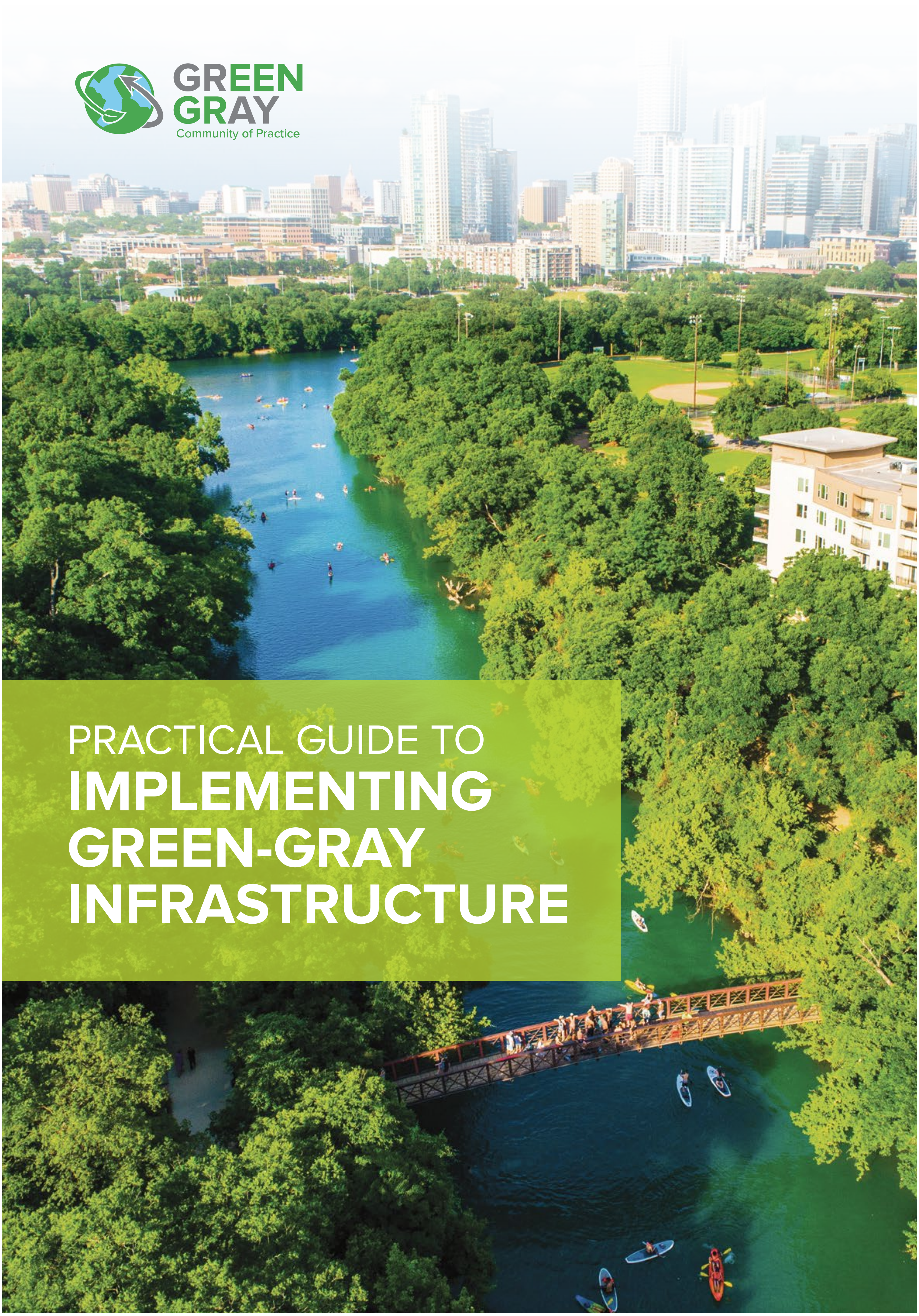
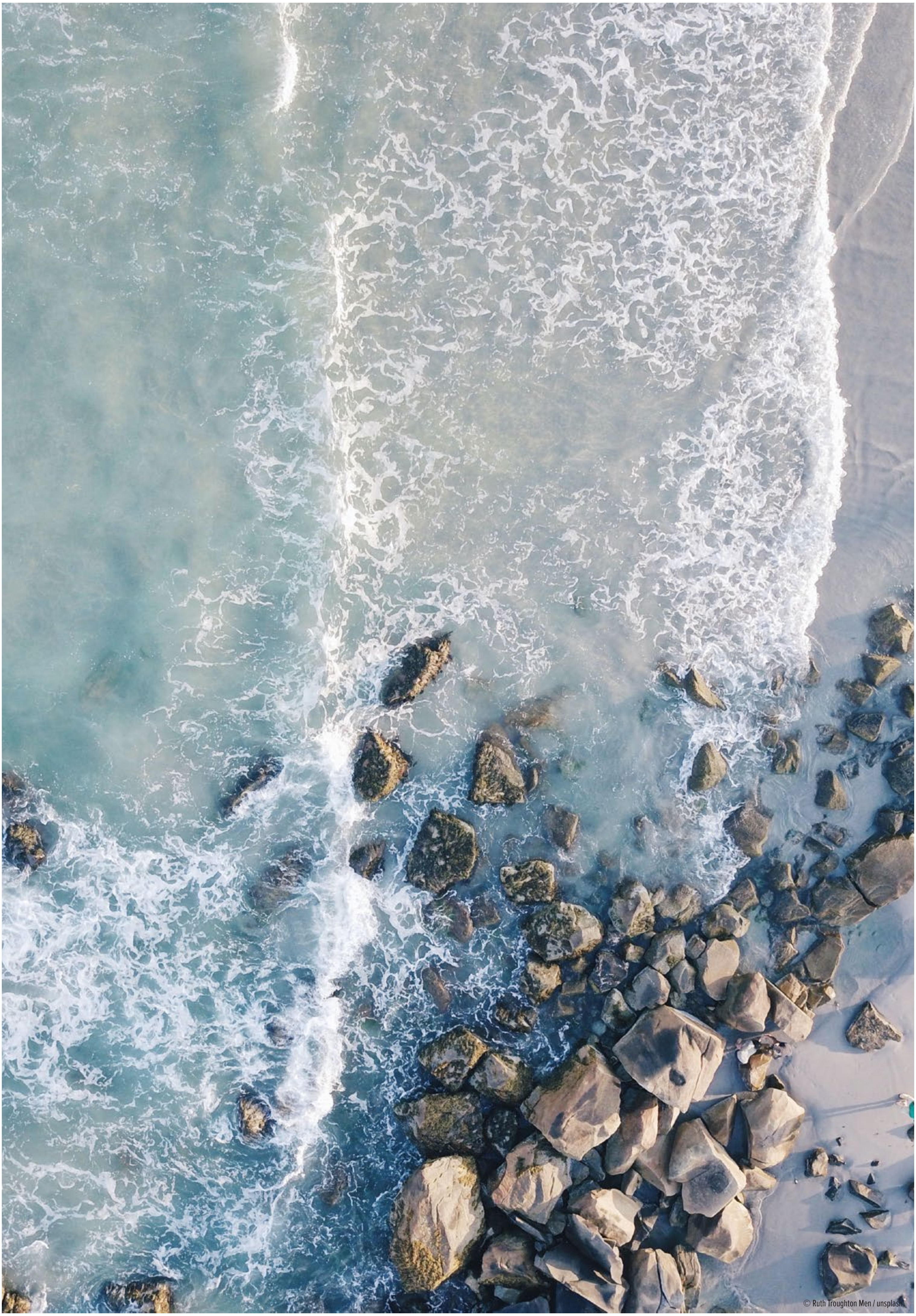
GREEN GRAY
Community of Practice



PRACTICAL GUIDE TO IMPLEMENTING GREEN-GRAY INFRASTRUCTURE



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Conservation International works to spotlight and secure the critical benefits that nature provides to humanity. Unique and valuable experience with ecosystem conservation and restoration, community co-design, and stakeholder leadership allows us to advise and collaborate with partners to lead green-gray initiatives around the world.

The *Green-Gray Community of Practice,* led by Conservation International is a collaboration across the conservation, engineering, finance, and construction sectors to generate learning and innovation to achieve climate adaptation benefits for communities, their future generations, and biodiversity.

This document has been published with:

Friends of Ecosystem-based Adaptation (FEBA), recognizing the critical role of green-gray infrastructure in advancing the goals of ecosystem-based adaptation, is a founding member of the Green-Gray Community of Practice. Led by IUCN, FEBA is a global collaborative network of more than 90 agencies and organizations working together to share experiences and knowledge, to improve the implementation of ecosystem-based adaptation activities on the ground, and to raise awareness and understanding of ecosystem-based adaptation in planning processes and multilateral policy frameworks.

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If you want to learn more about the guide and/or connect with its authors, please regularly check in at *https://www.conservation.org/projects/global-green-gray-community-of-practice* for updates on workshops and to become a member of the Global Green-Gray Community of Practice.

Our commitment to pre-competitive collaboration

In the private sector, ideas are money, and competitive advantage is often created and maintained by keeping plans, intentions, or strategies secret. However, to truly confront the seemingly insurmountable environmental challenges facing our planet, sometimes collaboration serves society better than competition does – and can be more profitable, too.

Complex challenges demand collective understanding and action. Particularly when it comes to risk management, sharing knowledge in a pre-competitive space is crucial for accelerating the pace at which green-gray projects can be designed, built, and managed to meet needs. Overcoming barriers and finding solutions to common problems will move everyone working on green-gray infrastructure forward.

The Global Green-Gray Infrastructure Community of Practice is a forum for collaboration across the conservation, engineering, finance, and construction sectors to generate and scale-up green-gray climate adaptation solutions. The multi-disciplinary Community of Practice has grown to over 70 member organizations spanning the globe, representing non-profit, academic, government and private organizations. We are working to:

- share ideas and facilitate collaboration;
- innovate and pilot new approaches;
- expand science, engineering, and policy activity; and
- implement and learn from projects in a multitude of geographies and settings.

In this Global Green-Gray Community of Practice, the private sector, non-government organizations, and academics share their needs and experiences, learning from one another about what works, what does not and what has not worked yet. Pre-competitive consortiums – such as this community of practice – create an opportunity to bring diverse stakeholders together and exchange perspectives that are integral to ensuring project success. By drawing on multidisciplinary expertise, collaborative outputs such as this Practical Guide can ensure the inclusion of diverse perspectives on ecological, social, economic, financial, policy, site assessment, design, engineering, construction, monitoring, and management considerations. In addition, pooling resources generates buy-in from contributors, reduces costs, creates more universal and accessible tools, and can bolster the credibility of outputs and the communication of key messages and recommendations.

We appreciate the collaborative spirit of all contributors who have made this practical guide possible. As the green-gray community of practice continues to build the knowledge base about how to implement green-gray infrastructure solutions, we are committed to pre-competitive collaboration to create fertile ground for innovation and new partnerships within and across sectors.

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EXECUTIVE SUMMARY

We all want a greener, safer, healthier world. Now and for future generations.

To achieve that outcome, we need to accelerate innovation and learning, and apply nature-based solutions such as green-gray infrastructure as a climate adaptation and disaster risk reduction strategy.

Combining "green" ecosystem conservation and restoration with "gray" conventional engineering approaches – using a hybrid green-gray approach – can generate more benefits for people and nature than either strategy applied alone. Green-gray infrastructure solutions are emerging but not yet in common use globally. This Practical Guide to Implementing Green-Gray Infrastructure is a step toward changing this.

In the next 20 years, an estimated US$ 94 trillion will be spent on infrastructure, globally. The trillions of dollars expected from post-COVID recovery investments provide an opportunity to influence the trajectory of those investments to build back better. Over the next 18 months, there will be an opportunity to lay the foundations for making recovery investments in infrastructure more sustainable and built to increase biodiversity and achieve the outcomes of climate adaptation and mitigation.

Our goal is to apply the tools, experiences, and techniques outlined in this Practical Guide to Implementing Green-Gray Infrastructure to leverage near-term investments to fundamentally shift the practice of civil engineering and construction towards designing and building with nature, using a hybrid green-gray infrastructure approach, that provides benefits of biodiversity and community climate adaptation.

In 2021 we will:

1. learn from and increase awareness of existing green-gray projects;

2. recommend design guidelines for nature-based and hybrid infrastructure solutions for effective results and long-term environmental, economic and social benefits;

3. design innovative models to drive investment into green-gray adaptation solutions for specific industries and infrastructure types; and

4. disseminate new tools, best practices, and investment opportunities to accelerate implementation of nature-based solutions.

Please, put this guide to use and join us!

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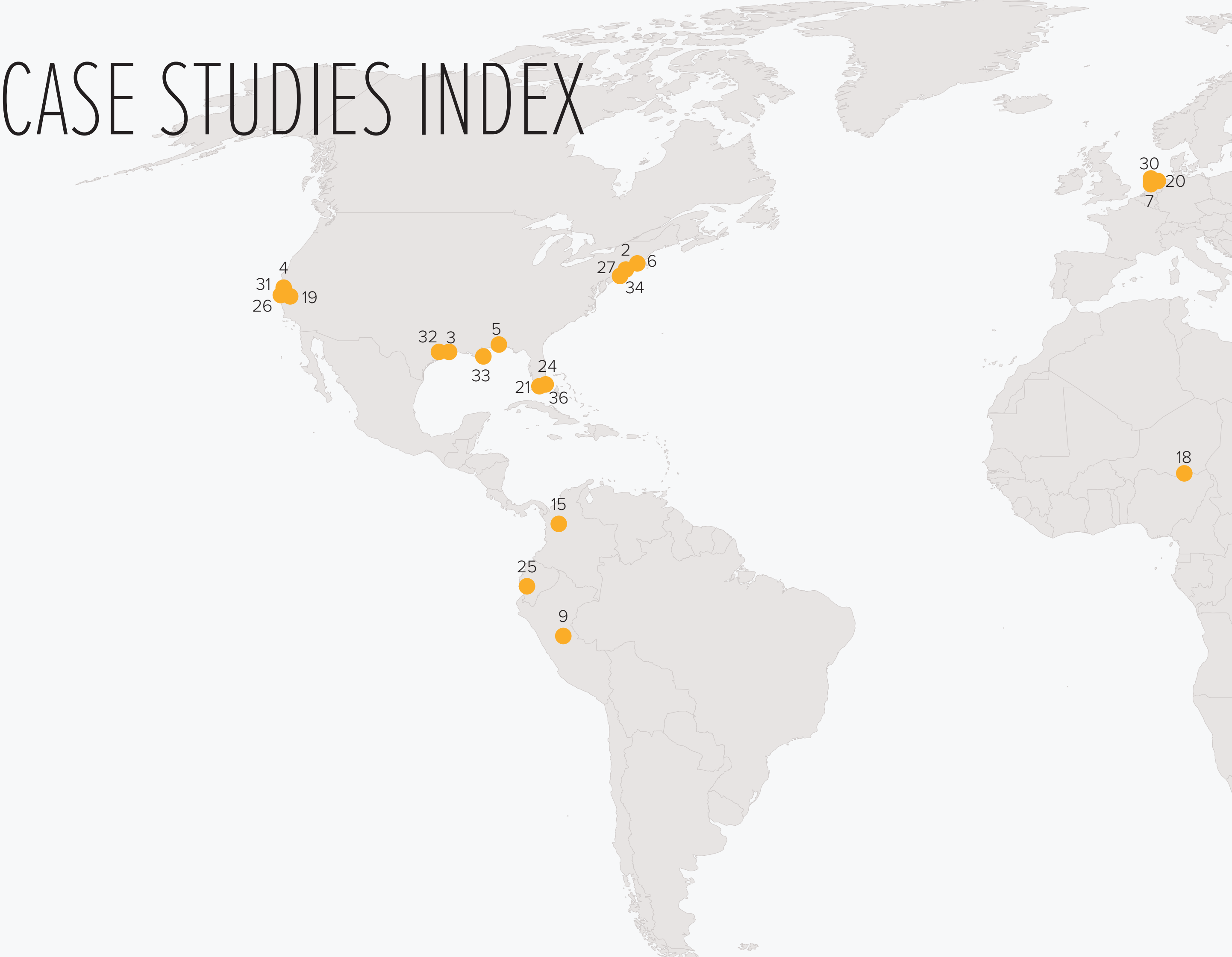

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INTRODUCTION

Climate change is one of the most dangerous threats facing humanity. Its impacts have already caused devastation to communities in many parts of the world, affecting people's lives and infrastructure in an unprecedented manner. The number of climate-related disasters has tripled in the last 30 years and more than 20 million people a year are forced from their homes by climate change.[1] The United Nations Environment Programme estimates that, by 2030, adapting to climate change and coping with damages will cost developing countries $140-300 billion per year.[2]

Simultaneously, nature is declining at unprecedented rates and species extinctions continue to accelerate, thus threatening the functioning of ecosystems as the foundations of human livelihoods, economies, food security, and much more.[3]

There is a critical need to find preemptive, innovative, and scalable climate adaptation solutions that protect, manage, and restore nature - now and for future generations.

Green infrastructure such as wetlands and forests can provide nature-based adaptation solutions for flood control and water security, alongside a host of co-benefits to biodiversity, livelihoods, and more. However, for communities exposed to extreme climate and disaster risks, green infrastructure alone may not provide adequate protection. Conventional gray infrastructure, in the form of seawalls and dams, can provide immediate protection but is often prohibitively expensive to build, maintain, and replace, and can create unintended negative impacts. By blending "green" conservation with "gray" engineering techniques, communities can incorporate the benefits of both solutions, while minimizing the limitations of using either green or gray infrastructure individually.

Green-gray infrastructure combines conservation and/or restoration of ecosystems with the selective use of conventional engineering approaches to provide people with solutions that deliver climate change resilience and adaptation benefits. This green-gray infrastructure design approach can apply in coastal, freshwater, and terrestrial settings and accomplish a variety of project goals.

1 Oxfam International (2020). *5 natural disasters that beg for climate action*. [Website] https://www.oxfam.org/en/5-natural-disasters-beg-climate-action

2 *ibid*

3 IPBES (2019). Summary for policymakers of the *Global Assessment Report on Biodiversity and Ecosystem Services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. Díaz, S. Settele, J., Brondízio E.S., Ngo, H.T., Guèze, M., Agard, J., Arneth, A., Balvanera, P., Brauman, K.A., Butchart, S.H.M., Chan, K.M.A., Garibaldi, L.A., Ichii, K.., Liu, J., Subramanian, S.M., Midgley,G.F., Miloslavich, P., Molnár, Z., Obura, D., Pfaff, A., Polasky, S., Purvis, A. , Razzaque, J., Reyers, B., Chowdhury, R.Roy, Shin, Y.J. Visseren-Hamakers, I.J. Willis, K.J. and Zayas, C.N. (eds.). Bonn, Germany: IPBES secretariat. 56 pp. https://doi.org/10.5281/zenodo.3553579
The report also highlighted the fundamental role of natural ecosystems in "reducing vulnerability to climate-related extreme events and other economic, social and environmental shocks and disasters".

GREEN-GRAY PROJECT GOALS

Flood Management. Many settlements, infrastructure, and agricultural areas are located near rivers or other bodies of water. Extreme weather events on site or upstream can lead to flooding damage, loss of life, and service interruptions.

Food Security. Communities rely on consistent availability and access to nutritious food. Dependency on external supplies and distribution networks or conventional agricultural practices can stress local food systems, especially in the face of climate change and other stressors.

Water Security. An adequate and reliable source of water is imperative to a community's well-being, livelihoods, and productivity.

Clean Water. Contaminated water supplies and untreated or uncontrolled runoff endangers human and ecosystem health and can pose problems for industrial, agricultural, and aquaculture production.

Erosion Control. Steep slopes and degraded areas are prone to landslides and related hazards which can undermine the safety and integrity of roads, buildings, and other infrastructure and endanger lives. For coastal examples of erosion control, see case studies categorized under Coastal Protection.

Coastal Protection. Coastal areas are susceptible to erosion, storm surges, damage from wave energy, and sea level rise.

Green-gray infrastructure approaches are emerging locally as innovative nature-based solutions but are not yet in common-use by engineers and practitioners globally. Barriers to the upscaling of green-gray approaches include lack of understanding, as well as rigid regulatory or funding policies (see Chapter 10). Fundamental to the successful application of green-gray infrastructure projects is an enabling environment that includes governance systems, socio-economic factors, financing, cultural aspects, as well as behavioral change and acceptance. Though the development of appropriate green-gray approaches will be context- and site-specific, the general set of tools and principles described in this Practical Guide are universally applicable.

This Practical Guide includes information useful at any stage in the development of a green-gray infrastructure project: identifying project goals, site selection, engaging stakeholders, identifying financing strategies, building the business case, design development, construction, monitoring and maintenance and recommending policies to enable, fund or require green-gray implementation. This Practical Guide applies to different regions, countries, and geographic settings, because many of the challenges and applicable solutions are similar across the globe.

This version of the Practical Guide is a collaborative effort of the Global Green-Gray Community of Practice and will be updated, based on user feedback and experiences implementing green-gray infrastructure projects. The guide is available for download at https://www.conservation.org/projects/global-green-gray-community-of-practice

This is a living document and the Community of Practice will continue to improve and update the guide as new information is discovered and as design techniques evolve.

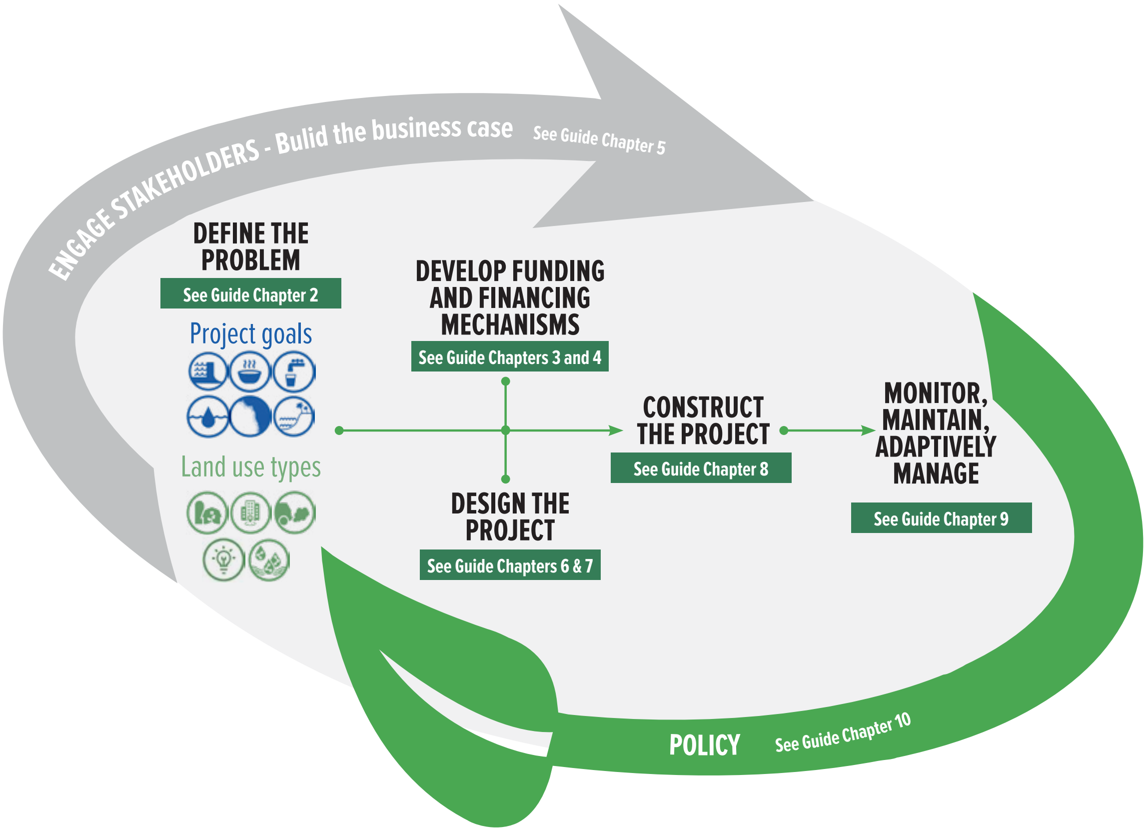
PURPOSE OF THE PRACTICAL GUIDE

This Practical Guide provides tools for identifying, funding, financing, planning, designing, constructing, and monitoring green-gray infrastructure projects, with the goal of increasing the resilience of vulnerable communities. These tools and case studies have been collected based on experiences of members from the Global Green-Gray Community of Practice, and includes input from local communities, local and national governments. The Practical Guide is intended to be used as a resource for selecting, funding, designing, and constructing green-gray infrastructure projects, as well as a tool for education and outreach.

WHO IS THE TARGET AUDIENCE?

This Practical Guide will be a tool for local and national governments, the private sector, consultants, and civil society organizations including:

- Engineers, architects, designers, and planners in government agencies and planning bureaus, local contractors, and finance organizations – such as development banks;
- Policy makers in local, regional and national governments;
- Environmental practitioners in non-government organizations.



HOW TO USE THE PRACTICAL GUIDE?

This document is divided into ten chapters, each begins with the chapter's purpose and objective.

1. Green-gray infrastructure solutions – defines the green-gray adaptation approach, benefits, and example applications in coastal, freshwater, and terrestrial settings.
2. Identifying and selecting sites – describes a process and tools for evaluating a community's climate vulnerability, engaging stakeholders and evaluating potential project sites.
3. Economic evaluations – introduction to approaches, analysis and rhetoric to familiarize green-gray practitioners with relevant principles.
4. Funding and financing – describes finance concepts relevant to green-gray infrastructure, so that non-economists and/or non-financiers can engage with financial practitioners.
5. Engaging stakeholders and building the business case – is a priority to catalyze a paradigm shift in development towards green-gray infrastructure solutions.
6. Design development – provides steps to develop concept sketches into ready-to-build, approved design plans.
7. Engineering guidance – reviews current engineering guidance applicable to green-gray design to inform decisions and to identify gaps for future research and development.
8. Construction – provides alternative construction models, activities, and potential risks to consider early in the design development phase.
9. Monitoring, maintenance, and adaptive management – introduces a multi-step feedback process linking project monitoring and evaluation frameworks, maintenance strategies, and adaptive management.
10. Policy – recommends how to include green-gray infrastructure into global, national, and local policy frameworks.

This green-gray guide identifies key goals a practitioner may be seeking to achieve, and where green-gray solutions, examples, or tools are relevant. Similarly, the guide identifies land use types where practitioners may be working and which solutions, examples, or tools are relevant to those specific land uses.

Icons for each identified goal and land use type are included throughout the guide as a visual cue to relevant information for practitioners. The following defines our common understanding of the land use type linked to each icon.

LAND USE TYPES

Urban Development. The high density of both population and conventional infrastructure in cities requires innovative solutions to reduce water and airborne pollution, reduce flood risks and urban heat island effects, and manage other hazards.

Transportation. The transport of people and goods via highways, roads, and waterways can be interrupted by flooding and landslides.

Water Supply & Sanitation. Managing the supply and purification of water for household, irrigation, and industrial applications as well as wastewater treatment, including gray and black water, is an essential service for municipalities. Conventional water infrastructure such as reservoirs and water treatment plants can work alongside ecosystems that filter and store water supplies.

Rural Development. Settlements outside of cities often depend directly on ecosystem services for livelihoods.

Energy. Energy conveyance and generation, through wind, solar, and hydropower for example, which rely on natural resources and processes.

Appendix 1 describes other approaches similar to green-gray infrastructure and a glossary of key concepts and terms.

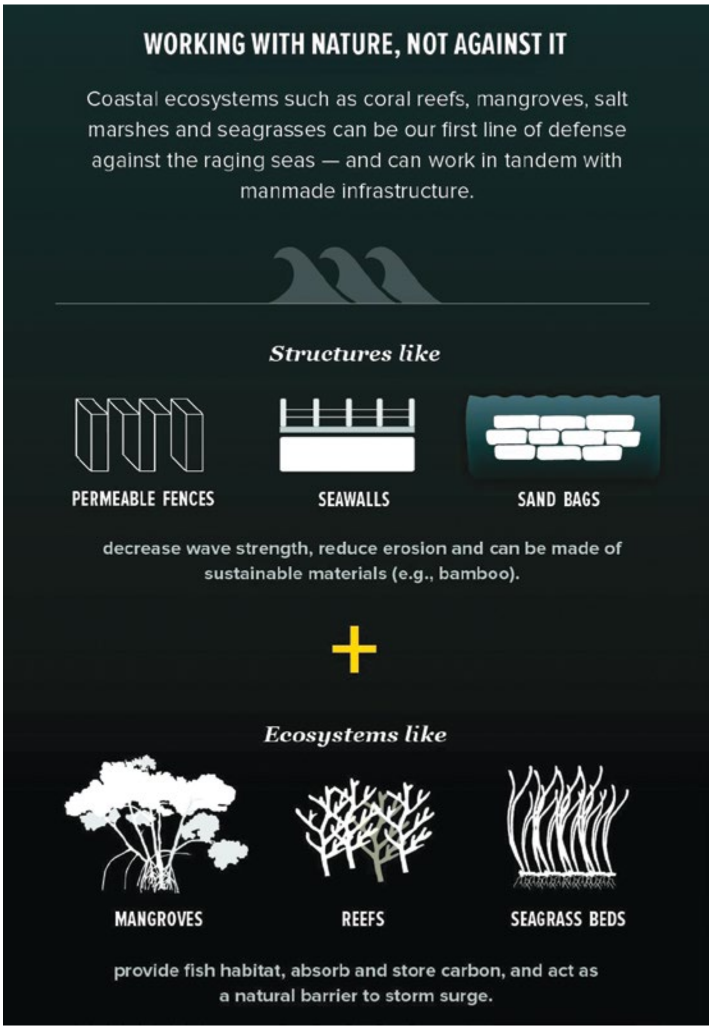
1. GREEN-GRAY INFRASTRUCTURE SOLUTIONS

As the climate changes, communities need to adapt to build social, ecological, and economic resilience. It is essential to identify effective adaptation strategies, appropriate to specific settings that take advantage of ecosystem structures and processes that form the basis for life-sustaining ecosystem services.

This module defines the green-gray adaptation approach, benefits, and example applications in coastal, freshwater, and terrestrial settings.

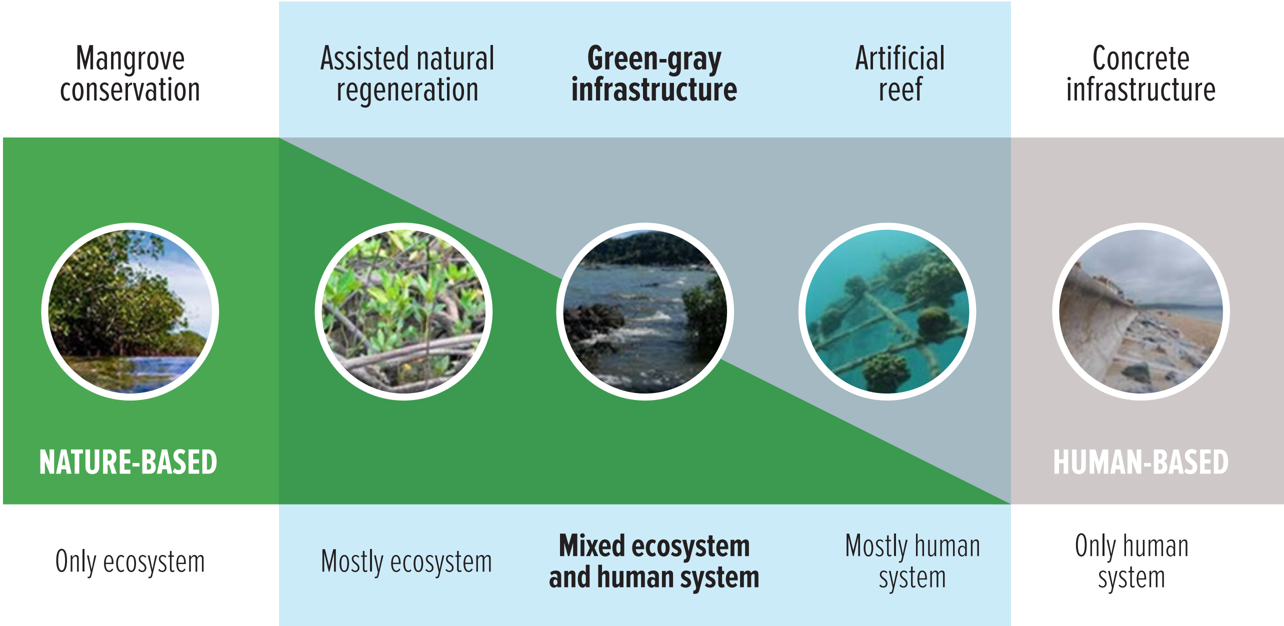
WHAT IS GREEN-GRAY INFRASTRUCTURE?

An example of green-gray infrastructure is where natural coastal ecosystems – such as mangroves, salt marshes, inter-tidal flats, seagrasses, and coral reefs – are combined with gray infrastructure such as breakwaters, to combine the values of wave attenuation and flood control of natural ecosystems with the benefits of engineered structures. In addition, the conservation and restoration of natural coastal ecosystems can extend the lifespan of gray infrastructure, while also supporting fisheries, regulating water quality, and sequestering carbon. **The combined solution can therefore be more comprehensive, robust, and cost-effective than either solution alone.**



SPECTRUM FROM GREEN TO GRAY

These solutions draw upon the best of our engineering achievements to create hybrid solutions along the green-to-gray spectrum



A broad range of potential solutions exist across the spectrum from green to gray infrastructure, where different combinations can be matched to the political, social, cultural, economic and natural systems at a site. On one end of the spectrum, as an example, mangrove restoration and conservation, as a purely green-infrastructure solution may be the most appropriate, or the best-fit approach for coastal protection. At the other end of the spectrum, in our most urban and built environments, a gray-only approach, such as seawalls, may be the best or only alternative. Green-gray infrastructure is an innovative approach drawing upon expertise and solutions from both ends of this spectrum.

The type of solution selected will generally depend upon (1) the project goal(s); (2) land use(s) in the vicinity; and (3) the ecosystem(s) native to the site. Other considerations such as the project cost, desired performance, and local policy and regulations, will also affect the decision about what type of solution to select. Monitoring, maintenance, and adaptive management are also integral to green-gray infrastructure project financing, design, and implementation.

Green infrastructure refers to natural systems including forests, floodplains, wetlands and soils that provide additional benefits for human well-being, such as flood protection and climate regulation.

Gray infrastructure refers to structures such as dams, seawalls, roads, pipes or water treatment plants.

Key elements of green-gray infrastructure projects:

1. Ecosystems are conserved and/or restored to provide measurable social, environmental, and economic benefits;
2. Includes selective integration of a conventional engineering approach; and
3. Provides a climate resilience and/or risk reduction benefit.

Critical elements that define the green-gray approach[4]:

1. Using science and engineering to produce operational efficiencies;
2. Using natural processes to maximize benefits (i.e. ecosystem services);
3. Increasing the value provided by projects by including social, environmental, and economic benefits; and
4. Using collaborative processes to organize, engage, and focus interests, stakeholders, and partners.

4 Adapted from Bridges, T.S., Bourne, E.M., King, J.K., Kuzmitski, H.K., Moynihan, E.B. and Suedel, B.C. (2018). *Engineering With Nature: an atlas*. Vicksburg, MS, USA: U.S. Army Engineer Research and Development Center. http://dx.doi.org/10.21 079/11681/27929.

WHAT ARE THE BENEFITS OF USING GREEN-GRAY INFRASTRUCTURE?

Green-gray infrastructure projects can provide multiple benefits, depending upon the project and the setting, such as:

- Climate change adaptation;
- Disaster risk reduction;
- Operational and maintenance cost reductions for infrastructure;
- Erosion reduction and coastal protection;
- Water security;
- Flood management;
- Food security, for example due to new agroforestry opportunities, sustainable aquaculture production, or enhanced irrigation water supply;
- Water quality improvements by filtering pollutants;
- Reduced air pollution;
- Job creation and support of local livelihoods;
- Cultural and educational opportunities for engaging with nature;
- Improvement of human health and wellness by reducing urban heat island effects, providing outdoor space for recreation, and reducing risks for future pandemics[5]; and
- Carbon sequestration and a low carbon footprint compared to conventional alternatives.

Green-gray infrastructure can provide a cost effective and longer lasting alternative compared to a purely gray infrastructure solution (See Chapter 3). The enhanced ecosystem services provided as a part of green-gray infrastructure through the conservation and/or restoration of ecosystems offer key co-benefits to infrastructure projects. When combined as part of a disaster risk reduction project, green-gray infrastructure also improves the adaptive capacity of a community by providing community organization training and supplemental support for livelihoods.

WHERE CAN GREEN-GRAY INFRASTRUCTURE BE APPLIED?

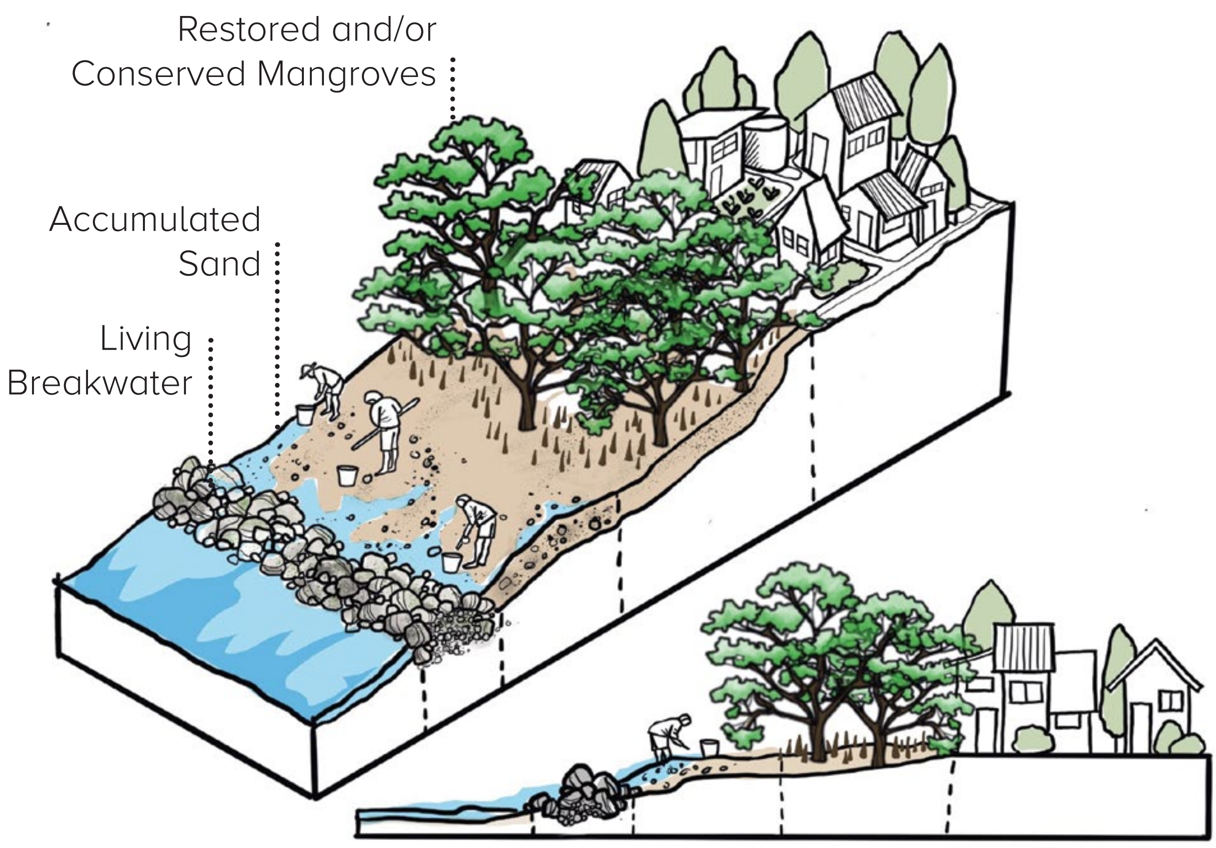
The green-gray infrastructure design approach can be applied in coastal, freshwater, and terrestrial settings and as an adaptation strategy for different land use types such as water and sanitation, urban and rural development, transportation, and for the energy sector. Similarly, as defined in the introduction, green-gray design strategies can achieve specific goals, such as food security, clean water, water security, coastal protection, erosion control, and flood management. The following built and multi-functional examples are organized by setting (coastal, freshwater or terrestrial), and icons indicate for each example and case study, the relevant goals and land use types where the green-gray solution could apply. These goals and land use types are meant only to be representative, but not inclusive of all the potential benefits or applications of green-gray solutions.

5 Dobson, A.P., Pimm, S.L., Hannah, L., Kaufman, L., Ahumada, J.A., Ando, A.W., Bernstein, A., Busch, J., Daszak, P., Engelmann, J., Kinnaird, M.F., Li, B.V., Loch-Temzelides,T., Lovejoy, T., Nowak, K., Roehrdanz, P.R., Vale, M.M. (2020). 'Ecology and economics for pandemic prevention.' *Science*: 369 (6502): 379-381. DOI: 10.1126/science.abc3189 https://science.sciencemag.org/content/369/6502/379/tab-pdf

COASTAL
GREEN - GRAY EXAMPLES

OYSTER REEFS / LIVING BREAKWATERS

reduce wave energy, facilitate sediment accumulation, and encourage colonization by shellfish to diversify livelihoods of local community members. While conventional breakwaters may be made from stone, concrete, or other building materials, a living breakwater intentionally incorporates natural habitat components, while still providing protection to the coastline. Living breakwaters provide opportunities for settlement and colonization by shellfish by creating complex structural components that provide shelter and habitat for various marine and aquatic species.



CASE STUDY 1:
LO-ONG AND BACJAWAN NORTE LIVING BREAKWATER

Location: Lo-ong and Bacjawan Norte, Iloilo, Philippines

Project Partners: Conservation International, Bechtel

Project Funder: French Facility for Global Environment

COASTAL PROTECTION · RURAL DEVELOPMENT · COASTAL

Photo source: Conservation International

Project Description: Living breakwaters were constructed as shallow, low profile rubble mounds with the objectives of (1) reducing wave energy to encourage sediment accumulation where mangrove seedlings could establish and thrive, and (2) colonizing the breakwater with shellfish to support livelihoods. Existing shellfish communities and the rock structures attract larvae that build up, over time, to form a complex and hard surface that dissipates wave energy.

In Lo-ong, two approximately 40 meter long, living breakwater sections were placed in a location where severe beach and cliff erosion had occurred. In Bacjawan Norte, an approximately 80 meter long, living breakwater made of a shallow rock mound was constructed to provide livelihood support through shellfish colonization and to trap sediments for mangrove restoration. The new structures facilitate sediment accumulation and reduce wave energy for mangrove rehabilitation, while natural colonization by shellfish enhances the livelihoods of local community members, particularly women and children, who harvest shellfish in the area. The additional livelihood benefits incentivize long-term maintenance of the living breakwater structures.

Ecosystem services restored or conserved: Restoration of mangroves, contributing to enhanced fisheries and regulation of floods.

Conventional engineering approach: Shallow, low profile rock breakwaters.

What makes this a good green-gray example? The breakwaters and mangroves have slowed the rate of beach and cliff erosion and the living breakwaters extend and expand the sediment retention and the mangrove restoration area.

CASE STUDY 2:
STRATFORD POINT LIVING SHORELINE: RESTORING COASTAL HABITATS TO MAINTAIN RESILIENCY AND FUNCTION

Location: Stratford, Connecticut, USA

Project Partners: Jennifer Mattei, Sacred Heart University Department of Biology, James O'Donnell, UConn Connecticut Institute for Resilience and Climate Adaptation (CIRCA) and Department of Marine Sciences, Kimberly Bradley, UConn CIRCA

Project Funders: U.S. Army Corps of Engineers Connecticut In-Lieu Fee Program, CIRCA Matching Funds, NOAA 2017 Coastal Resilience Grant

COASTAL PROTECTION | URBAN DEVELOPMENT | COASTAL

Source: Dixon, 2019[6]

Project Description: To create more resilient shorelines, enhance wildlife, and provide erosion control for coastal communities, precast concrete reef balls, coastal dune restoration and enhancement, and cordgrass marsh were constructed as a green-gray living shoreline. Precast concrete reef balls act as an artificial reef, reducing wave energy and interrupting the transport of sediments to slow the erosion of the inter-tidal zone, while also increasing accretion to improve inter-tidal marsh settlement. Marsh construction and restoration included planting 1.2 hectares of low marsh with smooth cordgrass and 0.6 hectares of high marsh with saltmeadow cordgrass. While coastal dune habitat was present, it was significantly deteriorated and therefore, enhanced through the further restoration of beachgrass and switchgrass. A long-term project monitoring plan has documented wave energy dissipation and fine-grained sediment accretion as a result of the concrete reef ball installation.

Ecosystem services restored or conserved: Salt marsh and sand dunes restored for erosion control.

Conventional engineering approach: Precast concrete "reef balls" as artificial reef

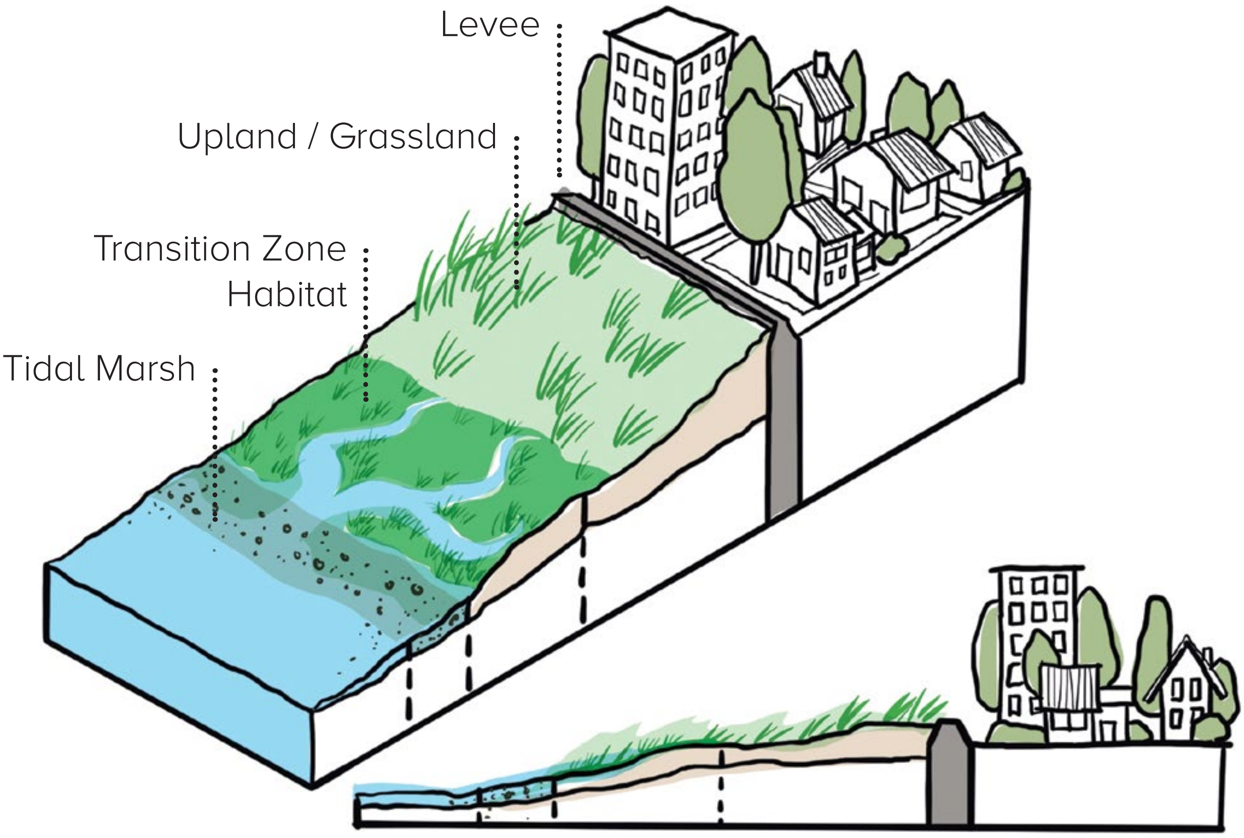
What makes this a good green-gray example? Project outcomes include climate change resilience with regard to storms, sea level rise and carbon sequestration, greater habitat connectivity, increased habitat for species of concern and water quality improvement. This project is one of the first living shoreline applications in Connecticut and can serve as a guiding template for coastal communities in need of erosion control. It has significantly eased regulatory and permitting processes for such projects in the future. Beyond providing critical ecosystem services and opening doors for the adoption of future projects, this living shoreline also serves as a living classroom for regional

6 Dixon, K (2019). As coastal waters rise, CT plots climate-change strategy. CTPost [Website] https://www.ctinsider.com/local/ctpost/article/As-coastal-waters-rise-CT-plots-climate-change-14905485.php

HORIZONTAL LEVEES

integrate coastal or freshwater ecosystem restoration and/or conservation with traditional levee design to achieve greater protection from floods and sea level rise than if either solution was applied alone.

Horizontal levee to protect from riverine flooding in Zaltbommel, Netherlands (flood wall on the dyke Voorendt, 2015).



CASE STUDY 3:
SABINE TO GALVESTON COASTAL STORM RISK MITIGATION STUDY

Location: Orange County and Port Arthur, Texas, USA

Project Proponent: US Army Corps of Engineers – Engineering with Nature, Galveston District

COASTAL PROTECTION · RURAL DEVELOPMENT · COASTAL

Source: © EWN - Engineering with Nature[7]

Project Description: This project seeks to reduce flood and storm risk reduction, using dredged material to create vegetated slopes that provide new habitat for marsh species, as well as to strengthen the risk reduction performance of segments of the proposed levee system. Additionally, the creation of inland floodwater retention basins would provide floodwater storage and more effective connection to the regional drainage system while also creating habitat and improving habitat connectivity. The excavation of these basins would provide additional dredge material for levee construction. Plans include enhancing the adjacent Pleasure Island as a storm buffer using dredged material to repair eroded coastline, create marshland and improve the northwestern berm. In all of these cases, dredged material would be used to bring the areas up to marsh elevation and then these areas would be colonized by and/or planted with salt-tolerant vegetation, which provides habitat as well as additional risk reduction.

Ecosystem services restored or conserved: Wetland, marsh and island restoration for floodwater retention and drainage through the creation of "floodrooms". Four segments of levee were identified to augment the standard levee core with a thickened, vegetated slope, with potential to reduce risks, create new habitat, and enhance aesthetics.

Conventional engineering approach: Floodwalls, levees, floodwater retention basins, including upland pits, drainage "floodrooms", and beneficial reuse of dredge sediment.

What makes this a good green-gray example? Sediment dredged, both for regular maintenance and more irregularly for channel deepening, has been identified as a resource for project construction. The design concepts prioritize the holistic combination of engineering performance relative to project criteria (in this case, managing flood and storm risk), ecological integration, and the creation of social value through recreational opportunities and aesthetic improvement.

7 Holmes, R., et al. Engineering with Nature + Landscape Architecture, Vol. II: Sabine-to-Galveston. https://ewn.el.erdc.dren.mil/renderings/reports/20191211_S2G_Report.pdf

CASE STUDY 4:
ORO LOMA HORIZONTAL LEVEE

Location: Alameda County, California, USA

Project Proponent: Oro Loma Sanitary District

COASTAL PROTECTION | CLEAN WATER | WATER SUPPLY & SANITATION | COASTAL

Source: San Francisco Estuary Partnership (2019)[8]

Project Description: The Oro Loma Horizontal Levee Project is a multi-agency and multi-jurisdictional project combining the expertise of numerous project partners to address multiple functions for the Oro Loma wastewater treatment facility. The $9.1 million Horizontal Levee Project took approximately two years to complete and will be monitored post-construction to evaluate its success. The project converted a four-hectare field along the San Francisco Bay's edge into a 30.3-million liter holding basin connected to an adjacent horizontal levee. The horizontal levee tests multiple functions including adaptive strategies for climate change and sea level rise, filtration of wastewater, as well as providing native habitat along the slope. Water entering the treatment facility will first go through a conventional treatment process and then pumped into a wet weather treatment basin. Bulrushes and cattails are part of the design to help remove 10-30 percent of nutrients through plant and microbial uptake. The water will then seep into the adjacent horizontal levee for additional treatment.

Ecosystem services restored or conserved: Wet meadow, riparian scrub, and swale-depression meadow restored for flood regulation and water purification. The levee slope comprises 12 different "experimental beds" referred to as "cells", containing several mixtures of substrates and vegetation/habitat types to enhance biodiversity.

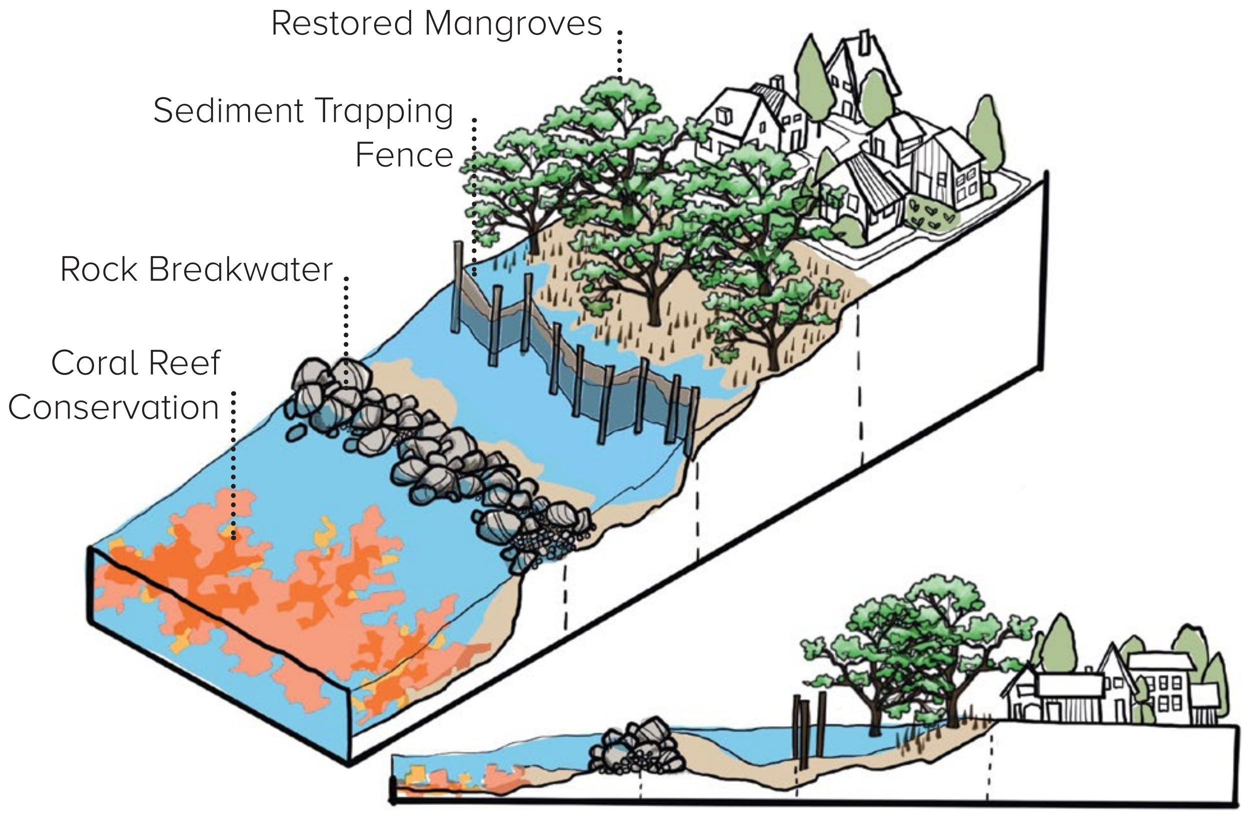
Conventional engineering approach: Floodwalls, levees, floodwater retention basins, wastewater treatment, wastewater outfall

What makes this a good green-gray example? Combines flood protection and wastewater treatment as an alternative to traditional gray solutions.

8 San Francisco Estuary Partnership (2019). Oro Loma Living Laboratory. https://www.sfestuary.org/oro-loma-experimental-levee/

OFFSHORE BREAKWATERS

reduce wave energy to buffer impacts of weather events to vulnerable communities and facilitate sediment accumulation for ecosystem restoration, such as for mangroves.



CASE STUDY 5:
LIGHTNING POINT SHORELINE RESTORATION

Location: Bayou La Batre, Mobile County, Alabama, USA

Project Partners: City of Bayou La Batre, the Alabama Department of Conservation and Natural Resources, Mobile County, and the National Fish and Wildlife Foundation, The Nature Conservancy

COASTAL PROTECTION | RURAL DEVELOPMENT | COASTAL

Source: Washington, 2009[9]

Project Description: Located in the hurricane-prone Gulf of Mexico region, Bayou La Batre is at high-risk for natural disasters associated with climate change. Nearly two and a half kilometers of segmented breakwater were constructed along the Bayou La Batre River, combined with construction and restoration of 16.2 hectares of coastal marsh, tidal creeks and scrub-shrub habitat to increase shoreline protection. Marsh habitats were created and will be sustained through the beneficial use of dredged material, while breakwaters will transform over time into fish and shellfish-sustaining reef habitat. These activities are expected to also increase protections for the nearby 51.4 hectares of coastal habitat within Bayou La Batre as part of the Alabama Forever Wild Land Trust Program.

Ecosystem services restored or conserved: Wetland and coastal marsh restoration for shoreline protection.

Conventional engineering approach: Beneficial use of dredged material, rock breakwaters

What makes this a good green-gray example? The Lightning Point restoration project prioritized the local community and their needs into all the project goals, ensuring that the benefits would be felt by those closest to the resource. Specifically addressed were community benefits, including area accessibility and improving boating, fishing and sightseeing opportunities. Also included was the construction of two new jetties to ensure navigation channel access, walking paths, and a parking lot, incorporating green infrastructure to improve stormwater management and water quality.

9 Washington, D. (2009). *Conservation groups restoring, protecting Bayou La Batre's Lightning Point.* https://alabamanewscenter.com/2019/04/26/conservation-groups-restoring-protecting-bayou-la-batres-lightning-point/

MARSH REVETMENTS

are rock structures placed at, or offset from, the eroding edge of a coastal marsh, roughly matching the relative position and elevation of the ecosystem. The structures reduce wave energy to enable ecosystem recovery and restoration, which then work together to protect the coastline (During et al., 2006[10]).

Source: Virginia Institute of Marine Science, 2020[11]

10 Duhring, K.A., Barnard, Jr. T.A., Hardaway, Jr. S. (2006). A *Survey of the Effectiveness of Existing Marsh Toe Protection Structures in Virginia*. Gloucester Point, Virginia: Virginia Institute of Marine Science. 25 pp. http://ccrm.vims.edu/publications/pubs/MarshToeRevtSurveyFinalReport.pdf

11 Virginia Institute of Marine Science (2020). *Marsh Toe Revetment*. [Website] https://www.vims.edu/ccrm/outreach/living_shorelines/design/sills_breakwaters/revetment/index.php

CASE STUDY 6:
ROSE LARISA PARK LIVING SHORELINE PROJECT

Location: Rose Larisa Park, East Providence, Rhode Island, USA

Project Partners: The Nature Conservancy, Rhode Island Coastal Resources Management Council, City of East Providence

Project Funders: A grant from the National Oceanic and Atmospheric Administration's Coastal Resiliency Fund. The Nature Conservancy raised additional matching funds with grants from 11th Hour Racing and the RI Coastal and Estuarine Habitat Restoration Trust Fund.

COASTAL PROTECTION | URBAN DEVELOPMENT | COASTAL

Source: ecoRI News, 2020[12]

Project Description: After unsuccessful attempts at reducing erosion through conventional engineering alone, a green-gray nature-based solution was adopted. The combination of salt marsh restoration and one-meter tall inter-tidal rock sills withstand wave energy from high tides and assist in sand accretion. Sand placement between the rock sill and an eroding bluff have been planted with native marsh plants, while both stone and coconut fiber logs were installed to reinforce areas and protect the slope adjacent to the public park.

Ecosystem services restored or conserved: Saltmarsh restored for coastal protection and erosion prevention.

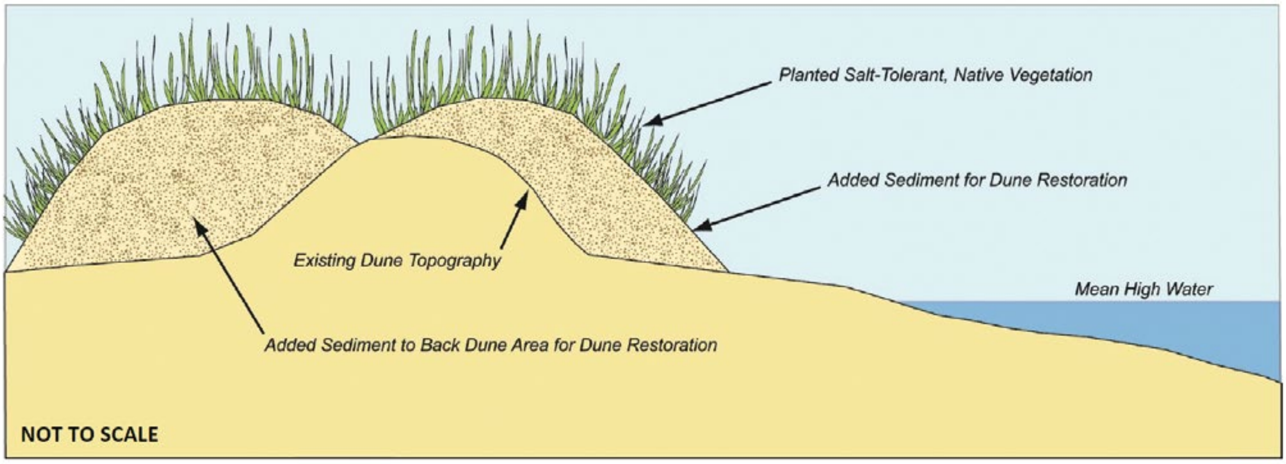
Conventional engineering approach: Inter-tidal rock sills

What makes this a good green-gray example? This experimental project served as part of a larger regional initiative to understand how hybrid approaches to sea-level rise and coastal erosion measure up to fully engineered approaches in terms of cost and efficiency. It is hoped that this project will lead to more restorative resiliency actions that incorporate not only community but also ecosystem health.

12 ecoRI News (2020). *'Living Shoreline' Projects Protect Vulnerable Coast.* https://www.ecori.org/narragansett-bay/2020/6/19/living-shoreline-project-protects-vulnerable-coast

SAND DUNE RESTORATION

with an engineered core, provides protection from high energy storm events and, when planted with native beach grass, also enhances habitat. Sediment to restore dunes is brought from off-site or from a coastal dredging project.



Source: https://www.conservationgateway.org/ConservationPractices/Marine/crr/Documents/Final_StateofthePractice_7.2017.pdf

CASE STUDY 7:
KATWIJK AAN ZEE SEA DEFENSE

Location: Katwijk, Netherlands

Project Proponent: Partnership between the municipality of Katwijk, the Rijnland District Water Board, the province of Zuid-Holland and Rijkswaterstaat (the executive arm of the Ministry of Infrastructure and the Environment)

COASTAL PROTECTION | RURAL DEVELOPMENT | COASTAL

Source: Voorendt, 2015[13]
This photo from the Katwijk, Netherlands, taken during construction of the engineered core of a sand dune restoration project in February 2014, shows the interior rubble-mound dyke consisting of a sand core, covered by basalt blocks on top of a geotextile filter layer which was embedded in an engineered sand dune. A parking garage was also included inside the dune to optimize the use of space near the coastal boulevard (Voorendt, 2015[14]).

Project Description: Katwjik's previous flood defense was no longer effective against storm surge and its structure was deemed too low to provide any protection against the effects of severe storms. This flood defense also did not provide equal protection to all parts of the village, and if elevated, would require removal of community structures and would negatively impact the village's relationship to the natural coast. Thus, it was decided to build a completely new "dyke-in-dune" flood defense structure. The integrated "dyke-in-dune" structure combines a sand dune with a stone interior, surrounded by other sand dunes; the stone dyke aims to reduce future erosion and decreases the height requirement of the surrounding dunes for accessibility and aesthetic purposes, while the additional dunes are meant to serve as the first line of defense prior to the concealed dyke. The rearrangement of the existing dunes and integration of the new structure required new sand placement to construct additional beach areas.

Ecosystem services restored or conserved: Beach and sand dunes restored for flood regulation and erosion control.

Conventional engineering approach: Dyke, sand dune with engineered core

What makes this a good green-gray example? This project maintains the current natural aesthetic of Katwjik, while providing both beach accessibility and flood protection to its community members. To address the increasing number of visitors, an underground parking garage was constructed and similarly concealed by dunes; a service to the community that also keeps beach views unobstructed.

13 Voorendt, M. (2015). *Examples of multifunctional flood defences*. Working report. Delft, Netherlands: Delft University of Technology. [Online report] https://d1rkab7tlqy5f1.cloudfront.net/CiTG/Over%20faculteit/Afdelingen/Hydraulic%20Engineering/Hydraulic%20Structures%20and%20Flood%20Risk/staff/Voorendt_M/Examples_of_multifunctional_flood_defences_2015-08.pdf

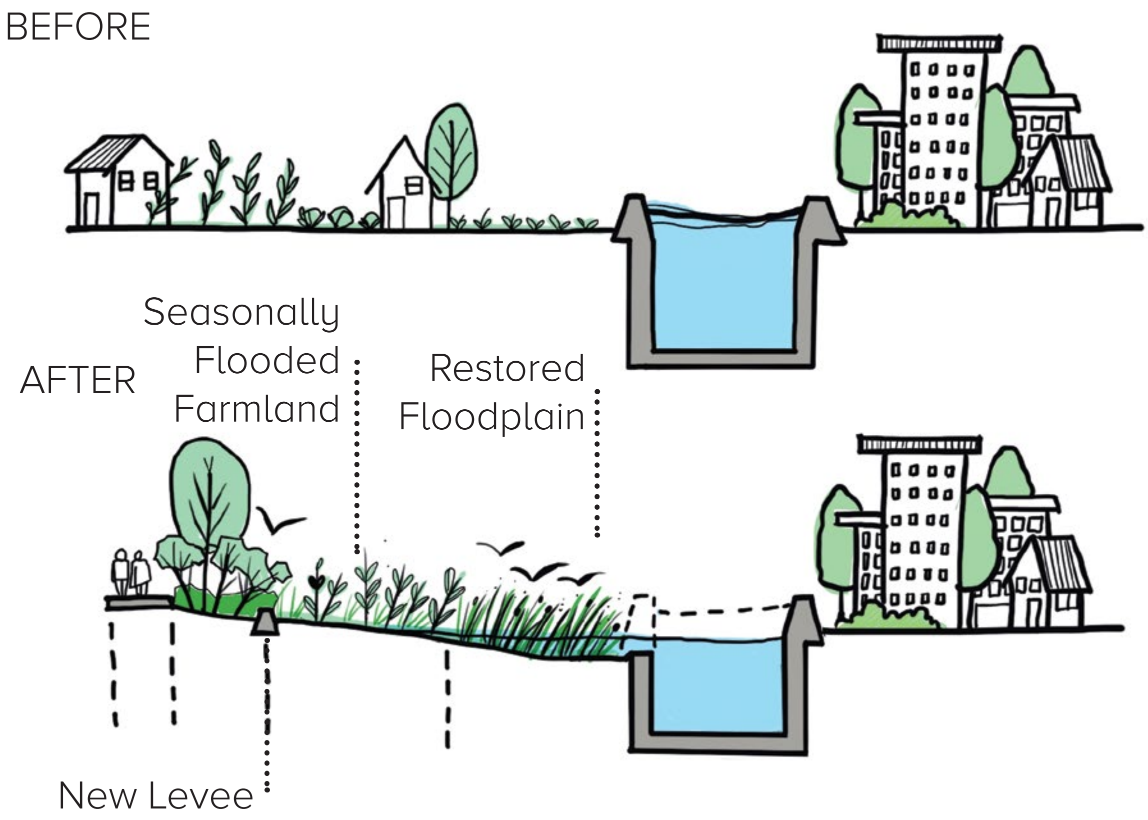
14 Voorendt, M. (2015). *Examples of multifunctional flood defences*. Working report. Delft, Netherlands: Delft University of Technology. [Online report] https://d1rkab7tlqy5f1.cloudfront.net/CiTG/Over%20faculteit/Afdelingen/Hydraulic%20Engineering/Hydraulic%20Structures%20and%20Flood%20Risk/staff/Voorendt_M/Examples_of_multifunctional_flood_defences_2015-08.pdf

FRESHWATER
GREEN-GRAY EXAMPLES

Sustainable urban drainage systems incorporate green, green-gray, and gray infrastructure solutions to re-establish or mimic natural drainage patterns within a developed area. Any of the following green-gray infrastructure examples could be implemented as part of a sustainable urban drainage system strategy.

RIVER RESTORATION FOR FLOOD MANAGEMENT

restores hydrological function through a variety of approaches, such as building terraced levees that reduce flooding, create habitats, improve water quality, and provide spaces for people to access nature.



CASE STUDY 8:
BISHAN-ANG MO KIO PARK

Location: Bishan, Singapore

Project Proponent: A collaboration between Singapore's National Parks Board and National Water Agency who initiated the Active, Beautiful and Clean Waters Programme

FLOOD MANAGEMENT · URBAN DEVELOPMENT · FRESHWATER

Source: Chensiyuan, 2014. - Own work, CC BY-SA 3.0,[15]

Project Description: A 63-hectare park re-designed to accommodate the dynamic processes of the Kallang River system, by restoring a three kilometer long, sinuous stream channel in place of a 2.7 kilometer long straight concrete-lined drainage channel. The resulting river and floodplain system increased system capacity by 40%, biodiversity by 30%, and recreational space by 12%, while costing 15% less than a concrete-lined canal. A site within the park was commissioned to test 12 restoration techniques new to the tropics, developing new knowledge and supporting healthy vegetation growth, and in a reiterative process, soil condition, slope and plant root strength. Lastly, design experts and clients invested heavily in the training of the construction team, who transformed the first sketches into built form.

Ecosystem services restored or conserved: Riverbank restoration for erosion control, water purification, and flood regulation.

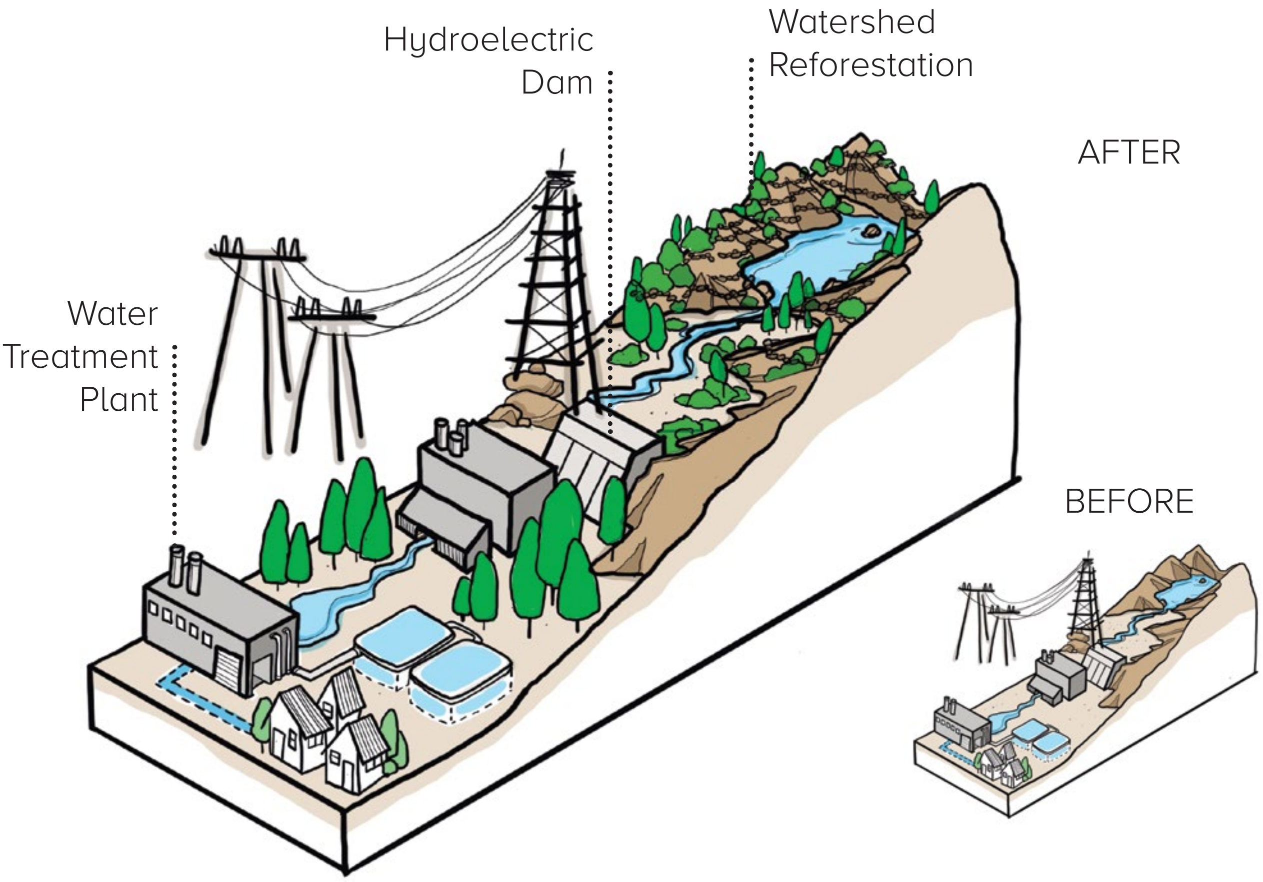
Conventional engineering approach: Three new bridges, a terraced riverside gallery, river platforms, stepping stones across the river and a water playground, fed with naturally cleansed river water, are all features that enable community connections to the river. A river monitoring and warning system with water level sensors, warning lights, sirens, and audio announcements provide early warnings of impending heavy rain or rising water levels.

What makes this a good green-gray example? In the heart of a dense urban area, the now vibrant park improves human health by creating public access to nature and opportunities to exercise, while simultaneously managing floods and improving water quality. In a zero-waste approach, all the concrete from the canal that was removed was used in the restored channel river bed, footpaths and the "Recycle Hill", a viewpoint for visitors to appreciate the green-gray river system.

15 Chensiyuan (2014). *Aerial panorama Bishan Ang Mo Kio Park 2014.* https://commons.wikimedia.org/w/index.php?curid=31233531

REFORESTATION AND FOREST CONSERVATION

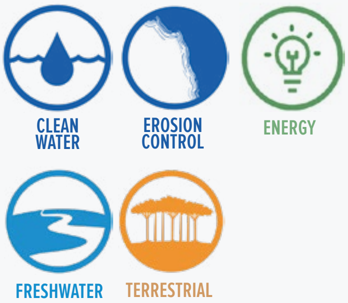
provides watershed protection, reduces sedimentation and helps regulate flows to hydropower plants, while also making water cleaner, and cheaper for downstream water treatment plants to clean for communities to drink.



CASE STUDY 9:
CLOUD FOREST BLUE ENERGY MECHANISM

Location: Latin America

Project Proponent: Conservation International and The Nature Conservancy



Source: Nordic Development Fund[16]

Project Description: The Cloud Forest Blue Energy Mechanism aims to mobilize domestic commercial finance to reforest and conserve cloud forests in Latin America that provide crucial benefits to the hydropower industry. It uses an innovative "pay for success" financing technique in which a hydropower plant pays for measurable ecosystem benefits provided by cloud forests within the plant's catchment – principally reduced sedimentation, increased water flow and improved water regulation.

Ecosystem services restored or conserved: Cloud forest restoration for water supply and quality. Cloud forests intercept water from fog and clouds, as well as from regular annual rainfall, providing unpolluted water to communities living downstream (Bubb et al., 2004[17]).

Conventional engineering approach: Dams, hydroelectric generation

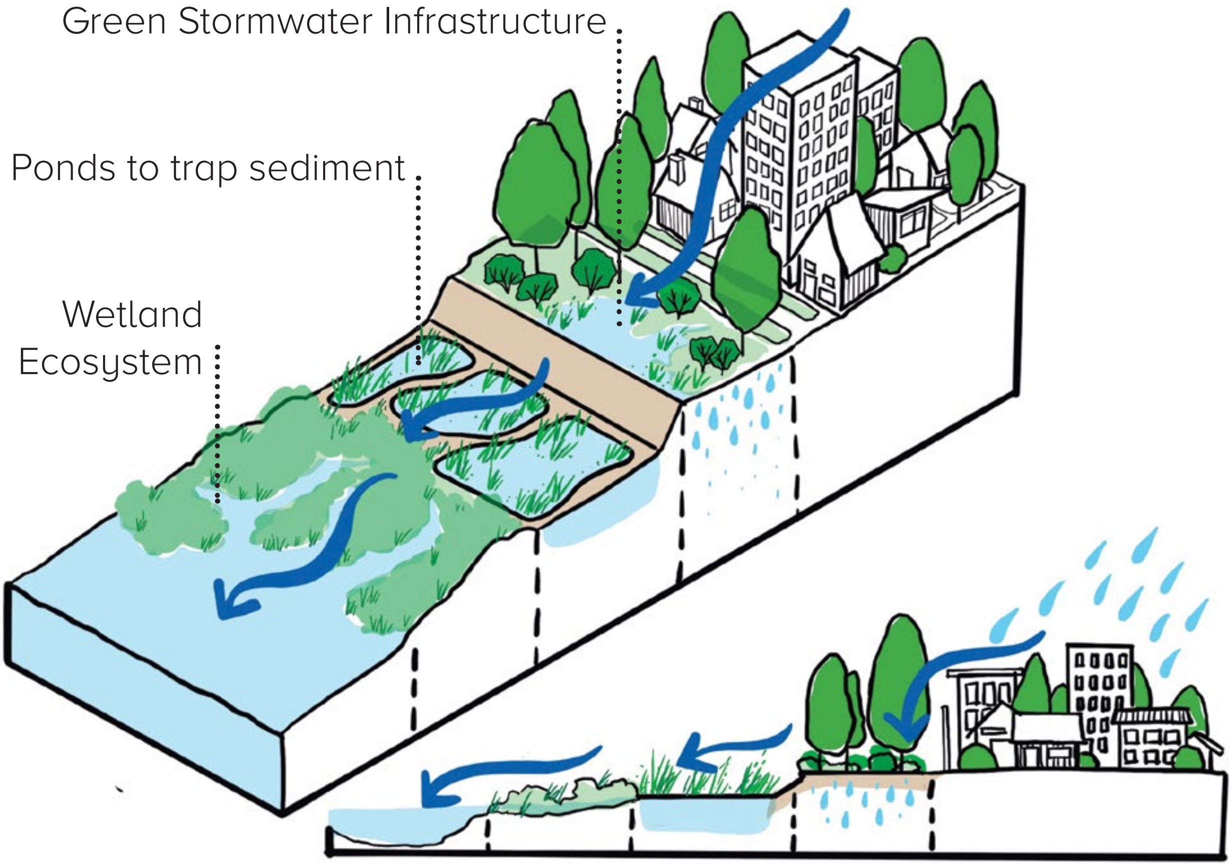
What makes this a good green-gray example? Cloud forests are rare (only 2.5% of the total area of tropical forests) and highly and uniquely biodiverse and deliver a multitude of clear benefits, but finance for conserving and restoring forests has fallen short of the need. This model brings together environmental valuation methods and pay for success financing to increase both the profitability and sustainability of hydropower operations, while funding restoration and conservation. Bio-engineered infrastructure can deliver short-term benefits to hydropower companies to control erosion and reduce sedimentation, thus generating early project income and improving bankability, while green-infrastructure grows and gradually assumes the larger proportion of cash-flow generation.

16 Nordic Development Fund (undated). *Cloud Forest Blue Energy Mechanism* [NDF C113]. https://www.ndf.fi/project/cloud-forest-blue-energy-mechanism-ndf-c113

17 Bubb, P., May, I., Miles, L., Sayer, J. (2004). *Cloud Forest Agenda.* Cambridge, UK.UNEP-WCMC. 36 pp. https://portals.iucn.org/library/sites/library/files/documents/2004-003.pdf

WATER QUALITY WETLANDS

use natural processes to clean stormwater, graywater, and/or wastewater, resulting in improved habitat and enhanced biodiversity. Stormwater wetlands clean runoff from urban spaces, reduce flooding, and can also create spaces for people to access nature.



CASE STUDY 10:
MEISHE RIVER GREENWAY AND FENGXIANG PARK

Location: Haikou City, China

Project Proponent: Haikou government contracted landscape architects from Turenscape

Source: Turenscape, 2020[18]

Project Description: All the green-gray infrastructure elements incorporated into the 80 hectare Fengxiang Park are intended to be cost efficiently replicated to other locations – concrete flood walls replaced with eco-friendly and flood resilient waterways, mangroves restoration areas, constructed wetlands to clean water, and recreation facilities for the community.

Where a concrete flood wall and a garbage dump once stood, there now is a series of interconnected terraces of constructed sub-surface flow wetlands along the riverbank, designed to clean water. These water quality wetlands can daily treat 6,000 tons of nutrient-rich urban runoff, to swimmable standards. They also clean 3,500 tons of sewage from local urban villages, again to contact-safe levels, with the addition of mobile pre-treatment equipment to remove pathogens. The two flows can be switched alternately or combined according to demands, and biomass from the wetlands is harvested and regularly decomposed into fertilizers for use in the landscape.

Ecosystem services restored or conserved: River, wetland, and mangrove restoration for controlling freshwater water pollution, including detoxification. Commonly called "the Earth's kidneys" wetlands act as filters, removing agrochemicals and other harmful waste from water (Ramsar, 2017[19]).

Conventional engineering approach: Interconnected terraces of constructed subsurface flow wetlands, with mobile pretreatment units, built along the riverbank with an inter-connected pedestrian and recreational network.

What makes this a good green-gray example? Wetlands are valued within the community and through integrated walkways that provide vistas and focal points to appreciate the open space, tens of thousands of visitors annually appreciate the improved water quality and ecology within the park. To celebrate the recovery of the Meishe River, which was only a memory for the city decades ago, Haikou was honored as one of the 18 International Wetland Cities by the Contracting Parties to the Ramsar Convention in 2018.

18 Turenscape (2020). *Meishe River Greenway and Fengxiang Park, Haikou China* https://www.turenscape.com/en/project/detail/4656.html

19 Ramsar (2017). Wetlands; a sustainable solution for water purification and security. https://www.ramsar.org/news/wetlands-a-sustainable-solution-for-water-purification-and-security-0.

GREEN STORMWATER INFRASTRUCTURE

uses vegetation, soils, and natural processes to manage water and create healthier urban environments. Green stormwater infrastructure can range in scale from site design approaches such as rain gardens and green roofs to regional planning approaches. Green stormwater infrastructure can enhance community resiliency by increasing water supplies, reducing flooding, combating urban heat island effect, and improving water quality.

CASE STUDY 11:
XIAMEN SPONGE CITY

Location: Xiamen, China

Project Proponent: Chinese central government funds around 15% to 20% of costs, with the remainder funded by local governments and private developers.

CLEAN WATER | URBAN DEVELOPMENT | ENERGY | FRESHWATER

Source: Meng, 2020[20]

Project Description: In 2013, China initiated its national strategy for "sponge cities" – "designed to retain, clean, and reuse stormwater" – with the hopes of making their cities more resilient to climate change through reduction of carbon emissions in urban areas, increased adaptability to environmental changes and disasters and increased water storage, purification and supply. Xiamen was among the first batch of pilot cities and was approved for construction in 2015. Since then, green space creation has begun in the form of green roofs, swales, rainwater storage ponds, and wetland construction. Across the country the initiative is expected to expand green space from 11,171 ha in 2014 to 18,647 ha in 2020, which contributes directly to urban carbon capture. The combined implementation of roads using permeable pavement, drainage and flood control systems and of green spaces has, thus far, allowed Xiamen to reach 70% control of their total annual runoff. This has already begun to address issues facing the city such as drought, pollution, and the urban heat island effect.

Ecosystem services restored or conserved: River and lake wetlands restored, rainwater storage ponds, and roof greening for flood regulation and carbon sequestration.

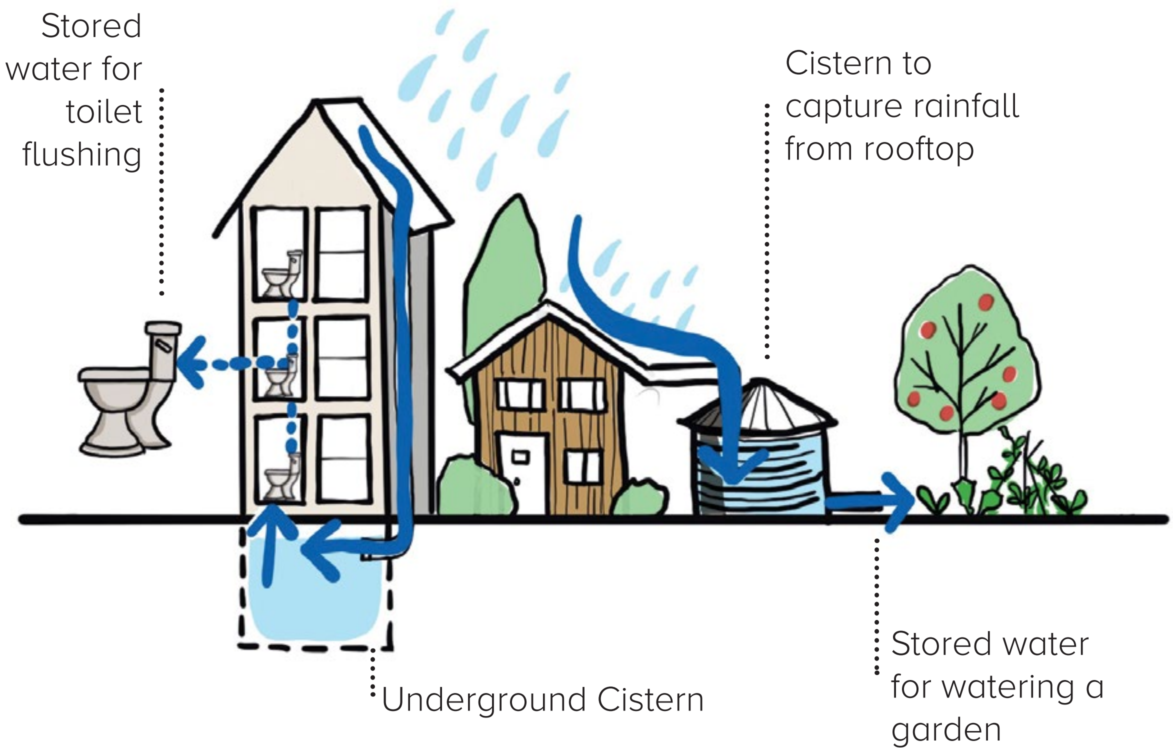
Conventional engineering approach: Permeable paving, drainage and flood control systems

What makes this a good green-gray example? Sponge city implementation leads to a reduction in the urban heat island effect; thus, energy consumption is expected to be reduced by more than 30% due to a drop in the use of electrical appliances such as air conditioners. Additionally, with greater control of rainwater runoff, emissions usually caused by production and supply of water to the city will also be greatly reduced. If green space creation equals the planned 18,647 ha, Xiamen would see a reduction of approximately 66,266 tons of carbon per year through green space, while also improving ecological, economic and social environments.

20 Meng, S. (2020). *Meet the Architect Whose Revolutionary "Sponge Cities" are Helping Combat Climate Change*. RadII [Website]. https://radiichina.com/sponge-cities-architect-yu-kongjian/

RAINWATER HARVESTING

is the practice of collecting and using rainwater from roof surfaces or other artificial above-ground surfaces. Although rainwater harvesting has been employed by communities for centuries, today, rainwater harvesting is becoming more common, as people seek ways to increase local resilience and use water resources more efficiently.



CASE STUDY 12:
CHULALONGKORN CENTENARY PARK

Location: Bangkok, Thailand

Project Proponent: Chulalongkorn University

Source: Holmes, 2019 [21]

Project Description: The 5-hectare park and a 1.3 kilometer long green street are designed to collect and treat water, decrease flood risks, reduce urban heat island effects, and promote pedestrian and bicycle transportation. The entire park acts as a retention basin, managing floods up to the 100-year recurrence interval. Storage tanks throughout the park ensure that every drop of water is captured and re-used. Features include a green roof with native grasses, constructed wetlands, and a detention pond to increase infiltration to groundwater.

Ecosystem services restored or conserved: Constructed wetland, retention pond, green roof, retention lawn for water purification, flood regulation, and carbon sequestration.

Conventional engineering approach: Water storage tanks, drainage and flood control systems.

What makes this a good green-gray example? The 'park-as-rain-tree' has become a symbol for the University and is restoring pre-development hydrology and native ecosystems within a quickly developing city facing water management and urban heat challenges accentuated by climate change effects.

21 Holmes, D. (2019). *Chulalongkorn University Centenary Park – green infrastructure for the city of Bangkok. World Landscape Agriculture (WLA).* https://worldlandscapearchitect.com/chulalongkorn-centenary-park-green-infrastructure-for-the-city-of-bangkok/

CASE STUDY 13:
SYDNEY PARK STORMWATER REUSE PROJECT

Location: Sydney Park, Sydney, New South Wales, Australia

Project Proponent: City of Sydney in partnership with Sydney Water, Transgrid and the NSW Department of Environment and Conservation

CLEAN WATER
URBAN DEVELOPMENT
FRESHWATER

Source: Goodlife Permaculture, 2016[22]

Project Description: Annually, approximately 50 million liters of stormwater is collected from Barwon Park Road through a diversion pipeline that directs flows through a pollutant trap, then to a bio-retention treatment system, before being stored in the park's wetland system. Additional water is pumped from the Munni Channel into the park's water harvesting and re-use facility, enabling an annual average of 840 million liters of harvesting and re-use within the park system. Pumps and pipelines circulate water through the wetland system, while creating a lush environment for people and nature, and reuse for irrigation.

Ecosystem services restored or conserved: Wetland restoration for water purification.

