

Resilience Insurance: Integrating Natural Assets and Nature-based Solutions into Risk Reduction Financing

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EXECUTIVE SUMMARY

This report provides insights to property and casualty (P&C) insurers and insureds (property owners) on how natural assets and nature-based solutions can support strategies to reduce insured losses from natural hazards (climate physical risks). This report is part of a project (hereafter "the Project") jointly led by the Natural Assets Initiative (NAI) and the Risk and Insurance Studies Center Inc. (RISC Foundation), with support from the Informal Insurance Sector Advisory Group (IISAG)—a group of insurers and related organizations that review, ground-truth, and provide feedback on the Project's research products (see Annex 1 for members and observers).

The term *natural assets* refers to the stocks of natural resources or ecosystems that contribute to providing one or more services required for the health, well-being, and long-term sustainability of a community and its residents (e.g., water filtration, stormwater management, climate regulation, flood risk reduction).

This report:

- Provides an overview of existing evidence on the relationship between natural assets and insurance risk mitigation strategies;
- Describes some of the challenges associated with capturing value from natural assets in an insurance context; and
- Offers recommendations and frameworks that can be considered to support natural asset health or nature-based interventions to reduce insurable risks.

It should be emphasized that although the literature review conducted for this Project found substantial evidence that natural assets contribute to risk reduction—particularly in a changing climate—there was a lack of empirical evidence demonstrating whether natural assets reduce insured losses or improve insurers' premium loss ratios. Consequently, our proposed approaches aim to begin testing these natural asset–insurance relationships and to document insights through pilot initiatives. Given this evidence gap, one of the key recommendations (Recommendation 1) is to pursue research that can close it—either through a controlled economic experiment that generates new empirical, monetized insurance data or through rigorous analysis integrating multiple, heterogeneous data sources to construct reliable evidence of the loss-reduction benefits of natural assets.

Natural assets and their derived services are varied, with idiosyncrasies across the type of asset, the geography, and the type of physical hazard exposure. This creates scalability and replicability challenges for any insurance-related initiative and also complicates the development of insurance solutions, as insurers may not have the breadth of expertise needed to assess such diverse natural systems, nor the risk appetite required to undertake complex and uncertain projects. To address these challenges, the report recommends (Recommendation 2) developing a set of generic guiding principles for insuring natural assets, identifying a specific Canadian natural asset to which these principles can be applied, and piloting the resulting insurance approach in collaboration with insurers to assess its feasibility and replicability.

Given that there are few examples to draw upon, this report focuses on the regulating services of natural assets that reduce risks arising from natural hazards. We view this as a tangible benefit to insurers and insureds, and provide evidence for a quantifiable relationship between natural assets and natural hazard risks as a foundation for valuing the risk reduction benefit of natural assets. We pursue this risk reduction benefit through the concept of *resilience insurance*, which combines risk reduction and risk transfer strategies to mitigate natural hazard risks using natural asset interventions or nature-based solutions.

The ways natural assets help regulate risks—such as flooding, erosion or other natural hazards—vary depending on the type of ecosystem and the type of hazard, creating unique links between specific assets and risks. As noted, these idiosyncrasies complicate the ability to develop a generalized framework for quantifying risk-reduction benefits.

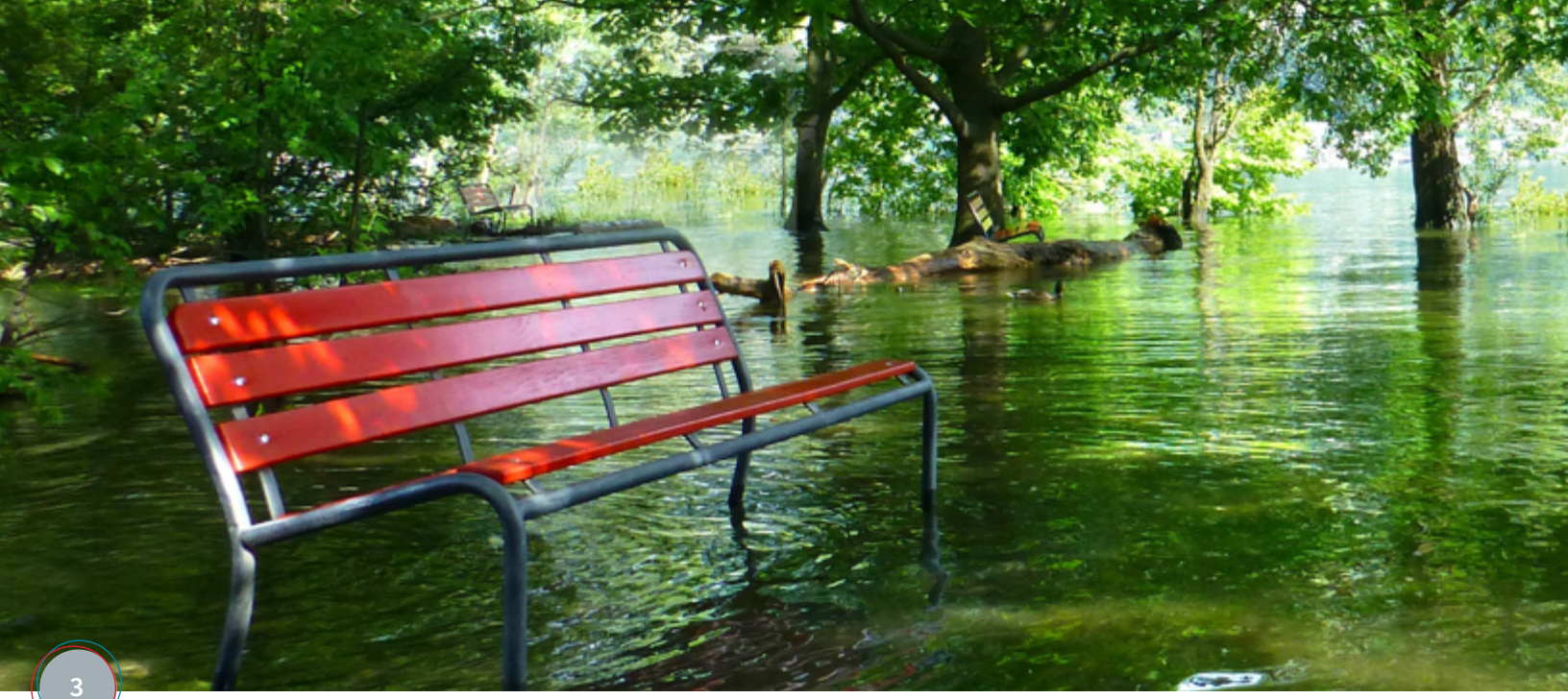
Therefore, to establish a tractable foundation for advancing our next recommendation, we narrow the focus of the report by geography, peril, and natural asset type—the chosen focuses being **urban areas** (due to the concentration of economic exposures), **pluvial flood risk** (a major hazard in urban areas), and **urban green infrastructure** (a nature-based intervention that can be used to reduce urban flood risk).

We discuss urban green infrastructure as a flood-risk mitigant based on its ability to reduce stormwater runoff, then develop a resilience insurance-like framework (Recommendation 3) that can be used to financialize the flood-risk-reduction benefit by identifying potential value-capture mechanisms. We define two stakeholders that benefit from flood-risk reduction: insurers and property owners. We then propose value-capture mechanisms that can be used to financialize the benefits received by these stakeholders.

We further examine environmental impact bonds (EIBs) as a funding mechanism to finance these interventions and develop a framework that can be used to estimate the risk-reduction value of the nature-based intervention by mapping the risk-reduction benefit to avoided losses and insurance-premium costs.

For insurers, we propose a performance-based financing arrangement using an EIB with the insurer as the outcome payor and insured losses as the performance metric. We base this arrangement on a similar EIB issued by the City of Atlanta (Department of Watershed Management), with a difference in the performance payor and performance metric.

For property owners, we outline two value-capture mechanisms that can be used to derive financial value from the risk-reduction benefit of urban green-infrastructure interventions: local improvement charges and tax increment finance.



INTRODUCTION

The risks and costs from climate hazards are rising globally,[1] while natural assets are being degraded through urban growth and industrialization[2]. The significance of this dual threat is expressed in a World Economic Forum Global Risk Report[3] that ranked these two threats among the top four global, long-term risks ((i) extreme weather events, (ii) critical change to Earth systems, (iii) biodiversity loss and ecosystem collapse, and (iv) natural resource shortages). Responses to these threats have stressed the need to improve resilience strategies that reduce vulnerability to hazards through cost-effective strategies that integrate nature to support conservation and restoration objectives.[4] Natural asset management (NAM) provides one pathway to integrate nature into resilience strategies.

NAM is an increasingly well-defined and structured process for identifying, accounting for, and protecting natural assets to preserve the vital infrastructure and non-infrastructure services they provide. It is based on standard asset management practices that all public sector entities in Canada must adopt. NAM has evolved in Canada from a single example in 2017 to over 150 examples of local governments and others taking action.

