COMMISSION FOR ENVIRONMENTAL COOPERATION

Nature-based Solutions to Address Flood Risks in Coastal Communities

Monitoring Efficacy

Report Series:

Co-Benefits

Retrofitting Existing Infrastructure

Monitoring Efficacy: Proposed Methodology and Indicators

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Abstract

Flood-risk management is a major concern for coastal urban and peri-urban areas, particularly when considering sea-level rise caused by climate change. Nature-based solutions (NBS) have the potential to meet many flood-risk management objectives while also providing social, environmental, and economic co-benefits. However, the uptake and implementation of NBS are limited by perceived uncertainty surrounding their efficacy. To advance the implementation of NBS, it is necessary to evaluate their impact through a process that can be continually improved upon and built to enhance or generate new foundational knowledge, and to formalize the use of NBS into policy instruments. Monitoring NBS to demonstrate successes and any lessons learned is one of the available tools for decision makers to manage and alleviate uncertainties associated with NBS.

This document supports the uptake of NBS in coastal communities across Canada, Mexico, and the United States, by providing decision makers with practical information and guidance related to monitoring NBS. The overall monitoring process, as well as administrative and technical considerations for developing a monitoring plan, are outlined, synthesizing information from key reference documents and guidelines. Practical applications of the monitoring process are illustrated through case studies. The impact of site setting and climate change on monitoring are summarized, and a brief comparison of the differences between monitoring conventional gray (i.e., hard) infrastructure and NBS is provided. In addition, a list of potential opportunities to help decision makers fill gaps and alleviate barriers to monitoring NBS is provided as a key takeaway of the report.

Executive Summary

Coastal communities across Canada, Mexico, and the United States are vulnerable to coastal hazards, including both flooding and erosion. Coastal flood risks are projected to intensify, due to increasing population densities near the coastline as well as the effects of climate change. Nature-based solutions (NBS) provide an alternative to conventional approaches to flood-risk management (FrM), such as dikes, levees, and seawalls. Conventional approaches to FrM tend to rely on structural methods and 'hard' materials, and may undervalue environmental, social, and economic co-benefits. In contrast, NBS rely on the use of natural or nature-based materials and processes, while also providing social, environmental, and economic co-benefits. Monitoring is an essential component of implementing NBS, with varied goals and numerous potential benefits, including:

- Assessment of flood-risk management performance;
- Assessment of co-benefits;
- Assessment of unintended impacts;
- Informing adaptive management;
- Compliance with project requirements (e.g., funding requirements);
- Knowledge sharing (e.g., research and guidance development);
- Improving accountability and public buy-in;
- Enabling the comparison of flood-risk management solutions; and
- Capacity building and job creation.

Despite the numerous benefits, there are several barriers and information gaps that hinder monitoring initiatives related to NBS, which may be broadly broken into four categories:

- Social/attitudinal (e.g., perception of monitoring as an unnecessary cost);
- Technical (e.g., lack of trained professionals or poor data distribution);
- Environmental (e.g., long-term variability of natural systems); and
- Institutional (e.g., lack of funding or regulatory hurdles).

This document is intended to support decision makers and FrM professionals in the broader implementation and monitoring of NBS. More specifically, it aims to address known barriers and information gaps, synthesize existing information, and provide practical guidance to plan, evaluate, and implement meaningful monitoring programs associated with NBS. The document does not provide in-depth technical guidance, nor does it provide an exhaustive review of the rapidly growing body of literature on monitoring methodology and NBS.

<u>The Monitoring Process</u>
Monitoring activities and the development of an adaptive management plan should start at the initial (scoping) stages of the NBS project. The monitoring program should be designed to be thorough and rigorous, but flexible enough to allow for any adaptation deemed necessary over the project's life. The overarching planning phases for monitoring mirror those for the implementation of NBS in general, and are as follows:

1. Scoping
2. Planning
3. Design
4. Implementation
5. Reporting
6. Evaluation

Monitoring activities should preferably occur throughout the project's life and include the collection of historical, baseline, compliance, and operational data. Notably, the collection of operational data is of particular importance for adaptive management of NBS to ensure the performance of flood-risk management and confirm that co-benefits have been realized. Accordingly, monitoring parameters and metrics should be directly linked to the performance objectives of the project. In addition, long-term operational data will help to provide data and knowledge for future projects.

Adaptive management is central to the long-term success of NBS and allows for continuous improvement of the NBS project as a whole, and of the monitoring program itself. Monitoring is foundational to providing the data needed to assess the performance of NBS and determine if/when interventions are needed.

<u>Administrative and Technical Considerations</u>
Developing and implementing a monitoring plan involves consideration of many administrative and technical considerations. Administrative considerations include such tasks as project scoping, definition of roles and responsibilities, defining data access and dissemination, and identifying sources of funding. Technical considerations include planning activities, such as establishing monitoring indicators, metrics and methods, techniques for monitoring, determining the necessary physical and temporal scales of monitoring, and developing a data analysis and reporting program. These considerations are discussed in detail within the report, and are briefly summarized below:

- <u>Scoping</u>: At this stage, the project team must identify needs, priorities, and trade-offs, as well as a theory of change.
- <u>Roles and responsibilities</u>: It is important to identify team members and stakeholders early in the planning process. Stakeholders and organizations to include in the monitoring plan development may include (amongst others): affected community members, Indigenous leaders, local community groups, nonprofits, government representatives, the academic community, and industry members.
- <u>Funding</u>: Funding is one of the major limiting factors for monitoring projects. It is therefore crucial to identify funding needs and develop a funding strategy early on. Potential funding sources include international finance institutions, government institutions, nonprofit organizations, and private sources.