Conventional engineering approach: Pumps and pipes

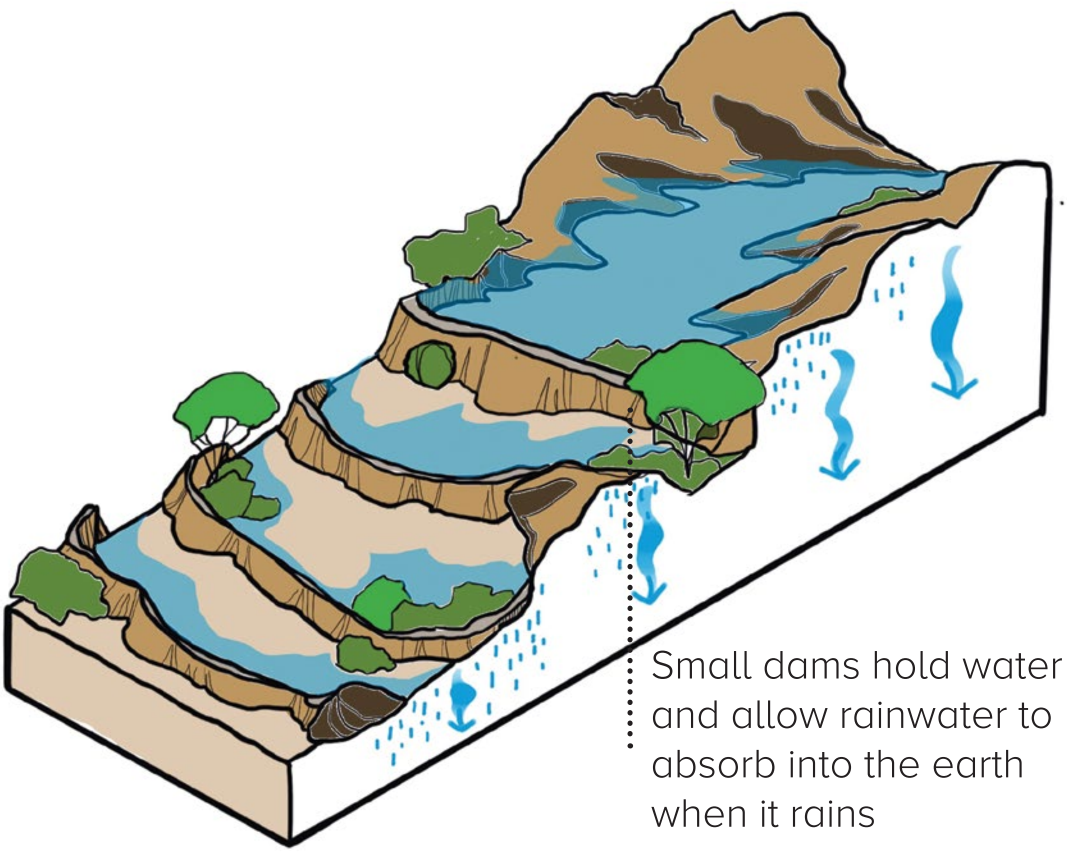
What makes this a good green-gray example? The stormwater treatment system incorporates the attributes and functions of natural ecosystems, integrating state-of-the-art science and environmental design with landscape design and public art to create essential civic infrastructure. Native animal habitat was carefully considered and improved as part of the project. The wetlands have the highest population of native bird species in the local area, including 22 wetland species.

22 Goodlife Permaculture (2016). *Sydney Park – A Stormwater wonderland.* [Website] https://goodlifepermaculture.com.au/sydney-park-a-stormwater-wonderland/

TERRESTRIAL
GREEN- GRAY EXAMPLES

INFILTRATION AND TREATMENT-BASED LANDSCAPES

increase groundwater infiltration to recharge aquifers, manage flood risks, and reduce erosion.



CASE STUDY 14:
PROMOTING WATER AND FOOD SECURITY AND ENVIRONMENTAL RESTORATION THROUGH THE CONSTRUCTION OF SAND DAMS

Location: Machakos, Makueni and Kajiado Counties, Kenya

Project Proponent: Project Partners: Equator Initiative, United Nations Convention to Combat Desertification, Open Society Initiative for Southern Africa, ENDA, Global Environment Facility, United Nations Development Programme

Project Funders: Utooni Development Organization, Government-recognized self-help groups (local communities)

FOOD SECURITY · WATER SECURITY · RURAL DEVELOPMENT · TERRESTRIAL

Almost mature sand dam in Kaiti seasonal river, Makueni County, Kenya. © Utooni Development Organization[23]

Project Description: Sand dams are an indigenous water management practice, thousands of years old. Made with local materials such as rocks and sand, and local labor, these structures address issues of food and water security, worsened by poor land management practices and climate change. Over 1,500 sand dams have been built in south central Kenya, along with pipelines and water tanks. Captured water is used to rehabilitate degraded land, create plant nurseries, increase forest cover using agroforestry practices, and recharge groundwater supplies. Upstream of the sand dams, 1,500 meters of built terraces capture and store water from large rainfall events to recharge groundwater and prevent sediment entering sand dams downstream. As a result of these terraces, and local groundwater recharge, agricultural yields increase. Each strategy supports a basic community need: sand dams supply water, drought-resistant crops provide food, tree planting and intercropping yield firewood, fruit and medicine and terracing conserves soil. By improving land management practices, these features serve as refuges in an arid landscape and provide humans and wild species with a buffer against climate change.

Ecosystem services restored or conserved: Arid and semi-arid land/ dryland restoration for water and food security.

Conventional engineering approach: Sand dams, constructed terraces, water tanks, pipelines

What makes this a good green-gray example? Women and girls are major beneficiaries of sand dam construction, because they dramatically reduce the hours women spend searching for water, creating more time for education and house chores. As sand dams recharge shallow groundwater supplies, native soils and plant species recover and birds, insects, and mammals return.

23 United Nations Development Programme (UNDP). (2015). Utooni Development Organization, Kenya. New York, NY, USA: Equator Initiative Case Studies Series. 11 pp

URBAN GREENING

includes creation and maintenance of green space, such as parks; planting and care of trees; and the creation of green stormwater infrastructure. Green spaces and plants in urban areas provide numerous environmental and community benefits. They can help to reduce flooding and sewer overflow by absorbing large amounts of stormwater, provide wildlife habitat, help to maintain air quality, reduce urban heat islands as well as provide green space for neighborhood socializing and community building.

CASE STUDY 15:
MEDELLIN GREEN CORRIDORS

Location: Medellin, Colombia

Project Proponent: Medellin City Authorities

URBAN DEVELOPMENT ENERGY TERRESTRIAL

Source: C40 Knowledge Hub, 2019[24]

Project Description: Like many cities, Medellín is affected by rising urban temperatures and the intensification of the urban heat island effect because of climate change. The Medellín Green Corridors project addresses this issue by creating green corridors, which span a total of 65 hectares, in urban spaces where they are needed the most, such as in abandoned or isolated areas. These corridors both connect existing green spaces and create new green spaces for an increase in habitat connectivity and overall urban biodiversity. To create parks, 8,300 trees and 350,000 shrubs have been planted, as well as borders along 18 roads and 12 waterways to provide shade and improve air quality to these congested areas. A 2-3°C drop in surface temperature has already been achieved, with a noticeable impact on the well-being of citizens. Additionally, the creation of green space allows for greater carbon sequestration. As plants continue to grow and the project evolves, these benefits are only expected to increase.

Ecosystem services restored or conserved: Urban green spaces created to reduce urban heat island effect and for carbon sequestration.

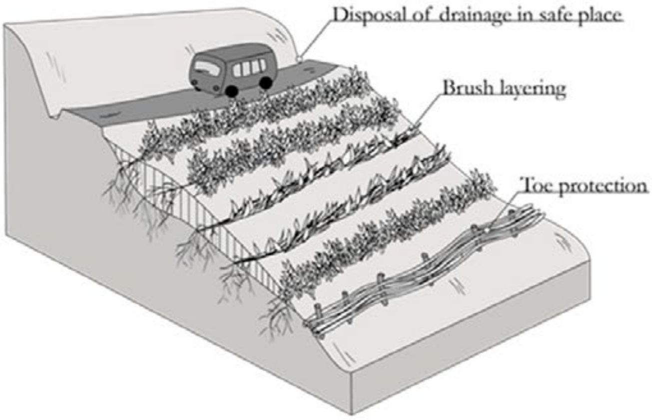
Conventional engineering approach: Streets, curbs, and sidewalks

What makes this a good green-gray example? Many abandoned spaces, once troubled by crime and drug use, have now been transformed into gardens, that are taken care of by community members from disadvantaged backgrounds who previously did not have access to work. With the emphasis on community improvement and involvement, this project yields a deep sense of community ownership.

24 C40 Knowledge Hub (2020). *Cities100: Medellín's interconnected green corridors. Case Studies and Best Practice Examples October 2019*, C40 Cities Climate Leadership Group, Inc. [Weblog]. https://www.c40knowledgehub.org/s/article/Cities100-Medellin-s-interconnected-green-corridors?language=en_US.

ROADSIDE SLOPE STABILIZATION

can integrate restoration of grasslands and/or forests to exposed slopes, with measures such as gabion baskets or check dams to manage runoff and prevent erosion. Rural roads serve as lifelines for many communities and are especially good candidates for green-gray techniques to prevent erosion, shallow landslides, and river sedimentation, which significantly reduce economic losses and environmental degradation, and even enhance local livelihoods.



Source: Devkota, S., Man Shakya, N., and Sudmeier-Rieux, K., 2019[25]

25 Devkota, S., Man Shakya, N., and Sudmeier-Rieux, K. (2019). Framework for Assessment of Eco-Safe Rural Roads in Panchase Geographic Region in Central–Western Nepal Hills. *Environments* **2019**, *6*(6), 59; https://doi.org/10.3390/environments6060059

CASE STUDY 16:
BIO-ENGINEERING FOR ECO-SAFE ROADSIDES IN NEPAL

Location: Panchase area of Western Nepal, near Pokhara and Syangja, Kaski and Parbat districts

Project Proponent: Local government authorities (Village Development Committees), Community members, IUCN, University of Lausanne - Switzerland, Government of Nepal, Department of Soil Conservation and Watershed Management (Nepal), supported by the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety

EROSION CONTROL TRANSPORTATION TERRESTRIAL

Source: Sudmeier-Rieux et al., 2017[26]

Project Description: The aim of the project Ecosystems Protecting Infrastructure and Communities in Nepal was to provide better services to rural and urban communities, such as access to markets and healthcare centers, as the Government of Nepal is pursuing a significant expansion of the road network. However, to connect to these new roads, many unplanned rural roads are funded and executed by smaller local governments and communities, without project oversight or the adherence to standards. Thus, these poorly designed roads, combined with the intensification of monsoon rains as an impact of climate change, have led to an increase in extreme flooding and landslide events. To address this, the "Eco-Safe Roads Project" was implemented in three districts in the Panchase area of Western Nepal. This project combined the planting of local deep-rooted species (chosen by the communities), with a structured element such as bamboo dams and fences or wall structures, to stabilize the roadside and ultimately provide erosion protection. Studies at the end of the projects showed that soil loss was reduced by 95% at one of the demonstration sites. The grasses planted to prevent floods and erosion are harvested during the dry season in one community and sold as fodder, providing income to communities.

Ecosystem services restored or conserved: Native grasses restored along roadsides for erosion control and flood regulation.

Conventional engineering approach: Check dams, gabion baskets, concrete channels

What makes this a good green-gray example? These green-gray measures are a low-cost approach to reducing the risks associated with landslides and flooding, while also improving local livelihoods through the sustainable use of planted grasses and the greater protection of agricultural land. Through the Eco-Safe Roads Project, a detailed guidance manual was created and disseminated, with the hopes of mainstreaming these practices and influencing policy, towards more resilient communities.

26 Sudmeier-Rieux, K., Adhikari, A. and Devkota, S. (2017). Nepal. In Monty, F., Murti, R., Miththapala, S. and Buyck, C. (eds). pp 41-47 *Ecosystems protecting infrastructure and communities: lessons learned and guidelines for implementation*. Gland, Switzerland: IUCN. x + 108pp. https://www.iucn.org/sites/dev/files/content/documents/epic_publication.pdf

2. IDENTIFYING AND SELECTING SITES

Cities, communities, ecosystems, and assets need protection from climate impacts. Green-gray infrastructure can play a significant role in doing just that.

This chapter describes a process and tools for evaluating climate risk, engaging stakeholders in the consultation process, and evaluating potential sites for green-gray infrastructure suitability.

After identifying climate vulnerable communities and visiting numerous sites with potential for green-gray infrastructure projects, the project planners have the task of selecting sites best-suited for green-gray infrastructure project construction. This module includes a tool to evaluate, rank and select green-gray infrastructure project locations that considers stakeholder priorities.

This chapter is most useful for (1) identifying potential sites across a region or landscape to pilot green-gray approaches and (2) prioritizing between sites in a master plan (e.g., a Resiliency Master Plan described in Chapter 4 and 10) so funds are optimally allocated or invested.

In some cases a practitioner comes to a site and is asked to solve a problem to achieve specific goals or meet specific criteria. In that case, the selection tool can be used to choose between design alternatives, but the site has already been identified.

HOW CAN WE IDENTIFY COMMUNITIES, CITIES, AND ASSETS WHICH CAN BENEFIT FROM GREEN-GRAY INFRASTRUCTURE?

Planners identify existing and future hazards and the associated impacts on their communities, cities, and/or assets along specific time horizons. They then identify projects, policies, or programs to manage or reduce those hazards. The estimated costs and timelines of those activities are then incorporated into capital improvement plans and budgets, and ideally implemented before the impact of the future threat materializes. Green-gray infrastructure can be one of the solutions planners identify to reduce vulnerability and increase resilience at specific sites.

Three methods can improve a planner's understanding of the hazards at specific sites where green-gray solutions could be most effective:

- Identifying potentially high-risk areas using hazard mapping
- Identifying vulnerable communities from a spatial database of climate and disaster vulnerable areas
- Understanding local challenges and context through participatory risk mapping

The following approaches can be used to initially identify communities, cities, and assets with the potential for successful green-gray infrastructure project implementation. These assessments help determine the overlap between an opportune location, a specific challenge (e.g. hazard), and vulnerable communities or assets which could benefit from a green-gray intervention. After this, the project team would meet with communities, city municipalities, and/or asset owners to conduct site assessments and evaluate applicability of green-gray infrastructure solutions.

A. Identifying potentially high-risk areas using hazard mapping.

Risk is often conceptualized as a function of hazard, exposure, and vulnerability. Hazards can be natural or anthropogenic and can interact with exposed and vulnerable people and places to result in disasters. Climate change may also be altering local and regional conditions, leading to changes in temperature and precipitation regimes which can affect the distribution or intensity of hazards. Hazard mapping allows practitioners to identify areas which may be affected by a hazard such as a flood event, storm surge, drought, or landslide. Hazard mapping typically relies on analysis using geographic information systems (GIS) and is often hazard-specific. For example, some of the challenges this guide highlights in the case studies are flood management, coastal protection, and erosion. The Pampanga River case study in this chapter includes an example flood hazard map.

B. Identifying vulnerable communities from a spatial database of climate and disaster vulnerable areas.

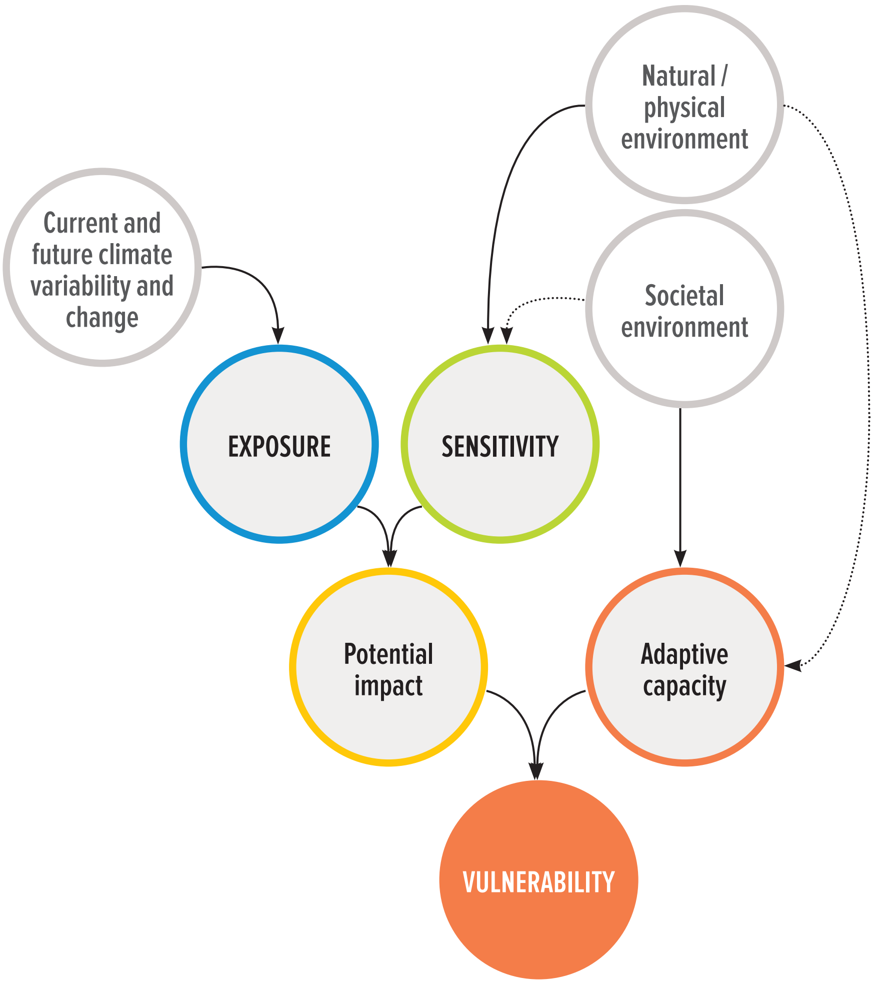
A map of climate vulnerable areas identifies populations with low, medium, and high vulnerability and the associated climate change and/or extreme weather events to which they are vulnerable to. There are many ways to measure vulnerability; most methods account for exposure, sensitivity and capacity, where:

$$\text{Climate vulnerability} = \frac{\text{exposure x sensitivity}}{\text{adaptive capacity}}$$

Figure 2.1 provides a visual of how physical, societal and climate factors contribute to the exposure and sensitivity of a community, city or asset which affects the potential impact of a climate event. The higher the adaptive capacity the less vulnerable to the impact of a climate event. Table 2.1 presents methods to assess components of climate change vulnerability.

Vulnerability Assessment tools applied in a participatory manner at the community, city or asset scale can provide a relative evaluation of potential climate change impacts and adaptive capacity. For example, the Integrated Coastal Sensitivity, Exposure, and Adaptive Capacity to Climate Change Vulnerability Assessment Tool offers a scoping and rapid reconnaissance of the vulnerabilities of integrated ecosystem services to synergistic climate change impacts. Information from Vulnerability Assessment tools can inform the green-gray infrastructure site selection and concept design development process.

Figure 2.1. Components of climate change vulnerability (Source: Fritzsche et al., 2014[27])



27 Fritzsche, K., Schneiderbauer, S., Bubeck, P., Kienberger, S., Buth, M., Zebisch, M. and Kahlenborn, W. (2014). *The Vulnerability Sourcebook, Concepts and guidelines for standardized vulnerability assessments*. Bonn and Eschborn, Germany: Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. 177 pp. https://www.adaptationcommunity.net/?wpfb_dl=203

Table 2.1. Methods to assess components of climate change vulnerability (source: Donatti et.al., 2019[28])

Component	Description	Ways to assess it
Exposure	Refers to changes in climate or weather (such as rainfall changes, temperature changes, changes in sea level, increased incidence of hurricanes and droughts) that are affecting/will affect the region where the target population lives.	• historical climate-related data • modeling work on how temperature and rainfall may change or studies/interviews on people's perceptions of changes in weather and climate. • Potential sources of data include: Climate Wizard (https://climatewizard.ciat.cgiar.org/)
Sensitivity of the system or ecosystem services	Refers to the impacts that changes in climate or weather cause on the livelihoods of the target population (such as by affecting crop production, fisheries harvest). and by affecting ecosystem services that they rely on (such as water and food, natural pest control, ecotourism)	• modeling of how changes in temperature and precipitation may affect crop production, provision of water and other ecosystem services • interviews of stakeholder's perceptions on how extreme weather events have changed crop productivity, water availability or other aspects of their livelihoods. • Potential sources of data include: Intergovernmental Panel on Climate Change reports, country National Adaptation Plans, World Bank's Climate Change knowledge portal.
Adaptive capacity of the target population	Refers to whether the target population is able to adjust to the changes in climate and weather and its impacts. Capabilities include human, social, financial, physical, and natural capital, institutions and entitlements, knowledge and information, decision-making and governance (such as. Africa Climate Change Resilience Alliance's Local Adaptive Capacity Framework, Holland et al.)	• census data that can inform the adaptive capacity of the target population (i.e. literacy, income, ownership of assets) that are available to the target population. • interviews with local communities' members or local experts to obtain information on aspects related to adaptive capacity when census data is not available or incomplete • Potential sources of data include: Living Standards Measurement Study; Conservation International's Resilience Atlas

Below are tools (e.g., assessments, indices, methodologies) to facilitate site selection by providing spatially relevant hazard maps and/or informational relevant to estimating vulnerability.

CatNet - Swiss Re's geo risk tool combines hazard, loss, exposure and insurance information with selected background maps and satellite imagery. The tool helps to provide visibility of climate change, catastrophic event impact, population density and more to planning decisions.

Swiss Re Institute's Biodiversity and Ecosystem Services Index to compare and assess high level dependencies and impacts.

Inter-American Development Bank's Disaster and Climate Risk Assessment Methodology Provides guidance for project teams, executing agencies, technical experts, and external consulting and design firms, on conducting disaster and climate change risk assessments in relevant operations, ensuring added value to projects.

The Nature Conservancy's Protecting Water Atlas is a suite of four apps that allows users to compare watersheds based on 1) additional social, economic and ecological benefits they would produce if protected or restored, 2) how and when water is being used inside different basins, 3) where water funds have been established and 4) which cities can reach their pollution reduction targets through conservation action and such associated costs.

The Nature Conservancy-led Natural Solutions Toolkit is a collection of spatial decision support tools and web apps that provide users with information to assess and compare numerous environmental features. Though all tools are not applicable worldwide, assessable features include but are not limited to, hazard risk and community vulnerability, floodplains and their flood risk reduction, carbon sequestration and water usage by watershed.

The International Centre for Integrated Mountain Development report, A Manual on Participatory Three-Dimensional Modelling, can serve as a resource for planning and implementing participatory three-dimensional modelling as a method for capturing and visualizing communities' spatial knowledge. While time-intensive in the field, it can be a powerful communication tool that engages community members and empowers them to better manage their resources.

28 Donatti, C.I., Martinez-Rodrigo, M.R., Fedele, G., Harvey, C.A., Andrade, A., Scorgie, S., Rose, C., and Alam. M. (2019). *Guidelines for designing, implementing and monitoring ecosystem-based adaptation intentions*. Virginia, USA: Conservation International. 40 pp. https://www.conservation.org/docs/default-source/publication-pdfs/guidelines-for-designing-implementing-and-monitoring-eba.pdf?Status=Master&sfvrsn=bccddc79_3

C. Understanding local challenges and context through participatory risk mapping

As challenges and context are often well understood by local communities, participatory mapping is increasingly recognized as an important contribution to hazard mapping and disaster risk reduction. This methodology empowers local communities by valuing their observational capacities and place-based knowledge rather than emphasizing their vulnerabilities. For instance, local community members can identify the location of frequent landslide zones and remediation actions suitable to community needs. Inviting input from community members through participatory mapping can also strengthen ownership and pave the way for further engagement throughout all stages of project planning and implementation.

Below is a list of potential invitees for a consultation workshop. Chapter 5 of this guide includes other recommendations and strategies for Engaging Stakeholders & Building the Business Case for green-gray infrastructure projects.

- Environment or agriculture/fisheries officer /forest officer (municipal/provincial depending upon resources)
- Planning and development officer (municipal/provincial depending upon resources)
- Disaster risk reduction officer (municipal/provincial depending upon resources)
- Engineering officer (municipal/ provincial depending upon resources)
- Key community leaders (village government and community organizations)
- Regional representatives from the national government (Environment and natural resources, public works and highways etc .)
- Water authority

These stakeholders (municipal or provincial staff) can be pre-interviewed to identify particularly vulnerable municipalities or communities and ensure representatives from these communities attend the workshop. If funding is not available for a larger workshop, interviews with these attendees can be conducted to identify sites for field evaluation. Table 2.2 provides an example agenda and approach used for a green-gray community consultation, participatory risk mapping workshop in the Philippines.

CASE STUDY 17:
PAMPANGA RIVER BASIN GREEN-GRAY OPPORTUNITY MAPS

Location: Pampanga River Basin, Philippines

Project Proponent: Conservation International with funding from Pisces Foundation

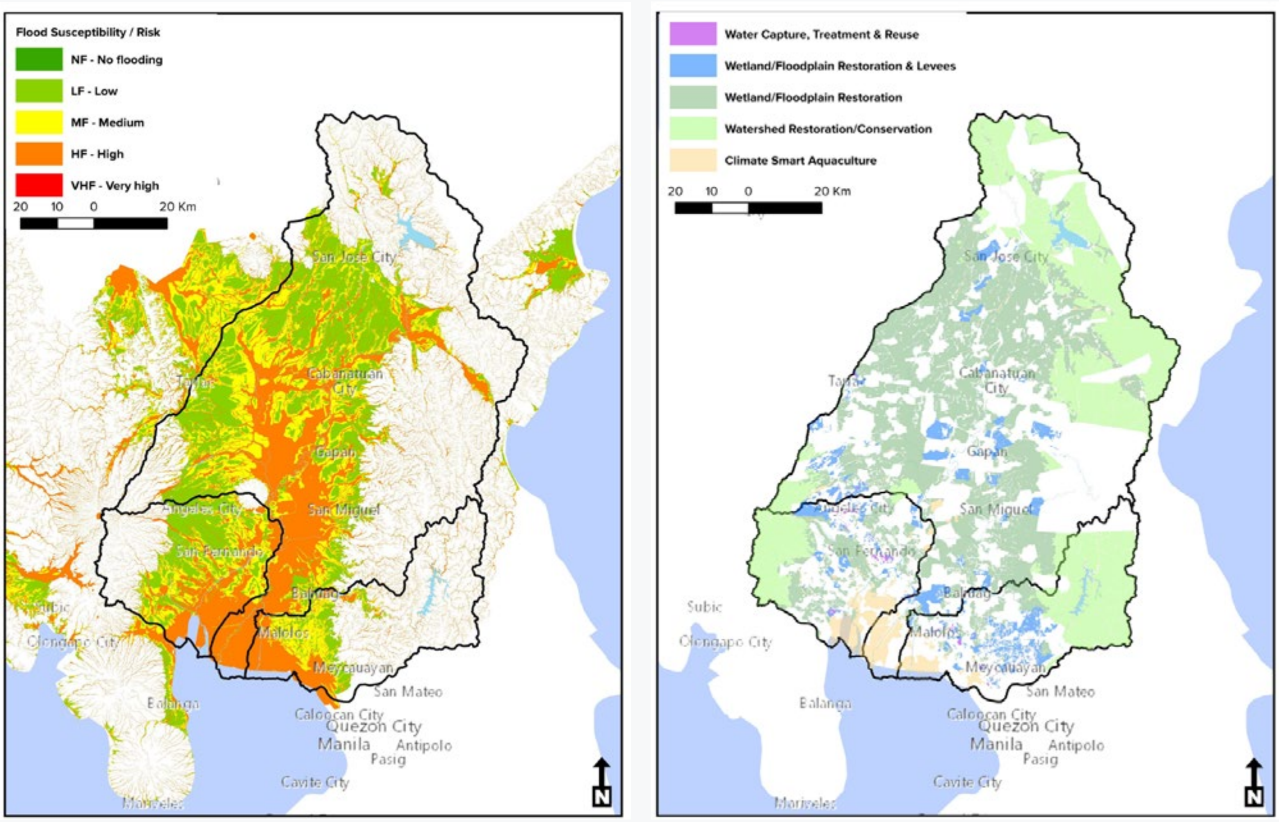
FLOOD MANAGEMENT | URBAN DEVELOPMENT | RURAL DEVELOPMENT | FRESHWATER

Project Description: This project designed and implemented an analysis to identify priority locations for conducting green-gray infrastructure site assessments using a novel spatial prioritization framework, in a watershed with high flood risks. The four data sets identified for use included: flood risk/susceptibility, land cover, population, and existing and/or proposed infrastructure projects. These spatial data sets were overlaid to predict where specific green-gray strategies would be most suitable. The green-gray interventions considered for applicability included watershed restoration and conservation, wetland and floodplain restoration, water harvesting, and climate smart aquaculture. Where the identified areas have a high potential for applicability of these green-gray solutions to reduce flood risk in the Pampanga River Basin.

Ecosystem services restored or conserved: Wetlands and floodplains restored for flood regulation.

Conventional engineering approach: Levees, water storage

What makes this a good green-gray example? The green-gray opportunity mapping analysis used readily available data and the methodology can be replicated in other contexts. Therefore, the approach for identifying these green-gray "hotspots" could be applied across the Philippines as well as in other geographies and contexts.



Example flood hazard map (left) and green-gray opportunity map (right) from the Pamapanga River basin, north of Manila.

CASE STUDY 18:
SUSTAINABLE WATER FUTURES IN SUB-SAHARAN AFRICA

Countries in sub-Saharan Africa need cleaner, less polluted surface waters alongside reduced flood risk, severity, and associated damage to assets. In water-scarce countries (e.g. Sahel region, southern Africa), better water retention is also needed throughout watersheds to improve availability during dry seasons. In all contexts, the quantity, timing, and spatial distribution of rainfall may shift as climate continues to change, and increased water demands pose additional risks to water security.

Nations typically construct dams and reservoir complexes for storing water to mitigate droughts and floods, generate power, and increase water availability for agricultural, industrial, and urban uses. Treatment plants clean water and wastewater, and pipes, pumps, and canals convey and distribute these resources. These engineered systems are vulnerable to mismanagement, deferred maintenance, sediment infilling, and changes in climate and/or water demand beyond design parameters. Yet ecosystems also store and clean water – on the stems and leaves of plants, in soils, and in wetlands, floodplains, and aquifers. The magnitude, temporal dynamics, and spatial distribution of engineered and natural storage systems are quite different, but integrated watershed planning and management, accounting for both the green and the gray elements of a basin, is essential to achieve water security at present and as global change continues.

From 2018 to 2020, roughly two dozen scientists, engineers, and policymakers from around the world convened to analyze sub-Saharan African water resource management challenges and opportunities.[29] **Spatial modeling and mapping of both ecosystems and conventional infrastructure explored the potential for leveraging green-gray infrastructure to improve water security in sub-Saharan Africa to manage floods and enhance drinking water and sanitation services. The result highlights the urgent need to accelerate the transition to next generation green-gray infrastructure systems across sub-Saharan Africa.** This work is ongoing and publications forthcoming.

29 National Socio-Environmental Synthesis Center. (2018). Planning for sustainable water futures in sub-Saharan Africa in the context of the SDGs

Table 2.2 Example of community consultation workshop used for green-gray projects in the Philippines

Activity/Workshop	Purpose	Methodologies used
Overview and objective of the site assessment	• Enhance understanding of objectives and purpose of the scoping study • Share methodology of the spatial prioritization study and insights into why this area was identified as a potential green-gray site.	Visual aids of digital or hard copy maps and charts were used along with facilitated discussions
Resource mapping	• Create a visual representation of natural resources and their uses in the area • Establish a starting point for participatory problem analysis and planning.	Divided attendees into smaller groups. Using a prepared map, asked the participants to overlay a plastic cover and draw the different resources present in their community.
Hazard mapping and analysis	• Identify hazards (particularly climate induced hazards) present in or affecting the community, specifically showing threats to lives, properties and livelihoods	Using the resource map from the earlier workshop overlayed a plastic cover on it and asked the participants to identify and draw the different hazards that are present and are threatening in their area.
Vulnerability analysis (exposure and sensitivity)	• Identify the elements at risk in the community due to the exposure of their location to hazards (e.g., households within 40 meters of the coastline) • Determine their degree of exposure to hazard/s of each identified elements at risk and importance to community life and survival • Determine their sensitivities to different climate related hazards	Using a vulnerability assessment matrix, asked the participants to describe the degree of exposure of each identified element at risk to each hazard/s.

Note that the above table may not be applicable in all instances, and is shown here merely to illustrate how a community workshop could be conducted.

WHAT INFORMATION SHOULD BE COLLECTED WHEN EVALUATING A POTENTIAL GREEN-GRAY INFRASTRUCTURE SITE?

Interviews

The site assessment and identification process starts with initial meetings with local governments and community members or asset owners. These consultation meetings will be conducted to understand local priorities and contextualize planning for the green-gray solution, by:

- Understanding how the local community interacts with the natural environment and how the environment connects to local socio-economic conditions;
- Collecting contextual information about local climate vulnerabilities, hazard risks, and impacts;
- Undertaking rapid biodiversity and environmental impact assessments;
- Defining the scale of the potential project or program (e.g., municipal, watershed, coastal);
- Introducing locally relevant green-gray infrastructure solutions based on the initial opportunity assessment; and
- Identifying potential suitable sites within the area of interest.

Existing Data Collection

Simultaneously the team will request and work to obtain existing background or secondary data – including compiling existing spatial datasets - about the site. Examples of documents to compile include:

- Disaster Risk Reduction Plan
- Local Climate Change Adaptation Plan
- Provincial or Municipal Development Plan
- Relevant maps such as:
  - Water and land use, including ecosystems
  - Marine and coastal protected areas
  - Resource maps (current and historical)
  - Topography
  - Bathymetry
  - Contingency plans
  - Floodplains
- Long-term climate projection
- Habitat assessments studies

Field Evaluation

Once the initial consultations are complete and existing data is collected, a multi-disciplinary design team conducts site visits to evaluate existing site conditions and green-gray infrastructure opportunities and constraints. During the consultations, identify the team needed for the site assessment. Team selection will depend upon the type of ecosystem (e.g., mangrove), vulnerabilities (e.g., freshwater supply and/or coastal protection), and infrastructure present (e.g., seawall, deep well) and consequent needs for context-specific knowledge and skills. The design team should include an engineer and/or landscape architect, who understands the importance of integrated green-gray solutions, and specialists familiar with the target ecosystems to be restored and/or conserved.

The goal of the site visit is to systematically analyze links between ecosystems, livelihoods, and hazards, to better understand vulnerability to climate change and the role of ecosystems and engineering solutions in adaptation.

Information collected during field evaluations includes:

Required Information	Examples
Site Location	Proximity to basic services, such as water and wastewater treatment, electricity, transportation hubs
Economic characteristics	Land productivity, resource use, land use type, infrastructure, transport
Environmental (physical) characteristics	Wind patterns, rainfall patterns, geology, topography, water sources, wastewater treatments, built infrastructure, easements
Environment (dynamic) characteristics	Location, extent, condition, ecosystem services, threats, existing management, historic ecosystem information. ('Restoration' in areas where the target ecosystem had not existed in the past is never recommended.)
Social characteristics	Demographics, livelihoods, existing social organizations, gender roles, basic services available (such as healthcare, communications and transportation options, existing (and quality of) contingency, disaster risk reduction – climate change adaptation plans, evacuation plans, natural resource management plans)
Institutional characteristics	Land tenure, land ownership, regulatory policies for land management, zoning, and potential implications for sustainability of funding and financing
Climate change impacts that the green-gray structure will address	Exposure, sensitivity, vulnerability and adaptive capacity
Description and sketch of concept design of potential green-gray infrastructure solution/s	The initial step in design development (described in Chapter 6)
Photos and videos of the site	For comparison of before and after intervention.

Appendix 2 to the Practical Guide includes specific questionnaires for a coastal site evaluation.

A number of other tools exist to evaluate potential Ecosystem-based Adaptation sites and can be considered or used in tandem with the approach proposed here. One example is ALivE, the Adaptation, Livelihoods, and Ecosystems Planning Tool[30], a computer-based tool, available through the International Institute of Sustainable Development.

WHAT SELECTION CRITERIA SHOULD BE USED TO SELECT SITES FOR GREEN-GRAY INFRASTRUCTURE IMPLEMENTATION?

A site selection tool provides a structured and objective method to separate high- and low-priority green-gray infrastructure project opportunities. A site evaluation matrix organizes selection criteria into an order of importance by assigning a numerical value to the priority of each item (Table 2.3). The benefit of this approach is its:

- Flexibility to add sites in the future and (re)evaluate/ compare using the same criteria.

30 International Institute for Sustainable Development (IISD)(2016). ALivE - Adaptation, Livelihoods and Ecosystems Planning Tool [Website] https://www.iisd.org/projects/alive-adaptation-livelihoods-and-ecosystems-planning-too.

- Ease to update when additional site information becomes available, for example about biotic, cultural, or geologic constraints; and
- Ability for project stakeholders to weight selection criteria. See Chapter 5, of this guide for other recommendations and strategies for Engaging Stakeholders and Building the Business Case for green-gray infrastructure projects.

Three (3) criteria have been selected to assess each site using a rating scale.

A. Climate vulnerability

"*Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt*" (IPCC, 2014[31]). It is expressed as a function of the sensitivity, exposure and adaptive capacity of the ecosystems and human communities therein (IPCC, 2014).

The assigned weight of the climate vulnerability selection criterion can be modified based on community and stakeholder input; the initial weight is 30%.

B. Community commitment

This criterion evaluates stakeholders, including the local government and community's, interest and long-term commitment to the project and their organizational capacities.

The assigned weight of the community commitment selection criterion can be modified based on community and stakeholder input; the initial weight is 35%.

C. Green-gray infrastructure applicability

This criterion evaluates the suitability of a green-gray infrastructure solution to address site-specific challenges. It is possible that particular sites are more appropriate for a purely green infrastructure or a purely gray infrastructure solution versus a hybrid approach.

The assigned weight of the green-gray infrastructure applicability selection criterion can be modified based on community and stakeholder input; the initial weight is 35%.

WHAT SPECIFIC QUESTIONS OR DATA ARE NEEDED TO EVALUATE A SITE USING THE SELECTION CRITERIA?

Each of the three (3) criteria has a more detailed description of what each criterion considers. Table 2.3 summarizes each of the selected criteria, sub-questions and associated rating scale. The higher the point assignment for a particular criterion indicates agreement with the question or, in the case of climate vulnerability, a lower point assignment indicates decreased sensitivity and exposure, and increased adaptive capacity.

Using Table 2.3 as a template, points are assigned to specific sub-questions based on specific site and/or community conditions. Each point value is multiplied by the weight of the associated criteria. The site score is the sum of all the points * criteria weights.

The sites are ranked based on score. The sites with the highest scores have the highest potential for implementing successful green-gray infrastructure solutions.

The ranked sites should be reviewed, and based on available budget, sites selected for green-gray infrastructure design development (Chapter 6). The site evaluation matrix provides a transparent process to assign weights to subjective criteria and prioritize where best to focus design funds.

31 IPCC (2014). Summary for policymakers. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (eds.) Field, C.B., V.R. Barros, D.J. Dokken, K.J. M ach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press. 32 pp. https://www.ipcc.ch/site/assets/uploads/2018/02/ar5_wgII_spm_en.pdf

Table 2.3. Summary of green-gray infrastructure site selection criteria

Criteria	Criteria Weight	Sub-Questions	Possible Points	
Climate Vulnerability	30%	Human/Social Dimension (Sensitivity)	2	Score = Sum of (Criteria Weight x Points)
		Degree to which an element is exposed to a climate-related hazard (Exposure)	2	
		Economic Safeguards/Ecosystem Quality (Adaptive Capacity)		
		Physical	2	
		Social	2	
		Ecosystem	2	
Community Commitment	35%	Local Government and Community Commitment to Project		
		Is the local government willing to endorse the project and work collaboratively with the project lead (e.g., Conservation International) and the local community to implement the project?	1	
		Is the local community committed to monitoring, maintaining, and possibly also constructing, the project?	1	
		Are local community socio-economic indicators positive?	4	
		Project Beneficiaries		
		How many people will directly benefit from the project?	2	
		How many people will indirectly benefit from the project?	1	
		Critical Infrastructure at Risk		
		What critical infrastructure will be affected, or damaged, if the green-gray project were not to be constructed?	1	
Green-Gray Infrastructure Applicability	35%	Site Conservation and/or Restoration Potential		
		Are the site conditions favorable to conserve or restore ecosystems?	2	
		Estimate (in hectares) the area available for restoration and/or conservation	2	
		Integration of "Green" and "Gray" Engineering Techniques		
		Do the "gray" project elements compliment the restoration/ conservation outcomes while also building resilience?	2	
		Is the green-gray solution cost-efficient in terms of its cost-benefit ratio (considering ecosystem, social, and economic costs and benefits)?	2	
		Climate Change Adaptation Potential		
		Will the proposed green-gray solution, in combination with other adaptation solutions such as evacuation plans and supplemental livelihood development, build resiliency?	2	

1. **Climate vulnerability**
   a. Human/social dimension (sensitivity) – Build questions that evaluate specific conditions that make a community (or portions of a community) more sensitive to the specific climate hazard. For example:
      1. How many households are constructed with light building materials? or
      2. How many households are likely to receive less water during a drought? or
      3. How many households are without back-up or alternative water supplies?

   b. Climate-related hazard/risk (exposure) – Apply a scale of relative exposure to the climate related hazard or risk at each site. Some sites have different exposures for the same hazard (e.g., storm surge from typhoons), whereas some hazards bring the same exposure to all sites. An example scale to compare exposure to typhoons:

1. What is the anticipated storm surge at each site, measured in meters?

c. Economic safeguards/Ecosystem quality (adaptive capacity) – Identify the physical, social, and ecosystem indicators that measure a community's resilience to a specific climate hazard. Note: for this criterion, the higher the adaptive capacity, the lower the assigned points in the site evaluation matrix. For example:
   1. What is the presence, quality, and abundance of ecosystems that will buffer the impact of extreme weather events (e.g., mangroves and/or coral reefs)?

Table 2.4 lists example physical, social, and ecosystem indicators of adaptive capacity.

2. **Community commitment** – Community commitments are critical to proceeding with project evaluation and design development.
   a. Local government and community commitment to project
      1. Is the local government willing to endorse the project and work collaboratively with the project lead and the local community to implement the project?
      2. Is the local community committed to monitoring, maintaining, and possibly also constructing the project?
      3. Are local community socio-economic indicators positive? (e.g., answer yes to all question in Table 2.5)

   b. Project beneficiaries
      1. How many people will directly benefit from the project?
      2. How many people will indirectly benefit from the project?

   c. Critical infrastructure at risk: What critical infrastructure will be affected, or damaged, if the green-gray infrastructure project were not to be constructed?

Table 2.4. Example indicators of adaptive capacity

Are any of the following indicators present in the community:		
Physical	**yes**	**no**
Evacuation center		
Sea wall(s)		
Road networks		
Alternative water supply		
Water treatment		
Social	**yes**	**no**
Evacuation and/or disastor risk reduction plans		
Watershed management plans		
Coastal resource management plan		
Community has first responder training		
Ecosystem	**yes**	**no**
Mangroves		
Coral reefs		
Seagrass meadows		
Ground water recharge features		
Stream/rivers connected to floodplains		
Well-vegetated watersheds		

Table 2.5. Example socio-economic criteria to consider for site selection (Source: Zoological Society of London Living Conservation & Philippine Tropical Forest Conservation Foundation, Inc., 2012[32])

Socio-economic Check-List			
Would you consider the community:	**Yes**	**No**	**Notes**
Open-minded			
Collaborative			
Easy to work with			
Willing to provide counterpart funds			
Willing to have their staff trained	should be yes to proceed		
Share a common vision with the project	should be yes to proceed		
Is a community organization:			
Present on site			
Registered			
Have constitution and by-laws			
Have structure			
Have a complete set of officers			
If no existing community organization:			
Does the community express willingness to organize			
Are partners (e.g., government, academe):			
Willing to provide technical/other support and guidance			
Do community members:			
Have access to financial services (normal times)			
Have access to after-disaster relief (finance, housing, etc.)			
Have insurance			

3. **Green-gray infrastructure applicability**
   a. Site conservation, sustainable management and/or restoration potential
      1. Based on environmental and biodiversity assessments of the site, are conditions favorable to conserve or restore ecosystems that will provide people with solutions that deliver climate change resilience and adaptation benefits? For example, if the target ecosystem is mangroves:
         a. Can the hydrology and soil conditions be feasibly modified to allow mangrove restoration?
         b. Are there nearby sources of mangrove seedlings?
         c. Are there conflicts with proposed restoration and/or conservation and existing land ownership or land use?

32 ZSL Living Conservation & Philippine Tropical Forest Conservation Foundation, Inc. (2012). *Community-Based Mangrove Rehabilitation Training Manual.* https://www.zsl.org/sites/default/files/media/2018-08/Mangrove%20Rehab_Training%20Manual.pdf

2. Estimate (in hectares) the area available for restoration and/or conservation.

b. Integration of "green" and "gray" engineering techniques
   1. Do the "gray" project elements complement the restoration/conservation outcomes, while also building resilience?
   2. Is the green-gray infrastructure solution cost-efficient in terms of its cost-benefit ratio (considering ecosystem, social, and economic costs and benefits)? (see Chapter 3 for methods)

Table 2.6. summarizes example data types needed to value project benefits and co-benefits.

Table 2.6. Example data types needed to value project benefits and co-benefits[33]

Benefits / co-benefits	Indicators and data needs	
	Physical measurements	Economic valuation
All provisioning services	Quantity harvested annually	Market price and shadow price
Carbon	Tons of carbon sequestered or emitted	Social cost of carbon; Carbon price
Water quality regulation	Changes in water quality parameters such as dissolved nutrients	Changes in water purification cost
Tourism	Changes in the number of tourist visits	Changes in the income of local businesses; Revenue earned
Water provision	Amount of water supplied for different sectors such as irrigation, domestic water	Beneficiary-specific value of water, such as tariff for domestic water consumption
Erosion control	Sediment loads in irrigation channels, hydroelectric dams, etc.	Dredging costs or equipement depreciation cost
Pollination	Changes in crop productivity	Cost of replacing natural pollination
Non-timber forest products	Total volume harvested by communities	Equivalent market price

c. Climate change adaptation potential - The long term impact and sustainability of an intervention should be considered in the context of ongoing climate change and considered at every stage of project development.
   1. Will the proposed green-gray infrastructure solution, in combination with other adaptation solutions such as evacuation plans and supplemental livelihood development, deliver climate change resilience and adaptation benefits?
   2. Has the potential for maladaptation been considered (i.e., through climate risk screening)? What measures can mitigate the risk of maladaptation?
   3. How will the project consider the impacts of climate change on the continued functioning and benefit provision of the project itself?
   4. Does the project qualify as a no-regret solution, offering benefits regardless of climate change impacts? How do these no-regret elements affect the feasibility or attractiveness of the proposed green-gray intervention compared to a conventional infrastructure- or purely ecosystem-based alternative?

