# Risk informed decision making for levees

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**Abstract.** Recent events including the establishment of national levee committees in many countries as well as the recent establishment of a Technical Committee on Levees at the International Commission on Large Dams points to the growing interest in levee safety. Additionally, the use of information obtained from risk assessments for levee safety management is becoming more prevalent throughout the world. Several countries are routinely applying this information to support decisions and prioritize actions in all aspects of the life cycle of a levee. An initial effort was given to gather information on the determination of risk related to levees and the application of that risk in making risk management decisions. In November 2018, representatives from Canada (British Columbia), France, Netherlands, United Kingdom, and United States met to discuss risk-informed decisions for levees. During the forum, each country representative shared how risk assessment information is applied to levee management decisions in their respective country. A report of findings from this workshop was presented as an oral presentation at the 2019 ICOLD Conference, and a number of additional countries were queried to expand the existing information. This paper will provide a comprehensive report of information collected from numerous countries on the collection and application of risk information to inform levee management decisions. Preliminary findings suggest that many countries are performing risk assessments but the use of that information to inform decisions is inconsistent and in many instances only using a component of the risk. It is anticipated that the findings from this effort will serve as the impetus for the development of consistent international practices in the management of levee safety.

## 1 Background

The use of information obtained from risk assessments for dam and levee safety management is becoming more prevalent throughout the world. At the 2018 ICOLD Congress the Commission approved the establishment of the Technical Committee on Levees with participation from 18 member countries. Most of these countries are actively doing risk assessments and using that information in their levee safety programs. Several countries are routinely applying this information to support decisions and prioritize actions in all aspects of the life cycle of a dam or levee. The framework for application of risk assessment information to inform operation and maintenance, inspections, incident or event management activities, and to some extent decommissioning, is fairly well established.

In November 2018, representatives from Canada (British Columbia), France, Netherlands, United Kingdom, and United States met to discuss risk-informed decisions for levees. During the forum, each country representative shared how risk assessment information is applied to levee management decisions in their respective country. This paper will provide details on how those five countries are using risk information to make levee management decisions. Additional information on how other countries, those queried during the following 2019 ICOLD conference, use risk are briefly discussed.

## 2 Risk and Components of Risk

### 2.1 Risk

Risk is a measure of the probability (or likelihood) and consequence of uncertain future events. If there is no chance of an event occurring, then there is no risk. If there are no consequences resulting from an event occurring, then there is no risk. There could be two situations that seemingly have identical risk, but what is driving the risk

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for each of the two situations can be extremely different. Risk can be expressed using the following equation:

$$Risk = fn\ (\text{probability, consequence}) \tag{1}$$

However, this is normally simplified to:

$$Risk = probability\ x\ consequence \tag{2}$$

## 2.2 Components of Risk

There are three components of risk. The term risk, when used in the context of levee safety, is comprised of:

- likelihood of occurrence of a load (e.g., flood, earthquake, etc.),
- likelihood of an adverse structural response (e.g., levee breach), and
- magnitude of the consequences resulting from that adverse event (e.g., casualties, economic damages, environmental damages, etc.).

Figure 1 shows the relationship between the factors that influence flood risk and probability and consequences.

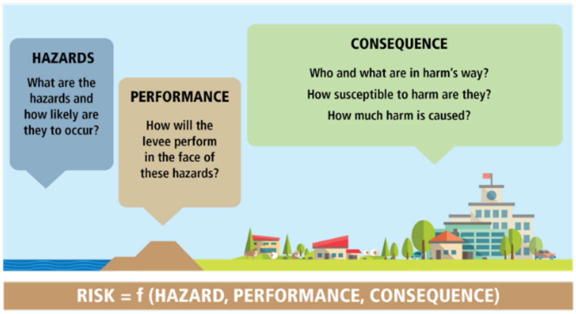


**Figure 1.** Components of Risk.

# 3 Forum

In November 2018, representatives from Canada (British Columbia), France, Netherlands, United Kingdom, and United States met to discuss risk-informed decision making of levees. During the forum, each country representative shared his or her agency's risk analysis process and how risk information is applied to levee risk management decisions.