- Indicators and metrics: Performance indicators for NBS should include engineering performance (such as flood-risk management) as well as ecological, social, and economic indicators. Selected indicators should be measurable, achievable, affordable and meet the constraints of resource availability. Metrics should be set to define project targets (or goals), including metrics that indicate when intervention is required.
- Methods and techniques: Measurements can be direct or indirect and provide qualitative, semi-quantitative or quantitative evaluation metrics. Standardized methodology and indicators are proposed and outlined in the associated guidance document: *Monitoring Efficacy: Proposed Methodology and Indicators.*
- Physical scale and locations: The physical scale of the overall monitoring program should be adjusted on a project-specific basis, depending on the size of the intervention, the project objectives and uncertainties, the expected scale of impact, and available funding for monitoring.
- Temporal scale and frequency: Monitoring data collection may occur on four characteristic frequencies: continuous, demand-driven, one-off, and periodic collection. The frequency and temporal scale (length) of monitoring should also be adjusted on a project-specific basis to meet overall project needs (e.g., funding constraints and physical characteristics of the area), including the adaptive management plan.
- Data analysis: Data analysis procedures will differ, depending on the type of monitoring data collected. Regardless, it is crucial to set quality assurance and quality control procedures early in the development of the monitoring plan. Procedures should include storing all relevant information and metadata, as well as documenting all forms of data manipulation.
- Data access and dissemination: Data access and dissemination should be considered during the scoping and planning stages of the monitoring program. Where possible, data should be made publicly available in widely accessible formats. There are multiple ways of presenting and disseminating data and results, including through scientific papers, reports, conference presentations, webinars, social media, data portals, and interviews.

The Efficacy of Monitoring NBS for Varying Site Settings and Climate Change

Variable environmental and site conditions, as well as changing climatic conditions, may impact the quality and reliability of monitoring results. Potential site characteristics that may impact the efficacy of monitoring can include limited tidal windows or daylight hours, excess vegetation growth or coverage, ice coverage, debris accumulation, storm damage, vandalism of equipment, limited proximity to resources (such as in remote areas), and overall site access. Climate change may also impact the efficacy of the monitoring programs through impacts to the functioning of monitoring equipment and techniques, and by shifts in baseline conditions and performance indicator targets. Monitoring is essential for understanding why and how site-specific conditions are changing and will lead to a better understanding of the impacts of climate change for informing future interventions.

A multi-year adaptive management approach to monitoring, combined with investigation of potential climate change impacts, is recommended to assist with the management of climate change effects. This long-term plan should focus on establishing milestones and identifying tipping points to when the monitoring plan may need to be revisited and modified, as well as if performance targets and baselines should be reassessed.

Opportunities and Future Initiatives

To help alleviate known data gaps and barriers, potential opportunities and future initiatives that may be implemented by decision makers are outlined in detail within the report. Notably, the creation of additional, sustained funding streams for long-term monitoring and adaptive management would be particularly impactful in removing barriers to implementation. Other key opportunities are briefly summarized below:

- Develop and/or recognize specific technical standards and guidelines to monitor the use of nature-based solutions.
- Develop public informational sessions and accessible materials on monitoring and adaptive management.
- Build technical capacity (through training programs) for local community members and professionals, particularly related to remote monitoring practices.
- Develop a community of practice to encourage knowledge-sharing.
- Work to make historical, existing, and future data and case studies publicly available in a recognized, centralized location.
- Emphasize (or mandate) monitoring, adaptive management, and public data distribution within guidelines, funding requirements, permits, applications, and Requests for Proposals.
- Simplify permitting processes (i.e., provide expedited processes) for the construction, monitoring, and adaptive management of nature-based solutions.
- Create additional funding streams for projects involving long-term monitoring, data analysis and data dissemination, and adaptive management.

Preface

The Commission for Environmental Cooperation (CEC) is a trilateral organization that facilitates cooperation between Canada, Mexico and the United States to conserve, protect and enhance the North American environment. In 2021, the CEC initiated a project to help guide the broader implementation of nature-based solutions (NBS) for coastal flood-risk management (FrM) in North American communities. The initiative may be broadly partitioned into three phases, as follows:

1. **An intersectoral workshop series** to lay the foundation for a North American community of practice, convene practitioners to scope needs and opportunities, and identify barriers to implementation of NBS.
2. **A set of guidance documents** to address knowledge gaps and further develop opportunities identified during the workshop series, and guide best practices related to implementing NBS.
3. **Webinars** to improve the uptake and usage of the guidance documents.

As part of the first phase of the project, DHI Water and Environment Inc. (DHI) was engaged to develop and host the workshop series. The workshop series consisted of seven sessions held over a five-week period in May and June 2022. The sessions focused on the following topics:

- 1A and 1B: Nature-based Solutions Co-Benefits
- 2A and 2B: Retrofitting Existing Infrastructure Using Nature-based Solutions
- 3A and 3B: Monitoring Efficacy of Nature-based Solutions
- 4: Summary Workshop

The workshop series saw the participation of 19 expert speakers and 76 participants, spanning a range of academia, private industry, government, and nongovernmental organizations from across North America. Group activities were included in the workshop series to build community, develop ideas, solicit feedback, and identify gaps and opportunities. Group activities included discussions of six different case studies, four sets of collaborative online activities, and two interactive question series. The participation and idea development from participants with diverse backgrounds and experiences provided a strong foundation for building both a community of practice and guidance documents on NBS in North America.

The second phase of the project involved addressing knowledge gaps identified in the workshop series through the development and publication of a comprehensive set of guidance documents on NBS within an urban and peri-urban North American context. This document forms part of a series of guidance documents, that are intended to be referenced as a whole. The guidance documents include:

- Co-Benefits
- Retrofitting Existing Infrastructure
- Monitoring Efficacy (this document)
- Monitoring Efficacy: Proposed Methodology and Indicators

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1 Introduction

Flood-risk management (FrM) infrastructure is relied upon across Canada, Mexico, and the United States to protect urban and rural areas alike, from flooding and erosion. Failure of these infrastructure systems can be catastrophic. For example, failure of the levee system in New Orleans (United States), during Hurricane Katrina in 2005, led to widespread flooding and destruction. Over 1,100 people died, more than 400,000 were displaced, and property damage exceeded billions of dollars (ASCE 2007). Coastal flood risks are projected to further intensify across North America over the coming decades due to increasing population densities near the coastline and the effects of climate change (Bush and Lemmen 2019; EPA 2017; INECC 2019).

Existing FrM infrastructure relies largely upon structural methods, like dikes, levees, and seawalls. Such conventional methods have a long history of application, and are well represented in scientific literature, guidelines, and standards. Because of their long history of use and extensive literature on design and performance, there is generally an underlying public trust that these techniques will perform as intended. By contrast, Nature-based solutions (NBS) rely on natural materials and processes or nature-based (hybrid) features, combining natural and structural components to provide flood-risk management, while also providing social, environmental, and economic co-benefits (Bridges et al. 2021b; Tien et al. 2020). Due to the complexity of working with natural processes, usage of NBS provide a variety of new design, monitoring, and management challenges. Definitive design guidance and standards are still being developed, but significant advancements have recently been realized (e.g., Bridges et al. 2021b; Doswald et al. 2021).

The uptake and implementation of NBS are limited by, among other factors, the perceived uncertainty concerning the efficacy of NBS within the context of:

- Extreme events such as severe storms, hurricanes, or flooding;
- Varying physical environments which may not allow for a standardized application of NBS;
- Consideration of temporal variations in performance throughout the year; and
- A changing climate.

Effective adaptive management and monitoring are key to alleviating these uncertainties.

Adaptive management is a structured and iterative approach, which enables users to continuously revise management measures (such as maintenance) to reflect changing conditions and variable project performance (Bridges et al. 2021b). Adaptive management is an integral and cross-cutting theme for the implementation of NBS (Bridges et al. 2021b; Silva Zuniga et al. 2020; World Bank 2017). Regular, long-term monitoring forms the foundation of effective adaptive management and future implementation of NBS.

This document aims to support the uptake of NBS in coastal communities by providing decision makers with practical information and guidance related to monitoring the efficacy and impacts of NBS and by addressing several previously identified data gaps and barriers. It forms part of a comprehensive set of guidance documents developed by DHI Water and Environment Inc. (DHI) on behalf of the Commission for Environmental Cooperation (CEC), which are intended to be referenced as a whole as support in implementing NBS for coastal flood-risk management across North America. The guidance documents include:

- Co-Benefits
- Retrofitting Existing Infrastructure
- Monitoring Efficacy (this document)
- Monitoring Efficacy: Proposed Methodology and Indicators

1.1 Objectives and Scope

An intersectoral workshop series was hosted by DHI in spring 2022 as part of an ongoing project by the CEC to support the broader implementation of NBS for coastal flood-risk management in North American communities (DHI 2022). The workshop series consisted of seven sessions, with 76 attendees from Canada, Mexico, and the United States. Two of the sessions focused specifically on monitoring the efficacy of NBS. During these sessions, attendees participated in idea generation and identification of data gaps, barriers, and opportunities related to monitoring NBS.

This document addresses knowledge gaps and barriers identified in the workshop series, synthesizes existing information, and provides practical guidance to plan, evaluate, and implement meaningful monitoring programs associated with NBS used to address flood risks in coastal communities. It is part of a comprehensive set of guidance documents, which are intended to support decision makers in implementing NBS for coastal flood-risk management across North America.

More specifically, this document aims to:

- Provide a value proposition for investment in monitoring;
- Summarize key administrative considerations for monitoring plans, including roles and responsibilities, funding challenges, and data access and dissemination;
- Summarize key technical considerations for monitoring plans, including indicators, methods, varying physical environments, and time and spatial scales;
- Provide case studies related to the role of monitoring in assessing the efficacy, performance, and resilience of NBS; and
- Where possible, address gaps and barriers identified during the previous intersectoral workshop series.

This document is intended to provide guidance and evidence that will support decision makers in the broader implementation and monitoring of NBS to address coastal flood risks in coastal communities. The guidance provided herein is intended to assist decision makers in all stages of the project process, from conceptualization through design and operation. The document does not provide in-depth technical guidance, nor does it provide an exhaustive review of the rapidly growing body of literature on monitoring methodology and NBS.

For further reading material and key documents on monitoring NBS, the reader is referred to Section 1.4.

1.2 The Value of Monitoring Nature-based Solutions

As part of the CEC workshop series on NBS (DHI 2022), experts from across Canada, Mexico, and the United States were asked to describe the value of monitoring NBS. Responses were grouped into the broad categories in Box 1.

Box 1. Activities which benefit from or require monitoring input

- **Assess FrM Performance**
- **Assess Unintended Impacts**
- **Comply with Project Requirements** (e.g., funding requirements)
- **Improve Accountability and Public Buy-In**
- **Capacity Building and Job Creation**
- **Assess Co-Benefits**
- **Inform Adaptive Management**
- **Knowledge-Sharing** (e.g., research and guidance development)
- **Enable the Comparison of FrM Solutions** (e.g., compare NBS against conventional structural methods)

A major known barrier (see Section 1.3) to NBS implementation is related to perceived uncertainty about performance over time in diverse settings and at various scales. Monitoring and adaptive management help to ensure that any deficiencies are proactively managed, reducing potential risks that FrM performance is not met or that intended co-benefits are not realized. Broad dissemination of that data further helps to improve public buy-in and supports future research on NBS. Knowledge-sharing may lead to new insights on NBS functioning and ultimately to the development of new technical guidance for future NBS implementation (Connop et al. 2016; Raymond et al. 2017). In addition, knowledge-sharing may enable evidence-based policy changes.

In practice, the scope and scale of monitoring initiatives need to be tied to the overall project needs, project risks, and funding limitations. Consequently, the value of monitoring depends on the specific project details and the type of NBS employed. Experts from the workshop series (DHI 2022) were also asked about the importance of monitoring over a range of FrM solutions. The experts indicated that monitoring was meaningful for all FrM projects; however, it was more important for projects which rely more on natural and nature-based features and thus that sit farther on the 'green' end of the 'green-gray' spectrum. The *Retrofitting Existing Infrastructure* guidance document provides a definition and additional information on the 'green-gray' spectrum.

1.3 Existing Data Gaps and Barriers to Monitoring

Box 2 provides a summary and expansion of barriers identified during the CEC's workshop series related to monitoring the efficacy of NBS (DHI 2022). Notably, there appears to be a consensus amongst practitioners that monitoring and adaptive management are fundamental to the effective implementation of NBS for flood-risk management. Despite this, there also appears to be an underlying perception amongst the public and some decision makers that monitoring is optional, or rather that it is not fundamental. This perception materializes itself in the lack of funding availability for long-term monitoring and adaptive management. Where funding does exist, it often only covers a short period following construction, typically of one to five years. In addition, integration of monitoring and adaptive management into mandatory project requirements appears to be lacking (DHI 2022).

This report aims to alleviate several of the identified data gaps and barriers where possible (as identified in Box 2), or, where not possible, to identify methods to address them through further initiatives (see Section 6). Barriers that are a focus of this report include social/attitudinal barriers and technical barriers which may be (in part) alleviated through additional information or guidance. Barriers that require additional action to be taken by decision makers (such as the establishment of funding sources) have not been addressed.

Additional data gaps and barriers related to NBS co-benefits, and retrofitting NBS to existing infrastructure, are outlined in the associated guidance documents: *Co-Benefits* and *Retrofitting Existing Infrastructure*. An extensive list of knowledge gaps from different perspectives (e.g., practitioner, scientific, community members, and private sector) is also provided in Dumitru and Wendling (2021).

Box 2. Barriers to monitoring the efficacy of NBS

Type of Barrier	Focus (this report)
Social / Attitudinal	
• Perception of monitoring as extra or unnecessary cost	✓
• Distrust in qualitative data and participatory monitoring	✓
Technical	
• Lack of integration of monitoring and adaptive management into planning, design, and implementation phases	✓
• Lack of definitive monitoring guidance, resulting in inconsistent approaches	✓
• Need for expert involvement across disciplines to effectively monitor co-benefits (e.g., involving social science experts)	✓
• Lack of trained and qualified professionals	○
• Personnel capacity and availability	○
• Specialized and costly equipment needs	○
• Long-term logistics challenging to manage	✓
• Physical access constraints	○
• Poor data distribution (e.g., a lack of transparency)	✓
• Incomplete or missing data (e.g., a lack of baseline data)	✓
• A lack of up-to-date, useable case studies and inventories (demonstrating both successful and unsuccessful outcomes)	✓
Environmental	
• Seasonal and long-term variability of natural systems	○
Institutional	
• Lack of funding	○
• Existing programs lacking mandatory monitoring requirements	○
• Focus on short-term horizons as part of existing programs	○
• Regulatory hurdles which impose timeline, funding, and access constraints	○
• Conflict between jurisdictional or agency requirements	○
• Corruption	○

Source: Adapted from barriers identified as part of the intersectoral workshop series on NBS hosted by DHI on behalf of the CEC in spring 2022.

1.4 Further Reading

Numerous publications were reviewed and referenced in preparing this report. These documents—as well as the CEC's workshop series on NBS—served as the foundation to develop the guidance, processes, and considerations outlined in this report. Key reference materials are listed below and may provide the reader with further information and technical guidance.

- Ev*aluating the Impact of Nature-Based Solutions - A Handbook for Practitioners,* European Commission (Dumitru and Wendling 2021)
- *Increasing Infrastructure Resilience with Nature-based Solutions (NbS): A 12-Step Technical Guidance Document for Project Developers*, Inter-American Development Bank (IDB) (Silva Zuniga, 2020)
- *International Guidelines on Natural and Nature-based Features for Flood Risk Management,* United States Army Corps of Engineers (Bridges et al. 2021b)
- *Nature-Based Solutions for Coastal and Riverine Flood and Erosion Risk Management*, Canadian Standards Association (CSA) and National Research Council of Canada (Vouk et al. 2021)

2 The Monitoring Process

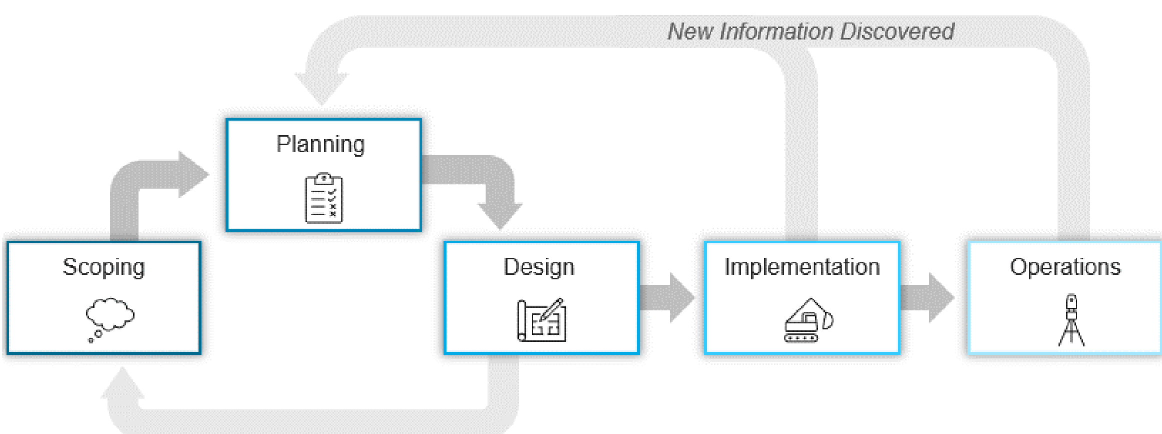
Given the intrinsic dynamic nature of NBS, one of the key principles for a successful NBS project is to expect change and to manage adaptively (Bridges et al. 2021b). Monitoring is therefore a vital component of the NBS project cycle. This section provides an overview of the overall implementation process for NBS, details the planning phases for monitoring specifically, outlines the different stages of monitoring, and describes the relationship to adaptive management. Case studies are included throughout this section to illustrate key concepts related to the design and implementation of monitoring initiatives.

2.1 Project Phases for Implementing NBS

A typical framework for the development of a NBS project encompasses five main phases: scoping, planning, design, implementation, and operations (Figure 1) (Bridges et al. 2021b). These phases are not a linear process, but rather cyclical. The cyclical process promotes continuous reassessment and updates to plans at any point along the project development.

For conventional FrM projects, monitoring is normally considered to be a part of the operations phase; however, for NBS, it is crucial that monitoring plans and performance assessment requirements are established early in the project cycle, during scoping and planning stages. This also includes starting the monitoring program to acquire sufficient baseline data prior to project implementation.

Figure 1. Framework for development of a NBS project



Source: adapted from Bridges et al. 2021b

2.2 Planning Phases for Monitoring NBS

Monitoring may be used to track the implementation process, providing feedback to the adaptive management, and to evaluate NBS performance against expected results, measuring progress towards pre-defined targets and changes from the baseline (Dumitru and Wendling 2021). NBS monitoring programs may also lead to a host of other benefits, as described in Section 1.2.

Designing a monitoring and adaptive management plan should start at the scoping stages of the project. De Looff et al. (2021) propose a comprehensive framework for the development of an adaptive management plan which includes key actions, including defining scope and performance metrics, developing funding strategies, designing a monitoring program, and identifying adaptive actions and scenarios. In summary, the overarching phases for monitoring are:

1. Scoping: Identify the scale and scope of the adaptive management plan, prioritize actions, define rightsholders and stakeholders, and develop funding strategies.
2. Planning: Identify parameters of concern, establish performance metrics, take inventory of existing monitoring networks, identify data gaps, and identify potential resources and staff to conduct the monitoring program.
3. Design: Develop a monitoring program (including baseline monitoring) prior to project implementation, determine the type of monitoring suitable for each performance metric, establish data collection and data management protocols.
4. Implementation: Conduct regular construction surveys and inspections, provide periodic monitoring and evaluation of the results.
5. Reporting: Review, synthesize and report data, communicate findings with the project team and contractor during construction and operations phases and inform other stakeholders.
6. Evaluation: Provide periodic monitoring and evaluation of the results, evaluate the NBS performance, propose modifications to the NBS (adaptive management) and reassess and adapt the monitoring program.

The monitoring program design should be thorough and rigorous but flexible enough to allow adaptation throughout its lifetime and also as the climate changes. The monitoring program must also be practical and economical, so that it does not become onerous to fund or to implement over time (Palinkas et al. 2022). A well-defined monitoring plan has enormous benefits in improving communication among the project team and in establishing a systematic performance evaluation (see Case Study 1).

Notably, the project's scale and complexity, its opportunities for funding, and other project particulars will dictate the level of effort that must be invested in monitoring. Administrative and technical considerations for developing a monitoring plan are detailed in Section 3 and Section 4, respectively.

2.3 Monitoring Stages

Monitoring should be incorporated throughout the entire NBS project cycle, either as a continuous process or triggered by specific events or needs (e.g., post-construction survey or data collected before and after a storm). Monitoring may be broken up into four broad stages:

1. **Historical monitoring** – helps to inform scoping and project planning and may involve reliance on monitoring work completed by others prior to project conceptualization.
2. **Baseline monitoring** – establishes existing conditions, acts as a reference to monitor performance, and informs the design.
3. **Compliance monitoring** (including construction monitoring and as-built surveys) – feeds into adaptive management during construction, informing modifications to the construction process, and extends post-construction to ensure compliance and establish a starting point for performance evaluation.
4. **Operational (long-term) monitoring** – used to evaluate performance over time and inform adaptative management, evaluate project benefits and impacts, and inform future projects.

A summary of potential tasks during the various monitoring stages is presented in Box 3. Given the importance of establishing a robust baseline for evaluating future NBS performance, it is essential to develop and maintain long-term, regional monitoring networks that can provide baseline data for NBS projects. Often, beginning data collection when a project is still in the conceptualization phase might not produce sufficient information to thoroughly define baseline conditions.

More detailed guidance related to monitoring methodology, including discussion of the Before-After Control-Impact (BACI) approach to monitoring, is provided in the associated guidance document: *Monitoring Efficacy: Proposed Methodology and Indicators.*

Box 3. Monitoring stages and associated actions

Historical	Baseline	Compliance	Operational
• Gather historical data, past monitoring data, and studies for the project location • Gather historical data from comparable projects (either similar physical environment or NBS type) • Evaluate existing monitoring networks for gaps (project-specific) • Determine if/which additional monitoring is needed (spatially and temporally) to inform design and baseline	• Implement baseline monitoring program • Evaluate baseline monitoring program using data analysis • Compare baseline monitoring data to historical data • Adapt baseline monitoring program, if needed • Consolidate information to be used in the design • Establish baseline conditions • Develop a communication and data plan to support construction • Develop compliance and operational monitoring plans • Define performance indicators and metrics	• Implement compliance monitoring program (typically including surveys and inspections) • Evaluate compliance monitoring relative to project baseline • Ensure clear and frequent communication with project team and contractor • Adapt monitoring methods and construction process, if necessary • Establish starting point for performance evaluation (as-built survey)	• Install instruments for long-term monitoring of physical properties • Conduct environmental, socio-economic and performance surveys, according to monitoring plan • Analyze and report the acquired data • Evaluate performance against baseline and starting point conditions • Assess potential unforeseen impacts • Manage NBS in response to monitoring data and according to adaptive management plan • Reassess monitoring plan and adapt, as necessary

Case Study 1. Swan Island Restoration

Swan Island Restoration:
Restoring Ecosystem Services and Coastal Protection

Chesapeake Bay, Maryland
United States

Swan Island is part of a marshy island complex in Chesapeake Bay, which, among other functions, provides coastal protection for the city of Ewell, Maryland, by acting as a natural breakwater (Whitfield et al., 2022). Due to the combined impacts of sea-level rise, land subsidence and inadequate sediment supply, coastal islands and marshes in the area are rapidly disappearing.

In 2019, the United States Army Corps of Engineers placed 60,000 cubic yards (approx. 45,900 m^3) of sediments, dredged from a nearby navigation channel, to restore the extent and elevations of Swan Island. Dunes and high and low marsh areas were created and 200,000 plants were installed (NOAA-NCCOS 2022). A thorough Monitoring and Adaptive Management Plan (MAMP) was developed by a multi-agency project team to track progress and serve as a blueprint for the monitoring and the adaptive management approach.

The MAMP outlines roles and responsibilities, monitoring methodologies and performance metrics, reporting standards, data management, and triggers for adaptive management. It was also envisioned to serve as a model for future restoration sites (providing a transferable approach) and committed to periodical updates (i.e., adaptive management) (Whitfield et al. 2022).

The project area has been monitored since 2018 (NOAA-NCCOS 2022). To evaluate performance and benefits of the project, and inform adaptive management actions, the necessary hydrodynamic, topographic, ecological, and sediment data parameters were collected. Monitoring initiatives included:

- Installation of four platforms around the island, with sensors to measure waves, currents, water level and available sediment in the water column.
- Annual ecological and topographic surveys, at fixed sampling locations, to document changes in elevation, vegetation, and sediment over time as the site matures.

Figure 2. Elevation measurements

Source: NOAA-NCCOS 2022

Preliminary results and performance evaluation two years after project implementation indicate that the restoration works achieved the desired elevations and that the high marsh area was healthy and growing (NOAA-NCCOS 2022). However, plantings in the low marsh area did not survive and the significant gaps in vegetative cover did not meet performance criteria. In response, additional plants were installed, including through an experimental strategy of clumped plantings.

At the time of this report, the project is still in the early stages of post-construction monitoring. However, the proposed adaptive management approach outlined in the MAMP has proven beneficial and has supported effective communication and coordination. Additional information may be found at NOAA-NCCOS (2022):
<https://storymaps.arcgis.com/stories/7156cfc6353048ad92ef80f737b77c29>.

Figure 3. Aerial Images of Swan Island in 2017 (pre-placement) and 2019, 2020 and 2021 (post-placement)

Source: NOAA-NCCOS 2022

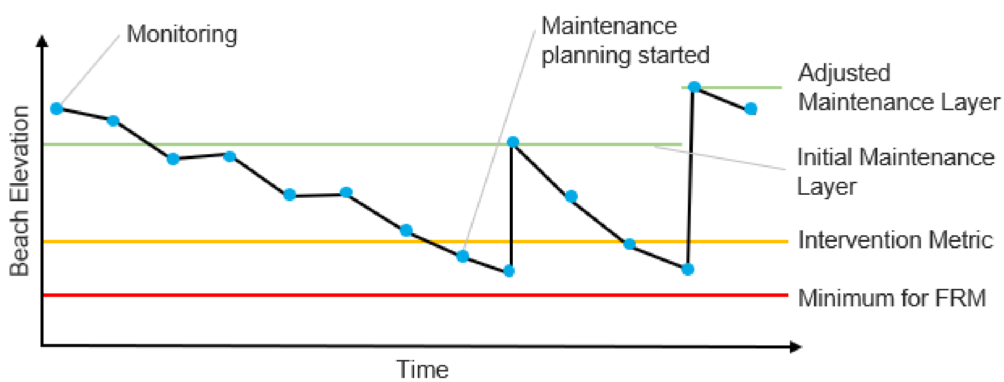
2.4 Relationship to Adaptive Management

Adaptive management is built on the principle of addressing and reducing uncertainties in NBS projects in a phased implementation. This type of management acknowledges the dynamic nature of the environment and focuses on the project aspects that can be controlled or adapted, increasing flexibility in planning stages and allowing the design to evolve over time (de Looff et al. 2021 and references therein). This is especially important within the context of climate resilience, given the uncertainties in climate projections and how those uncertainties play out in the environment over time. Adaptive management concepts and practices are central to the NBS project cycle (described in Section 2.1) and the monitoring planning cycle (described in Section 2.2).

Monitoring is vital to adaptive management as it provides essential data used to reduce uncertainties, evaluate NBS effectiveness, modify the NBS design or monitoring program, and promote developing knowledge on NBS. Therefore, the monitoring program must be designed together with the adaptive management plan. The selection of indicators and metrics to evaluate performance (discussed in Section 4.1) provides information to help tackle critical design and management uncertainties.

It is also important to understand the need for timely feedback between the monitoring program and adaptive management, which helps to facilitate action by decision makers, especially at such critical stages as during construction or when interventions are required post-construction (see Case Study 2). For example, Figure 4 illustrates how historical and ongoing monitoring data related to beach elevation (for example) could feed into decisions on when to undertake additional beach nourishment to meet FrM metrics. In this example, when monitoring data reveals that the beach elevation is below the intervention metric, planning is initiated for maintenance activities to ensure that the maintenance layer metric is achieved. Over time, the maintenance layer metric itself may need to be adjusted if monitoring results indicate that the maintenance layer is not lasting as long as desired or in consideration of potential future climate change impacts (see Section 5.2).

Figure 4. Conceptual model of monitoring data on beach elevation feeding into decision-making for adaptive management



Source: adapted from de Looff et al. 2021, 290

For additional information on adaptive management, refer to the *International Guidelines on Natural and Nature-Based Features for Flood Risk Management, Chapter 7: Adaptive Management* (de Looff et al. 2021).

Case Study 2. Hybrid dune construction at Cardiff State Beach

Hybrid Dune Construction at Cardiff State Beach:
Monitoring and Adaptive Management in Action

Encinitas, California
United States

Near Encinitas, California, a segment of Highway 101 is situated on a sandy spit and is fronted by Cardiff State Beach on its seaward edge. The beach and highway are exposed to high waves and water levels from the Pacific Ocean, which have resulted in over 40 highway closures due to wave-induced flooding and erosion (Winters et al. 2020). Past attempts to stabilize the shoreline have proven insufficient (Winters et al. 2021).

The City of Encinitas—in collaboration with numerous agencies, regulators, funders, industry members, and the academic community—initiated a hybrid NBS project to improve the area's resilience to coastal flooding and erosion, which are expected to worsen as sea levels rise (Moffatt and Nichol and San Elijo Lagoon Conservancy 2016). The project involved constructing a buried revetment with an extensive sand berm and a small, buried cobble berm toe (Winters et al. 2020). The berm was planted with native vegetation and fenced to improve habitat. Delineated beach access points were established for pedestrian access. The work was completed in June of 2019, and extended across approximately 880 lineal meters of shoreline. Notably, periodic maintenance of the works was anticipated (Moffatt and Nichol and San Elijo Lagoon Conservancy 2016) and an extensive beach monitoring program was planned, which involved pre-construction, construction, and post-construction drone-based surveys (Winters et al. 2020).

One of the goals of the "during construction" survey was to measure the revetment location and cobble sizes to generate subsurface layers for future modeling efforts. Post-construction surveys focused on capturing seasonal and storm-induced beach profile changes to evaluate FrM performance, inform adaptive management, and provide local data on the efficacy of this approach.

Monitoring between 2019 and 2021 showed extensive erosion on the lower beach and at the toe of the dune (Winters et al. 2021). Monitoring work informed the decisions to remove or trim fencing and undertake additional nourishment of the beach. Monitoring also captured unexpected gully formations near the pedestrian access points due to overland flooding, prompting emergency maintenance and spurring an additional hydrology assessment. Monitoring and adaptive management are expected to continue.

Figure 5. Dune construction after construction (left) and after two winter seasons of erosion (right)

Source: Winters et al. 2021

3 Administrative Considerations for a Monitoring Plan

This section outlines key administrative considerations for decisions that will relate to developing and implementing monitoring plans to support the use of NBS. It also includes a summary related to monitoring plan scoping, roles and responsibilities, funding challenges, and data access and dissemination. Technical considerations are summarized in Section 4. Case studies are included throughout this section to emphasize key concepts or administrative considerations of implementing a monitoring plan. More detailed guidance related to monitoring methodology and performance indicators are provided in the associated guidance document: *Monitoring Efficacy: Proposed Methodology and Indicators.*

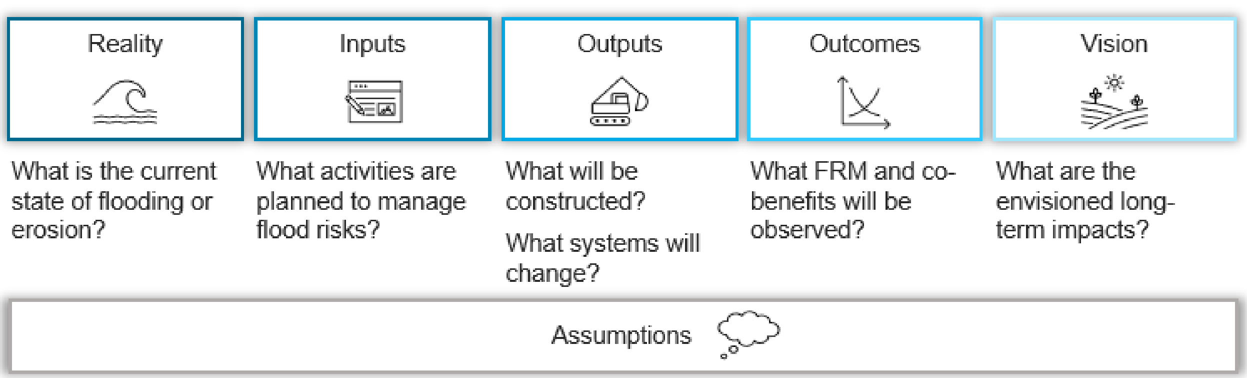
3.1 Scoping

Scoping the monitoring and adaptive management plan is the first phase of the monitoring plan cycle (see Section 2.2). Scoping requires building a clear understanding of project needs, including the problem, goals, and constraints of the project, to identify priorities and define the scale and scope of monitoring initiatives. During this stage, it is important to have a general understanding of the technical considerations (see Section 4) and to identify potential funding opportunities, project needs and stakeholder roles.

Administrative considerations are generally project-specific and should be carefully assessed at the project's onset. For example, a neighborhood-scale NBS aimed at protecting low-lying urban areas from catastrophic flooding should have a vastly different monitoring scope than a property-scale NBS intended to protect against minor flood-induced erosion. Identifying stakeholders, rightsholders and financial constraints is particularly important early on, during the scoping phase, in order to clearly establish roles and responsibilities (see Section 3.2) and identify funding gap opportunities to be filled (see Section 3.3).

Another key action for evidence-based management is establishing a theory of change, delineating a projected path on how the intervention is expected to produce change (Gertler et al. 2016). This theory can be used to evaluate the performance of the NBS and to derive and implement an adaptive management plan.

Figure 6. Theory of change for FrM projects



Source: adapted from Dumitru and Wendling 2021

3.2 Roles and Responsibilities

Project team members, rightsholders and stakeholders should be identified early in the overall NBS implementation process and the monitoring plan development process.

Regular stakeholder engagement and two-way communications are necessary to proactively identify needs, potential problems, and opportunities, both during monitoring plan development and implementation (Bridges et al. 2021b). Frequent communication also helps to build trust and accountability between the project team and stakeholders—fundamental to the uptake of NBS (see Section 1.3). Close cooperation between the scientific community, the project team, and policymakers during planning stages is essential to ensure the monitoring program starts early enough in the project and has sufficient focus to meet project needs and scientific standards (van Eekelen and Bouw 2021).

As part of the monitoring process, team members and stakeholders should be assigned clear roles and responsibilities (Silva Zuniga et al. 2020). These may be divided into several work categories, such as: key strategic decisions, specific research activities involved in monitoring, fieldwork, data analysis, storage and dissemination, and general support across all stages of the monitoring program.

Especially when multiple groups are involved in the process, it is important to identify interfaces and dependencies between the different roles to ensure all aspects of the plan are being covered and to avoid duplicate work.

3.2.1 Considerations for Who Should be Involved

Every NBS initiative is expected to require a project-specific group of individuals and organizations to support and inform the overall project and the monitoring program. Important stakeholders and organizations to include in the monitoring plan development may include affected community members, local community groups, nonprofits, government representatives, the academic community, and industry members. Rightsholders representatives, such as First Nations or Indigenous leaders, should also be consulted and involved. Case Study 3 highlights the creation of a project advisory committee (which included a diverse group of stakeholders, rightsholders, experts, and government representatives) to inform the successful completion of a dike realignment project in Nova Scotia, Canada.

As part of the CEC workshop series on NBS (DHI 2022), experts from across Canada, Mexico, and the United States highlighted the importance of community engagement and participation during planning stages and monitoring activities for NBS (Figure 7). Experts identified the participation of several parties as key to a successful and effective NBS monitoring program, including: government representatives, Indigenous leaders, the academic community (universities and research institutes), and the NBS project team (project managers and technical experts).

Figure 7. Word Cloud of answers from participating experts during the CEC workshop series on NBS, concerning who should be involved in planning and implementing monitoring

Source: DHI 2022

Case Study 3. Bay of Fundy Dike Realignment

Bay of Fundy Dike Realignment:
Collective Action and Collaboration

Truro, Nova Scotia
Canada

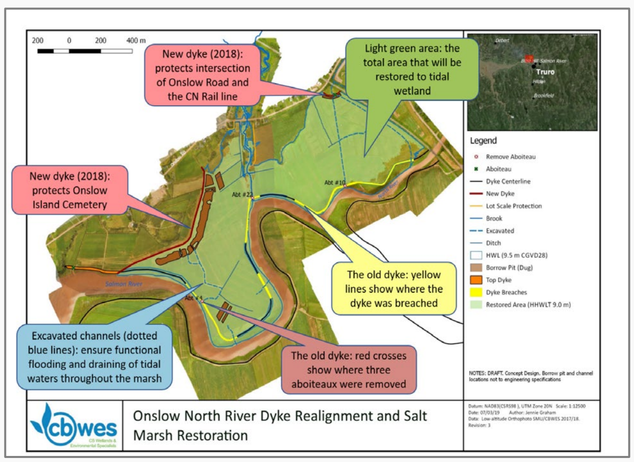
In October 2021, after years of planning, a managed dike realignment was completed along the Onslow-North River near the city of Truro, