Natural Hazard Risk Tolerance:

A Scoping Review

Report prepared by Dr. Tristan Pearce

Professor, University of Northern British Columbia



NOVEMBER 2026

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Pacific Institute for Climate Solutions

INTRODUCTION

The concept of risk is a key aspect of how decision makers assess the potential adverse impacts of, and response options to, potential hazards. Canada and, in particular, British Columbia, is exposed to a wide range of natural hazards including, but not limited to, avalanches, earthquakes, floods, hurricanes, landslides, severe storms, tsunamis and storm surges, volcanoes, and wildfires (Government of Canada, 2025). Gaining a better understanding of hazards and risks within B.C. gives decision makers and Canadians the information they need to make informed choices to help protect themselves and their communities, before, during, and after disasters.

It is readily accepted in the field of disaster risk management that risk is influenced by human decisions that include the exposure of people to a hazard and their underlying vulnerability to hazards (Blaikie, 2014; IPCC, 2022b). Another aspect of the human component of risk that is influenced by vulnerability is the willingness of people to bear risk, referred to as *risk tolerance*. Risk tolerance refers to how much risk an individual, organization, or government is comfortable with before electing to take risk mitigation actions. Further, risk tolerance is temporally dynamic and is influenced by recent near-misses, threat perception, and the broader constellation of perceived threats.

While Canada and its jurisdictions, for the most part, have well-established approaches for hazard risk assessment, the human components of risk, and specifically, risk tolerance, are less well-defined—mirroring work in other regions globally (Magnan, O'Neill and Garschagen, 2023; Marbaix et al., 2025). Excluding human components of risk and treating risk as solely a product of the physical characteristics of a hazard separates it from the social frameworks that influence how hazards affect people. An incomplete understanding of risk can lead to mitigation actions that are incongruent with local priorities, perspectives, and values, and could lead to the implementation of maladaptive measuresi (Magnan, 2016; Schipper and Mukerhji, 2024). Within a hazard risk assessment, risk thresholds as well as the probabilities of exceeding these thresholds should be identified collaboratively by researchers and local community members. These elements provide measurable boundaries that clarify when risks become unacceptable. The time between the identification of an acceptable level of risk and its exceedance is identified as a **window of adaptation**, allowing organizations/ governments to move from reactive measures to strategic, informed decision-making (Jones, 2001).

The aim of this scoping review is to identify best practices for defining and assessing risk tolerance. The review is based on publicly available information and focuses on giving a general assessment of how risk tolerance has been defined and operationalized in hazard risk management. The findings of this review are intended to contribute to a discussion on how an assessment of risk tolerance can be integrated into current hazard risk management approaches in B.C.

DEFINING RISK TOLERANCE

Risk analysis and risk tolerance are interconnected concepts used in various fields, including finance, project management, safety, disaster risk reduction, climate change, and natural hazards. Risk analysis involves developing an understanding of risk, while risk tolerance refers to the degree of uncertainty or loss an individual or organization is willing to accept. Understanding and managing risk tolerance is crucial for making informed decisions, achieving goals, and mitigating potential negative impacts.

There are many definitions of *risk* (Thywissen, 2006). Broadly, risk can be described as "the potential for adverse consequences for human or ecological systems, recognising the diversity of values and objectives associated with such systems" (IPCC, 2022a). In B.C., the British Columbia Emergency Management System (BCEMS) defines risk as "a concept that takes into consideration the likelihood that a hazard will occur, as well as the severity of possible impact to health, property, the environment, or other things of value" (Emergency Management B.C., 2020). *Likelihood* describes the probability or frequency of a hazard event. *Consequence* describes the effect or impact of a hazard on the natural, built, and social environments. Both likelihood and consequence may be expressed using either descriptive words (i.e., qualitative measures—minor, moderate, severe) or numerical values (i.e., quantitative measures—number of deaths, financial losses) to communicate the magnitude of the potential impact (Middelmann, 2007).

Risk is influenced by three factors: hazard, exposure, and vulnerability (Crichton, 1999; IPCC, 2022b). Thus, there are options for risk reduction through adaptation, by addressing one or more of the three risk factors (IPCC, 2019: Figure TS.4). A *hazard* refers to "a potential source of harm, or a situation with a potential for causing harm, in terms of human injury; damage to health, property, the environment, and other things of value; or some combination of these" (Emergency Management B.C., 2020). *Exposure* refers to "people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas" (UNISDR, 2009). *Vulnerability* is the degree to which the exposed elements will suffer a loss from the impact of a hazard and is a function of *sensitivity* or susceptibility to harm and capacity to cope and adapt (IPCC, 2022a) (Figure 1).

Risk tolerance plays a crucial role in determining the willingness, extent and type of hazard risk reduction measures that are implemented. Risk tolerance in the context of natural hazards refers to our willingness to accept or reject a given level of residual risk. Thus, individuals are prepared to "tolerate" some risks under certain circumstances in return for specified benefits (Middelmann, 2007). The term, *risk appetite* is often used interchangeably with risk tolerance and are related, but distinct, concepts. Risk appetite is the broad level of risk an organization or individual is willing to accept, and risk tolerance translates the broad appetite into concrete limits. These limits denote the extent and type of hazard risk reduction measures.

When discussing risk tolerance, it is important to consider the social, cultural, and economic contexts in which disaster risks occur and that individuals, organizations and governments do not necessarily share the same perceptions of risk and their underlying risk factors (UNDRR, 2017). *Acceptable risk*, or tolerable risk, is therefore an important sub-term. The extent to which a disaster risk is deemed acceptable or tolerable depends on existing social, economic, political, cultural, technical, and environmental conditions. In engineering terms, acceptable risk is also used to assess and define the structural and non-structural measures that are needed in order to reduce possible harm to people, property, services and systems to a chosen tolerated level, according to codes or "accepted practice" which are based on known probabilities of hazards and other factors. *Residual risk* is the disaster risk that remains even when effective disaster risk reduction measures are in place, and for which emergency response and recovery capacities must be maintained. The presence of residual risk implies a continuing need to develop and support effective capacities for emergency services, preparedness, response, and recovery, together with socioeconomic policies such as safety nets and risk transfer mechanisms, as part of a holistic approach.

