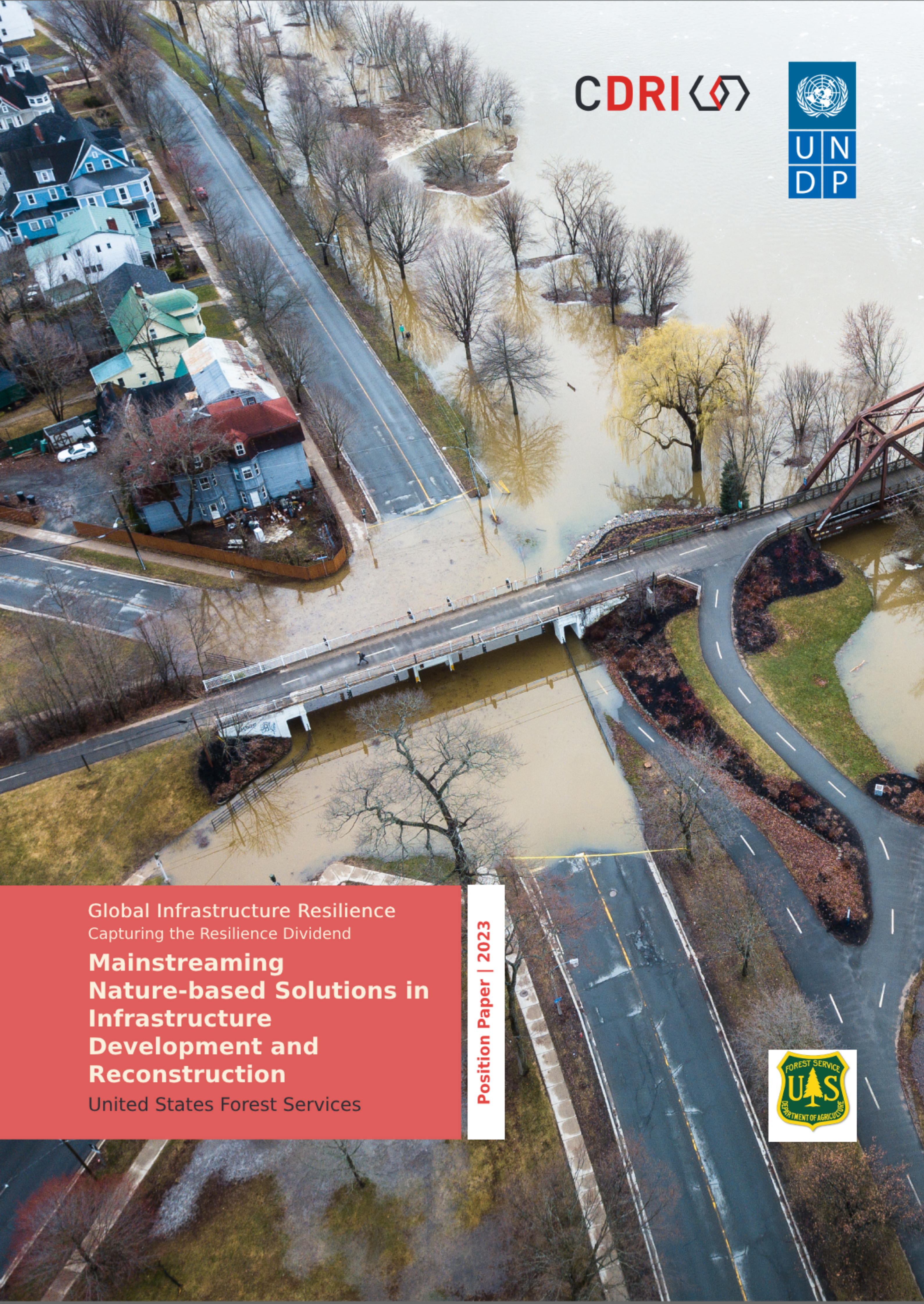

Global Infrastructure Resilience

Capturing the Resilience Dividend

Mainstreaming Nature-based Solutions in Infrastructure Development and Reconstruction

United States Forest Services

Position Paper | 2023

Pillar 3: Nature-based Solutions for Climate and Disaster-Resilient Infrastructure

Mainstreaming Nature-based Solutions in Infrastructure Development and Reconstruction

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INTRODUCTION

Resilient Infrastructure is Needed

Resilient infrastructure systems (Figure 1) are the keystones of functioning societies and are fundamental to human health and well-being. Interruption of these services frequently results in suffering, economic loss, sickness, and death. According to the World Bank, up to 70 percent of infrastructure disruptions are disaster-related, depending on the sector and region.[1] Disaster and climate risks have cumulative and compounding effects on already vulnerable and strained infrastructure systems and on the ability of countries to effectively address their vulnerabilities.[2]

The social and economic costs of disasters to infrastructure systems are significant. In 2021, natural disasters caused $252 billion USD in damage.[3] This figure only includes large and medium-scale disasters, underestimating the true costs of disasters. Evidence from national disaster databases highlights that small-scale, localized events are responsible for most of the damage to infrastructure systems[4]. Small-scale disasters often impact the poorest and most vulnerable who are least able to recover.[5]

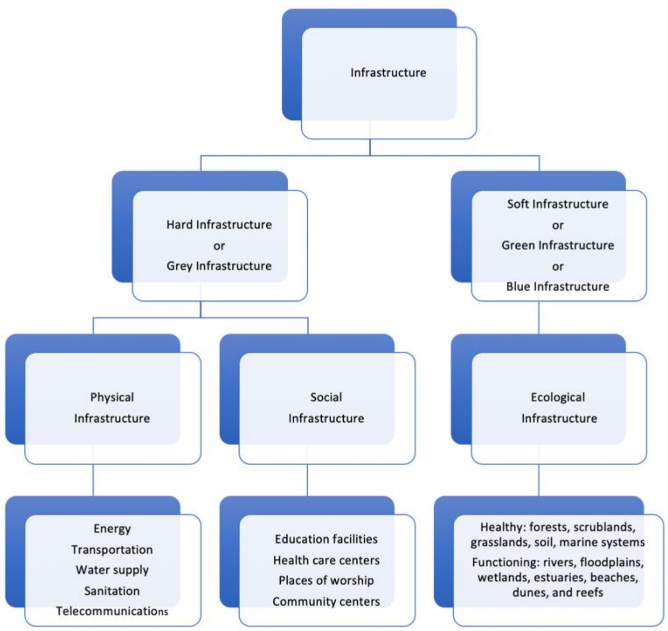

Figure : Infrastructure includes both hard or grey infrastructure that sustains our physical, social and spiritual needs as well as soft, blue, nature-based, or green infrastructure that integrate the ecosystems that sustain life on earth.

Due to rapid climate change, the intensity and frequency of extreme storms, floods, droughts, heat waves, landslides, erosion, and wildfire events are increasing. The impacts are widespread, affecting all places, people, and sectors. Many cities and communities are located adjacent to rivers or in coastal areas directly exposing infrastructure to storm surges, flooding, sea level rise, erosion, and wind hazards.[6]

Two-thirds of humanity is expected to live in urban environments by 2050, and 60% of the infrastructure to support them has yet to be built.[7] There is an unprecedented opportunity to build disaster-resilient infrastructure. Unfortunately, addressing disaster and climate vulnerability is not systematically considered in the priority setting, conceptualization, planning, design, construction, regulation, management,

[1] (Hallegatte et al., 2019)
[2] (Lustgarten, 2022)
[3] (CRED, 2022)
[4] (Nationen, 2015)
[5] (Hallegatte et al., 2020)
[6] (Thacker et al., 2021)
[7] (Deutz, 2017)

and financing of most infrastructure, particularly in low- and middle-income countries. The global trend has been toward increased risk-taking. Between 1970 and 2010, the world population increased by 87%, the population living on floodplains increased by 114%, and the population in multi-hazard coastal areas increased by 192%.[8] Rapid urban expansion has pushed the most vulnerable populations and infrastructure into areas with higher hazards, greater environmental degradation, and a lack of critical infrastructure. Often economic or political motivations for rapid expansion overshadow considerations of the risk of future damage and losses.

Figure 2: Gully erosion and loss of infrastructure from a powerful El Niño rainfall event, Lima, Peru 2022

The Global Commission on Economy and Climate estimated that USD $90 trillion of new and upgraded infrastructure investments in cities, energy, and land use systems will be required globally between 2015 and 2030.[9] Infrastructure system maintenance and protection are forecast to account for 88% of all global climate change adaptation costs, with water supply, treatment, and flood protection systems accounting for 54% of total projected costs.[10] To ensure the resilience of these global investments, rethinking infrastructure development is needed to promote practices that concurrently protect infrastructure, adapt to climate change, promote environmental integrity and biodiversity, and provide for social well-being.

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[8] (United Nations Office for Disaster Risk Reduction, 2013)

[9] (Rydge et al., 2015)

[10] (Thacker et al., 2021)

The Ecosystems that Economies and Livelihoods Depend on are in Decline

Healthy ecosystems sustain life on the planet and provide for ecological integrity, biodiversity, economic systems, and human well-being. Healthy ecosystems provide:[11]

Supporting services –e.g., nutrient cycling, soil formation, primary production
Provisioning services – e.g., food, water, wood, fibre, fuel
Regulating services – e.g., flood control, climate regulation, disease control, and water purification
Cultural Services – e.g., education, recreation, aesthetics, spiritual values

When ecosystems are degraded, they lose their ability to perform these critical functions. As of 2021, over a million species are under threat of extinction, 75% of the land surface area is significantly altered, 85% of wetlands are lost, and over half the world's corals are gone.[12] Degradation of ecosystems is limiting the ability of the earth to function, sustain ecosystems, and provide for the ecosystem services people have come to value and depend on (**see Annex 1 Case Study #1 Building resilient communities and wetland ecosystems in Uganda**). Ecosystem degradation, compounded by changes in warming and climate intensification, and increasing population results in increased risks to infrastructure.

The pace and scale at which we have impacted our environment over the last 100 years is unprecedented and could be matched by an even greater pace of protection and restoration. The IPCC states that "Maintaining the resilience of biodiversity and ecosystem services at a global scale depends on effective and equitable conservation of approximately 30% to 50% of the Earth's land, freshwater and ocean areas, including currently near-natural ecosystems *(high confidence)*." The idea of protection and restoration is embedded in the concept of nature-based solutions where intact ecosystems buffer the impacts to infrastructure.

Figure 3: Mangrove forests and other coastal wetlands protect against wave action, storm surge, tsunamis, sea level rise, coastal erosion, and extreme winds. Biodiversity and carbon sequestration are greatly enhanced. Maintaining and restoring these ecosystems increases infrastructure resilience.

[11] (Millennium Ecosystem Assessment, 2005)

[12] (IPBES, 2019)

Nature-based Solutions Add Value

With many countries needing to make large investments in infrastructure, there is an opportunity to shift the paradigm of infrastructure delivery towards designing and building with nature. Integrating ecosystem function, protection, and restoration into built systems with nature-based solutions creates climate- and disaster-resilient infrastructure - a win-win for the environment and society.

Nature-Based Solutions

"…actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems, which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services, and resilience and biodiversity benefits."[13]

Evolution of the Nature-Based Solution Concept

Over time, the concept of ecosystem services – what nature could provide for people – evolved into the concept of nature-based solutions. This evolution introduced a shift in perspective that nature is not only providing services for people, but also that people have a responsibility to protect nature so that the environmental integrity and biodiversity are maintained while providing societal benefits (Cohen-Stracham et. al. 2016, World Bank, 2006). Nature-based solutions encompass the idea that humans should work with nature, not against it, to create sustainable and resilient economies (Sowinska-Swierkosz and Garcia, 2022).

More recently, conservation groups and land management agencies are employing conservation practices intended to protect the environment. These practices are known by various names including ecological forest management; soil and water conservation; urban forestry; watershed management, and so on. As whole-systems thinking prevailed over single-species or single-resource management, terms like ecosystem-based management, forest landscape restoration; ecological restoration; bioengineering; protected area management; watershed health, and ecosystem-based adaptation have been used. Nature-based solutions can be thought of as an umbrella concept that encompasses all these terms (Wadhawan et. al, in press).

Many countries have recognized the need to ensure that the ecosystem services and the biodiversity that functioning ecosystems provide are protected as infrastructure development proceeds.[14] Different terms are used to describe these approaches including Green Infrastructure (EU), Green Growth (Viet Nam), Low-impact development (USA), Water-sensitive urban design (Australia), Natural Infrastructure (Peru), Ecosystem-based Adaptation (India) and so on.

The clear connection between the natural environment and the built environment is what distinguishes nature-based solutions from other natural resource conservation and land management practices such as landscape restoration and ecosystem management.[15] Well-designed nature-based solutions will protect, maintain or recover natural processes and ecosystem services, promote social well-being, and promote

[13] (UN Environment Programme, 2022c)

[14] (Millennium Ecosystem Assessment, 2005)

[15] (FEMA, 2021)

biodiversity for long-term ecological health.[16] These same solutions will also be instrumental in reducing the risks and costs associated with infrastructure loss and damage.

As we look to mainstream nature-based solution concepts and actions, it is important and helpful to have a set of criteria to form the basis of a necessary standard. Criteria developed by IUCN[17] serve that purpose.

1. **Nature-based solutions effectively address the societal challenges of climate change mitigation and adaptation, disaster risk reduction, economic and social development, human health, food and water security, and environmental degradation and biodiversity loss.**
2. **Design of nature-based solutions is informed by scale.**
3. **Nature-based solutions result in a net gain in biodiversity and ecosystem integrity.**
4. **Nature-based solutions are economically viable.**
5. **Nature-based solutions are based on inclusive, transparent, and empowering governance processes.**
6. **Nature-based solutions equitably balance trade-offs between the achievement of their primary goal(s) and the continued provision of multiple benefits.**
7. **Nature-based solutions are managed adaptively, based on evidence.**
8. **Nature-based solutions are sustainable and mainstreamed with an appropriate jurisdictional context.**

With this definition and criteria in mind, this chapter will focus on the interaction between nature-based solutions, and physical, social, and ecological infrastructure. This determines how nature-based solutions can be used to *complement, substitute or safeguard* traditional 'grey' infrastructure[5] and meet the IUCN criteria. Clarifying these terms, examples of nature-based solutions that complement grey infrastructure would be protecting or restoring watersheds (ecological infrastructure) that feed water supply reservoirs to regulate hydrologic processes and protect water quality. Nature-based solutions that could substitute for grey infrastructure might include deep-rooted vegetation that provides slope stability, thus eliminating the need for retaining walls or sea walls. An example of a nature-based solution that safeguards traditional grey infrastructure would be mangrove forests that protect shorelines from erosion, thus safeguarding nearby roads, buildings, and utilities from wave damage during storms. In many cases, over time, the effectiveness of grey infrastructure degrades as the effectiveness of nature-based solutions increases.

Currently, only 0.3% of investment dollars support nature-based solutions[18]. One study found that nature-based solutions cost 51% of grey infrastructure projects and 11% of all grey infrastructure could be replaced by nature-based solutions (ranging from 5% in the energy sector to 50% in the water sector). [19] In addition, nature-based solutions add more value to people and nature than grey infrastructure. A transition to funding nature-based solutions for infrastructure resilience could create an estimated 59 million jobs by 2030, with over half of those being livelihood-enhancing jobs that are directly related to ecosystem protection and restoration.[20]

UNEP and the University of Oxford conducted an assessment to determine how nature-based solutions, or "nature-based infrastructure," can help meet Sustainable Development Goals and achieve the goals of the Paris Agreement through mitigation and adaptation pathways. [21] Their findings suggest that nature-based

[16] (Bassi et al., 2021)

[17] (International Union for Conservation of Nature, 2020)

[18] (World Economic Forum, 2022)

[19] (Bassi et al., 2021)

[20] (World Economic Forum, 2022)

[21] (UN Environment Programme, 2022b)

solutions for infrastructure resilience can influence 115 of the 169 targets across all 17 Sustainable Development Goals. Nature-based solutions that enhance engineered infrastructure functions have the greatest ability to help attain SDG targets, followed by those that directly deliver infrastructure services, benefit the workforce, and protect engineered assets (see box for functional categories). Nature-based solutions have the potential to benefit most infrastructure sectors in myriad ways. They typically provide the greatest services to water-related infrastructure, due to the importance of functional ecosystems for water capture, storage, filtration, and transmission.

These findings suggest that incorporating nature-based solutions into infrastructure projects improves the chances of achieving the goals of the UNFCCC Paris Agreement. Nature-based solutions help decarbonize beyond carbon sequestration by reducing emissions across infrastructure lifecycles, avoiding land-use change, and extending infrastructure lifespans. Although all five functional categories contribute to strengthening infrastructure resilience and reducing vulnerability to climate change as committed to in the Paris Agreement, nature-based solutions' **protective** functions were found to be dominant.[22] These research results highlight the need and huge potential for including nature-based solutions in infrastructure development and retrofits to improve environmental integrity and social justice issues as measured by attaining the SDGs and the Paris Agreement goals.

Five functional categories of Nature-based Solutions with examples of each
(UN Environmental Programme, 2022b)

Deliver infrastructure services directly – wetlands deliver filtration functions

Enhance engineered infrastructure function – riparian forests reduce reservoir sedimentation

Protect engineered assets – agroforestry on hillslopes protects roads from landslides

Benefit the workforce – access to nature increases calmness and mental well-being, increasing productivity and reducing absences

Deliver a range of social, environmental, and economic co-benefits – building wetlands or planting orchards or wildflower meadows under transmission lines restricts tree growth and reduces the need for mechanical and chemical maintenance while improving carbon sequestration, biodiversity, enhanced tourism and liveability, new employment opportunities, and enhanced food security.

Nature-based Solutions Have Limits

Although nature-based solutions provide multiple values, there are limitations. They typically take longer to manifest benefits than grey infrastructure. Many solutions to ongoing environmental hazards require immediate response to protect infrastructure, societies, and economies. For example, grey infrastructure, such as a seawall, could be constructed immediately to deflect storm surges while mangroves could be established to complement the grey infrastructure.

Designing appropriate nature-based solutions requires different knowledge and skills than infrastructure engineers and architects typically have. Analysing the impact of the infrastructure on the environment, particularly through the lens of climate change, requires multiple natural resource specialists. Designing rain gardens or wetland features into urban infrastructure requires new skills and thought processes than simply connecting surface runoff to a storm drainage system. On a larger scale, when it is necessary to

[22] (UN Environment Programme, 2022b)

consider the condition of the upper watershed, for example, if there are flooding or fire concerns to infrastructure, developers and urban planners can work with a variety of diverse partners including private and public landowners to accomplish restoration objectives. Pilot projects that use innovative financing to accelerate the pace and scale of nature-based solutions might be initially expensive but transaction costs are reduced as investors and implementers become more comfortable with the projects.[23]

A fundamental priority is always the protection of healthy, functioning ecosystems. Restoring an ecosystem is more difficult and expensive than effective protection. High-priority areas for protection or restoration may not always be available or will require time for negotiations to proceed. This is especially true in cities where green space is limited. Meeting all environmental regulations, including completing environmental impact assessments, and acquiring permits needed to implement the restoration projects takes time and commitment. As with the pilot projects mentioned above, initial projects are always more time-consuming than subsequent projects if the first one is successful.

Purpose of This Chapter

Faced with the multifaceted challenge of strengthening disaster and climate resilience, transitioning to carbon neutrality and drawdown, and protecting the functioning ecosystems of the earth. Nature-based solutions offer multiple advantages that complement conventional "*grey only*" infrastructure.[24] The transition from basic research and development and pilot projects to widespread adoption of nature-based solutions concepts and practices needs to be facilitated and incentivized. A sense of urgency, the means to operationalize nature-based solutions as a core component of infrastructure planning and design, and the ability to implement projects at a pace and scale commensurate with the scale of the problems are currently lacking in many places.

The content of this chapter is applicable to a broad audience – all levels of government, engineers, disaster specialists, land-use planners, natural resource managers, educators, community leaders, natural scientists, and financiers.

[23] (Blue Forest Conservation, n.d.)
[24] (Chaeri Kim & Alison Shaw, In press)

NATURE-BASED SOLUTIONS ADDRESS ENVIRONMENTAL HAZARDS AND ENHANCE RESILIENCE

In this section, we introduce hazards to infrastructure (Figure 1). The following graphics suggest some of the types of nature-based solutions that can make infrastructure more resilient.[25] We present some of the resulting social, economic, and environmental outcomes that can be attained with the implementation of nature-based solutions in infrastructure development.[26]

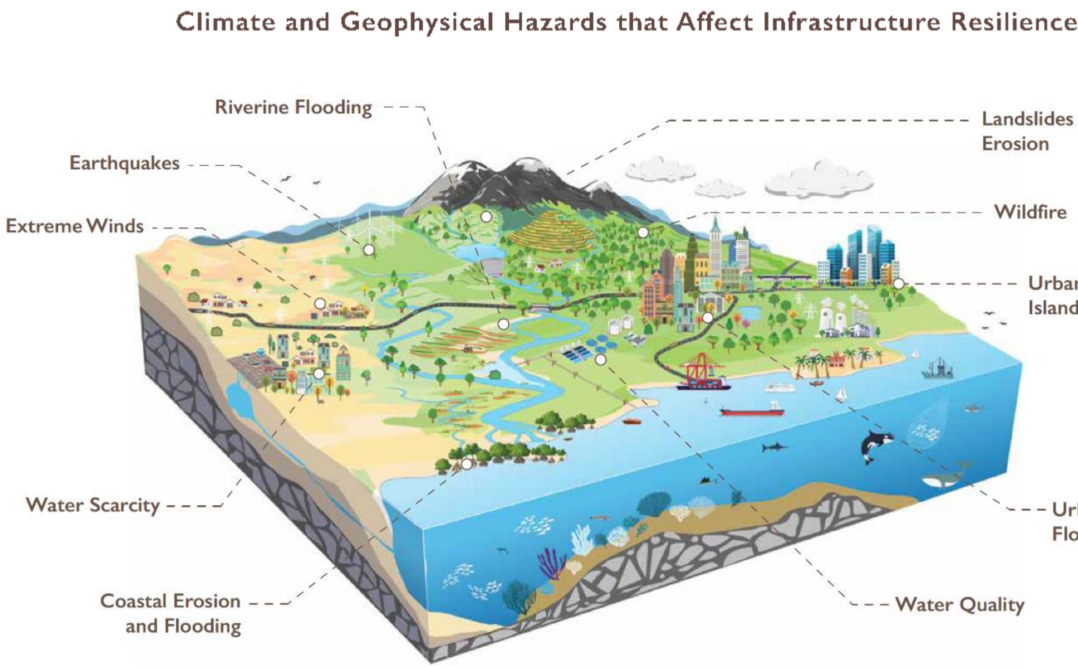

Figure 4:Climate-related hazards resulting from extremes in precipitation, wind velocities, and temperatures account for more than 91% of all internationally reported disasters (United Nations 2015b). Impacts include floods, droughts, heatwaves, wildfire and wind damage. Geophysical disasters (earthquakes, mass movement, and volcanoes) are responsible for the remaining 9%. Floods are responsible for most natural disasters at 43% with storms and associated extreme winds the second-most impactful disaster at 28% of reported disasters.

[25] (Center for Neighborhood Technology, 2011)
[26] (CRED, 2022)

Figure :Of all weather-related hazards, flooding affects the most people, with an annual average of 82.7 million people per year. Flooding disproportionately affects low-income countries (up to 5% of GDP) and the impacts are felt more long-term, while absolute costs are higher in richer countries. In the past 40 years, the occurrence of annual flooding damage more than doubled (Arnell and Gosling. 2016). As populations grow and more people, infrastructure, and cropland are placed in areas prone to flooding, greater disasters will occur (Winsemius et al. 2016). Employing nature-based solutions to avoid vulnerable areas and protecting and restoring watershed conditions will mitigate anticipated losses of life and economic opportunities.

Example - Mississippi River, USA   https://www.pbs.org/wgbh/nova/flood/deluge.html

Increased risk from grey-only Infrastructure	Reduced risk with nature-based solutions
the US Army Corp of Engineers tried to control the floods of the Mississippi River with the longest system of levees in the world. Millions of people moved on to the floodplain and wetlands bordering the river were drained for agriculture and construction. Today the Mississippi has over 1600 miles of levees and water control infrastructure. During the flood of 1993, 80% of private earthen levees failed. Most federal levees held but sent torrents of water towards less protected fields and towns inundating 8 million ha., and causing $15-20 billion USD in damage.	Originally the waters of the Mississippi spread over thousands of square miles of lowlands. Unlike cultivated farmland and paved cities and towns, wetlands and bayous are high in organic soils that absorb water and slow flood flows reducing damages. People living in the lowland bayous had traditionally built to withstand periodic flooding. Efforts are underway to restore bottomland hardwood forests and associated wetlands to reduce flood flows. $28 million USD has been invested.

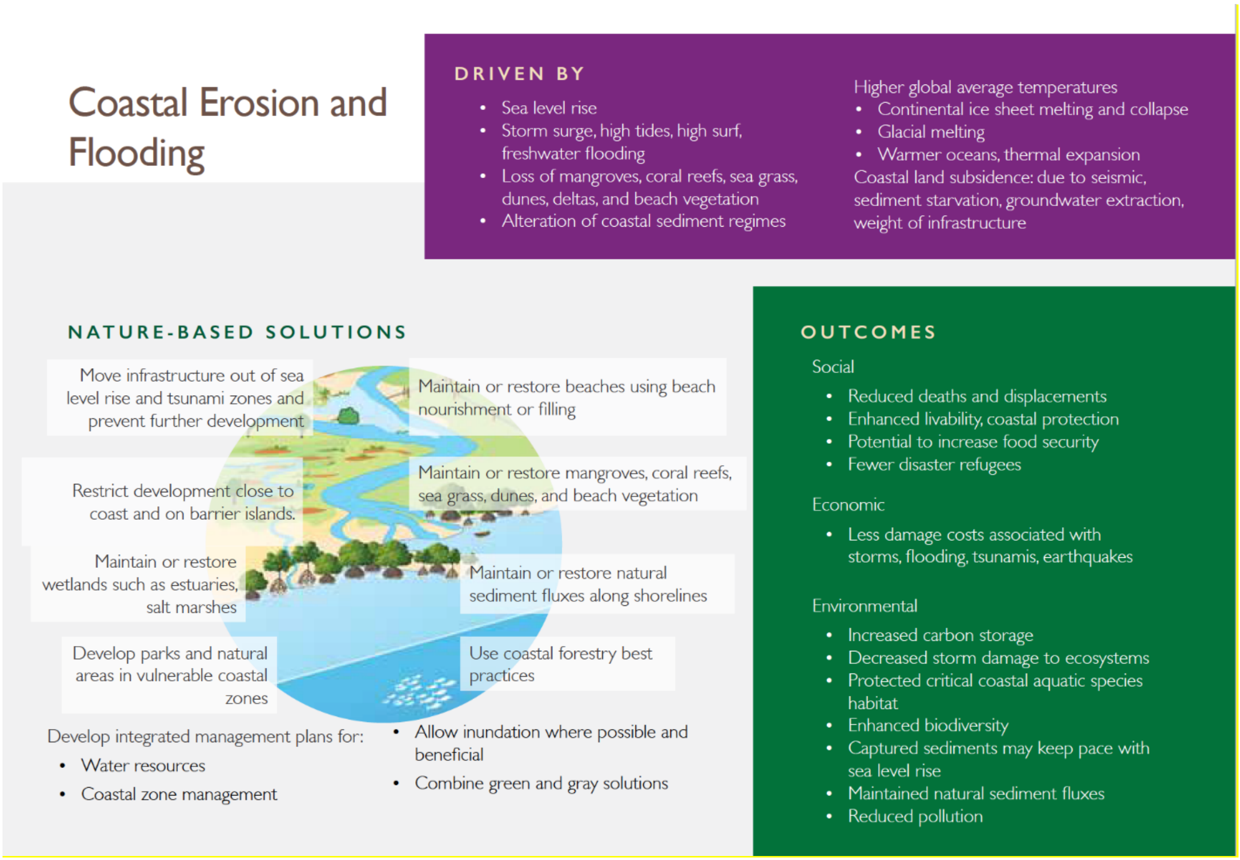

Figure 6: Coastal lands are particularly subject to flooding due to their proximity to the ocean and river mouths and deltas. Sea Level rise, in many places compounded by rapid land subsidence, is resulting in increasingly severe episodic flooding, inundation, erosion, and salinization. Recent modelling of extreme coastal flooding (Kirezci et al., 2020) projects that by 2100, 176-287 million people will be exposed to sea level rise and episodic flooding affecting $8 to $14.2 billion in assets or up to 20% of GDP. Critical infrastructure is at risk including housing, roads, railways, ports, military installations, water and sanitation systems, parks, communication networks, and nuclear power plants.

Quintana Roo, Mexico: https://www.nature.org/en-us/what-we-do/our-insights/perspectives/insuring-nature-to-ensure-a-resilient-future/

Increased risk from grey-only Infrastructure	Reduced risk with nature-based solutions
In 2005, two hurricanes hit Mexico's Caribbean coast causing $8 billion USD in damages and closing hotels and other businesses due to beach erosion and undermining of infrastructure. Coastal development impacts coral reefs ability to protect coastal communities because of pollution, trampling, disease and overfishing. Where coral reefs were damaged or removed, waves reached the 3rd story windows of some resorts. 98% of lodging and resorts were damaged and there was $4.8 billion USD in damages.	Coastal communities receive natural protection from coral reefs, beaches, wetlands, mangrove forests and dunes. A healthy coral reef can reduce up to 97% of wave energy before it hits the shore thereby reducing wave energy, storm surge, tsunami energy, and coastal erosion. The Nature Conservancy and the State of Quintana Roo 's National Parks Division have worked to restore coral reefs and established an insurance policy that funds coral restoration by trained community members when winds reach 100 knots. Hotel and business owners pay into the fund for their protection.

Figure 7: : In 2019, urban floods caused $45.9 billion USD in financial losses and nearly 4,500 deaths worldwide (World Resources Institute,2020). The Water Resources Institute model predicts that by 2030, without interventions, 147 million people and $712 billion USD in urban property damage will occur annually from flooding. Urban flooding is driven by proximity to rivers and coastlines, impermeable surfaces, and compacted areas that shed water rapidly, not allowing for slow infiltration and groundwater replenishment. Many solutions, such as rainwater capture, roof gardens, bio-swales, permeable pavement, urban trees, greenspaces for infiltration, and sound watershed management can effectively reduce flooding and flood-related damage.

Example – Kinshasa, Democratic Republic of Congo, Africa
https://www.tfrain.org/learn-more-urban-erosion-flooding-1

Increased risk from grey-only Infrastructure	Reduced risk with nature-based solutions
Runoff of precipitation from metal roofs, compacted areas, sidewalks, and roads result in urban flooding and intense gulley erosion which threatens powerlines, housing, roads, and businesses. Head-cut stabilization with hardened surfaces treats only the symptoms, not the cause of gulleying. Low-tech stabilization of head-cut filling with refuse is ineffective and pollutes crucial groundwater supplies.	Natural ecosystems (grasslands, forests, and shrubland) left undisturbed, allow for infiltration of nearly all precipitation. Installation of rain gutters and rainwater catchment systems enhance water security, can be used to irrigate permaculture gardens, reduce runoff and remove the cause of gulley formation while improving health and providing economic opportunities.

Figure 8: Population exposure to heat is increasing due to climate change. Globally, extreme temperature events are observed to be increasing in frequency, duration, and magnitude. Between 2000 and 2016, the number of people exposed to heatwaves increased by around 125 million. Currently, 56% of the global population lives in urban areas. By 2050, 7 out of 10 people will live in cities (World Bank, 2022). Concrete, pavement, tin roofs, and other hard and dark structures absorb and transmit infrared radiation more than natural landscapes resulting in urban heat islands. Heat islands experience average daytime temperatures of 0.5-4ºC (1-7ºF) and night-time temperatures 1-3ºC (2-5ºF) higher than surrounding areas with maximum night-time temperature increases recorded at 12ºC (22ºF) (US EPA, 2014). The European heat wave of 2003 is estimated to have caused the deaths of 70,000 people (Tong et al., 2021). The potential impact on mortality and the greater demand for energy resources to cool buildings will increase stress on both vulnerable communities and global energy supplies. The livelihoods and well-being of non-urban communities can also be severely disrupted during and after periods of unusually hot weather. For example, food and livelihood security may be strained if people lose their crops or livestock due to extreme heat.

Example – Delhi, India

https://news.abplive.com/explainers/explained-nasa-detects-heat-islands-around-delhi-amid-extreme-heatwave-know-what-it-is-all-about-1532079
https://www.thehindu.com/sci-tech/science/urban-heat-islands-in-india/article30830560.ece

Increased risk from grey-only Infrastructure	Reduced risk with nature-based solutions
According to NASA on May 5, 2022, nighttime temperatures in Delhi were 35-39°C (95-102°F). Urban heat islands result from construction materials including concrete, blacktop, street, urban geometry, heat generated from machinery, exhaust, and so on.	At the same time, rural agricultural land nearby Delhi cooled to around 15°C (60°F). Trees, vegetation and water bodies tend to cool the air by providing shade, transpiration and evaporation. The lack of trees in inner-city areas where poorer populations tend to live are often hotter than neighboring areas with more affluent neighbors and tree-lined streets.

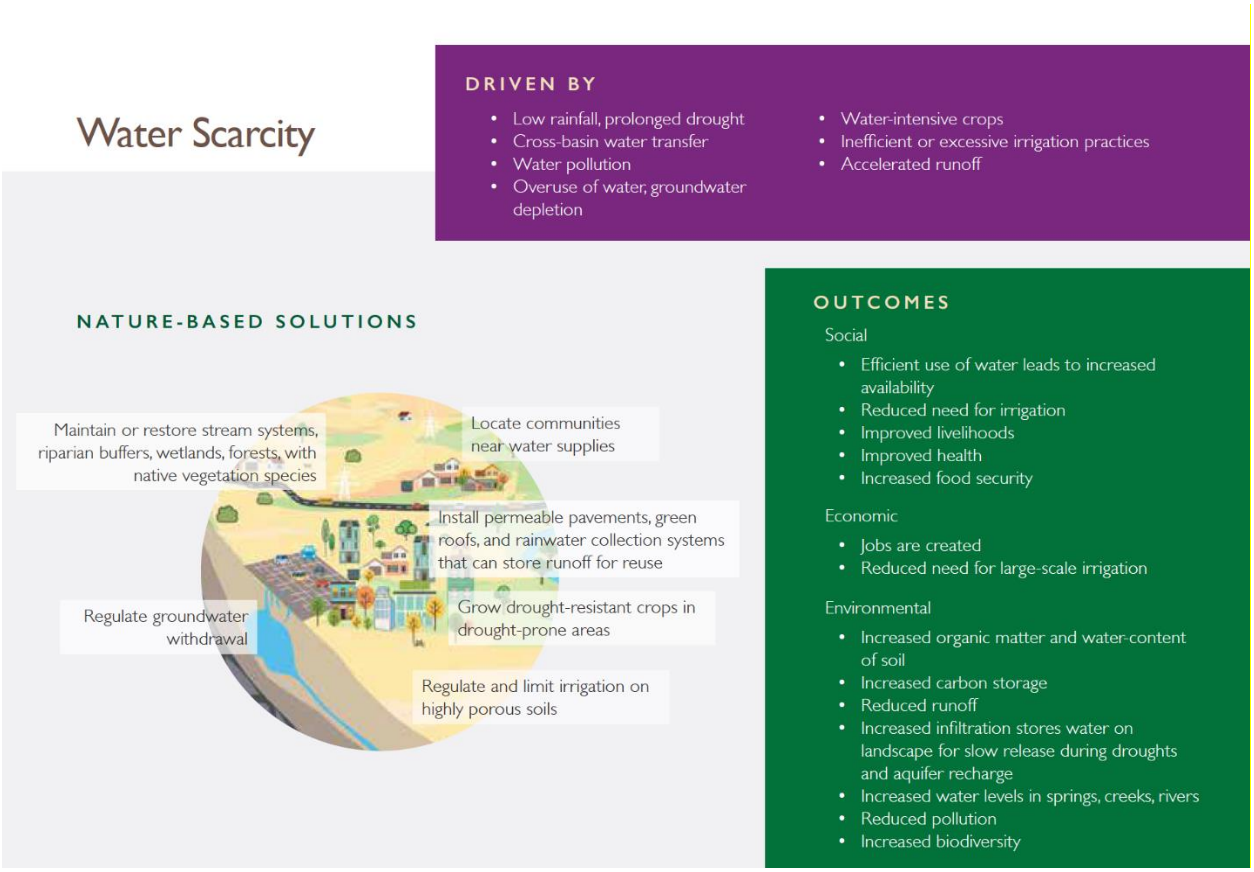

Figure 9: A reliable supply of potable water is essential for all people. Water is critical to many industrial sectors including energy, transportation, manufacturing, and agriculture. By 2025 it is expected that 2/3 of the global population will face water shortages (UNICEF, 2022)). Globally, agriculture uses 70% of fresh water with 60% of that wasted due to irrigation system leakages, evaporation, inefficient application, and planting water-thirsty crops in dry areas. Increasing water storage through application of nature-based solutions that use natural features to capture, store, infiltrate, filter, and recycle water and improve agricultural use of water can all help alleviate the water scarcity problem.

Example – Cape Town, South Africa – Business Case- Assessing the Return on Investment for Ecological Infrastructure Restoration
https://www.nature.org/content/dam/tnc/nature/en/documents/GCTWF-Business-Case-April-2019.pdf

Increased risk from grey-only Infrastructure	Reduced risk with nature-based solutions
Following a 3-year drought 2015 to 2018, Cape Town's water supply almost dried up. Unprecedented restrictions were applied to avoid complete loss. Traditional "grey" infrastructure solutions include raising the level of the dam, building a desalinization plant, drilling deeper into the aquifer, and water capture and re-use. Estimated costs for these hard infrastructure projects is USD $540 million. Only desalinization produces an equivalent amount of water to the nature-based solution but at 12X the cost.	Removal of non-native, invasive, water-loving, tree species in 7 sub-watersheds that supply water to Cape Town would sufficiently restore flows within 6 years to meet the growing population and increase flows over the next 30 years for long-term sustainability. The project would cost USD25 million, one sixth the cost of the grey infrastructure being considered. In addition, 350 new jobs would be created, native biodiversity and habitats would be restored, wildfire risk would decrease and local communities would be empowered.

Figure 10: "Deteriorating water quality is stalling economic growth, worsening health conditions, reducing food production, and exacerbating poverty in many countries," said World Bank Group President David Malpass. Highly polluted waters cannot function as water supplies or must undergo expensive treatment that is often infeasible. The percent of a water supply watershed forested has a significant effect on the cost of water treatment (Ernst et al., 2004). Many factors drive poor water quality including: poor watershed management practices that accelerate runoff and erosion; poor agricultural practices that lead to soil, chemical, and fertilizer runoff; garbage; sewage, and industrial outflows.

Example – Wetland Creation for Wastewater Treatment, Castelluccio, Italy
http://iridra.eu/attachments/article/112/ENG_Castelluccio.pdf

Increased risk from grey-only Infrastructure	Reduced risk with nature-based solutions
After the completion of the sewerage system of the village, a constructed wetlands system has been designed in replacement of an old activated sludge plant no longer adequate for the small winter population of the area and the large influx of tourists during the summer.	Natural or constructed wetlands accumulate waste treatment solids that can be used as organic agricultural fertilizers after 15-20 years. Surface waters provide recreational opportunities and native aquatic vegetation is planted in and around the wetland improving aesthetics of the area. Capture of subsurface flow recharges groundwater.

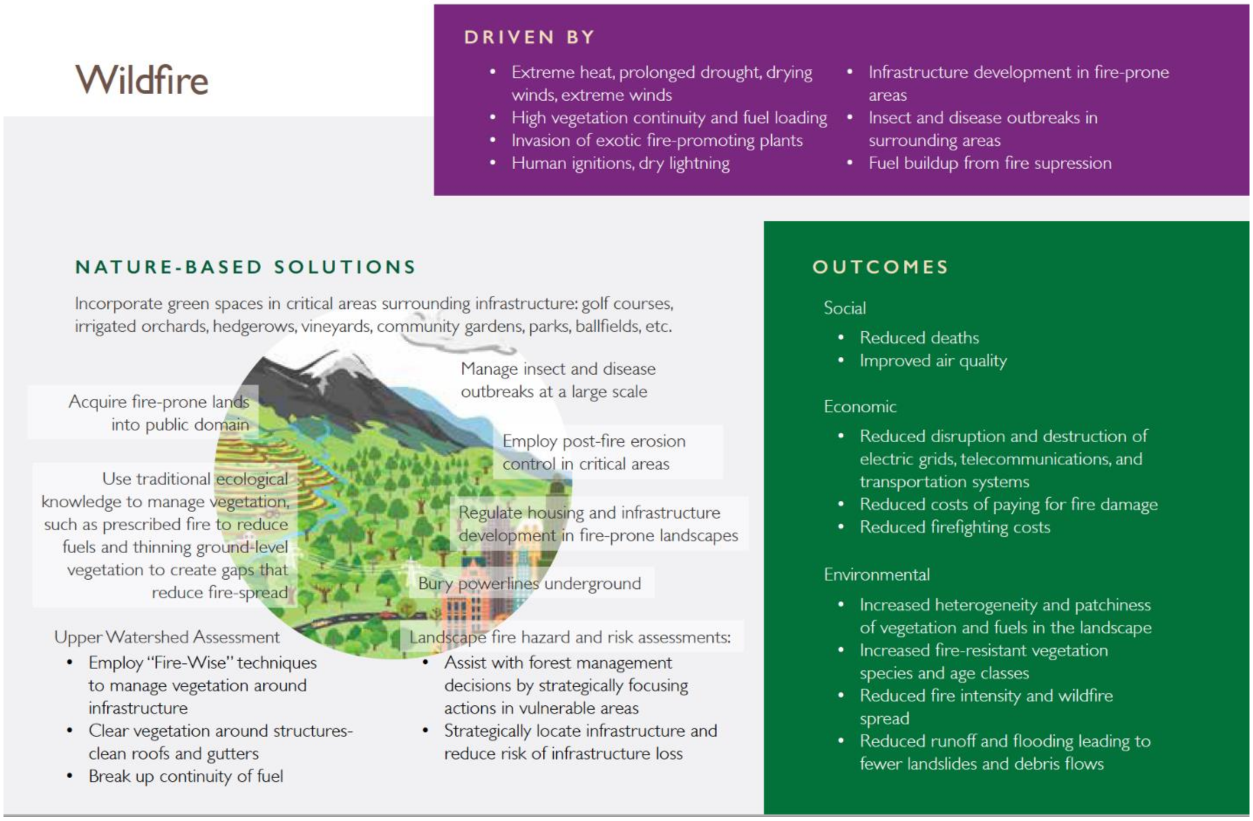

Figure 11: Increases in the frequency, size, and severity of wildfires have become a global crisis. Climate change is causing more fires even in areas with historically low occurrences (UNEP, 2022d). In the western US, researchers have found that, over the last 20 years, fires have quadrupled in size, tripled in frequency, and experienced an eightfold increase in the area burned at high severity (Iglesias et al., 2022). A focus on fire suppression over the last century has resulted in a build-up of live and dead fuels that is leading to huge, uncontrollable wildfires that are ecologically, socially, and economically devastating (UNEP, 2022d). The annual economic burden, in 2016 USD, of wildfire in the United States ranges from $71.1 billion to $347.8 billion with the largest share of the burden (64-84%) resulting from both short and long-term direct losses of life, health, structures, environmental damage and indirect losses of supply chains, foregone taxes, infrastructure and military disruptions, and general accelerated economic declines and the smaller share (11-18%) from the costs of preparedness, suppression, and legal, regulatory and R&D.(Thomas et al.,2017).

Example: Western US Wildland Urban Interface
https://www.nytimes.com/interactive/2022/09/09/climate/growing-wildfire-risk-homes.html

Increased risk from grey-only Infrastructure	Reduced risk with nature-based solutions
Many communities throughout the western US, each of which requires electric, communication, and water supply infrastructure are being built at an accelerated rate at the wildland interface. Traditional construction materials and proximity to dense forests result in many communities having extreme vulnerability and some communities destroyed by uncontrollable fire.	Ecological thinning of overly dense forests (resulting from a century of fire suppression) reduces the height of wildfire flames, allows for safer and easier access to firefighters, leaves forest structure intact, reduces erosion, and saves homes and communities.

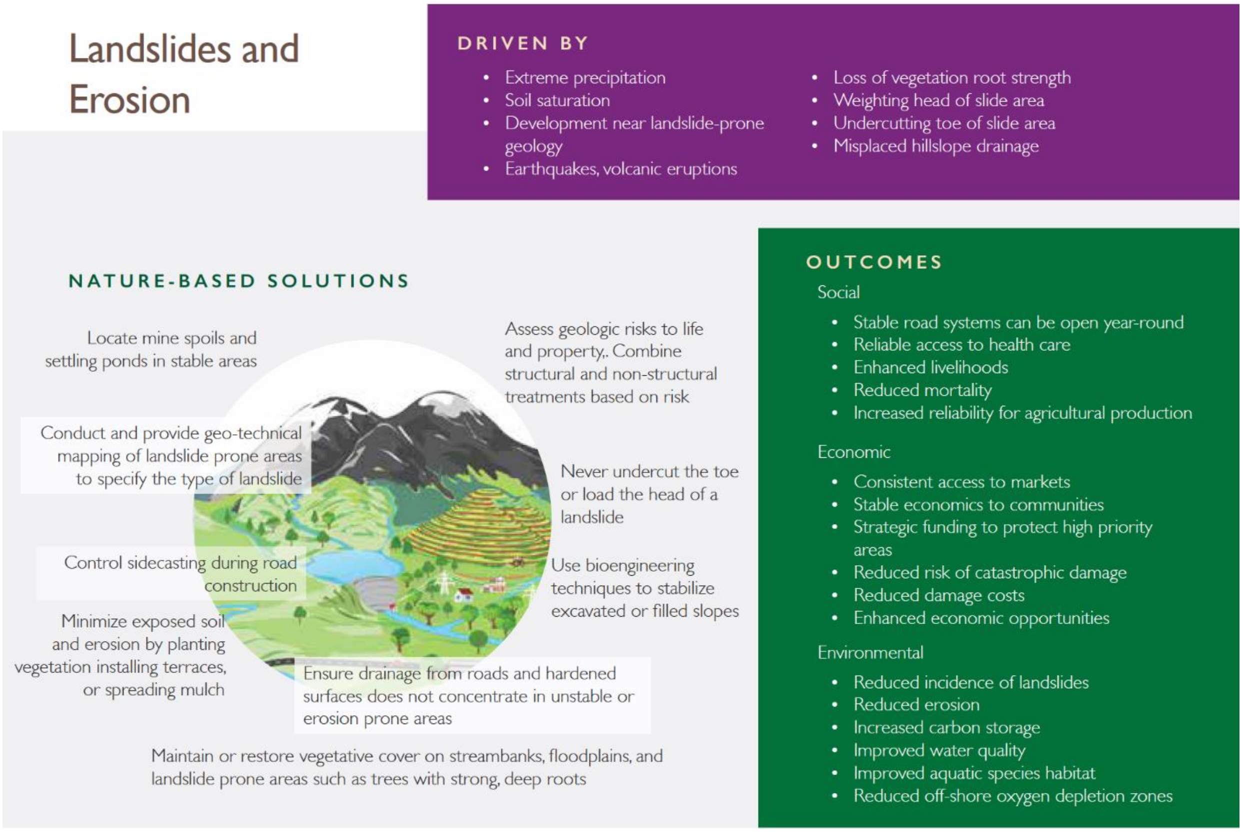

Figure 12:Transportation, housing, and commercial infrastructure siting should all be acutely aware of landslide hazards in project siting. Construction practices, especially project location, drainage, and maintenance activities result in landslides and erosion if not correctly sited, designed, and implemented and can account for a landslide density in mountainous terrains that is one and in some cases two orders of magnitude greater than other land use changes (Sidle et al., 2006). The social and economic impacts of landslides and erosion are not well quantified in the literature. However, landslides and erosion have implications for life and safety, emergency services, access to markets, food security, water quality, soil productivity, and aquatic life.

Example – Road Expansion in Nepal

https://www.dpnet.org.np/public/uploads/files/Trends_in_landslide_occurrence_in_Nepal%202021-09-17%2007-43-49.pdf https://blogs.agu.org/landslideblog/2019/09/03/dozer-roads/

Increased risk from grey-only Infrastructure	Reduced risk with nature-based solutions
Poorly located, constructed roads with inadequate drainage in steep mountainous terrain has resulted in a rapid increase in the number of fatal landslides throughout Nepal. Upland landscapes are progressively scarred with high-impact roads that seldom provide more than one or two years of access before failing. Road development is often conducted by personnel that have no education or training in environmental engineering.	Well-constructed road systems reduce the height of the road cut, follow the contour of the land, leave native vegetation intact on the hillslope, maintain natural drainage patterns to reduce landslides and erosion and protect stream channel. These nature-based solution practices reduce the incidence of landslides, protect the integrity of hillslopes, adjacent farms, and communities from the risk of landslide.

Figure 13: Earthquakes directly affect people, land, and infrastructure through shaking, displacement of land, and by triggering building collapse, landslides, rock fall, and avalanches. The impact of these similarly sized earthquake events in poor and rich countries illustrates how much more vulnerable low-income countries are, because of fewer earthquake-resistant infrastructure policies (CRED 2016). Earthquakes also trigger tsunamis. The 2004 Asian tsunami killed 226,400 people in 12 countries (CRED 2016). It was an event from which we learned the value of healthy and functioning coastal infrastructure of mangroves, estuaries, coral reefs, and barrier islands.

Examples – Haiti and San Francisco, USA
https://storymaps.arcgis.com/stories/156382f2727c40a28db502817f7d18f3
https://pubs.usgs.gov/of/1990/0253/report.pdf

Increased risk from lack of hazard avoidance	Reduced risk with hazard zone restrictions
In the Haiti earthquake of 2010, the most extensive damage occurred in areas where buildings and other infrastructure ware located on loosely-packed and waterlogged sediments that were subjected to liquefaction and amplified shaking, and on and below 39+ thousand landslides that resulted. Extensive development on these hazard areas resulted in much more death and damage than if the hazards had been recognized and avoided.	During the Loma Prieta earthquake of 1989 in the San Francisco Bay Area, which was of similar magnitude and proximity as the Haiti earthquake, only older development in the Marina District on unconsolidated and waterlogged sediments incurred severe damage. Publically-available hazard mapping and development zone restrictions on hazardous soils and landslide-prone areas mostly precluded widespread damage and deaths.

Figure 14: After flooding, cyclonic storms were the second most recorded disasters in 2021 (CRED, 2022). In the Philippines, Typhoon Rai affected 10.6 million people killing 457. Cyclone Nargis (Myanmar in 2008) took the lives of over 140,000 people (UNEP, 2017). Although these mega-disasters are rare, their occurrence and intensities are projected to increase with a warming planet (International Panel on Climate Change 2021). Low- and low-middle income countries bear the worst of these storms accounting for 93% of the deaths. Storm damage is the most expensive type of natural disaster with US$ 936 billion spent during the 1994-2013 decade (CRED, 2016).

Example –Haiti

https://www.sciencedaily.com/releases/2010/06/100607192725.htm

Increased risk from grey-only Infrastructure	Reduced risk with nature-based solutions
Communities in Haiti were wiped out due to poor construction techniques. Proper construction techniques are the best defense for hurricane /typhoon force winds.	Hedgerows with shorter bushes facing the prevailing winds help divert storm winds over buildings. Trees and shrubs with strong structures planted in deep soil and in clumps tend to survive storms. Prune dead branches prior to storms. Choose salt tolerant plants, rinse salt off plants following storms.

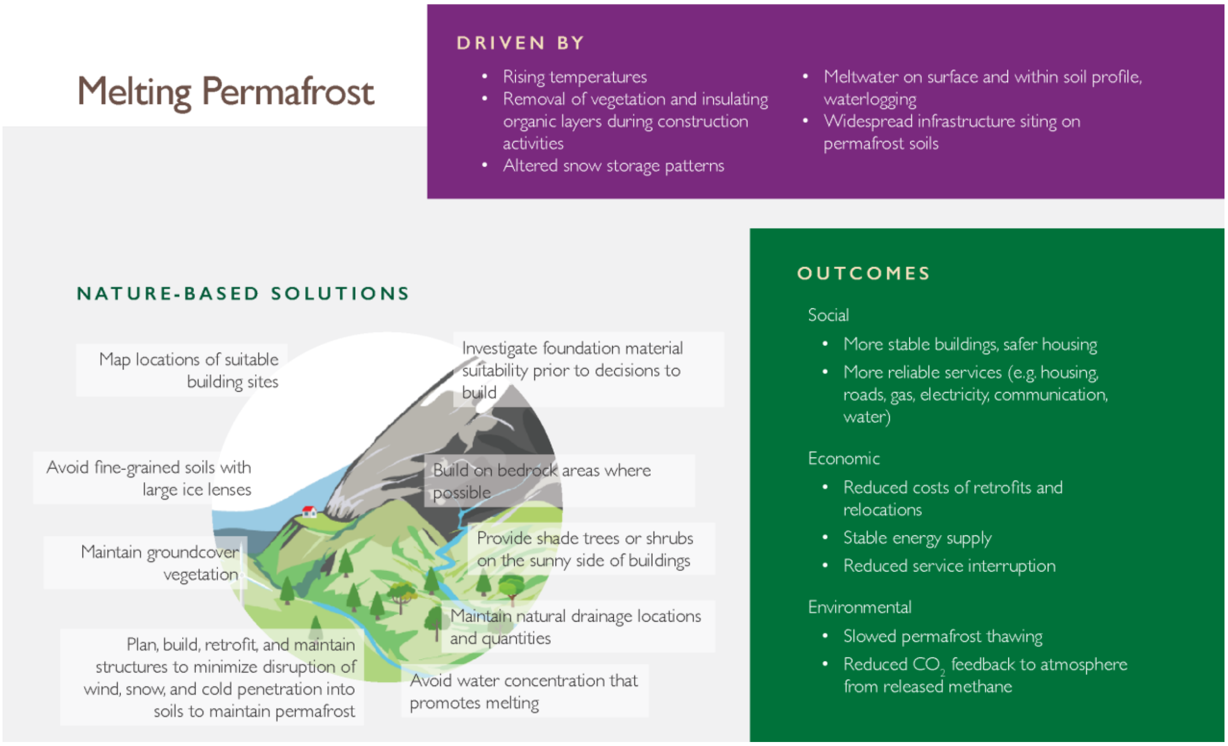

Figure 15: Permafrost largely occurs in the higher latitudes of the northern hemisphere accounting for 15% of the surface area of the planet. By 2050 permafrost melting could destabilize infrastructure affecting more than 3.6 million people. Melting of near-surface permafrost can pose a serious threat to the utilization of natural resources, and to the sustainable development and persistence of Arctic communities. 70% of infrastructure in the Arctic (homes, hospitals, roads, railways, and industrial sites are built on permafrost at risk of thawing. 45% of the oil and gas drilling sites in the Russian Arctic are in areas where ground thaw instability can cause severe damage. 20% of the Russian population and GDP comes from areas North of the Arctic Circle. These figures are not reduced substantially even if climate change targets of the Paris Agreement are reached (Hjort et.al, 2018).

Figure 16: Oil pipelines throughout the arctic are subject to cracks and breaks as piling is undermined by permafrost melting and impacts from wildfire resulting from drying surface vegetation. Photo credit Michael Coffey, Alaska Department of Transportation

CHALLENGES TO INTEGRATING NATURE-BASED SOLUTIONS INTO INFRASTRUCTURE DELIVERY

Despite the data supporting the role of nature-based solutions in contributing to climate and disaster-resilient infrastructure, substantial barriers exist that have prevented their widespread acceptance and implementation. A literature review of the challenges that tend to keep nature-based solutions as individual pilot projects or isolated occurrences championed by local advocates reveals that there are multiple challenges that can be categorized by education, policy, governance, and finance which are described in the following tables.

Figure : Climate change and growing population will affect younger people more than older people. The stakes for effective solutions will keep increasing. The world's reliance on coming generations will be of central importance. Higher education that focuses on nature-based solutions to environmental challenges is a priority adaptation and pressing need. University curricula are slow to change and often do not prepare students for current challenges. Developing and disseminating curricular materials on NbS is an obvious and urgent need. Credit: Smithsonian Conservation Biology Institute

Table 1: Common Educational Sector Barriers to Mainstreaming Nature-based Solutions

1. Education Sector Challenges	1A. There is a lack of core knowledge to design and implement nature-based solutions	The number of professionals who have deep knowledge in the planning, design, implementation, maintenance, and monitoring of nature-based solutions is lacking. Most infrastructure projects are planned and designed solely by engineers, yet the challenges are highly interdisciplinary.
	1B. Skills to map hazards, vulnerabilities, and ecosystem services are lacking	High-quality mapping at the appropriate scale of potential environmental hazards and the resources they affect are often missing or only available for a fee. This limits the ability of designers to recognize the need and value of nature-based solutions in infrastructure projects.

Table 2: Common Policy Sector Challenges to Mainstreaming Nature-based Solutions

2. Policy Sector Challenges	2A. There is a lack of policy, regulations, Best Practices, codes, and standards.	Environmental policy and regulation, if it exists, is often poorly enforced. Design standards that include and codify nature-based solution practices remain rare. Consequently, best practices for nature-based solutions are not established so expectations for environmental protection and resilience are low or absent.
	2B. Short-term economic gains are prioritized over environmental integrity.	Least-cost alternatives that can be quickly implemented are often chosen in development projects, which can preclude the inclusion of nature-based solutions. In urban areas, green space and other nature-based solutions opportunities are lost as the cumulative space allocated to the built environment increases over time with economic development.
	2C. There is a lack of political will and long term commitment.	Politicians tend to favor highly visible projects with immediate results that they can inaugurate during their tenure. Although proven effective, nature-based solutions tend to be slower to mature and provide tangible benefits in comparison with grey infrastructure, which makes them less likely to be prioritized by politicians or demanded by the public.
	2D. Learning from and preparing for disasters is not a priority.	When disasters occur, enormous capitol is spent in a rapid response to restore services and reduce suffering. This emergency response tends to replace in-kind, letting the immediacy of the repairs preclude longer-term assessment and analyses that could allow rebuilding in a way that reduces future risk.
	2E. Risk aversion	Funders, governments, and society are often unwilling to fund and support projects without assurance of clear, tangible, and immediate benefits. The benefits of employing nature-based solutions are often slow to develop, require additional costs, and may appear disconnected from the identified problem.

Table 3: Common Governance Sector Challenges to Mainstreaming Nature-based Solutions

3.Governance Sector Challenges	3A. Government departments typically operate in silos.	There is a lack of interaction between government departments and institutions leading to a poorly coordinated disaster-resilience policies, plans, and implementation. This counteracts the implementation of nature-based solutions, which requires interdisciplinary and cross-departmental coordination.
	3B. Budget cycles hinder nature-based solution project planning.	Centralized and short-term budget cycles hinder the design and implementation of nature-based solutions, which tend to require lengthy time frames for planning and for actions to yield measurable results.
	3C. Lack of transparency in infrastructure development decisions.	There is often a lack of multi-agency, interdisciplinary, and community engagement in project development. This means solutions tend to be narrowly focused and pushed from the top down, which eliminates the opportunity for all stakeholders to consider and include nature-based solutions.

Figure 18: Indigenous communities have preserved large tracts of Columbia's Amazonian rain forest for millennia based on a culture interwoven with nature. Their engagement in discussions of nature-based solutions is crucial. Source: https://www.context.news/nature/how-indigenous-culture-protects-colombias-

Table 4: Common Finance Sector Challenges to Mainstreaming Nature-based Solutions

4. Finance Sector Challenges	4A. Financiers and governments do not account for “the value of nature” and long-term resilience in cost/benefit assessments.	The current economic structures of infrastructure financing are inadequate to fully account for nature-based solutions since they fail to include the impact of infrastructure investments on the environment. In addition, the long-term benefits of protecting, supporting, or supplementing infrastructure with nature-based solutions are not accounted for.
	4B. There is a lack of financial planning and business model expertise in the environment and planning departments.	Sustainability of nature-based solutions, from planning all the way through maintenance, requires long-term financing. Yet governance structures and lack of expertise can hinder innovation in finance and business models to meet these needs.
	4C. The scale and scope of nature-based solutions practices is too small for private investor financing.	Large infrastructure and public works projects are typically viewed as the purview of the government and do not traditionally attract private funding. Yet financial returns and other benefits of small projects fail to attract private investors. There is a need for public-private partnerships to increase the scope and scale of projects to fill this gap.

OPPORTUNITIES TO MAINSTREAM NATURE-BASED SOLUTIONS FOR INFRASTRUCTURE RESILIENCE

The high costs and long lifespans of infrastructure mean that decisions made today will influence development pathways for decades to come.[27][28] There is an opportunity to influence those outcomes. Incorporating nature-based solutions into infrastructure development decisions can reduce or mitigate the impact of climate and geophysical disasters on societies, restore environmental integrity, combat biodiversity loss, and improve societal well-being.

The following section presents practical and effective actions toward achieving mainstreaming of employing nature-based solutions for infrastructure. The section is organized to reflect on the challenges highlighted in the previous section and proposes solutions to address those challenges. As such, we present the recommendations for mainstreaming in terms of education, policy, governance, and finance sector opportunities.

1. Prioritize Education Opportunities in Nature-based Solutions

Complete vulnerability assessments

Understanding the potential climate conditions that can further exacerbate geophysical hazards is as part of determining nature-based solutions for infrastructure resilience. Vulnerability assessment is the process of identifying, analyzing, and evaluating the potential impacts of climate-change-informed hazards on a system, sector, ecosystem, or region. It involves examining the exposure of the system to hazards, the sensitivity of the system or region to the hazard exposures, and the capacity of the system or region to adapt to those effects. The goal of climate vulnerability assessment is to identify the most vulnerable values, areas, and populations, so that appropriate adaptation and mitigation measures can be taken to reduce ongoing and potential impacts. Without credible vulnerability assessments, priorities for adaptation cannot be established or defended.

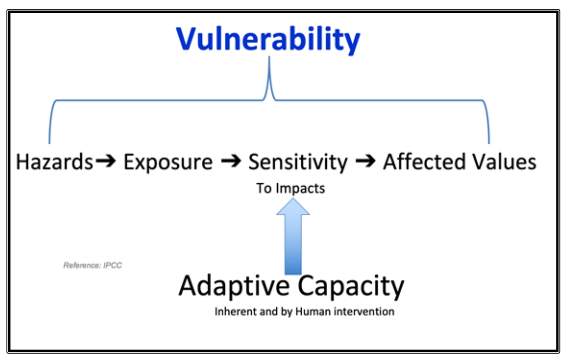

Figure :The model for vulnerability used by the Intergovernmental Panel on Climate Change (IPCC). The term "vulnerability" is often used interchangeably with "risk". Most risk models require knowing the probability of exposure to hazards. If this is known and included, risk and vulnerability are synonyms.

Techniques and guidance for vulnerability assessment are now widely available.[29] Climate vulnerability assessments can be conducted at different scales, from global to local, and can focus on various sectors, such as agriculture, water resources, health, and infrastructure. They typically involve the use of a range of data and tools, including climate observations and projections, GIS, and stakeholder engagement to identify the most vulnerable areas and populations and to understand the potential impacts of hazards on those areas and what can be done to modify sensitivity and exposure to reduce vulnerability (and thus increase

[27] (Håkanson, 2021)
[28] (UN Environment Programme, 2022b)
[29] (Cook et al., 2016)

resilience). The results of a climate vulnerability assessment can inform the development of adaptation and mitigation strategies, as well as guide decision-making related to promoting resilience and social justice.

Understand ecosystems, their conditions, and the ecosystem services provided

Mapping of global biodiversity hot spots and ecosystems of concern is available.[30] Refinement of this mapping at a local scale with community input will improve global mapping efforts. Ensuring that infrastructure does not impact or open access to these sites needs to be included as a nature-based solution in national infrastructure development plans. At a more local scale, infrastructure development planning should include mapping regional or national ecosystems such as rivers, lakes, wetlands, ecological types (forest, grassland, savannah, agricultural lands), coastal zones, and so on. The condition of those resources to provide the goods and services needed for infrastructure supply and protection needs to be determined. Figure 20 displays and example of the connection between a healthy ecosystem, a function of that ecosystem, and a service provided. The focus for identifying nature-based solutions should be predominantly on the protective functions of ecosystems that address geophysical hazards (storm water retention, wildfire resiliency, slope stabilization, infiltration and so on). Nature-based solutions can be employed to improve upstream or adjacent environmental conditions to ameliorate hazards to infrastructure.

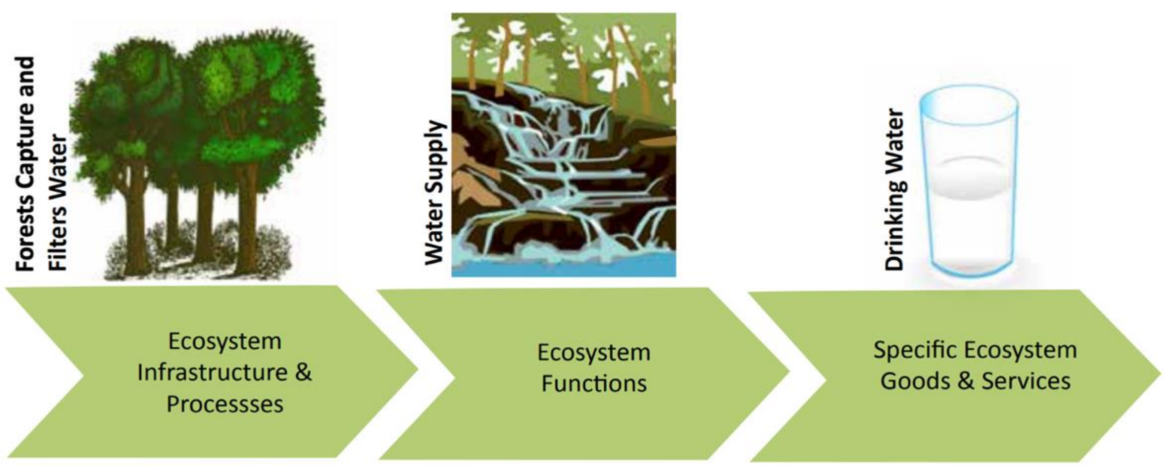

Figure 20: Mapping and understanding ecosystems, their condition that affects their ability to function, and the specific ecosystem services supplied are a crucial part of infrastructure master planning efforts. Source: Earth Economics

Map and disseminate geophysical hazard information

Developing infrastructure resilience requires a robust knowledge base of locations of hazards, ecological values, and vulnerabilities at scales of resolution that fully inform infrastructure planning, siting, and design. Without this information at the right scales (table 5), risk cannot be credibly assessed. Failing to gather and use this information can result in extreme economic, social, and environmental costs.

In many nations, hazard mapping is not readily available and there are no functioning risk information systems highlighting vulnerable infrastructure, environmental values and services, or vulnerable communities. There is little loss and damage data from previous disasters. If hazard data exists, some

[30] (Chaplin-Kramer et al., 2022)

governments and private entities do not make their hazard mapping data publicly available, citing proprietary use or requiring payment. This often prevents infrastructure practitioners from recognizing hazards and inhibits community engagement, increasing risks to infrastructure and society. Employing nature-based solutions with retrofit, or new infrastructure projects requires that developers recognize, locate, and assess this essential information.

Infrastructure that is resilient to disasters requires a scale-appropriate understanding of the types and locations of potential geophysical hazards. This includes, at a minimum, an assessment of the eleven climate and geophysical hazards identified in Section 2 of this report including flood-prone areas, areas susceptible to landslides and erosion, tsunami inundation zones, active fault zones, and liquefaction-prone soils, wildfire-prone areas, wind, and heat prone areas, and other relevant geophysical hazards.

Discerning hazard zones in the landscape requires specialists in geology, hydrology, wildfire, coastal processes, and so on. Discernment and mapping at a scale useful for planning, designing, and building infrastructure must be available and fully considered, or risks will be indeterminate and greater than necessary (Table 5). Broad mapping of hazards, at very large scales, from satellite remote sensing is of some limited value but is never sufficient for infrastructure planning and design. All good hazard mapping tools require that professionally developed, field-verified information is provided as base layers.

Free and open access to this information to enables informed infrastructure development planning. Figure 12 provides an example of the types of information that can be readily acquired by planners, developers and community members in general.