The protection, restoration, and enhancement of natural assets are increasingly recognized as a means by which communities can secure vital flows of infrastructure services such as drinking water filtration, stormwater management, flood and erosion management, and aquifer recharge, as well as co-benefits such as health outcomes, and the provision of social, cultural, and recreational amenities (often referred to as non-infrastructure or intangible infrastructure services).

There are numerous well-defined barriers to the uptake of NAM[5]. Some of these relate to the ability to

1 Banerjee, C., Bevere, L., Gahlot, S., and Puttaiah, M. (2025). Unseasonal fires trigger above-trend catastrophe losses in first half 2025. Swiss Re Institute.

2 World Economic Forum. (2020). Nature risk rising: Why the crisis engulfing nature matters for business and the economy.

3 World Economic Forum. (2024). The global risks report 2024. Insights.

4 Soto-Montes-de-Oca, G., Bark, R., and González-Arellano, S. (2020). Incorporating the insurance value of peri-urban ecosystem services into natural hazard policies and insurance products: Insights from Mexico. Ecological Economics, 169, 106510; Primmer, E., and Paavola, J. (2021). Insurance value of ecosystems: An introduction. Ecological Economics, 184, 107001; Banerjee, C., Bevere, L., Corti, T., Finucane, J., and Lechner R. (2023). Natural catastrophes and inflation in 2022: A perfect storm. Swiss Re Institute.

5 https://mnai.ca/media/2023/02/BC-Barriers-Report-FINAL-3.pdf | www.naturalassetsinitiative.ca/documents/natural-asset-infrastructure-in-bc-barriers-and-opportunities/

communicate the relevance of NAM in quantifiable risk management terms, others, to the availability of finance. Globally, financial investments in nature overall are small, both in absolute terms—equivalent to around 0.1% of global nominal GDP—and in relative terms[6]. According to the United Nations Environment Programme, the current US $154-billion per year financial flows to nature-based solutions (NbS) must triple in this decade to address the converging sustainability crises of climate change, biodiversity loss, and land degradation[7]. Notwithstanding the importance of nature and natural assets, few transactions pool private capital towards this asset class. As part of efforts to overcome barriers to NAM, innovative solutions are needed to integrate risk science, insurance, financing, and stakeholder governance to develop nature-related risk reduction solutions.[8]

Within this context, NAI and RISC, with support from the IISAG, developed the Project to provide Canadian property and casualty insurers with actionable insights on how natural assets and NAM can be an effective risk reduction strategy. The Project consisted of:

- Key informant interviews (The Nature Force - two interview participants; Restoration Insurance Service Company [RISCO] - one interview participant; WWF [World Wildlife Fund] Canada - one interview participant; UNCDF [United Nations Capital Development Fund] - one interview participant.)
- A 2024 literature review to investigate the relationships between NAM/NbS and insurance risks. In summary, the literature review found no off-the-shelf solutions for adapting natural asset integration into the Canadian insurance context; very sparse evidence of natural assets being recognized and valued within broader insurance or resilience frameworks; no examples of the risk-reducing value of natural assets being recognized during underwriting; limited instances where the natural asset itself is insured, such as coral reefs along the Mexican coast and in Hawaii, and natural assets insured in China using index-based insurance; examples related to urban flood risk mitigation in the US that may be transferable to urban centers in Canada; and, the idea that resilience insurance could be a mechanism by which natural assets are integrated into risk pricing. Based on these findings, the Project team developed Recommendation 1 (to generate empirical evidence through controlled experimentation or integrated multi-source analysis) and Recommendation 2 (to develop guiding principles for insuring natural assets and pilot them using a specific Canadian natural asset).
- A launch meeting with the IISAG in September 2024, and a meeting in January 2025 to share the results of the literature review and discuss next steps. Overall, the latter suggested a trend in the group to focus on resilience insurance as something to be explored further. Given scope and resource constraints, IISAG participants agreed that Recommendations 1 and 2 would remain important longer-term next steps but would extend beyond the boundaries of the current Project, leading the team to focus its efforts on developing Recommendation 3.
- This report consolidates the findings, inputs, and potential next steps. Accordingly, the Project advances Recommendation 3 by developing a resilience-insurance-oriented framework and associated value-capture mechanisms within a defined urban, pluvial-flood context.

This report examines resilience insurance as one approach to integrate natural assets or nature-based solutions into insurance arrangements. Nature-based solutions can support cost-effective disaster risk mitigation with similar levels of effectiveness as traditional grey infrastructure solutions while providing additional co-benefits, making them

6 naturalassetsinitiative.ca/wp-content/uploads/2024/07/NAI-investing-in-watersheds-report-2024pdf.pdf

7 wedocs.unep.org/bitstream/handle/20.500.11822/41333/state_finance_nature.pdf?sequence=3

8 Kelso, M. A., A. E. Stovall, B. G. Reguero, G. Franco, and M. W. Beck. 2024. “Nature-based solutions and risk management: Recommendations for integrating nature into risk science and insurance. UCSC and USACE, Washington, D.C

valuable solutions for reducing natural disaster risks and restoring nature.[9] Effectively integrating nature-based solutions into insurance models, however, has not been prominent due to several challenges, including financial barriers (high upfront costs, uncertain revenue sources, long return periods, and lack of investor awareness), governance barriers (lack of enabling policies and regulations, and slow corporate uptake), and informational barriers (lack of standardized metrics to measure ecosystem services, and the challenges involved with monitoring and evaluating natural assets at scale).[10] Natural assets also have multiple beneficiaries who value these assets differently based on various services received. In this report, we focus on the risk reduction benefit of natural assets and on insurers and insured as beneficiaries.

While the insurance literature increasingly recognizes ecosystems' protective role, these benefits are still unrepresented in standard risk models and financial instruments, pointing to an important but underdeveloped area of integration.[11] Evidence for the disaster risk reduction benefit from natural assets has been established in the ecological and economic literature.[12] This characteristic of natural assets is often described as the insurance value of ecosystems, defined ecologically as the capacity of ecosystems to maintain their functioning and stability when exposed to environmental disturbances, variability, or change.[13] The economic literature provides a complementary definition that is more commonly used. The economic insurance value of ecosystems is the monetary value of the risk-reduction benefits that ecosystems provide by reducing potential losses from environmental shocks. The economic definition has become prominent for cost-benefit analysis and policy decision-making.[14] In this report, we also follow the economic definition of the insurance value of ecosystems.

Studies have used different approaches to empirically and theoretically estimate the economic insurance value of ecosystems. Discrete Choice Experiments have been used to estimate households' willingness to pay for risk reduction benefits derived from forest ecosystem services,[15] urban green infrastructure,[16] and farmers' willingness to invest in climate risk reduction interventions in return for crop insurance premium reduction.[17] The estimated values tend to have wide ranges and are influenced by various characteristics. Studies have also modeled the

9 Vicarelli, M., Sudmeier-Rieux, K., Alsadadi, A., Shrestha, A., Schutze, S., Kang, M. M., Leue, M., Wasielewski, D., and Mysiak, J. (2024). On the cost-effectiveness of Nature-based Solutions for reducing disaster risk. Science of Total Environment, 947, 174524.

10 Pinkerton, Valerie, Sage Bucher-Melcer, Daniel Fairweather, and Charlie Pool. 2024. Through the wilderness. The role of insurance in unlocking nature finance. Howden. Pollination. October 2024.

11 University of Cambridge Institute for Sustainability Leadership (CISL). (2022). Why nature matters: Nature-related risks and opportunities for insurance underwriting. Cambridge, UK: University of Cambridge Institute for Sustainability Leadership; Kelso, M. A., Stovall, A. E., Reguero, B. G., Franco, G., and Beck, M. W. (2024). Nature-based solutions and risk management: Recommendations for integrating nature into risk science and insurance. UCSC and USACE, Washington, D.C

12 Dallimer, M., Martin-Ortega, J., Rendon, O., Afionis, S., Bark, R., Gordon, I. J., and Paavola, J. (2020). Taking stock of the empirical evidence on the insurance value of ecosystems. Ecological Economic, 167, 106451.

13 Dallimer, M., Martin-Ortega, J., Rendon, O., Afionis, S., Bark, R., Gordon, I. J., and Paavola, J. (2020). Taking stock of the empirical evidence on the insurance value of ecosystems. Ecological Economics, 167, 106451.

14 Paavola, J., & Primmer, E. (2019). Governing the provision of insurance value from ecosystems. Ecological Economics, 164, 106346.

15 Unterberger, C., & Olschewski, R. (2021). Determining the insurance value of ecosystems: A discrete choice study on natural hazard protection by forests. Ecological economics, 180, 106866.

16 Brent, D. A., Gangadharan, L., Lassiter, A., Leroux, A., & Raschky, P. A. (2017). Valuing environmental services provided by local stormwater management. Water Resources Research, 53(6), 4907-4921.

17 Jorgensen, Sisse Liv, Mette Termansen, and Unai Pascual. 2020. Natural insurance as condition for market insurance: Climate change adaptation in agriculture. Ecological Economics, 169, 106489.

flood-risk reduction benefit derived from coastal assets such as corals[18] and coastal wetlands,[19] using property prices as the exposure and yielding similarly wide-ranging value estimates. Flood-risk reduction benefits have also been modeled for peri-urban and urban natural assets.[20]

However, natural assets and their risk reduction benefits are very dispersed. Risk reduction characteristics vary with the type of natural asset, the hazard, and the local geography.[21] Evidence for disaster risk-reduction benefit from natural assets has been strongest in urban and coastal geographies and against flood hazards.[22] Studies have examined natural assets and nature-based solutions as alternatives to traditional grey infrastructure to reduce coastal storm surges, and coastal wetlands have been considered for reducing coastal flooding.[23] Sun and Carson (2020)[24] analyzed property damages caused by tropical storms and hurricanes in the US between 1996 and 2016 and found that counties with more wetland coverage experienced significantly less property damage. Using property value as an economic exposure, the average protection value was estimated to be $1.8 million/km^2 of wetland per year, with a median value of $91,000/km^2. The study showed that these values varied widely across US coastal counties based on property value exposures, wetland coverage, coastline shape, local elevation, building codes, and wind intensities. Moreover, the study showed that protection against storm surges was most noticeable against weaker storms.

Similar studies have been done along the Louisiana coast with similar outcomes demonstrating the protective value of wetlands,[25] and across the US coast, demonstrating the protective value of coral reefs.[26] Models, however, can overestimate (or underestimate) the protection value, and may not account for dynamic parameters such as climate change impacts.[27] More fundamentally, natural asset solutions designed to mitigate flooding do not directly create revenue streams needed to mobilize private capital, and there are other constraints, such as data challenges and the inherent uncertainty of climate hazards, which complicate project

18 Reguero, B. G., Storlazzi, C. D., Gibbs, A. E., Shope, J. B., Cole, A. C., Cumming, K. A., and Beck, M. W. (2021). The value of US coral reefs for flood risk reduction. Nature Sustainability, 4, 688-698; Beck, M. W., Losada, I. J., Menéndez, P., Reguero, B. G., Díaz-Simal, P., and Fernández, F. (2018). The global flood protection savings provided by coral reefs. Nature Communications, 9, 2186; Ferrario, F, Beck, M. W., Storlazzi, C. D., Micheli, F., Shepard, C. C., and Airoldi, L. (2014). The effectiveness of coral reefs for coastal hazard risk reduction and adaptation. Nature Communications, 5, 3794.

19 Sun, F., and Carson, R. T. (2020). Coastal wetlands reduce property damage during tropical cyclones. Proceedings of the National Academy of Sciences, 117(11), 5719-5725; Barbier, E. B. (2015). Valuing the storm protection service of estuarine and coastal ecosystems. Ecosystem Services, 11, 32-38.

20 Soto-Montes-de-Oca, G., Bark, R., and González-Arellano, S. (2020). Incorporating the insurance value of peri-urban ecosystem services into natural hazard policies and insurance products: Insights from Mexico. Ecological Economics, 169, 106510.

21 Mason, D.J., Miller, R.K., Mikulska, A.B., Lakshman, A.S., Lu, H.H., & Ross, K.C.S. (2024). Nature-based solutions. Evidence for hazard risk reduction and ecosystem service. Scaling up implementation and accelerating learning. The Institute for Defense Analyses.

22 Sudmeier-Rieux, K., Arce-Mojica, T., Boehmer, H.J., Doswald, N., Emerton, L., Friess, D.A., Galvin, S., Hagenlocher, M., James, H., Laban, P., Lacambra, C., Lange, W., McAdoo, B.G., Moos, C., Mysiak, J., Narvaez, L., Nehren, U., Peduzzi, P., Renaud, F.G., Sandholz, S., Schreyers, L., Sebesvari, Z., Tom, T., Triyanti, A., van Eijk, P., van Staveren, M., Vicarelli, M., & Walz, Y. (2021). Scientific evidence for ecosystem-based disaster risk reduction. Nature Sustainability, 4, 803–810.

23 Sudmeier-Rieux, K., Arce-Mojica, T., Boehmer, H.J., Doswald, N., Emerton, L., Friess, D.A., Galvin, S., Hagenlocher, M., James, H., Laban, P., Lacambra, C., Lange, W., McAdoo, B.G., Moos, C., Mysiak, J., Narvaez, L., Nehren, U., Peduzzi, P., Renaud, F.G., Sandholz, S., Schreyers, L., Sebesvari, Z., Tom, T., Triyanti, A., van Eijk, P., van Staveren, M., Vicarelli, M., & Walz, Y. (2021). Scientific evidence for ecosystem-based disaster risk reduction. Nature Sustainability, 4, 803–810.

24 Sun, F., & Carson, R. T. (2020). Coastal wetlands reduce property damage during tropical cyclones. Proceedings of the National Academy of Sciences, 117(11), 5719-5725.

25 Barbier, E. B., Georgiou, I. Y., Enchelmeyer, B., & Reed, D. J. (2013). The value of wetlands in protecting southeast Louisiana from hurricane storm surges. PloS one, 8(3), e58715.

26 Reguero, B. G., Storlazzi, C. D., Gibbs, A. E., Shope, J. B., Cole, A. D., Cumming, K. A., & Beck, M. W. (2021). The value of US coral reefs for flood risk reduction. Nature Sustainability, 4(8), 688-698.

27 Peter Sheng, Y., Paramygin, V. A., Rivera-Nieves, A. A., Zou, R., Fernald, S., Hall, T., & Jacob, K. (2022). Coastal marshes provide valuable protection for coastal communities from storm-induced wave, flood, and structural loss in a changing climate. Scientific Reports, 12(1), 3051.

planning and financing.[28] These challenges create barriers to translating the risk reduction benefits of natural assets into standardized and financial risk metrics that can reliably inform insurance models or investment decisions. As a result, even when protective value is demonstrated, it is not readily translatable into actuarial terms or financial instruments that could support insurance underwriting or investment.

In this report, we pursue a value capture framework that may financialize the risk reduction benefit. We focus on urban geographies, being areas with high economic exposures, and we focus on flood hazards, which are a major urban hazard. Whether the approach is transferrable and to what extent remains an open question for research and testing.[29] Our primary intent is to develop a framework that can be used to capture the value of the flood risk mitigation benefit derived from urban nature-based solutions. To develop this framework, we build on the resilience insurance concept from Reguero et al. (2020)[30], which formulates a quantitative framework to integrate natural hazard risk reduction interventions and risk transfer through insurance. The basis of this framework is the recognition that investments in hazard mitigation can generate value by way of reducing the costs associated with disaster impacts, and further, using natural asset interventions can be very cost-effective while also producing valuable co-benefits.[31]

We develop this resilience insurance concept around urban green infrastructure interventions, which are proven interventions for mitigating flood risk. We identify stormwater runoff volume as a general parameter to measure the efficacy of urban green infrastructure designed for flood-risk mitigation. We then propose value capture mechanisms that can be used to monetise the flood-risk mitigation benefit. To design the value capture mechanisms, we first identify insurers and insured (property owners) as two primary stakeholders that derive value from this benefit and then propose and discuss suitable mechanisms that can be used to monetise the value derived by these stakeholders.

For insurers, we propose a performance-based financing arrangement using an environmental impact bond with the insurer as the performance payor and insured losses as the performance metric. We conceptualize this EIB based on a previous issue from the City of Atlanta Department of Watershed Management, with the distinct difference between the performance payor and performance metrics. The City of Atlanta used volume of stormwater capture capacity as the performance metric, the issuer (the City of Atlanta) was the performance payor, and the urban green infrastructure was designed around two primary regulating services: flood mitigation and water quality improvement.

For property owners, we consider two common value capture mechanisms: local improvement charges and tax increment finance.

28 Pinkerton, Valerie, Sage Bucher-Melcer, Daniel Fairweather, and Charlie Pool. 2024. Through the wilderness. The role of insurance in unlocking nature finance. Howden. Pollination. October 2024.

29 Cao, W., Zhou, Y., Güneralp, B., Li, X., Zhao, K., & Zhang, H. (2022). Increasing global urban exposure to flooding: An analysis of long-term annual dynamics. Science of The Total Environment, 817, 153012.

30 Reguero, B. G., Beck, M. W., Schmid, D., Stadtmüller, D., Raepple, J., Schüssele, S., and Pfliegner, K. (2020). Financing coastal resilience by combining nature-based risk reduction with insurance. Ecological Economics, 169, 106487.

31 Vicarelli, M., Sudmeier-Rieux, K., Alsadadi, A., Shrestha, A., Schutze, S., Kang, M. M., Leue, M., Wasielewski, D., and Mysiak, J. (2024). On the cost-effectiveness of Nature-based Solutions for reducing disaster risk. Science of Total Environment, 947, 174524.



INSURER AND INSURED AS BENEFICIARIES: A RESILIENCE INSURANCE APPROACH

As noted, there is limited evidence of natural assets being recognized or valued within broader insurance frameworks; no known examples of their risk-reducing value being reflected in underwriting; and only a few cases where the natural asset itself is insured. Accordingly, the remainder of this report focuses on envisioning and outlining an approach that could be used to design models that could be piloted and tested in the Canadian context, recognizing that progress will depend on experimentation informed by the limited evidence currently available. For the purposes of this analysis, the approach, resilience insurance, considers the insurer and the insured as the key beneficiaries.