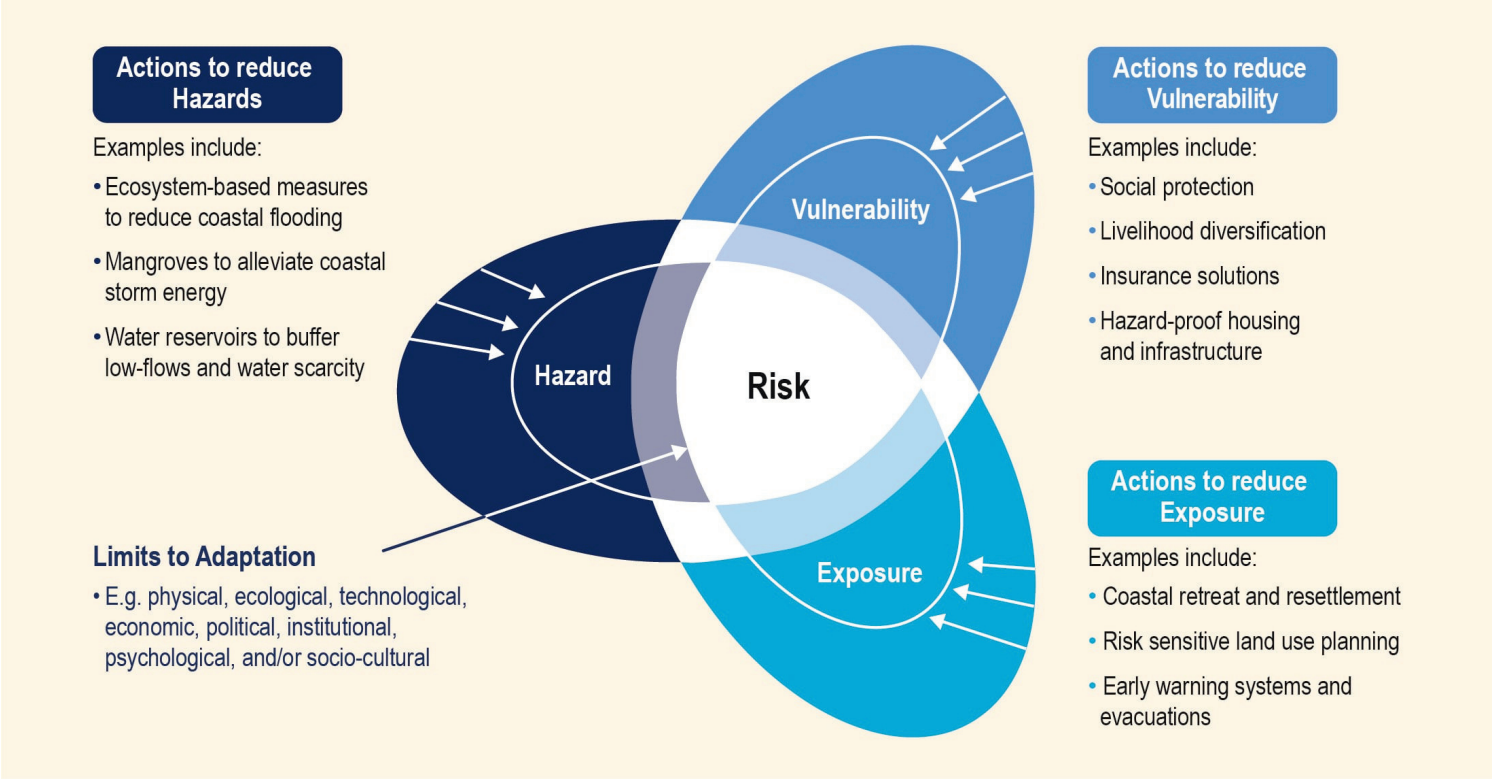

Fig. 1. *The risk assessment framework portrays risk as a triangle based on Crichton's (1999) risk triangle. The area inside the triangle represents risk and the sides of the triangle represent the three independent factors that contribute to risk: hazard, exposure, and vulnerability in equal proportions. Altering any of these three factors changes the amount of risk (IPCC, 2019).*

APPROACHES FOR OPERATIONALIZING RISK TOLERANCE

Risk tolerance has been operationalized in the literature in several different ways. Anderson et al. (2023) grouped different operationalizations of risk tolerance identified in a systematic review of peer-reviewed literature, into six thematic and overlapping categories: 1) balance of costs and benefits, 2) threshold of consequences, 3) direct elicitation, 4) decision-making and behaviour, 5) threshold of hazard characteristics, and 6) affective reactions. Depending on which of these thematic approaches was taken, risk tolerance can be quantified as a numeric threshold (e.g., deaths, frequency, meters); a range (e.g., money invested); a balance (e.g., cost-benefit ratio); a change in behaviour (e.g., evacuating or not); or a change in affective state (e.g., worry, anxiety).

In the articles that used direct elicitation, risk tolerance was operationalized either as yes/no respondent-defined threshold of acceptability or as a spectrum on a scale (e.g., seven-point Likert range of "not acceptable" to "totally acceptable") (Anderson et al. 2023, p. 311).

Six case studies are reviewed here to illustrate the operationalization of risk tolerance in hazard risk management. These case studies were chosen because they explicitly engage with the concept of risk tolerance within hazard risk assessments. Elements of the thematic and overlapping categories identified by Anderson et al. (2023) are evident in each case study.

1. District of North Vancouver, B.C.

In the District of North Vancouver (DNV), risk tolerance is treated as a numerical threshold or "target level" (Dercole, 2009). Tappenden (2014) defines tolerable risk as the maximum risk people are willing to live with in exchange for perceived benefits, whereas acceptable risks refer to generally minor risks that do not require management. To identify the tolerable level of risk to life from natural hazards, the district formed a Natural Hazards Task Force (2007). The task force consulted experts in the topics of natural hazards and risk assessment models, and solicited public input through an open house, a public meeting, and an online survey. This public input ultimately focused on arriving at an agreed upon quantitative risk-tolerance criteria. The result was a goal to reduce natural hazards risks to As Low as Reasonably Practicable (ALARP) followed with a two-tier risk tolerance criterion based on the probability that a hazard scenario results in loss of life for a particular individual, referred to as Probability of Death of an Individual (PDI). The unit of analysis for PDI is often the smallest spatial unit possible within a potentially affected zone, such as a building or land parcel. To achieve ALARP, it must be demonstrable that the cost to reduce a risk further is grossly disproportionate to the benefit gained (Dercole, 2009). The ALARP principle necessitates that tolerable risks are continually monitored and be further reduced below the stated tolerance levels when a notable reduction in risk can be reasonably achieved (Tappenden, 2014).

Individual risk is evaluated using numerical thresholds that define unacceptable risk:

- 1:10,000 risk of death per year from natural hazards for existing developments; and
- 1:100,000 risk of death per year from natural hazards for new developments.

The two-tiered nature of the risk tolerance criteria acknowledges that it is generally more attainable to reduce risk by altering proposed developments, as compared to existing structures (Tappenden, 2014). Risk tolerance criteria can be applied during the building permit, rezoning, new development, and subdivision application process by using up-to-date hazard maps to identify landslide and debris flow hazard areas and steer qualified professionals towards the appropriate engineering and geohazard guidelines.

An example of the operationalization of this risk-tolerance criteria is the debris flood risk assessment for Mosquito Creek, which flows through the densely urbanized DNV (Jakob et al., 2013). Assessing risk focused on understanding the characteristics of the hazard (e.g., debris flood hazard extent, velocity, and depth) for estimated 100-, 200-, 500- and 2,500-year debris flow return periods, and the probability of impacts for individuals and groups living within the hazard area. Vulnerability was an estimate of potential deaths, and the number of buildings damaged. For example, the number of deaths at each water depth were estimated by multiplying the mortality rate by the number of persons occupying buildings affected at a particular modelled water depth, for each event scenario. The results of the hazard risk assessment were then considered next to the risk tolerance criteria (i.e., Probability of Death of an Individual (PDI) to see if risk tolerance thresholds had been exceeded [Figure 2]).

Considering vulnerability as an outcome of the hazard risks separating natural hazards from the social frameworks that influence how hazards affect people, including their risk tolerance (Blaikie, 2014). During public meetings held to discuss the concept of risk tolerance criteria, District of North Vancouver residents expressed concerns regarding the capacity of quantitative risk tolerance criteria to capture the differing levels of risk tolerance among residents, in that some property owners may wish to accept a higher level of risk than others (Tappenden, 2014).

A handful of other local governments in B.C. have proposed or adopted risk tolerance criteria consistent with the DNV. For example, the natural hazards assessment strategy for coastal, creek, and hillslope hazards relevant to the Village of Lions Bay, submitted by Cordilleran Geoscience, suggests adopting an approach that is consistent with the DNV for assessing risk tolerance, which was later implemented (Cordilleran Geoscience, 2017). This may be partially due to the lack of provincially legislated guidance for risk tolerance to geohazards in Canada and B.C., and because the DNV process to develop risk tolerance criteria began in 2006, well before others, allowing time for studies to test the operationalization of the criteria (e.g., Jakob et al., 2013).

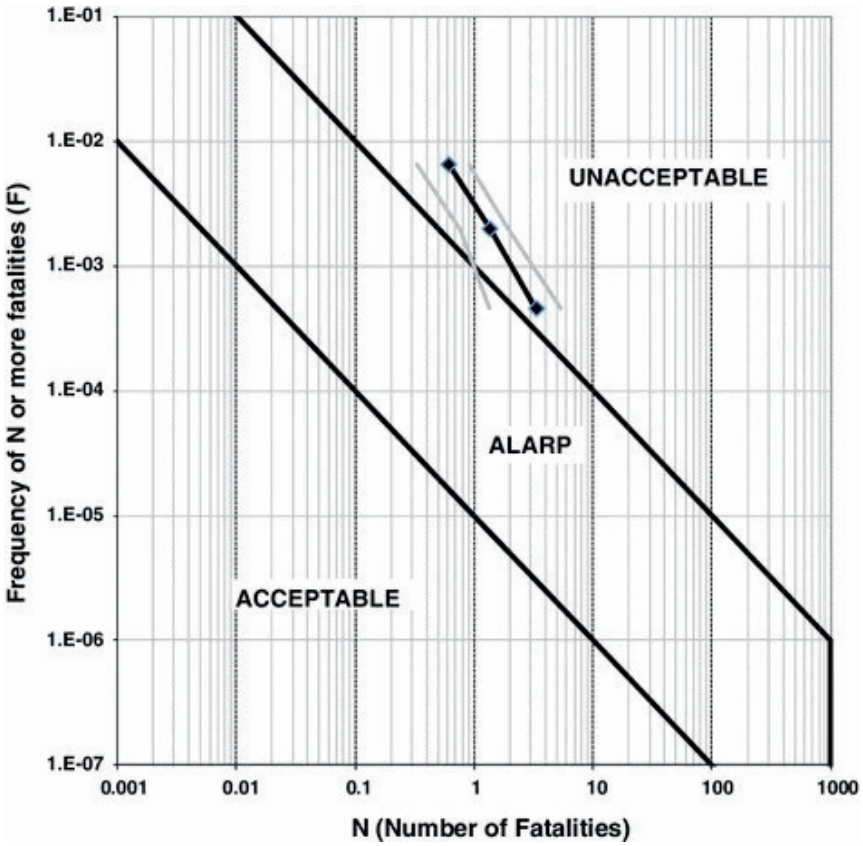

Fig. 2. *Relationship between mortality and water depth for different warning times (after Jonkman et al. 2008). The dashed line was hand-drawn as a reasonable conservative approximation to account for that fact that there would likely be no warning (Jakob et al., 2013: 1674).*

2. Cowichan Valley Regional District, B.C.

The Cowichan Valley Regional District (CVRD) natural hazard risk tolerance policy (2019) takes an approach that is broadly consistent with the DNV but goes further to define individual and group risk. Like the DNV, the CVRD uses Probability of Death of an Individual (PDI) criteria to establish thresholds or decisions made related to natural hazard risk management. When considering a single hazard scenario, PDI is the product of:

1. the annual probability of the hazard scenario occurring;
2. the probability that the hazard reaches the exposed individual;
3. the probability that the exposed individual would be in the impact zone at the time of impact; and
4. the probability of fatality given impact occurs with a certain severity.

Multiple hazard scenarios are compared by considering the probability of each event occurring and resulting in the estimated number of fatalities. Differences among individuals, such as age, general state of health, occupation, and other environmental factors (referred to as *sensitivity* in vulnerability terms) are accounted for numerically by using a higher temporal probability in calculations of individual risk.

Group risk considers the total expected number of fatalities that could result from a single hazard scenario. It is estimated by considering the same factors as individual risk, as well as the total exposed population within a potentially affected zone. Group risk reflects total losses from a hazard event, so it is possible to have a situation where individual risk is considered tolerable, but group risk is not tolerable due to the number of individuals affected. Group risk is typically estimated for a standard geographic area and the buildings within it referred to as the Consultation Zone (CZ). Consistent with the approach to defining risk tolerance thresholds shown in Figure 2, group risk tolerance can also be evaluated graphically on an F-N curve, as shown in Figure 3. The F-N curve defines three zones of risk: unacceptable, ALARP, and intense scrutiny. The zones are defined by the expected number of fatalities, N, and the annual frequency of an event causing N or more fatalities. Similar plots often also show a broadly acceptable zone below ALARP, however CVRD has chosen not to do this. Consistent with the DNV, the CVRD uses the same two-tiered risk tolerance criteria with more stringent criteria for new development.