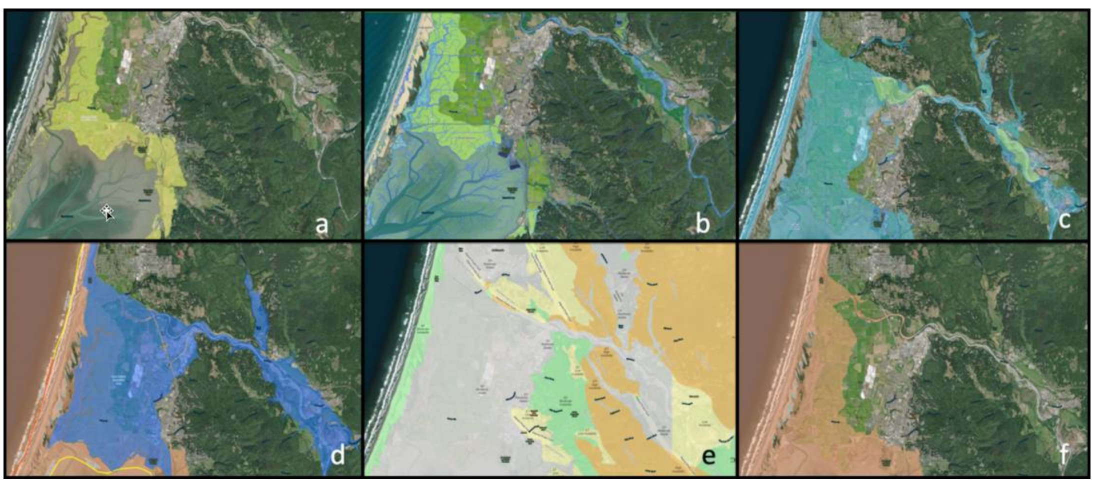

Figure12. Examples of publicly-available hazard and values mapping in coastal Humboldt County in NW California, USA. a) Sea level rise inundation at 1 and 2 meters (light green and dark green shading respectively) (b) Coastal wetlands (blue and light and dark green shading). (c) Legally defined flood-prone areas (FEMA Flood Zones - Blue shading). (d) Dam failure inundation zone (blue shading). (e) Earthquake faults and seismic hazard classes. (f.) Tsunami run-up hazards (orange shading). Other available mapping includes wildfire-prone areas; landslide hazards; natural resources values; slope steepness, aerial imagery; and community housing classifications. Source: https://humboldtgov.org/1357/Web-GIS

Table 5: Example of the types of geophysical hazard information that is needed at various scales to understand the potential of natural hazard impacts on infrastructure

HAZARD ASSESSMENT AND MAPPING DATA NEEDS, BY SCALE – EXAMPLES OF NEEDED DATA *(NOT comprehensive)*					
SCALE OF ASSESSMENT & MAPPING OF HAZARDS ↓	NATIONAL-GLOBAL SCALE	REGION (RIVER BASIN, PROVINCE, PREFECTURE, SECTORAL ZONING, AND SO ON)	LOCALITY (CITY, SMALL CATCHMENTS MUNICIPALITY, NEIGHBORHOOD, , FARM ZONES, AND SO ON)	SITE/PROJECT SCALE (E.G., MAIN ROAD, HOSPITAL, WATER TREATMENT PLANT, AND SO ON)	FREQUENCY - UPDATING
FLOODING	Location of major rivers	Location of rivers, streams, catchment areas, and their associated flood-prone zones	Areas prone to flooding from extreme storms, dam failures, sea level rise, king tides, and so on	Exact limits of flooding hazards and opportunism to mitigate. River morphology to define channel migration and avulsion risks.	Flood zones change with river morphology, extreme floods, urbanization and other development, and climate change. Changes in flood policy can require new zonation
LANDSLIDES AND EROSION	Presence of steep hillside topography	Generalize mapping of landslide-prone terrain.	Detailed mapping of landslides and landslide-prone hillsides.	Landslides and landslide hazardous geomorphology near existing or proposed infrastructure. Soil types prone to high erosion hazards	Landslide potential changes with timber harvest, roading, changes in hillslope drainage patterns, fire, development, and climate change. Reassess every 5 years or less
EARTHQUAKES	Tectonic setting	Major faults and geologic contacts. Areas of liquefaction prone soils and sediments that amplify shaking	Location of all active and potentially active faults	Faults and liquefaction prone soils and sediments in proximity to project infrastructure. Soil suitable for seismic resilience	Earthquake hazard zones are stable. Human exposure may change. Revise based on what is learned in earthquake disasters
WILDFIRE	Areas prone to drought and wildfire	Forest and other land types most prone to wildfire. Broad wildlife sensitivity based on vegetation, topography, wind patterns, access roads, fire suppression resources, wildfire history	Forest stands and patches most prone to wildfire. Detailed wildfire sensitivity based on vegetation, droughty soils, topography, wind patterns, access roads, and proximity to buildings and other susceptible infrastructure.	Vulnerable infrastructure in proximity to high-fire hazard areas, debris torrent and flood-prone areas. Response time for fire suppression resources Liabilities to adjacent values and entities	After fires, fuel treatment, significant blowdown, changes in suppression resources.
COASTAL HAZARDS	Coastal land, Land-Water Boundaries River Deltas	Erodible coastal morphology and exposure, flooding, salinization, tsunamis, high winds. Delta morphology changes and threats	Sea level rise inundation projections, salinization of surface and groundwater extent, extreme wind corridors. Generalized soil conditions.	Wind speed projections. Observations of episodic flooding Groundwater levels, salinity, corrosivity, soil suitability for construction	For each project, existing and nearby hazards should be assessed and mapped in detail and provided for the project environmental assessment
WATER AND AIR POLLUTION	General level of concerns	Major sources of air and water pollution Regional groundwater basins	All sources of air and water pollution. Patterns of population exposure to air and water pollution	Pollution sources that can affect project. Potential air and water pollution population exposure	Update when new sources of pollution appear.

Map existing and planned infrastructure

The location of all existing infrastructure should be mapped. This assessment will enable planners to understand how additional infrastructure needs, replacements and retrofits combine and interact with existing infrastructure, hazards, and sensitive populations.

Infrastructure siting in relation to mapped geophysical hazards as affected by climate change and regional environmental conditions is the foremost component in determining potential impacts to infrastructure. Rigorous and credible hazard mapping would allow practitioners to prioritize mitigating immediate risks to existing infrastructure and reduce environmental impacts. Employing nature-based solution that avoid construction within a hazard zone is the priority followed by developing plans to remove existing infrastructure from high hazard areas where possible. In addition to keeping infrastructure out of harm's way, infrastructure developers should be required to mitigate the impact of new and retrofitted infrastructure on the environment due to construction practices that degrade the environment, increase runoff, add pollutants, or destabilize slopes.

Map locations of highly vulnerable populations

The physical location of highly vulnerable communities and people should be mapped to understand how to provide and protect individuals and groups such as children, the sick and elderly, and the very poor. These highly vulnerable people are often located in geophysical hazard areas, such as near rivers, in wet areas, unstable hillslopes, adjacent to landfills and pollution sources, and unregulated settlements. Needed infrastructure that is undesirable for many, such as electrical transmission lines, landfill sites, and busy roads are often located in the poorest communities as they lack the political clout to influence siting decisions. This results in injustice that can be avoided or remedied by understanding where these communities are located and factoring environmental justice into planning and design.

Broaden the scope of infrastructure master plans

Infrastructure master planning strategically sets growth-related goals, objectives and priorities relating to infrastructure needs and locations. Infrastructure planning should be incorporated into all strategic plans such as National Development Plans and National Adaptation Plans. Vulnerability assessments provide baseline information for infrastructure planning. Incorporating nature-based solutions into infrastructure master plans requires that the scale of planning be done beyond the site design scale to understand the conditions of the surrounding landscapes at the regional or national scale (see Annex 1 Case Study #3 Hazard assessment and adaptation in southern Bhutan). Assessment of geophysical hazards, potential climate-induced changes to those hazards, and an understanding of the state of ecosystem function on those hazards should be an integral part of the master plan. This higher-level analysis provides an understanding of both the potential hazards to the planned infrastructure and the potential impact of the infrastructure on the environment.

Develop nature-based solutions curriculum and share It widely

Educated professionals who fully understand modern environmental engineering will be essential to building capacity for including nature-based solutions in infrastructure assessment, planning, design, and operation. Existing university curricula are often outdated, slow to change, and do not adequately address the challenges climate change and environmental disasters pose to infrastructure. Research and development programs that better describe and quantify ecosystem services, integrate nature-based solution values into modelling and cost-benefit accounting, and that improve on nature-based solution designs are needed. Well-designed and widely disseminated nature-based solution curricula are needed to for university-level students and working professionals (see Annex 1 Case Study #2 Green Shores Program: Building capacity and mobilizing knowledge networks to adopt NbS). All education resources identified below should be free and open to the public through sites like Open Education Resources and available in multiple languages. In addition, scholarships should be provided for government employees and working professionals to attend courses.

Assemble and disseminate a curated and annotated library of nature-based solution literature

Extensive research has revealed that a vast body of nature-based solutions literature already exists, with many important publications that can inform nature-based solutions in infrastructure development. However, these are widely dispersed, difficult to access, and have not been reviewed for veracity, relevance, or trustworthiness. Assembling and maintaining a carefully reviewed, curated, up-to-date, publicly available library of nature-based solutions publications will provide practitioners with easy access to readily available information. An annotated and topically-tagged collection that includes abstracts and document summaries would be especially useful for practitioners and policymakers. The curated collection would include existing guides, design standards, case studies, and more, with a focus on planners' and designers' needs. The library would ensure that the best resources are easily located, available to the widest audience, and provide material in multi-media formats from mobile apps to webinars and podcasts.

Cultivate communities of practice to develop and disseminate nature-based solutions

Communities of Practice (CoPs) are groups of people who share responsibilities, concerns, or a passion for the work they do, and learn how to do it better as they interact; CoPs exist for most domains of practice and knowledge. While they do not need to be "created," they can benefit from active cultivation. Regular gatherings, online hubs for sharing information, standard libraries, and developing informal networks for those facing similar challenges and learning opportunities can make CoPs stronger and more effective. Infrastructure CoPs include land-use planners, civil engineers, coastal specialists, foresters, infrastructure policymakers, hazard geologists, financing experts, and so on. Multiple, diverse CoPs should come together to develop best practices that address that complexity, conserve knowledge, and find solutions that accommodate each community's goals and concerns.

As an example, the Global Green-Grey Infrastructure Community of Practice is a forum for collaboration across the conservation, engineering, finance, and construction sectors to generate and scale-up green-grey climate adaptation solutions. The multi-disciplinary CoP has grown to a global membership exceeding 140 organizations in the NGO, academic, government, and private sectors working to[31]:

- Share ideas and facilitate collaboration
- Innovate and pilot new approaches
- Expand science, engineering, and policy activities
- Implement and learn from projects in varied geographies and settings.

Recognize and develop nature-based solutions best practices for infrastructure resilience.

Requiring strict, universal standards could make nature-based solutions interventions inaccessible to developing countries because adhering to strict standards is not practicable or profitable financially feasible and may not fit environmental and social contexts.[32]. To expedite implementation of nature-based solutions for infrastructure resilience when thoroughly vetted engineered design standards are not available or appropriate, adopting "Best Practices" is an alternative. "Best Practice" is a professional procedure that is

[31] (Corwin, 2022)
[32] (TARU Leading Edge, 2022)

accepted or prescribed as being correct or most effective. The term conveys a sense of acceptability, respect, and professional endorsement. It is a well-established concept that addresses local issues.

Developing disaster-resilient infrastructure best practices present challenges given the diverse global legal, governance, social, financial, geographic, and professional contexts. How can mainstreaming be accomplished given this diversity of context? In most places, resilience measures are scattered across various laws, regulations, guidelines, decrees, environmental documents, and manuals that are dispersed in multiple locations and formats. Because there is no single place to find what is required and recommended, practitioners often overlook important advice or requirements for implementing nature-based solutions.

Developing a "Framework of Best Practices" within the "Annotated Library of Nature-based Solutions" mentioned above would facilitate easy access to information and can be shared across a wide range of practitioners. This would entail researching existing best practices, standards, and professional conventions. In situations where best practices are currently not known or not well-documented, convening CoPs to discuss, develop, and disseminate new best practice procedures would be required. The degree of detail and localization is important and is best achieved by credible CoPs. Developing and refining Best Practices is often "bottom-up," and adoption is "top-down" or integrated across scales, countries, and CoPs.

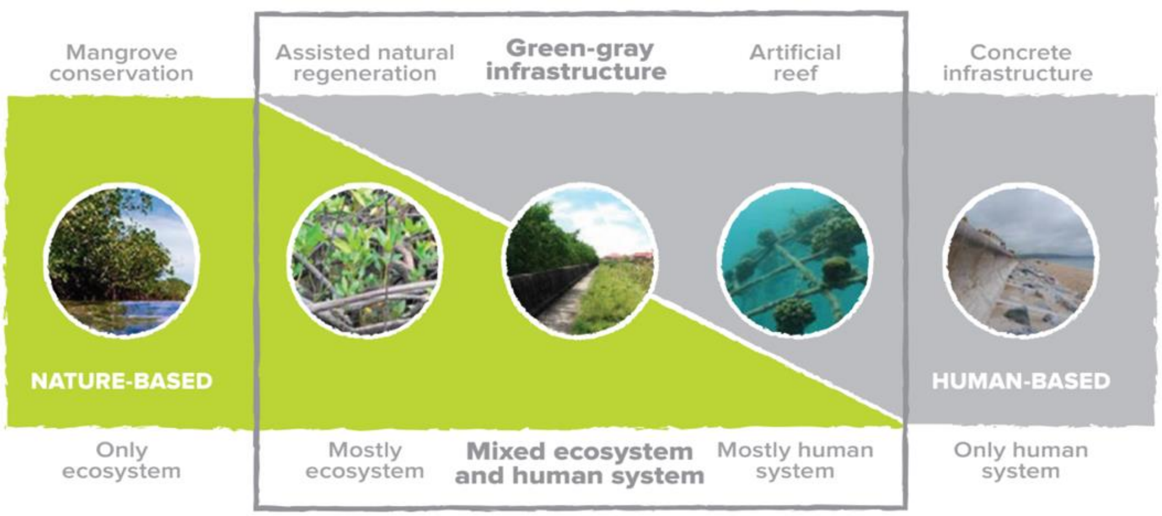

Figure18: Example of a range of coastal protection options from natural mangrove forests to highly engineered systems. Nature based solutions are highlighted within the green background area. Source: Conservation International

Create a nature-based solution design hub[33]

A "Nature-based Solution Design Hub" would be an evidence based nature-based solutions decision-making feedback loop to encourage collaboration across disciplines and geographies. This trusted data-sharing platform would leverage modern computing and information collection technology using an online, open-source structure. The system would be built and implemented by and for users to input knowledge and data, with a focus on crowdsourcing information about natural infrastructure technology, performance, and cost to inform descriptive methods and engineering standards. This voluntary, collaborative effort would focus on

[33] (Corwin, 2022)

providing science-based information to improve nature-based solutions design, selection, implementation, cost-effectiveness, and performance. The Hub would include a consolidated, publicly accessible repository of performance monitoring information, data entry spreadsheets, performance summary reports, monitoring guidance, and site metadata. Collaborative funding, participation, and ownership of this data platform are essential for success.

The Hub will:

1. Define common performance indicators and monitoring variables for different types of natural infrastructure projects for consistent and efficient monitoring and evaluation programs.
2. Identify specific hazards and nature-based solutions to improve resilience in that area.
3. Incorporate cost-benefit analysis input data and outputs to build a database of social, economic, and environmental costs and benefits associated with different types of nature-based solutions.
4. Identify case studies to share with policymakers, economists, and financiers. Narrative project descriptions show how natural infrastructure projects support sustainable development and galvanize financial institutions' interest and support.
5. Connect project developers with financiers as a "match-making" service.
6. Give engineers and regulators access to information to increase confidence in outcomes.
7. Conduct periodic reviews of common themes, outcomes, and findings and publish the results. This presents opportunities for powerful interdependency assessments.
8. Make publicly available data broadly and equitably accessible to help address climate justice.
9. Create opportunities for testing experimental approaches to nature-based solutions project design and execution and contribute to scaling-up successful approaches.
10. Have a real-time feedback loop from practitioners to designers, planners, and financiers to learn from and share successes - and failures – widely.

2 Include Nature-based Solutions in Strong Policy Platforms

Enact and enforce legislation to ensure program longevity

Many nations consider the impacts of the climate crisis to be a matter of national security and massive capital reallocation is necessary to create climate- and disaster-resilient infrastructure. Effective legislation affirms a long-term commitment to nature-based solution programs, giving investors confidence that nature-based solutions investments will support their goals. As an example, in June 2022, the EU Commission proposed the EU Nature Restoration Law that, if enacted, would establish legally-binding targets to protect and restore rivers, wetlands, forests, peatlands, marine, and urban areas to benefit biodiversity, climate, and people.[34] The Paris Agreement provided a framework to initiate similar actions across the globe.

Such legislation would need to either create or tier to existing environmental policy that protects air, soil, water, floral, and faunal resources. Working within established environmental policy helps government sectors achieve risk-reduction targets set by legislation.[35] National environmental policies can help mainstream nature-based solutions in infrastructure project design as they affect all infrastructure development projects and operations. Environmental analysis of every infrastructure project should be required prior to action. These analyses should be grounded in a scientific understanding of the on-site and off-site impacts on natural resources and environmental functions the project could affect. Most nations have environmental laws, but

[34] (European Commission, n.d.)
[35] (TARU Leading Edge, 2022)

the strength of those laws and consistent on-the-ground enforcement of them is the ultimate determinant of a nation's environmental quality.

Such legislation establishes that nature-based solutions be fully considered in all new construction and reconstruction projects and that effective monitoring and reporting are required. This would assure that there is accountability for enforcing environmental regulations, that projects are implemented as planned, and that the practices are effective in ensuring resilient infrastructure.

