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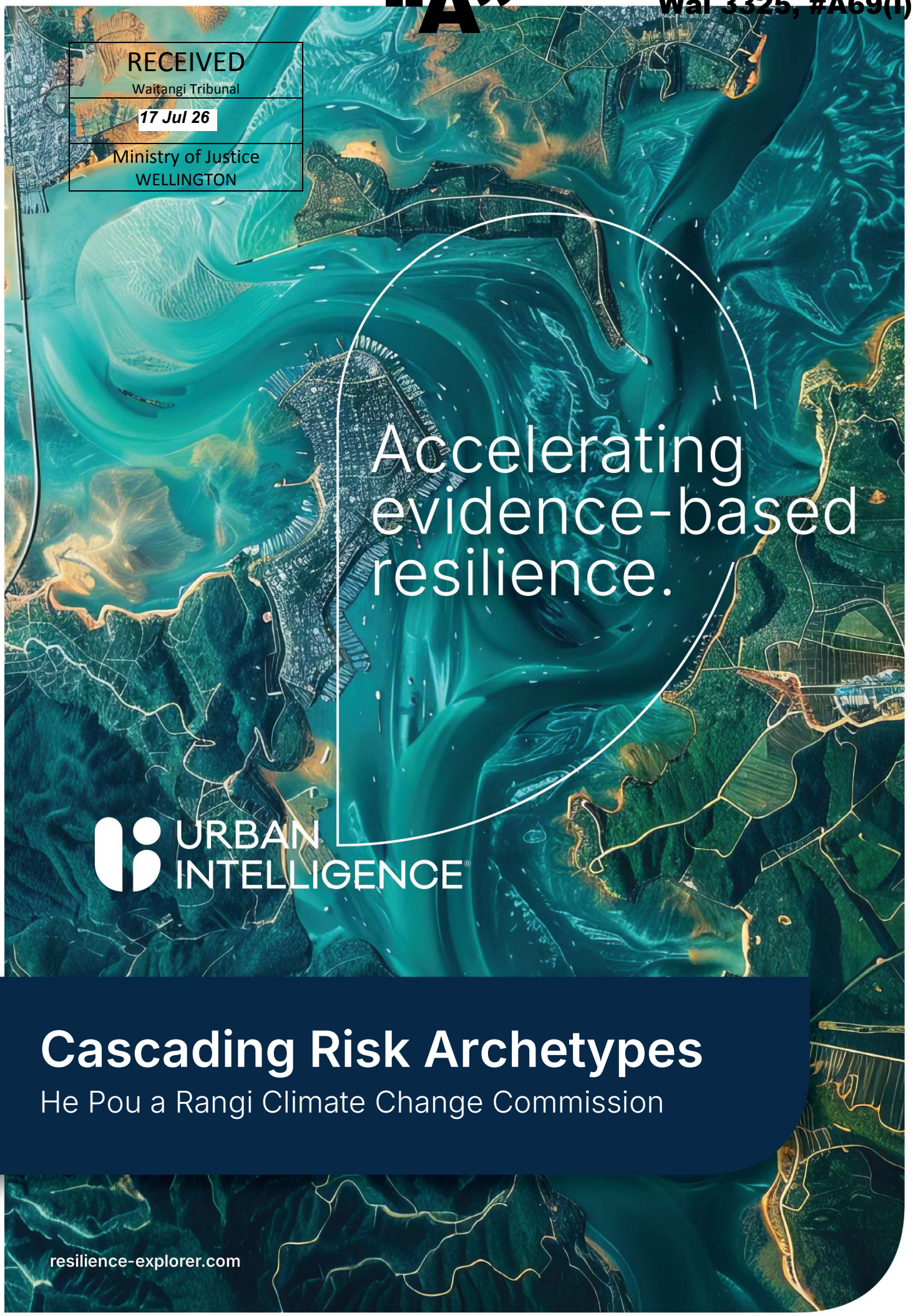

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1. | Introduction

The following document concludes a short contract based on ongoing research to summarise three cascading risk archetypes that the He Pou a Rangi Climate Change Commission can use to advance thinking on cascading risk in the forthcoming 2nd National Climate Change Risk Assessment.

Cascading risk (Figure 1) explores how risk cascades from a hazard or change through interconnected social and economic systems via a chain of cause and effect. As such, cascading risk is different from direct risk or compounding risk, which do not consider more than one element, for example, a bridge.

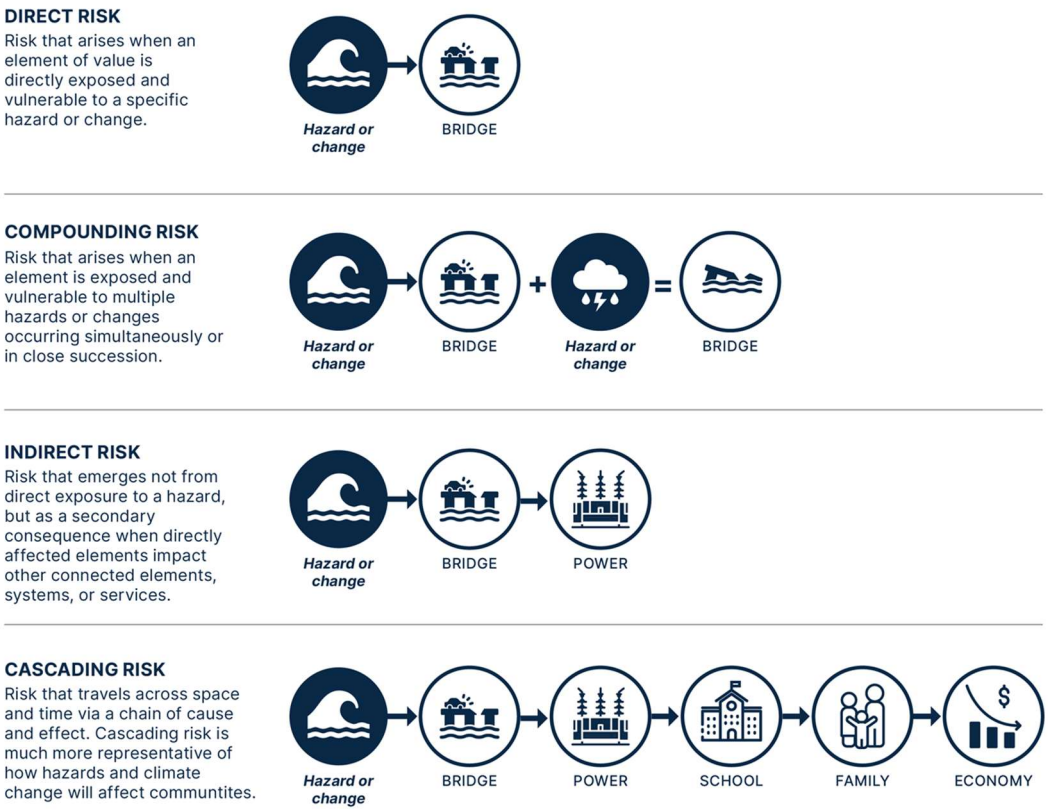

Figure 1. *Definition and illustration of direct, compounding, and cascading risk*

Three archetypes have been identified to elucidate cascading risk across a range of climate drivers and hazards. They are:

- A 'too much' cascade (disruption)
- A 'too little' cascade (contestation)
- A baseline shift (irreversible change)

The purpose of the three cascading risk archetypes is to provide a blueprint or consistent pattern of cause and effect applicable to all climate-related hazards and changes. Such blueprints allow:

a) A chain of cause and effect to be quickly developed to describe how a risk may ripple across multiple domains and where any important feedback loops may occur.
b) A consistent base to consider how to assess cascading risk across different domains.

Each archetype was developed as part of an MBIE Smart Idea Research Programme on cascading risk led by the University of Canterbury. The development process is not described here, but it includes co-creation of cascades with stakeholders and verification work at national and international conferences and workshops.

2. | Too Much (Disruption) Cascade

This chain of cause and effect (Figure 2) is triggered when there is, as the name suggests, too much of something, resulting in a range of factors that exceed their capacity to cope and provide the required/desired level of service. What transpires is a set of damage, repair and recovery steps that span all domains, seeking to return the system or asset to a state close to its original state. Examples of triggers include floods, heat waves (land-based or marine), coastal storms, or landslides.