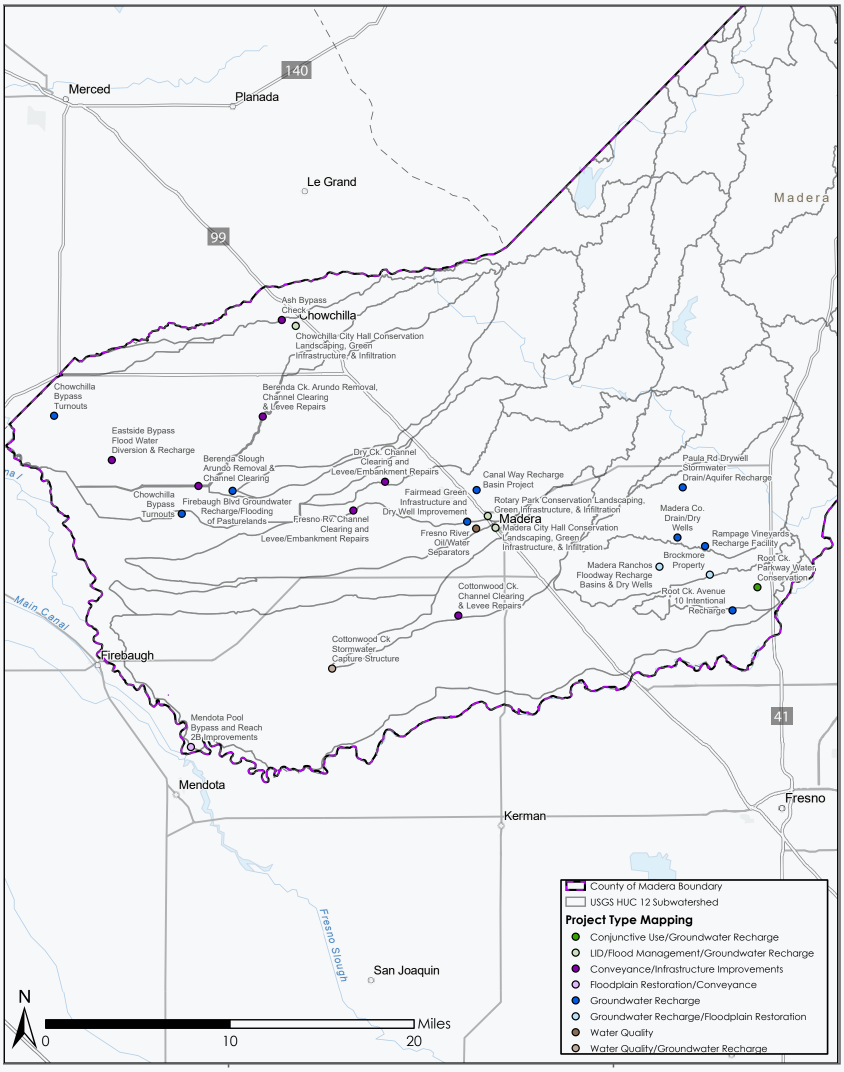
33 Donatti, C.I., Martinez-Rodrigo, M.R., Fedele, G., Harvey, C.A., Andrade, A., Scorgie, S., Rose, C., and Alam. M. (2019). *Guidelines for designing, implementing and monitoring ecosystem-based adaptation intentions*. Virginia, USA: Conservation International. 40 pp. https://www.conservation.org/docs/default-source/publication-pdfs/guidelines-for-designing-implementing-and-monitoring-eba.pdf?Status=Master&sfvrsn=bccddc79_3

CASE STUDY 19:
COUNTY OF MADERA STORMWATER RESOURCE PLAN

Location: County of Madera, California, USA

Project Proponent: County of Madera, funded through a California Proposition 1 planning grant

WATER SECURITY
CLEAN WATER
URBAN DEVELOPMENT
RURAL DEVELOPMENT
FLOOD MANAGEMENT
TERRESTRIAL



Map source: County of Madera (2017)[34]

Project Description: This Stormwater Resource Plan is a county-wide strategy to manage, as a resource, stormwater and dry weather runoff. As drought, climate change, and water quality impairments have affected California, a new focus has been placed on managing stormwater to maximize its capture and beneficial reuse. The objective of this plan is aligned to that goal: to identify and strategize the implementation of multi-benefit stormwater projects.

A project prioritization approach provided a structured and objective method to separate high and low priority projects. A prioritization matrix organized a diverse set of items into an order of importance by assigning a numerical value to the priority of each item. With input from stakeholders, a group of criteria was selected to assess the importance of each project and a rating scale established to assess how well a project satisfies that criteria. With input from county residents, technical experts, and stakeholders, each criterion was assigned a weight based on its relative importance.

The numeric rating a project was given for a particular criterion was multiplied by the criteria's weight to create a priority score for each project. The sum of all the weighted values across all criteria determines the project's total score. The total scores of all the projects were compared and the project ranked for suitability, based on stakeholder criteria and weights.

Ecosystem services restored or conserved: Wetlands, forests, and floodplains restored for flood regulation.

Conventional engineering approach: Levees, water storage, irrigation

What makes this a good green-gray example? The Madera County Storm Water Resource Plan is a first of its kind watershed-based stormwater plan that establishes an integrated and coordinated stormwater runoff management strategy. Using a range of approaches along the green-to-gray spectrum, the identified projects in the plan provide:

- groundwater recharge;
- low impact development / green stormwater infrastructure;
- conveyance and infrastructure improvements;
- floodplain restoration; and
- water quality improvements.

34 County of Madera (2017). *Storm Water Resource Plan.* Macera, CA, USA: County of Madera. 36 pp. https://www.maderacountywater.com/wp-content/uploads/2018/06/FINAL_MaderaSWRP_171228.pdf#page=12&zoom=100,86,96

3. ECONOMIC EVALUATIONS

To accelerate and scale the implementation of green-gray projects, practitioners need to be familiar with and apply economic and financial principles. The next two chapters describe economic and finance concepts relevant to green-gray infrastructure, ideally so that non-economists and/or non-financiers can engage with financial practitioners and identify tools, resources, and opportunities to facilitate funding for green-gray projects.

Economic approaches, analysis, and rhetoric can strengthen green-gray infrastructure projects, both in building the business case (Chapter 5) and in making a project more attractive and viable (e.g., to investors, users and land/resource users). Many different economic analyses apply to green-gray projects, including Cost-benefit analysis, Technical-economic analysis, Financial appraisal, Environmental valuation, and Triple-Bottom-Line Cost-Benefit Analysis. Each type of analysis provides insights for different decisions at different stages of green-gray project development. Altogether, they ground the identification of the most suitable funding/financing sources, so conducting multiple analyses can attract and enable stacking of different funding sources to a single project.

Economic analyses are widely trusted decision-support tools and recommended for greater adoption in green-gray infrastructure decision-making. Importantly, an economic analysis requires a biophysical assessment of each project alternative, which can be as straightforward as estimating ecosystem type and area. Additionally, there are inter-dependencies among different economic analyses. A good financial appraisal usually requires a solid cost-benefit analysis and a good understanding of the target investor type.

Identifying the various parties who benefit from a green-gray project and engaging them on commercial terms can support project implementation. This engagement can, in practice, be challenging because:

the benefits of green-gray projects are broader than conventional infrastructure;

quantifying the economic values of the wide range of social and environmental co-benefits of a green-gray project can be time- and data-intensive;

green-gray project beneficiaries and benefits need to link to potential funders/financiers;

though co-benefits create additional economic value, that value does not generally accrue to the project implementer, unless the regulator sets appropriate frameworks; and

it may be difficult to allocate the benefits to those who bear the costs.

HOW TO IDENTIFY THE MULTIPLE ECONOMIC BENEFITS, COSTS, AND RETURNS OF GREEN-GRAY PROJECTS

Evaluating green-gray solutions to inform the value and costs is important to:

1. inform project design and selection of the “best” or “most desirable” alternative to meet project goals (e.g., climate adaptation, disaster risk reduction, and/or other social or environmental benefits); and
2. justify the use of resources to investors, taxpayers, shareholders, and project stakeholders.

Economic analyses applicable to any project investment – including green-gray interventions – are:

1. Cost-benefit analysis,
2. Technical-economic Analysis (e.g., cost-effectiveness and life-cycle cost), and
3. Financial appraisal

Economic analyses that specifically capture ecosystem value or costs include:

4. Market/environmental valuation
5. True-cost accounting
6. Triple-Bottom-Line Cost-Benefit Analysis

Each type of economic analysis provides insights into different economic decisions in different stages of structuring green-gray solutions. These economic and financial analyses provide grounds for identifying the most suitable funding/financing source. Therefore, to attract and stack or assemble different funding sources to a single project, multiple analyses may be required.

1. **Cost-benefit analysis** uses welfare economics to justify an investment, given its socio-economic impact by quantifying benefits and costs in monetary terms for the projected impact of investment compared to existing alternatives (e.g., no project or a conventional infrastructure approach). The method requires a case-by-case evaluation of the ability of each alternative to deliver the intended project outcomes.

   Types of green-gray costs are summarized in Table 3.1 and green-gray benefits are described in Chapter 1. The environmental benefits and co-benefits will differ based upon ecosystem and project types, with examples in Table 3.2. Diverse economic actors can capture these benefits and co-benefits to support project implementation. For example, in the Climate Smart Shrimp case study in Chapter 4, beneficiaries can include fisherman, port operators, municipalities, and shrimp farmers. The problem is that though the co-benefits create additional economic value, that value does not generally accrue to the project implementer. The additional value transfers to parties other than the ones planning and implementing the project. It is difficult to route the benefits to those who bear the costs, unless local governments are funding the project.

   Cost-benefit analysis is a widely trusted decision-support tool, and thus is recommended for greater adoption in green-gray infrastructure decision-making. Multilateral financial institutions widely use cost-benefit analyses to allocate resources, provide insights into overall societal welfare gains, direct financial and sustainability impacts, and assess project risks. The United States of America, the United Kingdom and Canada have legislative requirements to evaluate public policies using cost-benefit analyses. Cost-benefit analysis is also a widespread practice in countries such as China, Bangladesh, and Kenya.[37]

   The World Resource Institute's Green-Gray Assessment[38] method allows stakeholders to value the costs and benefits of integrating green or natural infrastructure into water supply systems to improve performance. The method includes three pre-assessment steps and six main steps and provides recommendations on presenting results.

   There are several tools for quantifying the risk that climate change poses to the economy and to minimize the cost of adapting to that risk. The Swiss Re tool for a general assessment of risk indicates the avoided costs if a measure is taken. There are multiple risk models for estimating potential losses[39].

2. **Technical-economic analysis** includes measuring a project's cost-effectiveness and life cycle cost.

   Cost-effectiveness measures how well project alternatives efficiently deliver on the same objective. The two key steps are to:

   a. define a level-of-service, and
   b. determine which alternative delivers that level-of-service at the lowest cost[40].

   Life-cycle cost encompasses the project implementation component, considering the design, building, maintenance, and operation of the green-gray solution. It is critical for estimating the green-gray effective costs carried by project owners. Similarly, this analysis is particularly relevant for economic decisions aiming to minimize long-term costs for maintaining the desired service level.

   Life-cycle cost analysis also helps optimize capital and operating expenses, as more expensive designs often reduce the need to maintain and replace system components. When an existing engineering solution is already in place for providing a service, a life-cycle cost analysis can determine whether the initial cost of a new design offsets the operational cost savings it yields.[41]

37 Quah, E., and Toh, R. (2011). *Cost-benefit analysis: Cases and Materials*. Abingdon, Oxfordshire, UK: Routledge. 208 pp.

38 Gray, E., Ozment, S., Altamirano, J-C., Feltran-Barbieri, R. and Morales, A.G. (2019). *Green-Gray Assessment: How to Assess the Costs and Benefits of Green Infrastructure for Water Supply Systems*. Washington DC., USA: WRI. https://www.wri.org/publication/green-gray-assessment.

39 PreventionWeb (undated). Risk Models: Understanding disaster risk modelling. https://www.preventionweb.net/risk/models

40 Different alternatives can also be compared by their cost-effectiveness ratio, which is the net cost divided by the additional marginal outcomes due to implementing a solution (compared to business-as-usual).

41 USACE. (2020). Life Cycle Cost Analysis (LCCA) Key to project programming and design decisions. [Online presentation] https://rfpwizard.mrsi.erdc.dren.mil/MRSI/content/sustain/CX-KR%20Documents/LCCA/Best%20Practices/lcca-in-a-nutshell.pdf

Table 3.1 summarizes green-gray project costs. Optimizing life-cycle costs can be challenging for green-gray solutions, given the challenges of attribution, linearity, and identification of thresholds at which green-gray does not deliver the intended functionality.

Table 3.1. Green-gray project costs

Green-Gray Cost Category	Examples
Planning cost	Upfront planning cost for linking the project to the planning process.
Designing cost	Upfront costs for designing the solution, considering long-term uncertainties.
Opportunity Costs	Land costs, which for green-gray, can be less demanding than green-only alternatives but require more land than conventional approaches.
Transaction Costs	Cost to negotiate financial arrangements and enforcement commitment.
Cost of capital	The cost for financing the project, considering loan repayments and the cost of tying up capital.
Implementation	Capital Costs and Construction
Monitoring, Maintenance, and Adaptive Management (see Chapter 9)	Challenging to estimate the long-term cost because of (1) uncertainties related to climate and performance and (2) increased monitoring costs because ecosystems could be exploited or damaged for other purposes (e.g., logging)
Overhead due to long-term uncertainties	Expected cost for addressing long-term uncertainties

Table 3.2. Example benefits of green-gray projects

Project objective	Ecosystem	Green-Infrastructure provides:	Gray-Infrastructure complement:	Ancillary benefit
Climate regulation	Coral reefs	Wave attenuation	Storm surge protection	Ecotourism and livelihoods
Water security	Forests	Watershed/ catchment protection	Flood control	Water quality and quantity, livelihoods, aesthetics

CASE STUDY 20:
ROTTERDAM URBAN WATER BUFFER PROJECT[42]

Location: Spangen neighborhood, Rotterdam, The Netherlands

Project Proponent: Field Factors

Project Description: The Urban Water Buffer project is a hybrid solution for dealing with stormwater surplus and droughts in urban areas by locally collecting, storing, and re-using surplus stormwater.

This solution was compared against a conventional gray and fully green strategy for delivering the same retention capacity to deal with a 10-year rain event over the 50-year time frame. The fully green and the green-gray alternatives were marginally more cost-effective than the gray approach. However, the fully green design implied changing the land use of 35.000 m^2 and would have led to an opportunity cost of €13 million. In comparison, the hybrid solution required transforming only 13.330 m^2 for the same level of service, and the opportunity cost totaled only € 4,5 million.

Ecosystem services restored or conserved: Rainwater capture and reuse and green stormwater infrastructure for flood regulation.

Conventional engineering approach: Tanks, pipes, and pumps.

What makes this a good green-gray example? This project is an example of how green-gray solutions can overperform fully green solutions by requiring less land and avoiding land-use conflicts and decreasing opportunity costs.

Gray: Separated sewer and permeable pavement

Hybrid: Infiltration via public squares

Green: local, descentralized infiltration in public and private spaces

42 Le Coent, P., Hérivaux, C., Farina, G., Forey, I., Zi-Xiang, W., Graveline, N., Calatrava J., Martinez-Granados, D., Marchal, R., Moncoulon, D., Scrieciu, A., Mayor, B., Burke, S., Mulligan, M., Douglas, A., Soesbergen, A., Giordano, R., Kieran, D., Biffin, T., Peña, K., Van der Keur, P., Kidmose, J., Gnonlonfin, A., Douai, A., Piton, G., Munir, M.B., Mas, A., Arnaud, P., and Tacnet, J.M. (2020). *Nature Insurance value: Assessment and Demonstration. Deliverable 6.3. DEMO Insurance Value Assessment Report. - Part 5: NETHERLANDS Rotterdam DEMO EU Horizon 2020 Project, Grant Agreement N°730497.* 433 pp. http://naiad2020.eu/wp-content/uploads/2020/10/D6.3.pdf

3. **Financial appraisal** informs investment decisions by assessing a project's affordability and profitability, using data from the technical-economic analysis. The financial appraisal measures if a project can deliver monetizable benefits to determine if a project is a good investment opportunity. Monetizable benefits result in cash flow, the net amount of cash a project generates considering its life cycle costs, and revenues. Any benefits that do not result in cash flow are disregarded in the financial appraisal. There are techniques common to financial appraisals that measure worth, as defined in Table 3.3.

The analysis considers that one dollar today is more valuable than one dollar in ten years by estimating a discount rate[43]. A common challenge for financial appraisals is estimating the cash flow predictability in the future. To overcome those challenges, predicted returns must be adjusted based on potential risks. Methods to adjust predicted returns based on potential risk include:

- applying a Monte Carlo approach along key uncertainty dimensions, or
- increasing the discount rate over the project life.

Table 3.3. Techniques for financial appraisal

Net Present Value[44]	Internal Rate of Return[45]
The current worth of future streams of money, considering the time value of money.	Uses the Net Present Value formula for estimating the profitability of a project.
Return on Investment[46]	**Risk-Adjusted Value[47]**
Measures the efficiency of an investment as a total growth of an investment.	Cash profile (revenue stream in relation cost stream) adjusted by risks.

4. **Ecosystem/environmental valuation** uses the total economic value approach[48] and the Millennium Ecosystem Assessment[49] for estimating a monetary valuation of ecosystem services. Total economic value is the sum of values, in dollars, of all service flows that an ecosystem generates both now and in the future. It includes quantifying different types of value resulting from a project, including:

- direct value, which can be quantified monetarily and is either consumptive (e.g., fisheries) or non-consumptive (e.g., ecotourism);
- indirect value, which cannot be fully quantified (e.g., carbon sequestration, coastal protection);
- optional value that a resource is available for future use, and
- non-use values, that other people can use a resource (altruistic), future generations will be able to use a resource (bequest), and knowing a resource exists (existence).

43 The time value of money is represented in a discounting rate, considering that a dollar is more valuable today than in the future (e.g. opportunity cost or inflation). The higher the discounting rate used, the lower the present value of future streams of money. However, there are guidelines defining the default discount rate in the public sector.

44 Shrieves, R.E., and Wachowicz Jr, J.M. (2001). 'Free Cash Flow (FCF), Economic Value Added (EVA™), and Net Present Value (NPV): A Reconciliation of Variations of Discounted-Cash-Flow (DCF) Valuation.' The engineering economist 46(1): 33-52.

45 See: Lin, S.A. (1976). The modified internal rate of return and investment criterion. The engineering economist, 21(4): 237-247.

46 Phillips, P.P., and Phillips, J.J. (2006). Return on investment (ROI) basics: Alexandria, VA, USA: American Society for Training and Development. 200 pp

47 Damodaran, A. (2007). Risk-Adjusted Value. In A. Damodaran (Ed.), pp 99-143 in Strategic risk taking: a framework for risk management: Upper Saddle River, New Jersey, ISA: Pearson Prentice Hall. 388 pp.

48 The Economics of Ecosystems and Biodiversity (2010), The Economics of Ecosystems and Biodiversity Ecological and Economic Foundations. Edited by Pushpam Kumar. Earthscan: London and Washington.

49 Millennium Ecosystem Assessment (2005). Ecosystems and Well-being Synthesis report. Washington DC: Island Press. v+86 pp.

5. **True-cost accounting.** It provides an understanding of both social and ecosystem negative effects by a closer accounting of material flows and non-intended impacts. The steps for making visible those negative effects are[50]:

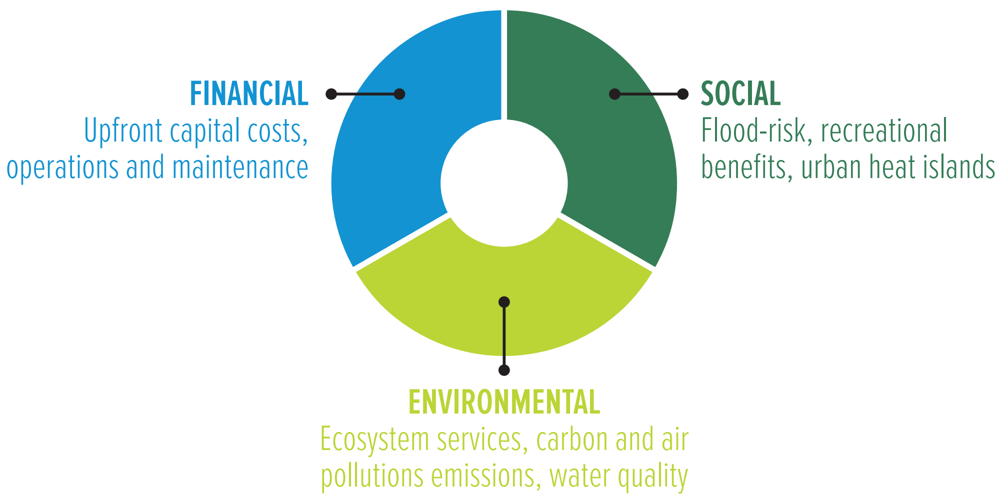
a. define the cost objective (which might be, for example, a product, production process, waste disposal, part of economic activity, or an industry);
b. specify the scope or limits of analysis (that is, what sub-set of all possible externalities are identified);
c. identify and measure external impact (which involves linking cost objective and the externalities arising from the cost objective); and
d. cost external impact (monetization of the externalities, or determination of the fuller cost associated with, but not already captured by, the current accounting for a cost objective).

6. **Triple Bottom Line Cost Benefit Analysis** is an evidenced-based economic framework that combines Cost-Benefit Analysis and Life-Cycle Cost Analysis. The triple bottom line refers to financial, social, and environmental dimensions, weighing the impacts (i.e., costs and benefits) to stakeholders of policies and projects.[51,52]

Triple Bottom Line Cost Benefit Analysis involves a comprehensive account of project benefits and costs over the entire life cycle and a side-by-side comparison of net benefits for alternatives. This approach offers the opportunity to recognize and evaluate all project economic, social, and environmental impacts objectively and transparently using empirical data and peer-reviewed literature. The comprehensive economic analysis makes explicit different sources of value relevant for identifying the right type of financing.

The Triple Bottom Line Cost Benefit Analysis is not the 'be-all and end-all'. The practice relies on the scientific ability to quantify complex incremental changes in ecosystems and populations to apply economic methods and monetize these incremental impacts. The method is limited in its function to monetize impacts that cannot first be quantified. These impacts must be acknowledged and qualitatively discussed, for example one significant category of quantitative data gaps is the option use-value and altruism, bequest, and existence non-use values.

WHAT IS THE TRIPLE BOTTOM LINE?



50 Bebbington, J., Gray, R., Hibbitt, C., and Kirk, E. (2001). *Full cost accounting: An agenda for action (No. 73)* London: Certified Accountants Educational Trust. 172 pp.

51 Boardman, A.E., Greenberg, D.H., Vining, A.R. and Weimer, D.L. (2011). "Introduction to Cost-Benefit Analysis" In Boardman, A.E., Greenberg, D.H., Vining, A.R. and Weimer, D.L. (eds) pp xx-xx in *Cost-Benefit Analysis: Concepts and Practice*. 4th ed. New Jersey, USA: Pearson. 560 pp.

52 TBL-CBA leverages Boardman et al. (2011) as foundational guidance to conduct CBA and it evaluates the incremental differences between a base case and alternatives.

CASE STUDY 21:
DOWNTOWN MIAMI GREEN-GRAY COASTAL RESILIENCE TRIPLE BOTTOM LINE-COST BENEFIT ANALYSIS[53]

Location: Miami, Florida, USA

Project Proponent: Miami Downtown Development Authority

COASTAL PROTECTION
URBAN DEVELOPMENT
CLEAN WATER
FLOOD MANAGEMENT
COASTAL

Source: Autocase, Impact Infrastructure (2019)[54]

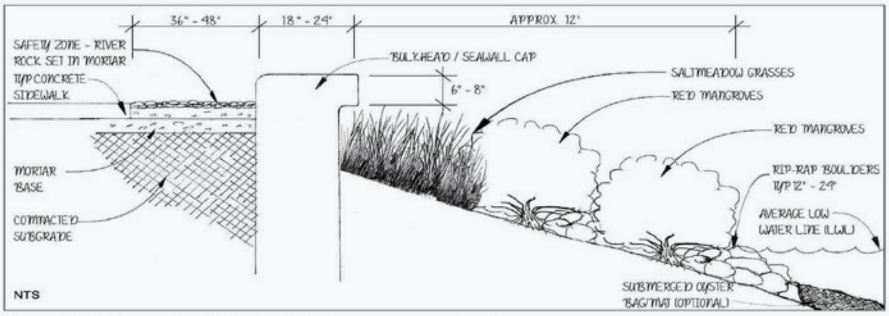


Figure A.6: Example of 7ft Sea Wall with Living Shoreline

Project Description: The market value for Downtown Miami properties is roughly $39B, representing more than 50% of the City's taxable property value. Damage to properties, infrastructure, and people due to natural hazards could have significant fiscal and social consequences. Hence, the Miami Downtown Development Authority engaged Impact Infrastructure to conduct a Triple Bottom Line Cost Benefit Analysis of green-gray coastal infrastructure. The analysis was carried out by makers of Autocase, the first automated Triple Bottom Line Cost Benefit Analysis software.

The Triple Bottom Line Cost Benefit Analysis estimated the costs and benefits of two coastal infrastructure designs along 13.4 kilometers of coastline in Downtown Miami, compared to an existing 1.5m tall sea wall. The analysis compared a 2.1m tall sea wall (gray infrastructure design) and the combination of a 2.1m sea wall and living shoreline of mangroves and seagrasses (green-gray infrastructure design).

Overall results indicate that coastal protection benefits outweigh the costs given the positive benefit-cost ratios and net benefits. While gray infrastructure designs return higher benefit-cost ratios, living shoreline features spur incremental benefits to the environment over purely gray designs.

Ecosystem services restored or conserved: Mangroves for flood regulations and seagrasses for wastewater purification and carbon sequestration.

Conventional engineering approach: Sea walls

What makes this a good green-gray example? These Triple Bottom Line Cost Benefit Analysis outputs indicate that a combined green-gray infrastructure design – such as the living shoreline additions to the 2.1m sea wall design – return greater net benefits. The higher returns stem from the additional co-benefits green infrastructure contributes to the community and environment, which do not occur with a gray-only design.

53 Autocase, Impact Infrastructure (2019). *Downtown Miami Urban Redevelopment and Sea Wall Infrastructure – Comprehensive Economic Analysis for Resilience and Community Impacts* [Online report] https://www.miamidda.com/wp-content/uploads/Miami-DDA-Final-Report-12_03_2018.pdf

54 ibid.

Table 3.4 summarizes the key questions each economic analysis type addresses and how it relates to other economic analyses.

Table 3.4: Economic analyses and how do they relate to each other.

Type of Analysis	The main question and (mainly) relevant for who?	Relation with other instruments
Tool for assessing any project including green-gray projects		
1. Cost-Benefit analysis[55,56]	Does the solution provide socio-economic and environmental welfare? • Public funding and financing • Grants • Concessional financing • Taxpayers and citizens	• Life cycle cost should be included in the Cost-Benefit Analysis. However, Cost-Benefit Analysis also counts non-direct costs (e.g., negative externalities[57]). • Cost-Benefit Analysis does not focus on optimizing a specific level of service in comparison to cost-effectiveness. Cost-effectiveness can be conducted after prioritizing benefits and co-benefits. • Cost-Benefit Analysis counts a larger set of benefits and costs than those relevant for a financial appraisal (e.g., non-monetizable benefits and negative externalities). • Cost-Benefit Analysis often uses market/environmental valuation for estimating environmental benefits. • Cost-Benefit Analysis can use true-cost accounting for estimating negative externalities. • Triple-Bottom-Line Cost-Benefit Analysis defines the categories for comprehensive Cost-Benefit Analysis.
2a. Cost-effectiveness analysis[58]	What is the cheapest alternative for reaching the desired level of service/ outcome? • Project sponsors • Public funding and financing • Grants • Concessional financing • Taxpayers and citizens	• Cost-Effectiveness Analysis does not identify co-benefits as Cost-Benefit Analysis does, and it does not require monetizing the value of desired outcomes. • Life Cycle Cost Analysis should be included as a component of Cost-Effectiveness Analysis. • Cost-Effectiveness Analysis has an indirect relation with financial appraisal (by including life cycle cost). • Market/environmental valuation is often irrelevant, given the pre-definition of a desired level of service. • Cost-Effectiveness Analysis only includes costs that are directly assumed by the project sponsors. Hence it might disregard true-cost accounting. • Compared to Triple Bottom Line Cost-Benefit Analysis, cost-effectiveness analysis does not value co-benefits besides the desired level of service.

55 For additional information on how to carry out the analysis see: Graveline, N., Joyce, J., Calatrava, J., Douai, A., Arfaoui, N., Moncoulon, D., Manez, M. De Ryke H., and Zdravko K. (2017) (2017). *General framework for the economic assessment of Nature Based Solutions and their insurance value*. [Online report] 57 pp. http://naiad2020.eu/wp-content/uploads/2018/11/4.1-2.pdf

56 For additional information on how to carry out the analysis see: National Academies of Sciences, Engineering, and Medicine (NASEM) 2020. *Incorporating the Costs and Benefits of Adaptation Measures in Preparation for Extreme Weather Events and Climate Change Guidebook*. Washington, DC: The National Academies Press. 190 pp. https://doi.org/10.17226/25744

57 In regard to the costs or negative impacts produced by the project which are borne by other actors or society

58 For additional information on how to carry out the analysis see: Görlach, B (2005). *Cost-Effectiveness analysis (CEA)*. 6 pp. [Online report] http://www.ivm.vu.nl/en/Images/CBA10_tcm234-161546.pdf

Type of Analysis	The main question and (mainly) relevant for who?	Relation with other instruments
2b. Life-Cycle Cost Analysis[59,60]	What is the total cost of owning a project? • Project sponsors • Public funding and financing • Private investors looking for financial return • Grants • Concessional financing • Taxpayers and citizens	• Life-Cycle Cost Analysis should be part of a solid cost-benefit analysis • Life-Cycle Cost Analysis should be part of a solid cost-effectiveness appraisal • Life-Cycle Cost Analysis should inform the cash-out in financial appraisal • Market/environmental valuation is often irrelevant for Life-Cycle Cost Analysis as the former deals with benefits • True-cost accounting points out negative externalities that should be compensated. If those costs remain external to the project, they are irrelevant for Life-Cycle Cost Analysis. • Life-Cycle Cost Analysis is a component of the Triple-Bottom-Line Cost-Benefit Analysis.
3. Financial appraisal (cash-flow analysis)[61]	Is there a positive cash-flow for making the project financially sustainable? • Project sponsors • Private investors looking for financial return • Public funding and financing	• Only benefits and costs that can be directly translated to "cash in" and "cash-out" should be included in the financial appraisal. • Cost-effectiveness has an indirect relation with financial appraisal (by including Life-Cycle Cost Assessment). • A cash-out builds upon life cycle cost. • Market/environmental valuation if the environmental services are translated into cash-in. • True-cost accounting can point out negative externalities that should be compensated – turning into cash-out. If those costs remain external to the project, they are irrelevant for financial appraisal. • Financial appraisal is one component of the Triple-Bottom-Line Cost-Benefit Analysis.
Tools for capturing ecosystem values and costs		
4. Ecosystem / environmental valuation[62]	What is the monetary value of ecosystem services? • Project sponsors • Public funding and financing • Private investors looking for financial/ • environmental return • Grants • Concessional financing	• Ecosystem Environmental Valuation should be included in Cost-Benefit Analysis. • Ecosystem Environmental Valuation provides a monetary value of ecosystems. Hence, it is not needed for Cost-Effectiveness Analysis. • Ecosystem Environmental Valuation provides values in terms of benefits. Hence, it does not have a relation with Life-Cycle Cost Analysis. • Ecosystem Environmental Valuation provides a monetary valuation of ecosystems. Nevertheless, no monetary valuation would automatically turn into cash-in. Only valuation (or percentage) that can be converted in cash-in should be included in the financial appraisal. • Ecosystem Environmental Valuation provides a monetary valuation of environmental benefits, while true-cost accounting a valuation of environmental costs. • Ecosystem Environmental Valuation is part of the Triple-Bottom-Line Cost-Benefit Analysis.

Type of Analysis	The main question and (mainly) relevant for who?	Relation with other instruments
5. True-cost accounting[63]	How do we account for the non-direct socio-environmental costs of economic activity? • Project sponsors • Public funding and financing • Private investors looking for financial/ • environmental return • Grants • Concessional financing	• True-cost accounting should be included in Cost-Benefit Analysis • True-cost accounting usually signals costs that are not considered in traditional Cost-Effectiveness Analysis. • True-cost accounting points out negative externalities that should be compensated – turning into a relevant Life-Cycle Cost Analysis category. Those costs should be included in the project as monetary compensation to count for Life-Cycle Cost Analysis. • True-cost accounting only counts for a financial appraisal if the non-direct costs turn into cash-out (e.g., as monetary compensations to pay) • True-cost accounting provides a monetary valuation of environmental costs, while Ecosystem Environmental Valuation quantifies benefits. • True-cost accounting should be part of the Triple-Bottom-Line Cost-Benefit Analysis.
6. Triple Bottom Line Cost Benefit Analysis[64]	Does the solution lead to profits, benefit the planet and people? • Project sponsors • Public funding and financing • Private investors looking for financial/ • environmental return • Grants • Concessional financing	• Triple-Bottom-Line Cost-Benefit Analysis defines the categories for comprehensive Cost-Benefit Analysis. • Triple-Bottom-Line Cost-Benefit Analysis does not focus on optimizing a specific level of service in comparison to Cost-Effectiveness Analysis. • Life-Cycle Cost Analysis is a component of Triple-Bottom-Line Cost-Benefit Analysis. • Triple-Bottom-Line Cost-Benefit Analysis identifies a larger set of benefits and costs than a financial appraisal. Only the “profits” component is relevant for financial appraisal. • Triple-Bottom-Line Cost-Benefit Analysis often uses Ecosystem Environmental Valuation for estimating environmental benefits for the planet • Triple-Bottom-Line Cost-Benefit Analysis can use True-cost accounting for estimating negative externalities impacting the planet and people

59 For additional information on how to carry out the analysis: USACE. (2020). *Life Cycle Cost Analysis (LCCA) Key to project programming and design decisions*. [Online presentation] https://rfpwizard.mrsi.erdc.dren.mil/MRSI/content/sustain/CX-KR%20Documents/LCCA/Best%20Practices/lcca-in-a-nutshell.pdf

60 For additional information on how to carry out the analysis: Altamirano, M. A., & de Rijke, H. (2017). *Costs of infrastructures: elements of method for their estimation.* [Online report] https://ec.europa.eu/research/participants/documents/downloadPublic?documentIds=080166e5be285378&appId=PPGMS

61 For additional information on how to carry out the analysis see: Table 3.4

62 For additional information on how to carry out the analysis see: McVittie, A., & Hussain, S. (2013). *The economics of ecosystems and biodiversity-valuation database manual*. 21 pp http://www.teebweb.org/wp-content/uploads/2014/03/TEEB-Database-and-Valuation-Manual_2013.pdf

63 For additional information on how to carry out the analysis see: Bebbington, J., Gray, R., Hibbitt, C., & Kirk, E. (2001). Full cost accounting: An agenda for action (No. 73, p. 172). London: Certified Accountants Educational Trust. 172 pp.

64 For additional information on how to carry out the analysis see: Boardman, A.E., Greenberg, D.H., Vining, A.R. and Weimer, D.L. (2011). “Introduction to Cost-Benefit Analysis” In Boardman, A.E., Greenberg, D.H., Vining, A.R. and Weimer, D.L. (eds) pp xx-xx in *Cost-Benefit Analysis: Concepts and Practice*. 4th ed. New Jersey, USA: Pearson. 560 pp.

4. FUNDING AND FINANCING

Meaningful engagement of non-financers with financial practitioners requires understanding the difference between funding and financing. As used in this context, “funding” refers to the source(s) of cash required for implementation over a project’s lifespan. A project’s funding model typically describes the source of long-term funding (e.g. taxpayer base, benefit off-takers, users and/or customers) and funding mechanisms (e.g. specific taxes, tolls, user fees etc.) used to support the project. By comparison, project “financing” refers to the sources of capital required for front-end investments in project development and establishment.

In general, the financial feasibility of infrastructure projects are determined based on the ability of project funding to repay initial financing and financing costs (e.g. interest expense on debt, required returns on equity) over the project’s lifecycle (or some other pre-determined time horizon). Green-gray projects have the potential to generate self-sourced funding, providing an investment opportunity for lenders/investors looking for financial return while providing important social and environmental outcomes.

In evaluating the potential sources of project financing or funding, it is important to identify the requirements, and risk and return objectives of public and private investors and the respective roles they may play within an overarching project financial model. Project investments need to align with landscape-scale (regional and watershed) plans, policy priorities, and investors’ mandates. This alignment can accelerate the funding, financing, and implementation of green-gray projects.

The community-of-practice has observed that:

- green-gray solutions are often regarded as a more cost-effective solution than conventional alternatives;
- gray solutions usually entail higher upfront, capital investments and longer term annual maintenance costs over the project life, compared to solutions with green components;
- when well-articulated at the landscape level, green-gray solutions provide numerous long-term benefits, including land security, climate regulation, and water security;
- green-gray solutions can outperform fully green solutions in economic terms as they can be less land demanding, which avoids land-use conflicts and leads to lower opportunity cost;
- the life-cycle cost of conventional infrastructure is often perceived as more certain than the green-gray life-cycle cost[65]; and
- green-gray solutions are less vulnerable to activities that can deplete natural capital compared to fully nature-based projects[66].

Further research is recommended to validate and quantify these observations.

This section highlights common sources and mechanisms that may be relevant to the funding and financing of green-gray infrastructure solutions.

WHAT SOURCES OF FUNDING CAN SUPPORT A GREEN-GRAY PROJECT?

Funding refers to the sources of cash affording the project’s execution and eventually leading to a profit. Funding examples include domestic budgets, grants, taxes and subsidies, and self-generated revenues from market-based instruments, market credits or payment for ecosystem services.

65 Altamirano, M.A., Benítez Avila, C.A., de Rijke, H., Angulo, M., Arellano, B., Dartée,K., Peña, K., Nanu, F., Mayor,B., Lopez-Gunn, E., Marchal, R., Pengal, P., Scrieciu, A., Mori. J.J. (2020). *Handbook for the Implementation of Nature-based Solutions for Water Security: guidelines for designing an implementation and financing arrangement*. 45 pp. http://naiad2020.eu/wp-content/uploads/2020/06/D7.3.pdf

66 Take the example of mangrove belts for coastal protection. Mangrove biomass can be depleted because of activities such as logging.

Domestic Budgets are an entry point for leveraging public funding within a typical national or municipal budget cycle. It can include fiscal earmarking during budget preparation, approval, execution, and monitoring.

Grants are a form of non-repayable financial assistance provided by domestic or international government authorities or by the private sector in the form of philanthropic donations from corporate entities, foundations, or international organizations. Public and philanthropic grants are increasingly used in blended finance schemes for large scale projects. While we have categorized grants as a source of project funding, in some cases, grants may be used as part of project financing structures.

International grants are often allocated to the least developed countries, and with some conditions to transition countries. Of the many international funds, there are three in the climate adaptation finance space with different criteria for awarding grants and high potential to apply to green-gray projects: The Green Climate Fund, the Global Environmental Facility, and the Adaptation Fund.

- The Green Climate Fund provides grants for achieving Paris Agreement goals. Green Climate Fund grants usually need to be matched by public funding or other sources, as the Green Climate Fund only covers the marginal or additional cost to make a project resilient.
- The Global Environmental Facility is available to developing countries to meet international environmental conventions and agreements' objectives. The grant establishes a clear co-funding policy for their grants: a 7:1 ratio co-financing for upper-middle countries (concerning development) and 5:1 for least developed countries.
- The Adaptation Fund grant covers the costs associated with implementing concrete adaptation activities that address climate change's adverse effects. Co-funding is not required, but it is possible and advisable.

Philanthropy can play an important role in catalyzing the start of a green-gray project. For example, philanthropic grants can be used to conduct the initial feasibility study or economic analysis that can then be used to bring in additional funding or financing for the next project stage. As the community works to mainstream green-gray practices, this stage is critical.

Taxes and Subsidies. Taxes are a compulsory contribution that can align directly and indirectly to a green-gray project. Directly, taxes can be imposed in the context of service delivery. Indirectly, suppose a project, or a portfolio of projects, are predicted to increase economic growth or enhance real property values, cities may increase tax revenue due to the project's expected economic development[67].

Subsidies are other policy mechanisms for funding projects, which are mainly economic tools for introducing transformative changes. Subsidies pay or reimburse project implementers for taking specific actions so that a commodity can remain competitive or support an undertaking considered in the public interest. Subsidies are usually limited to the initial stage of programs supporting transformative changes; planning instruments and regulations later assume the dominant role.

Self-generated Revenues: Market-based Instruments and Payment for Ecosystem Services. Self-generated revenues depend on the funding model of the project when it integrates ancillary benefits. These ancillary benefits must be monetizable. It is important to note that the self-revenue stream is the commodity produced by the sustainable use of ecosystems, where such a commodity has a market value. That self-generated revenue will only be available once the project is in operation.

Market-based Instruments. Green-gray solutions have a higher value potential in environmental markets, such as stormwater markets[68]. Stormwater markets create a trading mechanism between runoff retention suppliers and demanders that must reduce harmful stormwater runoff according to regulations. These demanders are typically developers of non-climate related infrastructure projects (e.g., real estate).

The emblematic example is the Washington DC stormwater retention market[69,70]. The market is regulated by the District of Columbia Water Utility (Public Utility) and the Department of Energy and the Environment. The latter certifies projects, including green-gray interventions, that can issue retention credits, manage database tracking transitions, and set a price. Demanders can purchase credits for meeting their legal obligations, introduce green infrastructure components in their project, or pay an in-lieu fee directly to the Department of Energy and the Environment.

67 Using tax incrementing financing mechanisms that forecast potential increases in tax revenue due to the project's expected impact on economic development or other drivers of real property valuation increases.

68 Bassi, A., Cueallar, A., Pallaske, G., & Wuennenberg, L. (2017). *Stormwater Markets: Concepts and applications*. Winnipeg, Manitoba Canada: International Institute for Sustainable Development. iii+30 pp. https://www.iisd.org/system/files/publications/stormwater-markets-concepts-applications.pdf

69 Department of Energy & Environment (DOEE) (2019). Stormwater Retention Credit Trading Program. [Website] https://doee.dc.gov/src

70 O'Neill, S., and Cairns, S. (2016). *New Solutions for Sustainable Stormwater Management in Canada*. Ottawa, ON, Canada: Sustainable Prosperity. 192 pp. https://institut.intelliprosperite.ca/sites/default/files/stormwaterreport.pdf

Payment for Ecosystem Services. A special case to consider is the payment for provisioning, cultural, and supporting ecosystem services. Payment for Ecosystem Services are schemes that translate those services' non-market value into financial incentives[71]. The canonical definition of payment for ecosystem service includes five elements[72]:

1. A voluntary transaction where
2. a well-defined Ecosystem Services (or a land-use likely to secure that service)
3. is being 'bought' by a (minimum one) Ecosystem Service buyer
4. from a (minimum one) Ecosystem Service provider
5. if and only if the Ecosystem Service provider secures Ecosystem Service provision (conditionality).

Four types of ecosystem services are susceptible to be structured as payment for ecosystem services: carbon sequestration, biodiversity protection, watershed protection, and landscape beauty[35]. Transaction units often include hectares of land managed, pounds of pollution kept out of water bodies, or volume (m^3) of runoff managed[73,74,75]. Those transactions can be arranged in user-driven agreements or environmental markets.

In a user-driven agreement, the buyer contacts directly with the seller. The buyer can be a single organization (e.g., utility) or an association of organizations taking collective action for pooling contributions for the greater impact, such as a water fund[76]. The most successful bilateral agreement is showcased by a watershed program's investment with a single downstream beneficiary – often a utility supplying water. These types of arrangements usually aim to provide water security upon full green infrastructure and conservation.

Carbon credits. A carbon credit is a tradable instrument representing "the reduction, avoidance or sequestration of one metric ton of carbon dioxide or greenhouse gas equivalent".[77] Carbon credits are traded in two types of markets:

1. the compliance market, such as under mandatory carbon reduction schemes at the national, regional, or international levels; and
2. the voluntary market, mainly to meet corporate social responsibility targets or offset individuals' carbon emissions[78,79].

Carbon credit projects located in coastal ecosystems are also referred to as 'blue carbon' projects. In the green-gray project context, carbon credits have been generated for around a decade for mangrove conservation, reforestation, and restoration projects. Examples include a compliance market mangrove project in Senegal under the Clean Development Mechanism[80], as well as voluntary market mangrove projects, e.g., in Kenya[81,82] or Myanmar.[83]

71 Engel, S., Pagiola, S., & Wunder, S. (2008). 'Designing payments for environmental services in theory and practice: An overview of the issues.' *Ecological Economics* 65(4): 663-674.

72 Wunder, S. (2005). *Payments for environmental services: some nuts and bolts*. Payments for Environmental Services: some nuts and bolts. *CIFOR Occasional Paper No. 42*. Bogor, Indonesia:Center for International Forestry Research. 5pp. https://vtechworks.lib.vt.edu/bitstream/handle/10919/66932/2437_009_Infobrief.pdf?sequence=1&isAllowed=y

73 *ibid.*

74 Bassi, A., Cueallar, A., Pallaske, G., & Wuennenberg, L. (2017). *Stormwater Markets: Concepts and applications*. Winnipeg, Manitoba Canada: International Institute for Sustainable Development. iii+30 pp. https://www.iisd.org/system/files/publications/stormwater-markets-concepts-applications.pdf

75 Bennett, G., Cassin, J., and Carroll, N. (2016). 'Natural infrastructure investment and implications for the nexus: A global overview.' *Ecosystem Services*, 17: 293-297.

76 Bennett, G., and Ruef, F. (2016). *Alliances for green infrastructure: State of watershed investment 2016*. Washington, DC, USA: Forest Trends' Ecosystem Marketplace. vii+62. https://www.forest-trends.org/wp-content/uploads/2017/03/doc_5463.pdf

77 Ecosystem Marketplace (2020). *Carbon Market: Overview*. https://www.ecosystemmarketplace.com/marketwatch/carbon/

78 Carbon Market Watch (2019). *Carbon Markets 101 – The Ultimate Guide to Global Offsetting Mechanisms*. 11 pp. https://carbonmarketwatch.org/wp/wp-content/uploads/2019/06/CMW-CARBON-MARKETS-101-THE-ULTIMATE-GUIDE-TO-MARKET-BASED-CLIMATE-MECHANISMS-WEB-FINAL-SINGLE.pdf.

79 Greenhouse Gas Management Institute (2019). Carbon Offset Guide – Mandatory and Voluntary Offset Markets. [Website] https://www.offsetguide.org/understanding-carbon-offsets/carbon-offset-programs/mandatory-voluntary-offset-markets/.

80 Clean Development Mechanism (2011). *Project 5265: Oceanium mangrove restoration project*. [Website] https://cdm.unfccc.int/Projects/DB/ErnstYoung1316795310.61/view

81 UN Environment (2019). *Mangrove conservation more valuable than ever thanks to carbon trading*. [Website] https://www.unenvironment.org/news-and-stories/story/mangrove-conservation-more-valuable-ever-thanks-carbon-trading

82 Plan Vivo (2010). *Mikoko Pamoja – Mangrove Conservation and Restoration Project in Kenya*. [Website] https://www.planvivo.org/mikoko-pamoja

83 Worldview International Foundation (2018). *Reforestation and restoration of degraded mangrove lands, sustainable livelihoods and community development in Myanmar, VCS project ID 1764*. [Website] https://wif.foundation/vcs-approval/

CASE STUDY 22:
CLIMATE SMART SHRIMP

Location: West Java, Indonesia

Project Proponent: Conservation International with funding from the Caterpillar Foundation

Project Description: This project reverses shrimp aquaculture's paradigm as an agent of mangrove deforestation by coupling sustainable intensification of shrimp farming with restoration to provide biodiversity and community climate adaptation benefits.

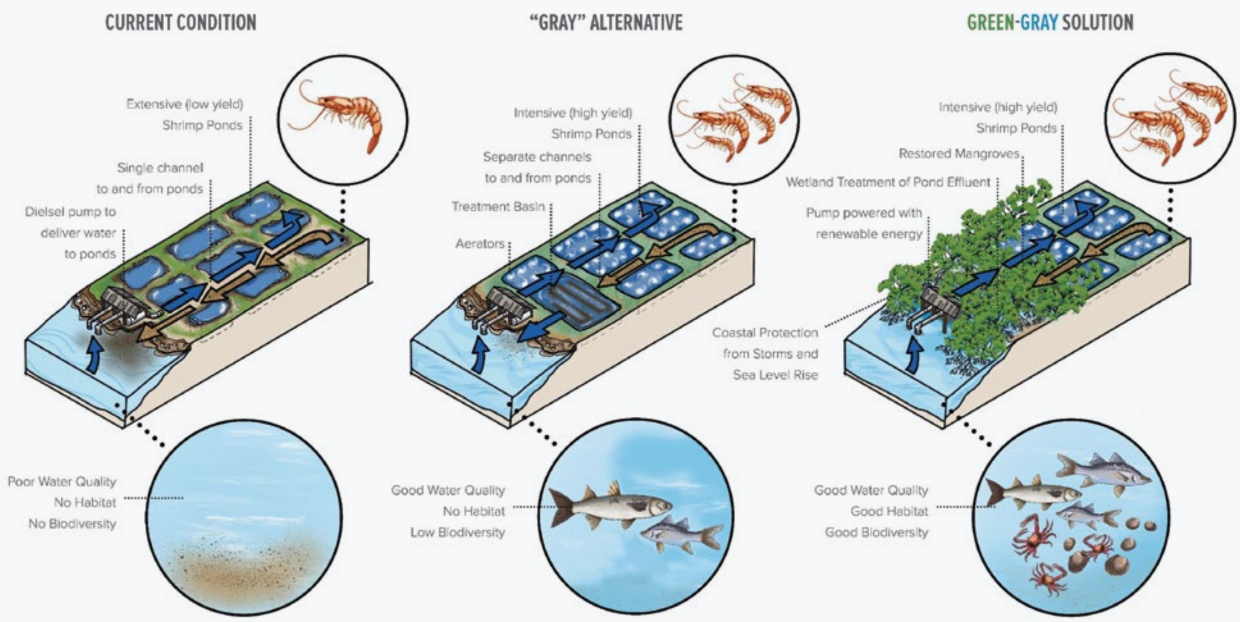
Farmed shrimp production grew by more than 1,000 percent over the last three decades to produce an estimated 6.5 million metric tons of shrimp in 2018. This dramatic growth has come at the expense of ecosystems. Shrimp production has destroyed more than 50 percent of mangrove forests globally, causing significant harm to the environment and the climate resilience of coastal communities. Mangroves serve as natural structural barriers that reduce coastal erosion, dissipate wave energy and storm surges, and provide habitat for aquatic and terrestrial species.

Climate Smart Shrimp is a novel approach that incentivizes mangrove restoration, while also increasing the amount of shrimp a farm can produce. By applying this model, shrimp farmers, local communities, and other stakeholders work together to sustainably intensify production in a portion of a farm's ponds to restore mangroves on the remaining ponds. Starting in 2021, Conservation International and partners will begin piloting this approach at a site in Indonesia. Years of inadequate management of the aquaculture sector have degraded the coastline and left communities vulnerable to climate impacts, such as coastal storm surge and sea-level rise. Accessing shrimp aquaculture as a sustained partner in mangrove restoration will increase both funding for restoration and expand the number and diversity of stakeholders conserving, protecting, and rebuilding natural infrastructure at scale.

Ecosystem service(s) restored or conserved: Coastal wetlands, mangroves for flood regulation and erosion control.

Conventional engineering approach: Dykes, weirs, levees, pipes, and pumps

What makes this a good green-gray example? The approach is grounded in a green-gray engineering philosophy, where "green" ecosystem conservation and restoration is combined with "gray" conventional engineering approaches to generate more benefits for people and nature than either strategy applied alone. The Climate Smart Shrimp model applies a green-gray climate adaptation approach to working with communities, farmers, supply chain companies, governments, and other stakeholders. They align efforts to restore coastal ecosystems, improve livelihoods, and reduce marine pollution while increasing productivity, profitability, and resilience on shrimp farms and catalyzing replicable investors' opportunities.



WHAT ARE THE MECHANISMS FOR FINANCING A GREEN-GRAY PROJECT?

Infrastructure projects require front-end investments for their planning, design, and realization. Financing is the term generally used for cash made available for covering project expenses, and it is expected to be repaid over time from cash flows derived from the project. There are different investors with diverse expectations of economic, social, and environmental returns. Table 4.1 summarizes the type of investors providing financing and their return expectations and includes advantages (+) and disadvantages (-) of financing sources.

Project financing strategies typically involve the use of some combination of debt and equity financing. In general, debt is financing provided by one party to another with the expectation of repayment over a specific time period. In contrast to equity financing, debt financing does not involve changes in ownership of project assets (i.e. debt financing is "non-dilutive"). Here, we describe two common debt instruments relevant to green-gray infrastructure financing: loans and bonds.

Bonds can be traded in capital markets, while a loan is a bilateral agreement between a financial institution and the beneficiary. The advantage of bonds over loans is that the former provides long-term securities that suffer less from short-term volatility[84]. However, they often require a large sum of transactions to offset the cost of preparing the deal. Bonds are also rated by qualified third parties, such as specialized research providers or rating agencies. The rating provides information on the credibility and risk-profile, along with the relevant characteristics for investors' fiduciary duty.

Loans. Loans are contractual agreements between two parties wherein one party agrees to lend a specified amount of financing ("Lender") to another party (a "Borrower") who assumes a repayment obligation. In addition to repayment of the principal amount of the loan, Borrowers are typically required to compensate the Lender an additional sum in the form of interest. While there are multiple factors which influence lending interest rates, interest can generally be viewed as the Lender's opportunity cost of providing funds to the Borrower.

In the context of green-gray infrastructure projects, project sponsors may explore loan financing from a range of both public and private lending institutions including domestic and international public financial institutions (e.g. development banks) and private financial institutions (e.g. commercial banks and non-bank lenders such as private debt funds, private foundations).

Table 4.1: Type of investors providing financing

Philanthropy	Concessional financing	Impact financing	Traditional financing
Addressing socio-environmental challenges without expecting any direct financial return on investment.	Addressing socio-environmental challenges. The expected financial return is below the market return on investment.	Focus on projects, where social outcomes can create an opportunity for market-rate return on investment.	Focus on market-rate return on investment
+ Address needs that are not profitable enough for a bankable deal. - Very limited and high competition - Access depends on meeting lender/donor conditions - Can create external dependency	+ Provides low interests and longer repayment terms. - Limited and high competition - Access depends on meeting lender/donor conditions - Low interest can create perverse incentives for over-borrowing and over-spending	+ Provides incentives for structuring solid commercial deals that deliver socio-economic value + Availability of resources - Reporting and monitoring non-financial values can be cumbersome - Not all projects delivering social value can create a market-rate return.	+ Provides incentives for structuring financially sustainable deals. + Availability of resources - Does not value socio-economic outcomes

84 Clapp, C., and Pillay, K. (2017). Green bonds and climate finance. In Markandya, A., Galarraga. I., and Rübbelke, D. (eds.) pp 79-105 *Climate Finance: Theory and Practice.* Singapore: World Scientific Publishing. 374 pp.

Depending on the Lender and the risk and return characteristics of the project, loan terms may be concessional or commercial in nature. Concessional loans typically feature terms that are substantially more generous than conventional commercial loans. These "concessions" may be in the form of below-market interest rates, longer-than average grace periods, or some combination of these features. Typically, concessional lenders are willing to extend these concessions in exchange for some beneficial social and/or environmental impact. By contrast, commercial loans are typically priced based on the risk-adjusted market rate of interest. Access to concessional finance depends on matching project characteristics with the Development Finance Institution (Table 4.2).

Loans may be extended as "secured" or "unsecured." Secured loans involve the pledging of certain assets of the Borrower as "collateral" (e.g. hypothecation). In the event of default by the Borrower, the Lender has the right to take possession of and sell the asset(s) used as collateral to recover the unpaid portion of the loan then outstanding. Conversely, an "unsecured" loan involves no collateral pledge. Generally, secured loans are issued at more favorable interest rates than unsecured loans for the reasons stated above.

Bonds. Bonds are debt securities issued by a borrower (referred to as the "Issuer") to one or more parties ("Bondholders") who lend funds to the Issuer through their bond purchase or subscription. Publicly traded bonds are differentiated from loans in that they may be standardized and issued in capital markets as financial securities. Various bond types may be applicable to green-gray projects:

Sovereign and municipal bonds. National governments issue sovereign bonds in capital markets. Countries issue these bonds as part of their larger budgeting and expenditure policy, and they eventually (co)sponsor projects by financing the cycles of the public budget. Municipal bonds refer to bonds issued by sub-national government bodies. These bonds are repaid by the general debt service of a country or municipality. Hence, the cost of capital depends on the credit profile of the country and/or municipality.

Bonds issued at a national or City level may possess tax exemptions, lower interest rates, and longer repayment periods[85]. Municipal bonds rely on cities' fiscal policy and they are often structured for financing large infrastructure projects that can link green components. General public funds back these municipal bonds.

Table 4.2. List of Development Finance Institutions providing concessional financing86

Scope operation	Type of recipient	Type	Examples and links for their financing products
Domestic	Public and private	National development banks	The Brazilian Development Bank (BNDES) Development Bank of Southern Africa (DBSA) China Development Bank (CDB)
International-domestic	Public	Regional development banks	Corporación Andina de Fomento (CAF) Caribbean Development Bank (CDB) New Development Bank (NDB)
International	Public and private	Bilateral development banks	Kreditanstalt für Wiederaufbau (KfW) Development Bank French Development Agency (AFD) Japan International Cooperation Agency (JICA)
International	Public and private	Multilateral development banks	World Bank International Finance Corporation (IFC) Asian Development Bank (ADB) African Development Bank (AFDB) Inter-American Development Bank (IADB) European Bank for Reconstruction and Development (EBRD) European Investment Bank (EIB)
International	Private	Bilateral development finance institutions	CDC Group, The United Kingdom FMO Entrepreneurial Development Bank, The Netherlands KfW DEG ,Germany

85 Clapp, C., and Pillay, K. (2017). Green bonds and climate finance. In Markandya, A., Galarraga. I., and Rübbelke, D. (eds.) pp 79-105 *Climate Finance: Theory and Practice.* Singapore: World Scientific Publishing. 374 pp.

86 OECD (2018), Rethink development finance for climate, in *Financing Climate Futures: Rethinking Infrastructure* pp 99-115. Paris: OECD Publishing. 132 pp https://doi.org/10.1787/9789264308114-9-en

Tax Increment Financing Bonds. In urban regeneration, municipal bonds are often supported by tax increases[87]. These bonds are backed by a percentage of projected future (and higher) tax collections caused by increased property values or new business. Sometimes, the bonds are also backed by a general fund to access cost-effective bond terms.

Green, Blue, or Climate Bonds. Green bond proceeds will be exclusively applied to finance or refinance, in part or full, new and/or existing eligible projects with green components. Credible green bonds have four core components:

1. use of proceeds,
2. processes for project evaluation and selection,
3. management of proceeds, and
4. reporting[88].

Such components can be verified by an external green assessment standard (e.g., Climate Bonds Initiative). Green bonds can help meet investors' fiduciary environmental, social, and governance requirements, and for issuers, the advantage is unlocking a diverse range of investors. Green bonds can be issued by public utilities, such as the San Francisco Public Utilities Commission, one of the largest municipal green issuers in the United States (USD 1.44 billion by 2019)[89].

Environmental Impact Bonds (pay-for-success) are an innovative form of pay-for-success debt financing. Payment to investors is linked to the achievement of the desired environmental outcome. For example, the Environmental Impact Bond for Watershed Protection in Washington D.C. using green infrastructure considers three performance tiers: expected performance (95% probability), overperformance (5%), and underperformance (5%)[90].

Equity Investors provide financing to project sponsors in exchange for an ownership interest in the project assets. In contrast to debt investors, equity investors assume the risks and rewards of the project and/or investment. Equity investors encompass a broad range of actors which, in the context of green-gray infrastructure, may include institutional investors (e.g. pension funds, endowments), and individual investors (e.g high net worth and ultra-high net worth individuals) or their asset managers (e.g. private debt or equity funds, family offices). While not all equity investors are oriented toward social and environmental returns, those with impact investing mandates or strategies can be an important segment of the market for green-gray project financing. Impact investors look for favorable risk-return profiles along with social and environmental impact. Impact investors use environmental, social and governance factors to evaluate such impact, and could be influenced to invest in a project based upon a project's triple bottom line cost-benefit analysis (see Chapter 3).

Risk-related financing mechanisms include blended finance and insurance.

Blended Finance is a structuring approach for strategically using public and/or philanthropic funding to mobilize private sector investment in sustainable development. Blended finance addresses the different return and risk appetites of various investors and is particularly relevant to blue infrastructure finance.[91] Blended finance most commonly includes concessional financing but does not have to. While blended finance does not define a standardized financing structure, there are four common structures (Table 4.3).

87 World-Bank. (2020). *Tax Increment Financing (TIF)*. [Website] https://urban-regeneration.worldbank.org/node/17

88 World-Bank. (2018). *Green Bond proceeds Management and Reporting*. [Online report] iv+19 pp. https://www.icmagroup.org/assets/documents/Regulatory/Green-Bonds/WBGreenBondProceedsManagementandReportingGuide-190918.pdf

89 Cooper, R., and Matthews, J. H. (2020). Water Finance and Nature-based solutions. K4D Helpdesk Report 857. Brighton, UK: Institute of Development Studies. 25 pp. https://opendocs.ids.ac.uk/opendocs/bitstream/handle/20.500.12413/15592/857_Water_Finance_and_Nature-based_Solutions.pdf?sequence=1&isAllowed=y

90 DuPont, C., and Cohen, B. (2019). *Conservation Investment Blueprint: Environmental Impact Bond for Green Infrastructure Developed based on the Case Study for Watershed Protection in Washington, D.C. by Quantified Ventures*. [Onlikne case study] 8 pp. http://cpicfinance.com/wp-content/uploads/2019/01/CPIC-Blueprint-Case-Study-Environmental-Impact-Bond-for-Watershed-Green-Infrastructure-by-Quantified-Ventures.pdf

91 Thiele, T., Alleng, G., Biermann, A., Corwin, E., Crooks, S., Fieldhouse, P., Herr, D., Matthews, N., Roth, N., Shrivastava, A., von Unger, M. and Zeitlberger, J. (2020). *Blue Infrastructure Finance: A new approach, integrating Nature-based Solutions for coastal resilience*. IUCN, Gland, Switzerland. 68 pp. https://bluenaturalcapital.org/wp2018/wp-content/uploads/2020/03/Blue-Infrastructure-Finance.pdf

Table 4.3. The common structure of blended finance and relevant examples

Common structure	Description	Examples
Concessional capital	Public, philanthropic or concessional investors provide grants of loans below-market terms to lower the cost of capital or provide an additional layer of protection to private investors.	• The Tropical Landscape finance facility (as co-funding projects)
Guarantee/risk insurance	Public, philanthropic or concessional investors enhance the risk profile of the investment using guarantees or insurance below-market terms.	• The World Bank provides a guarantee instrument for de-risking the Seychelles Blue Bond
Technical assistance	The transaction is associated with a technical facility to strengthen commercial viability and development impact.	• The Tropical Landscape finance facility (as providing technical assistance to projects) • The Emerging Africa Infrastructure Fund provides viability, technical, and environmental grant support
Design-stage grants	The design of the transaction is grant-funded, sometimes including project preparation.	• The World Bank provided concessional finance for structuring the Seychelles Blue Bond • District of Columbia Water Utility (a public utility company) provided public funding to develop the Environmental Impact Bond • The Emerging Africa Infrastructure Fund provides services such as bridging finance

Adapted from https://www.convergence.finance/blended-finance

Insurance. As risk carriers, insurers protect households, businesses, and governments by absorbing financial shocks from events such as cyclones, floods, droughts, earthquakes, accidents, and illnesses.

As risk managers, insurers help communities understand, prevent, and reduce risk through research and analytics, catastrophe risk models, and loss prevention. Insurers can advocate proper land-use planning, zoning and building codes, ecosystem-based disaster risk reduction, healthy lifestyles, and disaster preparedness as a way to reduce the costs of potential disasters.

Insurance services embedded within insurance products, such as simulations and early warnings of extreme weather, contribute to resilience and sustainable development. Remote sensing and other technology solutions are used to assess the impacts of events and changes in the landscape and be applied to monitoring and protecting nature-based solutions.

Insurance traditionally provides indemnity – compensation for damages or loss – and hence, is dependent on the assessment of actual damages and loss reports to confirm claim payments. However, the development of parametric solutions creates a lot more opportunities to mitigate risk and prevent loss. 'Parametric' index-based insurance covers the probability of a predefined event happening. It is an agreement to make a payment with a triggering event, so it is not attached to any physical property asset or infrastructure.

Redirecting existing insurance practices towards nature-based solutions, like green-gray infrastructure, encourages more commercial practices and private investment. Examples of insurance covers that can protect natural assets and enable nature-based infrastructure are listed in Table 4.4.

Table 4.4. Examples of insurance covers protecting natural assets

Insurance Cover	Description
Property	Covers the value of the asset, and costs associated with damages, such as removal of debris, clean-up and business interruption
Agriculture	Covers organic environments against specific weather perils, such as storm, typhoon, flood, fire, frost and hail
Environmental Liability	Protects against an infringement on third parties or public environments
Construction & Engineering	Protects project construction against material damage and loss, and the financial consequences of delays and disruptions
Political Risk	Covers in the event of confiscation, embargos, loss of license, expropriation and political violence

For financing purposes, projects may be organized under one or more project finance structures. Common project financing structures relevant for infrastructure projects are as follows:

Special Purpose Vehicles. A Special Purpose Vehicle is a legal entity created for a specific time-bound purpose to provide equity. The Special Purpose Vehicle (borrower) raises money from market capital to be repaid by expected revenues generated by the project (debt). Financers assess their investment risk based mainly on a project risk basis and the Special Purpose Vehicle risk profile. It is important to point out that Special Purpose Vehicles are organizational structures enabling the implementation of projects. Therefore, they should consider governance structures linking revenues, financing mechanisms, and ownership.

Public-Private Partnerships are a special type of project finance structures. In a Public-Private Partnership (P3) arrangement, a private Special Purpose Vehicle takes responsibility for the entire life-cycle stages and often establishes a direct agreement with a lender. In any case, the revenue of the P3 project is linked to performance. An example of P3 is the Clean Water Partnership in Prince George's County, Maryland[92]. The private party receives compensation and potentially incentive fees based on performance goals. In this case, the private party does not have to raise financing. Instead, compensation relies on the county's Clean Water Act Fee, public bonds, private activity bonds, private investments, utility fees, or grant programs.

Water funds are governance vehicles for channeling downstream beneficiaries to organize upstream catchment management activities of collective interest. Some are centrally managed vehicles. Some are simple memorandums of understanding. Some, but not all, are fiduciary trusts. Water funds promote collective action for selecting funding/financing sources to pay for the overall implementation program.

92 Georgetown Climate Center (2020). How to Pay for Green Infrastructure: Funding and Financing? [Online report] https://www.georgetownclimate.org/adaptation/toolkits/green-infrastructure-toolkit/how-to-pay-for-green-infrastructure-funding-and-financing.html?chapter#:~:text=Green%20infrastructure%20projects%20may%20be,Small%20Grants%20Program%20(UWSG).

WHAT NEW AND INNOVATIVE FUNDING/FINANCING MECHANISMS CAN APPLY TO GREEN-GRAY PROJECTS?

To accelerate funding and implementation of green-gray projects, project investments need to align with landscape scale (regional and watershed) plans, policy priorities, and investors' mandates. The following are opportunities to build financial and economic sustainability into green-gray project planning and implementation:

1. Link green-gray projects within a landscape and public policy context:

    a. Resiliency Planning process conducted at a river basin, coastal, or urban scale identifies climate and hazard vulnerabilities and opportunities for green-, green-gray, and gray infrastructure using an environmental, social, and governance framework. These plans can create a multi-level view of governance and value creation, with the potential to trigger willingness to pay. The landscape/urban planning perspective helps achieve a financial trade-off between profitable and less profitable but environmentally and socially valuable projects[93].
    b. The Nationally Determined Contributions for meeting the Paris Agreement can also be an instrument for defining long-term adaptation ambitions, funding, and financing needs, along with the role of green, green-gray, and gray solutions.
    c. Integrating green-gray projects and policies into broader landscapes and decision-making processes will accelerate funding and implementation.

2. Create portfolios of green-gray projects:

    a. Project portfolios can reduce costs for a particular intervention, mobilize funds for future investments, and be identified through a Resiliency Planning process.
    b. An equity fund manager could prepare the project pipeline and raise capital from investors/financial institutions. Similarly, these projects could be funded by issuing a bond specifically for green-gray infrastructure.
    c. The project portfolio could also be linked to a version of a Debt-for-Nature or Debt-for-Climate swap where the debt is alleviated in exchange for implementing green-gray infrastructure projects.

3. Climate Budgeting to make financial management more responsive to adaptation needs:

    a. A major source of long-term sustainability is introducing climate budgeting as a catch-all budget item to make the Public Financial Management process more responsive to climate adaptation needs. This practice can open the space to green-gray solutions sponsors for showcasing them as a cost-effective alternative to address needs. It is particularly effective to mobilize these instruments in early budget preparation:

        i. Introducing climate change considerations into public investment appraisal techniques (e.g., climate change impact appraisal).
        ii. Incorporate into the macroeconomic forecast adaptation financing ambitions with fiscal and debt sustainability objectives.
        iii. Including adaptation needs in annual budgeting and medium-term expenditure frameworks, including key performance indicators.
        iv. Adjusting budgeting guidelines and procurement.

4. Public Authorities have multiple avenues to enable green-gray projects:

    a. Establish fiscal incentives, stimuli, and enabling conditions for green-gray projects:

        i. Fiscal incentives can also be mobilized for landowners/investors to invest in green-gray solutions. Examples include tax exemptions, building fee discounts, or income tax relief for owners/occupiers who invest in green-gray infrastructure
        ii. Likewise, permitting can play an enabling or obstructing role for green-gray projects. Multiple types of permits may be needed to implement green-gray solutions, depending on legal mandates and jurisdictions.

93 Klijn, E. H., Edelenbos, J., & Hughes, M. (2007). Public-private partnership: A two-headed reform. A comparison of PPP in England and the Netherlands. In Pollitt, C., Van Thiel, S. and Homburg, V. (eds.) *New Public Management in Europe* pp 71-89. Hampshire, UK: Palgrave.

b. Re-allocate benefits to those bearing the costs:

i. The reallocation of costs-benefits can increase overall project costs due to negotiation and enforcement costs. Examples could include user fees or stormwater utilities.

c. Establish a mandatory regulation model that creates a market and crediting structure for a negative externality.

i. Examples include (1) Stormwater Markets in the United States, which are created by public authorities to comply with the Clean Water Act by providing economic incentives to introduce green components in-situ or off-site[94,95] and (2) mandatory compensatory mitigation markets in the United States for projects that surpass environmental impact thresholds.

d. Work with financial institutions to structure blended finance arrangements to enable green-gray projects.

5. Design green-gray projects to unlock private financing to generate revenue from project benefits that result in positive cash flow.

a. For example, green-gray projects could link to port operations or highway improvement and resiliency projects. In these cases, private investors provide equity to the green-gray project, while lenders provide loans. Revenue generated from the project, through, for example, sustainably produced shrimp or user fees, is used to repay the loan with interest and provide returns to investors.

6. Establish a database to systematically track the cost and performance values of green-gray projects.

a. Benefits include the ability to generate:

i. a detailed comparison of costs between green, gray, and green-gray projects;
ii. examples and proof of how benefits and co-benefits can be captured by diverse economic actors to support project implementation;
iii. detailed inputs to long-term public budgeting;
iv. a showcase of green-gray solutions cost-effectiveness; and
v. data to evaluate if gray solutions have higher upfront capital costs that green-gray solutions.

b. An example is the International Stormwater Best Management Practices Database developed by the American Society of Civil Engineers and the United States Environmental Protection Agency. It includes information on the cost and performance values of green components that can be linked in green-gray solutions[96].

3. Incentivize public authorities with economic incentives through Green Procurement Markets:

a. In Europe, Green Procurement is a voluntary instrument leveraging the public sector's purchasing power for the delivery of sustainable goods[97]. Member states and key stakeholders are developing criteria for green procurement that favorably contribute to the development of green Infrastructure and green-gray solutions.

94 Department of Energy & Environment (DOEE) (2019). Stormwater Retention Credit Trading Program. [Website] https://doee.dc.gov/src

95 O'Neill, S., and Cairns, S. (2016). *New Solutions for Sustainable Stormwater Management in Canada*. Ottawa, ON, Canada: Sustainable Prosperity. 192 pp. [Online report] https://institut.intelliprosperite.ca/sites/default/files/stormwaterreport.pdf

96 The International Stormwater Best Management Practices (BMP) Database (2020). https://www.bmpdatabase.org/

97 EU. (2016). *Supporting the Implementation of Green Infrastructure Final Report*. 203 pp. https://ec.europa.eu/environment/nature/ecosystems/docs/green_infrastructures/GI%20Final%20Report.pdf

Instruments to secure sustainability: from projects to portfolios

Securing sustainability should be defined within the project and at the level of the landscape/urban development portfolio. At the project level, the European Investment Bank provides a guideline to structure the development of project sustainability for green-gray project sponsor interested in unlocking private investment according to the European Investment Bank[98].

1. Get to know the financing basics;
2. Describe the business model and impact;
3. Prepare historical financial accounts;
4. Forecast future cash flows;
5. Identify risks and possible mitigants;
6. Review financial instruments and sources of capital; and
7. Assess appropriate legal structures.

On the other hand, Earth Economics advises local governments in the United States to link projects to portfolios. The first level of decision making corresponds to governance at the landscape level. Earth Economics' guidelines include:

1. Tipping the scale of green-gray infrastructure in the cycle of infrastructure planning;
2. Acknowledge that green is not going to replace the gray;
3. Define ownership of the life-cycle, emphasizing maintenance;
4. Enlist experts and stakeholders to conduct a regulatory review;
5. Augment the code with incentives; and
6. Review accounting standards with financial and legal terms.

Then, the municipality should structure a pipeline of projects whose linear arrangement would proceed as follows:

1. Capital engagement gets money for concepts;
2. Design the project;
3. Fields built project;
4. Utility maintains project; and
5. Consider public engagement in the process;

Moving projects to portfolios require linking funding consistently to financing, which best practices for the US cities for stormwater compliance go as follows:

1. Establish a stormwater utility
2. Explore community-based Public-Private Partnerships
3. Issue environmental impact bonds
4. Issue municipal bonds
5. Align taxes

98 European Investment Bank (2020). *Investing in nature: Financing conservation and Nature-Based Solutions*. [Online guide] 36 pp. https://www.eib.org/attachments/pj/ncff-invest-nature-report-en.pdf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5. ENGAGING STAKEHOLDERS & BUILDING THE BUSINESS CASE

Many different actors have the potential to influence the adoption and implementation of green-gray infrastructure projects and policies (such as politicians, decision-makers, planners, scientists or technical advisors, potential investors, users or service beneficiaries, tax payers, and local communities, including indigenous/ethnic groups).

Stakeholders need to be fully convinced of the advantages of implementing a green-gray infrastructure approach, so they can ensure its viability, effectiveness, and sustainability.

As part of stakeholder engagement, it is necessary to provide stakeholders with a persuasive business case that presents the rationale for a green-gray project, program or policy in terms that are relevant, credible, legitimate, and sustainable.

A successful business case typically depends both on technical "facts" and "evidence", and on creating an effective process of stakeholder engagement, dialogue, and communication.

Mapping and effectively engaging a broad set of stakeholders, and presenting a credible and compelling business case, is a priority to catalyze a paradigm shift in development towards green-gray infrastructure solutions.

WHAT ARE THE STEPS IN BUILDING A CONVINCING BUSINESS CASE FOR GREEN-GRAY INFRASTRUCTURE?

Although there are many different groups and players that have the potential to influence the uptake, viability and sustainability of a green-gray project, there is no universal business case. The evidence and arguments that will be the most convincing, depend on the target audience. To be effective, the development of the business case should be tailored to the audience and what they need or want to know about the project, including consideration of the procedures or decision frameworks they need to fulfill. The appropriate methods and information needs are then selected to be credible, convincing and relevant to the planning and decision processes to influence.

The following steps guide the development of a business case:

- Define the audience: clarify the target stakeholders (such as investor/financier, budget holder, policy-maker or project decision-maker, politician, scientists or engineers, local community, advocacy groups), their interests and needs, and clarify the purpose and focus of the business case that is being made.

- Frame arguments: tailor key messages to the needs for evidence or design modifications/emphases (reference Chapter 3 and 4 of this guide regarding economic appraisal and financing mechanisms).

- Compile evidence: source the data for key arguments and counter-arguments (including attribution of biophysical effects).

- Communicate and engage: communicating the business case (targeting, engagement, credibility/relevance/legitimacy, etc.).

Given the need to fit the business case to the purpose of the intervention, as well as to the target audience and/or decision process, a multi-sector approach is required to engage and motivate diverse stakeholder groups.

HOW TO IDENTIFY KEY GREEN-GRAY STAKEHOLDERS?

Stakeholders are organizations or social groups of any size that act at various levels (domestic, local, regional, national, international, private, and/or public), have a significant and specific stake in a given set of resources, and can affect or be affected by resource management. A successful green-gray project will require the support of a range of experts and stakeholders, as well as collaboration among them. These stakeholders should be engaged in the design development process (Chapter 6) and will define project characteristics such as siting, performance requirements, and ancillary benefits. They will also often contribute towards creating the conditions for green-gray implementation and ongoing maintenance – for example by contributing finance and other material inputs, securing decision approval, advocating and championing the project, managing and supporting infrastructure and monitoring its impacts, or using or paying for its products or services.

To build the business case for a green-gray project, one needs to determine ***how, for whom*** and ***to what practical and policy purpose*** the business case needs to be made. Part of this process includes charting the institutional landscape to identify interested and relevant stakeholders, including governing bodies and actors in the regulatory environment. Identify the most important stakeholders you seek to influence, such as:

- Ministries and government agencies relating to policy, legislation, finance, planning, and infrastructure;
- Corporate planners and decision-makers, including the board of directors;
- Community landowners, representative groups, community members,
- Non-Government Organizations, civil society groups, and local businesses
- Financial institutions including development and investment banks
- Private sector actors – contractors, developers, land owners, impact investors, technical experts
- Consumers and customers of the products and/or services that the project, program or intervention seeks to generate; and
- Tax-payers and shareholders.

There are various tools and considerations practitioners can use to identify key stakeholders in green-gray infrastructure investment decisions, and to determine their needs, interests and potential areas of influence. These include:

- Understanding the green-gray policy, legislation, institutional and decision-making context for a particular project or program;
- Defining the breadth and range of institutions, communities, and decision-making processes needed to implement the project (decision-makers, users and beneficiaries, cost-bearers, potential financiers, existing service providers, local land/resource users, managers, advocacy groups, politicians, etc.);
- Stakeholder mapping to facilitate alliance building and avoid conflicts; the results can inform strategic decisions on whom to engage; and
- Assessing networks of power, interest, and influence between stakeholder groups and how they might enable or act as barriers to the success of green-gray investments and implementations.

Appendix 3 includes a sample of practical tools for identifying key stakeholders: Stakeholder Mapping worksheet, Stakeholder onion, and a Power-Interest Grid.

HOW TO TAILOR THE BUSINESS CASE TO DIFFERENT NEEDS AND AUDIENCES?

Once the stakeholders are identified, it is important to understand the motivations, priorities, or decision-making processes that they will follow when considering whether the green-gray approach is acceptable or advantageous to them. This will, of course, vary for different stakeholders. For example, a politician may be most concerned about whether the project will increase popularity with their constituency. The Ministry of Finance or corporate finance head may need to ensure that certain financial and economic criteria are met. The developer or design engineer may require evidence of cost effectiveness or efficiency in delivering particular goods or services. Adjacent communities may need to be assured of local benefit-generation and economic multiplier effects.

Determining what the target audience "needs to know" or "wants to know" identifies the types of evidence and arguments, which will make the business case for convincing them. This directs the information that must be generated, and the most appropriate methodology that must be used to collect and analyze it. In some cases, the business case will depend on conventional financial appraisal or economic cost-benefit analysis methods. However, in other instances, a more visual or narrative story-telling approach may be required, which draws on local history and knowledge, less focus on the monetary and cost implications. A wide range of other types of information and analyses may be required in different contexts, for example political arguments, health or epidemiological information, evidence of disaster risk reduction, basic utilities and services, or other physical outcomes.

Additional considerations relate to ***how*** these arguments and evidence are generated and then communicated. It is not just the technical adequacy that matter ("*credibility*"), but also applicability to the interests and situation of the stakeholder ("*relevance*"), and the perceived validity and trustworthiness of the process of generating the information as being fair, unbiased and respectful of stakeholders' different values and beliefs ("*legitimacy*"). The methodology, process and information should follow and be tailored to the specific context and considerations. Rarely will the same message, or even methodology for information collection and analyses, be effective for all stakeholders.

Once the stakeholders are identified, determine the elements which will make the business case credible, convincing, relevant and legitimate to that audience. The economic or other methodology follows and is tailored to the specific context.

HOW TO COMMUNICATE THE BUSINESS CASE EFFECTIVELY AND CONVINCINGLY?

Communication strategies should be designed to "tell the story" to key decision makers and stakeholders and garner political will. The narrative must be tailored to the audience and stage of the project cycle. Quantifying benefits through economic analysis may be useful or necessary to shift political will and engage stakeholders such as governing bodies, but not necessarily. Other social, cultural and biodiversity benefits can be just as compelling, depending upon the stakeholder. An overall, cohesive strategy is needed for effectively communicating the business case. There are six elements that need to be addressed in any communication strategy:

- Why? Why is this necessary? What is the purpose?
- What? What is the message? (Content)
- Who? Who is the audience you are trying to reach?
- How? How do we reach these audience(s)?
- When? Are there key dates by which message needs to be given?
- Where?

Finally, ask the question "Did it work?" – i.e. evaluate whether the business case was communicated effectively.

There are three things a target audience will likely ask:

1. Why should they invest time or money into a green-gray infrastructure project, or give up resources or future access to resources?
2. Why is green-gray infrastructure important to them/their respective sector?
3. Will investing in green-gray infrastructure generate benefits? (See list of green-gray benefits in Chapter 1.)

Answering and tailoring responses to the relevant questions of value to stakeholders requires compiling evidence, including facts, figures, and relatable real-life stories. The evidence can be qualitative or quantitative, general or specific, from the region or country where the project is proposed, or an example from another country for inspiration. Chapter 3 summarizes economic analysis alternatives to estimate the costs and benefits of investing (or not) in a green-gray infrastructure project, which could be an important piece of evidence for stakeholders.

We all make decisions, not only based on analytical evidence, but also on emotions, instinct, intuition, values, ideology, culture, peer pressure and politics, to name a few. Focusing on the non-monetary benefits accruing to a green-gray project, and using stories to connect with stakeholders is often compelling. Non-monetary benefits can motivate stakeholder buy-in.

Using visual aids can become an integral component of the business case narrative to capture stakeholder interest. Landscape architecture renderings, for example, can be particularly effective to stir excitement for green-gray projects, especially with a large public presence, such as those in urban settings. Other media such as posters, short videos, fact sheets, and face-to-face conversations (whether in-person or virtual) are effective alternatives, but regardless, target the message to the audience. See Table 5.1 for communication pathways, including tools and materials, reach, and disadvantages.

Table 5.1. Communication pathways

Pathways	Tools and materials	Reach	Disadvantage(s)
Media (press)	Blogs; articles, interviews and press releases in newspapers; brochures, posters and flyers; magazines and newsletters; guides and manuals; information booklets.	Has a wide outreach.	Message cannot be changed, once released.
Media (radio)	Interviews; discussions	Has a wide outreach.	Depends on the quality of the interviewer and interviewee, as well as the moderator of discussions
Media (television)	Short (30 seconds to 1 minute) clips and 10 minute documentaries	Has a wide outreach.	Message cannot be changed, once released.
Electronic media	Emails; e-newspapers; websites; portals; CD/DVDs	Limited to those who have access to computers and the internet.	Message cannot be changed, once released.
Marketing	Advertising, including guerrilla advertising ('a strategy that focuses on low-cost unconventional marketing tactics that yield maximum results'); promotional material (stickers, banners, badges, billboards, light boxes, TV screens).	Has a wide outreach.	Message cannot be changed, once released.
Social Media	Blogs, networks, hashtags, fora, photo and video sharing, podcasts etc.	Has a dedicated following can become viral but is limited to those who have access to the internet or smartphones.	Needs a strong moderator to ensure that discussions, threads etc. keep within civil norms and keep focused.
Places of religious worship	Posters, flyers	Limited reach, but will be effective.	Messages cannot be changed, once released.
Private sector sites (banks, hotels, large supermarket, large shops etc.)	Light boxes, TV screens, products	Has a wide outreach.	Possible to change the message but will be expensive.

Adapted from: Hesselink, et al, 2007[99]

99 Hesselink, F.J., Goldstein, W., van Kempen, P. P., Garnett, T. and Dela, J. (2007). Education and Public Awareness, a toolkit for the Convention on Biological Convention. Montreal: IUCN, Commission on Education and Communication. 310 pp.

Blue Infrastructure Finance: a new approach, integrating Nature-based Solutions for coastal resilience

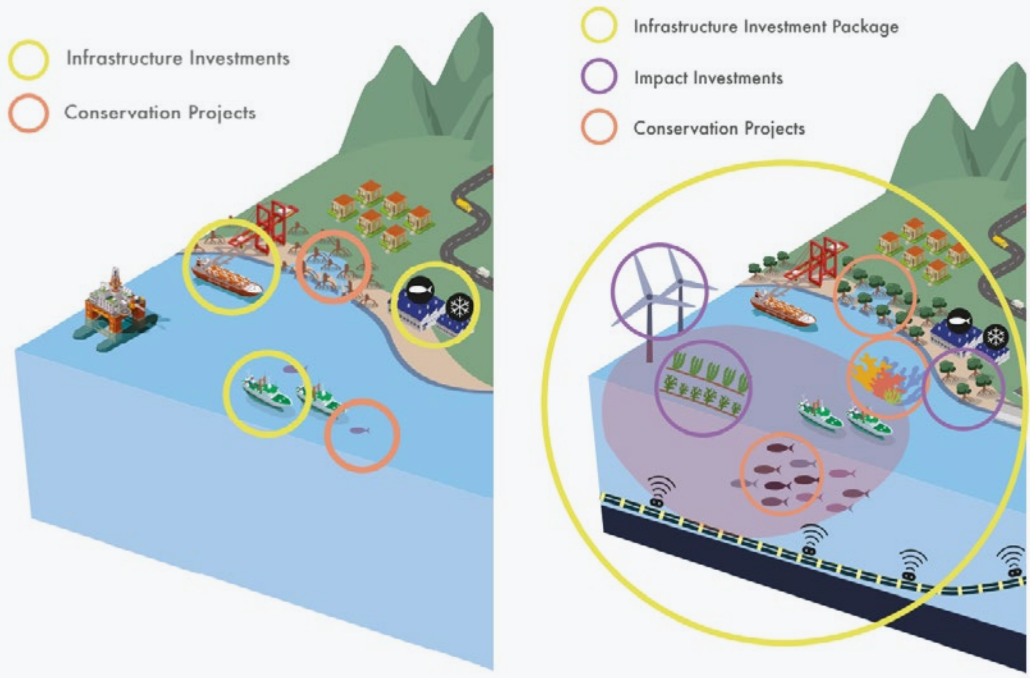
A report published by IUCN in 2020 as part of the Blue Natural Capital Financing Facility[100]

Blue infrastructure draws on the ecosystem services of coastal and marine habitats to develop green-gray infrastructure solutions, which can provide a wealth of benefits, including food, water, energy, shelter, and medicine as well as mitigation of and adaptation to climate change impacts. These co-benefits have significant economic value but securing adequate financing for such interventions remains a challenge.

This recently published concept report identifies specific barriers to securing sufficient financial resources for blue infrastructure projects and offers recommendations on how to overcome them. With the aim of influencing investment from the private sector and multilateral financing institutions, the report highlights the need to build a convincing case for the desirability, feasibility, and financial attractiveness of blue infrastructure.

A main conclusion of the report is that blended finance solutions can help de-risk blue infrastructure investments and attract a variety of financiers. **A conventional investment format views infrastructure and conservation in isolation without considering how synergies among them can address the interests and overlapping concerns of multiple stakeholders. By comparison, a holistic approach which incorporates an array of project components – including conservation projects and impact investments – can optimize green-gray infrastructure to reduce risks, while opening up opportunities for private sector investment and local revenue generation.**

A blended finance solution such as the one proposed for blue infrastructure finance requires continual engagement of multiple stakeholders, strong communication and tailoring of the business case to address a range of interests and concerns.



Conventional investment vs. Blue infrastructure finance

100 Thiele, T., Alleng, G., Biermann, A., Corwin, E., Crooks, S., Fieldhouse, P., Herr, D., Matthews, N., Roth, N., Shrivastava, A., von Unger, M. and Zeitlberger, J. (2020). Blue Infrastructure Finance: A new *approach, integrating Nature-based Solutions for coastal resilience. Gland, Switzerland: IUCN. 68 00 https://bluenaturalcapital.org/wp2018/wp-content/uploads/2020/03/Blue-Infrastructure-Finance.pdf*

CASE STUDY 23:

GREEN INFRASTRUCTURE STORYTELLING TO REDUCE FLOOD RISK WITH GREEN INFRASTRUCTURE IN UDON THANI, THAILAND

Source: Testado, 2017[101]

Location: Udon Thani, Thailand

Project Proponent: estudioOCA, with support from the U.S. Army Corps of Engineers. This effort was a continuation of U.S. Army Corps of Engineers implementation support to the United States Agency for International Development project "Building Resilient Asian Cities in the Mekong region". To date, using Thai funding, design and construction of a component of the Master Plan has begun.

Project Description: As one of the fastest growing cities in Southeast Asia, intended to double in both physical size and population by 2030, Udon Thani needed to find an approach to become an economic hub, while also addressing increased water supply and flood concerns. Through a USAID project "Building Resilient Asian Cities in the Mekong region"[102], the business case for a green infrastructure solution was envisioned collaboratively. To address questions on effectiveness, efficiency, acceptability and completeness, numerous actions were undertaken. These included the implementation of the principles of the Army Corps of Engineers Engineering with Nature approach, which stresses the use of science, engineering, natural processes and collaboration, along with a planning process described in Climate Risk Informed Decision Analysis[103], to structure uncertainties into a risk-informed decision process.

Stakeholder collaboration took many forms, such as the development of landscape architecture renderings specific to stormwater management enhancement, site visits, conceptualization, and other input to understand conflicts through three decision-maker workshops with the mayor and senior city officials. Given the deep uncertainties concerning rates of urbanization and changing intensities, durations and frequencies of storm events, "scenario bins" that integrated combinations of incrementally more stressful futures were developed collaboratively. As expected, greater resilience to a more extreme future came at a higher cost. However, each incremental investment for flood resilience also contained greater ancillary social and environmental benefits, such as public space for cultural events or parks and recreation. Highlighting such benefits led to more profound engagements with the public, mayor, and private sector stakeholders. This significantly affected political will and helped emphasize the strategic value of green infrastructure as a means for projects with immediate benefits to the public, and with real options for adaptability.

Ecosystem services restored or conserved: Wetland restoration for flood regulation and climate amelioration.

Conventional engineering approach: Engineered green space construction, channel construction, additional pump and drain incorporation

101 Testado, J. (2017). *estudioOCA wins Rockefeller Foundation grant to develop Green Infrastructure Master Plan in northern Thailand*. [Weblog] https://bustler.net/news/5833/estudiooca-wins-rockefeller-foundation-grant-to-develop-green-infrastructure-master-plan-in-northern-thailand

102 USAID (2014). *Mekong-building Climate Resilient Asian Cities Program*. [Weblog] https://www-origin.usaid.gov/asia-regional/fact-sheets/mekong-building-climate-resilient-asian-cities-program

103 UNESCO (2019). Climate Risk Informed Decision Analysis (CRIDA) [Website]. https://en.unesco.org/crida

What makes this a good green-gray example? Udon Thani's Green Infrastructure Master Plan is continuously being adapted and enhanced, as the necessity or public concern arises. The project continues to be collaborative, even in the implementation phase, and maintains trust and reliability between stakeholders, which contributes to its overall success. A second phase plans to incorporate adjacent peri-urban areas where most of the new urbanization is occurring, and also where the source of much of the additional storm runoff will be generated. Moreover, a more complete assessment of future risk of chronic failure in flood and drought management will be implemented.

Figure: Several workshops were held to collaboratively develop (and test using a stormwater model) different concepts for a Green Infrastructure Master Plan. (source: Photo by Guillermo Mendoza, USACE)

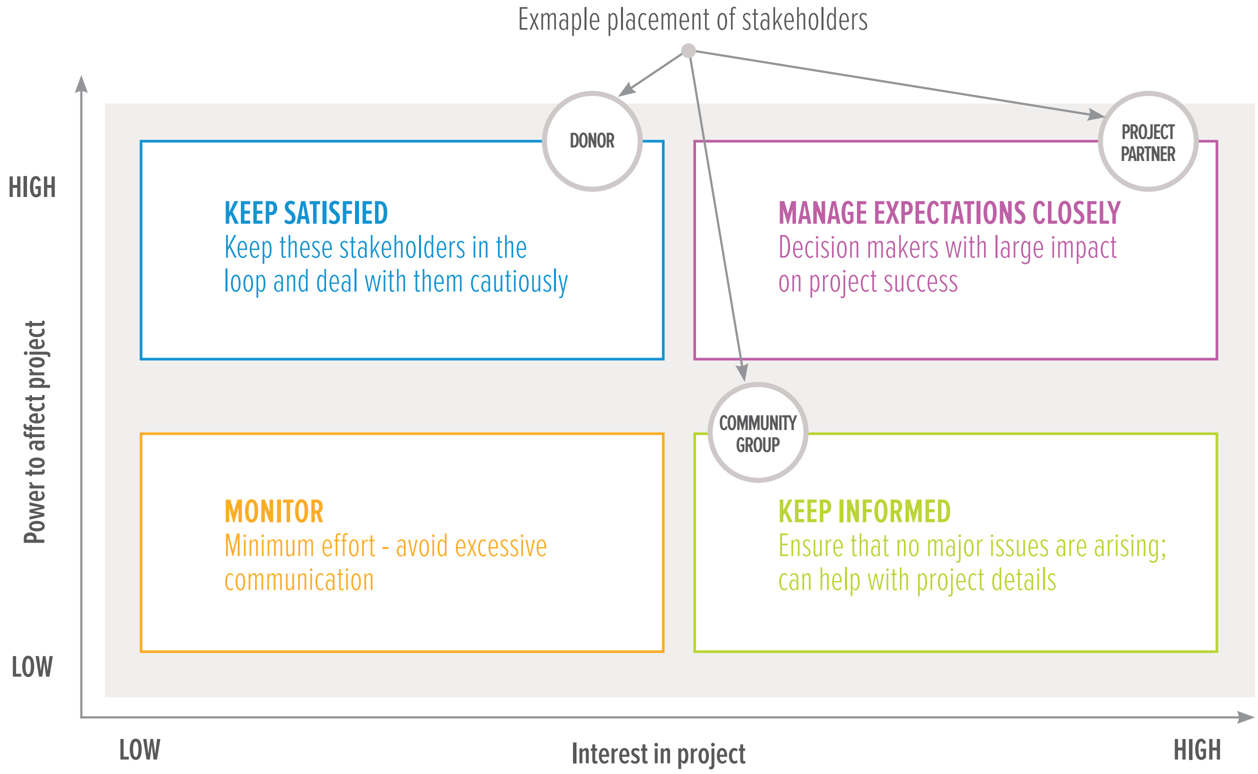
Figure: Examples of renderings for the main project typologies, including canal restoration, green street conversion, and retention park and wetland park restoration, used to promote ideas and dialogue (source: estudioOCA[104]).

104 estudioOCA (2017). *Udon Thani, Thailand - Green Infrastructure Master Plan*. [Weblog] https://www.estudiooca.com/udon-thani-1

WHY AND HOW TO ENGAGE AND MOTIVATE STAKEHOLDERS?

A multi-sector engagement approach should be applied to understand potential project benefits and beneficiaries. Project costs and benefits will likely accrue to different groups of people, so engaging a broad range of stakeholders can also clarify the responsibilities for financing components of an intervention for targeted benefits. For example, a project might serve to both enhance recreational opportunities and avoid flood storm surge damage, which can appeal to distinct stakeholder groups and funding sources. In addition, a successful project almost always requires collaboration and cooperation between different stakeholders, and/or may necessitate measures to balance trade-offs and to mediate or mitigate potential conflicts and areas of competition.

Most of the stakeholder identification and mapping tools included in Appendix 3 also provide a means of understanding the shared or competing interests of different groups, and of identifying potential areas of cooperation or conflict in relation to the green-gray project or intervention, as shown in the figure on this page. Based on the anticipated beneficiaries of the project, relevant outreach efforts can be created and incorporated into project plans. These engagements, which occur on different levels from local to national, need to be integrated throughout the project decision-making process.



The above figure explains the different approach we should have for the segregated/prioritized stakeholders[105].

High power – High interest stakeholders are decision-makers and have the biggest impact on the project success and hence, you must proactively manage their expectations.

High power – Low Interest stakeholders yield power and need to be kept in the loop and satisfied even though they are not interested. Interactions with these stakeholders should be cautious, because they may use their power to negatively impact the project, if they become unsatisfied.

Low power – High interest stakeholders should be kept adequately informed and to ensure no major issues arise. These people can often be very helpful with the details of your project.

Low power – low interest stakeholders should be monitored, but not bored with excessive communication.

105 Bdaiwi, Y. (2017). Stakeholder Analysis using the Power Interest Grid https://www.projectmanagement.com/wikis/368897/Stakeholder-Analysis--using-the-Power-Interest-Grid

Different aspects of sustainability and feasibility can be carefully selected and emphasized depending on each stakeholder group. For example, while private landowners may be incentivized to invest based on the long-term climate adaptation benefits, regulatory agencies rely more heavily on cost-benefit analyses for public infrastructure investment decisions. When developing the business case, think in advance of:

1. what counter-arguments each stakeholder will have for the proposed project,
2. potential points of compromise, and
3. how far you are willing to negotiate for the project.

Stakeholders can and should be brought together to develop the overall business case rather than working with each group individually. The following approaches can inform this integration:

- Identifying the needs and opportunities to engage with different groups.
- Creating opportunities for stakeholder participation beyond mere engagement, as appropriate and based upon the findings of stakeholder analysis.
- Use practical approaches for promoting cooperation, cementing alliances and mediating or resolving conflict among stakeholders at different stages of the green-gray project cycle.
- A long-term strategy for stakeholder engagement and communication should plan for a varied approach over the different stages of the green-gray project cycle.

CHALLENGES TO BUILDING THE BUSINESS CASE

To inform and persuade stakeholders to consider a green-gray approach, there are several challenges that can complicate the process:

- Sufficient ecological, economic, climate or social data may be lacking.
- The paucity of information on bio-physical linkages and causality can pose a problem.
- Evidence of the effectiveness of green-gray solutions or knowledge of how ecosystems and gray infrastructure interact is also frequently lacking. This is especially true at the site- or intervention-specific level.
- A successful business case often depends not only (or even not primarily) on “hard” or technical evidence, but rather on managing the process successfully, in a relevant, credible and legitimate way, which engages stakeholders.
- Coordination of political will from all stakeholders can be difficult, because green-gray projects are inherently multi-sectoral and multi-institutional. Project proponents need to work across sectors, including the construction sector, environmental sector, and socially-oriented governing bodies.

CASE STUDY 24:

EVALUATING THE EFFECTIVENESS AND COASTAL RESILIENCE BENEFITS OF GREEN-GRAY INFRASTRUCTURE IN MIAMI-DADE COUNTY, FLORIDA, UNITED STATES OF AMERICA

Location: Miami-Dade County, Florida, USA

Project Proponents: Supported by the Chubb Charitable Foundation and implemented by The Nature Conservancy contracted with Jacobs Engineering and the City of Miami.

COASTAL PROTECTION | URBAN DEVELOPMENT | COASTAL

Astronomical High Tide at Morningside Park; © Farris Bukhari/TNC

Project Description: Morningside Park, much like the surrounding City of Miami and urban landscape of Miami-Dade County, is exceedingly vulnerable to sea level rise. The low-lying site bordered by a residential neighborhood is at significant risk of flooding and shoreline erosion due to increasing King tides, storm events and the significant boat traffic and relatively large fetch of Biscayne Bay. To enhance resilience and build the business case for green-gray infrastructure, The Nature Conservancy and Jacobs Engineering undertook extensive modelling and evaluation of a cost-effective strategy that would both reduce flood losses from interval storm events and produce significant co-benefits for the community. This project concept included installing breakwaters or sills composed of riprap to provide habitat, expanding the intertidal zone, building a low-profile horizontal levee that would incorporate more resilient stormwater management and drainage structures, and finally, planting mangroves and other coastal vegetation to reduce wave energy, stabilize upland soils, and moderate urban heat island effects. Final evaluations calculated the benefit-cost ratio based on an aggregate 50-year project life to be 1.95 for current sea level and 1.38 for 0.46 meters of sea level rise. As a result of the knowledge provided, The Nature Conservancy and the City of Miami entered into an agreement to pursue the further design of such a project at Morningside Park.

Ecosystem services restored or conserved: Mangroves and coastal hammock for shoreline protections and prevention of erosion.

Conventional engineering approach: Breakwaters or sills and earthwork

What makes this a good green-gray example? Sufficient data on the effectiveness of nature-based solutions and the quantification of coastal resilience benefits for green-gray infrastructure are limited. Therefore, it was imperative for The Nature Conservancy to build successfully the business case for a scientific and technical audience for project acceptance. As a result of the extensive storm modeling and quantification of the value of ecosystem services such as, waste treatment, climate regulation and maintenance of genetic diversity, the green-gray infrastructure proposal for Morningside Park was more easily recognized and adopted as a viable solution.

6. DESIGN DEVELOPMENT

With a site selected, the design development process begins, and includes:

- Clearly defining the problem and project goals;
- Forming a design team with engineering and green-gray expertise;
- Collecting information about the site and becoming familiar with the local community;
- Soliciting community input on early design concepts, the design development process;
- Refining project cost estimates and financing strategies;
- Receiving approvals from applicable local, regional, and federal agencies overseeing the region or ecosystem where the project is proposed; and
- Finalizing the design plans with material and construction specifications.

Following the steps described in this module will advance concept sketches into ready-to-build, approved design plans. Though depicted as a series of steps, the design process is often iterative. New information, models, or stakeholder input can require previous assumptions to be revisited and design adjustments.

WHAT INITIAL STEPS ARE NEEDED TO DEVELOP A GREEN-GRAY INFRASTRUCTURE DESIGN?

The purpose of these initial steps is to assemble a design team that can clearly define the problem the green-gray infrastructure solution is intended to address and develop, with community input, initial design concepts to meet the project goals. There is no "one size fits all" and two sites are never the same. Therefore, it is imperative that you rely on the appropriate professional expertise and experience when it comes to project design[106].

Assemble a design team, that includes:

- restoration/conservation specialist(s) with expertise in the specific target ecosystem(s)
- trusted community liaison
- project manager / team facilitator
- climate/disaster risk expert
- engineer(s), one of whom will be the responsible engineer for the project (e.g., stamping and signing design drawings and overseeing construction). The responsible engineer could be the local municipal engineer or a hired consulting engineer.
- technical advisory committee consisting of respected professionals with expertise in the target ecosystem, approach, geography, etc.
- financier/economist

A technical advisory committee can provide complementary expertise to a design team that does not include all these skill sets.

1. Share amongst the team all existing site information and concepts collected through the site identification and selection process (see Chapter 2).

   It is likely that available site data is incomplete, especially for a detailed economic analysis. Throughout design development, the project team will need to consider the usefulness of data from nearby locations (e.g., benefits transfer), the relative value of qualitative versus quantitative data, and the associated level of uncertainty if the data are predictive or incomplete, and/or the cost to collect new information to build the business case or inform the project design.

2. Arrange site visits so all team members are familiar with the conditions, can meet community representatives and receive input of the concept developed during site selection. During these site visits, in addition to collecting information about the physical and ecological characteristics of a site (see Chapter 2 and

106 U.S. Federal Highway Administration (FHWA) (2018). *White Paper: Nature-Based Solutions for Coastal Highway Resilience.* Washing DC, and Fairhope, AL, USA: ICF and SCE. v+37. [Online paper] http://media.coastalresilience.org/SC/FHA_Coastal_Highway_Resilience.pdf

Appendix 2) team members should be asking relevant questions, such as[107,108]:

- Are there contamination issues at the site?
- Are threatened species potentially impacted by project implementation?
- Are endemic species an issue?
- Are cultural resources potentially impacted by project implementation?
- In urban areas, are underground or aerial utilities an issue?
- Is there adequate construction access to the site?
- Could existing habitat be impacted during construction?
- It is often necessary to visit a site many times because the time of day, season, and weather play important roles in site characterization.

3. Conduct a workshop with the design team to review the site-specific green-gray infrastructure opportunities and constraints. Outputs of the design review workshop include one or two design concept alternatives with cost estimates and identified data needs to complete the designs[109].

4. Once design alternatives have been identified, many projects will seek additional funds to collect needed data, finalize designs, construct the project and provide long-term project monitoring, maintenance, and adaptive management.

An overview of the design development process, that represents one possible project path is summarized in Table 6.1. At each step in the design development process the following information should be updated to compare solutions and guide the final design[110]:

- Costs: Capital, operation and maintenance
- Ecosystem services and co-benefits: quantified if important to build the business case with stakeholders (see Chapters 3 & 5)
- Risks and tradeoffs: Robustness to respond to risks, including potential ability to meet minimum acceptable performance standards and/or the adaptability of the design when facing these risks.
- Timeline to maturity and lifespan of project: How long will it take for the ecosystem(s) to reach maturity and provide resilience benefits?

Table 6.1. Overview of green-gray infrastructure engineering design development process

Design phase	Description
Concept	Concept sketches with potential design solutions produced after collection of existing data, initial site evaluation, and site visits by project design team. Often at this stage concepts could include 3-5 alternative approaches.
Design alternatives	Based on review of concept sketches by the community and design team, one or two design alternatives, with detailed cost estimates, generated along with updated estimates of project cost, and identified data gaps and next steps to complete the design.
Permit package	The design package at this stage incorporates all input from the community on a preferred design alternative and is often sufficient to seek permit approvals. The design package can include a specifications outline (or scope-of-work) that describes construction methods and materials, along with an updated construction schedule and cost estimate.
Final design	Refined design based on input from permit approval process, technical reviewers, and community stakeholders. Complete material and construction specifications along with identified safety measures to implement during construction.
Construction documents	Final design prior to construction that incorporates all comments from previous design deliverables and reviewers.

107 Bendell, B., Duhring, K.A., Priest III, W.I., Smith, K.M (2006). Management, policy, science, and engineering of nonstructural erosion control in the Chespeake Bay: living shorelines design [Conference proceedings] pp 7-31. https://www.livingshorelinesacademy.org/index.php/resources/literature/item/cbnerrva-design-2006.

108 These are usually covered through conventional Environmental Impact Assessment processes, often required by investors on assets for investment under frameworks like Equator Principles and a project-specific Environmental Impact Assessment would be undertaken, depending on local legislative requirements.

109 A good way to plan alternatives is to list all the features possible of the final structure and create scenarios with different priorities. This creates a few different scenarios that can be compared against each other.

110 Inter-American Development Bank (2020). *Increasing Infrastructure Resilience with Nature-Based Solutions (NbS).* Location: Inter-American Development Bank. 52 pp [Online document] https://publications.iadb.org/publications/english/document/Increasing-Infrastructure-Resilience-with-Nature-Based-Solutions-NbS.pdf

WHAT DATA IS NEEDED TO DEVELOP A GREEN-GRAY INFRASTRUCTURE DESIGN?

The data needs will be project and solution specific. Green-gray project design requirements are similar to conventional infrastructure projects. Designers should be mindful to collect data that will demonstrate the performance of co-benefits resulting from a green-gray design as needed for the business case (see Chapter 5). It is recommended that only data or modeling that will directly inform the design are collected, and efficient and economical methods are used to collect the necessary data. Examples of data that can be collected to inform a green-gray infrastructure design are:

- bathymetry and/or topography data, including mapping of existing infrastructure, such as water or wastewater systems and significant natural or artificial features or landmarks;
- sediment and/or subsurface soil characteristics;
- ecosystem mapping (existing and historic), including location, size, type, and health;
- Existing and historic ecosystem services provided by the ecosystem;
- A rapid assessment of species of flora and fauna, including identification of native species, threatened species, and invasive alien species;
- Hazard mapping (e.g., from floods, fires, typhoons, or sea level rise); and
- infrastructure critical to the livelihood strategies of communities.

When designing a green-gray infrastructure project, the design team should address many factors during each design phase, such as:

- affordability (e.g., costs and financial viability);
- technical feasibility;
- political feasibility;
- maintenance approach and costs;
- monitoring approach and cost;
- flexibility to adaptively manage the constructed project;
- maximum potential to restore and conserve ecosystems; and
- cultural appropriateness.

Common design mistakes originate from:

- under- or over-designing structures for their intended application;
- placing structures in locations that may exacerbate erosion;
- unintended or anticipated adverse effects[111], such as impacting migratory routes for wildlife or increase human-wildlife conflicts, resulting from an incomplete environmental impact assessment;
- optimizing for too narrow of climatic or environmental conditions; and
- not allowing room for ecosystem migration under future climate conditions (e.g., sea level rise).

Selecting species for use in green-gray infrastructure

Unless careful attention is paid to the selection of plants, the ultimate provision of ecosystem services will be compromised[112], in addition to substantial costs incurred and low survival rates[113].

Choosing the species to use.

For restoration in ecosystems other than in urban spaces, use native species rather than exotics. Even when exotics appear to be the better choice (for example, better root strength, or superior resilience against drought), it is always best to check the Global Invasive Species Database[114] to assess whether the species is a known invasive alien species elsewhere in the world. If the selected species is a known invasive alien species, it is best to use a precautionary approach, and use the next best choice. Local communities often know which species were in the area to be restored.

In general, a mix of species should be used, so that plant diversity is increased immediately.

111 U.S. Federal Highway Administration (FHWA) (2018). *White Paper: Nature-Based Solutions for Coastal Highway Resilience.* Washing DC, and Fairhope, AL, USA: ICF and SCE. v+37. [Online paper] http://media.coastalresilience.org/SC/FHA_Coastal_Highway_Resilience.pdf Accessed date month, year.

112 Cameron, R.W.F. and Blanůsa, T. (2016). 'Green infrastructure and ecosystem services – is the devil in the detail?' *Annals of Botany* 118: 377–391. https://doi.org/10.1093/aob/mcw129

113 Staas, L. and Leishman, M. (2017). Which Plant where? Species Selection for Urban Greening.[Online article] The 18th National Street Tree Symposium 2017. Treenet. https://treenet.org/resources/plant-species-selection-urban-greening/

114 Invasive Species Specialist Group ISSG (2015). The Global Invasive Species Database. Version 2015.1 http://www.iucngisd.org/gisd/

Choosing how to plant.

A mix of species should be planted randomly, rather than in rows, as randomness is part of nature.

Many mangrove restoration projects, after the Indian Ocean tsunami of December 2004, failed, largely because the knowledge of the ecology of mangroves was ignored. It is now known that restoring the hydrology – sometimes by simply digging a trench – is often sufficient for recruitment of seedlings.

Understanding ecological restoration[115] is, therefore, paramount.

Choosing where to plant.

There is always a need to know which species to plant where. For example, large areas of salt marshes are divided into the low marsh (near the water) and high marsh (at higher elevations), as the degrees of flooding and salinity vary from the marsh exterior to the interior shore inland[116]. Fewer, stress tolerant species are found in the low marsh and more competitive species are found in the high marsh. Planting high marsh species in low marshes or the reverse will not work.

Species for urban green space restoration.

For restoration in urban spaces, where there is a need to enhance the aesthetic value of the area, horticultural species, with showy leaves and colourful flowers, are often used. Here too, a double check with the Global Invasive Species Database is needed, as there are many species once introduced to a country as ornamentals, which have now become invasive.

In addition, a goal in urban settings is to increase urban biodiversity. The inclusion of butterfly-attracting (usually with showy, nectar-bearing flowers) and bird-attracting (fruit-bearing) plants and trees entice butterflies and birds; while flat, perching surfaces in ponds or similar water features, bring in dragonflies, enhancing urban species diversity. Once there are insects, insect-eating birds will follow, and so on, until there is a complete suite of predators and prey within such an urban system.

115 See the website of the Society for Ecological Restoration at https://www.ser.org/page/SERStandards for more information.

116 Elsey-Quirk, T., Mariotti, G., Valentine, K. and Raper, K.(2019). Retreating marsh shoreline creates hotspots of high-marsh plant diversity *Scientific Reports* 9:5795 https://doi.org/10.1038/s41598-019-42119-8

CASE STUDY 25:

IMPROVING FLOOD RESILIENCE IN THE DELTA CITY OF GUAYAQUIL BY IMPLEMENTING NOVEL TOOLS FOR URBAN DEVELOPMENT AND FLOOD MANAGEMENT

Location: Guayaquil, Ecuador

Project Proponent: Consortium Deltares, ESPOL, De Urbanisten and Rebel Group, in collaboration with the Municipality of Guayaquil

Source: McEvoya et al., 2019[117]

Project Description: Guayaquil is subject to extreme wet weather events, causing urban floods and damage. This project investigated flexible opportunities for green infrastructure to improve urban resilience in the Febres Cordero parish and reduce both current and future impacts from rainfall and high sea levels. Various green strategies were proposed, including: (1) increasing application of permeable pavements; (2) redesigning streetscapes to install bioswales, and; (3) reclaiming (partial) streetscapes for pedestrian functions and to maximize green infrastructure. Streetscape strategies were complemented by a proposed longshore green flood protection embankment in the tidal zone, which can later be strengthened with shoreline mangroves. This will reclaim valuable public space for recreation and urban water retention. Implementing the green-first approach offers a flexible means to improve urban resilience, while longer-term adaptation pathways include upgrades to existing gray drainage and flood protection infrastructure or managed retreat, depending upon the magnitude of future sea level rise. A short-term pathway of flexible measures to be progressively made in the coming decade or so were proposed, while keeping the longer-term gray infrastructure adaptations in mind for the future (if warranted by sea level rise).

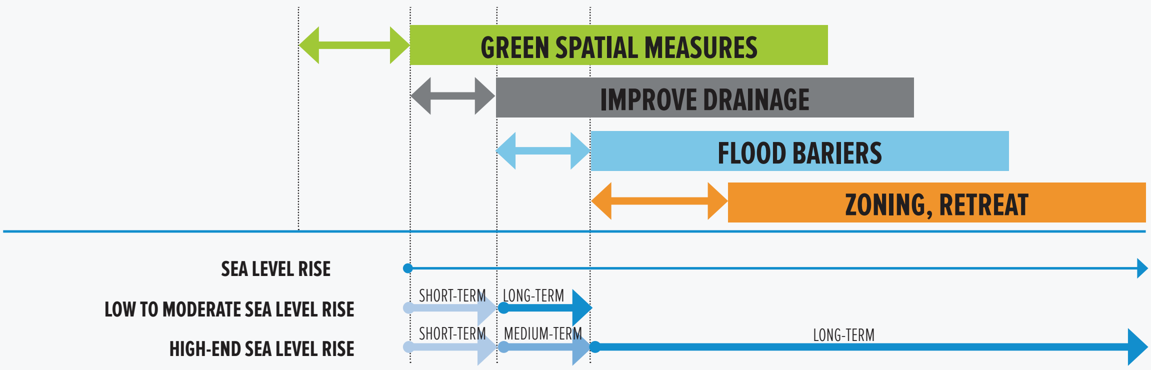


Figure: Long-term adaptive pathways for Guayaquil in the face of uncertain sea level rise. Yellow arrows indicate implementation times for each intervention.

Ecosystem services restored or conserved: Increasing green infrastructure in streetscapes provides valuable restoration of various urban ecosystem services.

Conventional engineering approach: Upgrade existing gray drainage facilities (e.g., pipelines, pump stations) and flood protection structures (e.g., levees) to cope with predicted maximum peak flows and sea levels for the future. However, these parameters are highly uncertain, and spatial competition within the streetscape constrains potential infrastructure options, hence the preference for nature-based solutions and a more adaptive approach.

What makes this a good green-gray example? The strategy prioritizes low-regret and flexible green interventions in the short-term and blends them into an existing gray setting. It contributes to longer term objectives, delivers a range of additional social and ecosystem benefits, and importantly, delays decision-making on larger infrastructure until the climate situation becomes clearer. The strategy nevertheless recognizes that additional gray interventions may be necessary in the mid- to long-term, should the impacts of climate change continue to worsen over time.

117 McEvoya, S., van de Vena, F.H.M., Garces Santanderd, A., Slingerb, J.H. (2019). The influence of context on the use and added value of Planning Support Systems in workshops: An exploratory case study of climate adaptation planning in Guayaquil, Ecuador. Computers, Environment and Urban Systems 77: 101353 https://doi.org/10.1016/j.compenvurbsys.2019.101353

WHAT PERMITS OR APPROVALS ARE NEEDED BEFORE CONSTRUCTION CAN BEGIN?

Permits or approvals are given by agencies overseeing the region where a project is located or agencies that regulate the type of proposed project. For example, different agencies may require permits depending upon if the proposed green-gray infrastructure project is in a coastal, freshwater, or terrestrial environment or if the proposed work is in the near-shore or along a roadway. Typically, the project proponent, or applicant, completes and submits a permit application to the permit approving agency for review and approval.

Each permit or approval application typically requires a unique set of information, and the amount of time to review and approve the application can vary depending upon the agency, project type, time of year, and quality of information submitted with the application.

In the early stages of a project, the design team, usually the project manager, should consult with local and national jurisdictions to identify the project permits and approvals required before construction can begin. Other approvals that may be needed prior to construction include:

- community organization (formal or informal) and/or landowner approvals;
- construction approvals internal to the implementing organization;
- endorsements from technical advisors;
- financier/investor approvals;
- local municipality and relevant government officials; and
- funder approvals, for example, if contracting with the local community to complete the construction, is outside the normal acquisition policy of the funder.

For some projects, a community-based environmental assessment can facilitate or complement a legally required review of the environmental aspects of a project. Community-based environmental assessments often occur outside of legal frameworks and use participatory methods such as interactive workshops, focus group discussions, community resource mapping, and/or site walks to understand and document environmental challenges and impacts. The outcome of the assessment can inform design development – specifically, selection between alternatives or modifying proposed designs to reduce and/or avoid potential impacts. Possible risks for ecosystems and the community should be monitored proactively throughout the project (See Chapter 9).

WHAT STAKEHOLDER AND COMMUNITY ENGAGEMENT AND EDUCATIONAL OUTREACH IS NEEDED AS PART OF A GREEN-GRAY INFRASTRUCTURE PROJECT?

Green-gray infrastructure is complemented by other adaptation solutions such as (but not limited to) livelihoods diversification, disaster risk reduction and adaptation capacity building, renewable energy and transport, partnership and alliance building.

Once a green-gray infrastructure site is selected, the information collected during the site assessment phase should be evaluated to identify the institutional capacity of stakeholders, particularly communities and the local government (See Chapter 2 and 5 for additional information). If gaps are identified in terms of the communities' ability to implement and maintain the green-gray intervention, the project team will need to tailor appropriate outreach and capacity building measures.

- Through the site identification and site selection process, evaluate if a functioning community-based organization exists in the community where the green-gray infrastructure project is proposed.
- Community members, stakeholders, and local governments will likely need additional organizational and capacity building to understand the project benefits and consider endorsing project implementation. Particularly in project and financial management if they are to be involved in the implementation of the project.
- Depending on the green-gray infrastructure construction model, communities may need additional organizational development (see Chapter 10).

The design development timeline must consider parallel efforts for educational, organizing, and capacity building activities. Specifically:

- regular community meetings (monthly throughout the project);
- training related to climate change adaptation, disaster risk reduction and ecosystem services (within the first six months of the project); and
- financial management and leadership training for all key community leaders (2-3 day workshops) with on-going mentoring.

CASE STUDY 26:
RESILIENT BY DESIGN'S BAY AREA CHALLENGE

Location: San Francisco Bay Area, California, USA

Project Proponent: Resilient by Design, local and national experts, community members and more

COASTAL PROTECTION | URBAN DEVELOPMENT | COASTAL

Source: Rebuild by Design, undated[118]

Project Description: The Resilient by Design's Bay Area Challenge brought together interdisciplinary teams of local and national experts, community leaders, elected officials and residents to recommend areas within the Bay that would benefit most from interventions aimed at increasing resilience to natural disasters (sea level rise, severe storms, flooding). The year-long challenge forged collaboration among 20 community organizations, 120 agencies, 140 community stakeholders, and 800 students who participated in the Youth Resilience Challenge. There were 39 public events. The project also consisted of 3-month-long, site-based learning for experts, culminating in nine designs that were diverse, inclusive, creative and effective at addressing not only environmental risk but also issues such as inequality. One of the final nine designs was the South Bay Sponge located in the South Bay and Silicon Valley area, a low-lying, fast-growing community. The South Bay Sponge's design would connect existing and constructed wetlands, at a large-scale, to create a landscape capable of managing flood waters while supporting varied wetland ecosystems, including floodable parks and green spaces.

Ecosystem services restored or conserved: Wetland restoration/construction for flood regulation.

Conventional engineering approach: Walkways, roads, levees, weirs

What makes this a good green-gray example? Beyond the vast collaboration required in the design phase, unprecedented cooperation across jurisdictions will be required to realize the vision. This large-scale involvement will ensure that vulnerable communities are not forgotten and that all necessary aspects of the project (financial, ecological, infrastructural) are cohesive and comprehensive. Design competitions like this could be models for sparking innovation and collaboration in vulnerable cities and communities around the world.

118 Rebuild by Design (undated). South Bay sponge. [website] http://www.rebuildbydesign.org/our-work/bay-area-challenge/south-bay-sponge

HOW TO PLAN FOR MAINTENANCE DURING DESIGN DEVELOPMENT?

Planning for maintenance can begin in the project design phase, starting with identifying the necessary maintenance activities, access routes, and temporary material storage areas on the design plans.

As the project design evolves, consider the type and frequency of maintenance that will be required. Coordinate with site managers and community members to ensure staffing, skills, and equipment will be in-place to perform the required maintenance once the project is installed.

Also during the design phase, identify how the maintenance will be paid for to ensure there is a long-term strategy to adaptively manage the project and ensure the project goals are achieved (See Chapter 4 and 9).

7. ENGINEERING GUIDANCE

Engineering solutions are required to adapt to a rapidly changing environment, especially associated with climate change and as aging infrastructure around the globe reaches the end of its intended lifespan. Every project has the opportunity to promote greater resilience through green-gray solutions.

By approaching engineering projects with a green-gray design philosophy, systems are strengthened for nature and people, with innovative and scalable solutions that simultaneously address the climate and biodiversity crisis.

To implement green-gray projects at scale, decision-makers, landscape architects, and engineers need familiarity and confidence applying the design options available. Creating that confidence requires an understanding of the appropriate applications and technical requirements for successful implementation. Only then can the practice of civil engineering and construction be fundamentally shifted towards designing and building with nature, using a hybrid green-gray infrastructure approach.

This chapter reviews current engineering guidance applicable to green-gray design with the goals of sharing knowledge and experience to inform design decisions and to identify gaps for future research and development.

WHAT ARE ENGINEERING DESIGN STANDARDS AND GUIDELINES?

Engineering standards articulate a fixed design method with prescribed design solutions and tolerances for well-known and given contexts. Engineering guidelines are generally more flexible and adaptable than engineering design standards, and allow for sharing of best practices based on data or experience collected across a range of demonstration or pilot projects. For a design engineer, following engineering guidelines and standards generally reduces the potential for negative impacts or for a project to not fulfil its intended outcome(s). Similarly, guidelines provide a tool for communicating best practice concepts without relying on individual case studies – concepts can be applied broadly and are useful for achieving implementation at scale, whereas case studies do not achieve this.

Performance standards evaluate the ability of a method or project to achieve intended outcomes, for example, for wave height reduction, sediment accumulation, or area of ecosystem restoration. Verified (repeatable and quantified) information about a conventional "gray" or green infrastructure practice to perform under certain conditions is incorporated into a project design, so that the entire project can achieve the project outcomes.

There are clear gaps within the design community for how to design with nature. Green infrastructure performance standards and design equations, for many applications, are currently not available. This lack of quantification is one of the key design challenges and difficulties, for innovating and designing green with gray infrastructure. For example, as far as the authors and editors are aware, there are no existing performance standards or engineering guidance documents, for restoring and conserving mangroves alongside seawalls or breakwaters.

We are at the front end of this research – learning by doing. Designing projects as experimental models, and collecting performance information for specific project components, will inform engineering guidance and design standard(s) development. Though they are challenging to study and evaluate, the Green-Gray Community of Practice will work in the coming decades to build green-gray projects and evaluate project performance and metrics to inform engineering guidelines.

In the meantime, there are existing design guidance documents to reference, which have been compiled and reviewed, as an accompaniment to this chapter.

WHAT GREEN-GRAY ENGINEERING GUIDANCE IS AVAILABLE TODAY?

The level of detail and availability of engineering design guidance for green-gray infrastructure projects depends upon the setting and context of the type of green-gray project. For example, if the project is focused on coastal, freshwater, or terrestrial ecosystems and what goals the project aims to achieve (see Chapter 1). For some types of green-gray techniques, for example, river restoration and green stormwater infrastructure, engineering guidance is available from a variety of sources. To assist green-gray practitioners identify the most applicable and relevant guidance for a given project, this guide has begun the process of compiling resources for planning and designing green-gray projects.

The Community reviewed over 50 green-gray design and engineering resources, across an array of settings to identify:

- strengths, weaknesses, and gaps;
- commonalities and principles across guidance; and
- where possible, links to case studies and lessons learned on what works and what does not.

There are clear gaps about how and if green-gray infrastructure solutions are included in these design documents and the level of engineering guidance provided.

On the Green-Gray Community of Practice website (https://www.conservation.org/projects/global-green-gray-community-of-practice), practitioners can access a database summarizing each reviewed guide, along with the ecosystems, conventional engineering approaches, and strengths, weaknesses, and gaps of each. The goal of the database is to serve as a resource for our engineering design community, when considering green-gray project alternatives. As new engineering guidance becomes available and/or as community members suggest guides to include, this resource will be updated. For example, landmark guidance from the United State Army Corps of Engineers on the use of Natural and Nature-Based Features for Coastal Resilience is expected mid-2021[119].

There are a wide range of materials and documents that provide guidance and case studies on green-gray infrastructure. We highlight below websites providing compilations of green-gray design guidance, case studies, and performance materials:

- The Dutch-based ***Ecoshape: Building with Nature***[120] is an interactive web portal, well-designed and separated into information about landscape types, pilots, and institutional measures.
- United States Army Corps of Engineers ***Engineering with Nature***[121] program resources.
- The ***International Stormwater BMP database***[122] tracks green-stormwater infrastructure cost and performance data.
- ***Panorama Solutions for a Healthy Planet***[123] is a partnership initiative to document and promote examples of inspiring, replicable solutions across a range of conservation and sustainable development topics, enabling cross-sectoral learning and inspiration.
- The ***Nature-based Solutions Evidence Platform***[124] from University of Oxford provides a consolidated evidence-base on the effectiveness of nature-based solutions for addressing climate change impacts, as an open-source, dynamic and updatable user-friendly online platform.
- The ***Naturally Resilient Communities***[125] tool highlights nature-based solutions and case studies of successful projects from across the USA so communities can identify what might work for them.

119 US Army Corps of Engineers (undated). Engineering with Nature, Natural & Nature-Based Features [Website] *https://ewn.el.erdc.dren.mil/nnbf.html*

120 Ecoshape (2020). *Building with Nature*. [Website] https://www.ecoshape.org/en/

121 United States Army Corps of Engineers (2020) *Engineering With Nature*. [Website] https://ewn.el.erdc.dren.mil/index.html

122 International Stormwater BMP Database (2020). *Home*.[Database] https://www.bmpdatabase.org/index.htm

123 Panorama Solutions for a Healthy Planet (2020). *Ecosystem-based Adaptation Solutions.*https://panorama.solutions/en/portal/ecosystem-based-adaptation

124 Nature-based Solutions Evidence Tool (2020). Nature-based Solutions Evidence Platform Oxford, UK: University of Oxford. https://www.naturebasedsolutionsevidence.info/evidence-tool/

125 Naturally Resilient Communities (2020). *Using nature to address flooding*. http://nrcsolutions.org/

- Publications and policies from the ***Maryland, USA, Department of Natural Resources, Chesapeake & Coastal Services***[126]
- ***Nature4Cities***[127] has developed a knowledge repository and various tools for nature-based solutions practitioners.
- The ***NATURVATION***[128] project (NATure-based URban innoVATION) is a 4-year project, funded by the European Commission and involving 14 institutions across Europe in the fields of urban development, geography, innovation studies and economics.
- The ***Climate Adaptation App***[129] gives urban designers, engineers or others insight in feasible measures for a project with a specific climate adaptation goal.

In addition to the guide review database and the list of references above, we have selected specific guides and resources to highlight as relevant to specific green-gray infrastructure types, land uses, and/or challenges. These guides are highlighted because they include a robust set of engineering design guidance information potentially useful to practitioners, such as:

1. Description of the green-gray approach (*e.g., purpose, benefits, and constraints*)
2. General design principles (*e.g., sizing equations and methods, operation and maintenance requirements, costs*)
3. Design Detail(s): *usually drawn in AutoCAD*
4. Design Specification: *word document with detailed instructions to the builder*

126 Maryland, USA, Department of Natural Resources Chesapeake & Coastal Service.https://dnr.maryland.gov/ccs/Pages/publications.aspx

127 Nature4Cities (undated). *Home*. https://www.nature4cities-platform.eu/

128 NATURVATION (2020). *Home*. https://www.naturvation.eu/

129 Climate Adaptation App. https://www.climateapp.nl/

Engineering Design Resource	Level of Detail in Design resource	Land Use: Water Supply & Sanitation	Land Use: Rural Development	Land Use: Energy
Guidance for Stream Restoration (Yochum, 2018) summarizes and links available guidance to design stream restoration projects, including many green-gray techniques.	Design Details	✓	✓	
‘Low-tech process-based restoration’ (LT-PBR) of Riverscapes (Wheaton et.al, 2019) details practice of using simple, low unit-cost, structural additions (e.g. wood and beaver dams) to riverscapes to mimic functions and initiate specific processes.	Design Principles	✓	✓	
Wetland Technology: Practical Information on the Design and Application of Treatment Wetlands (Langergraber, 2019) includes detailed design guidance and summaries for different engineered wetland types and applications.	Design Principles	✓	✓	
The Green Stormwater Infrastructure Design Guidebook developed by the Philadelphia, Pennsylvania Water Department is a resource for planners and designers, and the accompanying website provides comprehensive resources for planning, designing, permitting, constructing, and monitoring green stormwater infrastructure projects. This level of detail is what we can strive to provide for all green-gray infrastructure techniques.	Construction Specifications	✓	✓	
San Francisco, California’s Rainwater Harvesting Manual for Non-potable Residential Uses is a comprehensive and practical guide with general applicability to many locations around the world.	Design Details	✓	✓	
Nature-based Solutions for Coastal Highway Resilience: An Implementation Guide (Webb, 2019), is a detailed resource for coastal nature-based and hybrid solution selection, design, construction (permitting and funding), and maintenance. The guide is written specifically for the transportation sector, but has broad applicability for designing nature-based solutions.	Design Details		✓	✓
The Louisiana Coastal Protection and Restoration Authority (2017) has developed engineering standards for their coastal protection projects that incorporate marsh restoration and placement of dredge material. These include geotechnical, surveying, and marsh creation standards.	Design Details		✓	
Natural Shoreline Infrastructure: Technical Guidance for the California Coast (Cheng et al, 2017) directs planners in evaluating and deciding where, when, and how to use six types of Natural Shoreline Infrastructure (e.g. sand dunes, seagrass beds), for optimal results.	Construction Specifications		✓	
Living Shoreline Design Guidelines for Shore Protection in Virginia's Estuarine Environments (Hardaway et al, 2017) provides guidance on site evaluation, data collection, design criteria, and basic design details.	Design Details		✓	
Living Shorelines in New England: State of the Practice (TNC, 2017) provides a comprehensive overview of design recommendations, siting criteria and regulatory topics specific to New England. Includes 8x "profile sheets" with design guidance, including for sand dunes and bank protection with an engineered core, marsh restoration with armoring, and living breakwaters.	Design Principles		✓	
The World Wildlife Fund’s Natural and Nature-Based Flood Management: A Green Guide (WWF, 2016) was developed to support local communities around the world in using natural and nature-based methods for flood risk management and provides high level descriptions across a range of landscape types.	Description of the Approach	✓	✓	
Scotland’s Natural Flood Management Handbook is a good review of overall project development, design, implementation process with strong visuals and case studies to address both coastal and riparian flooding	Design Principles	✓	✓	

			Goal					
	Transportation	Urban Development	Erosion Control	Flood Management	Clean Water	Water Security	Coastal Protection	Food Security
		■	■	■	■			
			■	■	■			
		■			■	■		
	■	■	■	■	■		■	
		■	■	■	■	■		
	■	■	■	■			■	
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	■	■	■	■	■		■	
	■	■	■	■	■		■	■
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			■	■	■	■	■	
			■	■	■	■	■	

CASE STUDY 27:
MILLIONTREESNYC DESIGNED EXPERIMENTS MODEL

Location: New York City, New York, USA

Project Proponent: New York City Department of Parks and Recreation and non-profit New York Restoration Project

URBAN DEVELOPMENT TERRESTRIAL

The MillionTreesNYC site in Spring Creek, Queens. Source: Yale School of Environment, 2020[130]

Project Description: Between 2007 and 2010, the MillionTreesNYC project met its goal of planting and caring for one million new trees within the City of New York. Planted along streets, in parks, natural areas, schools, and on residential properties, the urban greening project contributes to the PlaNYC2030 Sustainability Plan. Portions of the tree planting effort were 'Designed Experiments' – designed and built to answer research questions and improve the study and shape of the built environment for future projects and innovations. Designed Experiments provide a framework for organizing relationships among ecologists, urban designers, decision makers, and citizens; an opportunity for testing ecological hypotheses; and a platform for experiential learning among multiple participants[131]. Data and lessons learned from these designed experiments are informing the ongoing maintenance and management of urban forests in New York City, and future tree planting efforts around the world.

Ecosystem services restored or conserved: Urban forestry for reducing heat island effects, improving flood management, air quality, and carbon sequestration.

Conventional engineering approach: Streets, curbs, and sidewalks

What makes this a good green-gray example? Combining ecological research into green-gray design, as part of small, medium, and large infrastructure projects will accelerate the ability to learn-from these novel and integrated approaches that combine ecosystems with conventional engineering solutions.

130 Yale School of Environment (2020). *A Roadmap for Embedding Ecologists into Urban Design.* [Weblog] https://environment.yale.edu/news/article/roadmap-for-embedding-ecologists-into-urban-design/

131 Felson, A.J., Bradford, M.A., Terway. T.M. (2013). Promoting Earth Stewardship through urban design experiments. *Frontiers in Ecology and the Environment* 11(7): 362–367 https://doi.org/10.1890/130061

HOW TO CONSTRUCT GREEN-GRAY PROJECTS USING A 'DESIGNED EXPERIMENTS' MODEL?

In the green-gray infrastructure context, designed experiments advocate for a strong partnership among engineers, researchers, and ecologists and the use of projects as ecological experiments.

A green-gray project team can design, construct, and monitor green-gray infrastructure pilot projects to test specific aspects of the approach. The goal of these projects is to generate replicable scientific conclusions about the ecological and engineering elements of a green-gray project to solve problems and inform future predictions about how green-gray infrastructure solutions will perform. The following steps for design, installation, testing, optimizing and sharing are proposed for the project team to follow to maximize the potential learning outcomes from green-gray projects:

- identify key project objectives and co-benefits (e.g. flood management and reducing urban heat island effects);
- define science questions and formulate hypotheses;
- design experimental models to test processes;
- Incorporate experimental models into the project design (e.g., placement, type, size of ecosystem and engineering elements);
- construct green-gray project;
- monitor the project and collect data;
- analyze data and make observations to inform future green-gray projects; and
- share results and findings (e.g., design details and methods).

Example research areas and questions that we propose to study for green-gray infrastructure projects, through a designed experiment approach include:

1. Level of function for green components across a spectrum of green-gray solutions;
    - How do ecosystem services increase in relation to an increase in the percentage of green in green-gray (gradient studies) across a ratio of green to gray?
2. Thresholds of functionality;
3. Evaluating longevity of performance of green-gray solutions;
4. Defining equivalent functions in green-gray performance compared to gray infrastructure – for example:
    - What configuration of green-gray can produce the same results as a conventional approach? (e.g., as a sea wall with a certain height);
    - How do artificial systems function over the long-term in comparison to natural systems? (e.g., coral reefs versus rock breakwaters); and
    - What ecosystem services exist as part of green-gray infrastructure, and can we incorporate as co-objectives?;
5. Gradient of highly constructed to more rural/natural (urban to rural gradient study) and local to watershed scale application and benefit of green-gray projects; and
6. Construction processes and impact on existing systems, testing construction processes, for example through processes of accretion.

The designed experiments approach also enables the incorporation of community science organizations to participate and contribute to data collection, outcomes, and building a database about project performance.

Chapter 9 includes additional information and resources for identifying indicators to evaluate green-gray project outcomes.

WHAT GLOBAL RATING SYSTEMS ARE RELEVANT TO GREEN-GRAY PROJECTS?

Sustainability rating systems and certification programs enable the design and implementation of project elements into an infrastructure project that otherwise would not necessarily be included. A rating system specific to green-gray infrastructure does not exist, but there are many that can apply or be combined, depending upon the project type and setting to advance project outcomes.

A desirable credential or certification creates an incentive and a step-wise process for project developers and designers to follow. Successful examples of these include the Leadership in Energy and Environmental Design (LEED) building certification that is recognized as a mark of quality and achievement in green building by certifying and verifying the design, construction, operations and maintenance of resource-efficient, high-performing, healthy, cost-effective buildings[132].

The organizations that create and administer such rating systems and certification programs also often offer additional benefits, such as opportunities for education and capacity building. They also cultivate communities of practice to enable idea-sharing and networking between project designers and managers who share similar objectives or face similar challenges. Disadvantages for rating systems include incurring additional costs for certifying a project, like registration fees, submission of documents, third-party inspection fees, and certification fees once a project is approved.

Following a rating standard can potentially improve a project's outcomes for sustainability and/or the environment. The ENVISION sustainable infrastructure system and IUCN Global Standard for Nature-based Solutions are two rating systems with potential applicability to green-gray projects. Applying these standards to projects within our community will provide an evaluation of the gradient of green-gray options the Envision and the IUCN Global Standard for NbS are currently well suited to evaluate.

Other standards, with potential connections to green-gray infrastructure projects include:

- ***Aquaculture Stewardship Council's*** (Stichting Aquaculture Stewardship Council Foundation, 2020[133]) responsible farmed seafood certification
- ***Greenroads*** (Greenroads, 2020[134]) sustainable transportation certification
- ***SITES***[135] certified landscapes help reduce water demand, filter and reduce stormwater runoff, provide wildlife habitat, reduce energy consumption, improve air quality, improve human health and increase outdoor recreation opportunities.

As we learn from and scale-up the application of global green-gray infrastructure projects, by fostering this community of practice, networking and knowledge development, it is possible that a rating system applicable to green-gray will be available in the future.

132 Leadership in Energy & Environmental Design (LEED) (2020). *What is LEED?*.[Website] http://leed.usgbc.org/leed.html#:~:text=LEED%20certification%20provides%20independent%20verification,healthy%2C%20cost%2Deffective%20buildings

133 Stichting Aquaculture Stewardship Council Foundation (2020). *Protecting, improving and restoring ecosystems.* [Website] https://www.asc-aqua.org/aquaculture-explained/how-does-buying-asc-labelled-seafood-change-things/protecting-improving-and-restoring-ecosystems/

134 Greenroads (2020). *The Greenroads Rating System*. [Website] https://www.greenroads.org/publications

135 U.S. Green Building Council (202). Sustainable SITES Initiative [Website] https://www.sustainablesites.org/certification-guide

Envision[136]**.** The Envision system was developed through a partnership between the Institute for Sustainable Infrastructure and the Zofnass Program for Sustainable Infrastructure at the Harvard University Graduate School of Design. Its 64 criteria cover issues across quality of life, leadership, resource allocation, climate and resilience, and the natural world, which focuses on interactions and impacts from siting, conservation, and ecology. Each criterion has a rating scale with different levels of achievements that range from an improvement over conventional practices, to restoring a community's social, economic and environmental assets. The framework is intended to support more sustainable decision-making at all phases of project planning, design, construction, operation, and decommissioning. To enable teams to get the most out of the Envision rating system, the Institute for Sustainable Infrastructure provides a collaborative tool suite that includes an in-depth planning guide, self-assessment worksheets, online assessment platform, online and in-person training modules. There are four award categories available through third-party verification, which is optional and costs vary by project size and membership level. The Institute for Sustainable Infrastructure also provides "Envision Sustainability Professional" (ENV SP) training, and at least one project member must have ENV SP credentials for the project to be eligible for verification.

Energy	Water	Waste	Transportation	Landscape	Information
Distribution	Treatment	Solid waste	Airports	Public Realm	Telecom
Hydroelectric	Distribution	Recycling	Roads / Highways	Parks	Cables
Coal	Capture / Storage	Hazardous	Bikes / Pedestrians	Ecosystem Services	Internet
Natural Gas	Stormwater	Waste	Railways	Natural Infrastructure	Phones
Wind	Flood Control	Collection & Transfer	Transit	Environmental Remediation	Data Centers
Solar	Nutrient Management		Ports		Sensors
Biomass			Waterways		

Figure: Infrastructure types applicable to the ENVISION standard[137]**.**

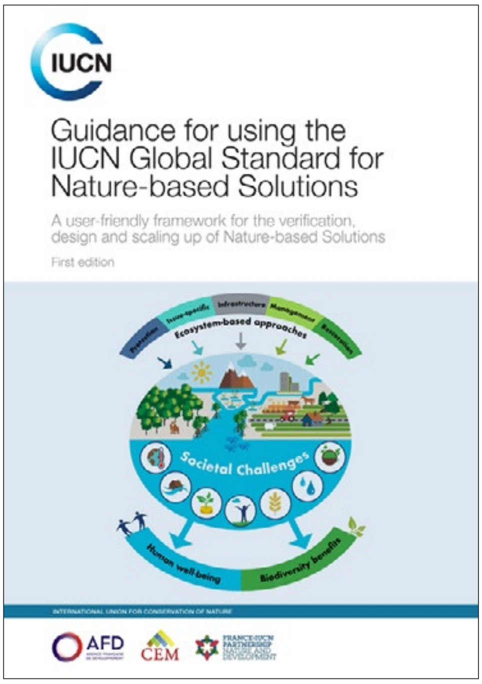
136 Institute for Sustainable Infrastructure (ISI) (2020). About ENVISION. [Website] https://sustainableinfrastructure.org/envision/overview-of-envision/

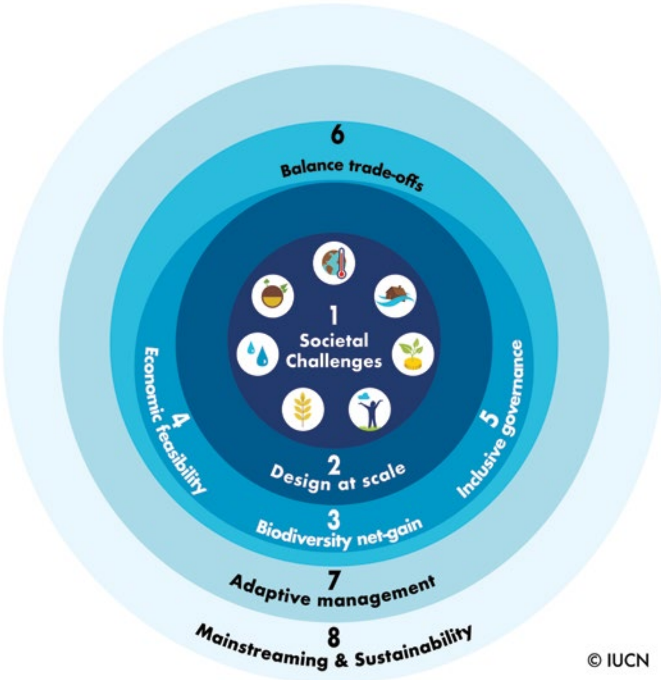
137 Institute for Sustainable Infrastructure (2018). *Envision: Sustainable Infrastructure Framework Guidance Manual*. 3rd edition. Washington, DC, USA: Institute for Sustainable Infrastructure. 189 pp. https://sustainableinfrastructure.org/wp-content/uploads/EnvisionV3.9.7.2018.pdf

IUCN Global Standard for Nature-based Solutions. The IUCN Global Standard for Nature-based Solutions (IUCN, 2020a)[138] serves as a facilitative framework for the design, verification and scaling up of nature-based solutions, which address societal challenges, including climate change adaptation and mitigation, disaster risk reduction, human health, food security, and water security. The Standard provides guidance toward a consistent approach to designing and verifying nature-based solutions, and a systematic learning framework to improve adaptability, sustainability, and effectiveness. Unlike Envision, this Standard consists primarily of a framework of guidelines, without any certification or credentialing system. The Standard details eight criteria, with 28 accompanying indicators, which all nature-based solutions should address:

- societal challenges,
- design at scale,
- biodiversity net gain,
- economic feasibility,
- inclusive governance,
- balancing of tradeoffs,
- adaptive management, and
- mainstreaming and sustainability.

Use of the Standard can lend credibility to on-the-ground nature-based solutions when speaking with investors, donors, and other stakeholders; provide recommendations for improvement; and promote engagement and communication across sectors. Governments, planners, companies, international organizations, donors, or financial institutions wishing to explore the potential for leveraging nature-based solutions can find more information on the IUCN webpage for the Global NbS Standard (IUCN 2020)[139].





© IUCN

138 IUCN (2020a). *Global Standard for Nature-based Solutions. A user-friendly framework for the verification, design and scaling up of NbS.*. First edition. Gland, Switzerland: IUCN. v+21 pp. https://portals.iucn.org/library/sites/library/files/documents/2020-020-En.pdf

139 IUCN (2020b). IUCN Global Standard for NbS [Website]. https://www.iucn.org/theme/nature-based-solutions/resources/iucn-global-standard-nbs

WHAT NEXT STEPS ARE NEEDED TO INCREASE THE IMPLEMENTATION OF GREEN-GRAY PROJECTS?

Green-gray infrastructure solutions are emerging, but not yet commonly used by engineers and practitioners globally. Our goal is to innovate the next generation of climate resilient infrastructure so that green-gray is a common and accepted infrastructure solution. To achieve that goal, we must:

1. Learn from and increase awareness of existing green-gray projects;

2. Identify common engineering design approaches of nature-based and hybrid green-gray infrastructure solutions for long-term environmental, economic, and social benefits;

3. Design innovative models to drive investment into green-gray adaptation solutions for specific industries and infrastructure types (e.g., ports and highways):

   a. Financial incentives are important for practitioners and decision-makers to justify the use of green-gray. In some cases, (e.g. US mid-Atlantic) the decision makers are the local entities, like the department of public works, who have some awareness of green-gray projects, but need evidence of the financial, social, and environmental returns of projects,
   b. Develop green-gray project models with quantified return-on-investment and internal rate of return to stimulate additional funding and make the business case for implementing green-gray solutions;

3. Through the Global Green-Gray Infrastructure Community of Practice, disseminate new tools, best practices, effective governance frameworks and investment opportunities to accelerate implementation of nature-based solutions.

   a. Communication and education will be critical for the uptake of green-gray infrastructure.
   b. Materials need to expose the multiple benefits (e.g. financial, social, environmental) of hybrid systems across multiple disciplines.
   c. Jargon/terms from conservation and restoration sectors may need to be 'translated' to conventional engineering terms, and vice versa, to align objectives.

Specifically for the development of engineering guidance, in 2021 the Global Green-Gray Community of Practice can collaborate to:

4. Identify and catalog green-gray case studies – Learn from and increase awareness of existing green-gray projects by researching case studies to learn from the design approach, engineering details, biophysical modelling, and performance metrics, with direct links to engineering guidelines.

   - Identifying, documenting, and socializing existing and additional pilot projects is an important step to catalyze the use and uptake of the green-gray approach.
   - Whether small municipalities or larger ones, developed or developing nations, or the global north and south addressing differences in governance and priorities, decision-makers want to look at other examples and case studies of proven successes, before implementing green-gray.

5. Deploy pilot projects – Fund, design, construct, and monitor pilot projects as experimental models, and collect performance information for specific project components, to inform engineering guidance and design standard(s) development.

6. Draft science-based green-gray engineering guidelines – Develop standards, design guidance, and testing protocols to evaluate fully nature-based and hybrid infrastructure solutions for effective results and long-term societal benefits.

   a. The community proposes to focus on developing guidelines, rather than standards, to give practitioners the flexibility to accommodate site-specific conditions. 'Standards' may be too constricting for hybrid systems when methodologies/guidelines would allow for modifications for local applications.
   b. Our community can focus on making visible all the potential unlocked in hybrid systems and facilitate the development of best practices and methods to integrate that approach to the conventional engineering, planning and infrastructure sectors, for both new projects and already built infrastructure.

8. CONSTRUCTION

Construction is often the largest cost in an overall project budget and selecting the best contractor to match a project's demands and budget is critical to delivering a successful project.

This Chapter describes alternative construction models, activities, and potential risks to consider early in the design development phase.

WHAT ARE GREEN-GRAY INFRASTRUCTURE CONSTRUCTION OPTIONS?

Three green-gray construction options are described in this module: community-build, design-build, and contractor build.

Community-Build

This model is specific to the community where the green-gray infrastructure project will be implemented. The community-build model emphasizes a people-centered approach and provides livelihood grants to community members to implement, maintain and monitor green-gray infrastructure projects. The immediate target groups that will benefit from this approach are the communities, where the pilot projects are located and local governments where the green-gray infrastructure projects will be installed.

To implement this community-build model:

- The design team determines if the community has the necessary capacity and skill set to construct the project. As needed, capacity building and training is provided to fill any knowledge or skill gaps;
- The community liaison and representatives from the community organization prepare a cost estimate to complete the work; and
- The community hires a foreman with appropriate qualifications and experience with similar projects to manage the construction activities. This person could be from within or outside the community.

Table 8.1 summarizes the anticipated activities, responsible parties and actions to mitigate risk in the community-build model.

Engaging local community organizations to build, monitor, and maintain the green-gray pilot projects has numerous benefits:

- Promotes ownership and responsibility for the projects and structures;
- Keeps resources local – both labor and materials;
- The community members are familiar with the area and local conditions;
- Engaging the community is cost efficient because there is no need to transport and/or lodge workers from elsewhere;
- The process builds community members', construction skills, by providing experience that can lead to supplemental livelihoods;
- As a result of leading the construction, the community is knowledgeable about monitoring and maintaining the systems and adapting the systems as needed.

The disadvantages, and associated risk mitigation action to engaging the local community organizations to build, monitor, and maintain the green-gray pilot projects include:

- Inexperienced community workers could be injured during construction. To mitigate this risk communities should review construction best practices and safety measures.
- Communities may not have enough skills to construct and/or maintain the structures. Additional training can be provided to mitigate this risk.

CASE STUDY 28:
BAGONGON, ILOILO, PHILIPPINES

Location: Bagongon, Iloilo, Philippines

Project Proponent:

Project Partners: Conservation International, Bechtel

Project Funders: French Facility for Global Environment, Swedish Postcode Foundation

COASTAL PROTECTION

RURAL DEVELOPMENT

COASTAL

Source: E. Abian, 2020

Project Description: Because of mangrove deforestation, an approximately 200 m width of coastline in Bagongon eroded. Most of the population is densely concentrated (489 households) in a cove, where the storm surge and wind wave potential are high. The green-gray project includes mangrove planting within sediments accumulated behind sediment trapping fences and new rock breakwaters for wave attenuation. The goal of the sediment trapping fences and wave attenuation structures is to promote beach growth where mangrove seedlings can be planted. The wave attenuation structures at Bagongon were placed on the "surf side" of the sediment trapping fences to reduce the effects of wind waves and storm surge on the communities until the mangrove rehabilitation occurs. Construction materials were locally sourced and include bamboo poles, bamboo mats, coconut coir mats, twine, sand, and rock. Once the restored mangrove ecosystem is established, the sediment trap and wave attenuation structure materials can be re-used in other locations to support similar beach growth and mangrove rehabilitation efforts.

Off-shore, marine protected areas conserve coral reef ecosystems, that provide additional risk reduction benefits. The community was engaged throughout the design development process and members of the Fisherfolk Association were hired to construct the project features. Table 8.1 identifies the community-build activities and risk mitigation strategies.

Ecosystem services restored or conserved: Mangroves and coral reefs restored for flood regulation and protection from storm surge.

Conventional engineering approach: Rock breakwaters and bamboo fences.

What makes this a good green-gray example? Since 2015, Conservation International and Bechtel have partnered to innovate green-gray infrastructure approaches for vulnerable coastal communities in Iloilo, Philippines. This unique partnership of a major environmental organization with an industry leader in engineering and construction – supported by multiple public and private funders, governments, and communities – is an innovative approach to tackle the challenge of disaster risk management in the most vulnerable places on our planet and inspired the creation of the Global Green-Gray Community of Practice.

Table 8.1. Example of Community-Build activities, responsibilities and risk mitigation actions from a community-build project in the Philippines.

#	ACTIVITY	RESPONSIBLE PARTY	RISK MITIGATION
PREPARATION, INCLUDING DESIGN/DRAWINGS, CONTRACTING, PERMITTING, PROCUREMENT, INSURANCE COVERAGE			
1	Grant Agreement	CI-Philippines and fisher associations	Flow down appropriate provisions from prime agreement.
2	Permitting	Community fisher association	CI-Philippines will support coordination and acquisition of necessary approvals and permits
3	Design/Drawings	Municipal engineer, hired by the fisher association	CI-Philippines will support the fisher association to coordinate design development consistent with the provided scope-of-work
CONSTRUCTION ACTIVITIES			
4	Build green-gray project	Fisher association	The municipal engineer will review and approve all work products for consistency with the design and scope-of-work
MONITORING; ACCEPTANCE OF MILESTONES BY QUALIFIED PARTY			
5	Monitoring	Fisher association	Based on a monitoring plan provided by CI-Philippines
6	Maintenance	Fisher association	As agreed, in the grant agreement between CI-Philippines and the fisher association

CASE STUDY 29:
COMMUNITY-BASED WATER STEWARDSHIP IN THE DONGJIANG BASIN

Location: Xiadong village and Lixi village of Xinhuilong Town, Guangdong Province, China

Project Proponent: Conservation International with funding from the Klynveld Peat Marwick Goerdeler (KPMG) Foundation

CLEAN WATER · WATER SUPPLY & SANITATION · FRESHWATER · TERRESTRIAL

The community water environment management team with a prototype of the constructed wastewater treatment wetland. (photo credit: Weiling Wu, Conservation International)

Project Description: The pilot communities currently have no wastewater treatment facilities, resulting in the direct discharge of sewage to nearby streams and a water supply reservoir, which negatively impact human and ecosystem health. Treatment wetlands use a combination of ecosystem and conventional treatment approaches to clean the water, improving ecosystem health and freshwater supplies. An innovative community-based participatory approach to designing, building, and maintaining wastewater treatment wetlands is being applied to improve sustainability and freshwater conservation. Community members and stakeholders are engaged in the entire project process beginning at site selection and investigation, and the drafting of a project implementation plan that establishes a core project implementing team and a water environment management team. The core project implementing team is composed of members from Conservation International and local partners and includes experts in water treatment, community and capacity building, nature education, and project management. The water environment management team, composed entirely of community members, co-designs the treatment system and is responsible for building and maintaining the new wastewater treatment wetlands in their communities.

Ecosystem services restored or conserved: Wetland and riparian habitats restored for water purification.

Conventional engineering approach: Anaerobic baffled reactors, pipelines, concrete.

What makes this a good green-gray example? This project model empowers local communities to become the main body of project actions and decision making. This model was developed based on learning from previous community scale wastewater treatment wetlands, where contractors outside the community designed and built the systems and then left upon completing construction. Most of the systems built by contractors from outside the community failed because people living with and using the systems did not have the training to understand how the systems worked nor how to maintain them into the future. Applying a community-build model, results in local knowledge, skills, and “ownership” over the long-term performance of the system.

Design-Build

Once a design alternative has been selected, but before a permit package is prepared, a design-build contractor is hired. The design-build contractor becomes a member of the design team. The team works collaboratively to finalize the design, often finding innovative solutions to improve the design based on the design-build contractor's input about constructability and material availability.

Benefits of a design-build construction model include:

- Usually good continuity and information communication occurs throughout the design and construction process.
- The build teams' input during design can result in time and material savings.
- If unexpected conditions are encountered during construction, a design-build team can be more flexible to respond and adjust.
- More specialized construction experience and access to specialized equipment, than in the community-build model.

Disadvantages of the design-build construction model include:

- Committing to a contractor during the design phase, when the full scope of the project is not finalized.
- May be more appropriate for medium-large scale projects, but not for small-scale.
- Reliance on people with expertise coming from outside the communities where the work will be done.
- The design-build team can be unknown and potentially untrusted by the community and be unfamiliar with local conditions and culture.

Contractor-Build

A traditional construction model where a contractor is hired once the construction documents are completed. The lead contractor typically hires sub-contractors to complete specific and specialized elements of the project construction. The model is initiated with a request for tender to outside contractors.

When selecting a construction option consider:

- If specialized equipment or skills are required for the implementation;
- Where materials will be procured, how materials will be delivered to the site, and where materials will be stored;
- Time of year when the project will be constructed, and if delays due to weather are likely;
- What erosion controls will be needed;
- The types of insurance coverages that will be required; and
- The workplace safety risks, safety prevention and training measures, and protocol for workplace injury.

Benefits of a contractor-build construction model include:

- More specialized construction experience and access to specialized equipment, than in the community-build model.
- At a large-scale, contractors can realize material, equipment, and time efficiencies that result in cost savings.

Disadvantages of the contractor-build construction model include:

- May be more appropriate for medium to large-scale projects, but not for small-scale projects.
- Reliance on people with expertise coming from outside the communities where the work will be done.
- The contractor team can be unknown and potentially untrusted by the community and be unfamiliar with local conditions and culture.

HOW CAN A PERFORMANCE-BASED PROCUREMENT MODEL BENEFIT GREEN-GRAY PROJECT CONSTRUCTION?

The conventional approach to construction procurement is a method-based contract that describes the work to complete, materials to use, treatments to apply, specific activities, and other issues. Alternatively, performance-based procurement emphasizes what the project must achieve, rather than how the contractor will achieve it.[140] A performance-based standard could, for example, require a healthy, mature ecosystem measured by dominant plant type, stem density, and height.

Benefits of a performance-based contract for construction include:

- Promoting innovative construction techniques; and
- Incorporating construction and maintenance into the contract.

Potential complications in applying a performance-based contract include:

- Estimating and defining the amount of time between performance assessments could be complicated if it takes a contractor multiple years (3-5) to achieve the performance target;
- The expertise required to select performance criteria and the availability of qualified inspectors; and
- To avoid complications from an entirely performance-based procurement model, consider two contracts: one pays for labor and materials and a second pays for performance.[141]

WHAT ACTIVITIES OCCUR DURING EACH PHASE OF GREEN-GRAY PROJECT CONSTRUCTION?

Pre-construction:

- Design and permits;
- Develop the project maintenance plan (see Chapter 9);
- Coordinate and meet regularly with the local community and adjacent landowners;
- Resolve any construction access concerns;
- Mobilize equipment and stage materials.

Construction:

- Regular communication with all members of the project and delivery team, contractor, any inspectors, and the community;
- Deploy erosion control and stormwater quality measures;
- Site grading to establish design elevations and slopes;
- Installation of project elements;
- Verify all elements included in the construction documents, installed as designed; and
- Clean site and demobilize (remove all equipment and materials from the site).

Post-construction:

- Obtain an as-built survey of the project site that includes all project elements.
- Monitor, maintain and adaptively manage the project site (Chapter 9), recognizing that the green infrastructure project elements may take years before achieving their full infrastructure service potential.

140 U.S. Federal Highway Administration (FHWA) (2018). *White Paper: Nature-Based Solutions for Coastal Highway Resilience.* Washing DC, and Fairhope, AL, USA: ICF and SCE. v+37. [Online paper] http://media.coastalresilience.org/SC/FHA_Coastal_Highway_Resilience.pdf Accessed date month, year.

141 A resource potentially helpful for the procurement process: Leung, V.A., Woiwode, N. and Smith, M.P. (2018). *A Procurement Guide to Nature-Based Solutions.* Virginia, USA: The Nature Conservancy. 26 pp.

HOW CAN INSURANCE PRODUCTS DE-RISK GREEN-GRAY CONSTRUCTION?

Insurance products can enable and de-risk ecological engineering and nature-based infrastructure construction. Traditional construction insurance covers, and revenue protection covers, provide assurance of project delivery and return on investment. Specifically, at the construction stage, insurance can de-risk:

- Start-up delays;
- Construction liability;
- Cover for damages and delays due to natural and man-made catastrophes during construction;
- Political risk; and
- Force majeure (unforeseeable circumstances that prevent someone from fulfilling a contract).

Additionally, by incorporating insurance solutions into the planning and design stage, the project is more attractive to investors as this increases certainty of completion, and delivery of target outcomes (see Chapter 4).

HOW TO OBTAIN FEEDBACK FROM THE COMMUNITY DURING AND AFTER CONSTRUCTION?

Communication is critical to avoid misunderstandings during construction, which can put at risk the current project, and any future projects.

A visible placard or board can be posted at the site that identifies the project partners along with contact information and can include a 'Pardon our Mess' message. Community members and stakeholders are encouraged to contact the project representative(s) to report any issues or comments about the project. Social media platforms can be used to provide project updates, conduct surveys, and solicit formal consultations.

See Chapter 5 for additional stakeholder engagement suggestions. The project's social monitoring framework, described in Chapter 9, can also document the community's perception of the project before, during and after construction.

CASE STUDY 30:
PRINS HENDRIKZANDDIJK REINFORCEMENT: INSURING A NATURE-BASED SOLUTION, DESIGNED TO PROTECT AGAINST RISING SEA LEVELS

Location: Island of Texel, Netherlands

Project Proponent: Water Board Hollands Noorderkwartier (principal), Jan De Nul NV (contractor) and Swiss Re (insurer)

COASTAL PROTECTION | RURAL DEVELOPMENT | COASTAL

Artist impression new Prins Hendrik sand dyke (Source: Feddes and Olthof in litt. Perk et al. 2019[143])

Source: Jan De Nul, 2020.[142]

Project Description: The island of Texel is situated on the most western side of the world heritage site on the Wadden Sea and considered the world's largest inter-tidal flat system. It is a popular tourist destination that welcomes about one million visitors every year and is exposed to rising sea levels and erosion.

To avoid the risk of a major failure, the local authorities were in search of an innovative concept. A dredging company found the solution: making use of and enhancing the local natural habitat by placing five million cubic meters of sand and planting two million marram grasses in order to create a landscape gradient.

The 2019 Prince Hendrik Sand Dyke project was one of the biggest dyke reinforcement operations in the Netherlands, with the sand dyke being constructed in front of the existing traditional rock/concrete dyke. Because of the sensitivities of the project, completion protections were required to obtain funding and proceed.

Swiss Re Corporate Solutions supported the construction of this nature-based solution with high levels of capacity and underwriting expertise. With a project value of EUR 25,000,000, Swiss Re provided a standard 'Construction All Risks' policy that protected against risks incurred during project construction, which covered:

- material damages to the project, due to weather events, design and execution errors;
- liability for damage to third parties, due to project works during and after construction; and
- property and assets of the principal - damages to the existing dyke during the construction.

The policy buyer was the dredging company who led the solution design and execution, however a 'Construction All Risks' policy insures all involved parties, which in this case included the municipality, water management agency, engineers, and contractors associated with the project.

Ecosystem services restored or conserved: Sand dunes and beaches restored for erosion prevention, as well as aesthetic value.

Conventional engineering approach: Levees/dykes and dredging.

What makes this a good green-gray example? Constructing innovative green-gray infrastructure projects can introduce a number of risks that are universal and unique to nature-based solutions. By incorporating insurance covers into nature-based solution projects, project developers, funders, and contractors can more confidently proceed with implementation and be assured of the target outcome. This project resulted in a revenue generating tourist site that is now larger, more beautiful with additional natural habitat, and more protected from erosion risks. The project also delivered additional € 1m benefits, with enhanced fish production, climate regulation, and water quality regulation. The 14,000 local residents were also very pleased with the result during the planning and construction process, as the insurance protections reduced risk of extended delays and disruptions. The project was delivered on time and won the WOW prize for best public collaboration.

142 Jan De Nul (2020). *Prins Hendrik Sand Dyke, The Netherlands.* [Website] https://www.jandenul.com/projects/prins-hendrik-sand-dyke-netherlands

143 Perk, L. van Rijn, L., Koudstaal, K and Fordeyn. J. (2019). A Rational Method for the Design of Sand Dyke/Dune Systems at Sheltered Sites; Wadden Sea Coast of Texel, The Netherlands. *Journal of Marine Science and Engineering* 7 (324) 1-25. https://doi.org/10.3390/jmse7090324 Accessed date month, year.

9. MONITORING, MAINTENANCE & ADAPTIVE MANAGEMENT

Green-gray infrastructure works in and with living ecosystems, which are adaptive and resilient to external pressures, evolving and performing more strongly with time. Conversely, maintenance requirements for gray only solutions often become more demanding and cumbersome over time, until they reach their 'design life', at which point they are obsolete.

Monitoring, maintenance, and adaptive management of both living ecosystems and gray infrastructure are integral to ensure project function and longevity.

- Monitoring should be designed to directly measure and evaluate the project's intended and unintended outcomes;
- Maintenance is critical to the longevity and effective function of a project; and
- Adaptive management iteratively improves the ability of a project to achieve its goals.

This module introduces a multi-step feedback process linking project monitoring and evaluation frameworks, maintenance strategies, and adaptive management.

WHY IS IT IMPORTANT TO MONITOR GREEN-GRAY INFRASTRUCTURE PROJECT OUTCOMES?

Project monitoring is critical to document and understand the strengths and weaknesses of each project, and to inform future green-gray project design and implementation through, for example, a designed experiments model (Chapter 7). Monitoring supports essential components of any project: understanding the strengths and weaknesses of project measures, avoiding maladaptation, and ensuring that project outcomes are attained.

With increased uptake of green-gray infrastructure projects globally, understanding the outcomes of interventions, as well as documenting and learning from good practices is more important than ever. Effective monitoring to document the effectiveness of interventions builds the evidence base for green-gray infrastructure, which can catalyze further political and financial investment in green-gray infrastructure and support its broader adoption globally.

Monitoring data will inform (1) recommended design modifications for similar techniques proposed at other sites; and (2) any necessary adjustments at the project site to achieve long-term project outcomes. These are aligned with testing under a designed experiments model as well as optimizing best practices in design guidelines and further implementation at scale.

Compared to conventional gray infrastructure, green-gray infrastructure projects can support a host of co-benefits. For example, design benefits for incorporating natural features include an ecosystem's ability, under the right conditions, to adapt to changing conditions (e.g., such as sea level rise) and rebound after an extreme event. That same ability to adapt and recover introduces uncertainty into the project outcome, when compared to a conventional gray infrastructure project, because ecosystems respond to external pressures and can evolve with time. Employing an adaptive management strategy, with a defined approach to modify the project upon encountering unintended outcomes, is one mechanism to manage this uncertainty.

Four steps for designing and implementing an adaptive management strategy for a green-gray project, which should be considered at the design development stage (Chapter 6), are to:

Step 1: Develop a monitoring and evaluation framework;

Step 2: Define indicators, baselines, and targets;

Step 3: Operationalize the monitoring and evaluation framework in a maintenance plan; and

Step 4: Use and communicate the results in an iterative process.

See the *Guidebook for Monitoring and Evaluating Ecosystem-based Adaptation Interventions*[144] for detailed guidance on each of these four steps.

HOW TO CREATE A MONITORING AND EVALUATION FRAMEWORK?

Monitoring should be designed to directly measure and evaluate the project's intended and unintended outcomes. The project monitoring and evaluation framework is based on the desired project results and should measure the outcomes of the green-gray infrastructure projects. Monitoring and evaluation is often required for climate adaptation projects that require an initial vulnerability assessment and then monitoring, to demonstrate improved resilience.

When designing a project monitoring and evaluation framework[145]:

- Identify objectives and define indicators;
- Collect baseline data that describes conditions prior to project implementation;
- Involve local communities and stakeholders in monitoring to achieve buy-in and enhance local capacity; and
- Develop a plan and budget for how the monitoring and evaluation framework will be implemented, potentially well past the time the project ends. Consider:
    - How will the information be collected?
    - Who will collect the information?
    - When will the information be collected and at what time interval?
    - Where will the information be collected?

- Create a plan for how monitoring data will be analyzed and how the results will be used to inform adaptive management.

    - Who will analyze the information? How and when?
    - Will the results be published? How will they be made accessible and communicated to stakeholders (and the wider public, if applicable)?
    - How can the results and lessons learned be shared with the wider green-gray community?
    - If monitoring reveals an unintended consequence or outcomes that fall short of intermediate goals, the project design team should reconvene to visit the site, evaluate the impact and recommend modifications to the green and/or gray infrastructure elements.

WHAT INDICATORS CAN BE USED TO EVALUATE GREEN-GRAY PROJECT OUTCOMES?

The indicators or criteria selected to evaluate green-gray infrastructure interventions will depend upon the intended results of the project. The project's performance, or ability to deliver these results, should be tracked closely in a project monitoring and evaluation framework and a project maintenance plan.

Of the several benefits accruing to a green-gray project, the following categories are possible to evaluate green-gray project outcomes. This will likely be in addition or complementary to measuring physical performance

144 GIZ, UNEP-WCMC and FEBA (2020). *Guidebook for Monitoring and Evaluating Ecosystem-based Adaptation Interventions*. Bonn, Germany: Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. 84 pp. https://www.adaptationcommunity.net/download/ME-Guidebook_EbA.pdf

145 Donatti, C.I., Martinez-Rodrigo, M.R., Fedele, G., Harvey, C.A., Andrade, A., Scorgie, S., Rose, C., and Alam. M. (2019). *Guidelines for designing, implementing and monitoring ecosystem-based adaptation intentions*. Virginia, USA: Conservation International. 40 pp. https://www.conservation.org/docs/default-source/publication-pdfs/guidelines-for-designing-implementing-and-monitoring-eba.pdf?Status=Master&sfvrsn=bccddc79_3

measures to inform engineering and design decisions, such as material strength, longevity, and integrity.

Climate adaptation and disaster risk reduction benefits – The reduced vulnerability and increased adaptive capacity of people to manage the identified climate and disaster risks are a primary benefit and can be monitored specifically by measuring the ability of people to take advantage of opportunities or to respond to damages associated with climate risks, hazards, changes and uncertainty. This could, for example, include estimating the reduced damage (e.g., fatalities and infrastructure loss) after an extreme weather event compared to a similar event pre-project.

Ecological benefits – The specific ecological benefits that will be monitored depend upon the project design and target ecosystem. For example, metrics to measure ecological benefits of mangrove restoration could include sediment accumulation and sediment stabilization, reduction of wave energy, mangrove seedling survival and growth, and the number of species (increased biodiversity). In this example, ecological monitoring could occur in (1) a control area, with no existing mangroves and outside the influence of the proposed green-gray infrastructure measures, (2) within the project area, and (3) in an existing natural mangrove area.

Social benefits – Social monitoring can provide quantitative and qualitative documentation of the short- and long-term social benefits of green-gray infrastructure projects. Social monitoring can be conducted through focus groups or household surveys. Potential metrics to measure short- and long-term social benefits include:

- Community members' perception of their security or safety if an extreme weather event were to occur (e.g., perceived risk before and after project);
- Community members' plan of action if notice of an impending extreme weather event were received;
- Community members' sense of well-being;
- Total community income over time as compared to trends in comparable communities; and
- Percent of community income derived from different livelihood types.

Other potential indicators include for project co-benefits include:

- Job creation and support for local livelihoods;
- Gender equality and women's empowerment (e.g., increased salaries, participation in meetings and involvement in decision-making);
- Recreation and human health (e.g., space for people to access and enjoy nature, improve air quality, reduce local temperatures);
- Food security (e.g., drop in income from tourism makes food security provided by "natural systems" critical for resilience);
- Economic benefits (e.g., reduced maintenance cost of infrastructure, reduced damages to assets and livelihoods from disasters); and
- Expanded role of marginalized groups (e.g., participation in planning, design, implementation, and monitoring, maintenance, and adaptive management).

Additional resources for identifying key performance indicators, assessment, and measurements methods include:

> *Blue Natural Capital Positive Impacts Management System*[146]
>
> The *Use of Natural and Nature-Based Features (NNBF) for Coastal Resilience, Final Report*[147] includes coastal landscape metrics in Appendix E. Chapter 4 encompasses performance metrics for ecosystem goods and services generated by nature and nature-based features and structural features in the post-hurricane environment.

WHAT ARE THE ELEMENTS OF A PROJECT MAINTENANCE PLAN?

Project monitoring, maintenance, and adaptive management are connected in a multi-step, feedback process that is outlined in a project maintenance plan. The maintenance plan operationalizes the monitoring and evaluation framework and includes:

1. Defining the "green" ecosystem and gray infrastructure assets to be maintained;

146 Herr, D., Baldwin, R., and Wilson, S. (2019). *BNC+ Framework Blue Natural Capital Positive Impacts Framework Blue Natural Capital Positive Impacts Framework*. [Online framework]. Gland, Switzerland and Grand Duchy of Luxembourg: IUCN & The Ministry of Environment, Climate and Sustainable Development. 30 pp.

147 Bridges, T.S., Burks-Copes, K.A., Bates, M.E., Collier, Z., Fischenich, C.J., Piercy, C.D., Russo, E.J., Shafer, D.J., Suedel. B.C., Gailani, J.Z., Rosati, J.D., and Wamsley, T.V., Wagner, P.W., Leuck, L.D., and Vuxton, E.A. (2015). *Use of Natural and Nature-Based Features (NNBF) for Coastal Resilience*. Washington, DC, USA: Engineer Research and Development Center, U.S. Army Corps of Engineers. xxxi+446 pp. https://usace.contentdm.oclc.org/digital/collection/p266001coll1/id/3442/

2. Identifying for each asset: (1) guidelines and steps for maintenance (e.g., pruning), (2) indicators to measure (e.g., ecosystem area), and (3) metrics;
3. Detailing the location of each asset, actions to be undertaken, and a maintenance schedule;
4. Applying a cooperative approach to exchange information with stakeholders, and help define and implement maintenance and monitoring practices;
5. Establishing training programs for technical and field staff on the maintenance activities;
6. Monitor performance of the assets, according to the project monitoring and evaluation framework, and report results and findings to the design team and contractors; and
7. Based on the results, modify the management to improve the project function.

Figure 9.1 provides a visual of the integrated elements of a project maintenance plan.

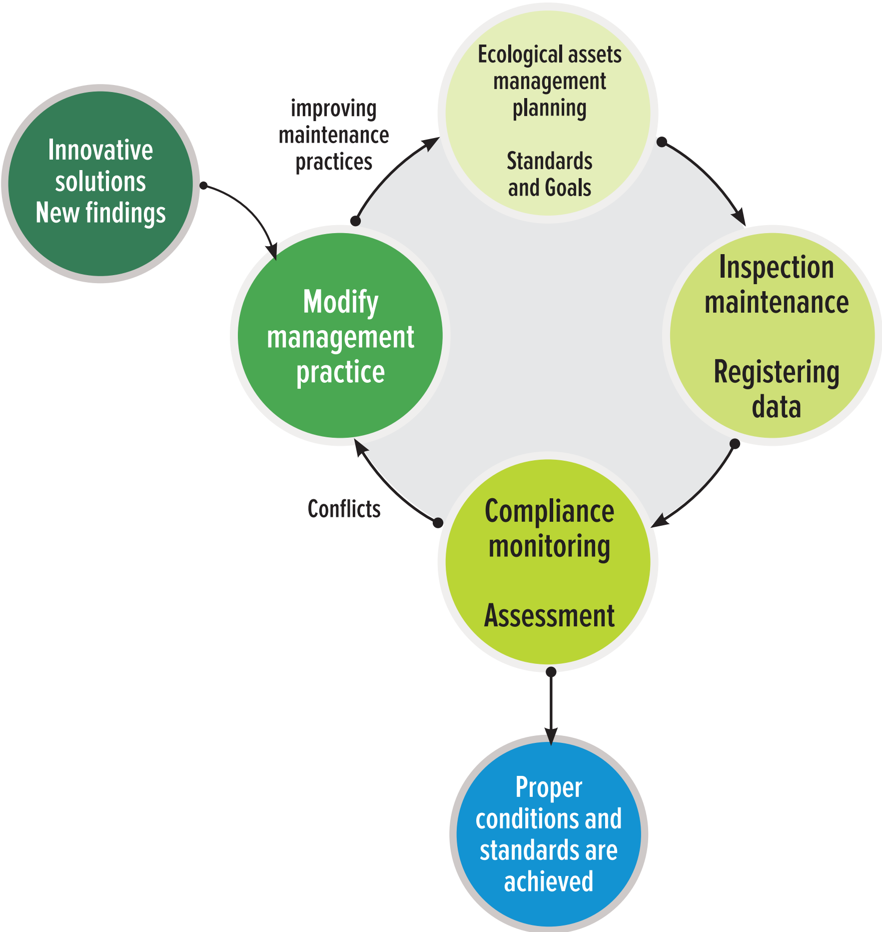


Figure 9.1. An iterative approach to adaptive management (source: Iuell et al (2003)[148])

Conventional infrastructure projects typically transfer to an operational company or organization to conduct maintenance, monitoring, and adaptive management. The green-gray maintenance, monitoring, and adaptive management plan should be ecologically minded and reflect the long-term conservation and restoration objectives.

148 Iuell, B., Bekker, G.J., Cuperus, R., Dufek, J., Fry, G., Hicks, C., Hlavác, V., Keller, V., B., Rosell, C., Sangwine, T., Tørsløv, N., Wandall, B. le Maire (eds.) (2003). *Wildlife and Traffic: A European Handbook for Identifying Conflicts and Designing Solutions*. Brussels, Belgium: European Co-operation in the Field of Scientific and Technical Research. 21 pp. http://www.iene.info/wp-content/uploads/COST341_Handbook.pdf

CASE STUDY 31:
HAMILTON WETLAND RESTORATION PROJECT

Location: Novato, inside San Francisco Bay, Marin County, California, USA.

Project Proponent: United States Army Corps of Engineers, State Coastal Conservancy, San Francisco Bay Conservation and Development Commission, Philip Williams and Associates and Environmental Science Associates

COASTAL PROTECTION

RURAL DEVELOPMENT

COASTAL

Source: US Army Corps of Engineers, undated[149]

Project Description: Using a combination of methods, this project sought to restore a former airfield to tidal and seasonal wetlands to enhance flood protection for nearby infrastructure including housing and agricultural lands. Around 4.6 million cubic meters of dredged material was used to raise the project site for marsh restoration, to establish inter-tidal berms and to enhance and realign the existing levee and incorporate a sloping wildlife corridor between the levee and nearby housing, thus creating a horizontal levee. The inter-tidal berms were engineered to provide protection against wind waves, while also increasing site sediment and assisting in channel development by eroding slowly over time. The creation of a 91-meter wildlife corridor was used in lieu of rock armoring to provide habitat connectivity, lend a hand to a healthier local ecosystem and provide recreational opportunities for the community. Full function of the site is not predicted until between 2030 and 2050, though positive results are already being seen with a survival rate of 50-75% of planted vegetation.

The project is in a 13-year monitoring and adaptive management phase, which allows unpredicted results to be addressed quickly and efficiently: such as the compaction of sediment, which reduced the height of the berms and parts of the levee, leading to partial erosion.

Ecosystem services restored or conserved: Inter-tidal marsh and seasonal wetlands restored for flood regulation and erosion control.

Conventional engineering approach: Beneficial use of dredged sediment, horizontal levee, inter-tidal berms, Managed realignment/retreat, Levee breach after placing sediment to raised elevation.

What makes this a good green-gray example? Dredged material was provided by the Port of Oakland's Harbor Deepening project; using this sediment decreased project costs, while also making good use of a resource intended for disposal. Additionally, the project's success so far can be attributed in part to multiple levels of community involvement. Planning committee members included 80 different stakeholders from various backgrounds in the community. Public outreach and involvement, including with local school groups, led to the planting of 35,000 plants in the seasonal wetland and wildlife corridor.

149 US Army Corps of Engineers (undated). Hamilton Airfield Wetland Restoration. [Website] https://www.spn.usace.army.mil/Missions/Projects-and-Programs/Projects-by-Category/Projects-for-Ecosystem-Restoration/Hamilton-Airfield-Wetland-Restoration/

10. POLICY

Enabling local, national, and even international policies, laws, and regulations are critical to drive the use of green-gray approaches, as well as for catalyzing the adoption of green-gray infrastructure at scale. Rigid regulatory and funding policies designed for gray infrastructure can hinder the uptake of green-gray infrastructure approaches. Recognizing this, recommendations for enabling policies include:

- updating existing regulatory frameworks, such as land-use planning and zoning;
- updating local ordinances and regulations;
- adopting Resiliency Master Planning standards; and
- mobilising fiscal incentives for landowners/investors to invest in green-gray solutions.

This chapter provides guidance for policymakers to set incentives and enabling conditions for green-gray infrastructure in local and national policies, laws, and regulations including those related to:

- Climate change adaptation;
- Disaster risk reduction;
- Erosion reduction and coastal protection;
- Water security and flood management;
- Food security for agriculture by supplying irrigation water and improving water quality by filtering pollutants; and
- Job creation and supplemental livelihoods.

Additionally, this chapter shows how local and national policies can contribute towards meeting international policy commitments.

HOW CAN POLICY UNDERPIN THE UPTAKE OF GREEN-GRAY INFRASTRUCTURE?

In the next 20 years, an estimated US $94 trillion will be spent on infrastructure globally. Rigid regulatory and funding policies, designed with gray infrastructure in mind, inadvertently maintain the status quo of channeling this investment into primarily gray infrastructure. Facilitating the uptake and implementation of green-gray solutions requires proactive policy interventions, supportive institutions, and robust and effective policy frameworks[150].