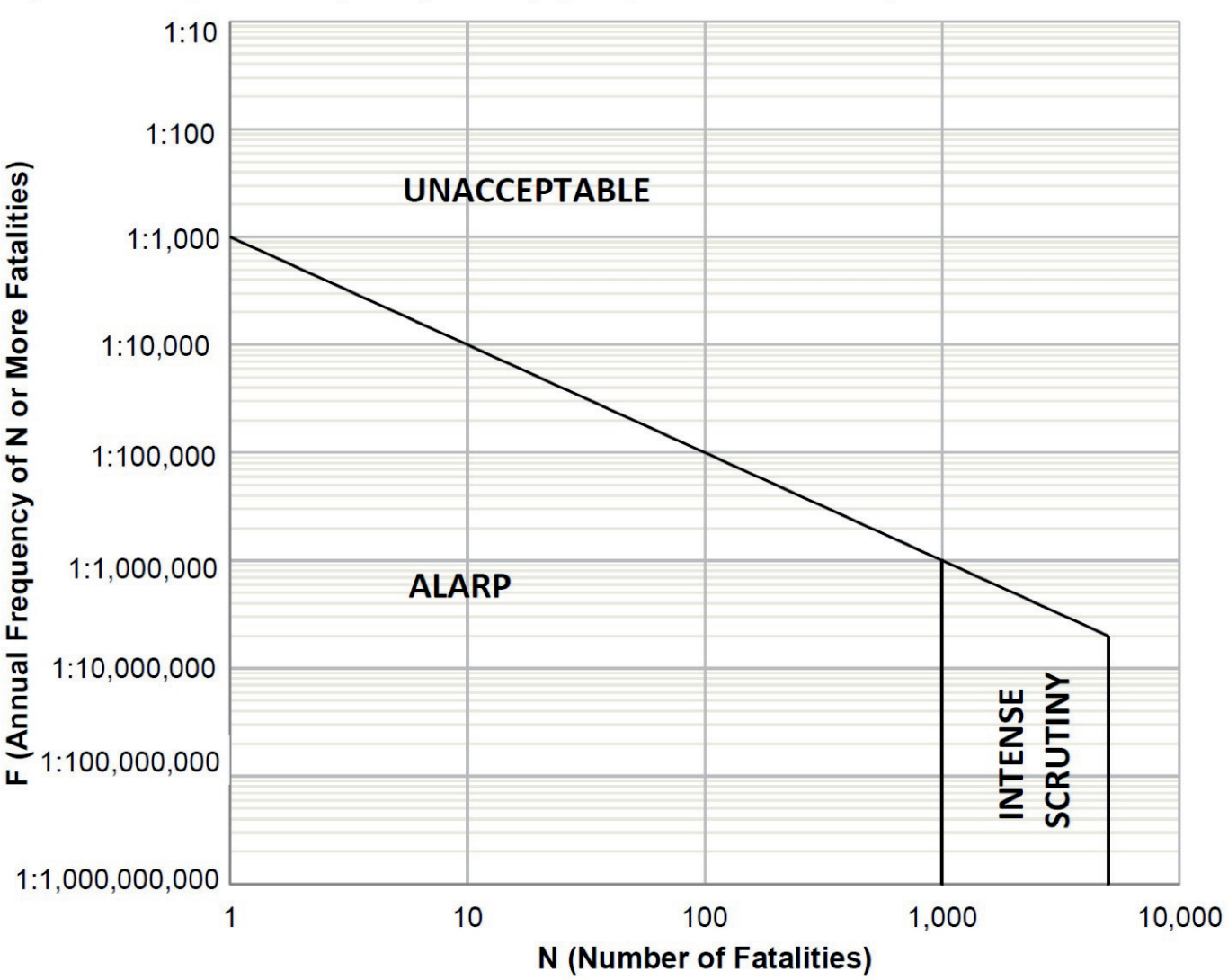

Fig. 3. *Proposed frequency/fatality group risk evaluation grid (CVRD 2019).*

3. District of Ucluelet — Tsunami risk tolerance approach

In the context of a potential tsunami event, the District of Ucluelet's risk management strategy follows the ALARP approach to managing risks and defines risk tolerance as what is *reasonable* and *practicable* in the community context. Risk thresholds are established by the District of Ucluelet, based on site-specific flood construction levels. Differing levels of risk tolerance are thus given to different types of infrastructure and land use, based on flexibility, feasibility, and relative importance to the community. New critical infrastructure, such as hospitals and utilities, are given a minimum acceptable elevation of 18 m above the estimated level of impact from a potential tsunami, whereas new buildings on existing lots are allowed a much lower minimum acceptable elevation (above the coastal storm flood construction level), reflecting differing priorities and perspectives on risk tolerance (Figure 4).

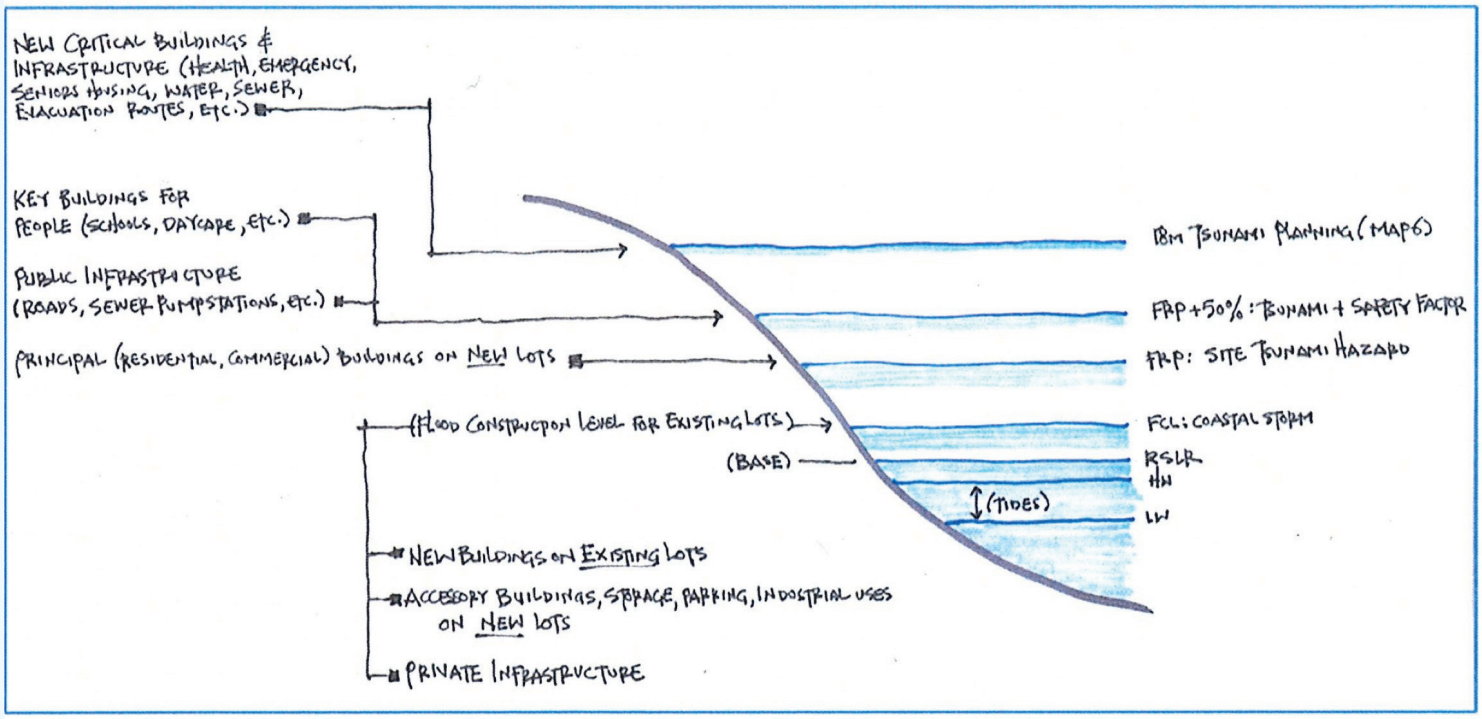

Fig. 4. *Minimum elevations for different users relative to modelled flood levels in Ucluelet, B.C. (District of Ucluelet, 2022).*

4. Maryland, U.S.A. — Flood risk tolerance approach

In Maryland, located on the east coast of the U.S.A, community member knowledge, perspectives, and project characteristics all contribute to the determination of flood risk tolerance (McClure, Land and Vogel, 2024). Flood risk tolerance is defined as the willingness of decision makers and community members to accept possible consequences of flooding. Determining flood risk tolerance can be used to help identify thresholds for adaptation actions. In Maryland flood risk is categorized as high, medium, or low and is subjective, reflecting diverse perspectives and tolerance to living with water (Table 1). The guidance document suggests that all community members, including underserved and overburdened populations, should have representation

within the decision-making group in the determination of flood risk tolerance through direct elicitation. The following questions are used when determining the appropriate level of flood risk tolerance for a project or project area:

- Is the project area currently affected by flooding? If so, how often?
- What are the public function and safety implications?
- What is the cultural, recreational, and historic value of the area?
- What is the sensitivity to inundation?
- For site specific projects:
  - Is replacement an option?
  - What are the associated costs or implications if the site is affected by flood waters?
  - Upon completion, how easily can this project be modified to withstand future water levels?

The frequency of flooding is taken into consideration when defining risk tolerance, as it is believed that in project areas that already experience some degree of flooding, decision-makers and community members might have a higher risk tolerance to projected future flooding.

	High tolerance for flood risk	Medium tolerance for flood risk	Low tolerance for flood risk
Description	Flooding is expected and has minimal impact	Some flooding can be tolerated and impacts can be variable	Flooding has detrimental impacts
Possible Project Characteristics	Low impact, importance or consequence to the community and/or replacement cost	Medium impact, importance or consequence to the community and/or replacement cost	High impact, importance or consequence to the community and/or replacement cost
	Easy or likely to adapt	Moderately easy or somewhat likely to adapt	Difficult or unlikely to adapt
	Little to no implications for public function and/or safety	Moderate implications for public function and/or safety	Substantial implications for public function and/or safety
	Low sensitivity to frequency and exposure to inundation	Moderate sensitivity to frequency and exposure inundation	High sensitivity to frequency and exposure to inundation

Table 1. *Project characteristics to consider when determining the level of tolerance for flood risk (Adapted from New Hampshire Coastal Flood Risk Summary, Part II [6]) (McClure, Land and Vogel, 2024).*

Examples of high, medium, and low tolerance for flood risk include:

- **High tolerance for flood risk**: e.g., land conservation projects that maintain an area as open space or natural areas and can be designed to accommodate flood waters.
- **Medium tolerance for flood risk**: e.g., understanding that flood impacts to buildings are undesirable, costly, and disruptive for the community, but most commercial and residential buildings can experience some flood impacts without compromising critical community functions.
- **Low tolerance for flood risk**: e.g., projects that are highly sensitive to inundation, and public safety and/or community day-to-day functions would be substantially affected if flooding occurs.

Decision makers' tolerance for flood risk can be used to select one relative sea level rise (RSLR) value to plan for within the range of available estimates. Projects with low tolerance for flood risk should consider RSLR estimates that are unlikely to be exceeded during the project's lifespan to avoid potentially severe consequences of inundation (i.e., high repair or replacement costs, substantial implications for public safety, etc.). Projects with high or medium tolerance for flood risk may consider RSLR estimates that are more likely to be realized during the project's lifespan because the consequences of flood impacts are less severe or there can be adaptations during the project's ultimate lifespan to minimize the impact. It may be relevant to divide the project area into sub-areas to evaluate what is at risk and whether the sub-area(s) has a high, moderate, or low flood risk tolerance.

5. California, U.S.A.

The *California Sea Level Rise Guidance* document (2024) provides a step-by-step approach to help decision-makers assess risk by evaluating a range of sea-level rise projections and the potential impacts and consequences associated with these projections (Figure 5). Considering the focus project's location and lifespan, decision makers evaluate the potential impacts and adaptive capacity of the project across a range of sea-level rise projections. Here, assessing risk involves the evaluation of two dimensions: 1) uncertainty (also referred to as *likelihood*), which can be analyzed and assessed using a spectrum of sea-level rise projections; and 2) impacts or consequences, which may require a combination of quantitative and qualitative assessment. *Risk tolerance* is defined as the level of comfort associated with the consequences of sea-level rise and associated hazards in project planning and design. *Risk aversion* is the strong inclination to avoid taking risks in the face of uncertainty. State and local governments should consider the risks associated with various sea-level rise projections and determine their tolerance for, or aversion to, those risks. It is recommended that the assessment of risk and adaptation planning should be conducted at community and regional levels, when possible, to reflect the highly localized nature of impacts and adaptations. The results of these analyses are intended to inform hazard management and development decision-making in the coastal zone across California.

The assessment begins (Step 1) by characterizing the nature of the hazard—sea-level rise, for the project using data from nearby tide gauges (water level recorders). In Step 2, the lifespan of the project and level of risk aversion (low, medium-high, and extreme) are evaluated to identify a range of sea-level rise projections to use in the assessment (Step 3). For projects with *low risk aversion*, modest projections of sea-level rise are used, which provide an appropriate projection for adaptive, lower consequence decisions (e.g., unpaved coastal trails), but will not adequately address high impact, low probability events. For projects with *medium-high risk aversion*, the one-in-200 year timeline should be used. The likelihood that sea-level rise will meet or exceed this value is low, providing precautionary guidance for less adaptive, more vulnerable projects or populations that are sensitive to sea-level rise (e.g., coastal housing developments). For projects with *extreme risk aversion* (low risk tolerance), the extreme sea-level rise scenario should be included in planning and adaptation strategies.

This would include projects with a design life beyond 2050 that have little to no adaptive capacity, would be irreversibly destroyed or significantly costly to relocate/repair, or would have considerable public health, public safety, or environmental impacts should this level of sea-level rise occur (e.g., coastal power plant). The extreme sea-level rise projection provides an understanding of the implications of a worst-case scenario.



Fig. 5. *Stepwise process to apply sea level scenarios in planning. The steps outlined in the figure provide a decision framework to evaluate the consequences and risk tolerance of various planning decisions and should be used to guide selection of appropriate sea-level rise projections, and, if necessary, develop adaptation pathways that increase resiliency to sea-level rise and include contingency plans if projections are exceeded (California Sea Level Rise Guidance, 2024).*

After the appropriate low, medium-high, and extreme risk aversion projections have been identified based on location and timespan, Step 4 is to conduct a vulnerability assessment to evaluate the potential impacts of projected sea-level rise on the project and the project's adaptive capacity. The first stage in the vulnerability assessment is to create exposure maps of sea level rise induced inundation and flooding under different sea level rise projections. The next stage is to evaluate *sensitivities*, the degree to which a place or asset is affected by sea level rise inundation

and temporary flooding. For flooding, this could be sensitivity to a one-time flood or sensitivity to multiple flooding occurrences. This involves identifying who is sensitive, to which impacts, in which ways, why, and how; the capacity of people, natural systems, and infrastructure to readily respond or adapt through existing policies, structures, finances and human resources; and the potential economic costs of failing to adequately plan for sea-level rise now or in the future. The process should prioritize social equity, environmental justice, and the needs of vulnerable communities and consider potential social, cultural, and economic impacts on the wider community. Characterizing vulnerabilities under a range of sea-level rise projections helps decision-makers to determine their tolerance for the risks associated with the consequences of over- or underestimating sea-level rise.

The information gathered in the first four steps of the framework is used in Step 5 to select sea-level rise projections based on risk tolerance and identify adaptation priorities to build resilience to sea- level rise. Here, decision makers may have a higher tolerance for risk (or lower risk aversion) when considering projects with a shorter lifespan, minimal consequences, flexibility to adapt, or low economic burden as a result of sea-level rise. As such, it may be appropriate to select low sea-level rise projections. However, for projects with a longer lifespan, less adaptive capacity and medium to high consequences should sea-level rise be underestimated, decision makers should take the more precautionary, more risk- averse approach of using the medium-high sea-level rise projections. Following a thorough assessment of adaptation options, a specific project or adaptation pathway is ultimately selected in Step 6. These steps should be done in close coordination with the community members and relevant regulatory bodies.

6. Aotearoa (New Zealand)

In Aotearoa, a framework to consistently define and understand risk tolerance was developed and integrated into current hazard risk management approaches. Aotearoa's hazard risk management generally takes the approach of: 1) understanding the hazard—using data, models, and historical data to learn as much as possible about possible scenarios and impacts (including multi-hazard or cascading hazards); 2) understanding the risk—risk assessment includes gathering information on exposure and vulnerability; and 3) managing the risk—the understanding of the risk the hazard presents is used to inform policy, planning, and practice. An identified gap in this approach is assessing risk tolerance.

A consistent terminology for risk tolerability is defined based on three levels of risk: *intolerable*—risk cannot be justified except in extraordinary circumstances; *tolerable*—risk is accepted only if the benefit gained is shown to outweigh the risk (using the ALARP principle); and *acceptable*—risk is broadly acceptable. An assessment of risk tolerance can be integrated into a range of methodologies for risk assessment, as long as the assessment generates a clear understanding of the known hazard and associated risk and includes a transparent decision process. Once a risk is understood, one can then consider whether they are willing to tolerate the consequences.

Tolerance to the known level of risk can be assessed, by considering the following (Figure 6):

- the timeframe the level of risk will be present for;
- what is being affected and to what extent;
- who bears the consequences of the risk or risk management options; and
- comparing the timeframes, consequences, and other factors against the pre-set risk thresholds to determine overall risk tolerability.

In this assessment of risk tolerance, risk is a temporal phenomenon, meaning it can vary over time due to changes in exposure, hazard, or vulnerability, or it may be acceptable in the present but become unacceptable at some point in the future. Also, some hazards (e.g., sea-level rise) might increase over time. A risk tolerance assessment should be able to reflect this by indicating that the classification of risk tolerance is flexible and will likely change over a different timeframe (e.g., currently *tolerable* could become *intolerable* over time).

Hazard events can result in a range of consequences, including primary, secondary, and tertiary impacts, and it is important to evaluate them in relation to each other. Impacts should be benchmarked against the possible range of outcomes for that specific type of consequence and then considered against the risk threshold criteria.

Community member engagement is essential in any risk tolerance assessment, particularly to identify who might be affected, in which ways, and how, and what is the capacity to adapt? Engagement should involve diverse groups of community members who might bear the consequences of the hazard event or risk management options, requiring a robust process for reconciling different views on risk tolerances. Engagement approaches should be modified to adhere to cultural factors of different groups recognizing local protocols, laws, beliefs, and worldviews. For example, the timeframes for risk tolerance for Māori extend well beyond policy years to generations. Any engagement requires consideration of the past, present, and future experiences and events, related to the assessment of risk, including risk tolerance and decision-making. An understanding of any equity challenges that communities may face must also be considered and treated with compassion.

Risk tolerance thresholds must be determined independently of any individual risk assessment. They should reflect societal views and priorities, e.g., what cost of damages becomes unacceptable, regardless of the hazard or risk. Results from individual risk assessments are compared to these pre-defined thresholds and timeframes to assess risk tolerance. Risk tolerance should be monitored over time to account for any changes, such as new information, or the nature of the hazard. There are uncertainties in any type of risk assessment, and the precautionary principle should be used where there are threats of serious or irreversible damage to enact cost-effective measures to manage risk. Risk tolerance also needs to be considered at different scales, including at national, regional, and local levels, depending on the scale of the hazard, relevant importance to different levels of society, and risk management governance.

What is the decision for, over what timeframe?				
What is the policy timeframe the risk tolerance decision will be managed over? What decision will the risk tolerance assessment inform?	~10 years	~30 years	~50 years	~100 years
	Government policy	Spatial planning	Built environment design	Climate change adaptation

What could, or did, happen?					
Use **scenarios** to assess the consequences of an event **or** use impact data, hazard and risk assessments to assess the consequences of an event. Use the considerations below to test the coping capacity.					
Social	**Economic**	**Governance/ Sovereignty**	**Natural environment**	**Cultural**	**Built**
How many deaths, injuries, or illnesses will occur? Will mental health or public wellbeing suffer? Will the impacts be felt equitably?	How much will it cost to repair any damage? Will the risk disrupt the local or regional economy? How much disruption is ok?	Will the ability to govern be impeded? Does public perception demand or prevent a certain action? Does the risk affect NZ sovereignty?	How will the environment be affected? Will irreversible damage be done to an ecosystem? Does the risk affect how the environment affects society?	Does the risk affect places of cultural or archaeological significance? Will the risk preclude future generations from some experience or resource?	Will the risk prevent normal use or function of buildings? Will the risk disrupt normal infrastructure or utility service levels?

Who is affected?	What is the scale?	Who lives with it?
Homeowners – insured, non-insured, renters. Iwi/hapū – housing, marae, urupā. Infrastructure providers – roads, power, communications. Council – regional and/or district; other stakeholders.	Local – affects those both in and out of the hazard extent. Regional – districts are affected. National – significant social and economic impacts.	Does this require a short-, medium-, or long-term fix? Are people empowered to modify their own risk? Is there an equitable spread of consequences?

Is this ok?
Use the pre-event (table 2) or post-event (table 3) criteria to guide decision-making using risk tolerance thresholds.

If not ok, how can the risk be treated?		
What are the options, and are they acceptable to the wider community, iwi/hapū, council, and infrastructure providers, both now and in the future?		
Who decides?	**Who pays?**	**Who lives with it?**
Who participates in the decision-making – what are their values? Is the process robust, transparent and documented? Who has the authority to enact a change?	Do those who create the risk experience it or pay for its treatment? What is the opportunity cost of doing nothing? Is it cost-effective to treat the risk?	Does this require a short-, medium, or long-term fix? Are people empowered to modify their own risk? Is it sustainable to just accept the risk?

Is this ok?		
Use the pre-event OR post-event criteria table to guide decision-making using risk tolerance thresholds.		
Acceptable	**Tolerable**	**Intolerable**
Broadly acceptable. Monitor and maintain assurance that risk remains at this level.	Risk is accepted if benefit gained is shown to outweigh the risk. Tolerable if the risk can be mitigated at a cost proportional to the benefit gained.	Risk cannot be justified except in extraordinary circumstances. Activity must cease until risk is removed or reduced.

Fig. 6. *Assessment of risk tolerance, Aotearoa (New Zealand Gov., 2025).*

The risk tolerance methodology is intended to be included in assessments of current and future risks. The result of the risk tolerance assessment should be a clear risk classification (i.e., acceptable, tolerable, or intolerable). Policies aligned with risk tolerance thresholds will enable consistent and effective management of the risk. Engagement on the available policy options will then direct the implementation of the chosen risk management response. Figure 7 illustrates the approach to hazard risk management in Aotearoa New Zealand, including the assessment of risk tolerance.

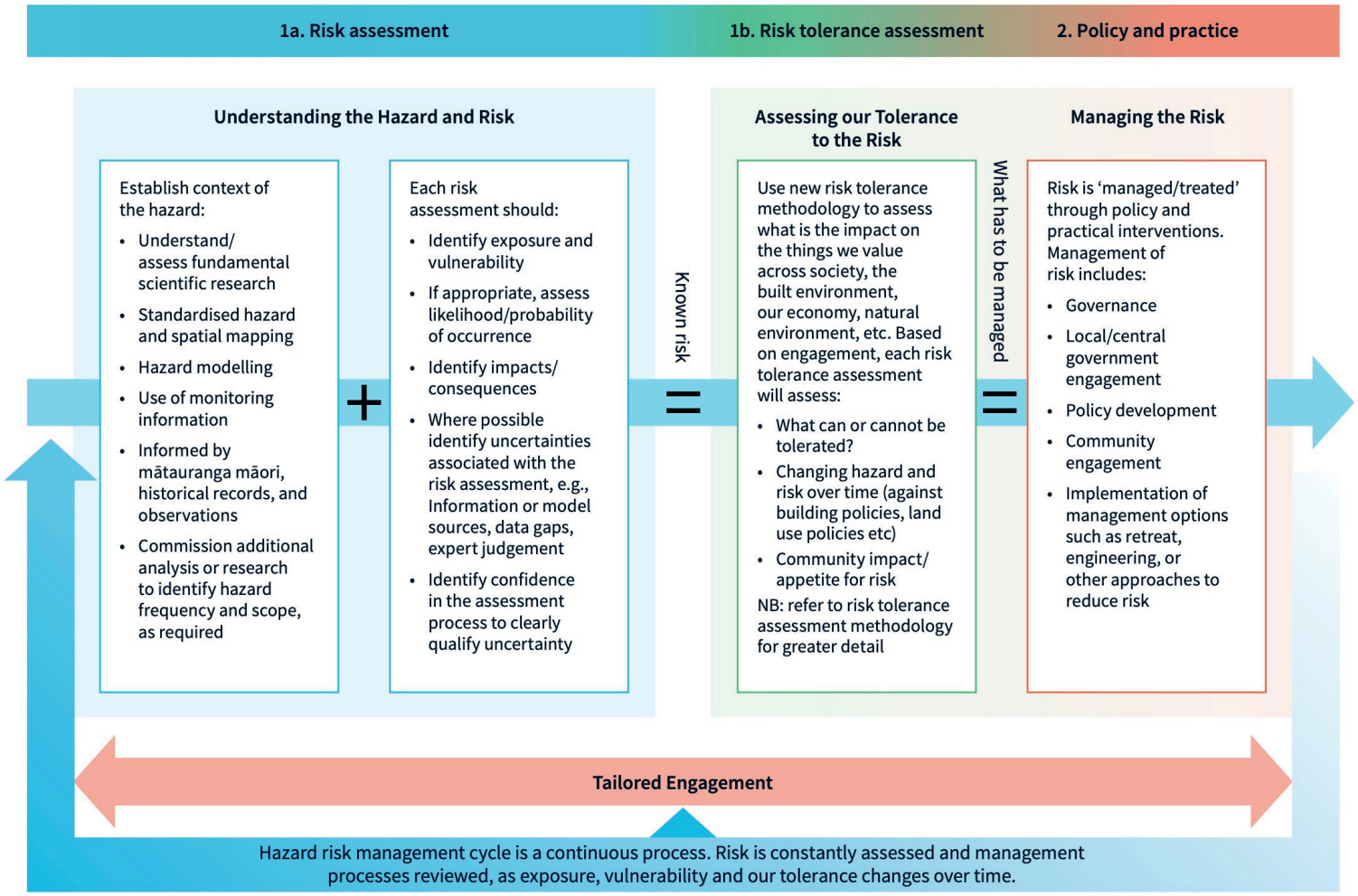

Fig. 7. *The figure shows the approach to hazard risk management in Aotearoa New Zealand, including the assessment of risk tolerance. Once risk is known, risk tolerance should be assessed in order to identify the appropriate risk management considerations, interventions, and options (NZ Gov., 2025).*

DISCUSSION

This scoping review describes how risk tolerance has been included in various hazard risk assessments. The main takeaways from the reviewed case studies are there is a common definition for risk tolerance and its constituents; approaches for assessing risk tolerance differ among the reviewed studies and so does the level of community engagement; and the classification of risk tolerance is flexible and will likely change over time, requiring hazard management to be a continual process.

The common definition for risk tolerance across the reviewed case studies is the willingness to bear a risk. The goal of an assessment of risk tolerance is to identify what is *acceptable*, or *tolerable risk*, which depends on a host of existing social, economic, political, cultural, technical, and environmental conditions. Risk above this threshold is considered *unacceptable*. A goal of risk management is to reduce risk below the tolerable threshold and "As low as Reasonably Practicable" (ALARP). There are several different approaches to defining risk tolerance thresholds depending on the risk assessment framework used. Usually, risk tolerance is considered once the known hazard and risk are understood, as an assessment of the willingness to tolerate the consequences. Risk tolerance thresholds are determined independently of any individual risk assessment and reflect the conditions of the hazard-prone area. Results from individual risk assessments are compared to these pre-defined thresholds and timeframes to assess risk tolerance.

In some instances, risk tolerance is treated as a numerical threshold or target level such as the Probability of Death of an Individual (PDI). These assessments tend to focus mostly on the nature of the hazard and possible impacts, and reduce vulnerability to an outcome of the hazard event (e.g., number of deaths, costs of damage). These assessments can be conducted at an individual or group level by extending the same factors as individual risk across the total population within the potentially affected zone. Differing levels of risk tolerance can also be given to different types of infrastructure and land use, reflecting their relative importance to the community. This approach provides a broad understanding of the potential impact of a single hazard event, but does not capture the differing levels of risk tolerance among community members or the multiple pathways in which a hazard event could impact the system.

In addition to describing the nature of the hazard and potential impacts, some hazard risk assessments also emphasize the human component of risk (vulnerability), which conditions risk tolerance. Community engagement is essential to identify sensitivities, adaptive capacity, and the potential economic costs of inaction. Taken together, identified vulnerabilities help to determine how tolerable a system is to a particular hazard potential and over different timeframes. Consideration of the diverse groups of community members who might bear the consequences of the hazard event or risk management must be taken to account, including cultural protocols and norms.

It is suggested that policies aligned with risk tolerance thresholds will enable consistent and effective management of the risk. Hazard risk management is considered a continuous process. Risk tolerance needs to be constantly re-assessed and management processes should be reviewed as exposure, vulnerability and tolerance change over time.

CHALLENGES / RESEARCH GAPS

In addition to these case studies, which focus on the practical application of risk tolerance in specific decision-making contexts, there is also a broader literature that has developed similar concepts and approaches, including work on tolerable windows, habitability, sustainability boundaries, safe operating spaces, and tipping points (e.g., Dearing et al. 2014; Lade et al. 2021; Matthews et al. 2025; Petschel-Held et al. 1999; Raymond, Mathews & Horton 2020; Rockström et al. 2024; Vea et al. 2020). This work offers broad level insights on the challenges and opportunities for work developing and operationalising risk tolerance.

Firstly, risk tolerance approaches face challenges in accounting for the cumulative and dynamic nature of risks across temporal and spatial scales. *Cumulative risk* refers to the compounding effects of multiple, interacting stressors—environmental, climatic, and socio-economic—that build up over time and across scales, often in non-linear and unpredictable ways (Simpson et al. 2021; Simpson et al. 2023). Cumulative risks emerge from the layering of slow-onset changes (e.g., sea-level rise, landscape change) with more acute shocks (e.g., heatwaves, floods, debris flows), intersecting with evolving vulnerabilities such as social inequality, infrastructure decay, or institutional fragility (Marbaix et al. 2025; Rindsfüser, Zischg & Keiler 2024).

Over time, these interactions can erode the adaptive capacity of institutions, communities, and ecosystems, ultimately shaping how risk is perceived and tolerated. For example, repeated coastal flooding—even if individual events are not catastrophic—can weaken public infrastructure, reduce trust in authorities, and strain local governance, particularly when compounded by fiscal austerity or short-term, politically driven responses (Duvat et al. 2021; Guzman 2025; Kehler & Birchall 2023; Magnan et al. 2022). While such patterns can lower tolerance, there is also evidence of adaptive learning, whereby communities and institutions adjust their tolerance thresholds through experimentation and innovation in response to emerging risks (Canosa et al. 2024; Naylor et al. 2020). Most assessments, however, treat risk tolerance as static or episodic, failing to capture its path-dependent and evolving nature (Estoque et al. 2023; Roa et al 2025).

Secondly, another challenge lies in how social determinants of risk and the role of human agency, behaviour, and feedback are represented. Risk assessments typically make simplified assumptions about human behaviour, overlook determinants of exposure and vulnerability, or focus on a limited set of techno-engineering options (e.g., Ford et al. 2018; Olazabal et al. 2024; Peng et al. 2021; Steger et al. 2021; Yoon et al. 2022).

This disconnect can hamper efforts to assess adaptation limits or the shifting space of viable adaptation actions under real-world constraints such as poverty, institutional inertia, uneven access to technology, or public perceptions of what is needed (Juhola et al. 2024). Crucially, it also constrains our understanding of risk tolerance — that is, how different individuals, communities, sectors, or institutions perceive and accept climate risks under evolving social, economic, and political conditions. Without accounting for these human dimensions and feedback, assessments may overestimate adaptive capacity or misjudge when risks are (un)acceptable, leading to maladaptive outcomes or missed opportunities.

Thirdly, risk assessments typically prioritize economic losses and direct health impacts, e.g., property damage, infrastructure failure, loss of life — but there is growing acknowledgment that non- economic dimensions such as cultural heritage, social cohesion, and ecological integrity are equally critical (Naylor & Ford, 2023; Puig, 2022; Puig, 2024). Non-economic risks are often marginalized due to a lack of standardized metrics and difficulties in assigning thresholds of tolerance (Bélisle et al. 2018).

For example, Indigenous communities may deem any loss of sacred land or biodiversity as intolerable or may emphasise intergenerational responsibility and relational understandings of land and wellbeing in defining what is tolerable (Ford et al. 2020; Redvers et al. 2022). Yet such values are rarely captured equally with economic considerations in formal assessments.

This reflects a key gap in that current frameworks often assume a narrow, technocratic view of risk tolerance. Addressing this requires embedding participatory approaches into research on risk tolerance to co-define what is considered tolerable or not (Ayandlade et al. 2023; Sterly et al 2025).

Finally, climate risk assessment remains hampered by disciplinary silos and a lack of meaningful transdisciplinary engagement. Dominant approaches—rooted largely in the natural sciences—often exclude social science insights, limiting our understanding of risk tolerance, which is not a purely technical or probabilistic construct, but one shaped by cultural values, historical experiences, institutional trust, and social dynamics. There is growing recognition of the need for bottom-up, people-centric approaches that integrate local knowledge with formal models, embrace uncertainty, and attend to the cultural, historical, and political dimensions of risk (Ayanlade et al. 2023; Cundill et al. 2024).

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Pacific Institute for Climate Solutions

PO Box 1700 STN CSC
Victoria, BC V8W 2Y2 Canada

T 250-853-3595
F 250-853-3597

pics@uvic.ca
climatesolutions.ca