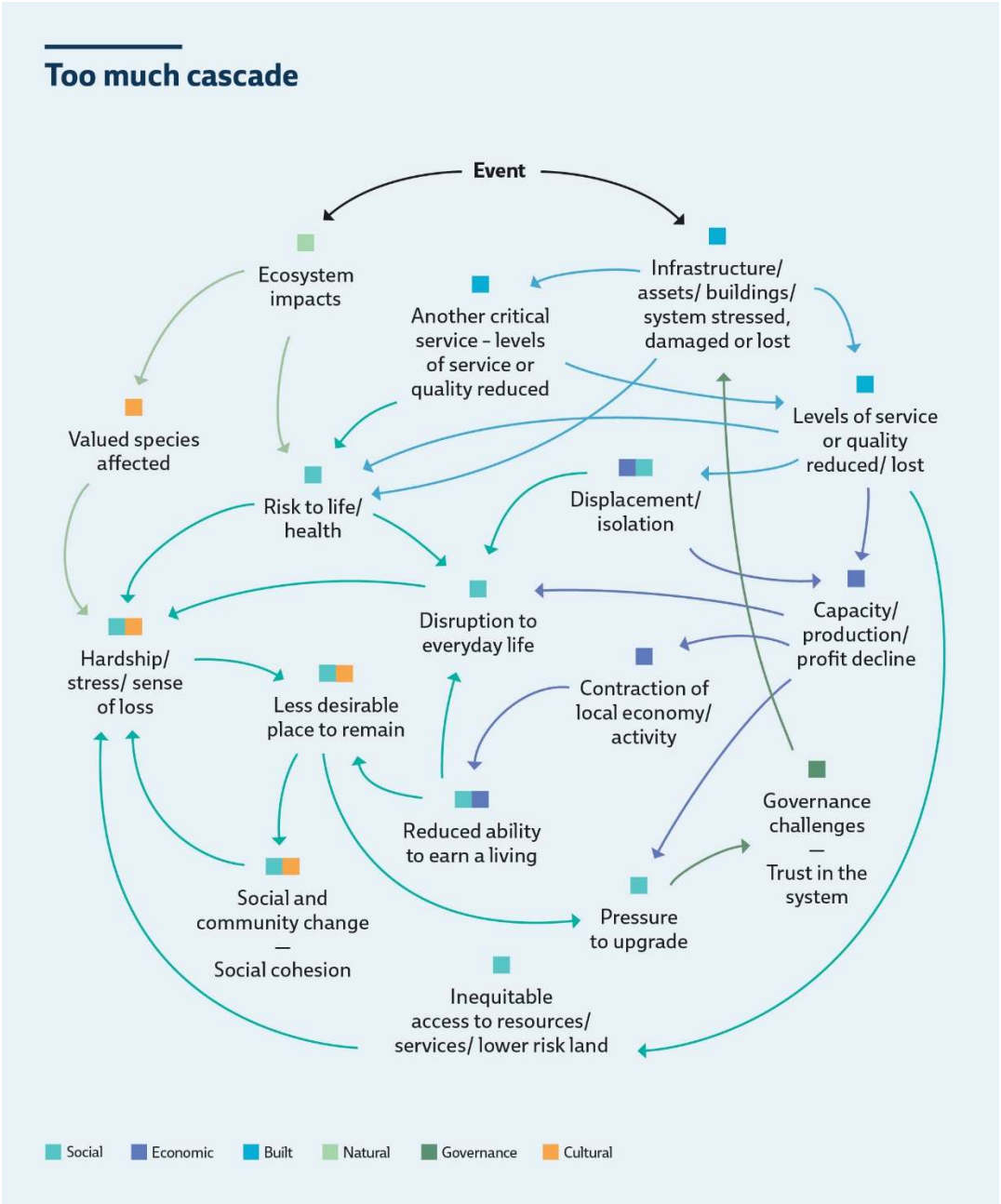

Figure 2. Disruption Cascade, noting that the colours represent the different domains (Credit –Content provided by Urban Intelligence, Image created by the Climate Change Commission)

The disruption cascade contains several smaller, notable cascades: Ecosystem and Cultural Cascade; Economic Consequence Cascade; Social Consequence and Change Cascade; and the Governance Pressure Cascade. These cascades are described in further detail below, using the example of a flood event.

2.1 | Ecosystem and Cultural Cascade

A flood can cause direct damage to ecosystems, for example, scouring and destruction of instream habitat. This can reduce habitat quality and abundance of valued species, disrupting the ability of communities to gather food or pass on traditional knowledge. At the same time, ecosystem contamination can affect the quality of local food and drinking water sources, posing potential risks to public health. As with the contestation cascade (Figure 3), the hardship created by sudden change can make an area less desirable to live in, contributing to community and social change. It also generates pressure on decision-makers to invest in infrastructure or other measures to reduce future risk. This pressure may or may not result in improved flood management. Either way, future events are likely to trigger the same chain of impacts again.

2.2 | Economic Consequence Cascade

The economic consequences of a flood spread through several interconnected pathways:

a) Damage to essential services that businesses depend on, such as power, water, sanitation, and roads.
b) Direct damage to businesses themselves, for example, building damage or loss of stock.
c) Displacement and isolation, for example, a business may need to relocate, lose access to its supply chain, or find that employees cannot reach their workplace.

Any one of these factors, on its own or in combination, can reduce a business's ability to operate, cutting production and revenue and causing a sudden contraction of the local economy. When businesses operate at reduced capacity, the ability of owners and workers to earn a living is disrupted. Further, when local businesses cannot operate at all, access to goods and services declines, and the community's ability to function as it normally would is undermined.

Any disruption to daily life can make the area less attractive to live in, contributing to community change and potentially reducing cohesion as the community's makeup shifts. It is worth noting that this effect is often sudden but could be temporary. Communities frequently come together and become more cohesive in the immediate aftermath of a flood; however, as the area becomes less desirable (particularly with repeat events occurring), change may become permanent, and pressure on decision-makers may grow.

2.3 | Social Consequence and Change Cascade

Social consequences unfold across a range of timeframes. In the short term, a flood poses risks to life and can isolate communities. This is followed by broader disruption to daily life and, over time, by potentially unequal access to resources, services, and safer locations with lower hazard exposure. These inequalities can build gradually, increasing hardship and reducing the desire to remain in the community.

A notable feedback loop exists here: as an area becomes less desirable, people leave, changing the community's composition and potentially affecting social cohesion, which in turn creates further hardship, making the area even less desirable. Social consequences also place pressure on governing institutions, and if governance fails to respond adequately, public trust in those institutions is likely to erode.

2.4 | Governance Pressure Cascade

Pressure on governance stems from both the immediate emergency response (which is not considered in this cascade) and the ongoing economic, social, and ecosystem cascades. When the response fails to meet community needs, trust in governing institutions is undermined. The decisions made, such as whether to upgrade infrastructure, replace damaged assets, or implement longer-term adaptation measures, directly shape how communities and systems recover, and how well they are positioned to withstand future events. More significant interventions have the potential to change future cascades.

3. | Too Little (Contestation) Cascade

This chain of cause and effect (Figure 3) is triggered when there is "too little" of a resource to support previous use or ecosystem services. In essence, this cascade is a contestation cascade in which scarcity drives competition for resources, generating cascading impacts and risks that ripple outward. This includes the impact on ecosystems resulting from competition among different users. Drought is a prime example of this cascade, but it also applies to competition for safe (i.e. risk-free) land for homes and businesses.

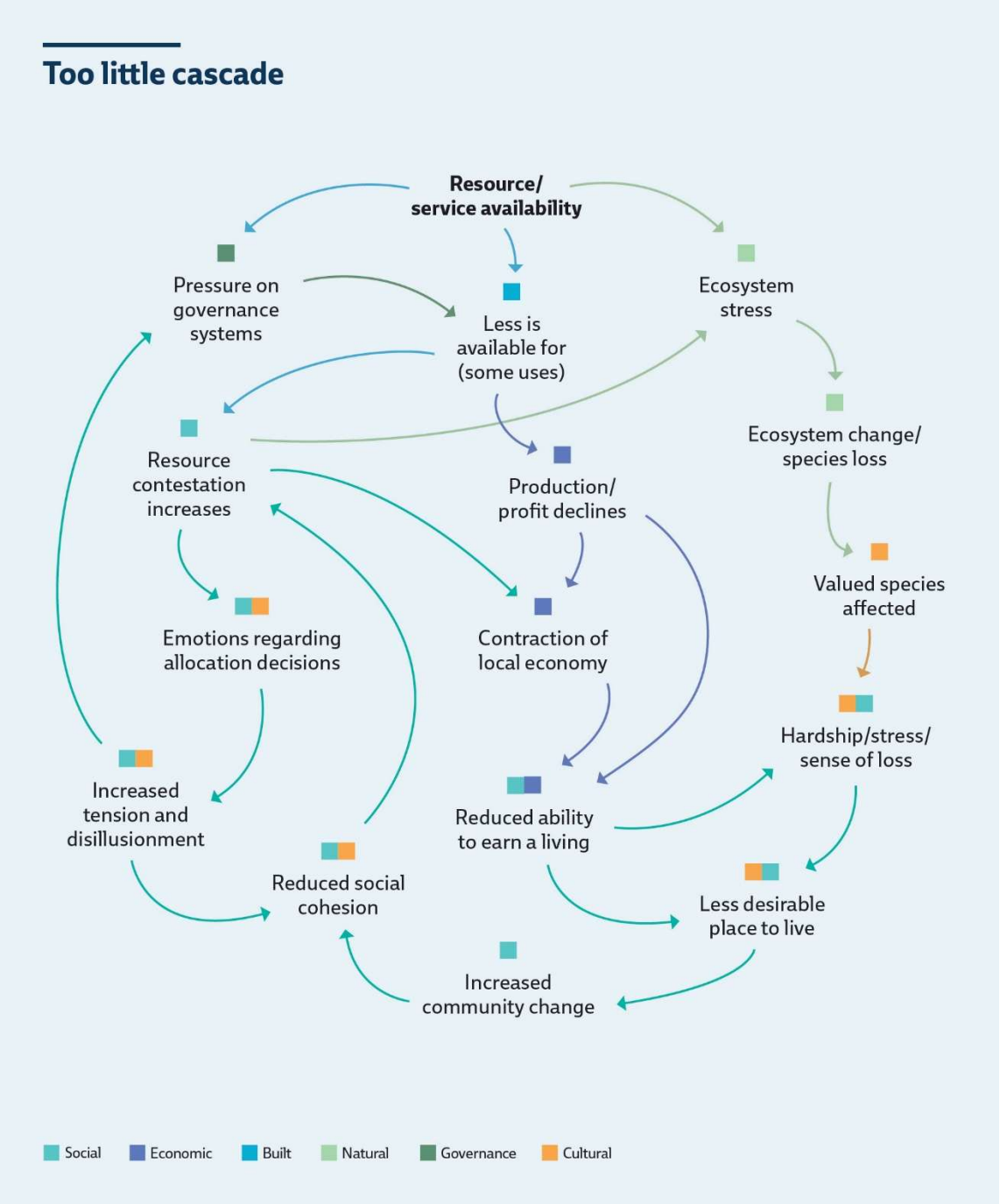

Figure 3. *Contestation Cascade, noting that the different colours represent different domains (Credit –Content provided by Urban Intelligence, Image created by the Climate Change Commission)*

The contestation cascade contains several smaller, notable cascades: Ecosystem and Cultural Cascade; Economic Consequence Cascade; Social Consequence and Change Cascade; and the Governance Pressure Cascade. These cascades are described in further detail below, using the example of water scarcity.

3.1 | Ecosystem and Cultural Cascade

Reduced water flow places stress on aquatic ecosystems by lowering water volumes and raising water temperatures, which can lead to changes in ecosystem composition and a decline in valued species. The loss of these species can disrupt cultural practices and the intergenerational transfer of knowledge within Indigenous communities. As the area becomes less desirable to live in, residents may relocate, altering the community's composition and potentially reducing social cohesion. Declining social cohesion can, in turn, increase competition over resources in terms of disagreements over who “should” have access to the scarce resource. If productive or human uses are promoted over ecosystems, this may further reduce the water available for ecosystems and intensify the original stress, creating a reinforcing cycle.

3.2 | Economic Consequence Cascade

Increased competition over water reduces the supply available for productive uses such as crop irrigation, leading to lower agricultural output and reduced profitability in the primary sector. Broader regional economic decline may follow, reducing the viability of local employment and business activity, and making the area less attractive as a place to live for residents and workers. This may cause community change, which may affect social cohesion. Where certain sectors are perceived to receive preferential access to a contested scarce resource, social divisions may deepen. Reduced cohesion feeds back into greater resource competition, while growing tensions over allocation decisions increase pressure on the institutions responsible for making those decisions.

3.3 | Social Consequence and Change Cascade

Social change occurs through the combined effects of ecosystem degradation, economic decline, and governance decisions. Changes within the community, such as shifts in community composition and rising inter-community tensions, feed back into the governance system, increasing the demands placed on institutions making resource allocation decisions. Communities may become increasingly disillusioned with the system of managing water over time.

3.4 | Governance Pressure Cascade

As resource availability declines, governance institutions may need to decide who has access to the resource and under what conditions. These decisions directly influence the social, economic, and ecological dynamics described above. At the same time, the consequences of those decisions generate feedback that further pressures governance systems, creating an ongoing cycle of decision-making under compounding constraints.

4. | A Baseline Shift (Irreversible Change) Cascade

When a baseline shift in system parameters occurs, a chain of cause and effect is triggered which can result in irreversible change or loss (Figure 4). The difference between this cascade and the previous two is a permanent shift in the system, whereas the systems in the previous two can return to their previous state between events.

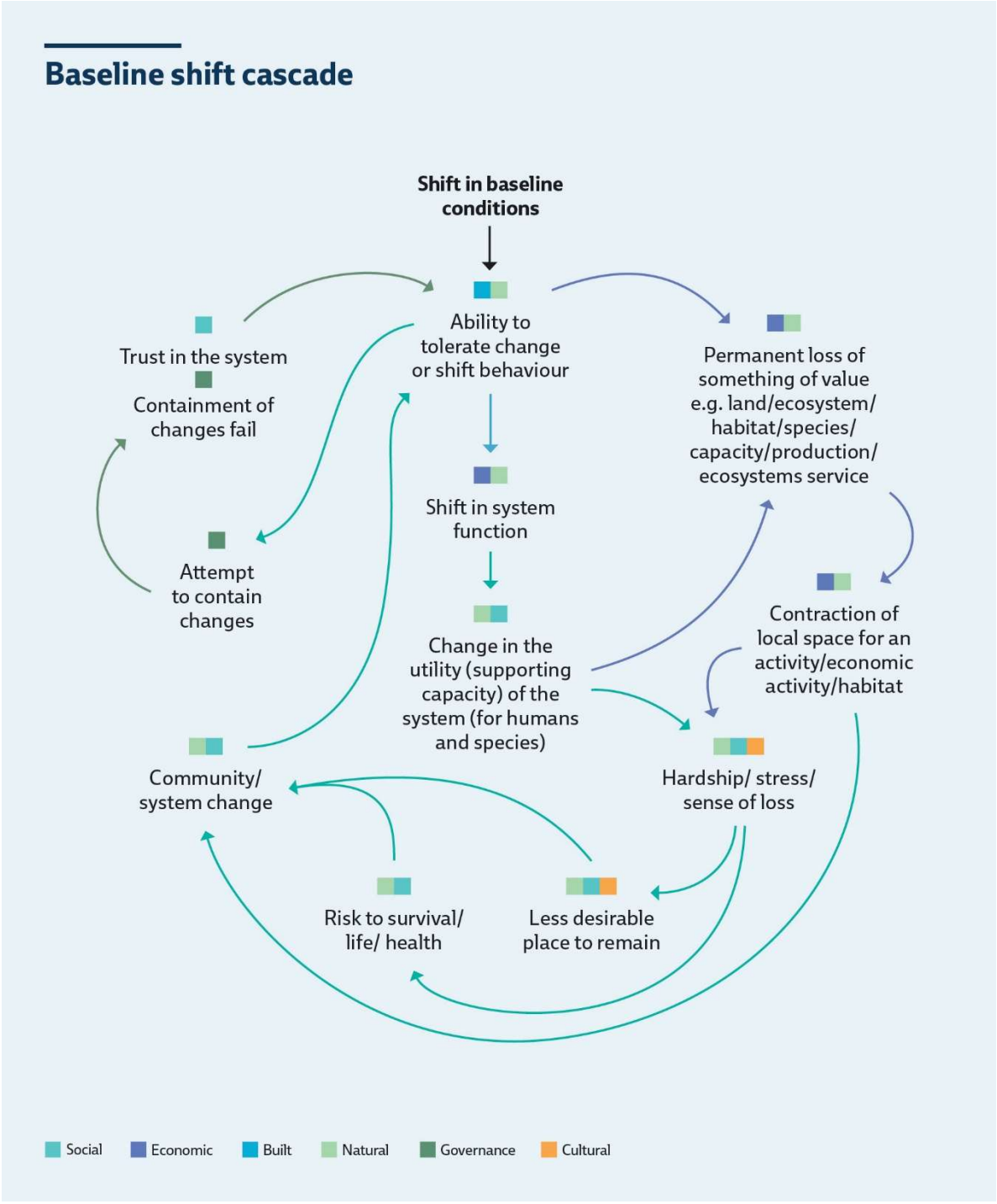

Figure 4. Irreversible Change or Loss Cascade, noting that the different colours represent different domains (Credit –Content provided by Urban Intelligence, Image created by the Climate Change Commission)

