdictions was conducted. Jurisdiction choices were sourced from my interviews with experts. New South Wales, England, and New Zealand were analyzed.

New South Wales is internationally regarded as a leader in dam safety. It has incorporated an Independent Statutory Body (ISB) to oversee dam safety, with its members required to be experienced in dam engineering and nominated by a relevant organization. It was the first regulator in the world to successfully incorporate the risk-based approach into regulatory practice. England uses engineering panels (EP) that reservoir owners are mandated to employ for certain functions. Frequent interactions between qualified engineers, the regulator, and reservoir owners ensure responsibilities are clearly defined and there are effective channels of communication. New Zealand does not have formal regulations for dam safety and thus was not analyzed in detail.

The main objective is to improve the regulatory capacity of British Columbia's Dam Safety Program. Other relevant objectives include cost effectiveness, stakeholder acceptance, and administrative ease. Three policy options were identified. The first is a modification of the current status quo, with an emphasis on interjurisdictional learning. The second and third options are the approaches used in New South Wales and England respectively.

All options were evaluated according to the identified criteria. The ISB was shown to have the highest potential for improvement in regulatory capacity, followed by the EP, and lastly the status quo plus option. The ISB was the costliest option, drawing its cost effectiveness into question. The EP has the greatest cost effectiveness when improvements in regulatory capacity are considered. The status quo plus option is expected to perform the best for the stakeholder acceptance and administrative ease criteria, because it does not require significant deviation from the current system.

Transitioning to the EP structure is recommended due its potential to increase regulatory capacity at a reasonable cost. It is recommended further analysis be conducted into the viability of the ISB system for British Columbia.

It must be considered that there is nothing more difficult to carry out, nor more doubtful of success, nor more dangerous to handle, than to initiate a new order of things. For the reformer has enemies in all those who profit by the old order, and only lukewarm defenders in all those who would profit by the new order, this lukewarmness arising partly from fear of their adversaries, who have the laws in their favour; and partly from the incredulity of mankind, who do not truly believe in anything new until they have had the actual experience of it.

Niccolò Machiavelli, *The Prince*, 1532

1. Introduction

1.1 The Evolution of Dam Safety Management in Canada

In Canada, dam safety is ultimately the dam owner's responsibility. The burden of care on owners to ensure the safety of their dams can be traced back to nineteenth century England. *Rylands v Fletcher* (1868) is a landmark case that determined strict liability for landowners bringing anything onto their land that does not naturally occur there (T. Bennett, personal communication, December 11, 2015), specifically the following principle of law:

> *"We think the true rule of law is, that the person who for his own purposes brings on his land and collects and keeps there anything likely to do mischief if it escapes, must keep it in at his peril, and, if he does not do so, is prima facie answerable for all damage which is the natural consequence of its escape."*
>
> *Mr. Justice Blackburn*

Historically, the safety criteria for dams have been left to the engineers tasked with designing and constructing the structure. In the 1950s, dams were generally designed to pass floods only. At the time, the United States was the leading authority on dam safety standards globally. Specifically, the U.S. Army Corps of Engineers set the engineering standards and other countries followed suit, including Canada (D. Harford, personal communication, January 15, 2016).

Until the late 1970s, no provinces or territories in Canada had formal dam safety regulations in place. Alberta was the first province to enact dam safety legislation in 1978. The Alberta regulations closely followed several catastrophic dam failures in the

United States, Teton River in Idaho and Buffalo Creek in West Virginia being the most memorable incidents (T. Bennett, personal communication, December 11, 2015; Campbell et al., 2010). In the early 1970s, the federal government transferred water resource assets to the provinces, an additional motivation for Alberta to develop this legislation (Campbell et al., 2010).

Quebec's Saguenay river flood of 1996 was a catastrophic event that 'jumpstarted' much of the provincial dam safety regulations in place today. Record downpours led to the failure of eight dams, resulting in ten fatalities and over $1.5 billion dollars in property damage. A subsequent inquiry into the disaster concluded that the dams and dikes in the affected area were poorly maintained. Québec developed their dam safety regulations in response to the inquiry's findings, developing the *Dam Safety Act* in 2000, in effect since 2002 (Auditor General of Quebec, 2015).

The breakup of the electricity sector drove Ontario to develop provincial regulations for dam safety in the late 1990s. The *Energy Competition Act* passed the Ontario legislative assembly in 1998, which authorized the creation of a competitive electricity market in the province. Ontario Hydro, which until that point had provided the majority of the province's electricity, was subsequently sectioned off into five separate companies. This new legislative framework necessitated the creation of Ontario's provincial dam safety regulation due to the absence of a single public utility responsible for the safety of hydroelectric dams in the province (T. Bennett, personal communication, December 11, 2015). Ontario finalized its regulation in 2011 after many delays.

In 1998, the International Joint Commission, the bi-national organization responsible for overseeing dams on boundary waters, released a report entitled *Unsafe Dams?* The report found that in the absence of a federal regulation for dam safety within Canada, there was an overreliance on dam owners to ensure the safety of their dams. An update to the report, released in 2006, found no significant progress had been made in terms of dam safety regulation in Canada. This report prompted Parks Canada to develop their own dam safety standards for the 225 dams they oversee across nine provinces (Donnelly, Bechai, Trias, Vaillancourt, & Roy, 2009; T. Bennett, personal communication, December 11, 2015).

1.2 The Current Regulatory Environment for Dam Safety in BC

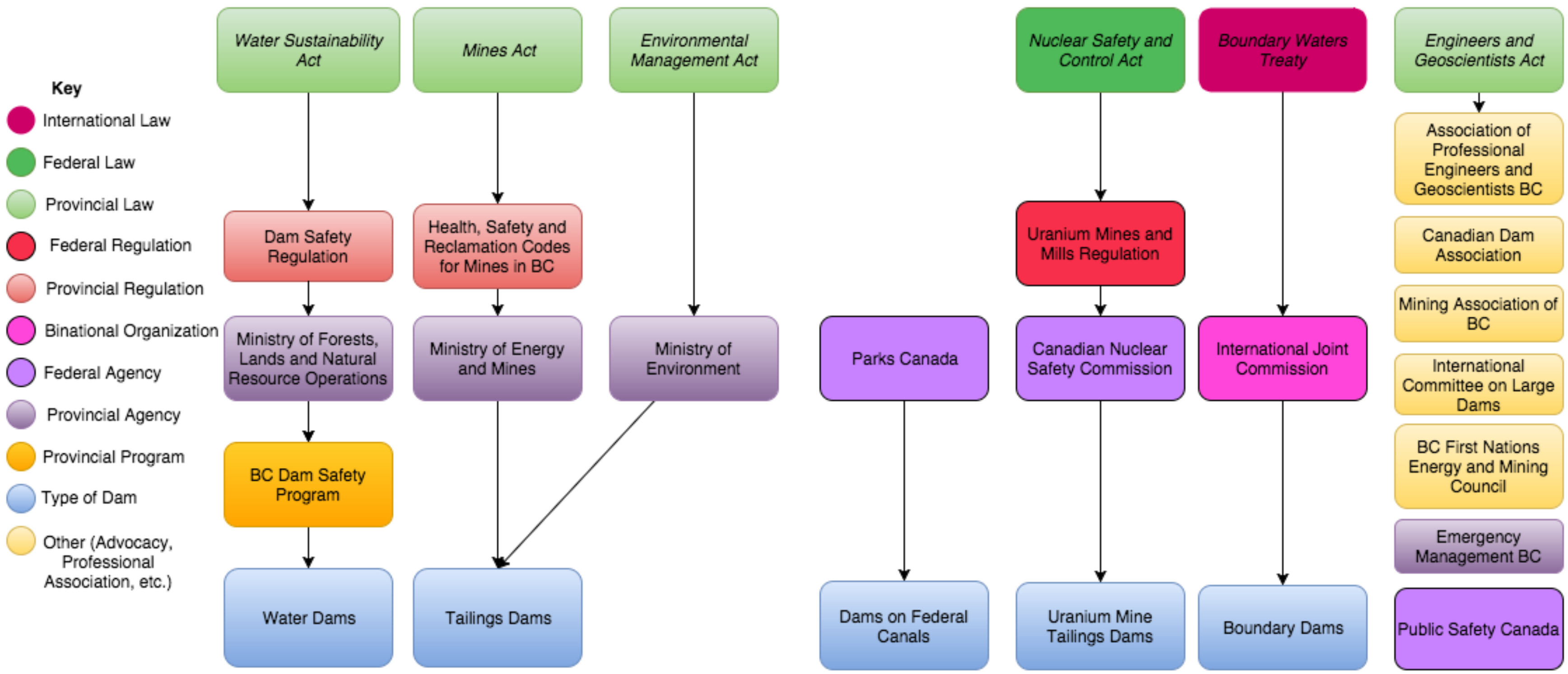

Figure 1: The Current Regulatory Environment for Dam Safety in BC

With the exception of dams across boundary waters and federal canals, regulatory oversight of dams is a provincial/territorial responsibility in Canada.[8] Currently, no federal regulatory body exists to oversee matters of dam safety, and the structure and scope of regulations vary greatly by province (Canadian Dam Association, 2010). Only four out of thirteen provinces and territories have explicit legislation pertaining to dam safety: British Columbia, Alberta, Ontario, and Québec.

The International Committee on Large Dams (ICOLD) is a non-governmental organization founded in 1928 that provides an international platform for knowledge exchange concerning dam engineering for ninety-five member countries. ICOLD releases regular informational bulletins, the result of technical committees that focus on different relevant issues. There are technical committees on both dam safety and public safety.

The Association of Professional Engineers and Geoscientists of British Columbia (APEGBC) is a not-for-profit organization regulating and governing professional engineers and geoscientists in the province. Under the *Engineers and Geoscientists Act,* APEGBC has the authority to investigate complaints relating to professional and/or ethical misconduct of its members and enact various disciplinary measures, including imposing a monetary fine, restricting practice, and temporarily or permanently revoking members' licenses (Association of Professional Engineers and Geoscientists of British Columbia, 2016).

The Canadian Dam Association (CDA), formed in 1997, is an amalgamation of the Canadian Dam Safety Association and the Canadian National Committee on Large Dams. The CDA is not a regulatory body, nor is it an advocacy group. Rather, it is a group comprised entirely of volunteers with a mission "to be the recognised leader in advancing knowledge and practices related to dams, consistent with social and

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[8] Dams on federal canals, for example the Rideau Canal, are regulated by Parks Canada, a federal agency. The International Joint Commission (IJC) oversees dams located on boundary waters (dams that cross the Canada-United States border). These 'international' dams are subject to the principles and procedures outlined in the *Boundary Waters Treaty* of 1909. Tailing dams associated with uranium mining are federally regulated by the Canadian Nuclear Safety Commission.

environmental values." The CDA currently exists as a platform for knowledge sharing about best practices amongst dam owners, operators, regulators, and other interested parties. Central to the CDA is the Dam Safety Guidelines publication, introduced in 1995.

The most recently available version of the CDA Dam Safety Guidelines was published in 2007. It consists of six sections of principles, processes, and criteria for managing dam safety, a result of collaboration and consultation with CDA members. The Guidelines are accompanied by technical bulletins that are of interest to engineering professionals involved in dam safety.

The Guidelines place the burden of responsibility of dam safety management on the owner of the dam, and the safety principles follow the **as low as reasonably practicable (ALARP)** approach to risk, described in Section 3.2. Dams are classified on a scale according to the severity of consequences should the dam fail, and the safety guidelines vary based on this classification. The CDA stresses the importance of addressing risks to people, property, and the environment. Additionally, economic considerations should not lead dam owners to impose intolerable risks[9], achieving a balance between ethical, social, and economic considerations.

While the Guidelines cover many important aspects of risk management, they are just that – guidelines only – and the CDA renounces any legal obligations in an event of dam owners following the Guidelines. The CDA has no regulatory authority over dam design, construction, and maintenance on any jurisdictional level, and no province references the Guidelines in their dam safety legislation. The CDA is comprised entirely of volunteers, and its continued operation is dependent on a few key members (Retired BC Engineer, personal communication, January 15, 2016). The burden of due-diligence falls primarily on the dam owner. While this may at first appear to be a limitation of the effectiveness of the non-binding nature of the guidelines, this allows the legislation to cover the bare minimum, i.e., what objectives must be met, but not how to meet them. This approach gives the dam owner autonomy over how to manage their dam safely, but the success of this approach greatly depends on the diligence and knowledge of dam

[9] The CDA guidelines define intolerable risk as an individual risk to permanent residents (downstream of the dam) of 10^{-4}/year or greater.

owners and operators. Tony Bennett, Director of Dam & Public Safety at Ontario Power Generation and the current President of the CDA summarizes it well: “there is an overreliance on Canadian dam owners being the good guys” (personal communication, December 11, 2015).

1.3 Regulating for Risk: An Emerging Approach to Dam Safety

> *Risk-regulation is, I suggest, not first and foremost about protecting people at all costs. It is about making trade-offs. Trade-offs between different risks; between risks to some individuals or groups, and risks to others; between costs and benefits. It is the nature of risk that, frequently, those who create the risk do not bear its consequences nor its wider costs. So the market does not function properly as a distributive mechanism. The State must intervene to regulate risk.*
>
> \- J.H. Bacon, former risk regulator
> Health and Safety Executive UK

Historically, the safety level of dams was left to its engineers to determine. Dams were usually designed to withstand only floods, using **probable maximum flood (PMF)** as the de facto engineering standard. The effect of seismic activity on the structural integrity of dams began to be considered in the 1960s, leading the **maximum credible earthquake** to gain traction as a design standard and become enshrined in practice. However, the end result is a number arbitrarily selected by the engineer tasked to come up with it, whether it is a strong earthquake or a large flood (D. Hartford, personal communication, January 15, 2016). The PMF is based on historical precipitation levels, but climate change has resulted in more extreme weather events in recent years. Therefore, engineering dams to withstand the PMF fails to consider current and future risks, an additional concern for overreliance on this engineering standard.