Resilience insurance combines traditional risk transfer with risk reduction incentives, often through investment in preventive measures that improve the ability to withstand, recover from, and adapt to hazard impacts. Traditional insurance generally works by transferring risk from individuals or organizations to insurers. It typically covers post-disaster losses but does not directly encourage—or explicitly reward—proactive risk reduction or preparedness. As climate hazards increase in frequency and severity, resilience has been emphasized to increase preparation and response to hazards. This has led to the idea that insurance should not only compensate for loss but also incentivize proactive risk reduction.

Resilience insurance provides a mechanism to realize resilience dividends, which refers to the benefits derived from risk reduction interventions when disasters occur (and the additional co-benefits derived from the intervention regardless of disaster incidence).[32] While this concept has been applied to both traditional (grey) infrastructure and natural infrastructure, there is a growing realization of the increased value of disaster risk reduction benefits from natural assets and the cost-benefit advantage that natural assets provide in many situations.[33] Natural assets and nature-based solutions not only offer critical risk-reduction functions but also deliver co-benefits such as biodiversity conservation and carbon sequestration. By extending the resilience dividend framework to these natural systems,

32 The World Bank & ODI. (2015). Unlocking the 'triple dividend' of resilience. Why investing in disaster risk management pays off." World Bank Policy Note.

33 Vicarelli, M., Sudmeier-Rieux, K., Alsadadi, A., Shrestha, A., Schutze, S., Kang, M. M., Leue, M., Wasielewski, D., and Mysiak, J. (2024). On the cost-effectiveness of Nature-based Solutions for reducing disaster risk. Science of Total Environment, 947, 174524.

decision-makers can capture both avoided losses and the broader ecological and socio-economic returns that enhance long-term resilience. The challenge rests in designing and implementing mechanisms that can be used to capture the resilience dividend from natural asset interventions.

In this report, we adapt the conceptualization from Reguero et al. (2020)[34] that builds on the ideas of ecosystem-based disaster risk reduction using natural asset interventions to reduce risks associated with natural hazard exposures. Reguero et al. (2020) formulate a quantitative framework to integrate natural hazard risk reduction interventions and insurance. The basis of this framework lies in the recognition that investments in hazard mitigation can generate value by way of reducing the costs associated with disaster impacts (avoided losses). However, these investments can carry large upfront costs. Often, risk owners (asset owners) may choose between risk reduction investment (hazard mitigation) or risk transfer (insurance). Through the resilience insurance approach, risk reduction is combined with risk transfer.

This resilience insurance concept has been demonstrated through several case studies showing its revenue creation potential. Munich RE and The Nature Conservancy[35] evaluated the impact of a nature-based solution (levee setback) on home insurance premiums associated with flood risk in a Missouri community, and showed that the intervention not only has the potential to reduce premiums, but the premium reduction can be sufficient enough to finance a municipal bond that could be used to support the financing of the intervention. The evaluation is based on the flood mitigation estimation of an actual levee setback construction that was publicly and philanthropically funded and completed in July 2021. Premium reductions, however, were estimated from insurance models.

Other case studies have also demonstrated similar outcomes for other natural hazards.[36] While these and other studies have provided quantifiable estimates of the potential risk-reduction benefit, implementable cases are lacking. Additionally, studies provide value estimates without a value capture mechanism. That is, how is the estimated value monetised? To support investment decisions, there is a need to create value capture mechanisms that can be used to establish revenue sources that can generate return on investments.

We examine potential value capture mechanisms that can be used to realize the resilience dividend from natural asset interventions. Natural asset interventions are highly context-specific, with very idiosyncratic risk reduction benefits[37] that depend on local environmental conditions. This complexity makes it difficult to generalize findings across contexts, or scale solutions without detailed, place-based assessments. Given these contextual sensitivities, we narrow our focus to specific applications where both the hazard and the potential for nature-based risk reduction are clear and pressing. Urban areas provide a compelling case: they concentrate population, infrastructure, and economic activity, making them areas of high exposure to natural disasters. Among these natural disasters, flooding stands out as a major and costly hazard globally.[38] Therefore, we focus on urban flooding as the hazard, and urban green infrastructure as the nature-based intervention used to deliver resilience dividends.

34 Reguero, B. G., Beck, M. W., Schmid, D., Stadtmüller, D., Raepple, J., Schüssele, S., and Pfliegner, K. (2020). Financing coastal resilience by combining nature-based risk reduction with insurance. Ecological Economics, 169, 106487.

35 Munich Re and The Nature Conservancy. (2021). Nature's remedy: Improving flood resilience through community insurance and nature-based mitigation.

36 The Nature Conservancy and MarshMclennan. Quantifying insurance benefits of a nature-based approach to reducing risk: Wildfire risk reduction buffers.

37 Mason, D.J., Miller, R.K., Mikulska, A.B., Lakshman, A.S., Lu, H.H., & Ross, K.C.S. (2024). Nature-based solutions. Evidence for hazard risk reduction and ecosystem service. Scaling up implementation and accelerating learning. The Institute for Defense Analyses.

38 Huang, G. (2021). Are cities safer than before? Frontiers in Sustainable Cities, 3, 713300.

RESILIENCE INSURANCE COMPONENT 1: URBAN GREEN INFRASTRUCTURE AND FLOOD-RISK MITIGATION

Green infrastructure (GI)[39] refers to networks of natural assets and nature-centric engineered assets that conserve natural ecosystem functions.[40] Urban applications of GI have been identified as an important response to climate change and urbanization challenges, providing important benefits such as flood attenuation, water purification, improved air quality, and urban heat mitigation.[41] The literature on urban green infrastructure (GI), however, has predominantly focused on implementations to improve stormwater management and, by extension, pluvial flood attenuation and water quality by preserving or restoring as much of the natural hydrology of an urban development site as possible.[42] These applications of urban GIs have also demonstrated favourable benefit-cost analyses,[43] and several cities and urban municipalities have pursued development plans that incorporate urban green infrastructure solutions for flood risk management.[44] Existing barriers, however, remain and span several critical areas such as governance, technical capacity, and business model viability to attract private capital.[45] We examine the literature to determine flood attenuation effectiveness and, in the process, determine performance measurements that can be used to measure the impact of urban GI on flood risk mitigation. We further examine the funding sources that have been used to finance urban GI developments.

There is a well-developed body of evidence around urban GI for stormwater management and pluvial flood mitigation. Several types of urban green infrastructure have demonstrated effectiveness in reducing stormwater runoff volume and intensity, supporting flood attenuation. Optimal design, however, is best pursued through integrated approaches with traditional stormwater solutions. The implementation and effectiveness of urban GI are also highly dependent on local conditions (e.g., space availability, topography, and soil geology), and to maximize the value of urban GI, it is important to prioritize relevant co-benefits.[46] While there are several other benefits derived from urban GIs, we focus on the flood mitigation benefits, which we establish as the key outcome of interest to insurers and many insured property owners.

Various types of urban GIs have been discussed in the literature with varying degrees of effectiveness at improving stormwater management. Both Gunnarsson et al. (2025)[47] and Mason et al. (2024)[48] provide a qualitative ranking of some of the more common urban GIs, with the rankings based on the potential contribution of each GI to a selected set of benefits. These rankings, along with other studies,

39 In some contexts, different references are also used (e.g., nature-based solutions, low impact development, blue-green infrastructure, and sustainable urban drainage systems – used in contexts that are specific to green infrastructure used to support stormwater management).

40 Benedict, M., and McMahon, E. (2006). Green infrastructure. Linking landscapes and communities. Island Press: Washington, DC.

41 Gunnarsson, M., and Barquet, K. (2025). Nature-based solutions in municipal stormwater management in Sweden. Costs, co-benefits, responsibilities, and policies. Stockholm Environment Institute

42 Ahiablame, Laurent M., Bernard A. Engel, and Indrajeet Chaubey. (2012). Effectiveness of low impact development practices: literature review and suggestions for future research. Water, Air, & Soil Pollution, 223, 4253-4273.

43 Gunnarsson, M., and Barquet, K. (2025). Nature-based solutions in municipal stormwater management in Sweden. Costs, co-benefits, responsibilities, and policies. Stockholm Environment Institute.

44 Green, D., O'Donnell, E., Johnson, M., Slater, L., Thorne, C., Zheng, S., Stirling, R., Chan, F. K., Li, L., & Boothroyd, R. J. (2021). Green infrastructure: The future of urban flood risk management? Wiley Interdisciplinary Reviews: Water, 8(6), e1560.

45 Schulte, I., Eggers, J., Nielsen, J., and Fuss, S. (2022). What influences the implementation of natural climate solutions? A systematic map and review of the evidence. Environmental Research Letters, 17(1), 013002.

46 Green, D., O'Donnell, E., Johnson, M., Slater, L., Thorne, C., Zheng, S., Stirling, R., Chan, F. K., Li, L., & Boothroyd, R. J. (2021). Green infrastructure: The future of urban flood risk management? Wiley Interdisciplinary Reviews: Water, 8(6), e1560.