In efforts to determine the extent that each agency uses risk related information, each of the five countries answered the following questions during the forum:

1. Is your agency/country using risk (or some component of risk) to inform decisions?

2. If so, which components (hazard, performance, consequence) of risk are being used?

3. In what stages of the levee life cycle is risk being used?

## 3.1 Canada (British Columbia)

In British Columbia, levees are considered structural mitigation works which are regulated under Dike Maintenance Act provincial legislation. According to the Professional Practice Guidelines: Legislated Flood Assessments in a Changing Climate in BC, as of 2018, there are approximately 210 structures in British Columbia regulated under the Dike Maintenance Act. A provincial Dike Safety Program has been established for inspection, assessment, and management of dikes regulated under the Dike Maintenance Act. Within British Columbia, a diking authority owns the levee, acquires legal access, and administers operation and maintenance, performs inspections, and is responsible for any repairs and restoration.

In addition to the structural mitigation works, Province-wide, there are 101 orphan dikes and erosion protection works which were either constructed or funded by the Province over the past 50 years to respond to emergency flooding situations or were built by others and abandoned. These works generally lack adequate planning and engineering design due to the emergency conditions under which most were constructed. They are not typically maintained or inspected by a diking authority. The province performs periodic risk assessments on these structures and will evaluate the condition of the orphan dikes, the associated risks, and what is needed to bring each up to provincial standards, and attempt to establish local diking authority (Fraser Basin Council, 2018).

*Is British Columbia using risk to inform decisions?*

Risk information in British Columbia is primarily used to prioritize investment and operation and maintenance decisions for both provincially regulated and orphan dikes. Information from risk assessments is also used in sea levee and seismic design.

Risk analyses are conducted on both structural mitigation works and orphan levees, and the information is used primarily for portfolio levee management investment decisions. For orphan levees, risk analyses can be used to inform individual levee management in order to bring them up to provincial standards as well as to inform the Province, local governments, and people living near these structures of the benefits and risks of these structures and to provide information and aid to local governments in making an informed decision about becoming the diking authority for these works.

In greater Canada, risk information is also used to prioritize funding for flood risk reduction projects through the National Disaster Mitigation Program. The National Disaster Mitigation Program was created as a five-year, \$200 million cost shared program. Eligible entities apply under one of four different funding streams to request money for completing flood risk reduction measures.

*What components of risk are being used?*

For structural mitigation structures regulated within British Columbia, a Dike Consequence Classification is determined for each levee. Various categories of consequences ranging from life loss and economic damages to loss of cultural resources are given a numerical score which results in an overall consequence score and ranking (Hahn, 2018). The consequence ranking allows direct comparison between the entire portfolio of levees to help prioritize funding and other safety activities. Consequences within a leveed area are also used to define the level of effort required for each risk assessment. As consequences increase, the required risk analysis methodology becomes more rigorous and the quality and detail of deliverables increases Dike Consequence Classification also informs seismic design (requiring dike in seismic areas that are rated High consequence to meet the seismic design performance criteria)..

For orphan dikes, a qualitative Risk Score is determined based on the combination of a Dike Failure Likelihood Score and a Consequence Score. During the risk analysis, the hazard is assumed to be a flood event with a return interval of 1/200 year. Dike Failure Likelihood is qualitatively assessed using inspection information and engineering judgment. Consequences are qualitatively assessed in various categories ranging from life loss to cultural loss

In the National Disaster Mitigation Program Risk Assessment Information Template, the flood hazard and consequences are narratively characterized by each applicant. Performance of the structure is not considered within the risk assessment.

For sea levees, a general characterization of risk (high, moderate, or low) is used to determine the crest elevation during levee design.

*What stages of the life cycle is it used?*

Risk information is used during planning, design, and operation and maintenance.

Risk informs the planning stage by helping risk managers prioritize funding through the National Disaster Mitigation Program. The National Disaster Mitigation Program was created as a five-year, $200 million cost shared program. Eligible entities apply under one of four different funding streams to request money for completing flood risk reduction measures.

Risk information is also used for sea levee and seismic levee design.

Risk analyses are mainly used during the operation and maintenance stage of the levee life cycle. For both structural mitigation works and orphan levees, assessments are used to determine and then prioritize risk reduction resources.

## 3.2 France

According to the ICOLD European and US Levees and Flood Defences: Inventory of Characteristics, Risks and Governance report which includes data from a national, comprehensive levee inventory , there are about 9,000 km of levees in France, about 8,000 km of inland and 1,000 km of marine levees. In 2014, France adopted a national flood risk management strategy with the following three objectives:

- increase the security of populations
- reduce the cost of damage
- greatly shorten the time to recover from disaster.

The French Ministry of Environment is in charge of setting levee regulation, but levee owners or managers are responsible for implementing regulations. Levee management organizations used to range from private entities like individuals or companies to local government; recent regulation defines the level of local authorities in charge of levee systems management. Unless already accredited by the Ministry of Environment, levee managers must employ accredited consulting engineering companies to conduct levee safety regulatory studies or to design new protection structures.

*Is the agency using risk to inform decisions?*

Risk information in France is used to inform investment and prioritize risk management decisions. Risk information can also influence design parameters.

In France, risk analyses are conducted prior to the authorization of a new levee system. They are also used to authorize the modification of existing levees. For existing levees, performance assessments and risk analyses are performed periodically, every 10, 15, or 20 years, based on the consequence classification. They are also conducted after significant events where levee condition may be impacted.

A performance assessment involves understanding the condition and structural integrity of a levee. A performance assessment considers both hydraulic performance (level of flood risk reduction) and structural performance (resistance to potential failure modes). A risk analysis provides an estimate of the level of risk associated with a levee considering both performance of the levee and vulnerability of protected assets. Understanding a levee's risk allows for optimized risk management.

*What components are being used?*

In France, the hazard component of risk is considered by identifying multiple loading conditions for levees. The Protection Level is defined as the top of levee elevation where overtopping first occurs in a given system. The Danger Level corresponds to the level above which the probability of structural failure is very high. The Safety Level corresponds to the level up to which the probability of structural failure of the levee is negligible. The required annual probability of exceeding the Safety Level and the Danger Level is determined through risk assessments. The population security level is the level up to which no person located in the leveed area is in danger (Tourment, 2017). During levee design different partial safety factors are applied to various hazard loadings (France CFBR, 2015).

Levee performance is considered during Performance Assessments and Risk Analyses which inform risk managers when levee rehabilitation is required.

The consequences component of risk is considered by classifying levees into one of three administrative classes.

Levees are classified according to their height and the population they protect into classes A (>30000), B(between 3000 and 30000), or C(between 30 and 3000). A number of levee safety activities or their fare dependent on the administrative class of the levee: inspection frequency and reporting requirements, risk analysis frequency and requirements, and procedures for performing major rehabilitation and modifications.

*In what stages of the levee life cycle is it used?*

Risk assessments are used during the planning stages, to authorize a new levee construction or modifications to an existing levee. Assessments are also used to prioritize operation and maintenance funding. Risk assessment information can also influence levee design partial safety factors.

## 3.3 Netherlands

Throughout the Netherlands, roughly 22,500 km of levee systems reduce flood risk to more than nine million people. Approximately 3,500 km of that are primary flood defenses which reduce risk against floods large enough to cause life risk and major economic damage (ICOLD, 2018). Safety standards for primary flood defenses are set in national legislation. The remainder of the levees are referred to as secondary flood defenses or regional flood defenses. These secondary or regional levees would have a smaller impact given a breach, and safety standards are set in regional provinces. The standards discussed in this document are only applicable to primary flood defenses.

Responsibility for flood protection in the Netherlands is shared by three levels of administration: central government, the provincial authorities, and the water authorities. Local authorities play a role in spatial planning, representing other interests such as housing and transport, and in communicating with the public (Netherlands Ministry of Infrastructure and the Environment, 2014).

*Is the agency using risk to inform decisions?*

In the Netherlands, risk assessment information is used inform investment and operation and maintenance decisions. Additionally, risk plays a key role in determining flood probability standards for levees.

The Netherlands sets individual risk thresholds within national legislation. The new standard is based on the risk of flooding. The possible consequences have been identified more effectively than in the past, with a greater focus on fatalities and victims. Individual life risk plays an explicit role in the updating of standards for levees. The government has decided that the probability of loss of life due to flooding may not exceed 1/100,000 per year in all protected areas of the Netherlands.

Every twelve years, risk assessments are performed on each levee to determine levee condition. If the risk assessment indicates that a particular levee has fallen below a target condition, major rehabilitation and modifications may be required and the levee becomes eligible to apply for flood risk reduction funding through a national Flood Protection Programme (Netherlands Ministry of Infrastructure and the Environment, 2014).

*What components are being used?*

The Netherlands uses the consequences component of risk for levee risk management. Levee design standards are derived using the mandatory local individual risk requirements set in national legislation, but are also influenced by economic and societal risk. Within the Water Act, it is mandated that everyone within the Netherlands should have an equal minimum level of protection. When societal and economic consequences are sufficiently high, a lower probability of flooding may be required. The consequences of flooding ultimately determine the maximum allowable probability of flooding that is acceptable for a levee (Netherlands Ministry of Infrastructure and the Environment, 2016).

The hazard and performance components of risk are indirectly used when considering investment decisions. During the risk assessments that are performed every twelve years, the current probability of flooding is estimated. If the estimated probability of flooding exceeds a particular “alert” value for a particular levee, rehabilitation is required to provide the minimum level of protection, as directed by legislation. Rehabilitation funding is then prioritized through a national program.

*In what stages is it being used?*

Risk informs decisions during levee planning, design, and operation and maintenance.

The Dutch Flood Protection Programme allocates funding for levee rehabilitation to systems with the highest risk. Once funding is received, rehabilitation to the levee must meet the standards set in legislation (Netherlands Ministry of Infrastructure and the Environment, 2014).

Levee design standards are derived from the national individual risk requirements set in law.

During the operation and maintenance phase of the levee life cycle, risk assessments are performed on a periodic basis, every twelve years, to verify levee performance and level of flood risk reduction. If the computed probability of flooding for any levee exceeds a pre-defined value, rehabilitation is required.

## 3.4 United Kingdom

There are an estimated 9,000 km of levees in England which reduce flood risk to properties from coastal and riverine flooding. There is an estimated 2.4 million properties at risk to flooding. Levees in the UK are managed in a national database called the Asset Information Management System (AIMS) (Mitchell, 2018).

The Environment Agency has responsibility for an overview of flood and coastal erosion risk management. It also builds, maintains and operated levees and flood defenses. Maritime Local Authorities control works relating to erosion from the sea. Local and Regional delivery is carried out by various organizations including Lead Local flood authorities, district councils, internal drainage boards, riparian landowners, water companies, reservoir owners, and highways authorities .

The Environment Agency manages around 45% of flood risk management assets on main rivers and the coast. Local Authorities, Internal Drainage Boards and individual owners and businesses are responsible for the remaining 55% (ICOLD, 2018).

*Is the UK using risk to inform decisions?*

Information from risk assessments is used for levee risk management in the United Kingdom.

Levees are managed through an Asset Performance Tools program which integrates key assessment activities throughout the life cycle of the levee. Activities are tiered so that the most complex, highest risk levees undergo the most rigorous assessment activities (United Kingdom. Department for Environment, Food, and Rural Affairs, 2014). Inspection frequency and level of risk assessment are dependent on information from risk assessments. Risk assessments are also used to determine when levee repairs are needed.

Consequence and Geotechnical Classes are used to adjust limit-state design partial factors and also impact the level of design and construction supervision required.

*What components of risk are being used?*

Inspection frequency is dependent on the probability and consequences of levee failure. Levees are categorized based on potential consequences. High consequence levees receive visual inspection every six months, whereas lower consequence levees may only be inspected once every two to five years. As a result of inspection, levees are further categorized by condition with grades ranging from 1 (excellent) to 5 (very poor). Depending on the condition rating, further inspection and risk assessment may be warranted (Mitchell, 2018). Levees that are below the target condition receive a post-inspection risk analysis (known as a RAFT assessment).

Levees that are unusual, complex, or high risk require a Modelling and Specific Fragility analysis (referred to as MDSF2), and levees that are so complex that they are not well represented in the other methods receive a detailed engineering investigation (Simms, 2018).

Levee risk information is also used to inform investment decisions.

*In what stages of the levee life cycle is it used?*

Risk information is used to inform decisions related to operation and maintenance, design, and construction stages of the levee life cycle.

## 3.5 United States

Water Resources Development Act of 2007 (WRDA 2007), which established the National Committee on Levee Safety. The National Committee on Levee Safety provided a number of recommendations for improving the state of levee safety within the nation. One of those recommendations was to, “Develop and Adopt National Levee Safety Standards that will assist in ensuring that the best engineering practices are available and implemented throughout the nation at all levels of government. ”

Within the US Army Corps of Engineers levee portfolio are approximately 14,150 miles of levees. Roughly 70% of these levees are operated and maintained by non-Federal levee sponsors. There are an additional 15,000 miles of levees outside the portfolio that have been inventoried, but there are also many miles of levees throughout the United States that have yet to be inventoried (USACE, 2018).

*Is the US using risk to inform decisions?*

The United States has organized its levee safety policy and decision making process around the risk framework. The Levee Safety Risk Framework is a process for decision making under uncertainty and consists of three basic activities: risk assessment; risk management, and risk communication. This framework provides an analytical way for gathering, recording, and evaluating information that leads to recommendations for decision or action related to levee systems. Risk is used to make informed decisions and to justify priorities and improve decision making throughout all stages of the levee life cycle. Risk-informed decision making is applied within levee safety programs on an individual levee system level and on a portfolio level (USACE, 2018).

*If so, what components of risk are being used?*

Levee safety decisions are informed by a risk estimate and characterization, which considers all three components of the hazard, performance, and the consequences. Risk estimates and characterizations can be used in portfolio management for prioritization of investments and other levee safety activities.

Other information based on the components of performance and consequences can be used to inform risk management. Information regarding the performance and consequences of a particular levee can be used to help prioritize individual levee activities such as future inspections and interim risk reduction measures.

In the absence of risk information, potential consequences, expressed in a Hazard Potential Classification, are used to prioritize levee safety activities (United States, 2019).

*In what stages of the levee life cycle is it being used?*

Risk assessment information may be used throughout the entire life cycle of a levee (United States, 2019).

Although risk is used most broadly during the operation and maintenance stage, risk assessments may be performed at any point along the levee life cycle. During the planning stages, risk is used to identify levee risk problems and opportunities, to characterize risk for existing (without project) conditions, and to evaluate and select various project alternatives.

Risk is also used during design and construction. During construction, risks identified during a risk assessment are monitored. Any unanticipated situations such as unexpected foundation, environmental, or hydraulic conditions are assessed and risk information is used to inform any subsequent changes (United States, 2019).

## 4 Other Responses

In an attempt to better understand the current situation regarding the use of risk to inform levee safety decisions, a survey was sent to all countries with membership on the ICOLD Levee Technical Committee. This represents the received responses and summary from that survey.

| | Is your country using risk to inform decisions related to levees? | If so, which components of risk are being used? | In what stages of the levee life cycle is risk being used? |
|---|---|---|---|
| Czech Republic | Yes | Hazard, Consequences | Planning, Operation |
| Finland | No | NA | NA |
| Germany | Yes | Hazard, Consequences | Planning, Design, Operation |
| Japan | Yes | Hazard, Performance, Consequences | Planning, Design |
| Iran | Yes | Consequences | Design, Operation |
| Norway | Yes | Hazard, Consequences | Planning, Design, Operation |
| Switzerland | Yes | Hazard, Consequences | Planning, Construction, Operation |

**Table 1.** ICOLD Survey Results

## 5 Conclusions

From discussions at the Risk-Informed Decision Making Forum and ICOLD, many countries are already conducting some level of risk assessment on the levees within their portfolios. While agencies are comfortable estimating and characterizing risk, there is variability in how risk information is used in levee risk management decisions. Most of the countries are using their risk assessments to inform investment decisions and operation and maintenance priorities, but there is more variability in how risk information is used in other areas of the levee life cycle.

In general, most countries, discussed in this paper, are not using a complete determination of risk, but rather a combination of hazard, performance, and consequence to inform decisions. Many of these countries are assessing the individual components of risk but not combining them to determine the actual risk. As such, levee management decisions have been based on one or more components of risk (the hazard, the performance, or the consequences), but have been predominantly focused on hazard or consequences, and much less on performance.

While most of the agencies are using risk information to inform investment decisions and operation and maintenance priorities, many countries also report the use of components of risk during the planning, design, and operation and maintenance phases of the levee life cycle. The components influencing planning and design tend to be hazard and consequences; operation and maintenance are more influenced by the consequences.

Although the actual use of risk information in levee risk management decisions is varied across countries, there was general agreement that risk assessments provide valuable information that can be used during all stages of the levee life cycle. While national levee safety efforts continue to evolve, it is likely that the use of risk information will also evolve.

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