Globally, dam safety legislation is weak. It stresses safety at all stages of a dam’s lifecycle, but recognizing that the probability of a dam failing can never be zero, just how safe is safe enough? And who should be responsible for determining the criteria for “safe”?

This question has led dam safety management to become less of an engineering issue and more of a societal one. As early as 1972, the American Society of Civil Engineers (ASCE) attempted to self-regulate this issue by introducing the idea of risk-informed decision making, but the engineering profession rejected it. In 1986, the US Bureau of Reclamation (USBR), a federal agency overseeing water resource management, including the maintenance of 475 dams, again attempted to bring risk 'onto the table' by releasing guidelines on decision making. However, these guidelines lacked a fundamentally important element: decision criteria. In 1987, ICOLD issued a bulletin that acknowledged that without first assessing the total risk level of a dam, optimally allocating limited resources and funds to improve a dam's safety was impossible. Since these developments, some progress towards risk-informed dam safety management has been made in certain jurisdictions. With its Napoleonic legal framework, the Netherlands has enshrined its risk acceptance criteria in law. The United Kingdom and Australia, both common law societies, have explicitly stated their societal risk tolerance (T. Bennett, personal communication, December 11, 2015; Hartford, 2008; D. Hartford, personal communication, January 15, 2016).

Engineering professionals play an important role in dam safety by providing useful information to dam owners and other interested parties. However, the traditional standards-based approach to dam safety focuses exclusively on the structural integrity of the dam, and neglects to consider important human factors impacting dam safety management, such as intervention, training, and communication. It may also give a false sense of security because it masks uncertainties (McDonald, 2010). Most importantly, prescriptive safety criteria do not reflect society's true risk tolerance. Determining a society's risk tolerance is much more complex than adhering to engineering standards. Societal preferences evolve over time, vary across groups, and trade-offs must always be made between different groups and objectives. To complicate matters further, risk is generally a very poorly understood and highly controversial concept, and there is no universally agreed upon methodology for assessing and managing risks.

Risk assessment is an emerging alternative to the traditional engineering standards based approach to dam safety management. In simplest terms, it is the process of identifying hazards, factors that may exacerbate the likelihood of the identified hazards, and estimating the probability of the hazard occurring and its consequences. While the terms '**risk**' and '**hazard**' often are used interchangeably, it is important to note they are not the same thing. Risks originate from hazards, which is why hazard identification is a crucial component of risk assessment. **Risk management** refers to "the complete process of identifying risks, understanding them, assessing them, and then making decisions to ensure that effective risk controls are in place and implemented. Risk management begins with actively identifying possible hazards leading to the ongoing management of those risks deemed to be acceptable" (Wilson, Buchanan, & McCutcheon, 2003).

But what exactly is risk? Technically, risk is defined as the product of the probability of an event (the hazard), and the consequences of that event. Mathematically, this is expressed as:

$$Risk = \sum_{i=1}^{n} f_i \cdot x_i$$

Equation 1: Mathematical Expression for Multi-hazard Risk

For n hazards, f_i is the frequency of the hazard, and x_i is the consequence of the hazard. Risk can be quantified as an annual monetary expenditure, deaths per year, injuries per year, and so on.

We are exposed to risk every day, even in the most mundane situations, such as traveling by vehicle or walking on a sidewalk. Risk of harm, whether it be economic, environmental, injury, death, or some combination of these, can never be fully eliminated. Often, risks can be drastically reduced to a minimal level that approaches zero. An extreme example would be mandating the maximum speed limit on a particular passage of road to be no higher than ten kilometres per hour. With this restriction, driving-related fatalities and injuries would likely be eliminated, but public opposition guarantees this risk-reducing measure would never be implemented. The implication is that some risks are acceptable to the public in certain amounts. In the case of dam safety, a standards-based approach to dam safety often achieves small reductions in risk at a high cost, and can lead to overinvestment in dam safety and over-engineering.

The fundamental benefit of a risk-based approach to dam safety is that it looks at the dam as a system and has the ability to consider multiple **failure modes** and combinations of events (T. Bennett, personal communication, December 11, 2015). However, a risk-based dam safety regulatory system takes an immense amount of time, dedication, and money to develop and implement, as will be discussed in the New South Wales case study in Section 4.

Despite its challenges and complexity, there is growing recognition globally surrounding the merits of a risk-based approach to dam safety. For dam owners, it promotes efficient use of resources by allocating them to the highest risk areas first, and provides the flexibility to control risks through both capital and non-capital investments (Demal, 2012). This report does not intend to dictate what risk analysis methodologies should be used when assessing a dam's safety, nor is it an attempt to establish the tolerable levels of individual and societal risk for those living downstream of dams throughout the province. These are feats that require extensive analysis and public engagement. However, addressing existing gaps in regulation will increase FLNRO's likelihood of successfully transitioning to a risk-based system in the coming years, and will provide other benefits identified in the best practice findings of the jurisdictional scan in Section 4.

1.3.1 Implications for Regulators

The social and political implications of moving to a risk-based approach to dam safety management cannot be underestimated. Not long ago, it was unthinkable to even consider the possibility a dam may fail. In the dam designer's opinion, the probability their structure will fail is zero (D. Hartford, personal communication, January 15, 2016). To transition from this notion of zero failure to acknowledging and even accepting certain amounts of risk is a significant cultural shift that cannot occur overnight.

For regulators, risk-informed regulation can further policy innovation and foster industry-developed risk management strategies. The trade-off is that risk-based dam safety is much more complex to regulate than the traditional engineering standards approach. Since risk-based regulation necessitates a **meta-regulatory** approach, monitoring compliance is much more difficult.

1.4 Regulation of Water Dams in British Columbia

Dams are abundant within British Columbia, and serve many important functions, ranging from mining waste containment to generating electricity. Seventy-nine hydroelectric dams, owned and maintained by BC Hydro, currently supply approximately 90% of the province's electricity needs (BC Hydro, 2015).

The objective of BC's water dam safety regulation is to mitigate the potential loss of life and/or property and environmental damage from a dam failure by requiring dam owners to: 1) regularly inspect and performance maintenance on their dams and 2) report any incidents and take remedial action as appropriate (Association of Professional Engineers and Geoscientists of British Columbia, 2014). Water dams first became regulated in British Columbia with the introduction of the *BC Dam Safety Regulation, 2000,* under the *Water Act.* This regulation remained in place until February 2016, when the introduction of the *Water Sustainability Act* repealed the *Water Act* and all regulations under it. On February 29th, 2016, the new regulation, *BC Dam Safety Regulation, 2016,* came into effect. A number of changes were made when the dam safety regulation was updated, including[10]:

- Updating the definition of a "dam" to include dams that capture groundwater
- Expanding the emergency plan requirements to mandate dam owners to share information with local authorities
- Requiring dams with multiple owners to designate a single primary contact
- Requiring owners of higher risk dams located on public-accessible land to post emergency contact information on site
- Requiring all dam owners to review downstream conditions on a consistent basis to ensure an accurate consequence classification
- Replacing the term 'professional engineer' with 'engineering professional', allowing persons holding an APEGBC limited license to conduct legislated dam safety reviews

[10] Summary of changes sourced from (GovTogetherBC, 2015)

Regulated dams require a water license to operate under the *Water Sustainability Act* and must abide by the requirements of the *Dam Safety Regulation, 2016*. Whether or not a dam is regulated, and whether it is subject to the entire regulation, depends on its height and storage capacity when the **reservoir** is at its full supply level. In the regulation, dams are classified on a scale according to the expected adverse consequences to human life, property, and the environment if they failed. Dam owners, not the regulator, are responsible for estimating the potential consequences should their dam fail and classify their dam accordingly. Dam owners self-report their dams' respective safety status at regular intervals, the frequency of which varies by the dam's consequence classification. In addition, dam owners are required to outline the actions they have taken since the last reporting period to ensure the safety of their dams.

All dams classified as significant, high, very high, or extreme consequence are subjected to the entire regulation regardless of their height or storage capacity (FLNRO, 2012). The following diagrams illustrate the distribution of regulated water dams in the province, and what dams the regulation applies to:

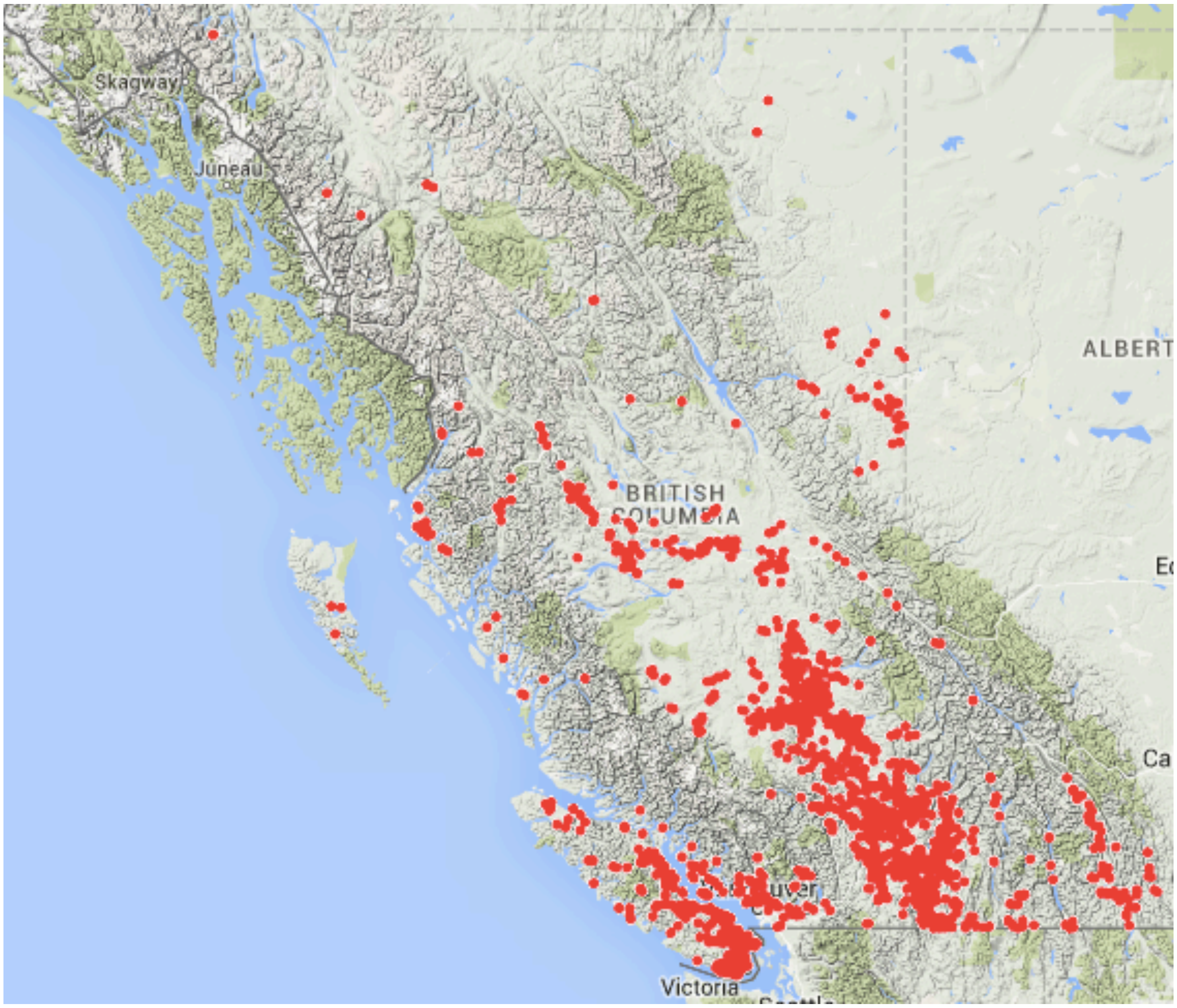


Figure 2: Distribution of Regulated Water Supply Dams in BC

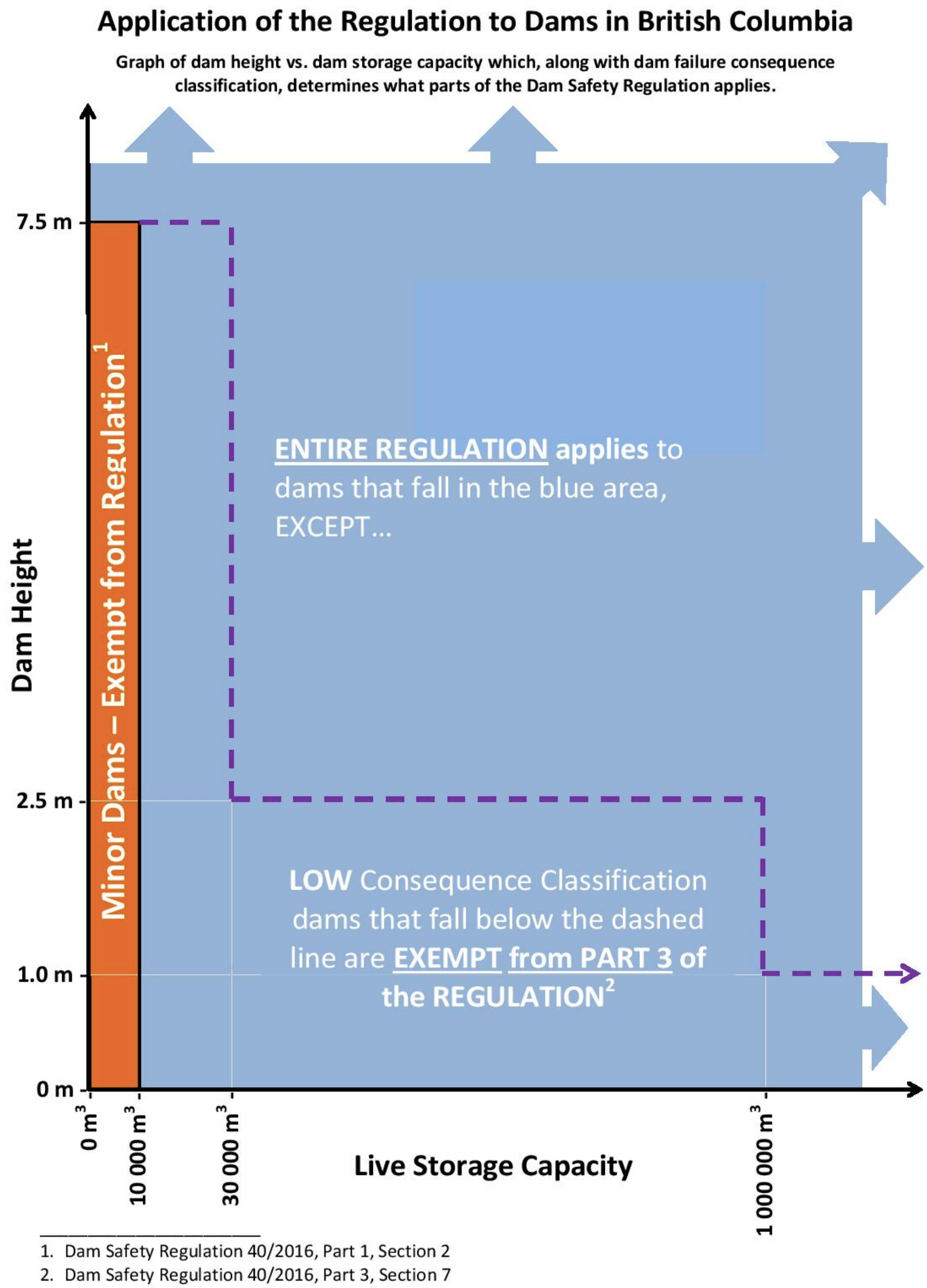


Figure 3: Eligibility of Water Dams for the BC Dam Safety Regulation

As of April 2016, 1,880 dams are regulated under the *Dam Safety Regulation, 2016* in British Columbia. Of these, 1,520 are subject to all sections of the regulation. There are 380 dams classified as high, very high, or extreme consequence that are the primary focus of the regulation requiring audits every five years, 555 dams classified 'significant' that are subject to audits once every ten years, and 585 dams with a consequence classification of 'low' that are not subject to regulator audits. (FLNRO representative, personal communication, April 5, 2016).

As with the rest of Canada, dam failures in the province have been relatively rare. From 1980 until 2010, an average of one dam per year failed (Ministry of Environment, 2010). When dams do fail, however, the consequences can be devastating. Dam failure can lead to loss of life, injuries, environmental and cultural impacts, disruptions to the population inhabiting the affected area, property damage, and economic losses (Canadian Dam Association, 2007).

These thousands of dams across the province pose varying severities of consequences should they fail. These consequences can range from inconvenient, such as flooding a golf course, to catastrophic with the potential of thousands upon thousands of fatalities. To illustrate an extreme example, the Mica dam is an earth-fill hydroelectric dam located on the Columbia River constructed in 1973. Standing at 240 metres tall, it is one of the largest earth-fill dams in the world. If this dam collapsed, it has the potential to destroy all downstream communities as far south as Portland, Oregon (D. Hartford, personal communication, January 15, 2016).

1.4.1 The Dam Safety Program

The compliance and enforcement portion of the dam safety regulation is carried out through the British Columbia Dam Safety Program (BCDSP), administered by the Water Management Branch of the Ministry of Forests, Lands, and Natural Resource Operations (FLNRO) (FLNRO, 2014).

Figure 4: Organizational Structure of the BC Regulator

The BCDSP "works to reduce risks associated with the design, construction, operation, maintenance, removal, and/or decommissioning of a dam" (FLNRO, 2016). It is comprised of staff known as Dam Safety Officers (DSO), who are defined in the *Dam Safety Regulation*, 2016 as "an engineer or an officer who is designated in writing by the comptroller." Dams spanning nine metres in height or greater are overseen by DSO staff based in Victoria, while dams less than nine metres are overseen by smaller, regionally focused offices. Five DSOs are based in the Victoria office and comprise the Dam Safety Section. The resulting DSOs are dispersed across the province in regional offices, with one DSO per office.

DSOs are the closest point of contact the dam owner has with the regulation. The responsibilities of DSOs include approving consequence classifications proposed by dam owners, remediation plans, invasive investigation plans, decommissioning requests, et cetera. DSOs also conduct regularly scheduled audits according to a dam's consequence rating to ensure the dam owner is in compliance with the regulations. During an audit, the DSO will complete a checklist (see Appendix B), which includes determining whether the dam's current consequence classification is appropriate. DSOs rely on a FLNRO-produced guidance document for determining consequence classification suitability, based on the CDA guidelines and collective experience (FLNRO, 2016).

1.4.2 Policy Problem

Through my interviews and literature review, I identified several problematic aspects of the current regulatory environment for water dam safety in British Columbia. For fear of the public perceiving it to be irresponsible use of public money, the BCDSP does not participate in an adequate amount of interjurisdictional learning opportunities that could assist its DSOs in keeping up-to-date with the latest industry best practices for dam safety management (Retired BC Engineer, personal communication, January 15, 2016). The current directory of DSO staff indicates that two out of twelve DSOs possess a professional engineering designation (FLNRO, 2016). The BCDSP lacks dam-specific engineering experience, which my interviews with experts confirmed is essential to effective regulation (T. Bennett, personal communication, December 11, 2015; L. McDonald, personal communication, January 19, 2016).

These findings can be summarized by the following policy problem: **"British Columbia lacks sufficient regulatory capacity to innovatively manage water dam safety".**

1.4.3 Limiting the Scope of Problem

Tailing dam safety will not be a focus of this report for a number of reasons. The recent Mount Polley incident has resulted in tailings dams already receiving considerable attention from government and other relevant parties. Tailings dams are inherently less safe structures than water dams due to being built up over long periods of time (in the case of the Mount Polley tailings dam, it was built up over approximately eighteen years before it failed). In contrast, usually the construction of even a large water dam takes only a few years in most cases (T. Bennett, personal communication, December 11, 2015; Hoffman, 2015). Tailings dams are regulated under the *Mines Act* and the *Health, Safety and Reclamation Code for Mines in British Columbia* (HSRC), administered by the Ministry of Energy and Mines (MEM). while water dams are regulated completely separately under the *Water Sustainability Act* and the *Dam Safety Regulation*.

In January 2015, the Mount Polley review panel, an independent panel comprised of three geotechnical experts, released their final report outlining the cause of the TSF failure, as well as a number of recommendations aimed at reducing the likelihood of subsequent tailing dam breaches. In December 2015, the BC Chief Inspector of Mines released a report detailing the root and proximate causes of the failure. This report also included many recommendations applicable to the regulator, mine operator, professional organizations, and industry. The lessons learnt from the Mount Polley incident are valuable and can, in some cases, be applied to the regulation of water dams as well. The findings that are relevant to water dams will be discussed in Section 5.

2. Methodology

2.1 Literature Review

To gain an understanding of the current regulatory environment in British Columbia surrounding dam safety, as well what the key drivers of changes in regulation across Canada have been, I conducted a literature review. The literature also helps gain an in-depth understanding of the most current risk-informed approaches to dam safety. The literature includes academic articles as well as conference proceedings and papers sourced from the Canadian Dam Association’s member portal. As well, I incorporate reports from various organizations such as ICOLD, APEGBC, and Environment and Climate Change Canada.

2.2 Expert Interviews

Expert interviews help to narrow and define the policy problem, inform my jurisdictional scan, and identify policy options. Interview participants included:

- Director of Dam and Public Safety, Ontario Power Generation and President of the Canadian Dam Association
- Principal Engineering Scientist, Dam Safety, BC Hydro
- Dam Safety and Risk Consultant, Australia
- Reservoir Safety Manager, Environment Agency, England
- Retired Engineer, British Columbia
- Engineer, Manitoba Hydro
- Dam and Reservoir Engineering Specialist, New Zealand
- Representative, FLNRO

I conducted eight interviews in total. Potential interview participants were identified through the literature review, media scans, direct referrals from my supervisor, and through the snowball sampling method. Once identified, potential interviewees were invited to participate through an email introduction explaining my project. The interviews were semi-structured, utilizing both informal discussion on the topic and questions directly from my interview guide. Appendix A contains a copy of the general format I used to conduct interviews. Interviews were conducted in person, by phone, or through a written questionnaire sent by email.

2.3 Jurisdictional Scan

To identify best practices associated with dam safety regulations and identify potential policy options, I conducted a jurisdictional scan, supplemented by interviews with individuals familiar with the dam safety scheme of the jurisdiction in question.

2.3.1 Criteria for Selection of Case Studies

The selected cases all exhibit aspects of risk-based regulation, meta-regulation, and regulatory excellence. Great Britain, the Australian state of New South Wales (NSW), New Zealand, and the Netherlands were consistently mentioned when I asked experts about jurisdictions with progressive and best in class regulation pertaining to dam safety.

Great Britain, NSW and New Zealand were selected because of their use of a common law system, which aligns with British Columbia's legal framework. As constitutional monarchies, they also align with British Columbia politically. The Netherlands presents many challenges due its use of the Napoleonic legal system, although its political structure is similar to that of British Columbia. The selected cases have comparable levels of GDP per capita, which is meant to act as a proxy for well-being. This is important because wealthier jurisdictions should have more resources to devote to ensuring dam safety, while a less well-off area is more likely to be focused on more urgent issues such as water quality.

3. Research Findings

3.1 Implications for Regulation: Dam Specific Issues

Dams are inherently complex structures, with long lifespans. The majority of dams in Canada were constructed during the 1950s, 1960s, and 1970s, rendering aging infrastructure a unique concern. The most recently available data from 2004 states the median age of Canada's large dams is forty years (Environment Canada, 2004). Managing the safety of dams is much more complex than other types of infrastructure, even nuclear energy. Dams are subject to various forces of nature, such as flooding and earthquakes, and are difficult to 'shut down' (D. Hartford, personal communication, January 15, 2016).

There are two features that separate dam safety from other types of regulation in Canada and create the need for special consideration and analysis. The first is the historically small number of fatalities resulting from dam failure. In Canada, five recorded dam failures have resulted in just eleven fatalities, the last incident occurring over fifty years ago in 1963 (Bennett, 2014). This notable absence of catastrophes contrasts sharply with other risk-exposed industries in Canada. As a result, it is difficult to get dam safety regulation onto the policy agenda, as provincial governments grapple with more salient issues. This lack of available measurable results also makes reforms more difficult to evaluate for effectiveness. Historically, disasters have acted as a catalyst for policy change by focusing the public's attention on a particular issue. The West Ray Mine disaster of 1992, where twenty-six miners were killed in a methane gas explosion in Nova Scotia, led to the creation of Bill C-45, increasing the criminal liability bore by organizations (T. Bennett, personal communication, December 11, 2015). Considering the relatively small number of dam failures that have had serious consequences, it is perhaps then not surprising Canada's lack of progress in dam safety legislation thus far. This warrants examination of the best practices for dam safety regulations in other jurisdictions. It must be recognized that while dam failures are rare, the probability of the structure failing can never be zero. Therefore, it is important to strive for proactive, rather than reactive, regulation (Hartford, 2009; L. McDonald, personal communication, January 19, 2016).

Another unique feature of dam safety is the nature of the risk associated with the presence of dams in communities. Urbanization and watershed development has led to increased development in dam breach inundation zones (Environment Canada, 2004). Dams can be built upstream of entire communities, exposing residents, businesses, livestock, and major infrastructure to risk. Unlike other sources of risk, avoiding the harms associated with dam breaches are not as simple as choosing to abstain from the activity in question, for example, a risk-averse individual choosing not to skydive. It is known that single events resulting in catastrophic losses are perceived as more problematic than multiple non-catastrophic events, even if the cumulative loss is greater (Hatch & Ontario Power Generation, 2015). Dams are a part of larger communities and serve countless valuable functions, from clean power generation to irrigation, flood prevention to mining waste containment. Dams are even constructed to support recreational activities such as boating and swimming, an important consideration for public safety planning (International Commission on Large Dams). Paradoxically, despite their many functions, dams are largely 'invisible', with minimal public attention devoted to them until something goes wrong. Regulation needs to be structured to protect those residing downstream of dams, since the majority of these downstream residents are usually unaware they are at risk (T. Deakin, personal communication, March 29, 2016).

3.2 Legal considerations[11]

The two most widely used legal systems in the world are the common law system and the Roman/Napoleonic code system. Canada uses the common law system with the exception of the province of Québec, which uses Napoleonic code in line with France. The common law system originated from judicial decisions based on tradition and precedent in England. Parts of Common Law may be unwritten, as precedent is an

[11] The differences between Common Law and Napoleonic code and the resulting implications on the development of risk acceptance criteria are outlined in Hartford, D. (2009). Legal framework considerations in the development of risk acceptance criteria. *Structural Safety, 31*(2), 118-123.

important consideration. Common law is based on the principle that unless it can be justified in court, what is not explicitly allowed is forbidden. In contrast, Napoleonic code explicitly defines what is unlawful and the corresponding penalties.

A society under common law will view, analyze and manage risk very differently than one under Napoleonic code or another system. In the Netherlands, a Napoleonic society, the courts have consistently returned the verdict that if the government seeks to impose stricter rules, it should do so through the law rather than relying on due diligence. In common law jurisdictions, the **ALARP** principle applies, leading due diligence to play a prominent role. This approach to managing risk, which has origins in the United Kingdom and has been enshrined in UK case law since 1949, implies risk must always be averted until there is a gross disproportion between the costs (referring to money, time, or effort) and benefits of doing so (Ale, Hartford, & Slater, 2015). In a common law context, the accuracy of analysis is not as important as would be in a Napoleonic setting. Rather, the importance lies in successfully demonstrating the gross disproportion after the fact in a court of law.

In 1978, as a result of a Supreme Court decision, due diligence was permitted as a defence for charges relating to health, safety, and environment statutes. Prior to the ruling, these cases were regarded as absolute liability, rendering it practically impossible to defend against such charges. Public welfare regulatory charges are now treated as strict liability, which allows the due diligence defence. This promotes a high standard of care amongst duty holders, because liability can be avoided if they are able to demonstrate they took reasonable care to prevent the event (Wilson, Buchanan, & McCutcheon, 2003).

3.3 Regulatory Excellence Literature

With mastery, we maintain regulation's unique attributes: expertise and objectivity. Without it, regulation risks becoming just another governmental body to be lobbied.

- Scott Hempling, Regulatory Literacy

The purpose of British Columbia's Dam Safety Regulation is social, with the goal of protecting people, property, and the environment from adverse effects associated with the presence of dams in wider communities. Dam owners grapple with an inherent conflict of interest, between their duty to not inflict harm on the greater public and their own financial self-interest, as dams require time, money and resources to maintain over their entire lifecycle. It is the regulator's duty to ensure the public interest is not harmed as a result of the dam owner's self-interest. The extent to which the regulator is effective at this is largely dependent on their ability to recognize when the dam owner should be challenged.

In 2014, the Alberta Energy Regulator (AER), Alberta's exclusive energy development regulator, launched a 'best-in-class' project with the objective of determining what constitutes regulatory excellence. To find out, the AER independently convened the Penn Program on Regulation at the University of Pennsylvania. Over one hundred and fifty participants with extensive interest and knowledge in oil and gas regulation and regulation more broadly took part in four dialogue sessions, resulting in a final report that identified several high-level principles that are applicable to all regulatory disciplines.

To assist regulators in achieving regulatory excellence, a checklist is provided, comprised of questions to the regulator can ask themselves. Divided into several functional areas, the items that are relevant to the policy problem are listed in Appendix C. These high-level principles will be useful when evaluating the policy options identified in Section 7.

4. Jurisdictional Scan

Table 1: Jurisdictional Characteristics

Jurisdiction	***British Columbia***	***New South Wales***	***Great Britain***	***New Zealand***
Population (2015)[12]	4.68 million	7.62 million	62.8 million	4.51 million
Area (km^2)	944,735	809,444	209,331	268,021
Political Structure	Constitutional Monarchy	Constitutional Monarchy	Constitutional Monarchy	Constitutional Monarchy
Legal System	Common Law	Common Law	Common Law	Common Law
GDP Per Capita (2014, CAD $)[13]	$51,136	$63,613	$60,130[14]	$57,536

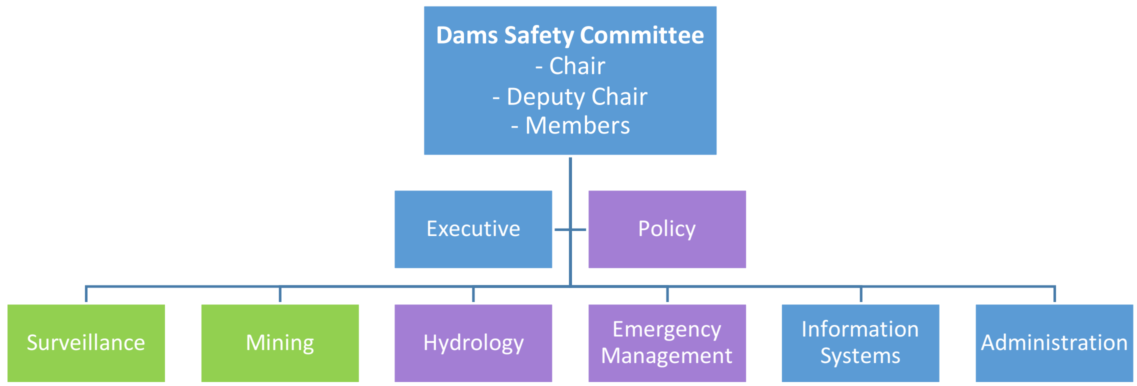
[12] *Statistics Canada, Australian Bureau of Statistics, Office for National Statistics UK*
[13] *World Bank, Statistics Canada. Converted to Canadian dollars using March 2016 exchange rates*
[14] Includes Northern Ireland

4.1 New South Wales, Australia

4.1.1 Background

Like Canada, dam safety is a state level matter in Australia. NSW is a state on the southeastern coast of Australia with tens of thousands of dams. Water supply dams and tailings dams are both regulated under the same scheme. Like British Columbia, NSW's dams vary in size substantially, from small dams located on farms to major water supply and hydroelectric dams such as the Warragamba dam that stands 351 metres high and supplies water to 3.7 million residents of the Sydney area (Dams Safety Committee, 2011; WaterNSW). NSW passed its *Dams Safety Act* in 1978. The following year, the Dams Safety Committee (DSC) commenced operations. In 1987, the Australian National Committee on Large Dams (ANCOLD), Australia's equivalent to the CDA, began preparing its guidelines on risk assessment, releasing them in 1994. The following year, NSW Labor, a branch of the Australian Labor Party, came into power in NSW, and continued to hold power for the next sixteen years, which was conducive to the DSC developing the risk-informed framework. In the summer of 1997, the first ever international meeting on the topic of dam risk assessment was held in Norway, with two DSC members and its Executive Engineer in attendance. By May 2002, the DSC had officially decided to pursue a risk-based approach to dam safety regulation by preparing a position paper on the topic. The NSW government endorsed the DSC's risk management policy framework in 2006, and in 2010 the DSC published its updated guidance sheets, fully implementing the risk-based approach. The DSC was the first regulator in the world to successfully incorporate this approach, including public safety tolerability criteria, into regulatory practice (McDonald, 2013).

4.1.2 The Dams Safety Committee[15]



Green: standing sub-committees

Purple: ad-hoc sub-committees

Figure 5: Structure of the Dams Safety Committee

Under the Dams Safety Act, 1978, The DSC is an independent, nine-member statutory body whose membership is sourced through nominations, with one member appointed as chairperson of the DSC by the Minister. It is supported by several sub-committees, which are comprised of experienced individuals including university professors and engineering consultants. Reporting directly to the Minister responsible for Primary Industries, and for Lands and Water, the DSC is responsible for:

- Monitoring the safety of prescribed dams
- Gathering information and keeping records about prescribed dams
- Reporting to the Minister on the safety of prescribed dams
- Recommending new dams to be prescribed under the *Dam Safety Act, 1978*

The DSC is comprised of members nominated by various organizations, including a hydroelectric corporation, water suppliers, and the Federal Council of the Institution of Engineers, Australia. It is important to note that members are independent

[15] Information about the composition and functions of the DSC were sourced through (Bradlow, Palmieri, & Salman, 2002), and the *Dams Safety Act, 1978 No. 96.*

and do not represent or act in the interest of the organization that nominated them. Section 8(3) of the *Dams Safety Act, 1978* states *"*A person shall not be nominated for appointment as a member unless the person is, in the opinion of the person making the nomination, experienced in dam engineering", with the exception of the member nominated by the Minister administrating the *Mining Act, 1992* to provide mining expertise. The DSC meets and consults together regularly, and are assisted by a staff of ten people providing administrative, financial, and technical support.

The DSC has statutory functions under both the *Dams Safety Act, 1978* and the *Mining Act, 1992*. While there are many thousands of dams in NSW, the DSC governs only a small portion of them, known as "prescribed dams", currently numbering three-hundred and eighty. These dams are listed in Schedule 1 of the *Dams Safety Act, 1978*. The DSC has the authority to order owners of prescribed dams to conduct surveillance, take measurements, and collect information, and provide the DSC with the findings from these actions. If the dam owner fails to fulfill their responsibilities, the DSC has authority to undertake the requested actions themselves and recoup the associated costs from the dam owner. If the DSC believes a prescribed dam is unsafe or likely to become unsafe, it has the power to issue a notice requiring the dam owner to take the actions specified in the notice in order to make or keep the dam safe. The owner is obligated by law to comply with the order.

The DSC relies heavily on the expertise and diligence of the engineers engaged by the dam owners for design, surveillance and safety reviews. Dam owners are required to send design and construction reports to the DSC in addition to surveillance reports, safety reviews, and emergency plans, but the DSC does not actually approve these documents or plans. Rather, if the DSC notices an issue of concern, it challenges the dam owner to demonstrate more fully that their proposal is adequately safe.

4.2 Best Practices from NSW[16]

4.2.1 The Regulator as an Expert

The DSC, with the exception of one member, is comprised of individuals with extensive prior experience and expertise in dam engineering. This is beneficial because it ensures the committee tasked with ensuring the safety of the prescribed dams understands the risks and complexities associated with dam safety management. The DSC members serving during the year of 2014-2015 had an average of thirty-two years of experience in dam engineering, or a combined two hundred and eighty-five years of experience (Dams Safety Committee, 2015). Additionally, the expertise and experience of the DSC allow it to recommend dams to be prescribed, and therefore regulated, under *the Act* based on the dam's failure consequence classification, rather than to regulate dams based on arbitrary minimum height and/or volume requirements. All dams classified as significant, high and extreme consequence are prescribed, as well as low consequence dams over fifteen metres in height. This saves valuable time and resources for the regulator, and ensures that the dams that pose a credible threat to public safety and the surrounding environment are being appropriately monitored.

In addition to being extremely experienced in dam engineering, the dedication of DSC members was demonstrated during the development and implementation of the risk-based approach to dam safety regulation, which took approximately a decade to develop. During this period, the DSC was provided with no additional resources to assist them with this task. Some DSC members and staff put in long hours of their own time to develop this new approach to regulation, and traveled internationally with their own funds.

4.2.2 Independence, Transparency, and Accountability

The DSC is an independent statutory body reporting directly to the Minister. This reduces the potential for political and other interests to get in the way of ensuring dam

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[16] Leonard McDonald, Dam Safety and Risk Consultant and former DSC chairman provided invaluable insight into what, in his personal opinion, are the best practices of NSW's dam safety regulation.

safety. The alternative approach of an advisory group within a government agency is more likely to be influenced by considerations beyond dam safety (L. McDonald, personal communication, January 19, 2016).

The DSC is a not-for-profit corporation, but shares many characteristics with the typical, for-profit entity, including an emphasis on human capital development, performance evaluation, strategic planning, and financial performance. It produces an annual report that the Minister tables in the parliament, and which is viewable to the public via its website. In this report, the DSC outlines their objectives, achievements, stakeholder engagement initiatives, and future plans. Also included in the report is an exhaustive list of the DSC's annual performance targets and how the DSC performed in each performance area during the year according to both qualitative and quantitative performance indicators. The publication of a comprehensive annual report holds DSC accountable to its stakeholders and the general public.

4.2.3 Goals-based Regulation

The DSC sets broad goals for the safety of its prescribed dams, giving the dam owner flexibility and autonomy in how it achieves these goals. The dam owner must keep the risks of their dam within the tolerable region and demonstrate they are **ALARP**. For example, a dam owner could satisfy the DSC's tolerable risk requirement a number of different ways, utilizing the expertise of engineers and consultants to estimate risks and the costs and benefits associated with risk-reducing initiatives to arrive at the decision that best serves their interests and makes the most sense for their unique circumstances.

Rather than set prescriptive standards telling dam owners exactly what to do, the DSC relies on the dam owner to demonstrate their proposed or existing dam is adequately safe, and works on a challenge basis only. In this context, "safe" means the dam complies with the DSC's current requirements, set out in a series of guidance sheets (Heinrichs, 2011). This cooperative approach can also be attributed to the very nature of the *Dams Safety Act, 1978.* By structuring the DSC as an independent committee advising the minister, it avoids enshrining a definition of dam safety in legislation, eliminating the problem of the regulation becoming overly prescriptive. Additionally, leaving standards-based stipulations out of legislation provides dam owners with more flexibility, and ensures regulations do not become easily outdated (L. McDonald, personal communication, January 19, 2016; T. Bennett, personal communication, December 11, 2015).

4.2.4 A Culture of Collaboration, Cooperation, and Continuous Improvement

The DSC considers and successfully incorporates an important aspect of dam safety management: stakeholder engagement. The DSC formally recognizes the importance of developing and maintaining a good relationship with owners of prescribed dams, and believes educating dam owners about their liability, responsibility, and the broad goals of the DSC will increase their willingness and likelihood to comply (Dams Safety Committee, 2015). The DSC offers regular training courses around the safe operation of water, tailing, and ash dams. Whilst formulating its guidance sheets between August 2006 and June 2010 following the government endorsement of the risk-based approach to dam safety regulation, the DSC held two stakeholder engagement sessions with dam owners, consultants, regulators from other agencies, and legal advisors, and elicited comments on draft versions of the guidance sheets during a feedback period.

The DSC is heavily involved with both ICOLD and ANCOLD. The DSC is a member of ANCOLD and has members and staff in attendance at every conference, and DSC members have served on the ANCOLD Executive and Secretariat. DSC involvement with ICOLD and participation in their annual meetings is very routine as well. Len McDonald, a former DSC member, credits the DSC's involvement with ICOLD and ANCOLD with creating an "international network which drew in and shared knowledge from many sources" (personal communication, January 19, 2016). The DSC also takes continuing the education and professional development of its members and staff very seriously – the topic is covered extensively in their annual report.

4.3 Pending Regulatory Changes

In May of 2012, the Commission of Audit advised the NSW government that the cost effectiveness of dam safety improvements mandated by the DSC warranted examination, and KPMG, an external consulting firm, was commissioned to conduct a review of *Dams Safety Act, 1978* and the DSC. The culmination of this was the *Dams Safety Bill, 2015,* new legislation intended to update and replace the *Dams Safety Act, 1978.* The bill passed parliament on September 17th, 2015 and received assent on September 28th, 2015. However, except for Clause 5 of Schedule 2, the new act is not yet in force. The Minister has stated an interim dam safety advisory committee will be appointed to set new 'standards' for dam safety, though it is unknown when this committee will come into force. As of early March 2016, the DSC continues to exist and operate under the *Dams Safety Act, 1978* (Blair, 2015). Due to the timing of research and lack of information surrounding how dam safety management under the new act will materialize, I examine the best practices from NSW's dam safety regulatory environment under the authority of the well-established *Dams Safety Act, 1978* only.

4.4 Great Britain

4.4.1 Devolution and country specific regulation

Four countries comprise the United Kingdom: England, Scotland, Wales, and Northern Ireland. As of March 2016, *The Reservoirs Act, 1975* is in force in Great Britain (England, Wales, and Scotland). Northern Ireland did not have statutory regulation pertaining to reservoirs until the introduction of the country-specific *Reservoirs Act (Northern Ireland), 2015,* administered by the Department of Agriculture and Rural Development.

Recently, the UK government introduced the concept of 'devolution', which enables specific countries within the UK to create their own regulation and statutory instruments to customize reservoir regulation for each country's unique needs (T. Deakin, personal communication, March 29, 2016). This has resulted in England and Wales each have different amendments and interpretations of the *Reservoirs Act, 1975.* Scotland passed its own legislation, *Reservoirs (Scotland) Act 2011,* which is scheduled to come into full effect by April 2016.

Due to these differences and recent and upcoming changes to localized regulatory systems, Great Britain's dam safety regulatory framework will be examined from the perspective of England only. This is because I have conducted an interview with a representative from the Environment Agency, the regulator in England, and consistently reference the Institution of Civil Engineers' 2014 publication *A Guide to the Reservoirs Act, 1975*, which provides guidance for the Act as it applies to England only.

4.4.2 Background[17]

Great Britain experienced several catastrophic dam failures during the late nineteenth and early twentieth century. Most notably, the Dale Dyke failed in 1864, resulting in two-hundred and fifty fatalities and destroying almost eight hundred houses in Sheffield, England. In 1925, the Skelmorlie, Eigiau, and Coedty dam failures in Scotland and Wales respectively led to the passing of the *Reservoirs (Safety Provisions) Act* five years later in 1930, the first form of dam safety legislation in the UK.

The current version of this legislation is the *Reservoirs Act, 1975*. The act does not explicitly make much mention of safety. In line with common law tradition and the precedent set by the *Rylands v Fletcher* case mentioned in Section 1, it is engineers' responsibility to identify and correct dams they deem unsafe, by whatever definition of 'safe' they subscribe to (D. Harford, personal communication, January 15, 2016).

In 2007, heavy rains and flooding caused a partial failure of the Ulley dam in South Yorkshire, England, leading seven hundred people to evacuate the area in anticipation of a complete failure (Horrocks, 2010). While this was fortunately averted, this near miss focused the public's attention on the multitude of aging dams across the UK. The resulting Pitt Review highlighted the benefits of risk-based dam safety regulation, which materialized in the *Flood and Water Management Act, 2010.*

4.4.3 Regulatory Framework

Dam safety in the England is viewed from the perspective of **reservoir** safety. The preamble to the *Reservoirs Act, 1975* states it is "an Act to make further provision

[17] The historical perspective on reservoir safety in the UK is sourced from (Institution of Civil Engineers, 2014).

against escapes of water from large reservoirs or from lakes or lochs artificially created or enlarged" (Institution of Civil Engineers, 2014). As a dam failure would likely result in the most hazardous escape of water from a reservoir, reducing the risk of dam failure is inherently an objective of the legislation.

Four distinct groups, each with unique responsibilities and powers, are recognized in the *Reservoirs Act, 1975*:

Undertakers possess ultimate responsibility ensuring the safety of the reservoir. They are the person(s) using the reservoir for a certain purpose. For a reservoir with no particular purpose, the undertaker is usually the owner or lessee of the reservoir. Undertakers are responsible for registering their reservoir with the appropriate enforcement authority, keeping a record of their reservoir, and employing qualified civil engineers (QCEs) for certain tasks.

Enforcement authority refers to the authority responsible for enforcing the Act. In England, the Environment Agency (EA) is the enforcement authority. The agency's duties are mostly administrative and legal in nature, but extend to both reserve and emergency powers it can exercise if needed. In cases where the enforcement authority is also the undertaker, the Secretary of State is responsible for ensuring compliance.

The Secretary of State serves various functions including overseeing enforcement authorities, appointing QCEs, and creating statutory instruments under section 5 of the *Act.* Currently, the Department for Environment, Food, and Rural Affairs (DEFRA) is the Secretary of State for England.

QCEs are civil engineers that are appointed to several panels the Secretary of State runs under section 4 of the Act. They are responsible for the design and supervision of newly constructed or modified reservoirs, the supervision of safety measures, and the ongoing inspection and supervision of reservoirs.

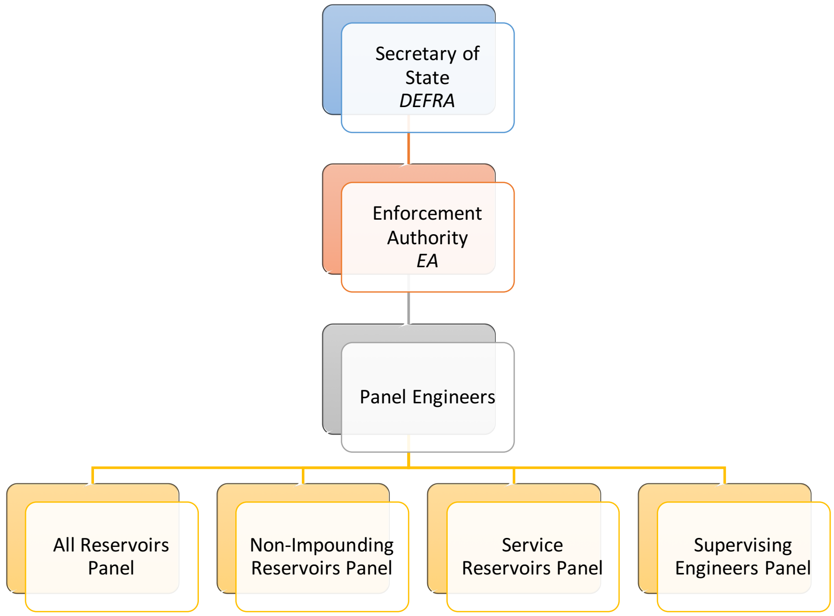

Figure 6: Regulatory Environment for Dam Safety in England

The panel structure is determined by the Secretary State, and is currently set up as shown in Figure 6. QCEs part of the All Reservoirs, Non-Impounding Reservoirs, and Service Reservoirs Panels are qualified to design reservoirs, supervise their construction, and inspect different types of reservoirs. QCEs in the first three panels are also able to work as supervising engineers for any reservoir. The panel structure relies on engineers' personal knowledge of their experience and qualifications and their professional judgement in deciding whether are adequately qualified to undertake a certain responsibility. Reservoir undertakers are required to commission panel engineers at various stages of their reservoir's lifecycle.

4.4.4 Incorporation of Risk Designation into Legislation

Schedule 4 of the *Flood and Water Management Act, 2010* modified the *Reservoirs Act, 1975,* with these changes coming into force in July 2013. At this time, risk designations were incorporated into the *Reservoirs Act*, as stated here in Section 2C(1):

> *The appropriate agency may designate a large raised reservoir as a high-risk reservoir if*
>
> *(a) The appropriate agency thinks that, in the event of an uncontrolled release of water from the reservoir, human life could be endangered, and*
>
> *(b) The reservoir does not satisfy the conditions (if any) specified in regulations made by the Minister.*

The appropriate agency depends on which country the reservoir is located within. The EA has decided the condition specified in section 2C(1)(a) is valid if any one of the following conditions is satisfied:

1. Loss of life is likely to be greater than or equal to one
2. For individual properties, the water flow rate is greater than or equal 3 m^3/s per metre.
3. Likely loss of life is calculated to be between 0.8 and 1, and a significant downstream population is at risk of flooding. ‘Significant’ is usually defined to be over two hundred people or twenty businesses downstream, though the EA may apply the precautionary principle in some cases.

The provision of risk designation modified the undertaker requirements under the *Reservoirs Act, 1975*. Non-high risk reservoir owners are not required to appoint a supervising engineer or inspecting engineer, something that is required for high-risk reservoirs. A construction engineer is required for construction and alterations of reservoirs regardless of the risk designation (Environment Agency, 2016).

As of April 2016, the Environment Agency is still in the process of designating reservoirs as ‘high-risk’ or ‘not high-risk’, but expects to classify approximately 10% of its 2,002 regulated reservoirs as not high-risk (T. Deakin, personal communication, March 29, 2016).

4.4.5 The Health and Safety Executive's Role in Reservoir Safety

The Health and Safety Executive (HSE) is the independent watchdog for work-related hazards in Great Britain (England, Scotland, and Wales), established under the *Health and Safety at Work etc Act, 1974.* Under that act, it has created an entire regulatory framework surrounding reducing workplace health and safety incidents. It is a non-departmental public authority within the UK government's Department for Work and Pensions. Accountable to the public, it aims to reduce work-related fatalities and injuries across hazard-creating industries and workplaces. Comprised of scientists, engineers, and analysts, it approaches risk management from a highly scientific perspective.

The HSE is somewhat of an anomaly, as other European nations have tended to let the market handle workplace injury through the utilization of private insurance schemes. The HSE's aggregative approach to workplace safety has been effective, drastically reducing workplace related injuries since its inception in 1975 (Health and Safety Executive, 2015). Despite its legislative powers and extensive scope, the HSE mainly works by guiding the behaviour of its regulatees. The former head, Jenny Bacon, stated, "We have to operate by raising awareness, expectations, and giving expert advice" (Wilkie, 1995).

The HSE is informed by various advisory committees and industry groups, both temporarily and permanently standing. It has issued guidance on how the *Health and Safety at Work etc Act, 1974* applies to both statutory and non-statutory reservoirs. Reservoirs below 25,000 m^3 (those exempt from the requirements of the *Reservoirs Act, 1975)* are inspected by the HSE as per the stipulations of the *Health and Safety (Enforcing Authority) Regulations 1998,* so long as the reservoir is associated with a work undertaking.

The **ALARP** approach to risk management is at the heart of HSE's culture. The HSE has stated that any regulatory action, approved code of practice, or guidance issued should be in line with what is 'reasonably practicable'. In essence, determining whether a risk is ALARP necessitates weighing the risk against the sacrifices associated with reducing the risk. To avoid reducing the risk, the duty holder must show that the sacrifice is grossly disproportionate to the benefits associated with the risk reduction measure.

The fact that a major regulatory body in UK takes this innovative approach to safety has significant implications for reservoir safety. The ALARP approach does not mandate committing significant resources to reduce a small amount of risk, which is often the outcome of the traditional standards-based approach to dam safety, described in Section 1.3. Rather, it allows the regulator to set broad goals for regulatees instead of being overly prescriptive. There is nothing preventing duty holders from taking a more stringent approach than what is considered ALARP, if they choose to do so.

The added flexibility afforded to duty holders comes with increased complexity and the need to exercise professional judgement on the part of the regulator, explaining the significant reliance on experts, both within the HSE and the Environment Agency. The HSE has produced numerous guidance documents that assist duty holders in determining whether their risks are ALARP. A drawback of the ALARP approach for duty holders is that determining whether their risks are ALARP is rarely a straightforward process with a clear answer, necessitating the use of judgement (Health and Safety Executive, 2015). It can also be perceived to duty holders as 'risky' in another sense, since they will not know whether the ALARP defence will stand up legally until they find themselves in a court of law.

4.5 Best Practices from Great Britain

4.5.1 Communication and Due Process with the Undertaker

The EA, not the undertaker, is responsible for classifying whether the reservoir is high-risk or not, and must do this as soon as reasonably practicable after the reservoir is registered. The EA utilizes flood maps, inundation mapping, inspecting engineer's reports, and any other relevant information to assign the reservoir a risk designation. If a reservoir meets the minimum volume requirements but is not designated to be high-risk, it is not subject to the full requirements of the Reservoirs Act. However, it must still remain registered with the EA in case its risk designation changes in the future.

In the case of a high-risk decision, *The Reservoirs Act, 1975* mandates the EA communicate to the undertaker the reasons for this provisional designation. If the undertaker disagrees with the decision, they can request the materials that the EA used to make the provisional designation, and can take up to three months to make a representation to the EA. The EA then issues a final risk designation for the reservoir after this representation period. Undertakers have the right to appeal the EA's final designation decision and have their appeal heard by the First Tier Tribunal, an independent body (Environment Agency, 2013).

4.5.2 Public Transparency and Risk Communication

The final risk designation of all reservoirs is published on the EA's website and is viewable to the public, even those that are not designated as high-risk. Under Section 2D of the *Reservoirs Act, 1975,* the EA is required to review the risk designation of reservoirs whenever it has reason to believe the existing designation is not appropriate. The undertaker or any third party can also request the risk designation of a reservoir be reviewed, although the qualifying criteria to initiate the review process have yet to be specified.

The enforcement authority is responsible for maintaining a public register of reservoirs, viewable to the public. The EA's public register of reservoirs is comprehensive including all engineering reports, certificates, and written statements.

4.5.3 Use of Experts

The use of QCEs to carry out the technical aspects of the *Reservoirs Act, 1975* is enshrined in legislation. Each panel is based on different functions, and the scope of each panel is outlined in the relevant statutory instrument. These panels advise the regulator on the technical issues of reservoir safety. The regulator can then 'translate' these findings into language that is understandable to the undertaker, who often does not have a technical background. This panel structure is also beneficial for undertakers who can select the engineer that is right for them (T. Deakin, personal communication, March 29, 2016).

Civil engineers can apply to be a panel member. In their application, the applicant must state their relevant qualifications, the professional institution(s) they are members of, and their employment history. The applicant's prior experience working with reservoirs is emphasized, and they are evaluated by a panel-specific competency matrix. The competency matrix for appointments to the All Reservoirs Panel is contained in Appendix D. The Secretary of State appoints QCEs after consultation with the Institution of Civil Engineers and determining that they are qualified for the specific panel.

Undertakers of 'high-risk' reservoirs are obligated to appoint a QCE from the appropriate panel during the design and construction of a reservoir, restoring an abandoned reservoir, and supervising and inspecting the reservoir at regular intervals. A supervising engineer must be continuously employed by the undertaker, and an inspection engineer employed to conduct a detailed inspection at least once every ten years. Non high-risk reservoirs do not require QCEs for the supervision and inspection functions. Only appointed QCE panel members, not general engineers, can execute the statutory requirements of the *Reservoirs Act, 1975* (Environment Agency, 2016; Institution of Civil Engineers, 2014). A listing of all current QCEs, including their contact information, is publicly available on the EA's website.

4.5.4 Emergency Preparedness

Following the summer 2007 floods, an independent review of how the situation was handled was conducted. The resulting Pitt Report made ninety-two recommendations in total, including updating the *Reservoirs Act, 1975.* The UK government accepted all recommendations and the reservoirs legislation was updated with the passing of the *Flood and Water Management Act, 2010*. The EA completed inundation mapping for every reservoir under the *Reservoirs Act* in England and Wales. These flood maps are available online, allowing the public to become informed about what risks they are exposed to. The 2013 modifications also provided a clearer definition of a flood plan, and what it should include (Environment Agency, 2014).

4.6 New Zealand

I initially identified New Zealand for jurisdictional review due to my interviews with dam safety experts. New Zealand's dam safety system works very well due to the existence of the New Zealand Society on Large Dams (NZSOLD), a technical committee operating under the Institution of Professional Engineers New Zealand (IPENZ), which is

New Zealand's professional engineering body. The main function of NZSOLD is "to advance the technology of dam engineering and support socially and environmentally responsible development and management of water resources." It is comparable to the CDA in that it is a society without any regulatory authority, but the connection to IPENZ subjects it to their governance structure, allowing it to benefit from independent oversight. NZSOLD functions well because it was structured to consider all the broad interests of all stakeholders involved in dam safety from its inception. It hosts a symposium every two years to facilitate information exchange, and a joint symposium with ANCOLD every five years. Both events are well-attended. The dam engineering 'fraternity' within New Zealand is small, which facilitates frequent interactions and knowledge dissemination. There is also a significant effort to ensure the younger generation of engineers learns from their older counterparts, through regularly scheduled young professional events (M. Gillon, personal communication, March 30, 2016).

New Zealand's dam safety system will not be analyzed in detail due its lack of explicit dam safety regulation. Dam safety regulations were developed in 2008, but were revoked in June 2015, before they ever came into force. Considering that British Columbia has regulated water dam safety since 2000, and recently released new dam safety regulations in February 2016, moving to an unregulated scheme is highly improbable.

4.7 Summary of Jurisdictional Scan and Comparison with British Columbia

Table 2: Interjurisdictional Comparison of Regulatory Frameworks

Jurisdiction	British Columbia	New South Wales	England	New Zealand
Regulatory Authority	Province	State	National	Regional Councils
Number of Regulated Dams	1,880	380	2,002	n/a
Input Capacity[18]	0.0064	0.0237	0.0055	n/a
Structure	Departmental program contained within government ministry Centralized main office and smaller regional offices	Independent Statutory Body (legal entity)	Panels of qualified civil engineers, administered by a government ministry	Technical committee for knowledge dissemination under the national professional engineering body No formal regulation
Owner License to Operate Dam	Mandatory	Not mandatory up to ‘maximum harvestable right dam capacity’	Mandatory	Mandatory – by regional authorities
Dam Consequence Classification Category Determination	Dam owner	Regulator	Regulator	n/a
Reliance on Experts Enshrined in Legislation	Limited	Yes	Yes	n/a
Public Register of Dams	Limited	Yes	Yes – extremely detailed	Yes – regional councils are required to maintain a register of dams under the Building Act
Incident Reporting	Mandatory	Mandatory	Mandatory	n/a
Use of Flood Inundation Mapping	Recommended Owner responsibility	Mandatory Owner responsibility	Yes – regulator produced	n/a

[18] Measured by number of regulatory staff per regulated dam.

Table 2 illustrates the major differences between British Columbia's regulatory framework for dam safety and other jurisdictions. Most notable is NSW's and England's use of experts, though the structure and scope of each system differs. In both of these other jurisdictions, the regulator, not the dam owner is responsible for determining the dam's consequence classification, alluding to higher regulatory capacity, likely from the reliance on experts enshrined properly in legislation. This is very different from British Columbia's current approach, which is a small program contained in the Water Management Branch and smaller officers dispersed across the province.

In terms of input capacity, New South Wales has the highest ratio of regulators to regulated dams, at 0.0237 regulators per regulated dam (nine DSC members overseeing 380 prescribed dams). England's input capacity is the lowest, with eleven regulators overseeing 2,002 reservoirs. However, this ratio does not include the 138 supervising engineers and 33 inspecting engineers currently appointed to reservoirs in the country (T. Deakin, personal communication, March 29, 2016). Upon completion of the risk designation process, only 1,800 reservoirs are expected to be classified as 'high-risk' and therefore subject to the majority of the stipulations of the *Reservoirs Act, 1975.* This will increase England's input capacity to 0.0061 regulators per regulated reservoir.

5. Lessons from Mount Polley[19]

5.1 Background of Incident

The Mount Polley Mine is a copper and gold mine located near Likely, British Columbia, located in the central interior of the province. The mine is operated by the Mount Polley Mining Corporation (MPMC), a subsidiary of Imperial Metals. At normal levels of operation, the mine employed four hundred people and processed over twenty thousand kilograms of ore daily (Hoffman, 2015). Prior to the disaster, mining waste (‘tailings’) and water were collected in a tailings storage facility (TSF) located three kilometres southeast of the main mill site. The TSF was contained by three embankments, spanning over four kilometres in length and reaching as high as fifty metres (Ibid).

Early in the morning of August 4th, 2014, the perimeter embankment of the Mount Polley mine TSF gave way, unleashing twenty-five million cubic metres of mining waste and contaminated water into Lake Polley, Lake Quesnel, and Hazeltine creek (Ministry of Environment, 2014). This breach had disastrous consequences, adversely impacting the local economy, First Nation groups, the surrounding environment, and Canada’s mining reputation internationally. An independent review of the incident traced the cause of the breach back to the initial design of the dam. The dam’s foundation was constructed on structurally unsound glacial deposits that were not known about (and therefore not considered in stability tests), leading to a foundational failure (Independent Expert Engineering Investigation and Review Panel, 2015).

[19] All findings and recommendations discussed in this Chapter are contained in (Hoffman, 2015).

5.2 Relevant Findings

As a result of the breach, the Ministry of Energy and Mines' Chief Inspector of Mines launched an independent investigation pursuant to Section 7 of the *Mines Act*, releasing its findings in December 2015, sixteen months after the incident. The resulting report identified the mechanisms for dam failure and dam breach, as well as the root causes of the event, which were all organizational in nature. The Chief Inspector of Mines acknowledges that the failure of a system as complex as the Mount Polley TSF cannot be attributed to a single physical factor. MPMC, the regulator, professional organizations, and hired inspectors all played a role in this event. The report included findings and nineteen recommendations relevant to MPMC, MEM, professional organizations, and the mining industry overall. The findings that are relevant to water supply dams are covered here.

5.2.1 Poor Processes and Policies Relating to Professional Reliance

The Regulator must have the capacity to assess the adequacy of the designer's work product, and when questions arise, must have an appropriate vehicle to receive substantive answers.

p.151

Professional reliance is commonplace many industries, but this is not properly understood or well defined. It can also lead to a false sense of security derived from design parameters. There are no adequate controls to mitigate loss of knowledge as a result of the Engineer of Record (EoR) changing, or transitioning from one engineering company to another. In the case of the Mount Polley TSF embankment failure, this role was poorly defined and the EoR frequently changed, resulting in a loss of valuable site-specific knowledge.

5.2.2 Poor Regulatory Oversight due to Lack of Technical Capacity

The Regulator has full authority to question, and request clarification of engineering specifications and design elements; however, it does not have the capacity to make full use of this authority in many cases.

p. 151

The regulator has the authority and responsibility to oversee the EoR's decisions, but lacks the technical capacity to appropriately comprehend and evaluate these professional opinions.

5.3 Relevant Recommendations

5.3.1 Support the Development of Internal Capacity of Regulator

Support developing the internal capacities and skills to provide the geotechnical and health and safety inspectorate to adequately enforce the Mines Act and Code.

p. 163

5.3.2 Adequate Record Keeping

[The use of a comprehensive records management system] would also enhance the ability of MEM to meet the expectations of the citizens of British Columbia for transparency and disclosure of all appropriate information pertaining to mine permits within the limitations of privacy considerations. Such a system could also support long-term, integrated decision making by the permittee and consulting professionals with responsibilities on mines.

p. 164

5.3.3 Collaborative Learning

The regulator, industry, professional bodies, and learning institutions should develop collaborative approaches to facilitate learning opportunities in a variety of formats.

5.4 Implications for Water Dams

Despite the differences between the Mount Polley TSF breach and any breach that could conceivably occur with respect to water dams, there are many shared organizational problems between the TSF regulator and the BCDSP, most notably lack of regulatory capacity, which is the policy problem I examine. The Chief Inspector of Mines' recommendations are useful when considering potential solutions to the capacity problems currently facing FLNRO and the BCDSP.

6. Criteria and Measures

6.1 Rating Method

Options will be evaluated using a 'High-moderate-low' colour coded scale. Achieving a rating of High means the policy option satisfies the criterion well. Moderate means the criterion is satisfied reasonably well by the policy with some concerns that will be discussed, and Low means the policy fails to satisfy the criterion.

The criterion of increased regulatory capacity requires a slightly different interpretation of the scale. The more effectively the policy option enables the regulator to answer 'yes' to the items in the regulatory excellence checklist, the greater the potential it has to improve regulatory capacity. Thus, if the policy option will equip the regulator with the competencies described in the checklist, it will receive a rating of High. If the policy option equips the regulator with the described competency somewhat, it is rated Moderate. If the policy option shows no regulatory improvement for the competency, it will be rated Low.

6.2 Increased Regulatory Capacity

The main goal of the policy is to improve the regulatory capacity of British Columbia's dam safety program. Regulatory capacity refers to the regulator's ability to understand the complexities associated with managing the safety of water dams, understand the risks, stay up to date with technological innovations, and challenge the dam owner when necessary. Regulatory capacity is somewhat of an abstract concept, influenced by human capital development, organizational culture, knowledge dissemination, and other factors. To assist in assessing each policy's effectiveness at increasing the BCDSP's regulatory capacity, the checklist in Appendix C is employed as a proxy for assessing regulatory capacity. These items are sourced from the AER's independently-convened study on regulatory excellence, discussed in Section 3.3.

It is worth noting that by assessing a policy's potential to improve regulatory capacity, this is meant to act as an overall indicator for improvements in public protection and safety, which is an important societal objective and very relevant to the goals of the regulation. Due to the challenges and limitations associated with attempting to measure improvements in safety directly, measuring incremental regulatory capacity improvement is a good alternative.

6.3 Cost Effectiveness

Cost effectiveness refers to the improvement in regulatory capacity resulting from a policy option, relative to the financial investment it requires ('bang for your buck'). This criterion combines the result from criterion 6.2, with the budgetary cost to government, since the government will need to bear the costs. Policy options that achieve the greatest increase in regulatory capacity to cost ratio will score high for cost effectiveness.

6.4 Administrative Ease

Administrative ease is a government objective relating to the level of complexity associated with the implementation and ongoing execution of a policy option. Policy options that are easily adapted to the current regulatory framework in place will score higher for administrative ease. Policy options requiring greater coordination between different actors, and greater accountability to the public or other stakeholders will score lower with respect to administrative ease.

6.5 Stakeholder Acceptance

Stakeholder acceptance refers to the degree the policy option is anticipated to be well-received by relevant stakeholders. The stakeholders I have identified for the purpose of my report include water supply dam owners and operators, FLNRO, APEGBC accredited engineers, hydroelectricity producers (BC Hydro and Fortis), and the general public (residents of British Columbia). Due to differing interests, preferences, and involvement of stakeholders, it is probable that a policy option that is well-received for one stakeholder may be very unpopular with another stakeholder. Therefore, the net effect for all stakeholders is considered when scoring policy options for this criterion.

Policy options that are likely to be well-received by the majority of stakeholders will score high for stakeholder acceptance.

7. Policy Options

7.1 Adjustments Applicable to All Policy Options

There are a few important items that should be incorporated regardless of what policy approach is taken. These are minor amendments that are relatively simple and inexpensive to implement, but will better align the BCDSP with what is currently considered good practice in other jurisdictions.

7.1.1 Expanded Public Register of Regulated Dams

One of the responsibilities of the regulator is to correct information asymmetries that exist between dam owners and the people that live downstream of dams who may be unaware of the risks. The current map of regulated dams provided by DataBC is insufficient to effectively inform the public. Expanding the public register to allow the user to search by postal code, view the consequence classification, relevant engineering reports, and the inundation zone of the dam in question will bring British Columbia in line with England’s approach, which was identified to have the most comprehensive public register system in the jurisdictional scan. FLNRO could coordinate with municipalities to get the topic of inundation maps on council agendas, which would raise public awareness about their importance and usefulness.

It is important to note that the regulator, not individual dam owners, should be responsible for developing the inundation maps. This is to ensure a consistent quality and detail of maps across the province, and to address variations in individual dam owners’ resources to complete such a task. If regulatory resources are limited, this process could be initiated through a pilot project, with higher risk areas mapped first.

7.1.2 Alignment of Inspection Frequency with CDA Guidelines and Clarification of Environmental Criteria

A water dam's consequence classification determines the frequency it is subjected to dam safety reviews and audits undertaken by the BCDSP. Dam owners with consequence classifications of significant, high, very high, and extreme are required to develop emergency plans for their dams. A dam's consequence classification is determined by the most severe consequences that could occur as a result of the dam's failure.

Despite the recent update to the Dam Safety Regulation in February 2016, the frequency of legislated dam safety reviews remains less stringent than what is recommended in the CDA guidelines. The guidelines are a result of collaboration and idea exchange between stakeholders across Canada, and constitute what is currently considered best practice in the Canadian environment for dam safety. The difference between the CDA's recommended inspection frequency and what FLNRO currently mandates is outlined in Table 3.

Table 3: Discrepancies between CDA Guidelines and BC Regulation

Dam Consequence Classification	Recommended Minimum Frequency	Required Frequency	Difference (years)
Extreme	Every 5 years	Every 7 years	2
Very High	Every 5 years	Every 10 years	5
High	Every 7 years	Every 10 years	3
Significant	Every 10 years	Not required	10
Low	Not required	Not required	0

In addition to this, the criteria used to measure potential environmental losses in the event of a dam failure are very vague in both the CDA Guidelines and the classification matrix contained in the *Dam Safety Regulation.* Vague criteria can lead to misclassification of dams, especially if this is the responsibility of the dam owner.

Inadequate recognition of environmental consequences likely was a contributing factor in the Mount Polley TSF incident, leading it to be classified as significant consequence which mandated formal inspections only once every ten years under MEM's regulatory scheme.

In Ontario, dams are classified according to the Hazard Potential Classification (HPC) system, and the environmental criteria are detailed and clear (T. Bennett, personal communication, December 11, 2015). It is recommended that British Columbia amend their environmental consequence criteria to resemble that of Ontario. Ontario's HPC matrix can be viewed in Appendix E.

7.2 Status Quo Plus

This option would not result in the radical restructuring of the BCDSP, but seeks to improve regulatory capacity by increasing involvement in interjurisdictional learning opportunities, implementing an expert rotation program, and gradually transitioning to hiring more qualified personnel.

7.2.1 Increased Participation in Learning Opportunities

It was identified earlier that the BCDSP staff do not participate in an adequate amount of interjurisdictional learning opportunities for political reasons. However, participating in forums that allow for learning and knowledge dissemination are crucial for improving regulatory capacity. At least one DSO from each regional office of the BCDSP, and as many as possible from the main office overseeing large dams, should be in attendance at the annual CDA conference every year. In addition, the CDA recently launched an online learning portal where members can purchase and watch recorded sessions from previous CDA conferences and workshops at their convenience. This would be a relatively inexpensive way for staff to upgrade their knowledge without traveling to attend conferences in person.

The CDA is currently developing an online working group, tentatively titled *Communities of Interest*, which would provide a discussion forum for dam owners and other stakeholders to discuss current issues they are facing. These communities would be structured around the CDA's technical bulletins and provide a discussion platform for any CDA member in any province (J. Malenchak, personal communication, March 30, 2016). When it launches in autumn of 2016, BCDSP could monitor the topics of discussion, particularly focused on issues applicable to British Columbia, to stay informed about the current issues facing dam owners and other stakeholders.

Participation in international events, such as the annual ICOLD conference, would inform staff about international best practices and issues other jurisdictions have faced or are currently facing, although this incurs higher costs than events within Canada.

The issue of the public perceiving conference attendance by government workers as unnecessary government expenditure can be mitigated through public education campaigns surrounding the functions of dams, why they are important, their risks, and the consequences should they fail. This will demonstrate why it is important for the BCDSP to stay updated about current dam safety issues.

7.2.2 Dam Safety Expert Visiting Program

The BCDSP would benefit from working closely with a dam safety expert, who could join the program on a short-term contractual basis. For this initiative, the BCDSP would host an internationally recognized dam expert from within Canada, or another common law country. The expert would be involved in the day-to-day functions of the BCDSP, and accompany DSOs on audits and other duties on an ad-hoc basis.

The selection criteria for visiting experts would be their international reputation in the realm of dam safety. A good way to measure this would be looking at the number of articles a candidate has published and conferences presented at. BC Hydro, the public utility supplying hydroelectric power to the province has a notable dam safety section with internationally regarded people managing the safety of major hydroelectric dams. Engaging a BC Hydro representative would be a 'close to home' introduction to pilot the effectiveness of such an initiative.

7.2.3 Competence-Based Hiring of DSOs

This option would not modify the existing structure of the BCDSP (with the exception of the contractual expert for certain periods), so the current DSOs would remain until they retire or transition to other roles. When hiring to replace a departed DSO, a conscious effort should be made by FLNRO to hire people with prior experience in water dam engineering and/or risk assessment. An additional effort should be made to hire people with relevant engineering accreditations, especially if a candidate experienced in dam engineering cannot be sourced.

7.3 Independent Statutory Body Overseeing Dam Safety

The establishment of an Independent Statutory Body (ISB) comprised of dam engineering and risk assessment experts requires significant modifications to the current regulatory structure. This would create a discreet entity under the *Dam Safety Regulation, 2016,* comprised of experts centralized in one location to gather data, knowledge, and experience, undistracted and free from influence.

This policy option is modeled off of the approach used in New South Wales. Different organizations would nominate ISB members to FLNRO, and the Minister of FLRNO would appoint a chairperson. Since tailings dams are regulated under a different scheme, the inclusion of a member experienced in mining is not required. The nominating organizations could only be determined after public consultation and speaking to NSW about their experience, but BC Hydro, APEGBC, Worksafe BC, and the BC Water and Waste Association are some obvious contenders.

In the long-term, this is expected to reduce the regulatory burden, as dam owners are expected to demonstrate their dams are safe to the ISB by meeting the broadly established goals. The ISB would exercise its regulatory powers (issuing orders, completing orders itself) only when absolutely necessary.

The major benefit of this option is a group of competent experts experienced in dam engineering working in close contact with each other, supported by a team of equally competent sub-committees and staff. It aligns with many of the facets of regulatory excellence. The major drawback is that such a system is expensive, especially during its set up, and could be viewed by stakeholders as being overly bureaucratic.

7.4 Engineering Panels

This option is the approach used in England. In this system, a series of engineering panels (EP) would be established, and dam owners in the province would be required, under the *Dam Safety Regulation, 2016* to employ these engineers for certain functions during their dam's lifecycle. Qualified engineers would be sourced through an open application process, not through nominating organizations like the ISB. The hiring criteria for engineers would be based off of the competency matrices England employs (see Appendix D for an example), with the specific competencies customized for each specific panel.

This option requires a high level of coordination with APEGBC, since panel engineers must be accredited. This option is not as expensive as an Independent Statutory Board. Supervising and Construction engineers are employed directly by dam owners, and the independent inspecting engineers would be self-employed or employed by consultancies. The province can charge an application fee for engineers to apply to a panel, as England currently does. This will help recoup some of the costs associated with amending the legislation, educating dam owners about the new requirements, and setting up the new system. Additionally, panel appointments would last for a limited period of time, at which point the engineer would have to re-pay the application fee to be considered for re-appointment.

As interpreted for BC, this option is not starkly different from the current approach used in British Columbia. Owners of regulated dams are obligated to use an engineering professional accredited by APEGBC to complete legislated dam safety reviews, as well as for any invasive activity. It is also not uncommon for owners of larger or more complex dams to employ engineers for duties in addition to those mandated under the *Dam Safety Regulation, 2016*. The difference is the formal accreditation process to become a panel engineer, and the close coordination between panel engineers and the regulator. In the current system, a DSO may meet with an engineer hired by the dam owner only once every five years as per the audit schedule. Enshrining engineering panels in legislation is a way to ensure the regulator has ‘feet on the ground’ and most importantly, the findings are brought back in a consistent and well-defined manner. It is then the regulator’s responsibility to communicate risk to the public, mainly through a detailed public register, explained in Section 4.5.2.

A significant difference from the current approach is that responsibility for determining the consequence classification of regulated dams would be shifted from the dam owner to the regulator. On receipt of a new water dam license, the regulator would be required to examine the site, design and construction plans, inundation maps, and any other relevant information to determine the consequence category accurately and wholly.

8. Evaluation of Policy Options

8.1 Regulatory Capacity

Table 4: Evaluation of Policy Options by Regulatory Capacity Development

Checklist Item	Status Quo Plus	Independent Statutory Body	Engineering Panels
Does the regulator possess appropriate levels of autonomy to ensure its decisions are made consistently with expert judgment and in the long-term public interest?	Low	High	High
Does the regulator have a sufficient level of staff members who are highly trained and keep up with developments and emerging trends within their scope of work?	Low/Moderate	High	Moderate
Does the organizational culture support and value learning, innovation, and public service?	Moderate	High	High

Does the regulator actively investigate and seek to generate new knowledge of poorly understood risks, potential areas of concern, and regulatory impacts?	Moderate	High	Moderate
Does the regulator ground its decisions on a solid understanding of the industry it is regulating, including an ongoing awareness of technological innovations?	Moderate	High	High
Does the regulator provide open access to its information in a manner that is accessible and comprehensible both to industry users and to the broader public?	Moderate	High	High

Based on the checklist evaluation, it is evident that the ISB is most effective at increasing regulatory capacity, followed by the EP option, and lastly by the status quo plus option.

A major limitation of the status quo plus option in terms of improving regulatory capacity is the time it will take to develop. Increased participation in learning opportunities and a dam expert visitor program will be very beneficial to developing capacity, to the extent it is executed correctly by the BCDSP. Sending a single representative to the annual CDA conference is in line with what the BCDSP already does, and it must be questioned how effective this level of participation will be in terms of sustained knowledge dissemination within the BCDSP. However, if multiple DSOs are consistently involved in varied learning opportunities, it would have a material impact on regulatory capacity at an efficient cost compared to the other options. The timeframe for evaluation also matters. With respect to the visiting expert program, policy learning will also take more time than the ISB or panel options, since the existing DSO structure remains in place. Regulatory capacity development under the ISB and EP options is catalyzed by modifying the current regulatory structure significantly.

Table 5: Summary of Evaluation of Policy Options

Criterion	**Status Quo Plus**	**Independent Statutory Body**	**Engineering Panels**
Regulatory Capacity	Low/Moderate	High	High/Moderate
Cost Effectiveness	Moderate	Moderate	High
Administrative Ease	High	Low	Moderate
Stakeholder Acceptance	High	Low/Moderate	Moderate

8.2 Cost Effectiveness

The creation of an ISB is expected to be the costliest option, followed by the EP, and finally the status quo plus option. However, when the gain in regulatory capacity is considered, The EP option achieves the greatest improvement in capacity at the lowest expected cost. The ability to charge application fees for panel engineers also increases the viability of this option, though it will have to be examined whether this would have an adverse impact on recruitment efforts.

When determining cost effectiveness, there are some uncertainties with regards to how regulatory capacity will develop over time and also the longer-term impact on regulatory burden. If British Columbia adopts an ISB, based on what is known about NSW's experience, the number of regulated water dams could be relatively small contained to the current 1,800 dams subjected to the regulation. As discussed in Section 8.1, it is also plausible regulatory capacity would steadily increase in the case of the status quo plus option, increasing its cost effectiveness over time.

8.3 Administrative Ease

The status quo plus option is the most straightforward policy to implement due to the continued use of DSOs and no requirement to amend the regulation (with the exception of aligning the consequence classification frequency with the CDA guidelines and clarifying the environmental criteria). The EP option is somewhat complex due the modification of the current BCDSP structure, and the need to source qualified engineers for the panels.

The ISB option is by far the most complex to implement and requiring the highest level of coordination amongst different actors. The nominating organizations must be established, and potential ISB members must be nominated. The ISB must be incorporated as a legal entity under the *Dam Safety Regulation, 2016*, and the organizational structure determined. Supporting staff must be recruited, and many other considerations that will require a high level of coordination and restructuring.

8.4 Stakeholder Acceptance

Determining stakeholder acceptance is challenging because different groups have varying amounts of knowledge, interest, and involvement surrounding dam safety in British Columbia. The status quo plus option is likely to have the highest initial acceptance level, as it is not a significant deviation from the current system. BC Hydro is not likely to favour this option because it does little to move towards better supporting the risk-informed approach it currently utilizes in its internal dam safety program. Dam owners would be mostly indifferent, since it does not materially change their current responsibilities and duties under the *Dam Safety Regulation, 2016,* though clarification of the environmental consequence classification criteria may be appreciated. FLNRO would likely have a moderate to high level of support for this option because it does not significantly disrupt the current system, and devotes more resources to DSO development. The general public is not expected to have a strong opinion on this policy option, unless the media addresses the increased costs to the public as a result of DSO staff participating in interjurisdictional learning opportunities. Without adequate public education, this may be a politically unpopular option for that reason.

The EP option is likely to receive mixed reviews. APEGBC is likely to support this option as it better enshrines reliance on professionals in legislation. BC Hydro is likely to support this option, as it is more conducive to the risk-based approach. Dam owners could view this option unfavourably since it mandates they hire certain engineers for certain functions, but having the autonomy and flexibility to choose the panel engineer that works best for them is a mitigating factor. Additionally, if BC moves to more risk-based approach in the coming years like England's system, it could potentially relieve some low-risk dam owners of this obligation. The general public is expected to neither strongly support nor discourage this option. If communicated effectively by the regulator, the public could appreciate the added credibility of the regulator as a result of the engineering panels.

The ISB is expected to be the least well-received option, due to its significant deviation from the status quo, and both perceived and real costliness to set up and administer. The public and FLNRO may view the ISB as overly bureaucratic. However, dam owners are likely to favour this option, as long as the benefits are effectively communicated to them. The goals based approach to regulation that an ISB would employ increases the dam owner's flexibility to manage their dam to their liking. BC Hydro would also likely support this option because it is well structured to support risk-informed dam safety management principles and processes.

9. Recommendation

Based on the evaluation policy options, I recommend FLNRO implement the engineering panels option. This option achieves an effective balance between improving regulatory capacity and the costs of doing so, in terms of both financial cost and resource commitments. By adopting this structure, FLNRO, dam owners, and the general public alike will benefit from many of the best practices observed in the case of England. This approach will also prepare the regulator to adopt a risk-informed approach in the future.

While the ISB is the clear winner in terms of regulatory capacity development, there are serious concerns as to whether it could be successfully applied to British Columbia's unique situation, or whether it would lose many of its merits and become unnecessarily bureaucratic. The EP properly formalizes professional reliance in legislation, and aligns itself with APEGBC, a professional body that has shown it is equipped to handle dam safety with the production of its own guidelines for conducting dam safety reviews.

An important consideration for the recommended option to be successful is the need for frequent interactions between panel engineers and the regulator. This ensures the regulator stays updated on the current status of regulated dams, as well as any issues dam owners are facing. Since engineers are dispersed across the province according to the distribution of water dams, valuable site-specific information may be lost if they do not converse with the centralized regulator frequently.

10. Conclusion

This research provides an overview of the current regulatory framework for water dam safety in British Columbia, and how dam safety management has evolved over the past sixty years. It examines the merits and drawbacks of a risk-informed approach, and explores the broader implications of this philosophy for both dam owners and the regulator. I have evaluated the regulator's capacity under the status quo, and determined it is insufficient to carry out the main goals of the regulation, as well as rendering it unlikely to successfully adapt to a risk-informed approach to dam safety.

Challenges I experienced mostly related to the timing of research. When I began this research, the *Water Sustainability Act* and the *Dam Safety Regulation, 2016*, were not yet in force and there were uncertainties to the extent the new act and regulation would differ from their predecessors. The jurisdictions I examined for best practices were also at various stages of transition in their own regulatory systems. An additional limitation was the inability to interview a representative from FLNRO until late into my research, though this was eventually successful.

As the risk-informed approach to dam safety develops, further research must be focused around how to best structure policy to achieve the desired societal outcomes. Performance bonds, which would require owners of higher-risk dams to put forth a bond totalling the expected value of damages should their dam fail at the time of acquiring a license under the *Water Sustainability Act,* is one possible tool to incentivize dam owners to control their risks. This is a practice already exercised in the mining industry, and would ensure dam owners are not able to declare bankruptcy to avoid financial penalties in the event of negligence. The applicability of performance bonds to water dam safety merits further research.

The policy option selected accounts for implementation and feasibility concerns that were not extensively addressed in this research, but will undoubtedly be a factor in the 'real world'. Mandating dam owners appoint qualified engineers from regulator-administered panels is a good compromise in terms of shifting some regulatory responsibility to industry, and adequately defining professional reliance in legislation. It is expected to develop regulatory capacity that will be useful in the future as the complexities of a risk-informed society come to fruition. The success of the recommended policy is heavily dependent on clear and effective communication channels between dam owners, engineers, the regulator and the public. The alternative approach, the ISB, incorporates a broader skill set into an advisory board and staff with expertise in dam engineering, risk assessment, and communications. Both approaches strive toward the same broad goals, but are executed very differently. British Columbia must ensure that no matter what approach is taken, there is sufficient capacity to support it. A knowledgeable regulator will successfully bridge the gaps that exist between dam owners, engineers, regulators, and the public.

With this said, I caution against the complete dismissal of an ISB. It is a system that British Columbia could potentially work towards, using the engineering panels as a stepping-stone to build capacity. While there are significant implementation and stakeholder acceptance concerns, this is not reason alone to completely abandon an approach. As the risk-informed approach develops over the coming years, more will be known about its complexities, benefits, and drawbacks. At that time, it will be more apparent what role the regulator should play, and whether the engineering panel approach is sufficient to achieve the desired outcomes determined by the societal and individual risk criteria.

A risk-informed approach is more complex than the traditional approach to dam safety management. There will always be uncertainties, rendering professional judgement extremely important. The main point from this research is the importance of people for good regulation. The organizational details are secondary to the skills, knowledge, and experience of the regulator, and the processes in place, both formal and informal, to disseminate these. Without sufficient human capital, the regulatory structure, no matter how impressive, is for nothing.

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Appendix A.

Semi-Structured Interview Guide

1) What is your experience and background in dam safety? What led you to become involved/interested in this issue/field?

2) In Common law societies, ensuring dam safety is primarily the dam owner's responsibility. In your opinion, how do you think regulation should be structured to best support this and achieve the desired social outcomes?

3) How important do you think it is for the regulator to be knowledgeable about dam engineering?

4) Do you feel the current regulatory environment for dam safety is adequate in British Columbia? If not, what aspects do you feel need to be addressed?

5) What policies/actions do you think would aid in addressing these issues? [if the participant identifies issues in response to question 4]

6) What barriers or limitations do you anticipate if this policy/action was introduced?

7) *(if participant if from other jurisdiction*) In your opinion, what are the best features of the dam safety regulations in *jurisdiction*? How does this regulation differ/stand out compared to other jurisdictions/countries?

8) How does the entire dam safety management 'system' work in *jurisdiction?* For example, how do professional organizations, industry, dam owners, regulators, and other stakeholders interact and engage with each other?

9) Is there anything I have not brought up in the interview that you would like to talk about?

Appendix B.

Dam Audit Check Sheet (BC Dam Safety Program)[20]

BRITISH COLUMBIA

DAM SAFETY AUDIT PROGRAM

AUDIT CHECK SHEET

Dam : ______________________________ Date : ______________

							Risk Level : (see over)
Failure Consequence Rating:	E	VH	H	S	L		
Failure Probability Rating :	Lrg	Mod	Sm	VSm			1 2 3 4 5

This Audit is not an Inspection of the dam. The dam owner is responsible for dam surveillance and inspections. This is an audit of the dam owner's dam safety program.

DAM SAFETY REGULATION REQUIREMENTS

	Yes	No	N/A	Follow Up?
Consequence Rating Appropriate?				
Alterations or Hazards occurred recently?				
Owner Reported any recent alterations or hazards?				
Emergency Plan Prepared?				
Emergency Plan Submitted and Updated?				
OMS Plan Prepared?				
OMS Plan Submitted?				
Reservoir Operation as per OMS Manual?				
Maintenance Suitable?				
Surveillance Suitable?				
Annual Inspection Suitable?				
Sign posted on dam? (Crown land only)				
Dam Safety Review Status Acceptable?				

Comments & Site Observations: ______________________________

Dam Owner / agent present for audit? Y ☐ N ☐ Copy given to Dam Owner / agent? Y ☐ N ☐

Printed Name of Dam Safety Officer	Signature	Date
Printed Name of Dam Owner / agent	Signature	Date

Updated: November 2013

[20]

Appendix C.

Regulatory Excellence Checklist[21]

Does the regulator possess appropriate levels of autonomy to ensure its decisions are made consistently with expert judgment and in the long-term public interest?

Does the regulator have a sufficient level of staff members who are highly trained and keep up with developments and emerging trends within their scope of work?

Does the organizational culture support and value learning, innovation, and public service?

Does the regulator actively investigate and seek to generate new knowledge of poorly understood risks, potential areas of concern, and regulatory impacts?

Does the regulator ground its decisions on a solid understanding of the industry it is regulating, including an ongoing awareness of technological innovations?

Does the regulator provide open access to its information in a manner that is accessible and comprehensible both to industry users and to the broader public?

[21] Sourced from (Coglianese, 2015)

Appendix D.

Competency Matrix for All Reservoirs Panel (England)[22]

ALL RESERVOIRS PANEL - COMPETENCE MATRIX

Dates

Application	
Current appointment	
Expiry	

Name | | Date | |

	COMMENTS	S	N
Fellow or Equivalent			
Knowledge of - Reservoir Act			
Knowledge of - Statutory Instruments			
Supervising Experience or equivalent			
Length of reservoir experience			
Experience with different reservoir types :			
design			
construction supervision			
A.R. Inspection attendance			
Familiarity with :			
concrete			
embankments			
others			
Knowledge of pertinent disciplines			
Familiarity with UK hydrology			
Knowledge of current reservoir safety issues			
Knowledge of Health & Safety issues			
Access to specialist advice			
Approach to CPD			
PI insurance cover			
Fitness :- mental			
physical			
General/Additional Comments			

Key:
S Satisfactory
N Not Satisfactory

Recommendation **YES / NO**

[22] Contains Environment Agency information © Environment Agency and database right

Appendix E.

Ontario Technical Guidelines Hazard Potential Classification[23]

Hazard Potential	Life Safety	Property Losses	Environmental Losses	Cultural – Built Heritage Losses
Low	No potential loss of life.	Minimal damage to property with estimated losses not to exceed $300,000.	Minimal loss of fish and/or wildlife habitat with high capability of natural restoration resulting in a very low likelihood of negatively affecting the status of the population.	Reversible damage to municipally designated cultural heritage sites under the Ontario Heritage Act.
Moderate	No potential loss of life.	Moderate damage with estimated losses not to exceed $3 million, to agricultural, forestry, mineral aggregate and mining, and petroleum resource operations, other dams or structures not for human habitation, infrastructure and services including local roads and railway lines. The inundation zone is typically undeveloped or predominantly rural or agricultural, or it is managed so that the land usage is for transient activities such as with day-use facilities. Minimal damage to residential, commercial, and industrial areas, or land identified as designated growth areas as shown in official plans.	Moderate loss or deterioration of fish and/or wildlife habitat with moderate capability of natural restoration resulting in a low likelihood of negatively affecting the status of the population.	Irreversible damage to municipally designated cultural heritage sites under the Ontario Heritage Act. Reversible damage to provincially designated cultural heritage sites under the Ontario Heritage Act or nationally recognized heritage sites.
High	Potential loss of life of 1-10 persons	Appreciable damage with estimated losses not to exceed $30 million, to agricultural, forestry, mineral aggregate and mining, and petroleum resource operations, other dams or residential, commercial, industrial areas, infrastructure and services, or land identified as designated growth areas as shown in official plans. Infrastructure and services includes regional roads, railway lines, or municipal water and wastewater treatment facilities and publicly- owned utilities.	Appreciable loss of fish and/ or wildlife habitat or significant deterioration of critical fish and/ or wildlife habitat with reasonable likelihood of being able to apply natural or assisted recovery activities to promote species recovery to viable population levels. Loss of a portion of the population of a species classified under the Ontario Endangered Species Act as Extirpated, Threatened or Endangered, or reversible damage to the habitat of that species.	Irreversible damage to provincially designated cultural heritage sites under the Ontario Heritage Act or damage to nationally recognized heritage sites.
Very High	Potential loss of life of 11 or more persons.	Extensive damage, estimated losses in excess of $30 million, to buildings, agricultural, forestry, mineral aggregate and mining, and petroleum resource operations, infrastructure and services. Typically includes destruction of, or extensive damage to, large residential, institutional, concentrated commercial and industrial areas and major infrastructure and services, or land identified as designated growth areas as shown in official plans. Infrastructure and services includes highways, railway lines or municipal water and wastewater treatment facilities and publicly-owned utilities.	Extensive loss of fish and/or wildlife Habitat or significant deterioration of critical fish and/or wildlife habitat with very little or no feasibility of being able to apply natural or assisted recovery activities to promote species recovery to viable population levels. Loss of a viable portion of the population of a species classified under the Ontario Endangered Species Act as Extripated, Threatened or Endangered or irreversible damage to the habitat of that species.	