47 Gunnarsson, M., and Barquet, K. (2025). Nature-based solutions in municipal stormwater management in Sweden. Costs, co-benefits, responsibilities, and policies. Stockholm Environment Institute.

48 Mason, D., Miller, R., Lakshman, A., Lu, H., Mikulska, A., Ross, K. (2024). Nature-based solutions. Evidence for hazard risk reduction and ecosystem services. Scaling up implementation and accelerating learning. Institute for Defense Analyses.

point to several common GIs (e.g., bioretention cells, green roofs, permeable pavement, and urban wetlands) that are highly effective at improving stormwater management and pluvial flood attenuation by improving runoff reduction (peak and volume), infiltration, evapotranspiration, and water quality.[49] The literature also indicates that various parameters impact the effectiveness of urban GIs, making it difficult to identify a single implementation that is superior, and combinations of suitable site-specific types provide optimal performance against storm events, given that different GI types may perform better under different storm conditions.[50] More importantly, optimal flood attenuation design is best achieved through hybrid traditional-GI implementations.[51] Despite the well-documented effectiveness of urban GIs, effectiveness does wane in the presence of extreme precipitation events, and operation and maintenance requirements may demand new technical capacities relative to traditional urban stormwater infrastructures.[52] What is most important from the literature, however, is that urban GIs have been demonstrated as effective implementations for flood attenuation. What is needed is the design of viable business models that can help scale up their implementation.

RESILIENCE INSURANCE COMPONENT 2: PERFORMANCE MEASUREMENT OF URBAN GREEN INFRASTRUCTURE

The primary performance metric used to measure the effectiveness of urban GI against flood risk mitigation is stormwater runoff volume. We propose using normalized insured losses (e.g., loss per dollar of insured value) within a specifically defined location as an indirect performance metric that follows from stormwater runoff volume and provides a suitable performance measure for insurers. Studies have used insurance claims data as a proxy for flood severity to map the relationship between urban rainfall incidence and intensity to flood incidence and severity on a municipal scale[53] and at the individual property level,[54] establishing precedence for statistically mapping flood hazard parameters to flood risk, which can be extended to evaluate the risk mitigation impact of urban GI.[55] Using insured losses as a performance metric is better aligned with insurers' perception of business value, whereas most prior studies have relied on metrics that are not easily translatable into the language of business value creation for insurers.[56]

49 Ahiablame, Laurent M., Bernard A. Engel, and Indrajeet Chaubey. (2012). Effectiveness of low impact development practices: literature review and suggestions for future research. Water, Air, & Soil Pollution, 223, 4253-4273.

50 Qin, H. P., Li, Z. X., & Fu, G. (2013). The effects of low impact development on urban flooding under different rainfall characteristics. Journal of environmental management, 129, 577-585.

51 Liao, Z. L., Zhang, G. Q., Wu, Z. H., He, Y., & Chen, H. (2015). Combined sewer overflow control with LID based on SWMM: an example in Shanghai, China. Water Science and Technology, 71(8), 1136-1142.

52 Gunnarsson, M., and Barquet, K. (2025). Nature-based solutions in municipal stormwater management in Sweden. Costs, co-benefits, responsibilities, and policies. Stockholm Environment Institute.

53 Sörensen, J., & Mobini, S. (2017). Pluvial, urban flood mechanisms and characteristics–assessment based on insurance claims. Journal of Hydrology, 555, 51-67; Torgersen, G., Bjerkholt, J. T., Kvaal, K., & Lindholm, O. G. (2015). Correlation between extreme rainfall and insurance claims due to urban flooding–case study Fredrikstad, Norway. Journal of Urban and Environmental Engineering, 9(2), 127-138.

54 Spekkers, M. H., Kok, M., Clemens, F. H. L. R., & Ten Veldhuis, J. A. E. (2013). A statistical analysis of insurance damage claims related to rainfall extremes. Hydrology and Earth System Sciences, 17(3), 913-922; Zhou, Q., Panduro, T. E., Thorsen, B. J., & Arnbjerg-Nielsen, K. (2013). Verification of flood damage modelling using insurance data. Water Science and Technology, 68(2), 425-432.

55 Sörensen, Johanna, and Tobias Emilsson. (2019). Evaluating flood risk reduction by urban blue-green infrastructure using insurance data. Journal of Water Resources Planning and Management, 145(2), 04018099.

56 Kelso, M. A., Stovall, A. E., Reguero, B. G., Franco, G., and Beck, M. W. (2024). Nature-based solutions and risk management: Recommendations for integrating nature into risk science and insurance. UCSC and USACE, Washington, D.C

RESILIENCE INSURANCE COMPONENT 3: FINANCING URBAN GREEN INFRASTRUCTURE

Although evidence supports the flood mitigation benefits of urban GI, implementation barriers remain. The literature identifies several key barriers (e.g., public awareness of the benefits of GI, expertise in designing, developing, and maintaining GIs, urban planning policies that lack GI integration, and funding sources)[57], and chief among them are financing barriers where public funding dominates.[58] A proposed approach to develop solutions for financing barriers is to identify and delineate the beneficiaries of urban GIs and design innovative financing mechanisms that derive financial value from these beneficiaries.[59] To formulate strategies that can reduce barriers to financing, there is a recognition that the role of specific categories of stakeholders (namely, corporations, insurers, real estate firms, and water utilities) needs to be examined more due to the high level of relevance these stakeholders may place on the co-benefits derived from urban nature-based solutions.[60] In this regard, two questions become relevant: (i) who pays for specific co-benefits, and (ii) how do they pay (that is, what is the financial mechanism to realize a revenue source from the specific co-benefit)?

For the former question, this report focuses on insurers and insured as beneficiaries. For the latter question, we propose value capture mechanisms that could be used to realize revenue sources from the risk reduction benefit of urban GIs.

RESILIENCE INSURANCE COMPONENT 4: DEVELOPING VALUE CAPTURE MECHANISMS

We put forward a framework that is informed by Toxopeus (2019)[61] and Mayor et al. (2021)[62] and is developed around an urban nature-based solution with a risk reduction business model. The archetype of this business model is intended to use upfront investments to reduce future financial costs associated with pluvial flood hazards (by increasing resilience to flooding). To develop a framework for this risk reduction business model, we define the value proposition, value delivery, and value capture as outlined in Mayor et al. (2021).

- **Value proposition:** what value will be delivered by the nature-based solution?
  - Flood risk mitigation
  - Reduction of insured losses (insurers)
  - Stabilization of premiums or mitigation of premium increases (insured)
  - Increase in property value (insured – property owner).
- **Value creation and delivery:** who is needed to create and deliver the value proposition?
  - Multiple stakeholders (e.g., municipality, insurers, contractors, funders, property owners).
- **Value capture:** how much will it cost to deliver the value proposition, and how will the product or service be financed?
  - The value capture mechanisms are outlined in subsequent sub-sections.

57 den Heijer, C., and Coppens, T. (2023). Paying for green: A scoping review of alternative financing models for nature-based solutions. Journal of Environmental Management, 337, 117754; Toxopeus, H., & Polzin, F. (2021). Reviewing financing barriers and strategies for urban nature-based solutions. Journal of Environmental Management, 289, 112371.

58 Biasin, A., Toxopeus, H., Pettenella, D., Polzin, F., & Masiero, M. (2024). Financing Urban Nature-Based Solutions (NBS): a literature review from funders' perspective. Nature-Based Solutions, 100195.

59 Biasin, A., Toxopeus, H., Pettenella, D., Polzin, F., & Masiero, M. (2024). Financing Urban Nature-Based Solutions (NBS): a literature review from funders' perspective. Nature-Based Solutions, 100195.

60 Biasin, A., Toxopeus, H., Pettenella, D., Polzin, F., & Masiero, M. (2024). Financing Urban Nature-Based Solutions (NBS): a literature review from funders' perspective. Nature-Based Solutions, 100195.

61 Toxopeus, H.S. (2019). Taking Action for Urban Nature: Business Model Catalogue, NATURVATION Guide.

62 Mayor, B., Toxopeus, H., McQuaid, S., Croci, E., Lucchitta, B., Reddy, S. E., Egusquiza, A., Altamirano, M. A., Trumbic, T., Tuerk, A., García, G., Feliu, E., Malandrino, C., Schante, J., Jensen, A., and López Gunn, E. (2021). State of the art and latest advances in exploring business models for nature-based solutions. Sustainability, 13(13), 7413.

Table 1 maps urban GI to suitable value capture mechanisms by traversing the service, the parameter that proxies delivery of the service, identifying the beneficiaries of the service and the financial benefit derived from the service, and defining a value capture mechanism that can be used to capture the financial value from the service.

Table 1. Mapping the Benefits of Urban Green Infrastructure to a Suitable Value Capture Mechanism

Natural Asset	Regulating Service	Parametrizing the Service	Beneficiaries	Financial Benefit	Value Capture
Urban Green Infrastructure Intervention	Flood regulation	Stormwater run-off reduction[63]	Property insurers	Reduction of insured losses	Pay for performance
			Property owners (insured)	Stabilization of insurance premiums	LIC (local improvement charge)
				Increase in property value	TIF (tax increment finance)

NATURAL ASSET

We focus on urban green infrastructure interventions, where there is a proven body of evidence that demonstrates effectiveness for pluvial flood mitigation.