Meet the commitments of the Paris Agreement and the 2030 Agenda for Sustainable Development

The Paris Agreement requires each country to report its climate action strategy every five years in the form of Nationally Determined Commitments (NDCs). As of 2020, NDCs submitted were insufficient to keep global temperature rise below 2°C. [36] Through NDCs, countries can significantly increase global climate action by mainstreaming and accelerating the role of nature-based solutions. As of 2020, developing countries' NDCs have included more nature-based solutions than wealthy countries, leaving a huge opportunity for wealthy countries to increase their commitments. Most countries' nature-based solutions-related NDCs focused on forest protection and restoration, but nature-based solutions for infrastructure resilience can offer many additional benefits. Incorporating all potential nature-based solutions, such as protecting and restoring rivers, wetlands, coastal and marine ecosystems, improving soil and forest health in wildlands, agricultural lands, and urban areas, into countries' NDCs would be a win-win for climate action, disaster resilient infrastructure, the environment, national finance, and communities. The United Nations Development Program offers a Toolkit to help nations mainstream nature-based solutions that could be incorporated into the NDCs.

Implementing nature-based solutions at a large scale to protect infrastructure will accelerate the timeline to achieving the 2030 Agenda for Sustainable Development. Properly functioning infrastructure systems are essential for people to live and work in healthy and safe environments. Environmental restoration policy that addresses the suite of agriculture, forestry, and other land uses, backed by ambitious restoration targets, will go a long way to protecting economies and societies, especially the most vulnerable populations, restoring environmental integrity, and tackling climate change.[37]

Include nature-based solutions in national plans

All strategic plans, such as National Adaptation Plans, National Infrastructure Plans, and National Development Plans must start with a "nature first" premise and should harmonize sectoral plans to prioritize functional landscapes that support all species and maintain human well-being.[38] New cross-sector partnerships are needed within government sectors and between subject-matter experts and local community members to ensure these plans address environmental and societal issues. Through national plans, nature-based solutions could become a normative component of all infrastructure development efforts. Lower level plans, including master development plans for urban and rural areas, can then tier to the "nature first" philosophy of national plans and look more holistically at the relationship between proposed infrastructure development in the immediate environment and within the larger landscape to better understand hazards and vulnerability.

Protecting ecosystems and doing little or no harm to the environment is the first order of business. Policies that focus on protecting healthy functioning ecosystems should usually be a priority over policies that restore ecosystems. However, many environments have already been degraded and require some form of restoration to provide the functions that protect "grey" infrastructure. Many of the practices that can be implemented to

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[36] (Seddon et al., 2020)
[37] (United Nations Environment Programme, 2019)
[38] (UN Environment Programme, 2022a)

restore agricultural lands, forests, wetlands and river systems, mangrove and coral restoration, for example, are known but need to be adopted at larger scale to be effective.

Perform post-disaster assessments, create knowledge, and build back better with nature-based solutions

Local government officials have an obligation to build resilience into their communities through disaster preparedness. However, disaster response receives a great proportion of international attention and funding. Pre-disaster planning and preparedness utilizes only 12% of allocated funding even though investing in preparedness saves the taxpayer $6 for every $1 spent.[39][40]Policies that focus on preparedness are both efficient and fiscally responsible.

Learning from disaster can help mainstream nature-based solutions. Infrastructure failures often have obvious causes, though sometimes the root causes are hidden and require detailed analysis to discover and diagnose. The reasons for system failures are typically known to many but "don't come up", as people are reluctant to convey bad news or highlight system failures.[41] Developing an organizational culture of investigating and correcting infrastructure failure would accelerate learning and adaptation. Interdisciplinary teams with diverse skills and perspectives improve discovery processes and can devise creative and innovative solutions. Understanding the root causes of failures and future prevention requires detailed, systemic analysis.[42][43] Because effective progress is not possible without robust failure detection, analysis, and adaptation, using knowledge gained from analysis of disasters helps nature-based solution practitioners implement solutions that offer better outcomes.

Disaster response is typically swift, often chaotic, and focused on restoring services, creating a safe environment, and relieving victims' immediate pain and suffering. Repairs occur as rapidly as possible when crucial infrastructure is interrupted, often simply replacing what was damaged and in the same location. Failure analysis would analyze and evaluate the root causes and compounding factors behind the disaster. For example, upper watershed damage, inappropriate land uses, loss of wetlands, and poor or inappropriate levee construction may have been a flood's true cause, though infrastructure and residents in the lower watershed suffered the damages. Post-disaster assessments open a window of opportunity to rebuild better, taking nature-based solutions into account in reconstruction and recovery plans. Groups like the South Asian Alliance of Disaster Research and Geotechnical Extreme Events Reconnaissance teams can help facilitate learning and changes in disaster response protocols and how to reduce loss and damage in future disasters. Governments and funding entities can ensure adaptations to previous system failures are a prerequisite to recovery funding.

3 Create Transparent and Inclusive Governance Structures

Nature-based solutions projects require holistic system evaluation on-site and in the broader area at a catchment or regional scale, helping ensure governance is accountable, transparent, participatory, and inclusive (**see Annex 1 Case Study #4 Overcoming fragmented governance at the watershed scale**). Successful nature-based solutions design requires addressing underlying causes of problems and risks – an understanding that comes from multiple-scale assessment by a broad spectrum of community members, professional, governmental, academic, and other disciplines.

[39] (Horn, 2022)
[40] (Pew Trust, 2018)
[41] (Bella, 1997)
[42] (Harvard Business Review, 2011)
[43] (Oliver-Smith et al., n.d.)

Break down organizational silos

To effectively address the complex issues surrounding climatic and geophysical hazards, multiple government departments need to work effectively together. One option that accomplishes this objective is to alter budgeting processes to fund projects and activities rather than funding individual departments. Making the budget process goal-oriented would encourage inter-departmental cooperation and coordination. For example, health and human services, urban forestry, public works, city planning, and others would have to work together to reduce urban heat island impacts. This process builds bridges that strengthen institutional knowledge, builds relationships, develops new skills, and shared experiences, and reduces interdepartmental competition while developing stronger, more integrated projects. Participatory groups can then review, revise, and provide input on these projects.

Institute interdisciplinary planning

The incorporation of nature-based solutions requires an interdisciplinary, systems approach to achieve sustainable infrastructure development. Interdisciplinary planning is essential to ensure the complexity of issues surrounding nature-based solution design, implementation, operations, and monitoring are understood and carefully developed. Typically, infrastructure projects engage civil engineers and architects under the guidance of engineering principles, planning regulations and building codes. Adding interdisciplinary expertise can improve project planning and implementation outcomes. Physical scientists (geology, hydrology, soil science) are aware of environmental variables that could affect or be affected by a project. Wildlife biologists and botanists can disclose the habitat and biodiversity implications. Social scientists and anthropologists can describe the social dynamics and cultural aspects that can affect the project effects to communities, including issues of land tenure and environmental justice. Persons with local and indigenous knowledge can advocate for and advise solutions that fit specific environments and local cultures. Financial experts can help the group understand the components needed to secure funding. These interdisciplinary skills are required to prepare credible environmental assessments and perform environmental cost-benefit analyses that include an assessment of ecosystem services and biodiversity potentially affected by a project. Group members must be willing to listen and learn from the experiences each member brings to the table.

Encourage participatory planning through collaborative groups

Participatory planning of infrastructure projects is perhaps the best way to influence governance. Solving problems through participatory engagement and collaboration makes development decisions more transparent by allowing the group to communicate with government officials. Participatory engagement ensures the development process includes all people to make institutions, policies, processes, and services accessible and responsive to everyone. Participatory engagement increases accountability; creates greater public visibility, and influences governments to use resources wisely and according to public needs.[44] Participatory planning builds community ownership and long-term engagement in the operation, maintenance, and monitoring of nature-based solutions projects.

Employing nature-based solutions will require new and innovative partnerships that unite formerly disconnected disciplines.[45] For example, implementing a successful stormwater upgrade with nature-based solutions could bring together civil engineers, neighborhood groups, government regulators, landscape architects, natural resource professionals, horticulturalists, bicycle advocates, and financiers, to name a few. All these groups are important for assessing, designing, implementing, operating, maintaining, and monitoring

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[44] (Brechenmacher, n.d.)
[45] (Green et al., 2016)

stormwater management nature-based solutions. Were this a strictly grey infrastructure project, only the environmental department and civil engineer would typically be involved (**see Annex 1 Case Study #5 Green infrastructure for stormwater management**). To address the scope and scale of some hazards, transboundary partnerships at sub-regional, regional, and national levels may be needed. For example, land use planning and land use in the Himalaya and Terai regions of Nepal and northern India need transboundary cooperation to address society resilience and flooding impacts on infrastructure.

Monitor and communicate results

There are opportunities for new communities of learners to understand the capacity of nature-based solutions to compliment, substitute, or safeguard historically grey infrastructure (**see Annex 1 Case Study #6 Viet Nam coastal communities adapt to climate change**). These learners include local government officials, civil engineers, community members, investors, insurers, and MDBs, among others, who may not have managed or previously thought about how natural systems function for infrastructure resilience. For these groups, monitoring must provide evidence-based proofs of concept. This requires standardizing quantitative metrics on data types, costs, benefits, and performance over the long term which is important to developing benchmarks for success and comparing nature-based solutions across different interventions, sectors, contexts, and engineered solutions.[46]

Successful monitoring provides the necessary information to answer questions efficiently with minimum effort and cost; this is essential for adaptive management.[47] Monitoring is necessary to:

- Establish that what was promised and prescribed was implemented, and is timely enough to make any necessary corrections.
- Ensure transparency and show progress, achievements, and impacts on goals and objectives
- Communicate positive or negative results to ensure relevant knowledge is transferred for accountability and adaptive management.
- Show investors progress toward reaching investment goals and evidence for scaling up actions.[48]

One of the most important things to monitor is if the project was constructed as planned. Implementation monitoring is often overlooked and underutilized.[49] Third party certification may be needed to ensure that nature-based solutions were implemented based on standards, when they exist, and professionally sanctioned best practices when they don't. Government inspectors or multi-party monitoring groups could provide certification. For many nature-based solution practices, until a significant environmental hazard occurs to test the functionality, it may not be practical to certify that a nature-based solution delivers as expected. The concept of "Pay for Performance" which is often a requirement in investments, therefore, may not be appropriate for nature-based solution applications.[50]

More complex monitoring that proves the efficacy of a project should be mandated in selected places to test assumptions and validate the efficacy of designs. This should usually be conducted by research organizations that have the time, technical ability, human resources, and focus necessary to complete the research over the long term and provide critical feedback on the findings to the nature-based solutions communities of practice.

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[46] (UN Environment Programme, 2022a)
[47] (Furniss, 2014)
[48] (Buckinham et al., 2019)
[49] (Furniss, 2014)
[50] (Blue Forest Conservation, n.d.)

Monitoring and feedback can lead to the adaptation of designs, adoption of additional and more expansive projects, and help prioritize and focus nature-based solutions to enhance beneficial outcomes.

Linking well-designed, well-funded, and committed monitoring activities will support mainstreaming nature-based solutions. For example, linking monitoring programs established by the UN Sustainable Development Goals, the Paris Agreement, The Bonn Challenge, The UN New York Declaration on Forests, The UN Decade on Ecosystem Restoration and regional commitments like the 20x20 Initiative in Latin America and others, will provide for social, economic and ecological nature-based solutions project monitoring at the global scale.[51]

4 Utilize Innovative Finance Mechanisms

The Finance Chapter of this flagship report focuses on issues relating to the mobilization of capital to fund resilient infrastructure assets and finance disaster risk. Below are the components need to build a business case for financing nature-based solutions. This includes understanding the value of ecosystems, engaging with partners in conservation programs, and building a robust pipeline of fundable nature-based solution projects.

Build a business case for nature-based solutions

There are many reasons for investing in nature-based solutions. Many businesses and government programs depend on ecosystem services including clean and abundant water, fertile soils, healthy forests, and biodiversity to stay viable. Business leaders often state that achieving sustainability goals is their number one motivation for investing in nature followed by increasing their market brand and managing regulatory requirements, promoting employee well-being, and mitigating natural disaster risks.[52] These priorities can be used by those proposing to include nature-based solutions to enhance climate and disaster-resilient infrastructure to build a business case for investment.

Providing "proof of concept" that a nature-based solution will be effective by itself or in concert with grey infrastructure continues to be a challenge. The solution to this problem is not *more* proof, but rather making the existing proof *available* to, engineers, designers and decision-makers. The "proof of concept" on nature-based solutions applications and efficacy is rooted in natural resource management literature. The lack of proof is not due to lack of research findings or documentation on the effectiveness of nature based solutions, it is tied to weak access to and distribution of this information or a lack of education about how nature and natural hazards work. The annotated library mentioned in the education section would make this type of information more readily available.

For example, one study of water companies in the US showed that for every 10% increase in forest cover above a water source, there was a 20% decrease in water treatment costs. Water treatment costs were 211% higher for a watershed with 10% forest cover compared to a watershed with >60% forest cover.[53] For this reason, the US has, as a nature-based solution, protected watersheds by limiting human disturbance above municipal water supply points. A similarly robust body of evidence shows the linkages between nature-based solutions, land management techniques, and benefits to reducing runoff, flooding, fire, coastal erosion, and so on.

Require environmental cost-benefit accounting and valuation of ecosystem services

Cost-benefit accounting has long been a core tool used to evaluate policy and investment efficacy. However, traditional accounting for major development projects often fails to analyze environmental and social impacts.

[51] (Buckinham et al., 2019)
[52] (The Nature Conservancy, n.d.)
[53] (Ernst et al., 2004)

Environmental cost-benefit analysis is the application of cost-benefit analysis to projects that affect or are affected by the natural environment.[54]

These assessments would improve the likelihood that including nature-based solutions in infrastructure projects would have a greater cost-benefit ratio than grey infrastructure alone. Globally, environmental accounting methodologies and their use in cost-benefit analyses vary widely. The task requires interdisciplinary input from natural scientists, engineers, and economists to minimize uncertainty and accurately account for all costs and benefits to societies and the environment.[55][56] These analyses can help improve environmental policy and infrastructure development decisions and should be required in project funding. To qualify for funding, the project's social and environmental benefits should exceed the social and environmental costs.

Monetize ecosystem service values

Costanza in 2014 noted that "valuation of ecosystem services is often confused with commodifying or privatizing nature. However, valuation lets us build a more comprehensive, balanced picture of the assets that support human well-being and human interdependence with the well-being of all life on earth. We cannot underestimate the importance of the change in awareness and worldview these valuations facilitate."[57] Land is a precious commodity, especially in developing urban areas. Without monetization of its value for infrastructure protection, and strictly enforced regulations that forbid development, high-hazard areas will continue to be contested and developed. In addition, pressure to develop portions of urban areas that can be used as open space for such things as cooling, aesthetics, and livelihood enrichment will be developed unless valued for their environmental, social, health and economic benefits. Outside of urban areas, development values for resource extraction such as mines, timber or conversion to another land use often fail to consider the value for that land, in its natural state, to deliver infrastructure services (wetland flood attenuation), to enhance infrastructure function (sediment and erosion control), to protect engineered assets (mangroves minimizing wave action to protect coast telecommunication networks) and co-benefits including increased ecotourism, food security and employment opportunities. Failing to evaluate ecosystem service values relates to a lack of requirement to do so, a lack of realization that ecosystems and ecosystem services have value or a lack of understanding of how to monetize ecosystem service values.

Table : Example of individual ecosystem values per acre for ecosystems that provide services to protect the water source above a municipal water intake Eugene Water and Electric Board, 2017)

Highest Natural Asset Value ($/ac/year)	
Wetlands	$34,888
Lakes and Rivers	$3,041
Riparian Forests	$6,717
Forests	$3,677
Shrub and Scrub	$2,710
Grassland	$695
Agriculture	$644

[54] (Organization for Economic Cooperation and Development, 2018)
[55] (Water Solutions Institute - Colorado State University, 2021)
[56] (Center for Neighborhood Technology, 2011)
[57] (Costanza et al., 2014)

Table : Example of the types of ecosystem services and their values per acre based on avoided costs at the water treatment plant resulting from the protection of riparian forests (Eugene Water and Electric Board

Benefit	**Value ($/ac/year)**
Avoided Sediment	$3.22
Avoided Nitrogen	$20.19
Nitrogen Interception and Removal	$148.83
Sediment Interception and Removal	$3.24
Carbon Sequestration and Storage	$262.34
Total Benefits	$437.83

There are several methods (e.g., replacement costs, market pricing, hedonic pricing, avoided costs, etc.) utilized to monetize the economic value of ecosystem services. Due to the time required to gather the raw data for most of these valuation methods, however, many groups use the benefit transfer method, which accumulates information from studies done in similar ecosystems in other areas, to provide a low and a high value range of ecosystem type and service values to similar ecosystems in which they are working.[58] Improvement in the confidence of the benefit transfer methodology can be accomplished through in-depth studies shared by the community of nature-based solution practitioners. A full disclosure of assumptions and limitations of valuations is needed. Often many services cannot be awarded a monetized value. Once an ecosystem service value is determined, aggregating that value for the area of concern representing that service and then adding aggregated values for all ecosystem services affected provides decision-makers with a full view of potential costs and benefits (**see Annex 1 Case Study #7 In defense of biodiversity in Intag, Ecuador**).

Valuations of ecosystems varies by locality and by ecosystem type. Table 6 shows an example of the value of various ecosystems used for development of a water quality protection program by the Eugene Water and Electric Board, USA. Table 7 displays an example of the values of ecosystem service obtained from protection of riparian forests. Several other ecosystem services, like habitat values, disaster risk reduction, recreation and tourism values, water temperature benefits, and cultural values would add to total ecosystem value but were not assessed in this study. Even lacking the full analysis of benefits, EWEB's future costs for protecting riparian forests under the watershed protection program was estimated at $1,980 for a given acre, while the net present value of benefits was $7,131 per acre. This represents a return of approximately $2.60 for every $1 EWEB invested over a 20-year period due to a reduction in water quality treatment operation costs resulting from the implementation of nature-based solutions to protect the environment above the water treatment plant.[59] When adequately valued, ecosystem services can often justify the implementation of nature-based solutions.

Link to conservation finance programs

A variety of conservation finance instruments have been used to secure the protection and management of lands in ways that protect desired ecosystem services (see box). Conservation finance programs need to ensure

[58] (Plummer, 2009)
[59] (Eugene Water and Electric Board, 2017)

the development of strong, community-based, local institutions. Engaging communities upfront in project design and establishing communities of practice to carry them into the future is critical. The viability of any conservation finance program, those lasting through generations, depends on the ability of local institutions to keep things going. [60]

Conservation Finance Programs
Payment for Ecosystem Services
Conservation Easements
Conservation or Mitigation Banking
wetlands, habitats, biodiversity
Water Quality Trading
Reducing Emissions from Deforestation and Forest Degradation and REDD+
Debt for Nature Swaps
Green Bonds
Resilience Bonds

When developing programs that pay for ecosystem services, it is important to prioritize payments to the lands that have a significant effect on the infrastructure of concern. Not all land systems provide the same level of ecosystem services or risk reduction. For example, a water company may fund landowners whose property drain directly into a water supply reservoir or stream system above their water intake system. The landowners would be funded based on the condition of their lands to reduce erosion and increase water infiltration to replenish groundwater. Similarly, cities or downstream communities could make payments to landowners to maintain or restore wetland and riparian areas to increase stormwater storage and attenuate storm flows to minimize flooding and improve water quality downstream. Threats to these important ecosystem service functions (deforestation, mining, rainforest conversion for palm oil, soy, cattle grazing, and so on) should be identified and ecosystem service payment rates and schedules established to equitably compensate landowners for not converting their lands to these other, often lucrative, land uses.

Ecosystem Service Buyers
Public – Government agencies, Multi-lateral organizations
Public-Regulated – Public agencies, Private companies
Private Voluntary – Corporations, Philanthropic groups
Private – Eco-certified product producers, Individuals users

Hard infrastructure has a definable user base such as those who use electricity from a hydropower plant; building owners or renters who benefit from reduced energy needs from the insulation value of green roofs; agricultural, transport, and delivery users of stable road systems; communities or powerline companies that are protected from wildfire; and so on. A known user base helps in identifying ecosystem service buyers (see box).

Ecosystem Service Sellers/Providers
Private/ Indigenous landowners
– farmers, ranchers, forest owners
– need secured tenure rights
Government agencies
Non-governmental organizations
Community groups

By assessing potential infrastructure hazards and determining the geographic source of that hazard, ecosystem service sellers or providers can also be identified. Ecosystem service sellers or providers (see box) are those landowners whose treatment of the land affects adjacent and downstream infrastructure resilience. Infrastructure developers would benefit from paying the owners of identified lands to manage their lands for desired ecosystem service functions. Protecting lands from degradation has a greater potential to supply needed ecosystem services than trying to restore ecosystem functions on degraded landscapes. Payment rates could vary based on the ecosystem condition.

[60] (Pham et al., 2013)

Use intermediaries to finance projects at scale

According to a 2016 Forest Trends and JP Morgan report, over $3.1 billion in sustainable investment capital was idle due to a lack of investment opportunities in conservation finance and only 51% of government climate funds had been deployed due to a lack of projects in the pipeline or projects that were too small for private finance.[61] As a result, conservation-focused investors have not had sufficient opportunities to support nature-based solution projects.[62] Determining how to accelerate the pace and scale of implementing nature-based solutions will enhance mainstreaming efforts.

Bundling nature-based solutions projects into investment packages that mutualize risk across sectors, may draw private investors' interest and create a centralized funding source for local nature-based solutions practitioners to access. This structure in no way minimizes the need for local groups whose forte is in developing relationships, building trust, and gaining local knowledge over the years as they work together to accomplish their goals. This structure allows local groups to prioritize the identification of environmental challenges, participatory planning, and project implementation while providing investment opportunities.

Blue Forest Conservation (**Annex 1 Case Study #8 Implementing nature-based solutions at scale**) and Initiative 20x20 exemplify organizations that provide this type of support to local groups. Both groups have developed long-term public and private partnerships, built a collective of investors, and supply a robust pipeline of nature-based solution projects ready for funding.[63] Private funds supplement government funding for climate-related nature-based solutions projects and greatly increase the pace and scale of implementing nature-based solutions for infrastructure resilience.[64] Initiative 20x20 is a regional fiscal intermediary group launched in 2014 to change the dynamics of land degradation in Latin America and the Caribbean. Currently, eighteen countries and three regional programs have committed to improving more than 52 million hectares of land by protecting and restoring forests, farms, pasture, and other landscapes by 2030, thus supporting the Bonn Challenge and the New York Declaration on Forests. Over 85 technical organizations, institutions, impact investors, and funds have contributed $3.09 billion USD in private investment to Initiative 20X20.[65]

5 The Way Forward

Climate- and disaster-resilient infrastructure is an achievable goal. Attaining this goal requires that we view natural systems as an integral infrastructure component and are diligent in strategic infrastructure planning and development. This requires awareness that infrastructure vulnerability is contingent on ecosystem function, and an understanding of when, where, why, and how environmental hazards occur both from and to infrastructure. Vulnerability assessments are the first step in determining the priority and scale of actions to reduce or eliminate risks. Requiring and funding vulnerability assessments should be integrated with financing infrastructure projects. Decision-making in funding and siting nature-based solutions should be transparent and address social justice issues.

As nature-based solutions are employed to restore ecosystem services and protect infrastructure, **ongoing ecosystem degradation cannot continue.** Ecosystem degradation degrades the resilience of all

[61] (Climate Policy Initiative, 2021)
[62] (Hamrick, 2016)
[63] (Gartner et al., 2022)
[64] (Blue Forest Conservation, n.d.)
[65] (Initiative 20x20, n.d.)

systems, including infrastructure. However, current economic drivers, including many government subsidies and measures of prosperity, encourage natural resource degradation and depletion at a rate far faster than regeneration. The UN System of Environmental and Economic Accounting promotes updating economic standards to include a broader framework for well-being and sustainability that includes social capital and environmental-economic accounting measures.[66] As nations begin to accept and employ these new measures of prosperity, the attitude toward the value of healthy and functioning natural systems will change, and support for nature-based solutions will expand.

Developing nations that are the least responsible for climate-warming emissions disproportionately bear the brunt of its impacts. These nations have the greatest need for disaster-resilient infrastructure development and retrofits.[67] At the COP27, nearly 200 nations reached a landmark decision to provide financial assistance to developing nations through the establishment of the "Loss and Damage Finance Fund". This crucial funding can be used to implement nature-based solutions to ensure climate- and disaster-resilient infrastructure and facilitate the pace and scale of implementation that is needed. Mainstreaming nature-based solutions would transform the way governments, societies, and individuals engage to protect and restore natural systems.

The **mainstreaming strategies** introduced in this chapter will **move nature-based solutions from isolated projects into normative actions.** The key is to elicit the knowledge hidden throughout societies and across professional disciplines. In the context of nature-based solutions, asking, listening, designing, and revising plans with community input helps everyone be more informed and better understand the issues, risks, and challenges they face. The process invites communities to work together toward developing solutions that will work for their circumstances and their cultures. [68] Incorporating nature-based solution practices into infrastructure development can be accepted by society, championed by governments, and fully supported by developers, civil organizations, and non-governmental organizations.

Increasing an individual's and a community's understanding of their vulnerability to climate and geophysical hazards **motivates action**. Combined with a realization that employing nature-based solutions can minimize the loss and damage from natural disasters, a broad, bottom-up support for the nature-based solution's concept can be established. People will come to trust that implementation of nature-based solutions will have positive environmental, social, and economic outcomes. This is where 'Communities of Practice' excel. Large communities of practitioners have strong connections to various groups that they can use to grow the support for nature-based solutions. Communities of Practice can instill confidence and provide assurances by supporting innovators in the field and determining project design standards to widely share best practices to assist other communities facing similar issues.

Building bridges of communication and support among different groups, including government, local communities, and NGOs **can build trust, credibility, and legitimacy** for nature-based solutions. Communicating across the various parts of organizations, between departments, or within communities breaks down silos and challenges existing biases. By freely sharing information in an open governance structure, otherwise disparate groups can support each other in their efforts and build strong coalitions to mainstream nature-based solutions. Only when people hear of innovative concepts being successfully implemented from multiple trusted sources do they consider adopting and funding something new—

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[66] (United Nations et. al., 2021)
[67] (Lustgarten, 2022)
[68] (Centola, 2021)

ultimately taking nature-based solution concepts from locally-championed and isolated projects to widely spread normative practices.

The following outcomes can be achieved by widely employing nature-based solutions:

1. **All infrastructure is planned, located, designed, and maintained to resist damage during natural disasters and can be readily rebuilt to be more resilient when disrupted or destroyed.**
   a) Natural hazard and ecosystem service recognition and mapping inform decisions made by those involved in planning, designing, authorizing, and funding infrastructure
   b) Students and professionals in relevant disciplines are taught the principles of "state-of-the-art" nature-based solutions and how they are incorporated into planning and design.
   c) Best Practices are established by engineering and environmental planning "Communities of Practice" so that nature-based solutions and disaster resilience are trusted, expected, and routine.
2. **Nature-based solutions for resilient infrastructure are prioritized, codified, monitored and fully integrated by governments for investment, financing, and implementation.**
   a) Governments create and enforce policies and funding that support the adoption and economic viability of nature-based solutions.
   b) Pre-disaster planning is prioritized and disaster response efforts gather and share infrastructure damage analytics to learn what fails and what survives and why.
   c) Effective monitoring assures accountability that projects are implemented as planned and that the practices are effective in ensuring resilient infrastructure.
3. **Infrastructure resilience is increased by maintaining or improving critical ecosystem services, including climate and flood flow regulation, clean water, and erosion control, while supporting biodiversity.**
   a) Healthy forest, shrub, grass, savanna, and agricultural lands can adapt to climate change, are resilient to wildfire, drought, and flooding, and provide abundant clean water downstream.
   b) Wetlands are functioning and rivers have access to natural floodplains, lessening flooding extent and severity and protecting communities and infrastructure.
   c) Coastal shoreline ecosystems maintain stable and robust vegetation and reef systems to protect inland resources from sea level rise and storm surges.
4. **Infrastructure and associated nature-based solutions benefit local communities and support livelihoods, including sustainable traditional land-use practices.**
   a) Local communities are integrated into decision-making processes during the design and implementation of nature-based solutions opportunities.
5. **Nature-based solutions are implemented at the pace and scale needed to reduce climate and geophysical hazards to infrastructure**.
   a) New financial initiatives are created that value ecosystem services, resistance and resilience to disasters, and fully account for life-cycle costs and benefits.

ANNEX 1: CASE STUDIES OF NATURE-BASED SOLUTION PROJECTS

Case Study #1: Building resilient communities and wetlands ecosystems in Uganda, Africa

Case Study #2: **Green Shores Program: Building capacity and mobilizing knowledge networks to adopt NbS British Columbia, Canada**

Case Study #3: Hazard assessment and adaptation in southern Bhutan

Case Study #4: Overcoming fragmented governance at a watershed scale: Carruthers Creek Watershed Plan - Toronto, Canada

Case Study #5: Green infrastructure for stormwater management, Portland, Oregon USA

Case Study #6: Viet Nam coastal communities adapt to climate change

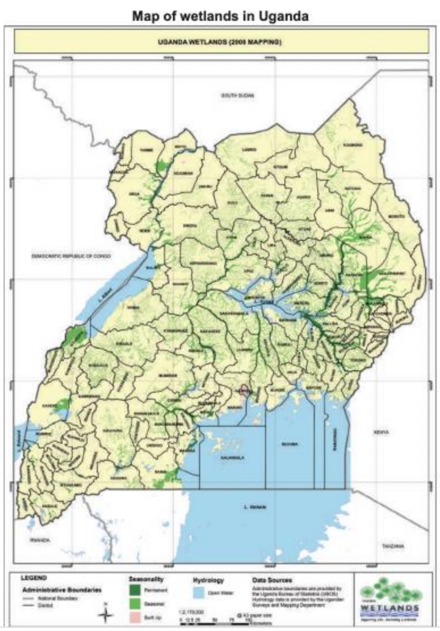
Case Study #7: In Defense of Biodiversity in Intag, Ecuador

Case Study #8: Implementing Nature-based Solutions at Scale – Blue Forest Conservation -Western USA

Case Study #1
Building resilient communities and wetlands ecosystems in Uganda

Societal Challenge Addressed: Thirty percent of wetlands in Uganda were lost between 1994-2000 with a 50% loss of wetlands in the Kampala watershed. An estimated 4 million people who live in and around Uganda's wetlands rely on them for food security. The impact of climate change increasing the duration and intensity of heavy rains, coupled with illegal wetland filling for industrial, residential, and agricultural expansion, dumping of industrial and fecal waste, over exploitation of water, fisheries, building, and craft material is increasing the degradation of wetlands and associated ecosystems. Floods are worsening downstream in the capital city of Kampala.

Scale of Design: This project will target south-western and eastern regions in Uganda, home to some of this country's most vulnerable people – more than half of them women.



Biodiversity Net Gain: Wetland restoration will restore both aquatic and wetland obligate species.

Economic Feasibility: Loss of wetlands has resulted in a loss of annual productive value of US$ 2.4 – 4.8 trillion annually and loss of natural capital is decreasing Uganda's GDP by 15% annually. This project will help Uganda to restore critical wetland functions including: replenishing ground water, improving flood control, and enhancing the livelihoods of subsistence farming communities through fishing and agriculture. It will also enhance the skills of people to diversify their livelihoods and become more resilient to climate shocks. While this climate initiative is based on grant financing, positive spillover effects are envisaged in the private sector as new revenue opportunities will open for people in rural areas.

Inclusive Governance: This project has a strong knowledge management component and a focus on inclusion of more women and youths, given that this category forms a big proportion of the population that depends on agriculture for livelihood. Through a shared understanding of the value of wetlands with a bottom-up conservation approach, sustainability of conservation efforts can effectively be implemented at the local level.

Balanced Trade-offs: Balancing the needs of factories, residents, local crop farmers, and urban and rural communities with the demand of sustainable environment management is a challenge.

Adaptive Management: This project will employ nature-based solutions to flood control and waste management and will assist the Government of Uganda in taking climate change effects into account in managing wetlands, thereby enhancing its resilience to climate change and protecting vital economic resources.

Mainstreaming and Stability: Uganda was the first nation in Africa to establish a National Wetland Policy supporting wetland protection and conservation efforts. Through a shared understanding of the value of wetlands with a bottom-up conservation approach sustainability of conservation efforts can effectively be implemented at the local level.

Contact/Source:

https://www.greenclimate.fund/project/fp034

https://www.undp.org/uganda/news/govt-undp-adc-partner-restore-wetlands

Case Study #2

Green Shores Program: Building capacity and mobilizing knowledge networks to adopt NbS:

Societal Challenge Addressed: Climate change, especially storm surge, sea level rise, and coastal development pressures result in flooding of communities, beach and coastal terrace erosion, pollution, and loss of coastal and marine biodiversity. To address this exposure and the fundamental lack of understanding and capacity for coastal protection options, the Green Shores program is designed to educate decision-makers and practitioners to consider naturalized responses as a buffer against a changing landscape.

Scale of Design: The Green Shores Program is delivered by the non-profit Stewardship Centre for British Columbia (SCBC). The program was originally developed in British Columbia (BC) and has now expanded to other northern hemisphere shorelines, including Nova Scotia in Canada.

Biodiversity Net Gain: The approach supports utilizing nature-based solutions that protect riparian forests, coastal ecosystems, waterways, and habitats, supporting resilience of native species such as wild salmon. Local demonstration sites reflect how NbS provides habitats by planting native species, removing non-native plants and other non-natural systems, while also providing environmental and social benefits.

Economic Feasibility: This innovative initiative utilizes diverse funding sources including grants from a variety of sponsors ranging from individuals, real estate groups, foundations and the Federal Government.

Inclusive Governance: The program facilitates an inclusive process that brings First Nations, local government staff, developers, community members and other relevant stakeholders together. Technical design workshops facilitate collaborative NbS design activities and the sharing of local knowledge to facilitate project implementation. These groups transfer the knowledge and support for the program to the larger community through their individual networks.

Balanced Trade-Offs: The program provides technical support to help assess trade-offs between options and realize the social, economic, and environmental benefits. The report, *Green Shores 2020: Impact, Value and Lessons Learned,* shows the social impacts and extended cost-benefits of the projects in BC.

Adaptive Management: Green Shores, delivered through partner academic institutions, provides understanding of the importance of monitoring over time, encouraging indicator development and adaptive management.

Mainstreaming and Stability: Technical NbS guidance is provided at local government, shoreline development entities, and homeowner scales. The program builds awareness for the need for local action planning, research and evaluation, and builds capacity through one-on-one coaching, and incentives, such as milestone-based certification. Green Shores Credits and Ratings Guides helps homeowners, builders, and developers identify benefits of NbS and key opportunities thereby encouraging on-the=ground action and implementation. The SCBC will continue to expand its programs on the west coast in BC and to the east coast in Atlantic Canada.

Contact: DG Blair, Executive Director, Stewardship Centre for BC, DG@stewardshipcentrebc.ca
https://stewardshipcentrebc.ca/green-shores-home/

CASE STUDY #3
Hazard Assessment and Adaptation in Southern Bhutan

Societal Challenge Addressed: The city Phuentsholing on the Himalayan foothills adjacent to the Indian border is highly susceptible to riverine and glacial dam-break flooding, earthquakes, windstorms, and landslides.

Scale of Design: Nationwide assessment applied to a highly vulnerable and important city of

Biodiversity Net Gain: Avoiding development in hazardous areas or allowing only development consistent with low risks allows some lands within the city to support biodiverse habitats.

Economic Feasibility: The assessment and adaptation required considerable effort and coordination. The Global Environment Facility (GEF) funded the National Adaptation Programme of Action (NAPA) to enhance resilience to climate change impacts and natural disasters. Similarly, the Asian Development Bank supported the Disaster and Climate Risk and Vulnerability Assessment in 2018. Implementation incurs an opportunity cost for areas that are precluded from most or all development. Direct and indirect costs of disasters are expected to be far less than without the planning, both to people and the critically important hydropower infrastructure. There are little or no direct costs to land-use restrictions other than the normal administation of land-use codes.

Inclusive Governance: The process was fully transparent, interdisciplinary and inclusive. It assessed and mapped vulnerabilities across all development sectors represented by the five main working groups (Agriculture and Livestock, Forestry and Biodiversity, Health, Water Resources and Energy, and Natural Disasters and Infrastructure). After hazards and vulnerabilities were identified, the groups then worked on adaptation strategies that would best address those vulnerabilities.

Balanced Trade-offs: The opportunity costs of precluding development in high-hazard areas are far less than the costs of disasters to people and infrastructure.

Adaptive Management: The process resulted in a National Adaptation Programme of Action that identifed a broad range of adaptive options, a cost-benefit analysis, and priority setting for needed actions.

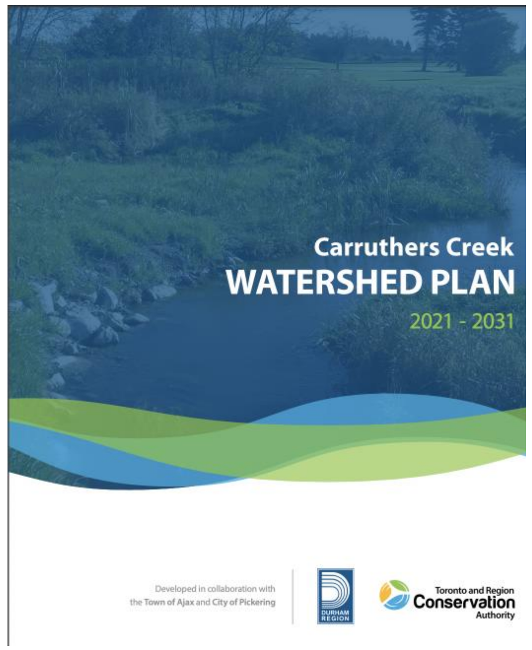
Mainstreaming and Stability: The NAPA, conceived within the framework of sustainable development planning, serves as an important tool to attract foreign assistance. The NAPA is intended to be applied as a 'living' document—the national government is dedicated to review the NAPA periodically after actual implementation of the first priority projects within the context of the Royal Government's FYP (5-Year Plan) cycle.

Reference: Bhutan National Adaptation Programme of Action, 2006. National Environment Commission Royal Government of Bhutan. GEF and UNDP

CASE STUDY #4
Overcoming fragmented governance at a watershed scale
Carruthers Creek Watershed Plan – Toronto, Canada

Societal Challenge Addressed: With a rapidly growing population surrounding Toronto, Canada's largest city, Carruthers Creek watershed lost a quarter of its natural land cover over a decade. Analysis of natural assets, climate hazards, and development stressors (natural cover, growth) raised concerns for flooding, impaired water flows and water quality, heatwaves and extreme weather threatening communities, ecosystems, and agriculture in the region.

Scale of Design: The Toronto Regional Conservation Authority (TRCA) emphasizes the watershed as an ecosystem-based scale of analysis. The TRCA, through the Carruthers Creek Watershed Plan, facilitates water sustainability and storm water management across multiple jurisdictions by establishing specific goals and objectives related to nature-based solutions such as land use, the water resource, and terrestrial heritage systems.



Biodiversity Net Gain: The project identifies biodiversity support and habitat creation, and carbon sequestration as co-benefits of watershed management.

Economic Feasibility: While the plan makes natural asset management and green infrastructure recommendations, there is little emphasis on the political and/or funding levers needed to move the plan to implementation.

Inclusive Governance: This plan showcases a more regional approach to NbS management utilizing inclusive governance and collaboration. Local and regional government agencies worked with other stakeholders (e.g., watershed residents, landowners, farmers, developers, golf course operators, and environmental non-government organizations), and the public. The Mississaugas of Scugog Island First Nation also engaged in the planning process.[1]

Balanced Trade-Offs: The CCWSP prioritization balances climate impacts on the watershed's natural hazard areas and water resource systems and to address resulting consequences for land use decisions and infrastructure. The plan established specific guidelines for ecosystem compensation to replace the loss of the non-significant natural features by permitted development.

Adaptive Management: Aquatic and terrestrial monitoring indicators, including surface and ground water quality, are used to update the watershed plan components.

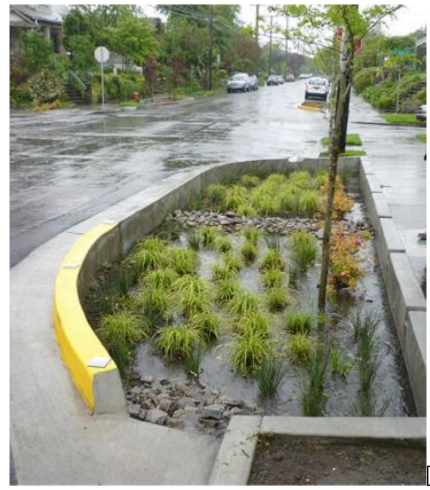
Mainstreaming and Stability: The plan's management framework recognizes the importance of coordinating management at the watershed scale and using green infrastructure as a key approach to addressing climate change adaptation and ecological integrity in the watershed. It illustrates the advantages and trade-offs of watershed governance and how more holistic conservation planning, in this case, through a regional conservation authority, can be used to better understand water systems, protect natural assets and advance green infrastructure in future development.

Contact: Toronto and Region Conservation Authority. carruthers@trca.ca

[1] It must be stated, that in many regions of Canada, First Nations territorial claims are still in dispute. Though still controversial and underexplored, NbS, at the territorial, bio-regional, and watershed scales may present a fruitful opportunity to learn from and work alongside First Nations, their traditional ecological knowledge, and territorial sovereignty/co-management opportunities.

Case Study #5
Green Infrastructure for stormwater management, Portland, Oregon USA

Societal Challenge Addressed:
Urban Flooding, Water Quality, Biodiversity, Heat Islands, Livability, Climate Change,



Scale of Design: Stormwater runoff causes risk within the existing combined sewer and stormwater systems. Through an integrated design of gray and green infrastructure including underground piping, ecoroofs, green streets, bioswales, raingardens, sumps and disconnected downspouts, Portland is removing and storm water from its sewer systems – reducing the number of combined sewer overflows into the Willamette River and providing water quality treatment and flow control for stormwater directly discharged to streams. Storm water management is required for both private development and public capital projects, on property and in the right-of-way. This large-scale implementation requires engagement across city departments to develop standards, implement projects, and provide ongoing maintenance of facilities.

Biodiversity Net Gain: Since 2000 about 59,000 trees have been planted, increasing the tree canopy by 9.3% in industrial, commercial and residential areas, and adding over 2,200 ac. (900 ha.) of tree canopy city-wide. In addition, over 550 eco-roofs covering over 38 ac. (15 ha.) have been planted benefiting stormwater management, urban heat reduction, pollinators, and birds.

Economic Feasibility: Detailed modeling of the combined sewer system determined that it can be more cost effective to reduce pipe surcharging that leads to basement sewer backup risk using green technology rather than upsizing existing pipes, in certain areas of the city. Portland funds its construction projects through borrowed revenue bonds and pays the debt service and principal on the bonds through the revenues from the city's sewer and stormwater rates.

Inclusive Governance: The City of Portland demonstrates a clear commitment and creative thinking through its outreach and communication and volunteer programs, its public/private partnerships, grant funding programs, and its collaborative planning and implementation with communities. Education, site visits, public meetings, demonstration projects, and 'fix it fairs' held in low-income neighborhoods providing workshops on simple retrofits, all help with finding community leaders and experts to advocate and ensure strong community support for becoming a leading sustainable city.

Balanced Trade-offs: With buy-in from residents, street parking has been reduced, an important factor for gauging support of the green streets initiative. Eco-roofs add to development costs, but also add public benefits in terms of urban heat reduction, air quality improvement, and pollinator habitat, and amenities for users of the new or redeveloped properties.

Adaptive Management:
Getting buy-in from different city departments, needing scientific research and external experts to quantify benefits, and challenges with green street designs all beset the initial efforts of the program. Monitoring and evaluation reports provide feedback and ensure effective programs are being implemented, programs are modified based on feedback and lessons learned.

Mainstreaming and Stability: The city's regulations have been fundamental in improving the quality of the river and addressing storm water management in response to National Pollutant Discharge Elimination System Permits, the Clean Water Act and the Safe Drinking Water Act standards. They have a Stormwater Management Manual for both new construction and retrofits, require green roofs in portions of the city, and have a strong "Green Street Stewards Program" that partners with community members. **Contact/Source:** https://www.portlandoregon.gov/bes/34598

Case Study #6
Viet Nam coastal communities adapt to climate change

Societal Challenge Addressed: Impoverished coastal communities in Viet Nam are impacted by frequent flooding and storms, with 60,000 houses damaged or destroyed each year causing huge economic impacts. The rural poor are at especially high risk given their reliance on natural resources for their livelihoods, particularly in agriculture and fisheries. This project strengthens storm and flood protection for coastal communities in Viet Nam through nationwide climate risk assessments, combining innovative architectural solutions through the design and construction of resilient housing with nature-based solutions by planting and rehabilitation of mangrove and Nipa Palm forests.

Scale of Design: The project covers 3260 km of coastline and all 28 coastal provinces of Viet Nam with techniques applicable to expand to other SE Asian nations.

Biodiversity Net Gain: Coastal fisheries, mangrove, and Nipa Palm ecosystems are restored enhancing biodiversity.

Basket boat rides in Cam Thanh nipa palm forest (Photo: baoquangnam.vn)

Economic Feasibility: Storm and flood resilient housing designs will be showcased, benefitting up to 20,000 people. To create storm surge buffers, 4,000 hectares of mangroves will be planted creating local jobs. Fisheries supporting coastal livelihoods and ecotourism opportunities will be enhanced through basket boat tours into mangrove and palm forests creating stable jobs for women and men and protecting infrastructure.

Inclusive Governance: This is a project between The United Nations Development Program (UNDP), in collaboration with the Vietnamese government and the Green Climate Fund (GCF). Local community members are engaged in project design, implementation and maintenance.

Balanced Trade-offs: Local communities are learning about multiple values of mangroves versus short term gains from mangrove destruction and shrimp farming. In addition, it has been realized that over exploitation of Nipa Palms not only reduces coastal stability but also limits eco-tourism opportunities.

Adaptive Management: Increasing storm intensities causing winds, storm surge, and flooding will determine if housing design are adequate to protect housing

Mainstreaming and Stability: By engaging residents in project design and enhancing understanding of the ecological values and sustainable management of mangroves and Nipa Palm forests, the project has helped coastal residents to stabilize their livelihoods and get involved in ecological and environmental protection.

Contact/Source:
https://www.greenclimate.fund/project/fp013

Case Study #7
In Defense of Biodiversity in Intag, Ecuador

Societal Challenge Addressed: The community of Intag is faced with the choice of extracting significant copper reserves versus basing their economy and future growth on valuing the ecosystem services of the area.

	Agricultural lands	Grasslands	Lakes/Rivers	Pasture	Pasture/Agricultural	Bamboo	Cloud Forest
Aesthetic and Recreational	x		x		x		x
Biological Control		x			x		x
Cultural and Spiritual							
Disturbance Regulation							
Erosion Control	x	x					x
Gas and Climate Regulation	x	x				x	x
Genetic Resources							x
Habitat Refugium & Nursery		x	x			x	x
Medicinal Resources							
Nutrient Cycling	x						x
Pollination	x	x			x		x
Raw Materials	x					x	x
Soil Formation	x	x		x	x	x	x
Waste Treatment		x	x			x	x
Water Regulation		x	x				x
Water Supply		x	x			x	x
Food Production	x	x	x		x		x

x — Ecosystem service produced and valued in this report

Ecosystem service produced but **not** valued in this report

Ecosystem service not produced by land cover class

Scale of Design: 150,000 hectares – 2 globally significant biodiversity hotspots. The Ecosystem Valuation methodology used in the Intag community is transferable globally.

Biodiversity Net Gain: The seven land-cover types analyzed are: cloud forests, agricultural lands, pastures, a mix of agricultural and pastures, rivers, and lakes, native Andean alpine grasslands, and native bamboo.

Economic Feasibility: Intag government has estimated 318 million tons of copper ore in the ground valued at $85 billion (2011). Yet copper mining has significant downstream landscape and social costs as well as remediation costs which have been excluded from mining economic analysis. The Ecosystem Service Valuation (ESV) found that 17 of 23 ecosystem services across the land-cover types in Intag provide the regional and national community an average of $447 million in yearly benefits.

Inclusive Governance: Ecuador's innovative constitution gives rights to nature. "Nature has the right to exist, persist, maintain and regenerate its vital cycles, structure, functions and its processes in evolution." Ecuador's mining law states that "…all mining investors must respect the right to the communities' information, participation, and consultation regarding environmental management of all mining activities." Many members of Intag's community have worked over 2 decades to develop and implement an alternative and prosperous vision of the region's economy, which does not include mining. In 2022, Intag community leaders used the 2011 ESV report to support an amicus brief in a lawsuit against the Ecuadorian government over mining concessions. This case is headed to Ecuador's Supreme Court, where it is likely to establish a key precedent for the fate of other cloud forests in the country.

Balanced Trade-offs: The overall conclusion of the report is that economic development within the Intag region is best achieved by tapping the vast value that ecosystem goods and services. Well managed, the resources of the Intag region can provide for sustainable, equitable and prosperous development in the region and nation. Copper development will carry great costs. It is a risky venture dependent upon global economic trends.

Adaptive Management: This study provides decision-makers an opportunity to shift from addressing issues and challenges at a single jurisdiction and single issue to taking an integrated approach of developing a sustainable economy in which natural capital is an integral part of wise investments that maintain or rise in value over time.

Case Study #8

Implementing Nature-based Solutions at Scale – Blue Forest Conservation – Western USA

Societal Challenge Addressed: Wildfire risk, flooding, damage to infrastructure, water scarcity, threaten communities and infrastructure.

Scale of Design: Pilot project to exemplify ways of partnering with public agencies to fund forest restoration activities up-front with private investment dollars thereby increasing the scale of project activity and demonstrating the efficacy of the program. The success of this $4million pilot project brought in private investor funds of $25 million. Potential to expand.

Biodiversity Net Gain: Reducing loss of forest to wildfire maintains existing wildlife habitats while increasing habitats for those species requiring less dense forest structure. Aspen and meadow restoration and removing invasive weeds enhance plant and animal biodiversity in habitats associated with those ecosystems.

Economic Feasibility: Grants from private foundations that agreed to a 1% return on their investment, paved the way for other private investors who agreed to a 4% return on investment. Benefiting infrastructure entities, paid the investments back with proceeds generated from avoided wildfire costs, and improved water quality and quantity which resulted in increased hydropower production. Benefiting entities used funds generated from thinning activities to pay contracts and pay for additional ecosystem restoration work. Ecosystem valuation cost-benefit accounting convinced benefiting and investing entities that their return in benefits outweighed their contribution to the project.

Inclusive Governance: Blue Forest Conservancy coordinated with a wide variety of partners and stakeholders, both public, and private, to accomplish this project. Collaborative efforts included developing an economic analysis, determining appropriate engagement and contracting mechanisms, and bringing innovative financial models to market.

Balanced Trade-offs: Blue Forest Conservation weighed the cost of innovation versus scaling current models of forest landscape restoration and found that the use of The Forest Resiliency Bond allowed public agencies to increase the pace and scale of forest landscape restoration. Traditional funding mechanisms are insufficient to tackle the scale of the wildfire problem.

Adaptive Management: Figuring out how public agencies could interact with private funders was both a challenge and inspiration. It took several years to figure out solutions to determine a contracting process to meet the individual requirements of all parties. This included being willing to drop a "pay for performance" requirement of investors because of a lack of appropriate criteria.

Mainstreaming and Stability: This pilot project paved the way for the future use of this instrument for nature-based solutions to restore landscapes. Two government agencies and seven other organizations signed an MOU to form a forest partnership. In addition to private finance capital, blended finance mechanisms can also influence the public sector to play a catalytic role and participate in new forms of financing to benefit its own goals and objectives.

Source: https://www.convergence.finance/resource/the-forest-resilience-bond-case-study/view

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