Similar to the other cascades, the irreversible change cascade contains several smaller, notable cascades: Ecosystem and Cultural Cascade; Economic Consequence Cascade; Social Consequence and Change Cascade; and the Governance Pressure Cascade. These cascades are described in further detail below, using the example of sea-level rise.

4.1 | Ecosystem and Cultural Impact Cascade

A permanent shift in environmental conditions, such as rising sea levels, can push species and ecosystems beyond the limits they can tolerate. For example, mangroves or salt marsh communities may no longer be able to survive in their current locations as water depths rise beyond their physiological tolerance. These ecosystems or species may be able to shift by moving inland into shallower water, but where there is no room to do so due to land elevation or physical barriers, they may decline in extent or be lost entirely.

When an ecosystem shrinks, changes, or a species disappears, the benefits it provides to both human communities and other species are reduced. This loss of supporting capacity can compound, driving further declines in ecosystems and species. The loss of valued ecosystems and species can create hardship, making both the ecosystem and the surrounding (human) communities less desirable places to remain, contributing to further change in natural and human communities. Indigenous communities may experience significant cultural losses, particularly where the ability to carry out traditional practices depends on the presence of specific species or environments. As sea-level rise continues, this process can compound, causing further ecological decline and cultural loss.

4.2 | Economic Consequence Cascade

Rising sea levels can lead to more frequent coastal flooding and higher groundwater levels, reducing the area of productive farmland available and limiting the remaining land's capacity. For example, restricting some land to seasonal grazing. This contraction of usable agricultural land reduces productive capacity and can contribute to a decline in the local primary sector economy. As economic conditions worsen, people may leave the area, and those who remain, landowners and workers, face growing hardship and an increasingly difficult decision about whether to stay. Community change can make it harder for those remaining to sustain their way of life, further accelerating community change.

4.3 | Social Consequence and Change Cascade

The social consequences of this cascade build gradually through a series of compounding changes and losses that affect many aspects of daily life, for example, the reliability of infrastructure, the functioning of productive industries, the loss of ecosystems and species, and the erosion of culturally important knowledge and practices. Communities may adapt for a time by adjusting how they operate, accepting reduced services, fewer job opportunities, or changes to their way of life. However, as conditions continue to worsen, this process is likely to become a downward spiral that progressively affects community health, wellbeing, and composition.

4.4 | Governance Pressure Cascade

Pressure on governance systems builds up as changes in conditions that exceed what communities are willing or able to accept accumulate. A typical response to a change is an intervention aimed at maintaining the system in its current form, for example, constructing sea walls or actively managing at-risk species. However, as the underlying conditions continue to shift, the effectiveness of these interventions will gradually decline, and efforts to manage the change will begin to fail. Additional interventions may be attempted, but a series of failures is likely to erode public trust in the institutions responsible. This cycle of intervention and failure is likely to repeat, driven by the ongoing shift in baseline conditions, until no viable options remain.

5. | Discussion and Conclusions

The three archetypes of cascading risk help explain how different types of climate-related changes or hazards may propagate across interconnected social and economic systems and what feedback loops may exist.

They can be used to develop a narrative of cascading risk for any location by following the pattern and adding in the appropriate local contextual information. In some cases, cascades can be used in combination, with two cascades occurring together or in quick succession.

It is worth noting that the cascades do not attempt to quantify the relationships between the factors or the uncertainty associated with them; they only highlight that a relationship exists. However, this does not preclude future quantification and evolution of the method.

Cascades remain a simplification of a complex system, meaning that although cascades offer greater insights into the complexity of risk than focusing on direct impacts alone, they are still simplifications.

The presence of potential vicious cycles (reinforcing loops that produce undesirable outcomes) within each cascade indicates that the impact and risk of the cascade can intensify quickly. At this stage, identifying the potential for the emergence of unwanted cycles is as far as this approach can go. We suggest noting the possibility in a narrative and indicating that, as climate change intensifies, the cycle could become more impactful.

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