REGULATING SERVICE

While we focus on the flood regulating benefit, several other benefits are derived from urban green infrastructure (e.g., water quality improvement, urban heat island reduction, carbon sequestration, among others). To fully realize the value of urban green infrastructure, the relevant beneficiaries need to be identified, and financing mechanisms are needed to capture the financial value attributed to these beneficiaries.[64] For our focus, we limit this arrangement to the flood mitigation beneficiaries.

PARAMETRIZING THE SERVICE

The primary performance metric used to measure flood mitigation benefit from urban green infrastructure has been stormwater runoff volume. This metric has also been used to define the outcome target in the design and issuance of EIBs to fund urban green infrastructure projects in several US cities. Table 2 lists four notable cases. In all four cases, the outcome beneficiary (payor) was a public entity, which was also the issuer of the EIB.

63 Stormwater runoff reduction leads to a reduction in flood risk, which for (i) property insurers, reduces insured losses, (ii) for property owners (insured), reduces insurance premiums and increases property prices. In other words, this is the metric that captures (parameterizes) the urban GI characteristic that will determine financial benefit (reduction of insured losses, premiums, or increases in property value).

64 Biasin, A., Toxopeus, H., Pettenella, D., Polzin, F., & Masiero, M. (2024). Financing Urban Nature-Based Solutions (NBS): a literature 2review from funders' perspective. Nature-Based Solutions, 100195.

Table 2. Performance Metrics Used to Measure Stormwater Run-Off Reduction in Four US Cities

Urban Green Infrastructure Outcome Parameter	Outcome Measurement	Outcome Payor
Stormwater run-off reduction	% reduction of stormwater runoff per average year per impervious acre.	District of Columbia Water and Sewer Authority.
	Gallons of stormwater volume storage capacity added.	City of Hampton.
	Gallons of stormwater captured by the green infrastructure improvements.	City of Atlanta Department of Watershed Management.
	Acres of green infrastructure development.[65]	Buffalo Sewer Authority.

In the subsection that follows we provide more details on the City of Atlanta's EIB design and use this to inform our own framework to capture the flood risk mitigation value of urban GI for insurers as beneficiaries.

CITY OF ATLANTA ENVIRONMENTAL IMPACT BOND[66]

The EIB issued by the City of Atlanta defined two performance tiers based on the volume of stormwater capture capacity of the GI intended for development and implementation. Table 3 outlines the EIB arrangement. The EIB was issued to investors at a below-market rate yield, and a performance payment would be paid by the City of Atlanta (Department of Watershed Management) to investors if the performance target was achieved.

Table 3. Performance Tiers Defined for the City of Atlanta Environmental Impact Bond

Performance	Baseline Performance	High Performance
Fixed Interest Rate	~3.55%	~3.55%
Performance Payment	0	$1 million
Yield	Below market rate	Above market rate

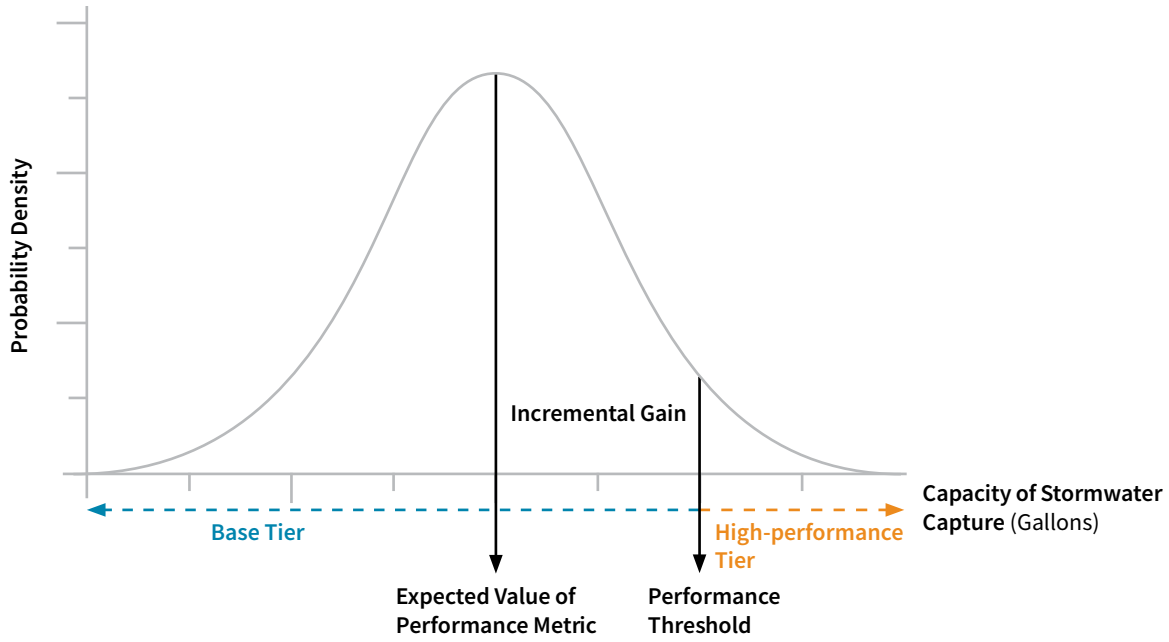
65 In the case of the Buffalo Sewer Authority, the performance metric was defined by amount (acres) of green infrastructure installed, which indirectly links to the volume of stormwater capture capacity.

66 Medori Hallauer, A., Behrend, G., Bell, D., Tyagi, A., & Cohen, B. (2019). Financing resilience in Atlanta using an environmental impact bond. In Innovations in stormwater capture. Alternative delivery, O&M scenarios & best management practices, multi-agency collaboration and workforce development. Southern California Water Coalition.

The performance payment was calculated so that the conditional yield (if performance payment is made) on the EIB is above the market rate. The issuing yield is below the market rate, which represents a sharing of risk with the investors (that is, the issuer pays a lower rate if the outcome is within the baseline performance tier), and the above-market rate yield shares the reward with the investors if the environmental outcome is in the high-performance tier. The premise of this arrangement rests on the understanding that a larger volume of stormwater capture brings improved benefits across the two major areas of responsibility for the beneficiary. These major benefits are flood mitigation (avoided losses related to flooding) and water quality improvement (avoided costs related to water treatment for the city). The performance payment can be viewed as sharing the financial value of these benefits with the investors in exchange for the investors' willingness to share the risk associated with underperformance.

To determine the performance tiers, a probability analysis was conducted to estimate the range of stormwater volume capacity (with associated probabilities) that could be achieved from the green infrastructure implementation. An economic model was also developed to quantify the economic benefits that would be derived from the GI implementation and the relationship between stormwater volume capture and these benefits. The economic model estimates financial values associated with flood risk reduction and water quality improvement, as well as other ancillary benefits derived from the green infrastructure implementation that may not link directly to stormwater volume capture capacity (e.g., air quality and urban heat mitigation). These ancillary benefits link to revenues and avoided costs for the City of Atlanta. The performance payment was then designed as a percentage of the increase in the incremental value over the value derived from the expected project outcome (see Figure 1).

Figure 1. Depiction of the City of Atlanta Environmental Impact Bond Performance Tiers



There are several notable points that arise from the City of Atlanta's EIB:

- Stormwater volume capture is used as a proxy for flood risk mitigation as opposed to a more direct metric such as insured losses.
- The benefits identified from the green infrastructure intervention focus on both flood risk mitigation and water quality improvement, and the economic value derived from the green infrastructure further extends to other ecosystem regulating services such as urban heat mitigation and air quality, which increases the estimated economic value of the implemented project.
- The beneficiary is the City of Atlanta, and other direct beneficiaries are omitted (insurers, property owners).

We consider adapting this EIB arrangement to use insured losses as a performance metric, which is associated with insurers as the beneficiary.

BENEFICIARIES

We identify insurers and insured (property owners) as beneficiaries, who we consider to have large risk exposure to urban flooding, and for whom we can conceptualize a reasonable value capture for the flood risk mitigation benefit derived from urban GIs.

FINANCIAL BENEFIT

The financial benefit derived for insurers and property owners from stormwater runoff reduction is defined to be insured loss reduction (reduction of average annual loss, which directly benefits insurers through lower claim payouts), premium cost reduction, and property value increase.

VALUE CAPTURE

We strive to design a value capture mechanism that connects each beneficiary of interest with the financial value being derived.

FOR INSURERS: PERFORMANCE PAYMENT USING ENVIRONMENTAL IMPACT BONDS

For insurers, the financial benefit is defined as a reduction in insured losses (e.g., average annual loss). Estimating the reduction derived from a GI intervention carries aleatoric uncertainties linked to flood risk and the accompanying losses (the intensity and duration of pluvial events being the most critical of these uncertainties). Using a performance-based payment mechanism, we can actualize this reduction for insurers using an EIB design based on the City of Atlanta's EIB arrangement.

We conceptualize an EIB with insured losses as the performance metric. This performance metric aligns the regulatory service of the GI intervention with the financial incentive desired by insurers. Underperformance is shared between the issuer and the investors. Like the City of Atlanta EIB, the issuer of the EIB would likely be a municipality, but the performance payor is an insurer (or group of insurers).

While the execution of EIBs can be technically and financially complex, involving multiple stakeholders, we argue that the mechanics of the instrument naturally lends itself to this value capture given the inherent need to actualize a performance outcome (determine the risk reduction value that actually occurs) and attribute this outcome to the benefiting stakeholder (the outcome payor).



PROPERTY OWNER AS BENEFICIARY: DEVELOPMENT VALUE CAPTURE MECHANISMS

Property owners benefit from lower flood risk and lower insurance costs. In the approaches proposed below, they would "pay back" the initial cost of green infrastructure over time, either through a small charge on their property taxes (LIC) or by sharing in the increase in property value (TIF). This makes the investment self-financing based on the value of the risk reduction the GI provides.

This subsection explores two options to recover the capital outlay allocated to urban GIs that reduce flood risk for property owners (insured). The use of each depends on the "revenue" (capital recovery) source. LIC is used if insurance premium reduction is the source of capital recovery. TIFs can be used if property value (increase) is the source of capital recovery. The use of TIFs stems from the understanding that property values can benefit greatly from risk reduction interventions and may be easier to assess as compared to insurance premium reductions.

FOR PROPERTY OWNERS: LOCAL IMPROVEMENT CHARGES (LIC)[67]

Local Improvement Charges (LICs) are a common capital recovery mechanism used by municipalities to help cover the costs of public infrastructure improvements that are intended to benefit specific neighbourhoods. The property owners in the benefiting neighbourhood are levied a charge, which is repaid over time through their property tax assessment. LICs have also been used as a financing mechanism to recover costs associated with financing energy efficiency retrofits for residential and commercial buildings. We consider LICs as a mechanism to recover the capital costs associated with urban GIs intended to reduce flood risk. The risk reduction is expected to reduce insured losses and premiums associated with insured losses for the property owners. This cost reduction is estimated and captured via the LIC assessment.

LIC provides a long-term repayment arrangement that stays with the properties that benefit (LIC repayment periods typically range from 5 to 15 years). The critical challenge for applying LIC in this context would be the difficulty associated with determining

67 Peters, R., Horne, M., & Heap, N. I. (2004). Using local improvement charges to finance building energy efficiency improvements: a concept report. Pembina Institute for Appropriate Development.

the assessment value that each property will pay if the assessment costs are based on the premium reduction or avoided losses provided by the GI intervention for each property.

In summary, property owners pay a charge proportional to the benefit they receive from the GI (as they would for any other service of benefit), which represents the economic value of the flood risk reduction.

FOR PROPERTY OWNERS: TAX INCREMENT FINANCE (TIF)[68]

Tax increment financing (TIF) is a mechanism used by municipalities to recover the capital costs associated with redeveloping economically depressed urban districts that would not be expected to attract development without government incentives.[69] TIF is designed on the premise that public infrastructure can generate private investment by reducing business costs that may be associated with relocation and expansion. These infrastructure costs can be levied on the businesses or residents who directly benefit.

The mechanism is designed around property tax value capture. The redevelopment being financed is expected to increase property taxes above their defined baseline value, and this value additionality is captured as project revenues. A common defining characteristic of a TIF design is that the district being redeveloped is considered blighted, which typically describes a deteriorated state of neighbourhood infrastructure.[70] We consider extending the blighted characteristic to include neighbourhoods exposed to high levels of flood risk, which can depress property values.[71]

The design of a TIF arrangement requires a municipality to designate an area as a TIF district. Once the TIF district is established, a baseline property valuation is assessed, and property taxes will be ordinarily levied on this baseline while the TIF district is active. All property tax levied on the valuation assessment above the baseline (the incremental assessed value) will accrue to the designated TIF authority. Using a TIF arrangement would replace the need to rely on insurance premium data to measure the financial impact of the urban GI intervention on property owners. The portion of the incremental property tax attributable to the TIF authority is used to recover the cost to implement the GI (along with other infrastructure costs that may have been incurred).

IMPLEMENTATION ARRANGEMENTS

A diverse range of cost-recovery arrangements have been used to realize revenues from resilient infrastructure financing. These cost-recovery mechanisms have typically centred on direct government payment approaches or user-fee approaches.[72] While there are cases to draw lessons from, revenue mechanisms to realize resilience dividends are at a nascent stage, especially where private sector financing is concerned. We examine several innovative financial arrangements that have been proposed to monetise resilience dividends and incentivise investments in urban green infrastructure,[73] and suggest an arrangement that may be suitable for the value capture mechanisms outlined earlier.

68 Haider, M., and Donaldson, L. (2016). Can Tax Increment Financing Support Transportation Infrastructure Investment? Institute on Municipal Finance and Governance, No. 25; Carroll, D. A. (2008). Tax increment financing and property value: An examination of business property using panel data. Urban Affairs Review, 43(4), 520-552.

69 TIF legislation is established in AB (The Community Revitalization Levy via the Municipal Act - 2005), MB (Community Revitalization and Tax Increment Finance Act - 2009), and ON (Tax Increment Finance Act - 2006). Notable TIF projects have also been implemented in AB.

70 Byrne, P. F. (2006). Determinants of property value growth for tax increment financing districts. Economic Development Quarterly, 20(4), 317-329.

71 Bin, O., and Polasky, S. (2004). Effects of flood hazards on property values: evidence before and after Hurricane Floyd. Land Economics, 80(4), 490-500; Bin, O., and Kruse, J. B. (2006). Real estate market response to coastal flood hazards. Natural Hazards Review, 7(4), 137-144.

72 The World Bank Group. (2025). Financing climate adaptation and nature-based infrastructure.

73 The World Bank Group. (2025). Financing climate adaptation and nature-based infrastructure. Lloyd's. (2018). Innovative finance for resilient infrastructure. www.lloyds.com/innovativefinance; www.climatefinancelab.org/ideas/climate-insurance-linked-resilient-infrastructure-financing-cilrif; www.climatefinancelab.org/ideas/restoration-insurance-service-company-risco.

INSURERS

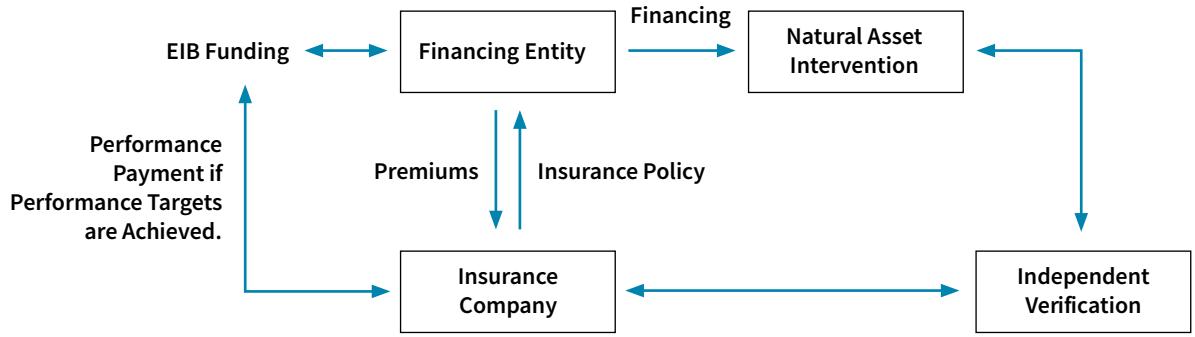
For insurers, we use an EIB with the insurer paying a performance fee for risk reduction based on realized avoided losses. If the intervention delivers risk reduction, investors get an increased return on investment, and a reduced return on investment if performance is not met. Figure 2 provides a generalized flow of funds diagram demonstrating the connection between the key components in this arrangement. The arrangement is designed on a community level, which is the scale that may support the most effective implementation of urban green infrastructure for flood risk mitigation.[74] Urban green infrastructure interventions are also optimal at community scales, where various GI facilities can be integrated and combined with traditional drainage systems to maximize performance.[75]

In Figure 2, funding is provided through the issuance of an EIB, likely issued by a municipal entity. Variants of this could include the use of project financing entities to issue the bond, insofar as a dedicated revenue stream is linked to the entity to service the bond payments. Technical assessments are performed to set baseline measurements and performance targets. Raised capital is used to deliver the green infrastructure intervention intended to mitigate flood risk. Ex-post cash payout is made for avoided losses after a disaster incident based on what would have been lost versus what was actually lost. If the natural asset intervention reduces actual losses below an established threshold, the insurer pays an avoided loss dividend.[76] In extreme hazard scenarios that exceed the GI system's capacity, no performance payment is paid by the insurer; instead, a parametric insurance policy can provide a hazard-triggered payout to the financing entity, ensuring the project remains financially stable.

PROPERTY OWNERS

For property owners, an arrangement is derived as in Lloyd's (2018)[77] based on the concept of performance contracting. Property owners are understood here as residential property owners, but the idea could be potentially extended to commercial or public property. The generalized flow of funds diagram is provided in Figure 3a. The arrangement involves upfront investment in urban green infrastructure that would reduce flood risk in return for a share of future insurance premium savings captured through local improvement charges. Figure 3b provides a flow of funds diagram under the TIF arrangement, which diverges from Lloyd's (2018) conceptualization. Performance contracting is not required since revenues are derived from the incremental value assessment received through the TIF authority. These arrangements can be applied to residential communities where there are many dispersed but similar assets (properties) that are all exposed to flood hazards.

Figure 2. Flow of Funds Diagram



74 Green, D., O'Donnell, E., Johnson, M., Slater, L., Thorne, C., Zheng, S., Stirling, R., Chan, F. K., Li, L., & Boothroyd, R. J. (2021). Green infrastructure: The future of urban flood risk management? Wiley Interdisciplinary Reviews: Water, 8(6), e1560; Munich Re and The Nature Conservancy. (2021). Nature's remedy: Improving flood resilience through community insurance and nature-based mitigation.

75 Liu, W., Chen, W., & Peng, C. (2014). Assessing the effectiveness of green infrastructures on urban flooding reduction: A community scale study. Ecological Modelling, 291, 6-14; Qin, H. P., Li, Z. X., & Fu, G. (2013). The effects of low impact development on urban flooding under different rainfall characteristics. Journal of environmental management, 129, 577-585.

76 The avoided loss dividend is linked to the performance target, which is verified by a third-party agent to preserve independence.

77 Lloyd's. (2018). Innovative finance for resilient infrastructure. www.lloyds.com/innovativefinance

Figure 3a. Flow of Funds Diagram (Generalized Arrangement for Property Owners)

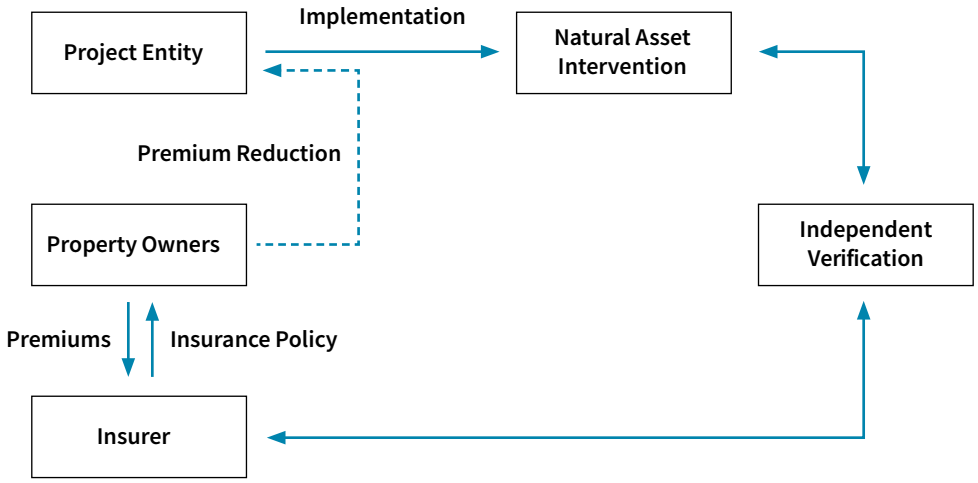
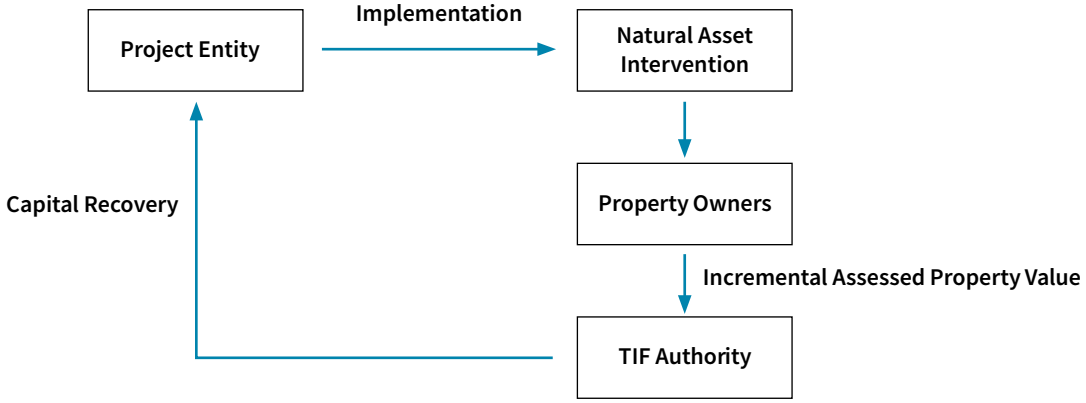


Figure 3b. Flow of Funds Diagram (TIF Arrangement)



There are important challenges to consider for these proposed arrangements.

- Risk reduction is contingent on hazard incidence and severity. Therefore, performance payments, in Figure 2, will be contingent on hazard impact. If no hazard occurs, no performance payment will be triggered.
  - This arrangement may be most suitable on a municipal scale and integrated with catastrophe risk financing.
  - Premium savings in Figure 3a will only accrue if the insurer explicitly recognises the risk reduction and attributes a lower premium. Premium pricing is complex and impacted by several factors (e.g., the risk being insured, the hazard zone, administrative costs, and existing market dynamics), which can all impact the realization of premium reduction post-GI intervention. When premium reduction materializes, the value also needs to be sufficient to satisfy reasonable benefit-cost requirements. TIF arrangements are also limited by existing legislation. These arrangements may be most suitable on a community scale, with low-cost interventions for short-return-period events (more frequent and less severe)



CONCLUSION AND PROPOSED NEXT STEPS

Natural assets play a vital role in mitigating disaster impacts by reducing impact severity and associated losses. This characteristic plays a critical role in reducing avoided losses, which may ultimately lower premiums, decrease claim frequency, and reduce insured and uninsured losses. This report outlines and discusses an approach to connect insurance companies and property owners, as key beneficiaries of this risk reduction benefit.

The report identifies insurers as one major stakeholder group that benefits from the flood mitigation feature of urban green infrastructure and proposes a performance-based financing arrangement using an EIB, with the insurer as the performance payor and insured losses as the performance metric. We conceptualize this EIB based on a previous issue from the City of Atlanta Department of Watershed Management, with the distinct difference between the performance payor and performance metrics.

The EIB demonstrates an innovative approach that can be used to finance impact-based, resilient projects that may struggle to acquire funding using traditional financial instruments. Beyond its financing potential, this approach also provides a mechanism to address the current evidence gap needed to demonstrate to insurers that natural assets can measurably reduce insured losses. Because the EIB model allows insurers to make payments ex post—and only when performance is verified—it both safeguards their financial exposure and generates real-world data on the effectiveness of natural asset interventions. Performance-based financing may therefore improve the efficacy associated with funding allocation for resilience projects while simultaneously opening access to investors seeking to align their financial returns with environmental impact, transferring the risk associated with delivering specific outcomes to investors. This can be useful when the delivery of outcomes is uncertain, and investors have a good ability to influence the outcome.[78] Any pilot initiative to test this concept would need to account for the province-specific framework governing municipal bond issuance.

We also identify property owners as the other major stakeholder group that benefits from the flood mitigation feature of urban GI. Choosing the property owner as the beneficiary allowed for the application of two common value capture mechanisms: local improvement charges and tax increment finance. We acknowledge the omission of renters who benefit from flood mitigation, and we also acknowledge that

78 Hall, D. (2017). Greening the future: a case for environmental impact bonds. Policy Quarterly, 13(2), 41-48.

property owners will include uninsured properties. It is also important to recognize the omitted benefits that may be delivered by an urban GI intervention when we limit focus to just flood mitigation (for property owners, this may be a green neighbourhood value premium on their property value, among other benefits).

Insurance is used to transfer portions of risks associated with future losses into more manageable periodic insurance premium payments. If the risk of future loss is reduced using resilience measures, then the periodic premium payments should also fall. This allows insurance to be used as a mechanism to monetise risk reduction benefits. By designing mechanisms around insurance premiums and insurable losses, the risk reduction benefit of urban green infrastructure can be monetised against urban flood risk.

Looking ahead, the challenge is to pilot one or more of these concepts in a Canadian context, to evaluate the results, and as warranted, to scale to additional sites. Pilots could be structured in different ways. Namely, a physical pilot could be developed to collect data showing that, for example, without a GI intervention, precipitation, damage and losses would be higher. A second pilot could test the EIB concept and or the LIC and TIF concepts. A third could involve the actual insurance of a natural asset. Any such project would require partner local governments, insurers, and funding sources. Exploring these implementation options represent the next phase of this work.



ANNEX 1: IISAG MEMBERS AND OBSERVERS

MEMBERS

Name	Organization
Huma Padani	Toronto Dominion Insurance
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Brianne Kelly	World Wildlife Fund Canada

OBSERVERS

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Thea Silver	Royal Bank of Canada
Peter Urbanc	Municipal Finance Authority of BC
Verena Kraus	UNEP Financial Initiative
Vincent Loiselle	Infrastructure Canada





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