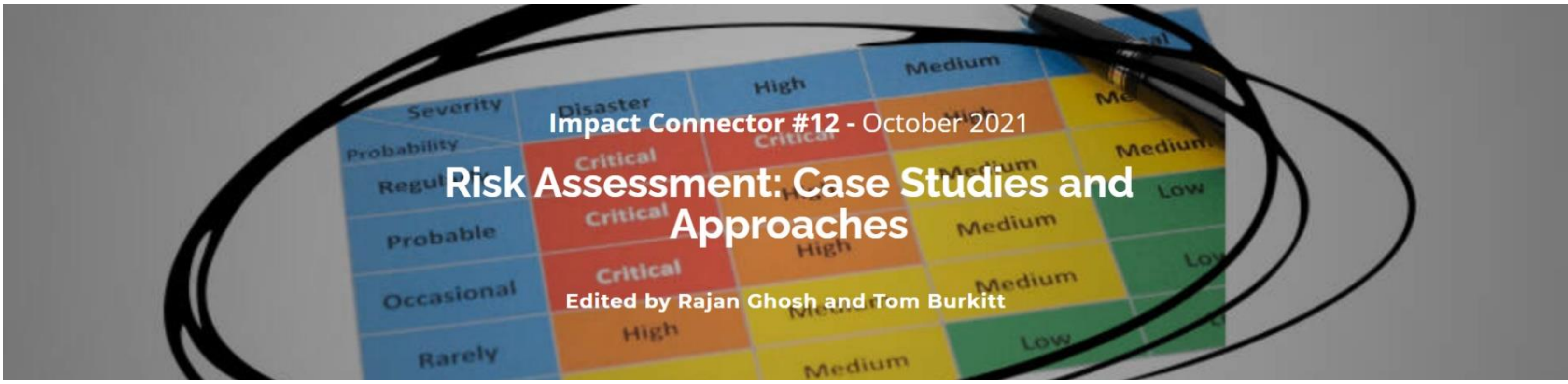
Impact Connector #12 - October 2021
Risk Assessment: Case Studies and Approaches
Edited by Rajan Ghosh and Tom Burkitt

Introduction

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Firstly, we wish to acknowledge the efforts of the contributors to this special edition of the NZAIA Impact Connector. These are very demanding times for everyone and yet they've delivered a diverse and very engaging set of articles.

Thank you all.

With this edition of Impact Connector, we're focusing on risk and impact assessment. Risk assessment and impact assessment are disciplines that have evolved in parallel and have an intriguing and overlapping relationship. Indeed, debate continues about whether they are, in fact, distinctly different or not.

We won't resolve the debate here, and it's not our intention to do so. We can and will, however, refer you an excellent early treatise by Andrews (1) on the subject and Martina Zelenakova's paper (2) on the integration of risk assessment with the environmental impact assessment (EIA) process. From these you can explore the relationship between the disciplines.

This edition of Impact Connector serves as an introduction to risk assessment and offers new and innovative ways of understanding and responding to risk. It also describes case studies where a variety of methods were applied to understand the risk from natural hazards and climate change. We don't explore public health risk or many other sub-domains of risk assessment and, intentionally, the focus has been on risks presented by natural hazards.

We begin with an engaging piece from Jack Krohn of the Victorian State Government in Australia that challenges our overuse of jargon and offers a perspective on the application of impact and risk assessment from Australia. This sets the scene well for our other papers.

We then hear from Rob Bell, who after many years leading a critically important research programme on natural hazards and risk with NIWA, provides justification for an adaptive approach to responding to uncertainty. Both risk assessment and impact assessment can incorporate this paradigm when specifying approaches to mitigate risk and impact over time.

Then Matt de Boer of the New Zealand Climate Commission, and formerly with Northland Regional Council (NRC), gives his perspective on how risk assessment helps inform an understanding of the impacts of climate change and how he and his former team at NRC approached climate risk assessment and adaptation planning in Northland Region of New Zealand.

Damon Coppola then writes about values-based impact assessment and emergency management, an approach where risks to what is valued by communities, including their vision of development, must be analysed and communicated clearly in order to engage communities effectively in addressing the potential impacts.

One of the toughest challenges in risk assessment is quantifying and communicating uncertainty. Bapon Fakhruddin and John Handmer of Tonkin & Taylor and RMIT University, respectively, give us an engaging example of how they've addressed this in the context of flood risk management.

John Kreft and Mark Easton have been establishing a very clever platform for monitoring rockfall risk for Waka Kotahi – The New Zealand National Transport Agency. It was the ambition of Waka Kotahi to have a near real-time impact-based forecasting system for rockfall risk along its state highway road corridors, and this paper describes how this was achieved.

Some of you will be familiar with how the insurance sectors assesses risk and seeks to understand the losses associated with likely future events. We're fortunate to have Ryan Crompton & Paul Somerville of Risk Frontiers contribute an interesting paper on their work to 'normalise' the losses associated with historic natural hazards in New Zealand.

Bapon's second contribution is with his colleague, Richard Reinan-Hill, and they describe how they have achieved seamless forecasting of weather and climate impacts. This important work sets a precedent for future impact-based forecasting and early warning systems.

Finally, we offer a short story about how key data gaps were addressed in a comprehensive multi-hazard risk assessment completed for the State Government of Uttarakhand in Northern India. This study is typical of projects invested in by the World Bank and other international development agencies as they invest in strengthening capacity for disaster risk reduction.

So, quite the variety. Enjoy!

Tom & Rajan

References

(1) Andrews, R.N.L (1990). “Environmental impact assessment and risk assessment: learning from each other” in Environmental Impact Assessment Theory and Practice (ed Wathern, P.), Routledge Press.

(2) Zelenakova, Martina (2017) Risk Analysis within Environmental Impact Assessment: A review. Proceedings of the 17th International Multidisciplinary Scientific GeoConference (SGEM2017)

If you haven't seen it, have a look at Stephen Fry's and Hugh Lawrie's hardware shop sketch.

Customer Fry is going through his list of requirements such as grollings, frotting pencils (felching pens being out of stock) and a spill-trunion and shopkeeper Lawrie (after clarifying whether the spill-trunion should be bevelled or otherwise) lifts the items from the relevant shelf. It's a celebration of jargon.

Subject matter experts love their jargon. Professions, hobbies, pastimes have their own words that have no utility outside that construct. You can exclude, or at least baffle, outsiders with terms that they don't understand. But it gets more confusing when a word that is allocated a meaning that is specific to a particular context also serves another purpose (or range of purposes) outside that context.

Impact assessment as a discipline has its own modest share of jargon. We talk of screening, scoping, review, and of impacts with meanings that are quite specific in the impact assessment context. A discussion about any of those aspects depends for its usefulness on the participants having the same understanding of the key word in the context of the discussion. As a birder as well as an impact assessor, I can move effortlessly between the very different notions of "scoping" a distant bird and "scoping" an impact statement.

"Risk" is commonly mentioned in the context of impact assessment. In Victoria's *Ministerial guidelines for assessment of environmental effects under the Environment Effects Act 1978*, in fact, "risk" appears 31 times [1]. Confusion can arise because the word is used in subtly different ways at different points in the document. So, what are these different nuances that "risk" is meant to convey?

There is the notion of a "risk-based approach", *to ensure that required assessment, including the extent of investigations, is proportionate to the risk* [sorry!] *of adverse effects*. There is a definition of "potential effects" as including *potential changes or risks to environmental assets*. There is risk as the potential for an adverse effect, as a product of likelihood and magnitude, which in turn brings in the concept of uncertainty. And there is "risk to [human] health", in a discussion about hazards. One recent Victorian Environment Effects Statement (EES) included a chapter on "Hazard and risk", relating specifically to dangers on human health and well-being, including due to a potential catastrophic event such as an explosion.

Most proponents preparing EESs in Victoria undertake some form of environmental risk assessment. This is valuable provided it contributes to an enhanced understanding of potential environmental effects, because that is the explicit focus of the Environment Effects Act – the potential for significant effects on the environment [2]. However, while "impacts" and "effects" can be regarded as jurisdictional synonyms, the discipline of environmental impact assessment is not characterised by the same elements as environmental risk assessment.

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Impact assessment is about identifying and characterising potential impacts on the environment (which in Victoria is defined in the Ministerial guidelines as including social, economic, and other elements of human surroundings, not just the biophysical environment). Those impacts might be unavoidable in the context of the project if it proceeds – for example, loss of native vegetation from the footprint of the pit for a proposed quarry. Vegetation loss is therefore an impact that can be addressed with certainty – if the project proceeds, the vegetation will be removed. But what of the migratory wildlife that might not be present at the time of clearing, or the apex predator for which the site represents part of its home range? How do we characterise the potential for an adverse effect on those values? What of the groundwater dependent ecosystem a little distance away, which might or might not be at risk due to groundwater drawdown as the pit is deepened and dewatering creates a cone of depression in the water table? Aren't those risks rather than impacts?

An impact is no less an impact for being uncertain. The referral criteria in Victoria's Ministerial guidelines (setting out thresholds for referral of projects for the Minister's decision on the need or otherwise for an EES – screening, in a word) without exception refer to "potential" effects. The fact that an effect might or might not be realised does not make it any less an effect to be considered or assessed. Environmental impacts or effects that are attended with some level of uncertainty are not, therefore, environmental "risks" rather than "effects". The uncertainty factor might influence choices about ways to mitigate or to manage the effect if it eventuates, or to the degree that it eventuates, but it is the effect that demands assessment.

Environmental risk assessment can be useful in allocating priority and resources for investigating potential effects. In Victoria, relatively few projects are subject to assessment through a requirement for an EES, and those projects commonly raise concerns about potential effects on multiple environmental assets. But even then, it is likely that there are priority issues and issues less likely to be strongly material to the assessment. A proposed wind farm in a remote rural location may have potentially significant effects on biodiversity or landscape values, but is unlikely to be approved or refused on air quality grounds. By undertaking a preliminary environmental risk assessment, the proponent team can put some objective shape around a basis for identifying the issues most likely to be influential in the assessment outcome.

Investigations of potential impacts arising from priority “environmental risks” will generate new information which was not available at the time of the initial risk assessment. This might lead to a conclusion that the priority for further investigation is lower than first thought, for example if field studies reveal that habitat for a particular threatened species of concern does not exist in the project area. If new information leads to revised conclusions about the relative level of environmental risk, that could better inform decisions about the effort to be deployed into subsequent or continuing environmental investigations.

The level of impact arising from an identified risk might be reduced by applying or committing to targeted mitigation measures. The potential impact on a threatened aquatic species might be mitigated by preventative measures to stop wastewater from a project entering aquatic habitat or my treatment of wastewater to remove contaminants of concern before it enters the waterway. In risk terms, the first measure would reduce the likelihood and the second would reduce the consequence. Contingency plans can provide for mitigation measures to be implemented if monitoring indicates that an impact which was identified as possible but uncertain in the assessment is found to be occurring.

To some extent, perhaps, the “impact” vs “risk” argument might be semantic. But as practitioners in a field into which many of our stakeholders might stray only occasionally, we can save a lot of tension and a lot of time by using language consistently to avoid cross-purpose arguments. Our discipline is impact assessment. Disciplined use of terms, especially those that can convey multiple meanings in different contexts, is a worthwhile investment in clarity and effective communication with proponents, stakeholders, regulators, and colleagues.

Footnotes

[1] By contrast, “impact” appears eight times and “effect” appears 203 times. The document comprises 31 pages.

[2] Dating as it does from the first decade of environmental impact assessment, Victoria’s legislation adopted the word “effects”, whereas almost all environmental impact assessment legislation provides for the assessment of environmental impacts, and a Victorian EES corresponds closely with the concept broadly referred to as an “EIS” in other jurisdictions.

Introduction

Stationarity, which assumes the probabilistic characteristics of hazard extremes and risk can be extrapolated from observational records, is now an ill-suited for dealing with the continually changing risks we face, the inherent deep uncertainties and any downstream tipping points [1].

Driven by rising sea level, ongoing change in risk is unequivocally the new norm for coastal environments. This includes the growing inland reach of coastal processes, such as salinization, groundwater rise, and flood hazards affected by climate change and sea-level rise (Figure 1). As rates of sea-level rise accelerate, adaptation will need to occur at a faster pace and/or a larger scale.

Figure 1: Ohiwa Harbour brimful during a high perigean-spring (king) tide on a sunny day: 1-Feb-2014 [Credit: R Bell]

Consequently, a different approach to risk or impact assessments and risk treatment must explicitly include the: i) increasing rate of change in risk over time; ii) interlinkages and feedbacks within the system including cascading impacts [3]; iii) compounding of coastal and freshwater hazards e.g., flooding; and iv) deepening uncertainties stemming from multiple possible coastal-climate futures, but where the direction of travel is certain.

Being explicit about planning and/or design timeframes is now a critical component of risk/impact analysis [4], when considering adaptation, whether using nominal or policy-driven timeframes (thereby artificially closing off ongoing changes in risk) or taking a realistic view of the permanence of the built environment and land-use decisions. Even short-term or incremental adaptation can lead to path dependency to a particular course of action or maladaptation down the track as climate-related risks unfold [5].

For managing the rising coastal risk and what to do about it (adaptation), risk and impact assessments and the evaluation and treatment of risk, can generally categorized into specialist but often disparate activities (and for which I have had personal involvement):

1. national or regional climate-change risk assessments and adaptation plans [e.g., 6];
2. resource-management plans, policy statements, consenting and risk reduction under the existing Resource Management Act 2001 (RMA) and future reforms [7];
3. design, upgrades or asset maintenance for infrastructure or lifeline utility services at national level or local government e.g., 30-year infrastructure management plans;
4. civil defence and emergency management (CDEM) group plans and the National Disaster Resilience Strategy; and
5. climate-related disclosures of exposure to short-, to long-term risks and opportunities that climate change presents for financial and insurance entities and businesses.

Ongoing, foreseeable, climate-related risks are and will be keenly felt in coastal environments on the back of the rise in mean sea level already in A-NZ (0.2 m since early 1900s [1]) and sea-level rise continuing for centuries, with emissions reduction only slowing the rate of rise [1, 2, 8]. As an example of the urgency to address coastal risk exposure, the first national climate-change risk assessment completed last year [6], identified impacts related to coasts and coastal lowlands as a component in 9 of the top 10 prioritized climate risks to address.

So how can we address time-varying and uncertain climate-driven risks in the non-stationary era we now face?

The problem space

Conventional practice in risk or impact analysis usually adopts the *consequences* × *likelihood* construct for risk, summarizing the analysis with heat maps that identify the combinations that potentially pose the highest risk. This provides a consistent basis for comparing different natural hazards, but it often disadvantages emergent climate-risks that so far barely register on the short-term priority list for risk treatment. This framing reinforces a static approach, or at the most fits around a planning or design timeframe dictated by the policy, standard or planning process at hand e.g., 5-10 years (Long Term Plans, CDEM Group Plans), 30 years (Infrastructure Management Plans, consents) and 100 years for coastal hazard-risk assessments. *Likelihood* poses the biggest challenge to nail down with a continually rising risk, particularly from sea-level rise and its downstream impacts and implications.

For instance, coastal flooding (Figure 1) will become increasingly more frequent over the next few decades on the back of a rising mean sea level [1, 9], so likelihood will quickly blow out over coming decades to be virtually certain (despite the uncertainties about how quickly we get to that state). Alternatively, the MfE coastal guidance [8] recommends focusing on the time-varying *consequences* and associated adaptation thresholds, rather than trying to second-guess what future climate scenario to use or worse, assign a probability to a specific climate scenario (which is not supported by any peer-reviewed literature).

Seemingly, we have lost sight of the high-level definition of risk in the ISO 91000 risk management standard, being "*the effect of uncertainty on objectives*". Embracing the inherent uncertainties associated with different possible coastal-climate futures, the intersection between the rising hazard exposure and community or stakeholder objectives at *adaptation thresholds* (the intolerable conditions we don't want to see happen or loss of a key value), forms a more open-ended and adaptive approach that are informed by risk or impact assessments.

The solution space

Starting with a set of scenarios, the adaptation pathways approach, as recommended in ISO14090 standard for climate change adaptation [10], provides a flexible solution and engagement space to devise alternative pathways that perform across a range of possible futures. The pathways (comprising short-term actions and long-term options) can then be stress-tested against the scenarios, using results from risk or impact assessments, to determine the effectiveness, flexibility and robustness of options and the possible time bounds on their "shelf life" before a switch must be made to the next option or stage in a sequence. One such approach is Dynamic Adaptive Pathways Planning or DAPP, which has been embedded in the national coastal guidance published in 2017 by the Ministry for the Environment [8]. Financial and business climate-risk assessments also use a stress-testing approach using a range of future scenarios [e.g., 11].

DAPP for a vulnerable community or infrastructure network is typically visualised in a pathway map analogous to a decision tree or a "metro map" (Figure 2). It depicts different routes to achieve a destination (objective or level of service), including switches to an alternative option before an "end-of-line" adaptation threshold (vertical bar) is reached [8, 9, 11]. DAPP embraces deepening uncertainty by focusing on decision making over time that is scenario neutral (i.e., does not rely on a choice of a design or most-likely scenario). The essence is proactive and dynamic planning of alternate pathways of investment decisions that together achieve agreed objectives over long planning timeframes, responding to how the near-future conditions are unfolding [6, 8]. The preference for certain pathways over others will depend on the trade-offs between their costs (including cost of delay), side-effects and benefits, and the expected shelf-life of options.

As with any adaptive management approach, DAPP relies on monitoring indicators of change against early signals and triggers (decision points). By allowing for sufficient implementation lead time in defining the trigger, a timely switch to the next option or pathway can avoid the preagreed *adaptation threshold* for the relevant receptor or system. These thresholds are primarily informed by risk and impact assessments on what level of hazard exposure would mean objectives or levels of service are no longer being met [5, 8, 10, 12] This bottom-up approach working with a threshold (could be adaptation or a water quality limit), which is independent of scenarios or time initially, contrasts with the prevailing top-down "predict-then-act" approach of assessing potential risk using a preferred, most-likely, best-estimate or worst-case scenario and adopting its associated timeline for treating risk, planning, consenting or engineering design.

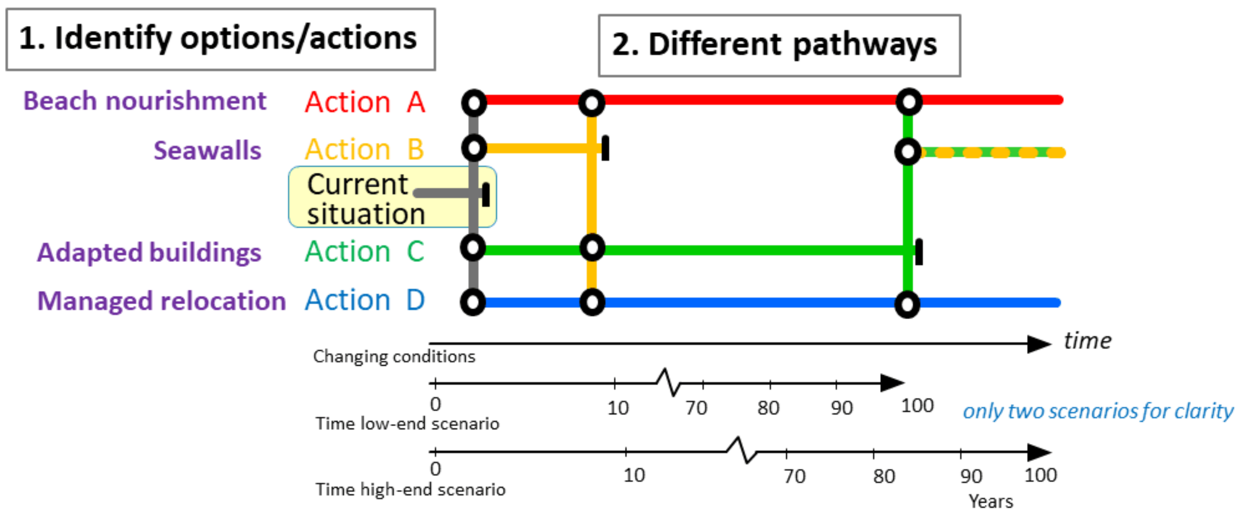


Figure 2: Example dynamic adaptive pathways planning metro map, with adaptation thresholds [8].

Adaptation pathways, incorporating an adaptive approach, provide three key benefits after [13]:

- **Flexibility:** Adaptation pathways such as DAPP explicitly embrace uncertainty and change. Uncertainties can also include societal, cultural, economic, political, environmental, and technological change, as well as climate change and sea-level rise. Monitoring early signals and triggers and regular reviews are a necessary adjunct to DAPP for timely switching to the next option or another pathway. For low-lying coastal areas, this may necessitate pathways that pre-emptively plan for the end goal of managed retreat, through a portfolio of short-term actions and sequences [9, 12].
- **Cost-effectiveness:** Because DAPP considers multiple pathways or integrated portfolios of actions/options [12] for timely adaptation, it helps reduce the risk of over- or underinvesting in adaptation or being unprepared to inform the response after a major hazard event. Planning alternatives over a long period allows relevant agencies to spread or defer large capital costs for future projects over time and allow efficient planning and funding of projects [13].
- **Transparency and more certainty in decision-making:** Because triggers and adaptation thresholds are set ahead of time (but can be adaptive over time as well), pathways allow for transparently integrating climate adaptation considerations into existing decision-making processes, including spatial planning, to support implementation. The ability to collaboratively engage and plan alternatives over a long

period also provides some certainty for communities and stakeholders on the way forward along a preferred pathway – but with flexibility to switch pathways when needed.

New role for risk and impact assessments

Successful and cost-effective adaptation in coastal lowlands over the 21st century and beyond, will need to be adaptive (flexible) and agile, responding to monitoring the ongoing changes within a backdrop of continuing deep uncertainty.

A shift is needed for risk and impact assessments, from assuming stationarity within a conventional “predict-then act” paradigm, to using scenario analysis and adaptive pathways (e.g., DAPP) covering a range of possible futures.

Longer, rather than nominal or “required policy” planning timeframes, are necessary to avoid path dependency (i.e., “picking a winner at the outset”) or future maladaptation. The challenge is how do we enable and realize an adaptive paradigm?

The reform process underway on our resource management system, including statutes for spatial planning, and adaptation to climate change (to enable managed retreat), provides an opportunity for a national conversation and a reset towards adaptive planning in our coastal lowlands, as seas continue to rise.

References

[1] Bell, R.G. (2021). How will our coasts and estuaries change with sea-level rise? Implications for communities and infrastructure. *In*: Hon. Helen Clark (ed.), *Climate Aotearoa: What’s happening & what we can do about it*. p. 61-92. Allen and Unwin Publishers, Australia.

[2] Oppenheimer, M. et al. (2019). Sea level rise and implications for low-lying islands, coasts and communities. *In*: Pörtner, H.-O. et al. (eds.), *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate*. https://www.ipcc.ch/srocc/

[2] Arias, P.A. et al. (2021). Technical Summary. *In*: Climate Change 2021: The Physical Science Basis. Contribution of Working Group 1 to the 6th Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press. In Press.

[3] Lawrence, J.; Blackett, P.; Cradock-Henry, N.A. (2020). Cascading climate change impacts and implications. *Climate Risk Management 29*: 100234. [Open Access]

[4] Logan, T.M.; Aven, T.; Guikema, S.; Flage, R. (2021). The role of time in risk and risk analysis: implications for resilience, sustainability, and management. *Risk Analysis*. https://doi.org/10.1111/risa.13733

[5] Lawrence, J.; Boston, J.; Bell, R.G.; Olufson, S.; Kool, R.; Hardcastle, M.; Stroombergen, A. (2020). Implementing pre-emptive managed retreat: Constraints and novel insights. *Current Climate Change Reports 6(3)*: 66-80, Springer. [Open Access]

[6] MfE (2020). *National Climate Change Risk Assessment for New Zealand: Main Report – –*

Arotakenga Tūraru mō te Huringa Āhuarangi o Āotearoa: Pūrongo whakatōpū. Prepared by a consortium led by AECOM, including Tonkin + Taylor Ltd, NIWA and Latitude and several independent contractors. Ministry for the Environment Publication ME 1506, Wellington, 133 p.

[7] Grace, E.; France-Hudson, B.; Kilvington, M. (2020). Reducing risk under the RMA. *Build 177*: 71-72, April/May. https://www.buildmagazine.org.nz/articles/show/reducing-risk-under-the-rma

[8] MfE (2017). *Coastal hazards and climate change: Guidance for local government*. Bell, R.G.; Lawrence, J.; Allan, S.; Blackett, P.; Stephens, S.A. (Eds.), Ministry for the Environment Publication No. ME 1292. 284 p + Appendices.

[9] Stephens, S.A.; Bell, R.G.; Lawrence, J. (2018). Developing signals to trigger adaptation to sea-level rise. *Environmental Research Letters 13(10)*: 104004, 11 p. [Open Access]

[10] ISO (2019). *Adaptation to climate change – Principles, requirements, and guidelines*. ISO 14090:2019(E), International Organization for Standardization, 28 pp.

[11] Task Force on Climate-related Financial Disclosures (2020). Guidance on scenario analysis for non-financial companies. October, 131 p.

[12] Kool, R., Lawrence, J., Drews, M. and Bell, R. (2020), Preparing for sea-level rise through adaptive managed retreat of a New Zealand stormwater and wastewater network. *Infrastructures 5(11)*: Paper 92, 19 p. [Open Access]

[13] Kay, R.; Messerschmidt, M.; Marks, M.; Liu, J. (2021). Ramping-up climate adaptation through a "pathways" approach. ICF International article. https://www.icf.com/insights/environment/climate-adaptation-pathways-approach

nzaia
ngā aho tapu

At the time of writing Matt was Climate Resilience Coordinator at Northland Regional Council and chair of Climate Adaptation Te Taitokerau. He is now working as senior analyst at He Pou a Rangi, the New Zealand Climate Change Commission. This work is the viewpoint of the author and does not represent the views of either Northland Regional Council or the Climate Change Commission.“

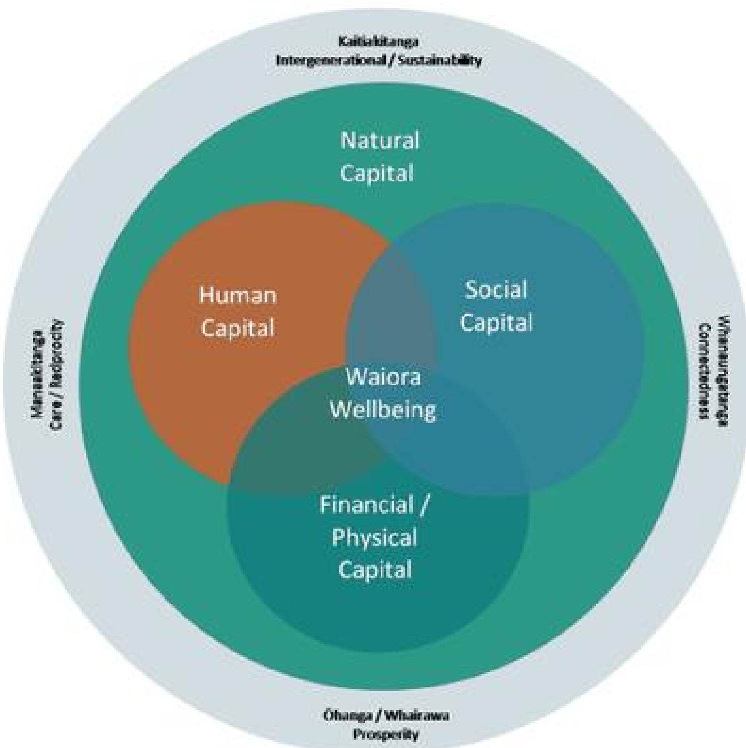
Climate adaptation involves using understandings of projected climate impacts on society and the natural environment to develop appropriate flexible responses, often using a risk management approach.

Due to the complexities associated with understanding climate risks, adaptation practitioners face challenges in developing appropriate and effective adaptation actions and policies. Obstacles include inherent uncertainty in the type, timing, severity and interactions of climate hazards and stressors, complexities arising from their cross-scale, cascading and cross-sectoral interactions, and idiosyncratic consequences on different elements of society and the environment.

Other issues relate to the diversity of evidence and varieties in underlying assumptions and the ability of risk assessments to provide guidance for adaptation decision-making and planning [1]. While risk assessment is a commonly used tool by local government to characterise climate risks, additional work and creative application is required to advance its use as an effective adaptation decision-support tool. This discussion piece explores ways in which risk assessments have recently contributed to the understanding of climate impacts for local government in Northland, New Zealand.

Risk assessment involves formal methods and processes to describe the nature and level of risk for an event or action, commonly estimated by multiplying the consequence of a hazard event with its likelihood. Risk registers are used by local governments to compare risks across financial, organisational, reputational, and operational domains; at the time of writing, climate change risks top the risk register for one Northland council. One assessment of organisational risk in Northland was calculated by comparing how well different climate hazards were understood (i.e. data maturity), the role councils play in managing the hazard (level of responsibility) with the potential consequences. This helped give an indication of priority actions for councils to manage different climate risks, including information gathering, policy development, adaptation planning and risk management interventions. These priorities were key to informing the development of a regional adaptation strategy.

New Zealand's first National Climate Change Risk Assessment [2] considered the impacts of multiple hazards on societal values grouped into five broad 'value domains' (the natural environment, built environment, human, economy and governance domains). This approach provides a pragmatic way to create high-level qualitative summaries of climate change impacts from multiple hazards but tends to compartmentalise and separate socio-ecological values, creating a fragmented framing of climate risks. For adaptation practitioners, the approach can create problems in a practical sense when attempting to develop adaptive solutions for climate hazards that cut across different domains.



The He Ara Waiora framework (Ministry for the Environment, 2019)

When developing a 'first-pass' climate risk assessment, Northland councils responded by using systems diagrams to show causal interactions between climate hazards and affected areas of society and the environment. This approach helped describe cascading impacts between domains and hazards, such as where responses to drought can lead to the lowering of water tables, affecting springs and river flows and compounding the impact of saline intrusion due to sea level rise in coastal communities. Nonetheless, feedback from iwi and hapū indicated that the approach still failed to incorporate a te ao Māori worldview in its framing of societal values.

Exposure assessments are common quantitative climate risk assessment approach used by councils, for instance using spatial analysis to count the number of affected 'value elements' (e.g. houses, marae) that might be impacted by sea level rise and coastal hazards. While this process is relatively straightforward, quantifying consequences is less so. An example is where indicators such as criticality measures, or depth damage loss assessments are used to understand consequence for council infrastructure assets. While this approach is efficient in that can use existing data, it often ignores impacts such as those on wider network connectivity, and the differential impacts between communities, which are more difficult to define.

The development of more nuanced risk assessment methodologies attempts to resolve this issue, such as the IPCC's definition of climate change risk for the AR6 report[3] which acknowledges the important role of vulnerability in assessing climate risk. Vulnerability assessments can be plagued by both the practical limitations of available tools and data, as well as conflicting framings and value systems in deciding what evidence is included and how it is assessed. Many vulnerability heuristics use combinations of census data such as indices of social deprivation as a proxy[4], potentially missing key factors that may be in fact primary drivers of sensitivity or adaptive capacity.

For instance, remote Māori communities in Northland show some of the poorest social deprivation statistics in the country, including per-household income. However, these same communities led highly responsive and effective drought responses in the 2020 summer drought where many remote marae, communities and farms ran out of water. Drawing on extensive community relationships, Māori communities quickly developed systems of water distribution to the needy, independent of, and arguably more efficiently than, well-resourced local government responses. Responses to Covid19 have been similarly well-coordinated in Northland Māori communities, indicating a high level of adaptive capacity.

Different knowledge systems and worldviews bring alternative approaches for engaging with climate change impacts and framing conversations on climate change adaptation. While they can be complementary, they can also present incommensurable evidence and conflicting value systems and without appropriate processes to integrate different perspectives, can inhibit the development of appropriate adaptation responses. In 1995, Funtowicz and Ravetz[5] argued that the interface of science and society was witnessing the emergence of new problems characterised by being long-term, novel and complex, with the best scientific representation by untestable models that include large uncertainties in variables. In addition, they observed that decision-making processes on environmental risk were becoming fraught due to uncertainty in knowledge, high decision stakes, values in dispute and a growing sense of urgency.

Over twenty-five years later, these observations are no less relevant, and it appears that in addressing the impacts of climate change, we are still to realise practical methodologies that 'enhance the process of the social resolution of the problem, including participation and mutual learning among the stakeholders, rather than a definite "solution" or technological implementation'[6]. What is needed is a deliberative approach involving the co-production of knowledge (including local, indigenous and expert knowledges), the democratisation of expert, political and bureaucratic power, and processes to ensure the inclusion of 'values without a voice' of non-human taonga and future generations. Encouragingly, local governments are adopting more inclusive engagement processes in assessing risks, but we have a long way to go.

One Northland example is in the co-development of mutually agreed coastal hazard information. Following the publication of new coastal hazard maps, there were conflicting community views on the accuracy of the models. In response council engineers, farmers, and drainage managers collaborated to ensure that topographic models derived from LiDAR data reflected the on-ground reality. Clear, grounded communication helped facilitate this process, although differences remain in perceptions of sea level rise values that exceed the lived intergenerational experiences of locals.

Facilitating collaborative adaptation engagement and planning with communities, including using the 'dynamic adaptive pathways' approach advocated by the Ministry for the Environment[7], is one way councils can co-develop long-term adaptation solutions with communites, bringing together both regulatory (such as land-use planning policies and rules) and non-regulatory (such as the provision of infrastructure, information, spatial planning and support for communities) solutions. This approach includes a step devoted to understanding community values and "what matters most". However, as promising as the prospect of co-designed adaptation planning seems, questions arise concerning the influence of power and framing, what constitutes acceptable knowledge and evidence, and conflicting values in decision-making processes.

Northland councils are developing place-based approaches to adaptation engagement that use methods appropriate for local communities, using region-wide climate hazard data to understand and map community adaptation needs. Exposure assessments were undertaken using a spatial analysis of a small range of community indicators against 3 hazard types (coastal erosion, storm surge flooding and high-tide flooding) at three scenarios (represented by timeframes and indicative sea level rise values). Alongside a consideration of community attributes (like population size, cultural values and desire for self-determination), the exposure assessments informed the development of adaptation profiles for around 70 communities. These profiles identify areas with urgent need or desire for adaptation planning, and help define the types of engagement approach appropriate at the local level. Councils have received feedback from Māori that in some locations, hapū- and iwi-led planning processes will be more appropriate than a council-led process; in others the administration and resources required to develop adaptation plans mean a larger role for councils.


Photo: RNZ / Alexa Cook

Further work is required to ensure that adaptation planning processes embed Māori perspectives; a first step in that process is developing appropriate risk assessment approaches. Hapū and iwi have reiterated the need for tools to consider climate impacts on cultural resources, papakāinga and marae, to enable hapū-led adaptation planning at the local scale. This bottom-up approach will help communicate climate risk in meaningful ways with Māori communities, potentially by working with local knowledge-holders to set parameters how to appropriately combine Western science and risk analysis with indigenous knowledge and apply this in appropriate planning contexts. The approach will also support iwi and hapū to develop their own adaptation plans, by providing tools, hazards advice and other support, while ensuring data sovereignty.

Reducing uncertainty in hazard data and impact consequences is not sufficient to address the issues facing local government in using risk assessments to develop adaptation actions and policies. Moving toward increased participation by communities and tangata whenua in climate risk assessments is a necessary step toward the resolution of incommensurable evidence and conflicting value frameworks in adaptation planning.

References

[1] Adger WN, Brown I, Surminski S. 2018 Advances in risk assessment for climate change adaptation policy. Phil. Trans. R. Soc. A 376: 20180106. http://dx.doi.org/10.1098/rsta.2018.0106

[2] https://environment.govt.nz/publications/national-climate-change-risk-assessment-for-new-zealand-main-report/

[3] Reisinger, Andy, Mark Howden, Carolina Vera, et al. (2020) The Concept of Risk in the IPCC Sixth Assessment Report: A Summary of Cross-Working Group Discussions. Intergovernmental Panel on Climate Change, Geneva, Switzerland. pp15 retrieved from https://www.ipcc.ch/site/assets/uploads/2021/02/Risk-guidance-FINAL_15Feb2021.pdf

[4] See for example: https://www.ehinz.ac.nz/indicators/population-vulnerability/social-vulnerability-to-natural-hazards/

[5] Funtowicz, S. O., & Ravetz, J. R. (1995). Science for the post normal age (pp. 146-161). Springer Netherlands.

[6] Mayumi, K., & Giampietro, M. (2006). The epistemological challenge of self-modifying systems: governance and sustainability in the post-normal science era. Ecological Economics, 57(3), 382-399.

[7] https://environment.govt.nz/publications/coastal-hazards-and-climate-change-guidance-for-local-government/

nzaia
ngā aho tapu

Values-Based Impact Assessment & Emergency Management

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Conventional emergency management practices generally focus on limiting harm to health, life, and property, even as disasters exact an increasingly profound toll across all facets of life – social, economic, and even political. Such a limited conceptual framework leaves practitioners ill-equipped to manage the resulting impact assessment needs of both traditional and emerging hazard events.

By framing the impact of disasters according to a more comprehensive set of measures captured in the community’s identity and function - a construct known as Values-Based Emergency Management (VBEM) – practitioners will enhance impact assessment accuracy and effectiveness.

Why a focus on Community Values?

The principal distinction between VBEM and more traditional emergency management practices is that resilience is achieved, in part, by preserving a community’s values. Typically captured in the community’s vision, goals, and objectives, values represent the common “set of priorities that reflect one’s feelings of connection to a community.” [1]

Because so much of how a community defines itself is intangible, accurate pre-disaster risk and post-disaster impact assessments require a deep understanding of these values. People, property, the economy, and the environment are certainly important; however, devoid of a more comprehensive understanding of the community they fit into, these factors are like unassembled pieces of a larger puzzle. They offer few clues to differentiate one place or population from another and are incapable of providing a meaningful roadmap for recovery.

To strengthen community and national resilience, emergency management practitioners must redefine risk to allow a more holistic notion of disaster impact on a community. This begins with an understanding of how a given community identifies and measures its values.

Establishing Resilience as a Policy Goal aligned to Community Values

Although resilience is rooted in the concept of risk, there is no industry-standard definition for this term. Common among the many variants is the idea that risk is the product of two factors: 1) the likelihood that an adverse event will occur; and 2) the consequences that would result. This can be represented as follows:

Risk = Likelihood X Consequence [2],[3]

Despite its ubiquitous use as a planning basis [4], this measure fails to recognize that preserving community viability is the ultimate resilience motive. It is no doubt important to know how many buildings floods inundate or earthquakes topple, or the number of people drowned or crushed in such events. But if asked to define one's community, a person is less likely to inventory buildings and cite demographics than to describe its geographic setting (e.g., coastal or lakeside), its culture (e.g., an artists' enclave or a community of immigrants), its industry (a mining or farming community), or its social proclivities (e.g., environmentally-conscious or physically-active), among other intangible factors.

Communities take shape around visions from which community members can find purpose. Such visions and the values they represent are generally complex and collective (shared by community members). While it is perhaps difficult for individual community members to describe or list them all, these intangibles are fundamental to identity and inarguably valid. The loss of community character, culture, and identity, more so than any loss of a building or a person, represents a significant existential threat (which is not to suggest that human life is not valuable).

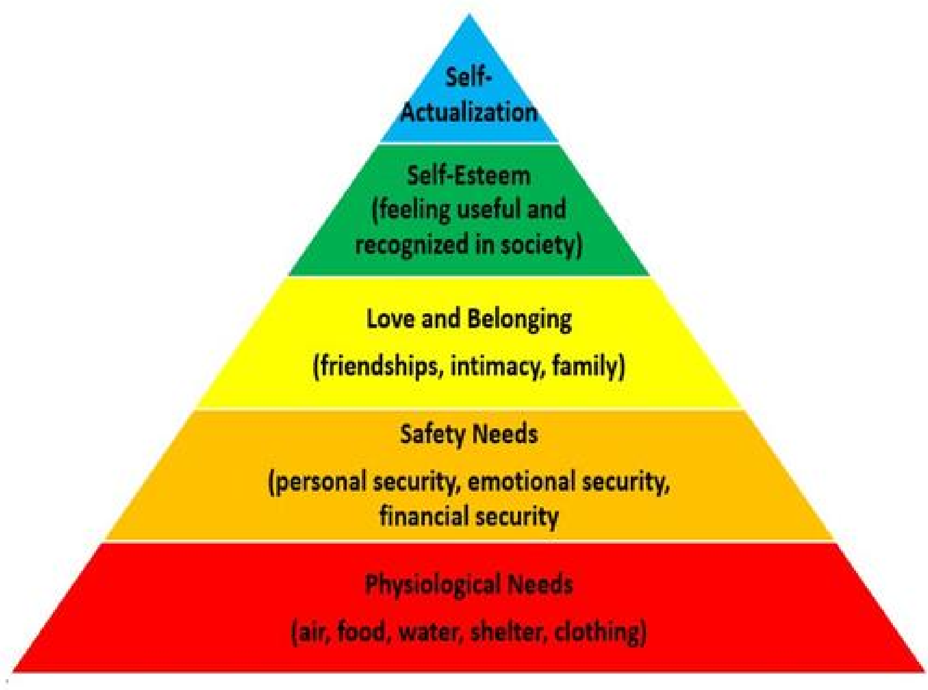
Past impact assessments have been hindered by a notion that community identity exists in the physical inventory of people, buildings, and infrastructure. This was evident in the aftermath of Hurricane Katrina, for instance, when many questioned whether it made sense to rebuild New Orleans considering the number of people who had died, and the property damages sustained. However, community leaders rejected these claims on the grounds that New Orleans holds irreplaceable value in its culture, its music, and its history – all of which lack alternatives. They argued that the city's culture must be recovered and retained, even if buildings and people continue to be threatened. Washington Post writer Adam Kushner captured these sentiments as follows:

"New Orleans has no place in a cost-benefit analysis, because what it offers — what it adds to America — cannot be counted. Its value is avowedly sentimental, and it was folly to believe that a culture could be weighed in this way."[5]

While culture may be discounted as sentimental or impossible to monetize, it is just one of many intangible factors driving community identity. In practice, when communities are stressed, resilience quickly becomes a matter of protecting the unique way of life the community offers. The concept of a community represents the sense of belonging and purpose residents cannot find elsewhere. Its appeal forms the basis of financial and economic value - of homes, of salaries, of investment potential, and much more.

Many jobs, for instance, are intimately linked to a community's representative notions - unique features or factors that have nothing to do with the property or people quantified in traditional risk measures. Residents of oceanside communities choose to live with the threat from multiple major hazards not because they are blind to such threats but rather because they find irreplaceable value in closeness to the water. Coastal homes, moved 10 miles inland, would lose considerable appeal if all other factors remained constant.

There exist models that enable us to better understand the drivers of community value, as captured in residents' collective 'needs and wants'. At the most basic level, there are physiological needs that include affordable and safe food, clean air and water; shelter; and clothing. Our second-level needs focus on sustainment of life and survivability, and include employment, physical safety and security, and health. Together, these represent the basic needs of any society. Where community differentiation becomes more apparent is in how the community vision, goals, and objectives matches residents' higher-level expectations (what we might consider their 'wants'). This could be the enjoyment of family, the ability to form friendships, to participate and contribute to the community, or achievement of self-respect and self-actualization. Abraham Maslow captured this progression in his 'Hierarchy of Needs.'



Maslow's Hierarchy of Needs

Our understanding of long-term community resilience must therefore consider the full scope of *what is at risk* if it is to effectively drive disaster management activities (including impact assessment). In the private sector, this is accomplished by defining risk not in terms of loss probabilities or impacts but by the achievability of objectives.

This represents a philosophical shift in that risk is not measured in terms of the absolute disruptive or damaging nature of an event but rather of the ability of the organization to continue *function and thrive*. For communities like Christchurch following the 2011 earthquake, just as was true in New Orleans following Hurricane Katrina or any of the tourist and aquaculture communities impacted by the 2004 Indian Ocean earthquake and tsunami, assessing impacts to long-term community viability required a far more comprehensive understanding of community values than was captured in standard emergency operations plans or as guided by standard risk assessments.

Recommendation

Rather than basing planning processes on a scoping of community hazards, communities can adopt a VBEM construct by defining community success (and the associated challenges).

Values must become the community-based equivalent to the 'objectives' that are secured through application of business risk management practices. Risk, therefore, becomes a measure of confidence that such values will persist, and not just the likelihood and inventory of physical consequences, and resilience in turn becomes a quality achieved not by simply reducing hazard risk but rather by assuring the maintenance of what the community values.

Response assessments will undoubtedly focus on the requirements associated with life saving and sustaining needs as well as limiting property damages, but long-term recovery needs to be driven by an assessment framework that reflects the foundations of community value.

References

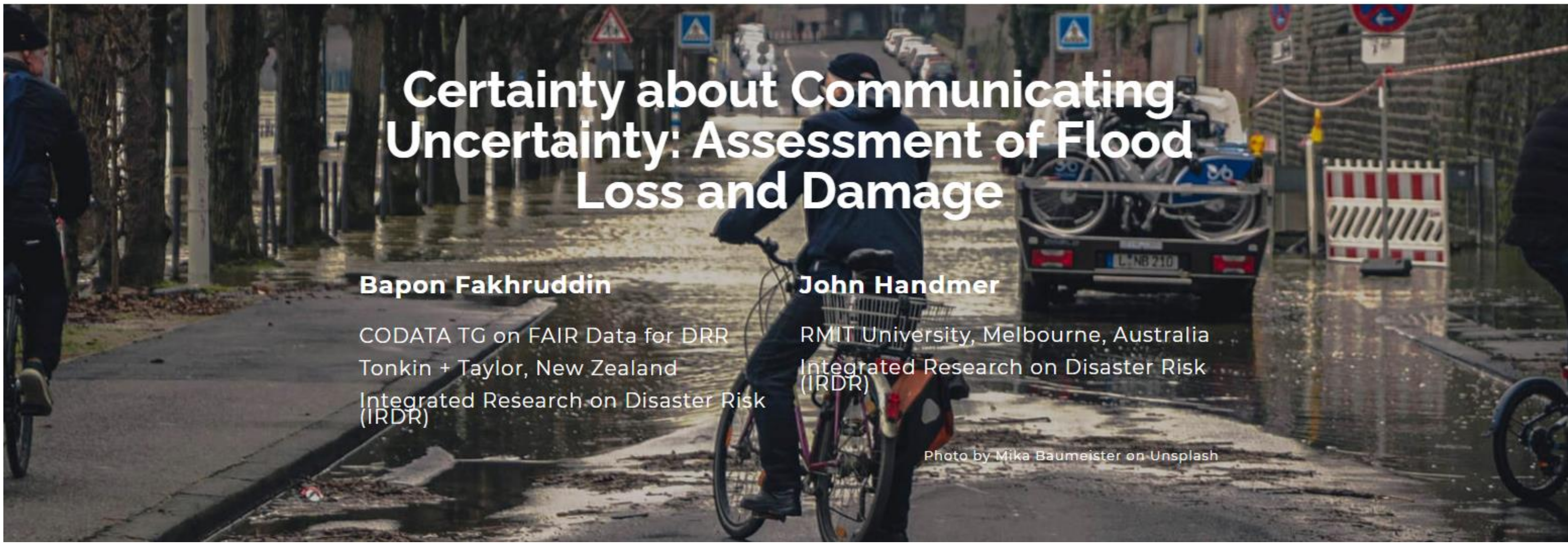
[1] Wray-Lake L., Christens B.D., Flanagan C.A. (2014) Community Values. In: Michalos A.C. (eds) Encyclopedia of Quality of Life and Well-Being Research. Springer, Dordrecht. https://doi.org/10.1007/978-94-007-0753-5_482

[2] Ansell, J., Wharton, F., 1992. Risk: Analysis, Assessment, and Management. John Wiley and Sons. Chichester, UK.

[3] In some instances, vulnerability is factored into the equation, although it can be argued that this is redundant given vulnerability is the basis of consequence severity.

[4] Hazard risk, as measured using the formula 'Risk=likelihood X consequence', is a factor in most community plans, including the general plan, the emergency operations plan, all-hazards mitigation plan, resilience plan, recovery plan, land use plan, and others.

[5] Kushner, Adam, 2015. I'm From New Orleans, But I Didn't Understand Why We Needed to Save It. Washington Post. August 28. http://wapo.st/3rF23ey.



Introduction

Uncertainty in flood loss and damage assessment is inevitable due to the flaws in data accuracy and reflecting the simplification of a complex system that is inherent to any assessment. Understanding the level of uncertainty in flood loss and damage assessment would help decision makers to understand the overall loss in future events, improve planning and allocation of their resources to protect from and respond to a flood event.

Statistical information on uncertainty may be difficult to interpret and hence it may not be used when making decisions related with flood risk management at many levels, including by insurance companies and farmers (Poortvliet et al., 2019). If uncertainties are known and communicated properly, flood loss and damage assessment would improve effectiveness and efficacy of decision making, and in turn reduce the actual flood loss and damage.

A common framework and standardized techniques for communicating uncertainty to decision makers are not readily available. This research has developed a framework for communicating uncertainty for flood loss and damage assessment to the end users based on the floods in Thailand.

Uncertainty in Flood Loss and Damage Assessment

Flood impacts (losses and damages) are calculated through flood risk assessment. The flood risk assessment provides information about the vulnerability and exposure to floods and what measures can be taken to reduce the risk. It has inbuilt uncertainty, which may be aleatory or stochastic (natural variability) and epistemic (deficiencies by a lack of knowledge or information). Aleatory uncertainty may be quantified using statistical methods.

To understand the uncertainty and its implications, uncertainties in data used for hazard, exposure and vulnerability calculation needs to be holistically analysed. Natural variability can occur due to temporal variability, spatial variability and individual heterogeneity. Knowledge uncertainty focuses on the model development factors, parametric breadth and numerical accuracy of available data, and the type of model used in relation to decision making needs (De Groeve at. al., 2014).

Hazard assessments derived with parametric approaches have a high level of uncertainty. Higher degrees of accuracy may be achieved with data-intensive physically based flood models, however uncertainties are still associated with each step of the process (Morrs et. al., 2005).

Exposure and vulnerability data contain uncertain quantities. The relevance of spatial and time scales is critical for baseline data selection. Data collected in each phase of disaster risk management could reflect different variabilities and uncertainties, such as incomplete knowledge about each phase and timelines. The flood impact would be significantly varied at various timelines for disaster management (Figure 1). This uncertainty is also confounded by the effects of land use changes (Kundzewicz, 2013), population growth, and urbanization (Salman & Li, 2018), etc.

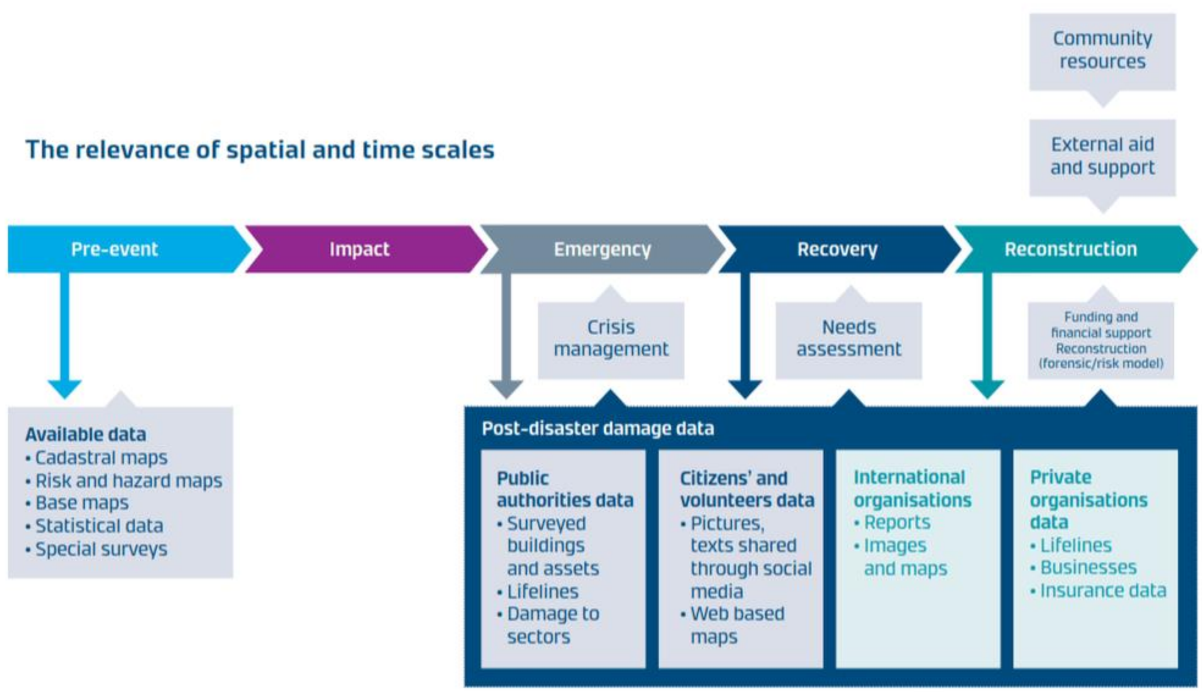


Figure 1: The relevance of spatial and time scales data for disaster management

Updated Uncertainty Classification Framework

We used the *updated uncertainty classification framework* proposed by Romão and Paupério (2014), that was built based on the uncertainty classification framework described by Skeels et al. (2010) and the Pedigree Parameter of the Numeral Unit Spread Assessment Pedigree (NUSAP) method described by Funtowicz and Ravetz (2006). Survey and focus group discussion were used for primary data collection and literature review for secondary data collection for the case study to test the framework.

Uncertainty Classification Framework

The original framework (by Skeels et al., 2010) was developed based on a movement away from a generalized treatment of aleatory and epistemic uncertainties. The updated framework is established on a (modified) hierarchy and connectivity among six types of differentiated uncertainties including measurement, completeness, inferences, disagreement, credibility and human error. Romão and Paupério (2014) identified the inability to account for a human error and proposed additional consideration for this type of uncertainty in the updated framework (Figure 2).

Typically the process used to solve a problem can be described in three stages, where each stage has a more advanced state of data processing and one of the six types of uncertainties expressed in the stages. Uncertainties relating to disagreement, credibility, and human error are considered at all three stages (Figure 2).

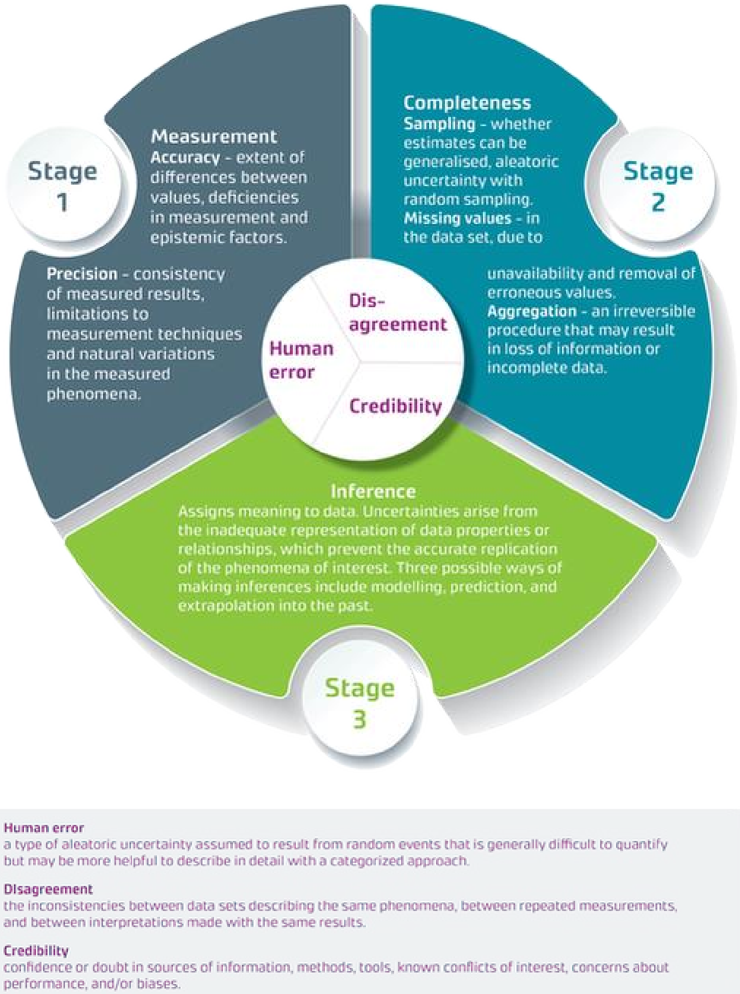


Figure 2: Six Types of Uncertainty and their relationships (Source: Fakhruddin 2017, Romão and Paupério, 2014)

The Pedigree Parameter of the Numeral Unit Spread Assessment Pedigree

The Pedigree parameter is a matrix where problem-specific criteria are assigned scores based on a customizable numerical scale (De Groeve et al., 2014). For each stage, uncertainty scores range from 1.0 (high uncertainty) to 5.0 (low uncertainty). In all three stages, human error is consistently identified as the most significant evaluation criteria contributing to uncertainty in the flood damage assessment process. The matrix structure does not have any formal requirements; the rating scale, number and type of criteria are selected to reflect the needs of each problem.

The Numeral Unit Spread Assessment Pedigree (NUSAP) method provides a systematic framework for synthesizing qualitative and quantitative uncertainty assessments and the information is organized in a coherent and easily understandable way. Consequently, it can be applied to complex models of natural phenomena. The Pedigree parameter specifically evaluates the strength of relevant values by considering both the background by which it was produced and the status of the value following processing. This helps to focus research efforts on the most problematic or weakest model components. By providing an in-depth and comprehensive overview of the sources and nature of the uncertainties, the method serves as an effective way for all participants (i.e. scientists, stakeholders, policy and decision makers) to become more aware of their interaction with the data at different stages, thereby supporting a transparent and extended peer review process. The main disadvantage, however, is that it can be a time intensive procedure. The NUSAP method to flood loss and damage assessments can be applied at multiple stages:

- the initial examination of uncertainties and assumptions
- decision to perform expert or stakeholder elicitation
- the selection of experts
- the choice of pedigree criteria
- problem visualization with diagnostic diagrams
- reporting and communicating findings
- interpreting results and integration in the decision-making process.

To determine disaster losses, data acquired at the first stage can either be used as an indicator to represent actual loss or be applied as input for further processing (Romão and Paupério, 2014). Therefore, the degree of uncertainty is dependent on the extent of processing per stage.

Case Study: Thailand Flood Damages

A limited sample size (*n* = 10) was chosen to gather preliminary data about the flood impacts on farmers in the study area of Banghpa Inn and Wangnoi districts in Bangkok, Thailand. Respondents included farmers who worked on their properties or rented land. The respondents' ages ranged from 29 to 67 years old, with an average of 49 years. All participants received at least primary level education. Most participants lived on the farm since birth, with the shortest length of residence of 8 years. Based on the ages and farming experience, it may be assumed that they have sufficient experience to make decisions to safeguard and optimize the returns of their labour. However, due to the partial or limited ownership of the farms and/or differential education levels, certain participants may not have the ability or adequate knowledge to make significant changes related to the uncertainties facing agricultural production in the future. However, the complexity of the system might make this impossible in practice, within a reasonable time. As well we could find that our increased knowledge tells us that the system becomes chaotic and unpredictable at a certain point. These require an evolving process to enhance knowledge.

The range of average score varies for each stage. Scores at Stage 3 were lowest, implying that the levels of uncertainty associated with relating data processes to realizing project objectives are notably higher than at the first two stages- stage 1: 3.3 to 4.0; stage 2: 3.3 to 4.0 and stage 3: 3.0 to 3.7.

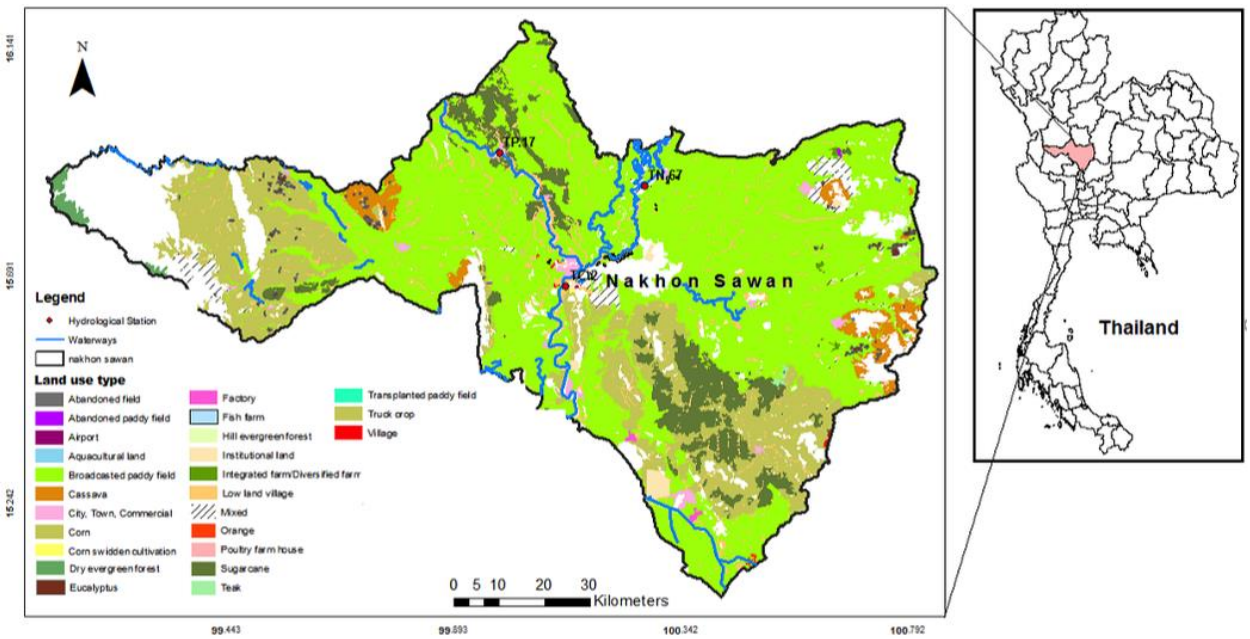


Figure 3: Case study area in Thailand

This assessment reveals that the uncertainties associated with the first three stages of data acquisition, processing, and inference are consistently attributed to human error. Furthermore, the interpretation of the modelled data at the final stage should also be re-examined to ensure that all assumptions and generalizations are valid. Elimination of these two sources of uncertainty would improve the credibility of the information presented to decision makers.

Conclusion

The *communicating uncertainty framework* was applied to the case study in a basic way to provide an impression about the relative uncertainty of key areas within the flood loss and damage assessment and results communication processes. The findings demonstrated how the proposed uncertainty framework could be used to identify areas within data management and transformation process that could benefit from improvements.

Uncertainties due to human errors and inferences were identified as the most significant contributors to flood loss and damage data calculation. Subsequent decisions based on flood exposure and vulnerability information could be improved if uncertainties from these areas are minimized and the insights provided by end users are addressed. The other general type of uncertainty was irreducible, at least through science. This includes some human behaviour, including negligence, corruption, other priorities, politics and so on. The importance here is that a lot of effort goes into trying to reduce the uncertainty that is not amenable to reduction through standard science.

A formal procedure could be developed to select key experts to perform the uncertainty assessments. Selection criteria could include educational background, impartiality and scope of involvement in the project. It would be beneficial to consider developing criteria for evaluation matrices with groups or experts and stakeholders, so that the areas of concern are clearly represented and can be directly addressed.

In addition to communicating uncertainty information, it may be useful to investigate different risk elements and their consequences to reduce known uncertainties (i.e. whether the prediction of loss and damages by physical modelling is the best approach). The results from the survey and focus group discussions can be integrated to better communicate scientific results to end users.

References

De Groeve, T., Poljansek, K., Ehrlich, D., and Corbane, C. (2014). "Current status and best practices for disaster loss data recording in EU member states", JRC Scientific and Policy Reports.

Fakhruddin, Bapon (2017). Communicating Uncertainty for Flood Loss and Agriculture Damage Assessment. Building Resilience Conference 2017. University of Auckland

Funtowicz, S. and Ravetz, J. (2006). "Risk management as a post-normal science", Risk Analysis, 12(1): 95-7.

Kundzewicz, Z. (2013). "Floods: lessons about early warning systems", Late Lessons from early warnings : science, precaution, innovation, EEA Report No 1/2013 : 347-368.

Morrs R. E., Wilhelmi O. V., Downton M. W., Gruntfest E. (2005). Flood Risk, Uncertainty, And Scientific Information for Decision Making. Lessons from an Interdisciplinary Project. American Meteorological Society.

Poortvliet, P.M., Knotters, M., Bergsma, P., Verstoep, J., Van Wijk, J. (2019) On the communication of statistical information about uncertainty in flood risk management. Safety Science. 118, 194-204.

Romão, X. and Paupério, E. (2014a). "Annex 2: Study of uncertainty for quality assessment of loss data". JRC Scientific and Policy Reports.

Skeels M., Lee B., Smith G., Robertson, G.G. (2010). Revealing Uncertainty for Information Visualization. Information Visualization. 9(1), 70-81

Improving Understanding of Rockfall Geohazard Risk in New Zealand

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WSP New Zealand

1 Geohazard Risk in New Zealand

The presence of geological hazards, such as discrete rockfall events and large-scale slope failures, is well known and nothing new to Aotearoa. The extreme topography and climatic range of both Te Ika-a-Māui and Te Waipounamu results in transportation corridors that have to navigate challenging terrain, resulting in infrastructure and users often being subject to geohazards.

This is a short paper highlighting the importance of utilising greater extents of readily available data to inform on the Life Safety risk posed by geohazards to the users of highway networks in New Zealand, with the end goal of reducing their impacts in a cost-effective and sustainable manner. It also provides an overview of how continuously consumable and relevant data can be used to automatically provide indicative risk estimates, at scale.

2 The Kaikōura Earthquake

The 7.8 Mw Kaikōura earthquake of 14 November 2016 resulted in ~10,000 landslides which closed State Highway 1 (SH1) along the Kaikōura coastline between Oaro and Clarence. The Main North Line railway was also closed due to landslides and damage to rail infrastructure. In response, the North Canterbury Transport Infrastructure Recovery (NCTIR) alliance was established between Waka Kotahi NZ Transport Agency (Waka Kotahi) and KiwiRail, successfully restoring and upgrading these vital transport links over a few short years.

3 Change Catalyst for Approach to Risk Management

When NCTIR operations in Kaikōura mostly ended in March Waka Kotahi were left with a large inventory of geohazards and geotechnical structures to manage and maintain. The '*continued and optimal performance of these GeoAssets are recognised by both Waka Kotahi and KiwiRail to be critical in the provision of a safe and resilient transport corridor*' (Easton 2021). Rockfall and landslide events are still occurring along the corridor due to the evolving hillside condition and vegetation cover, post-earthquake.

Figure 1 shows the aftermath of a rock impacting a moving vehicle in 2019, highlighting the levels of risk that still exist along the corridor which Waka Kotahi, as a road controlling authority, has a duty of care to manage. As such, there was a need to shift focus away from recovery and transition to a holistic network life safety risk management approach.

Figure 1 - Aftermath of discrete block impacting moving vehicle south of Kaikōura

4 Estimation of Risk

Risk is no arbitrary concept, rather a measure and is best estimated using sound data. One of the many successes of the NCTIR alliance has been the variety and volume of data collected. Figure 2 shows at a large scale, the concentration of 1,000+ slope movements recorded between 2017-2020. This simple visual draws the reader's attention to the hotspot of incidents and gives an indication of where there are potential problems needing to be addressed.

Figure 2 - GIS visualisation of Slope Movements observed in Kaikōura

However, risk is simply not defined by a slope's ability to yield rockfall debris, i.e presence of the hazard. To fully understand the risk to the road user from these geohazards, the attributed data within these events (magnitude, frequency) have to be interrogated and integrated with other available data including the traffic volume, vehicle speeds and the geological variables of the yielding slopes. The combination of these data provides metrics including:

- **Probability** – the extent to which something is likely to happen (a slope failure and reaching element at risk), usually expressed as a number between 0 and 1.
- **Likelihood** – derived from the probability of rockfall detachment (Pd) and the likelihood of the rockfall reaching the element at risk (Pt).
- **Temporal** – the time spent in the path of a rockfall by the element at risk.
- **Vulnerability** – the level of potential harm from a geohazard event (e.g. death or serious injury).
- **Consequence** – the outcome of an event, often expressed qualitatively as criticality.

With strong datasets, each of these variables can be associated with statistically valid numerical values and therefore the outputs can be quantitative in nature providing actual rather than relative estimation of risk (Figure 3).

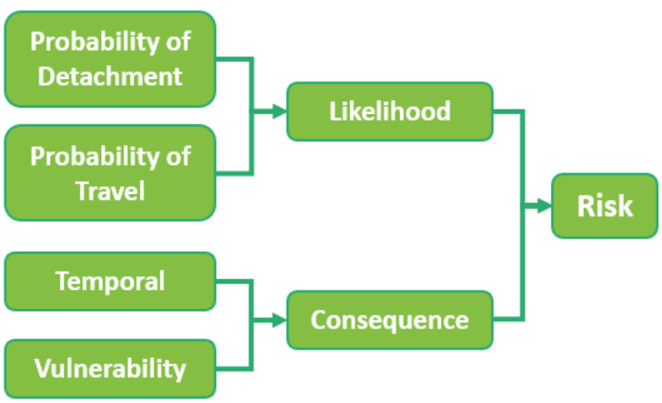

Figure 3 - Flow diagram of rockfall risk estimation

The assessment of risk for any given geohazard requires an experienced practitioner who focuses on detailed capture and documentation of each hazard. Traditionally this process can be very time and resource-hungry typically, making a full qualitative risk assessment an exception, not a norm.

Given the number of known geohazards continuing to develop along the Kaikōura coastline, a more efficient approach to estimate and triage all risks across the corridor was necessary.

5 Automating Slope Failure Risk Estimation At Scale

Due to the volume of data, variance in formats, wide range of sources and the varying levels of completeness, a novel approach innovated collaboratively by WSP and Waka Kotahi, was developed.

The processing is undertaken automatically using industry standard data manipulation software, Feature Manipulation Engine (FME). FME is an 'Extract, Transform, Load' (ETL) platform which streamlines the translation of spatial and textual data. It was chosen as the platform for this project due to its ability to connect to Application Programming Interfaces (API) to consume data from online sources instantaneously, translate and combine these data in a controlled way and publish new information to online endpoints. The built system in FME uses a likelihood and consequence product rule approach (NSW RMS 2014) as described earlier, together with geological scale event return period frequencies (e.g. order of magnitude), to robustly and consistently assess risk posed by geohazards.

By the automation of the NSW RMS 2014 approach, driven by in-field data capture,, FME and supplementary APIs provisionally estimates risk at scale for hundreds of sites in near real-time and a fraction of the time taken to physically do so. Given the number of geohazards assessed, this provides Waka Kotahi the ability to triage those carrying the highest risk to road users and prioritise detailed geotechnical inspections.

6 Visualising Estimated Slope Failure Risk

It is important that the estimation of risk is not perceived to be a ‘black box’ approach where risk impact practitioners are unaware of the process and not therefore fully understanding of the outcomes. To avoid this and to provide a fully transparent solution, this system frequently updates online GIS repositories and databases which drive a series of informative dashboards displaying the following:

- The current risk of any known geohazard (Figure 4), given historical activity, to inform long-term mitigation strategies, such as installing geotechnical structures where necessary. Information included: location and magnitude distribution of historical slope movements with photographs and monthly performance of geohazards.
- Status and condition of existing geotechnical structures to ensure risk to road users is kept to a minimum.
- Short-term changes in risk due to forecast meteorological conditions such as rainfall, high winds, freeze/thaw (Figure 5).

These interactive dashboards have given risk impact practitioners, responsible for the safety of New Zealand’s state highways, a vehicle to own and drive risk mitigation strategies.

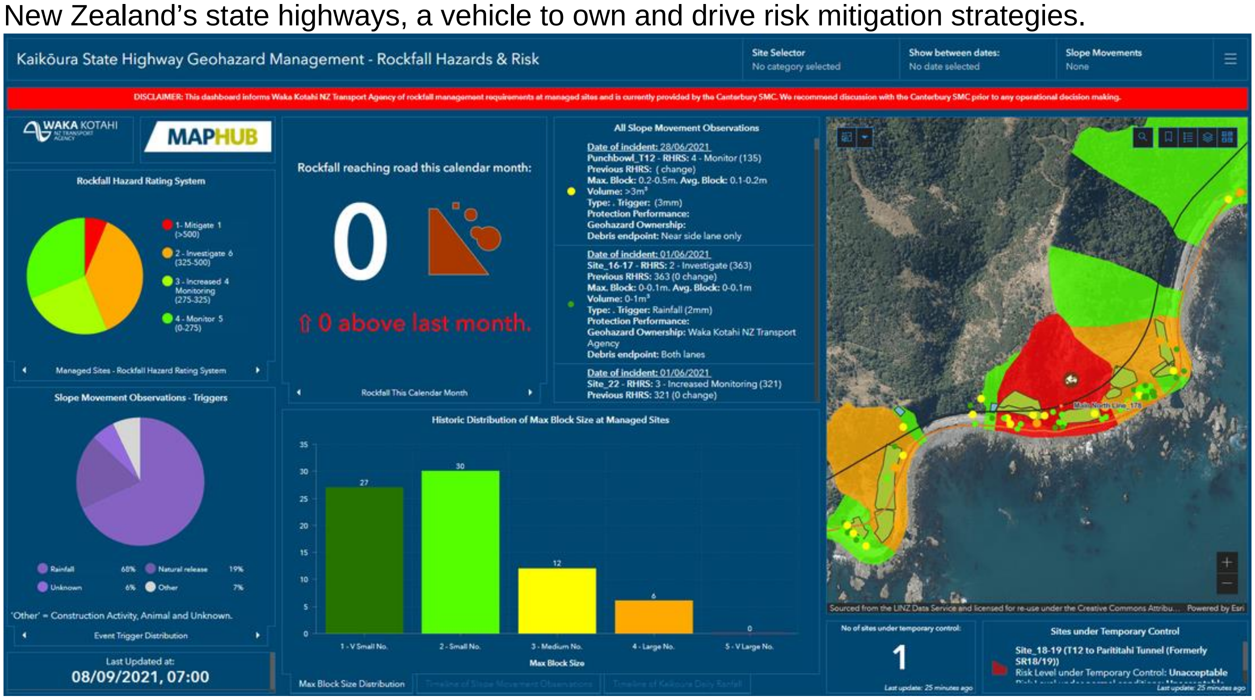

Figure 4 - Estimation of current rockfall risk

Whilst understanding long-term baseline risk is key in defining mitigation strategies, it is also as important to consider the immediate and short-term risk form geohazards to road users due to forecast meteorological conditions. From a quantitative perspective, rockfalls occur mainly during, or shortly after, periods of intense precipitations. The collected data in Kaikōura puts the percentage of rockfall events due to rainfall or wind at 79%.

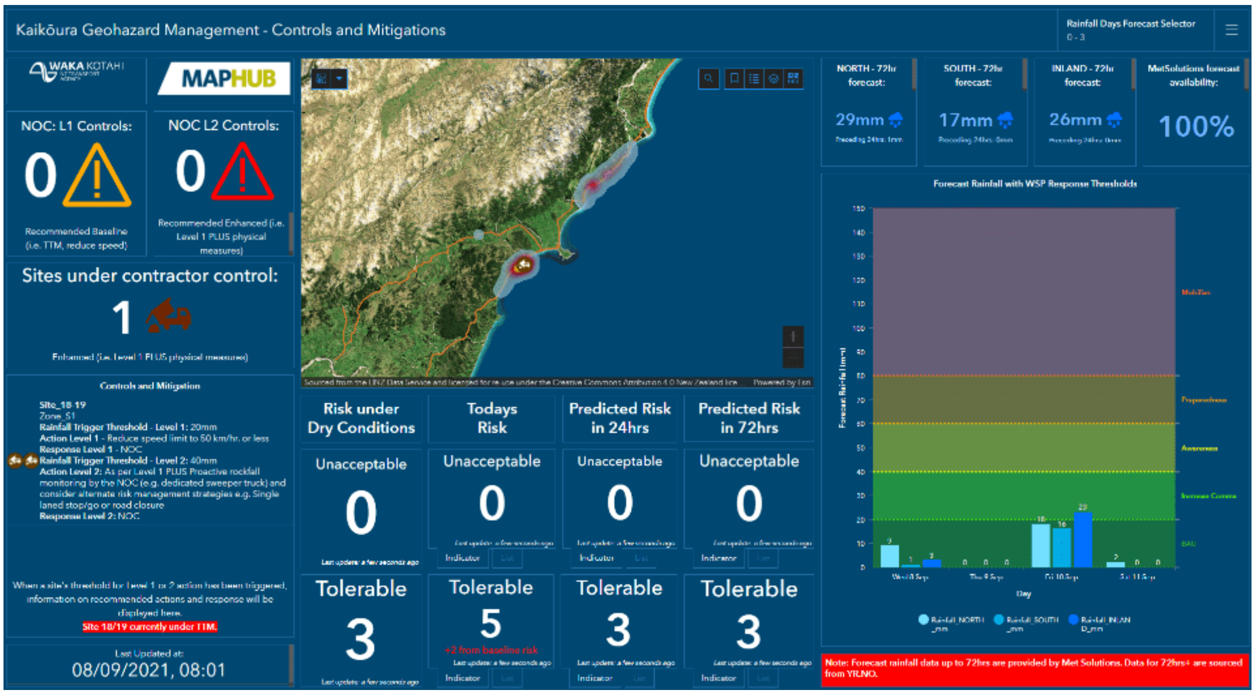

Figure 5 - Predicted changes in risk due to forecast meteorological conditions

Using observed rockfall events (collected in a standardised format with magnitude information) and pairing with meteorological conditions (e.g. recorded rainfall depth or wind speed) on the day of occurrence, enables a probability of future rockfall at particular rainfall intensities or wind speeds, to be estimated. This is a proactive approach to short-term risk management where risk practitioners can make decisions to enact temporary mitigation (e.g. moving the element at risk away from the hazard through a lane drop or closing the road) at sites where risk to the road user is predicted to increase to an unacceptable level.