Progressive policies and regulator buy-in underpin investment into green-gray projects (see Chapter 4 and 5). Enabling policies for green-gray infrastructure can provide resources for implementation and enforcement, by earmarking public funds and setting policies that unlock funds from sources such as land value capture, tariffs, and insurance. Potential policy points of entry for the integration of green-gray infrastructure and allocation of investments include:

- Ensuring green-gray is eligible for federal funding and financing mechanisms that support national climate adaptation, coastal protection, flood management, stormwater, drinking water, and wastewater systems. Applicable financing mechanisms are discussed in detail in Chapter 4.

- Mainstreaming green and green-gray infrastructure design regulations into national and municipal planning and development processes, for example through land use planning and approval procedures.

- Linking green-gray projects to municipal projects such as port operations or transportation investments can also encourage private investment.

- Updating existing regulatory frameworks to require municipal scale zoning and planning to consider and include green-gray infrastructure, including updating local ordinances and regulations. Examples include

150 Browder, G., Ozment, S., Rehberger Bescos, I., Gartner, T., and Lange, G-M. (2019). *Integrating Green and Gray: Creating Next Generation Infrastructure.* Washington, DC: World Bank and World Resources Institute. 134 pp. https://openknowledge.worldbank.org/handle/10986/31430 .

streamlining the permitting of green-gray solutions, depending on legal mandates and jurisdictions.

- Mobilising fiscal incentives for landowners/investors to invest in green-gray solutions. Examples include tax exemptions, building fee discounts, and income tax relief for owners/occupiers who invest in green-gray infrastructure.

- Policies can establish green-gray education and capacity building efforts by:

- Developing local, national, and regional community of practice networks to build capacity and create funding mechanisms to sustainably fund, operate, maintain, and assess green-gray infrastructure projects. These networks could commit to voluntary obligations to investment support and green-gray implementation, along with new construction projects and investment support.

- Implementing and disseminating a communication and education campaign on the true costs, savings, risks, and avoided hazards associated with green-gray investments.

- Establishing a grant program for curricula development and career training programs for jobs in green and green-gray infrastructure, for example, through agreements with local universities and skills training programs.

- Mainstreaming tools for data-driven decision-making, such as asset management software and life-cycle cost analysis.

WHAT ARE ACTIONS THAT POLICYMAKERS CAN TAKE TO SUPPORT GREEN-GRAY INFRASTRUCTURE?

(1) Draft and maintain a policy digest that documents:

- Existing laws and regulations for opportunities to promote green-gray;
- Identify where modifications are needed to remove barriers to implementation; and
- Map stakeholders with roles and responsibilities relevant to the implementation of green-gray infrastructure

(2) Update existing regulatory frameworks to create enabling conditions for green-gray infrastructure, as well as compliance mechanisms:

- Identify regulatory norms that hinder investment in and implementation of green-gray infrastructure (such as land-use planning and zoning, building codes, and safety regulations).
- Incorporate green-gray opportunities into local ordinances and regulations, ensuring that regulations are enforceable.
- Provide the resources and capacity required to enforce laws and regulations.

(3) Modify policy frameworks to require municipal scale planning to include green-gray infrastructure:

- Require city and master plans to consider and include green-gray infrastructure projects;
- Adopt Resiliency Master Planning standards. In our current climate crisis, resiliency must be considered alongside planning for growth, capacity, and regulations in a system or municipal master plan, and to reduce the magnitude and/or duration of disruptive events. Resiliency Master Planning should identify, prioritize, and plan for a range of solutions across the green-to-gray infrastructure spectrum.

(4) Allocate post-disaster recovery funding to green-gray infrastructure

- Green-gray infrastructure plays an important role in both preparedness and recovery from natural disasters. By “building back better” with green-gray infrastructure, policymakers have the potential to address underlying drivers of disaster risk and create more resilient infrastructure to future disasters before they occur. This will result in less expenditures.

(5) Develop, adopt, and widely socialize Green-Gray Engineering Guidelines:

- Only when Green-Gray Engineering Guidelines are developed, adopted, and practiced will it be possible to fulfill green-gray policies at scale. See Chapter 7 for a current state-of-the practice.

HOW CAN COUNTRIES USE GREEN-GRAY INFRASTRUCTURE TO MEET INTERNATIONAL COMMITMENTS?

A growing number of international agreements include high-level commitments to promote nature-based solutions such as green-gray infrastructure, that enhances resilience of both humans and ecosystems, reduces disaster risks, and improves safeguards for biodiversity conservation. Local actions to accelerate the uptake of green-gray infrastructure can meet national-level commitments on climate change, disaster risk reduction, and sustainable development.

As national governments are working to both set and operationalize their commitments under the 2030 Agenda for Sustainable Development, the United Nations Framework Convention on Climate Change's Paris Agreement, the Sendai Framework for Disaster Risk Reduction, and the Convention on Biological Diversity, green-gray infrastructure approaches can offer alignment on reporting across conventions including:

1. **United Nations Framework Convention on Climate Change (UNFCCC)** - In the Paris Agreement under the UNFCCC, countries committed to transform their development trajectories to set the world on a course towards sustainable development and limit global warming to 1.5° to 2° C above pre-industrial levels, as well as committing to a long-term goal for adaptation to foster climate resilience.

   The Paris Agreement requires each country to prepare and maintain successive nationally determined contributions (NDCs) that it intends to achieve post-2020, while the national adaptation plan (NAP) process facilitates adaptation planning in least developed countries and other developing countries. As countries revise and prepare both NDCs and NAPs, there is a major opportunity to increase global ambition on strengthening the role of nature-based solutions, such as green-gray infrastructure, in national climate change commitments. Specific, measurable, and robust targets for green-gray infrastructure in NDCs and NAPs send a strong signal, both internationally and domestically, of national policy priorities with the potential to, in turn, drive resources, financing, and further action.

   Article 10 of the Paris Agreement addresses the importance of fully realizing technology development and transfer among countries to improve resilience to climate change. The contributions of further scientific evidence for green-gray infrastructure, as well as the Green-Gray Engineering Standards (Chapter 7), contribute to the capacity building of countries on technology development for climate-resilient infrastructure.

2. **United Nations Office for Disaster Risk Reduction (UNDRR)** - UNDRR is the United Nation's focal agency for disaster risk reduction, overseeing the implementation of the Sendai Framework for Disaster Risk Reduction 2015-2030, and supporting countries in its implementation. The Sendai Framework has a number of targets relevant to green-gray infrastructure, including Target C5 on direct economic loss resulting from damaged or destroyed critical infrastructure attributed to disasters and Target D4 on the number of other destroyed or damaged critical infrastructure units and facilities attributed to disasters. The Global Platform for Disaster Risk Reduction of the UNDRR has recognized that "*Disaster resilient infrastructure is key to achieve the vision of risk-informed development. There is a strong need to capitalize on the co-benefits of ecosystem-based approaches and leverage the complementarity across blue, green and gray infrastructure*", and that *"nature- and ecosystem-based approaches should be promoted to achieve the objectives of resilience dividend and integrated in disaster risk reduction strategies at all levels."*

   The Sendai Framework emphasizes the need to address underlying causes of disaster risk and to prevent the emergence of new risks. Traditional gray infrastructure approaches typically address protection needs without addressing underlying drivers of risk. By incorporating and making common-place the use of green-gray infrastructure approaches in national disaster risk reduction strategies, these underlying drivers can be addressed at local and national levels.

3. **The Convention on Biological Diversity (CBD)** - The CBD seeks to achieve the following three main objectives: the conservation of biological diversity; the sustainable use of the components of biological

diversity; and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources. The CBD has recognized in Decision 14/5 that "*Climate change is a major and growing driver of biodiversity loss, and that biodiversity and ecosystem functions and services, significantly contribute to climate change adaptation, mitigation and disaster risk reduction*". Following this, the CBD adopted the *Voluntary Guidelines for the Design and Effective Implementation of Ecosystem-based Approaches to Adaptation and Disaster Risk Reduction* in 2018[151], which includes the role of green-gray infrastructure as an adaptation and disaster risk reduction strategy. The Voluntary Guidelines recognize that depending on local conditions and climate projections, green-gray infrastructure solutions may work best in terms of public health, social cohesion, urban biodiversity and mitigation, creating win-win solutions for the environment, society and the economy.

Article 6 of the Convention calls for Parties to develop National Biodiversity Strategies and Action Plans (NBSAPs) for the conservation and sustainable use of biological diversity and integration into relevant sectoral or cross-sectoral plans, programmes and policies. Green-gray infrastructure approaches can be mainstreamed through NBSAPs implementation and investment planning processes.

The CBD Post-2020 Global Biodiversity Framework is currently under deliberation. The role of nature-based solutions such as green-gray infrastructure, is expected to be reflected strongly in the framework, offering countries a long-term opportunity to forge synergies across frameworks for effective monitoring, reporting and verification.

4. **Sustainable Development Goals (SDGs)** – The economic, climate, and social benefits of green-gray infrastructure are linked directly to the implementation of multiple Sustainable Development Goals. Green-gray infrastructure can provide sustainable, climate resilient solutions to many of the global challenges the SDGs seek to address, while optimizing synergies and reducing trade-offs.

Of the 17 Sustainable Development Goals, and their 169 associated targets, green-gray infrastructure directly contributes to achieving 11 goals and 41 (or 24%) of the targets. Table 10.1 identifies direct links between green-gray infrastructure and the SDGs.

151 Secretariat of the Convention on Biological Diversity (2019). Voluntary guidelines for the design and effective implementation of ecosystem-based approaches to climate change adaptation and disaster risk reduction and supplementary information. *CBD Technical Series No. 93*. Montreal, Canada: CBD. 156 pp.

Table 10.1

SDG	Target	Green-Gray Relevance to the SDGs
1	1-5: By 2030, build the resilience of the poor and those in vulnerable situations and reduce their exposure and vulnerability to climate-related extreme events and other economic, social and environmental shocks and disasters.	Green-gray projects improve the resilience of highly vulnerable communities and have the potential to catalyze local, regional, and international implementation of green-gray infrastructure projects that conserve and restore natural ecosystems.
6	6-6: By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes.	By design, green-gray infrastructure projects restore and conserve water-related ecosystems.
9	Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation. (specifically 9-1 and 9-A)	The goal of integrating green and gray tools and techniques is to produce innovative and resilient infrastructure. The Global Green-Gray Community of Practice fosters inclusion to further innovation, adoption, and adaptation.
11	Make cities and human settlements inclusive, safe, resilient and sustainable. (specifically 11-5, 11-7, 11-B)	Green-gray projects work to make vulnerable communities safer and more resilient while also promoting the adoption of policy that maximizes the efficiency of sustainable natural resource restoration and conservation.
12	12-8: By 2030, ensure that people everywhere have the relevant information and awareness for sustainable development and lifestyles in harmony with nature.	The purpose of the Green-Gray Infrastructure Practical Guide is to raise awareness about a nature-based solution that conserves and restores natural systems to achieve sustainable development and climate adaptation outcomes.
13	Take urgent action to combat climate change and its impacts. (specifically 13-1, 13-2, 13-3, and 13-B)	Green-gray projects strengthen community resilience and adaptive capacity, with oppoprtunties to promote and raise awareness for broader integration of green-gray infrastructure, as a strategic policy to combat climate change and its impacts, with opportunity to lead to action in small island developing States.
14	14-2: By 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans.	Green-gray infrastructure projects restore coastal and marine ecosystems to make oceans more healthy and productive.
15	Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss. (specifically 15-2 and 15-9)	Green-gray projects restore and protect ecosystems, such as forests. Distribution and training about this Practical Guide will support integrating ecosystem and biodiversity values into national and local planning and development processes.
17	Strengthen the means of implementation and revitalize the global partnership for sustainable development. (specifically 17-3, 17-6, 17-7, 17-9, 17-14, 17-16, and 17-17)	The Global Green-Gray Community of Practice and this Practical Guide will promote the dissemination and diffusion of environmentally sound technologies to enhance sustainable development. We are mobilizing a global network to enhance international support and partnerships for effective implementation of green-gray infrastructure strategies.

CASE STUDY 32:
THE TEXAS COASTAL RESILIENCY MASTER PLAN

Location: Texas Coastal Zone, USA

Project Proponent: Texas General Land Office (GLO)

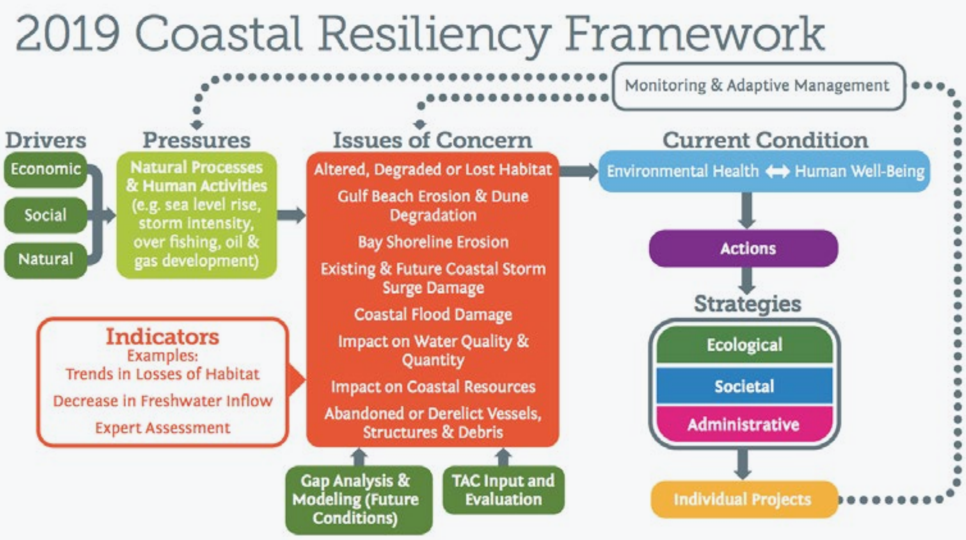
COASTAL PROTECTION | EROSION CONTROL | FLOOD MANAGEMENT | COASTAL

Project Description: The 2019 Texas Coastal Resiliency Master Plan is a large-scale framework that addresses the most pressing coastal threats on the Texas Coast, with a focus on nature-based projects. First, the Master Plan formally defines concerns that require the most attention, such as degraded habitats, erosion, storm damage, and flooding. Advanced coastal modeling predicts where these concerns are most likely to occur. Next, principal actions are identified, for example, wetland protection and shoreline stabilization or watershed planning, to address the pre-defined concerns. These actions intend to more broadly incorporate both green and gray elements to push for a "multiple lines of defense approach" for resiliency. The Master Plan defines nature-based, green-gray projects both coastwide – such as the Dune Management and Access Plan – and also within specific locations – such as the Old River Cove Restoration project. The Dune Management and Access Plan generally uses the construction and restoration of dunes to reduce storm surge impacts. The Old River Cove Restoration project uses dredge material and wetland restoration to restore islands to protect the area from erosion, storm surge and flooding. The Master Plan will be updated every four years with the implementation of adaptive monitoring and management between formal plans to allow for flexibility with an ever-changing coast.

Ecosystem services restored or conserved: Coastal ecosystems including beaches, dunes, and wetlands restored for erosion control, flooding regulation, and enhancing habitat productivity (in turn, increasing biodiversity).

Conventional engineering approach: The Texas Coastal Resiliency Master Plan contains multiple projects meant to enhance the resiliency of the coast as a whole and continues to grow and expand with each new edition. Some of the conventional engineering approaches include the beneficial use of dredged materials, breakwaters, stone groins and concrete rip-rap for shoreline stabilization.

What makes this a good green-gray example? The Texas Coastal Resiliency Master Plan exemplifies the Resiliency Master Plan approach, operating under the knowledge and guidance of a Technical Advisory Committee, with expert stakeholders from universities, non-profits, foundations, governmental agencies and more. The Master Plan divides the Texas Coast into four regions, with solicited input from the Technical Advisory Committee to pinpoint appropriate actions for region-specific and comprehensive coastwide resiliency. Furthermore, an Ecosystem Services Technical Working Group was created to find opportunities to integrate nature-based and green infrastructure elements into conventional "gray" infrastructure projects, to enhance coastal protection and mitigation outcomes.



Source: The Adaptation Clearinghouse, 2011[152]

152 The Adaptation Clearinghouse (2011). *Texas 2019 Coastal Resiliency Master Plan*. Austin, TX, USA: Texas General Land Office. Xi+221 pp. https://coastalstudy.texas.gov/resources/files/2019-coastal-master-plan.pdf

CASE STUDY 33:
LOUISIANA'S COMPREHENSIVE MASTER PLAN FOR A SUSTAINABLE COAST

Location: Louisiana Coast, Louisiana, USA

Project Proponent: Louisiana's Coastal Protection and Restoration Authority

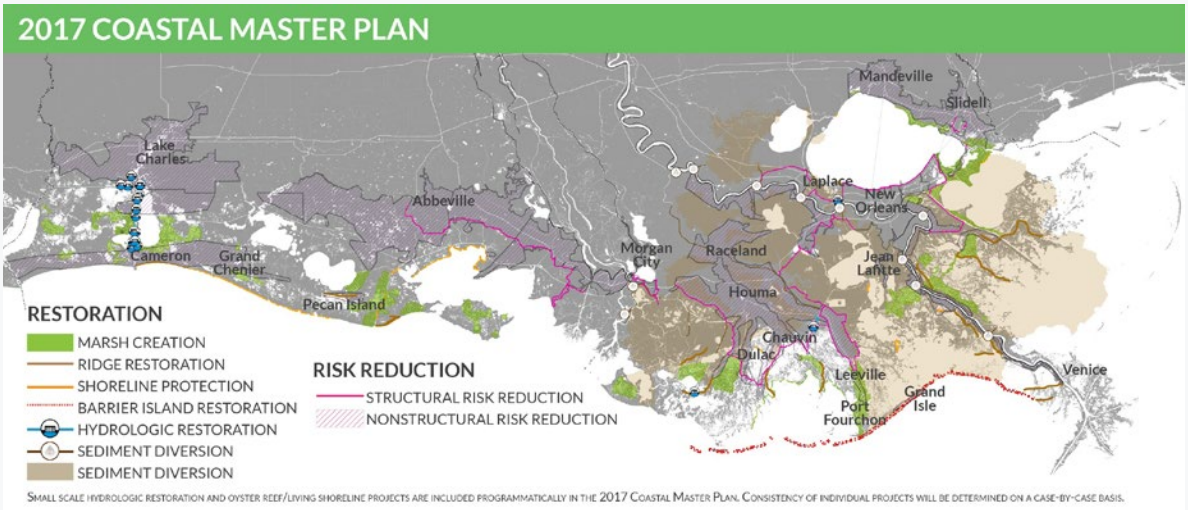
COASTAL PROTECTION | EROSION CONTROL | FLOOD MANAGEMENT | COASTAL

Project Description: Louisiana's Coastal Protection and Restoration Authority adopted their first Comprehensive Master Plan for A Sustainable Coast in 2007. Authorities realized that implementing smaller, standalone projects provided fewer benefits than projects at the larger regional scale. Master Plans are cumulative, with the ultimate goal of building a cohesive coastline, with fully-functioning ecosystems providing storm surge and flooding benefits to coastal communities. Master Plans are updated and released every five years, with a specific plan of action that explicitly incorporates projects related to flood risk reduction and wetland restoration, to achieve coastal resiliency. These Master Plans integrate proposals from multiple sources, including non-profit agencies, government officials, churches and the general public. A continuous planning process is created for each selected project with construction, maintenance and adaptive management measures identified and recorded so that projects can be implemented once funds are accessible. The Master Plans have thus far completed or funded 135 projects with 14,569 hectares of land restored, 453.8 kilometers of levee improvements and also the construction of 96+ kilometers of barrier islands and berms, all towards a more sustainable future for Louisiana's coasts.

Ecosystem services restored or conserved: Wetland restoration for flood regulation.

Conventional engineering approach: Louisiana's Comprehensive Master Plan includes several conventional engineering approaches across multiple projects. Such approaches include breakwaters, levees, weirs and sill and wall structures.

What makes this a good green-gray example? Louisiana's Comprehensive Master Plan exemplifies the Resiliency Master Planning approach and as the Gulf of Mexico experiences more frequent and intense hurricanes because of climate change, Louisiana's coastal restoration projects are being put to the test. The reduced impacts observed in restored areas of the multiple hurricanes already seen in 2020 are, as Louisiana Governor John Bel Edwards said, "a testament to the nature-based solutions that we've implemented, and the strategy of developing restoration and protection in a comprehensive manner."



Source: Coastal Protection and Restoration Authority of Louisiana, 2017[153]

153 Coastal Protection and Restoration Authority of Louisiana (2017). *Louisiana's Comprehensive Master Plan for a Sustainable Coast*. Baton Rouge, LA, USA: Coastal Protection and Restoration Authority of Louisiana. 171 pp. http://coastal.la.gov/wp-content/uploads/2017/04/2017-Coastal-Master-Plan_Web-Book_CFinal-with-Effective-Date-06092017.pdf

CASE STUDY 34:
BUILDING BACK BETTER WITH GREEN-GRAY INFRASTRUCTURE: REBUILD BY DESIGN'S HURRICANE SANDY REBUILDING TASK FORCE COMPETITION

Location: New York City, New York, USA

Project Proponent: Rebuild By Design, Rockefeller Foundation (lead funding partner for RBD), Community Development Block Grant Disaster Recovery funds that Congress appropriated to the U.S. Department of Housing and Urban Development for Hurricane Sandy Recovery.

COASTAL PROTECTION

COASTAL

Project Description: In the aftermath of destruction left by Hurricane Sandy in 2012, the US Department of Housing and Urban Development, in collaboration with the Presidential Hurricane Sandy Rebuilding Task Force, began the Rebuild by Design competition. The Rebuild by Design competition sought to develop new projects that addressed climate and community resilience, using environmentally-focused approaches, while purposefully integrating input from a variety of experts and stakeholders including research and design experts, businesses, policymakers and communities. Ten project applications were selected and after nine months of comprehensive research and engagement, six final projects were awarded $930 million by the federal government. Living Breakwaters, one of the projects to be funded, is located in Tottenville, Staten Island, New York, one of the hardest hit communities during Hurricane Sandy and was historically protected by extensive oyster reef habitat that has been completely devastated. To increase protection against wave action and erosion, Living Breakwaters will consist of approximately one kilometer of rubble mound structures along the shore for future oyster installation and cultivation in conjunction with sand placement to restore the shoreline to the width it was in the 1970s.

Ecosystem services restored or conserved: Oyster reefs for flood regulation.

Conventional engineering approach: The final funded projects of the Hurricane Sandy Rebuilding Task Force Competition were diverse and include varying elements of conventional engineering approaches. Some of these approaches include the use of breakwaters, berms and permeable pavement.

What makes this a good green-gray example? The Living Breakwaters project is notably collaborative, designed to enhance already existing resilience initiatives including the Tottenville Dune and Coastal Dune Plantings project and the Billion Oyster project. Incorporating the Billion Oyster project will significantly strengthen the breakwaters and bring back a healthy reef ecosystem, this further strengthens the existing dune system, providing a comprehensive structure for coastal protection. As with all the Rebuild by Design proposal finalists, Living Breakwaters has a strong focus on community outreach and involvement, leading to high approval rates of project initiatives. The Living Breakwaters Citizens Advisory Committee was created for diverse stakeholder representation via an advisory role to the project implementation and continuation.

Source: SCAPE, 2007[154]

154 SCAPE (2007). *Living Breakwaters: Design and Implementation Staten Island, NY. Project Overview* [Website]. https://www.scapestudio.com/projects/living-breakwaters-design-implementation/

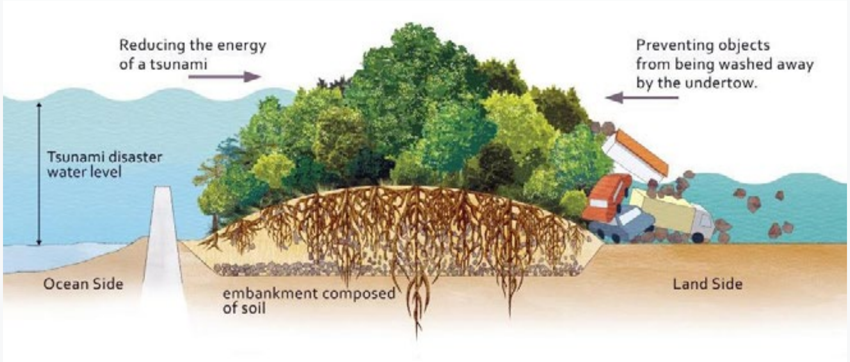
CASE STUDY 35:
GREEN-GRAY INFRASTRUCTURE AS NATIONAL DISASTER RISK REDUCTION POLICY IN JAPAN

Location: Japan

Project Proponent: National and Local Governments of Japan

COASTAL PROTECTION

COASTAL



Source: https://morinoproject.com/english (IMAGE) Ministry of Environment, 2016[155]. (DESCRIPTION)

Project Description: Japan has long recognized the importance of coastal forests for disaster risk management, with examples of using forest protection to prevent coastal damage in as early as the 17th century. With the implementation of Japan's Forest Law in 1897, this protection was formally conveyed with the creation of Reserved Forests, specifically protected for their disaster risk management functions. On March 11, 2011, Japan was struck by an earthquake, tsunami and subsequent nuclear disaster. Post-disaster, it was documented that structures such as engineered sand embankments or tidal dykes near coastal forests were better preserved and resulted in increased protection to nearby communities, by decreasing wave energy and blocking debris. Coastal forests without such barriers or without deep enough root structures, thus being uprooted by the earthquake, were less suited to withstand the tsunami's force and in some cases actually increased damage.

After the disaster, Japan used these lessons learned to prioritize green-gray infrastructure as part of recovery policies and planning. Japan's NBSAP (2012-2020) stresses the importance of conserving and restoring ecosystems for reducing disaster risk, established with lessons learnt from this disaster. Eco-DRR and green-gray infrastructure are further mainstreamed nationally in the following policies:

The Fundamental Plan for National Resilience, which states the government's intention to "promote ecosystem-based disaster risk reduction according to the characteristics of each region by assessing the disaster-preventing/mitigating functions of ecosystems, such as coastal forests and wetlands, during disaster events, as well as other functions provided during non-disaster times".

The National Spatial Planning policy of Japan, as well as the National Land Use Plan, both set out to "promote green infrastructure that utilises diverse functions of natural environment in social infrastructure development and land use, towards developing sustainable and attractive national land and local communities."

Ecosystem services restored or conserved: Coastal forests conserved for protection from extreme weather events (tsunamis).

Conventional engineering approach: The use of conventional engineering approaches varied by region. Some of the approaches adopted include breakwaters, dikes, seawalls and the use of tsunami debris to elevate the ground and enhance tree root stabilization.

What makes this a good green-gray example? Japan's long history of ecosystem-based disaster risk management, mainstreamed as national commitments to international frameworks as well as national policies, has triggered leadership and local action on green-gray infrastructure in the country. National and local governments are working together to disseminate information on best practices for achieving the most effective coastal forests for disaster risk reduction.

155 Ministry of Environment (2016). Protection Forests (Case 3): Disaster Prevention and Mitigation through Conservation and Revitalization of Ecosystem in Ecosystem-based Disaster Risk Reduction in Japan p 13. Tokyo: Nature Conservation Bureau, Ministry of Environment. 18 pp. https://reliefweb.int/sites/reliefweb.int/files/resources/eco-drr-1.pdf

CASE STUDY 36:
PRIORITISING GREEN-GRAY INFRASTRUCTURE IN LOCAL REGULATORY FRAMEWORKS: CHESAPEAKE BAY LIVING SHORELINE LAWS AND MIAMI'S SUSTAINABLE BUILDINGS PROGRAM

Location: Maryland, USA, and Miami, USA

Project Proponent: State and local governments

Ecosystem services conserved or restored: Coastal marshes for flood protection.

Conventional engineering approach: Some of the conventional infrastructure approaches used in Chesapeake Bay include the beneficial use of dredged material, marsh sills and breakwaters.

Challenge: Coastal protection | **Land use type**: Multiple | **Setting**: Coastal

COASTAL PROTECTION

COASTAL

Project Description: At the local level, policymakers can mainstream the use of green-gray infrastructure approaches by prioritizing the approach in local ordinances and regulations.

In Maryland, with the goal of mainstreaming the use of nature-based solutions to help protect communities and local economies from climate change, the state government designed the "Resiliency through Restoration" initiative. As part of this Initiative, the Maryland Department of Natural Resources provides financial and technical assistance to local government and non-profit partners through a state-funded grants program. Technical assistance includes project identification, design of climate-resilient restoration practices, and implementation guidance and training. Maryland adopted this approach into a regulatory approach with the *New Tidal Wetland Regulations for Living Shorelines* (Maryland Department of Environment, 2013[156]), which mandates that improvements to protect a person's property against shoreline erosion must consist of marsh creation or other nonstructural shoreline stabilization measures that preserve the natural environment unless a waiver is obtained.

Across the United States, another example of mainstreaming green-gray infrastructure into local regulatory frameworks is demonstrated by Miami-Dade County's Sustainable Buildings Program. As mandated by Sections 9-71 through 9-75 of the Code of Miami-Dade County ("Standards for Construction of Country Buildings, Roads, Bridges and Causeways") green building standards and practices must be incorporated into the planning, design, construction, management, renovation and maintenance of local infrastructure. By incorporating the mandate for sustainable construction standards in local regulations and regulatory agencies, policymakers are able to mainstream green-gray approaches to support the local economy, reduce carbon emissions, and safeguard natural resources.

156 Maryland Department of Environment (2013). New Tidal Wetland Regulations for Living Shorelines Effective February 4, 2013 https://mde.state.md.us/programs/water/WetlandsandWaterways/Pages/LivingShorelines.aspx

HOW CAN GREEN-GRAY INFRASTRUCTURE BE INCLUDED IN POST-COVID STIMULUS PACKAGES?

"We talk of "life before Covid-19," but that life wasn't fair nor was it sustainable – either economically or environmentally. So we have a choice: the world can pursue a recovery that favors the wealthy, runs on fuel that triggers environmental calamity, and holds back women and girls. That path would result in an inequitable, unsustainable future that fails humanity, one ravaged by war, environmental degradation, and pandemics. Or the world can choose a future where everyone has the opportunity to realize their full potential and climate disaster is avoided. In that future, humanity's power would be unleashed—making us all richer, safer, and healthier—and the planet would be saved." – Dr Rajiv Shah, Rockefeller Foundation, 2020[157]

Global, national and local policymakers have a responsibility now more than ever before to increase inter-sectoral collaboration in addressing the linkages between economic recovery, community resilience, and both human and ecosystem health, thereby protecting the ecosystem services that safeguard human health and societal resilience. As countries and communities prepare plans and funding packages in response to the COVID-19 pandemic, we have the opportunity to "build back better" by prioritizing green-gray infrastructure solutions as part of a green economic recovery. **The following principles of recovery have been prepared to support investing in sustainable and resilient infrastructure and are endorsed by the Green-Gray Community of Practice.**

157 Shah, R. (2020). $1 Billion for a Green and Equitable Recovery. [Weblog] https://www.rockefellerfoundation.org/blog/1-billion-for-a-green-and-equitable-recovery/

Investing in Sustainable and Resilient Infrastructure
"Principles for Recovery"

1. Decisions on infrastructure spending for post-COVID-19 recovery should begin with strategic planning that is aligned with the 2030 Agenda for Sustainable Development and the Paris Agreement, and considers systemic linkages between sectors and across space and time.

2. To avoid future crises, infrastructure should ensure resilience through integrated, systems-level planning and built-in flexibility and redundancy.

3. To rapidly revive employment, infrastructure investments should support all levels of enterprise (including the informal sector), involving collaboration with subnational institutions.

4. Economic considerations should be balanced with investments in social infrastructure to promote health, wellbeing and gender equality - bringing wider benefits to communities.

5. Prioritizing natural infrastructure will help reduce emissions, deliver essential services (such as water and sanitation), protect people and assets from hazards and support renewed increases in economic activity.

6. Infrastructure investments, including those in digital infrastructure, should facilitate new sustainable lifestyles, patterns of mobility and modes of operation in both urban and rural areas post COVID-19.

7. New infrastructure assets and development sites may not be necessary where existing infrastructure can be rehabilitated and retrofitted, or where using previously developed land can fulfil the same needs.

8. Any physical construction should not compromise ecosystems and biodiversity, erode human rights, or destabilize politically fragile contexts.

9. In the context of supply chain disruption risks, infrastructure systems should use sustainable technologies and local, green materials to enhance resource efficiency, create local jobs and provide culturally appropriate solutions.

10. In striving for a quick economic turnaround, infrastructure decisions should not bypass consultation and transparency processes, undermine environmental safeguards, or generate unsustainable debt.

Appendices

APPENDIX 1. OTHER APPROACHES SIMILAR TO GREEN-GRAY INFRASTRUCTURE

There are many terms and concepts connected to green-gray infrastructure. Here we mention a few key terms, along with their similarities and differences to green-gray infrastructure.

Ecosystem-based Adaptation encompasses a broad set of approaches to adapt to climate change, that include the management of ecosystems and their services to reduce the vulnerability of human communities. The CBD defines EbA as "*the use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people to adapt to the adverse effects of climate change*"[161]. Green-gray infrastructure is a type of ecosystem-based adaptation that includes conventional gray infrastructure.

A number of key products have been produced detailing guidance on the overall EbA approach, including the Friends of EbA (FEBA) *Making Ecosystem-based Adaptation Effective: A Framework for Defining Qualification Criteria and Quality Standards*[162], the *Guidebook for Monitoring and Evaluating Ecosystem-based Adaptation Interventions*[163], as well as the *Guidelines for Designing, Implementing and Monitoring Ecosystem-based Adaptation Interventions*[164].

Ecosystem-based Disaster Risk Reduction (Eco-DRR) is the sustainable management, conservation and restoration of ecosystems to reduce disaster risk, to achieve sustainable and resilient development[165]. Eco-DRR deals with both climatic and non-climatic hazards, such as geological disasters like earthquakes, landslides, and volcanic eruptions.

Nature-based Solutions (NbS) are defined by IUCN as "actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits"[166]. As an umbrella term, NbS encompasses approaches of working with nature, such as ecosystem-based adaptation and ecosystem-based disaster risk reduction. Operational approaches such as EbA and Eco-DRR demonstrate the application of NbS to address a particular societal challenge – in this case, climate adaptation and disaster risk reduction. NbS as an overarching concept is used to support communication and mainstreaming of these different subsets across international multilateral agreements/global frameworks and their audiences.

161 CBD (2010). *Decision X/33. Biodiversity and climate change*. *https://www.cbd.int/decision/cop/?id=12299*

162 Friends of Ecosystem-based Adaptation (FEBA) (2017). *Making Ecosystem-based Adaptation Effective: A Framework for Defining Qualification Criteria and Quality Standards (FEBA technical paper developed for UNFCCC-SBSTA 46).* Bertram, M., Barrow, E., Blackwood, K., Rizvi, A.R., Reid, H., and von Scheliha-Dawid, S. (authors). Bonn, Germany, London, UK, Gland, Switzerland: GIZ, IIED, and IUCN. 14 pp. https://www.iucn.org/sites/dev/files/feba_eba_qualification_and_quality_criteria_final_en.pdf

163 GIZ, UNEP-WCMC and FEBA (2020). *Guidebook for Monitoring and Evaluating Ecosystem-based Adaptation Interventions*. Bonn, Germany Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. 80 pp. https://www.adaptationcommunity.net/download/ME-Guidebook_EbA.pdf

164 Donatti, C.I., Martinez-Rodrigo, M.R., Fedele, G., Harvey, C.A., Andrade, A., Scorgie, S., Rose, C., and Alam. M. (2019). *Guidelines for designing, implementing and monitoring ecosystem-based adaptation intentions*. Virginia, USA: Conservation International. 40 pp. https://www.conservation.org/docs/default-source/publication-pdfs/guidelines-for-designing-implementing-and-monitoring-eba.pdf?Status=Master&sfvrsn=bccddc79_3

165 Monty, F., Murti, R., Miththapala, S. and Buyck, C. (eds.) (2017). *Ecosystems protecting infrastructure and communities: lessons learned and guidelines for implementation*. Gland, Switzerland: IUCN. x + 108pp. https://portals.iucn.org/library/sites/library/files/documents/2017-045.pdf

166 IUCN (2020). IUCN Global Standard for Nature-based Solutions. *https://doi.org/10.2305/IUCN.CH.2020.08.en*

Nature-based Engineering approaches such as **Building with Nature, Engineering with Nature and Ecological Engineering** are types of green-gray infrastructure that include ecosystem restoration and/or conservation but may or may not provide disaster risk reduction and/or climate change adaptation solutions. The terms are often used interchangeably in different contexts.

Building with Nature - an approach to hydraulic engineering that harnesses the forces of nature to benefit the environment, economy and society[167].

Engineering with Nature - the intentional alignment of natural and engineering processes to efficiently and sustainably deliver economic, environmental and social benefits through collaborative processes[168].

Ecological Engineering - the design of ecosystems for the mutual benefit of humans and nature[169].

167 EcoShape (2020). *Building with Nature*. [Website] https://www.ecoshape.org/en/

168 Engineering with Nature (2020). *Home page.* https://ewn.el.erdc.dren.mil/

169 *Ecological Engineering*: the Journal of Ecosystem Restoration https://www.journals.elsevier.com/ecological-engineering

APPENDIX 2. COASTAL GREEN-GRAY INFRASTRUCTURE SITE ASSESSMENT

Coastal site assessment and data collection for green-gray infrastructure project suitability

(1) Site Location

Site Name
Community Name
Longitude
Latitude
Proximity to basic services (e.g., distance to town)

(2) Physical Characteristics

Describe existing community infrastructure –- how are the homes, streets, paths configured?

How does the community get its water?

Draw and label on a map the location of water supply infrastructure (e.g, wells or springs)

What are the risks or limitations that could, or are currently, impacting water security (e.g., saltwater intrusion or drought)?

Does the community have any form of sanitary sewer collection or treatment? If so, describe.

Draw and label on a map the location of sanitary sewer infrastructure (e.g, wastewater treatment).

Draw and label on a map the location of infrastructure or facilities used for disaster risk reduction (e.g., evacuation centers).

Draw and label on a map the location of infrastructure or facilities considered economic or social assets for the community.

Describe wind patterns at the site and how these vary based on the typhoon and monsoon season. Label wind directions during different seasons on a map.

Is there any existing built infrastructure for coastal protection? If so, describe the location, size, type, condition, and identify on a map.

Where is the closest/best available information about local tides?

Where is the closest/best available information about local rainfall (e.g., depth and intensity)?

Describe local geology and soil types. Draw and label on a map, regions with known specific soil and geology characteristics?

What is depth to bedrock at different locations across the site?

In different areas of the site are surface soils more sandy, silty, or clayey?

Draw and label on a map, areas of (1) local erosion, (2) existing drainage channels and names, (3) primary beach access points.

Sketch a profile of the beach.

Site Name

Community Name

(3) Social Characteristics

Number of people/households living in the site

Number of people/households within 40 meters of coastline

Number of people/households living in the community

Primary livelihood

Secondary livelihood

Does the community have an existing disaster preparedness / response system?

- Is there an early warning system? (If yes, identify important elements on a map)
- Are there evacuation maps? (If yes, take photo)
- Does the community conduct evacuation drills?

What is the availability of basic services (e.g., healthcare, transportation, communications)?

Healthcare	Transportation	Communications	Other?

Socio economic checklist			
Would you consider the community:	Yes	No	Notes
Open-minded			
Collaborative			
Easy to work with			
Willing to provide counterpart funds			
Willing to have their staff trained	should be yes to proceed		
Share a common vision with theproject	should be yes to proceed		
Is a community organization:			
Present on site			
Registered			
Have constitution and by-laws			
Have structure			
Have a complete set of officers			
If no existing community organization:			
Does the community express willingness to organize			
Are partners:			
Willing to provide technical/other support and guidance			
Do community members:			
Have access to financial services (normal times)			
Have access to after-disaster relief (finance, housing, etc.)			
Have insurance			

Site Name

Community Name

(4) Ecosystem characteristics –

Ecosystem assessments establish the composition and structure of the ecosystem, its status and health provides baseline information for informed decision-making for project suitability. Such assessments also allow for the identifying priority conservation areas.

Obtain relevant geo-referenced information of boundaries of different ecosystems.

Does the community have an existing coastal resource management plan?

Ecosystem	Location (& draw on map or track on GPS)	Condition	Existing Management	Historic Information
Forests				
Mangroves				
Salt marshes				
Inter-tidal flats				
Seagrass				
Coral Reefs				
Other				
Other				

Using the geo-referenced data, draw maps of areas of ecosystems seen.

Species inventory

Obtain relevant geo-referenced information such as where which species was seen, breeding sites of animal species).

For species, the method used (such as quadrats[170], transects[171] and opportunistic sampling[172]) will determine the information collected, but basic information – such as the following – is needed.

170 Quadrats (traditionally square frames) sampling is a method by which organisms in a certain proportion (sample) of the habitat are counted and used to estimate the abundance, density and distribution of herbaceous plants or seedling.

171 Systematic sampling along a randomized transect – usually a line.

172 Non-random sampling.

Survey area:			Site ID:			
Survey team member:			Date:			
Name of species	Time observed	Number observed	Type of observation (visual, auditory, signs)	Habitat	Latitude	Longitude

Ecosystem services[173]

Ecosystem services include provisioning services, supporting services, regulating services and cultural services (see below)

Provisioning services related to coastal ecosystems:

Service element (add as needed)	Ecosystem1 (name)	Ecosystem2 (name)	Ecosystem3 (name)
Lime			
Food fish Ornamental fish			
Curios/ornaments			
Fruits/vegetables Timber/fuelwood			
Medicines			
Sand			

Supporting services related to coastal ecosystems:

Service element (add as needed)	Ecosystem1 (name)	Ecosystem2 (name)	Ecosystem3 (name)
Sustaining biodiversity			
Primary production			
Nutrient cycling			

173 Adapted from Miththapala, S. (2009). *Incorporating environmental safeguards into disaster risk managemen*t. Volume 3: Tools, techniques and other resources. Colombo: Ecosystems and Livelihoods Group, Asia, IUCN. viii+142 pp.

Regulating services related to coastal ecosystems:

Service element (add as needed)	Ecosystem1 (name)	Ecosystem2 (name)	Ecosystem3 (name)
Carbon sequestration			
Prevention of coastal erosion			
Protection from storms and tidal surges			
Flood control			
Pollution control/treatment			

Cultural services related to coastal ecosystems:

Service element (add as needed)	Ecosystem1 (name)	Ecosystem2 (name)	Ecosystem3 (name)
Coastal recreation and tourism			
Education and research			
Sustenance of traditional knowledge			

Assessment of the threats to coastal biodiversity[174]:

Major threat	Contributory factors	Indicators to assess severity
Habitat deterioration/ degradation	Reclamation/transformation	Area reclaimed (ha/acres/km^2).
	Clearing of vegetation (mangrove and scrubland)	Area cleared (ha/acres/km^2).
Pollution	Organic pollution	Levels of DO[175], BOD[176], COD[177]. Oil spills/leakages (amount leaked/ spilled, areas affected, animals (fish, birds, etc.) affected.
	Chemical effluents	Nitrate and phosphate levels, algal blooms. Levels of heavy metals, biocide residues, indicator species (i.e., dragonflies, molluscs, annelids, surface insects, micro-crustaceans etc.).
	Sewage disposal	Coliform bacteria[178], algal blooms.
Direct loss/ Exploitation	Poaching	Information gathered from forest rangers (frequency of incidences). Number of traps observed in the wild. Frequency of gunshots heard at night. Bushmeat available in surrounding areas.
	Removal of vegetation	Number of large trees cut (based on remaining stumps). Information gathered from the Department of Wildlife/Forest Department (frequency of incidences).
	Over-exploitation of live animals and plants for commercial trade/ornamental purposes/medicinal purposes/ consumption	Direct field observations of species collections. Data gathered from collectors (number of individuals collected, weight, etc.) Data gathered from government departments.
Spread of invasive alien species	Introduction and spread of invasive alien flora	Area of invasion (ha/acres/km^2)
	Introduction and spread of invasive alien fauna	Population numbers if IAS fauna. Reduction of native fauna due to predation (area).
Natural hazards	Floods	Number of dead animals.
	Storms/hurricanes	Number of dead animals, vegetation destroyed (area/number of trees).
	Drought	Number of dead animals and trees.

174 Op. cit

175 Dissolved oxygen

176 Biological Oxygen Demand is a measure of the amount of oxygen required to remove waste organic matter from water

177 Chemical Oxygen Demand quantifies the amount of oxidizable pollutants found in surface water

178 The presence of coliform bacteria are an indication that there is fecal matter in the water.

(5) Description of climate change problems or threat that the GGI concept will need to address

Describe any negative impacts caused by climate events/trends (e.g., sea level rise or extreme weather events)

Climate Event/Trend	Describe Negative Impact (if any)	Impact Location (& draw on map)	Number of Affected Households	Threats	Other
Sea Level Rise					
Extreme Weather Event					
Flooding					
Storm Surge					
Other					
Other					

APPENDIX 3. STAKEHOLDER ANALYSIS TEMPLATE AND TOOLS

Stakeholder Mapping Worksheet

Stakeholder	Project/ Output	Impact How much does the project impact them? (low, medium, high)	Influence How much influence do they have over the project?	Interests What issues are important to the stakeholder?	Role How could the stakeholder contribute to or block the project?	Strategy for engaging the stakeholder	Contact person	Notes
Government (national, i.e. ministries/agencies)								
Government (local)								
National non-governmental agencies (i.e. NGOs)/ national civil society organizations (CSOs)								
Local community members, groups and businesses, community-based organizations (CBOs)								
Private sector (e.g. contractors, developers, landowners, impact investors, technical experts)								
Financial institutions and funding sources								
International organizations (i.e. INGOs), Inter-governmental organizations								
Academics								

Tools for stakeholder analysis