Ultimately, this allows the relevant authorities to proactively manage the evolving risks posed by geohazards to road users at acceptable or tolerable levels, whilst at the same time undertake longer-term assessments to either invest in permanent mitigation or consolidate the current approach (e.g. addition of instrumentation and smart technology).

7 The road ahead

The presence of geohazards along lifelines such as the mountainous transport corridors of New Zealand is well known. The risk of geohazards to the road users is likely to increase given the continued evolution of slopes and hillsides capable of producing a failure, together with the projected increase in traffic volume. Therefore, the understanding of risk and what it means for lifelines such as transportation corridors is more important than ever.

Building a geohazard management system capable of rapidly estimating life safety risk to road users, effectively managing geotechnical structures and using meteorological forecasts to predict short-term changes in risk levels, is achievable. Starting off at a local scale, with a wealth of great quality data as demonstrated with Kaikōura, is an effective way of highlighting the benefits of good data collection in a standardised format which has enabled the growth into a system which the roading authority now uses to make timely operational decisions.

This paper has provided an overview of what has been achieved so far using this data and how the geohazard management system it drives, provides a near-real time indication of risk estimation. Ultimately this system helps Waka Kotahi to conform to its policy of providing a safer and more resilient road network, ensuring available funds are proportionally invested where the greatest returns are realised.

References

Easton, M. (2021). Comparison of the Rockfall Hazard Rating System versus the New South Wales Roads and Maritime Services Guide to Slope Risk Analysis (2014) for rockfall Life Safety risk management.

Easton, M. (2021). Integration of GeoHazard Management Plan: additional hazards and metrics NSW RMS (2014). Guide to Slope Risk Analysis. Version 4. New South Wales Government, Roads and Maritime Services.

Introduction

In an paper published in March this year, Risk Frontiers normalised the Insurance Council of New Zealand's (ICNZ's) Disaster List. Normalisation is the process of estimating the costs to the insurance sector of historic events if they were to occur now under current societal conditions. Normalisation is necessary to draw conclusions about trends in the cost of natural disasters and the impact of climate change.

As with other normalisation processes that Risk Frontiers has completed for the Insurance Council of Australia, the methodology employs changes in the number, size, and nominal cost of new residential dwellings as key normalising factors. The methodology is further described below, and the key results are presented. Additional results, discussion and policy implications are contained in the published paper.

The Insurance Council of New Zealand's (ICNZ's) Disaster List documents private sector insurance payouts caused by natural perils. It dates from April 1968 with losses due to Ex-Tropical Cyclone Giselle and the sinking of the Inter-Island ferry, the Wahine, with the loss of 51 lives. The database is national in geographic extent and multi-peril in line with most homeowner and contents insurance policies in this country. Perils responsible include earthquakes and various manifestations of severe storms including flooding, hailstorms, tornadoes and high winds. In contrast to Australia, where over a similar time period some 94% of losses were attributable to weather-related perils, earthquakes have been by far New Zealand's costliest peril. Special consideration was given to the Canterbury Earthquake Sequence (CES) because it is such a dominant feature of the loss history.

Our analysis predominantly dealt with reported losses paid out by private insurers; however, it also considered claims paid by the Earthquake Commission (EQC) for major events since 2000. Prior to July 2019, the EQC payout was capped at NZD 100k and NZD 20k for residential building and contents damage respectively and also provided for some types of damage to land. Beyond these limits, private insurance was (and is) available to cover the balance of greater claims. After reviews of EQC following the Canterbury Earthquake Sequence (CES) building damage limits have been increased to NZD 150k and EQC does not now cover contents damage.

Loss Normalisation

Our approach follows that of Crompton (2011) whereby an insured loss (inclusive of EQC costs where available) in season *i* (*Li*) in the dollars of the day (NZD) is converted to a season 2018 normalised loss (L2018) according to

L2018 = Li × Ni,j × Di,j × Zi (1)

where *i* is the 12-month 'season' extending from 1 July year *i* to 30 June year *i+1* during which the loss event occurred. The division by Australian financial years rather than calendar years was adopted, in-line with Crompton and McAneney (2008), to take account of the southern hemisphere seasonality of the meteorological perils.

j is the set of New Zealand regional councils (of which there are 16) impacted by the event. These regions form one of several interrelated structures outlined under Stats NZ's Statistical standard for geographic areas 2018.

Ni,j is the dwelling number adjustment factor, defined as the ratio of the total number of residential dwellings in region *j* in season 2018 to the total number in season *i*. Dwelling number data have been drawn from New Zealand census data reaching back to 1966.
Di,j is the dwelling value adjustment factor, defined by the ratio of the nominal value of new dwellings in region *j* in season 2018 to the nominal value of new dwellings in region *j* in season *i*. Changes in *Di,j* are due to three main factors: inflation, improvements in the quality of housing stock and changes in the average size of dwellings. These factors all contribute to the cost of re-building after a disaster event.

Zi = Si,total/Si,new adjusts for the changing size of new dwellings vis-à-vis the total building stock after accounting for demolitions (Crompton, 2011). Si,total is the ratio of the average size of *all* existing dwellings in season 2018 to the average size of *all* dwellings in season i. Similarly Si,new is the ratio of the average size of *new* dwellings in season 2018 to the average size of *new* dwellings in season i.

Both dwelling value and size were derived from Building Consents data, available at Stats NZ Infoshare.

Normalising Losses from the 2010-2011 Canterbury Earthquake Sequence (CES)

Special consideration was given to normalising insured losses arising from the CES because of subsequent changes to land-use planning regulations in and around Christchurch and the introduction of more stringent building codes. Elimination of large tracts of houses vulnerable to liquefaction resulted in a large reduction in the number and nature of the properties exposed to future earthquakes. These reductions are unprecedented in New Zealand, and no comparable adjustments would apply for other historical New Zealand earthquakes between 1968 and 2019. To deal with these changes, which will undoubtedly influence future losses if an event like the CES were ever to be repeated, Equation (1) was modified with two additional adjustment factors:

$$L_{2018} = L_i \times N_{i,j} \times D_{i,j} \times Z_i \times LE \times BC \quad (2)$$

where LE accounts for the reduction in the liquefaction exposure because of the designation of red-zoned areas where building is now prohibited and BC accounts for the increased stringency of seismic construction codes introduced in the wake of the CES.

Based on our analysis we estimate that the private insurance sector and EQC losses, normalised to account for the building code change as if buildings were to be brought up to code, are reduced further, in the ratio of 33% and 72% respectively. The effect of the code change is to reduce the damage ratio (DR = claims cost/replacement cost of building) for the new code level (peak ground acceleration = 35%g) up from its pre-CES value (22%g); in short, buildings built in compliance with the new code will be more resilient to seismic ground shaking. The adjustment factors LE and BC are different for private insurance sector and EQC losses, so equation (2) was applied separately to each loss and the result then summed to give the overall normalised event cost. For all other events except the CES, LE and BC default to unity.

Results

Table 1 ranks the top 10 most costly normalised loss events. Earthquake losses rank first, second and third, with the 2010 CES the most costly at NZD 20.1 billion (including EQC costs). Losses due to CES have been aggregated (as is the case in the Disaster List) because of the difficulty of accurately distinguishing losses caused by individual earthquakes within the sequence. The remaining entries are largely attributable to different manifestations of extreme weather, including the loss of the Inter-Islander ferry in ex-tropical cyclone Giselle in April 1968.

Time series of seasonal aggregated event losses are shown in Figure 1 (A,B) in both their raw and normalised forms respectively. The time history is dominated by large earthquake events particularly the CES losses. Excluding the Christchurch, Kaikoura and the Bay of Plenty earthquakes, McAneney et al. (2021) found that the raw data, which now are dominated by weather-related events, show an increase in the losses over time, but once these are normalised for the societal changes we know to have occurred, there is no significant increase in losses with time.

Table 1. Top 10 most costly normalised event losses. Source: McAneney et al. (2021).

Rank	Season	Event	Location	Nominal Loss ($M)	Normalised Loss ($M)
1	2010	Canterbury Earthquakes	Canterbury	33,114	20,060*
2	2016	Kaikoura Earthquake	Canterbury, Wellington, Marlborough	2862	3212*
3	1986	Bay of Plenty Earthquake	Bay of Plenty	192	2290
4	1983	Invercargill & Southland Floods	Otago and Southland	46	498
5	1967	Loss of Wahine	Wellington	10	383
6	1987	Cyclone Bola	Taranaki, Hawkes Bay, Gisborne, Northland	37	310
7	2003	Lower North Island Storm Damage	North Island (excluding Northland), Marlborough, Canterbury	119	303*
8	1968	Canterbury Storms	Canterbury	7	276
9	1978	Otago Floods	Otago, Southland	10	219
10	1976	Wellington & Hutt Valley Floods	Wellington	6	183

*Including EQC contributions

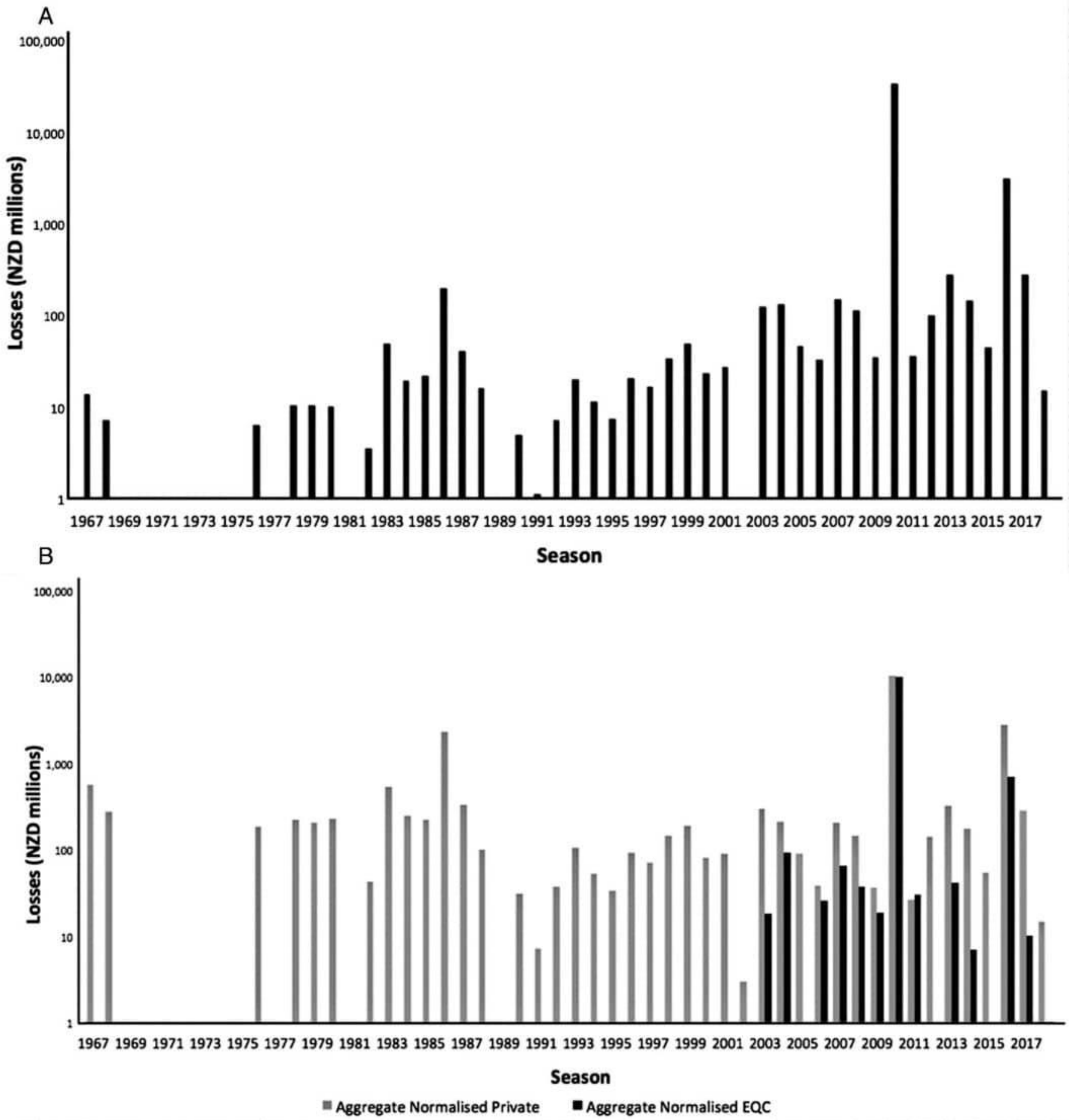

Figure 1. (A) Nominal annual aggregate losses by season in the dollars of the day; (B) annual aggregate losses normalised to season 2018 societal and demographic conditions, showing private and EQC contributions. Source: McAneney et al. (2021).

Conclusions

The Insurance Council of New Zealand's Disaster List documents private sector insurance payouts caused by natural perils since April 1968. We normalised these and, where possible, payments made by the Earthquake Commission, as if historical events were to impact current societal conditions. The methodology employs changes in the number, size and nominal cost of new residential dwellings as key normalising factors. Since 1968, earthquakes account for 79% of the normalised losses with the 2010–2011 Canterbury Earthquake Sequence (CES) at NZD20.1 billion the single most expensive event. The redlining of residential suburbs shown to be vulnerable to liquefaction, and the introduction of more stringent building codes, are estimated to reduce normalised losses for a repeat of the CES by about one-third. More frequent losses due to extreme weather, notably storms of tropical, sub-tropical and extra-tropical origin, when combined and after adjusting for changing societal factors, show no trend over the period 1968-2019.

About Risk Frontiers

Risk Frontiers specialises in catastrophe loss modelling, climate risk and resilience. We provide innovative science-driven research, analysis, and solutions to build safe and resilient communities. Risk Frontiers is the longest-running natural hazard research centre and consultancy in the Australasian region. In New Zealand, we maintain our probabilistic Earthquake catastrophe loss model, QuakeNZ, and a natural hazards and climate risk register for every address in New Zealand.

References

Crompton RP and McAneney KJ. 2008. Normalised Australian insured losses from meteorological hazards: 1967-2006. *Environ. Sci. Policy* 11: 371–378.

Crompton, RP 2011a. *Normalising the Insurance Council of Australia Natural Disaster Event List.* Report prepared for the Insurance Council of Australia by Risk Frontiers. 9pp.

McAneney, John, Matthew Timms, Stuart Browning, Paul Somerville, and Ryan Crompton (2021). Normalised New Zealand natural Disaster insurance losses: 1968–2019. Environmental Hazards https://doi.org/10.1080/17477891.2021.1905595

Introduction

The conclusions of the Sixth Assessment Report (AR6) issued by the Intergovernmental Panel on Climate Change (IPCC) warn that reaching net zero greenhouse gas emissions by 2050 is now “too little too late”, meaning that it will not achieve the long-term temperature goals identified in the Paris Agreement to limit global warming to 1.5°C by the end of the century. The main findings are consistent with the Fifth Assessment Report (AR5), but further highlighting the urgency of achieving carbon neutrality while also adapting to the many unavoidable effects of climate change. In New Zealand, the National Climate Change Risk Assessment conducted in 2020 identified priority climate change-related hazards for present day, 2050 and 2100 and highlighted identified 43 priority risk across five domains and 10 most significant risks.

Climate risk is typically considered in two categories: physical risk and transitional risk. Reporting requirements for climate-related financial disclosure were proposed by New Zealand Ministry for the Environment and the Ministry of Business, Innovation and Employment (MfE, 2019)[1]. The Task Force on Climate-Related Financial Disclosures recommends consideration of macroeconomic shocks or financial losses caused by storms, droughts, wildfires and other extreme events, or by changing weather patterns over time. However, currently this is not often seen in organizational climate risk assessments except by the insurance industry. The complexity in determining climate-related physical risk is significant. Identifying consistent and accurate climate risk is necessary to inform disclosure.

While significant advancements have been made, forecasting short range (days-week-months-years) climate-enhanced extreme weather events is still a gap in traditional natural hazard and climate risk assessments. The need for improved weather and climate forecasting to inform multiple hazard risk assessment and subsequently evidence-based decision making has never been stronger. Seamless integration of weather and climate information for risk assessment is critical as the climate’s atmospheric and oceanic motions and the extreme weather they can generate are interconnected[2]. The potential increase in occurrence and intensity of extreme weather events as a result of climate change and the increasing population in vulnerable areas only reinforces this need.

Forecasting the impacts of short-, medium- and long-term climate variability and their relationship to extreme weather events would provide forward-looking, decision-useful information that can be included in risk planning and management.

Seamless integration of weather and climate information for risk assessment

Over the last 20 years, Tonkin + Taylor conducted impact assessment for weather and climate information and designed early warning systems for multiple hazards. In this work, it became evident that information about future hazard over different time scales (days, weeks, months, years, decades and over 100 years) is key for risk-based decision making. Integrating weather and climate predictions into the risk assessment framework would provide different time scales risk assessment for appropriate actions.

The benefits of seamless hydrometeorological predictions are well tested in many parts of the world and currently under research (Wetterhall et al., 2018; Fakhruddin et al., 2021) (Figure 1). A framework for integrated, system-based climate risk evaluation is needed and may be developed by collaboration of scientists and experts from climate and meteorology fields.

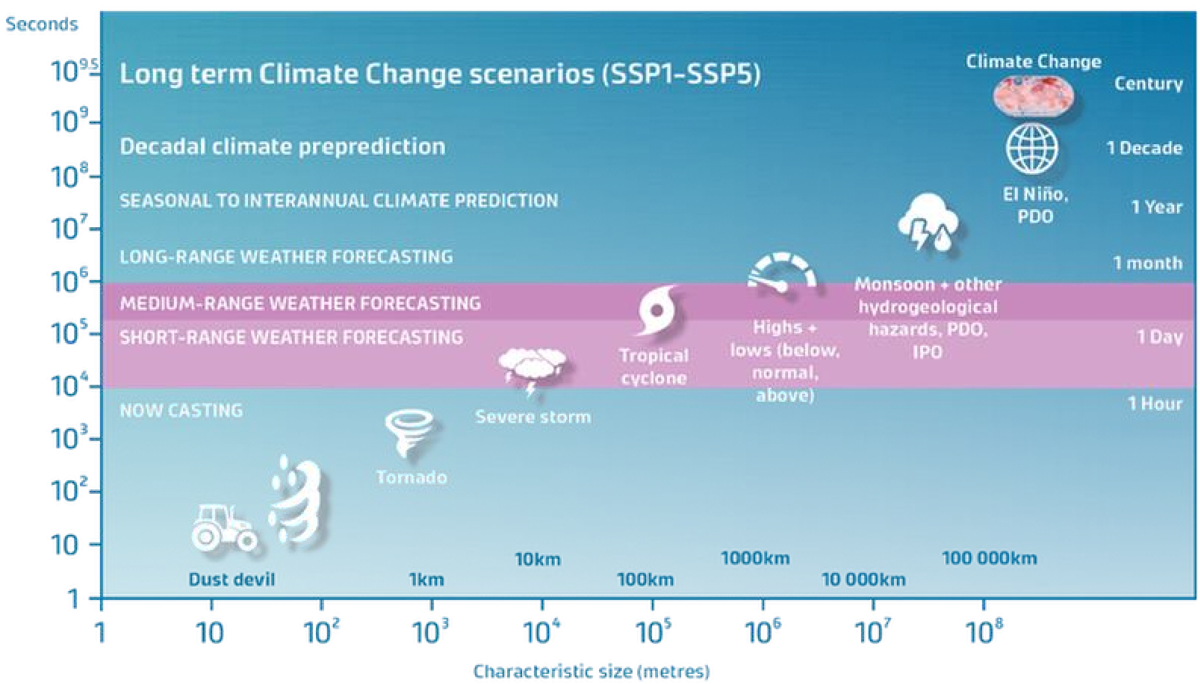

Figure 1: Range and scale of natural hazards due to climate change (Modified from WMO, 2015)

Our future expectations

The world is moving to Fifth Industrial Revolution, a new Renaissance Age (WEF, 2019). Our technology is moving rapidly to ensure creativity and common purpose to use for open access and FAIR (i.e., findable, accessible, inter-operable and re-usable) principles. New Zealand communities have long been waiting to see an inter-operable, open access, transparent, intuitive, flexible, collaborative, reliable, expert supported, secure, open sourced, fast and user-friendly visual platform for risk assessment. RiskScape 2.0 is such a risk modelling tool under development and could support impacts from natural hazards and climate change (GNS, 2020).

A collaborative platform to understand climate change and weather impacts is essential for climate intelligence. This kind of platform could draw from multiple data-driven computational models for different timescales (hours, days, weeks, months, years, decades and century). These computational models are based on local, regional and global climate and weather prediction model data, linked to exposure and vulnerability. A seamless integration of weather and climate products – short-range, medium-range and long-range forecasting - can better support the decision-making process for users by helping them understand the short-, medium- and long-range risks and uncertainties. This platform could target climate related hazard forecasting and scenario-based analytics for wider climate drivers. Additionally, the platform would be developed with consideration for future integration of broader risk and financial and assets modelling, for the purpose of climate-related financial disclosure reporting. Figure 2 shows the conceptual framework for seamless integration of climate and weather information to generate foreseeable future risk information for client decision making.

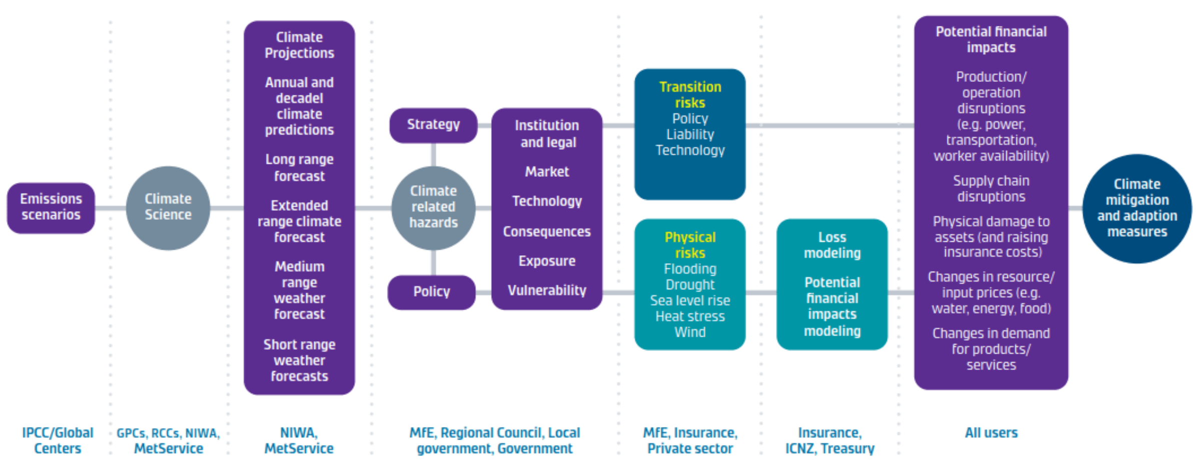

Figure 2: Climate science and risk evaluation for a foreseeable future (T+T, 2020, adopted based on UNEP FI, 2020)

As climate risk evaluation contains inherent uncertainty, reviewing data on varying timescales provides refinement of decision making. The system could be called a “system of a systems”, where end-user feedback is critical as are mechanisms to incorporate feedback into the system to continuously improve the need-based information for specific users.

Conclusions

The importance of accurate and timely weather and climate data for decision making increases. At the same time, different climate change impacts do not occur in isolation. Therefore, disaster and climate action plans must be organised to manage concurrent disaster risk and their compounding and cascading impacts. An integrated weather and climate platform could provide seamless climate induced hazards and risk scenarios based on various temporal scales and their associated uncertainty in the information. This climate change intelligence, combined with hazards assessment, would provide scenario-based risk assessment options for decision making for various climate risks including extreme weather events. Improved understanding of physical risks relating to climate change could provide greater detail for climate change risk assessments and support an impact assessment of the core elements of a recommended climate-related financial disclosure (governance, strategy, risk management, and metrics and targets). This platform is the first step towards achieving a collaborative platform for a financial and physical impact assessment that could provide high-quality, scenario-based consistent reporting in New Zealand.

The national and regional climate risk assessment in New Zealand and the IPCC AR6 have given us a fair warning of what is to come. It is now up to us to boldly embark on a visionary re-think and re-design of our future. We have a once-in-a-lifetime opportunity to re-imagine and build a climate-ready and resilient world. Squandering this has unthinkable consequences.

Footnotes

[1] Disclosure could likely apply to listed issuers, banks, general insurers, asset owners, all local government organisations, lifeline utility providers and asset managers.

[2] The interaction of climate and weather is demonstrated by an atmospheric-oceanic phenomenon that affects weather worldwide, the El Niño Southern Oscillation (ENSO). The atmospheric motions are also interconnected and nearly continuous: a small-scale atmospheric motion can band together to create larger-scale systems (e.g., convective storms could cause floods, droughts, storms and wildfires).

References

Fakhruddin Bapon, Peter Gluckman, Anne Bardsley, Georgina Griffiths, Andrew McElroy (2021). Creating resilient communities with medium-range hazard warning systems. Progress in Disaster Science, 2021

GNS (2020). User requirements of RiskScape2.0 software and opportunities for disaster risk research in Aotearoa- New Zealand

MfE (2019). Ministry for the Environment & Ministry of Business, Innovation & Employment. 2019. Climate-related financial disclosures – Understanding your business risks and opportunities related to climate change: Discussion document. Wellington: Ministry for the Environment.

NCCRA (2000). First national climate change risk assessment for New Zealand. https://www.mfe.govt.nz/climate-change/assessing-climate-change-risk

NCCRF (2019). Arotakenga Huringa Āhuarangi: A Framework for The National Climate Change Risk Assessment for Aotearoa New Zealand. https://www.beehive.govt.nz/sites/default/files/2019-09/National%20Climate%20Change%20Risk%20Assessment%20Framework%20.pdf

Wetterhall, F. and Di Giuseppe, F. (2018). The benefit of seamless forecasts for hydrological predictions over Europe, Hydrol. Earth Syst. Sci., 22, 3409–3420, https://doi.org/10.5194/hess-22-3409-2018.

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Innovating with Online Data to Understand Risk and Impact in a Data Poor Environment

Tom Burkitt & Michael Meadows

1 Introduction

This paper describes innovative and replicable techniques used by the team on the Disaster Risk Assessment of Uttarakhand in India to overcome technical challenges when compiling data on the exposure and vulnerability of buildings and people (specifically tourists). We hope readers find the narrative from overseas interesting but it's also possible that the techniques described here could be replicated in New Zealand and across the Pacific to fill data gaps and support risk and impact assessments.

1.1 Uttarakhand

Uttarakhand is highly susceptible to natural hazards, including earthquakes, fluvial floods, flash floods, and landslides. It is situated in Northern India, bordered by Nepal and China (Tibet), and several large and active seismic fault lines bisect the state. Heavy rainfall and steep terrain in the hilly areas exacerbate flash flooding risks, and landslides are very frequent occurrences, thereby threatening lives and requiring costly regular repairs to infrastructure. In many ways, the terrain is not unlike parts of New Zealand, although it is far more densely populated, with over 10 million inhabitants in one state.

Exposure in the state is highly dynamic in space and time, and Uttarakhand's population is growing rapidly. It is industrializing and urbanizing at a rapid rate, with urban areas drawing an increasing number of people from the more remote and hilly rural areas. Over time, these trends continue to increase the exposure of urban communities to hazards, particularly flooding and earthquakes

1.2 Composition of risk and the disaster risk management cycle

In catastrophe hazard modelling, risk is defined as the product of 1) hazard likelihood and severity, 2) exposure (both economic and human), and 3) the vulnerability of infrastructure and the human population. Adaptive capacity is a sub-component of vulnerability and represents the ability of the community, asset, or entity to adapt to the impacts of a hazard and thus reduce its inherent vulnerability in future. Effective disaster risk management is a defining characteristic of resilient societies, and a resilient community is able to manage and limit exposure to threats, minimize its vulnerability, and adapt reasonably well. Impacts of hazards on communities, economies, and systems are both direct and indirect, and probabilistic risk assessment aims to understand these impacts and identify which factors contribute most to the overall risk for a given location, type of asset, community or source of revenue.

A useful cyclical framework for Disaster Risk Management is illustrated in Figure-1. This is, in theory, a virtuous and fully integrated cycle, where improvements in each phase of the cycle should increase resilience in communities over time, and risk assessment and analysis are components of mitigation in the cycle. Effective mitigation defines actionable mid to long term responses and interventions to minimize the risk posed by uncertain future events.

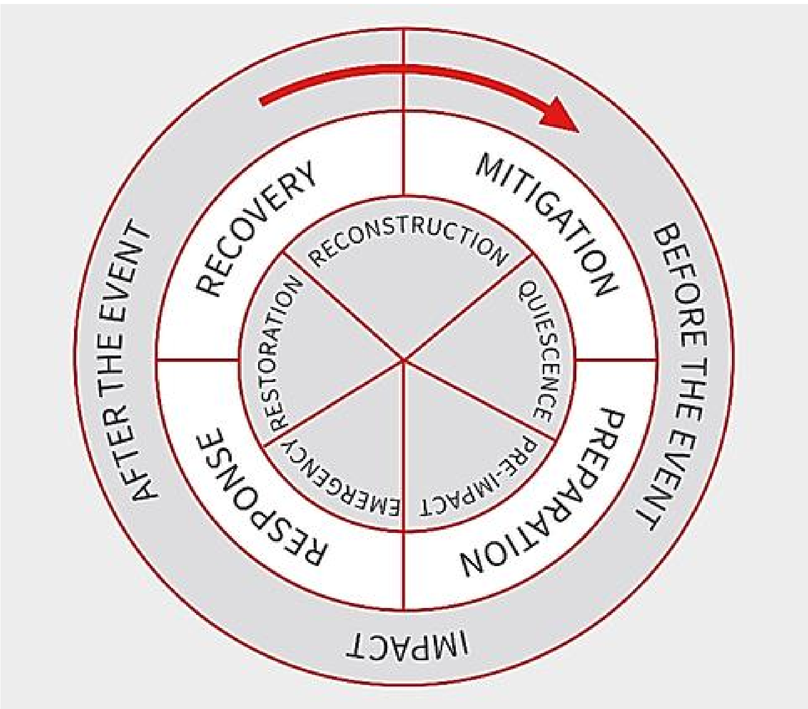

Figure-1. A schematic representation of the Disaster Risk Management Cycle (from Alexander, D.E., Principles of Emergency Planning and Management, Oxford University Press Inc, USA, 2002)

2 The Disaster Risk Assessment of Uttarakhand

Hazards themselves are very difficult or, in the case of earthquakes, presently impossible to prevent from occurring or to mitigate or control directly. In Uttarakhand, the priority of the World Bank-funded “Disaster Risk Assessment of Uttarakhand” project was to reduce risk and build resilience by focusing on reduction of ***exposure*** and ***vulnerability***, whilst exploring how to build adaptive capacity.

There is a very high dependency on primary and secondary data for the hazard modelling and for the development of the exposure and vulnerability data sets, and risk assessments often stimulate innovation in data acquisition. The approach adopted was to leverage trusted secondary sources of data as much as possible, but that presented a huge challenge in itself as most available data lacked either completeness or coverage. This article presents examples of two techniques that were used during the study to build adequate building exposure datasets (with appropriate detail and state-wide coverage), and to understand the spatial and temporal distribution of tourists.

3 Innovative Approaches to Scaling-Up Exposure Data

Two specific technical challenges that the project faced were 1) to ensure sufficient coverage of building-level information and b) to understand the movement (spatial and temporal) of tourists across the state.

3.1 Predictive analysis of building typologies and vulnerabilities across the state

The predominant building types in a settlement (town or village) heavily influence its risk profile. For this reason, it was essential to identify the various building typologies found around the state and then map their distribution in as much detail as possible.

Based on preliminary field surveys and consultation with local experts, we confirmed fifteen (15) typologies or structural classes as being sufficiently representative of the state's structural diversity. Vulnerability curves were developed for each typology in order to estimate the expected damage resulting from the different levels of hazard intensity, measured in Peak Ground Acceleration (PGA) for earthquakes and water depths and velocities for flooding.

The remaining and formidable challenge was to map the distribution of each typology across the entire state and to do this rapidly and with sufficient accuracy. This was not possible using field surveys alone given the short timeframe, and attempts to map each typology individually using remotely-sensed imagery failed, due primarily to the lack of a correlation between typology and roof material (or any other building property visible from space) as well as the prohibitively high cost of high-resolution imagery.

Instead, the project team built a web-based collaborative and "crowd-sourcing" application, whereby trained volunteers quickly traced and demarcated built-up areas and isolated building clusters manually, using a backdrop of lower-resolution yet appropriate and freely available satellite imagery. Within five weeks, building clusters in over 73,000 tiles were digitized successfully. Systematic quality assurance measures ensured the reliability of this impressively detailed dataset of built areas and building clusters across the whole state.

The team then developed random forest regression models (a machine learning algorithm consisting of decision tree ensembles) to predict the relative proportion of building types in any given building cluster. The model was trained and validated using 23,000 individual building surveys from 425 towns/villages across all 13 districts in the state, selected to ensure coverage of the full diversity of the state's buildings (in urban and rural areas, hills and plains, accessible and remote).

Inputs to the model consisted primarily of aggregated responses to the most recent Census (quantitative and qualitative), supplemented by remotely-sensed datasets related to economic activity (such as night-time light levels). Predictions made for each of these Census aggregation units (i.e. the expected distribution of building typologies in that “block”) were then dasymetrically mapped to the building cluster polygons digitized within that block (proportionate to their area), generating high-resolution maps of building distribution across the entire state.

In a relatively short period of time, that approach enabled the project team to produce a detailed map of Uttarakhand’s structural diversity; an essential component for the state-wide risk assessment. Figure-2 illustrates an example of the final output and how the information could be aggregated up from building cluster to different scales.

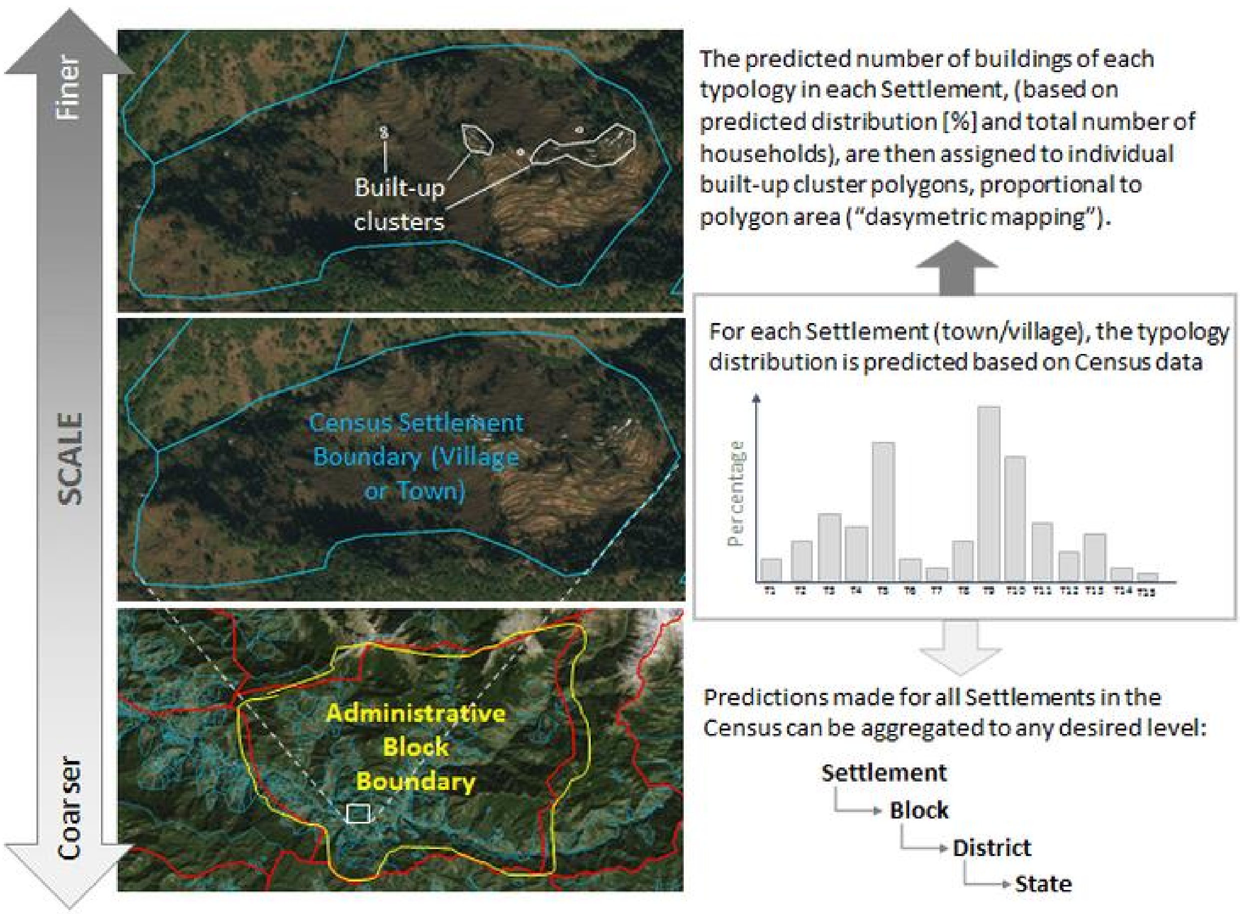

Figure-2. Results of the predictive model for building typology distribution and exposure.

3.2 Web crawling to expand understanding of tourist exposure

Official statistics exist giving the number of total annual visitors for major tourism destinations, but that data provided no information about the spatial and temporal distribution of tourists over the course of a year or where they may cluster. Additionally, Uttarakhand lacks a geospatial inventory of hostels, hotels, and guesthouses.

The approach to overcome these limitations quickly was to mine the wealth of information freely available online, focusing on booking/review websites (such as TripAdvisor and Booking.com) and anonymized metadata from social media sites hosting photos (Flickr). These data sources have inaccuracies, but they have proven to have usable and valuable metadata, good scale and coverage in 2017 (that coverage is growing), and they have proven sufficiently reliable for defining aggregated zones or "hotspots" of tourism activity in spatial and temporal terms. The data of these zones were corroborated by other sources and through stakeholder consultation.

From geotagged and public photos hosted on Flickr, selected metadata were extracted: location coordinates (and precision), date, time, and categorization of the establishment or site. For all attractions found on booking/review websites (points of interest, hotels or restaurants), we extracted location coordinates as well as the number of reviews (as a rough indication of popularity) and a qualitative measure of how expensive that site was (relative to other options in the state). The team processed the data to remove duplicates and ignore outliers for location, but most inaccuracies were tolerable given that the intention was to derive 'activity zones' (based on kernel density functions) rather than precise points for specific establishments.

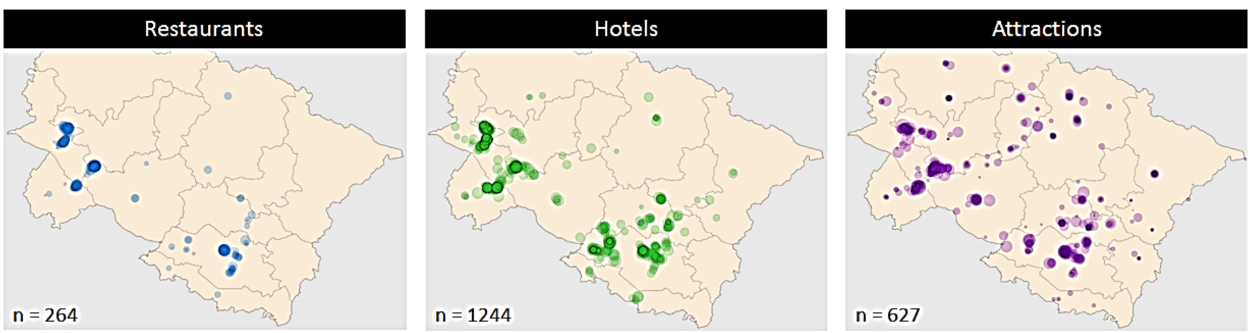

Figure-3: Example of cluster for establishments extracted from Trip Advisor. Marker size is proportional to the number of reviews, an indicator of popularity.

An increasing number of photographs are posted to social media sites on a daily basis, and many of these photographs have embedded metadata showing exactly where and when the photo was taken. For tourist exposure assessments, these can be a valuable resource, so long as care is taken to ensure privacy is respected and data are aggregated before use. While most social media platforms now strip out this metadata information by default, others retain it or leave it up to the person uploading the photograph to decide. An example of the latter type is Flickr, where users have uploaded almost 55,000 geotagged photographs taken in different parts of Uttarakhand, providing a fascinating insight into the attractions and events frequented in recent years.

As an example, Figure-4 shows all geotagged photographs taken in the month of October, in and around the towns of Haridwar and Rishikesh, which are significant sites of Hindu pilgrimage. Individual photograph locations are shown as white points, while the hexagonal bin heatmap indicates relative concentrations of tourism activity in the area.

As is the case for information extracted from booking/review websites, the quality of metadata for photographs was variable and there were some limitations. For example, they did not necessarily correspond to tourist activity, as local people who want to share an interesting aspect of their own town or village would also take photos. Additionally, the useful data was limited to those individuals with access to a GPS-enabled device such as a smartphone, meaning only a subset of the entire tourist population was represented. The data also only indicated locations deemed “photo-worthy”, rather than representing a full log of everywhere that tourists might spend their time while travelling around the state.

Despite these limitations, these datasets have both provided useful information on likely tourist distributions that would otherwise be difficult or impossible to estimate (such as tea-shops along mountain highways, perched over precipitous drops to take advantage of the views, as highlighted by dense clusters of photo points). By using relative densities of hotels, photographs, etc. rather than absolute numbers, it was possible to define and differentiate tourism activity zones with a reasonable degree of confidence.

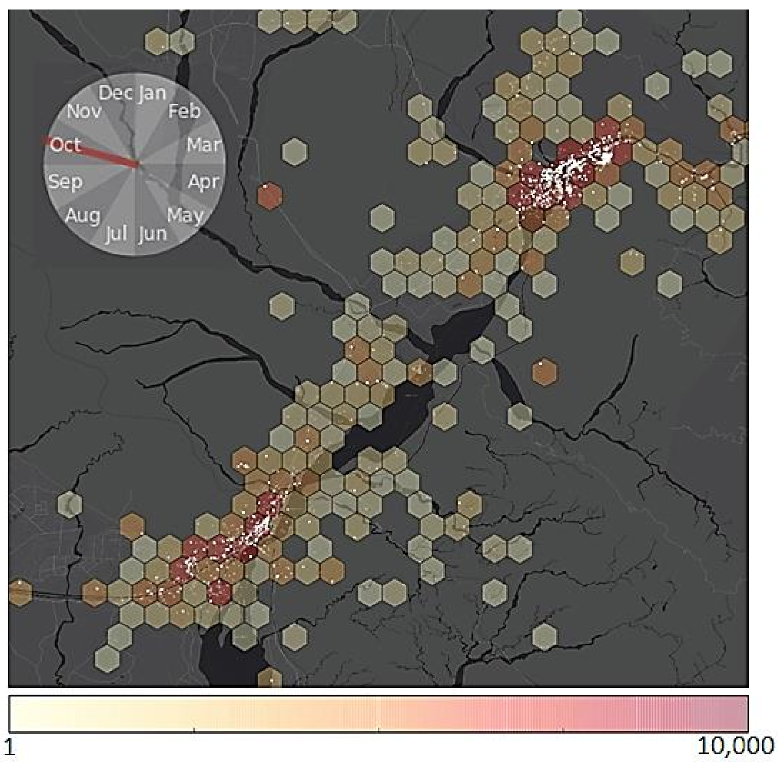

Figure-4: Geotagged photographs (white spots) as a proxy of tourism spatial and temporal clustering in the urban areas of Rishikesh and Haridwar in October. Hexagon colour represents density of photographs and the scale is logarithmic.

4 Linkages to urban resilience

This paper has outlined two simple approaches that illustrate leveraging the power of social media and online content aggregators to scale up coverage and supplement existing data on infrastructure and visitor exposure in urban and rural locations. The data gave a better understanding of the spatial and temporal variabilities across the state, and that allowed the team to define better structural and non-structural interventions to reduce risk and build resilience.

Rapid digitization and increased connectivity provide opportunities to exploit social networks, big data, and machine learning throughout the Disaster Risk Management Cycle (Figure-1). However, it was observed that decision-makers presently lack capacity and understanding to exploit these opportunities fully or plan to avert any emergent threats. However, it is recognized that Uttarakhand's socioeconomic standing is such that it has the potential to leverage new technologies and become a digital leader in the risk management domain.

DHI's Experience:

DHI Water & Environment (DHI) is a global non-profit consulting and research organisation that has been in operation for over 55 years and has approximately 1200 staff operating out of over 25 offices globally. DHI recently delivered the Disaster Risk Assessment of Uttarakhand in India for the World Bank Group and is also delivering a programme in Bhutan to strengthen national disaster risk assessment and management systems.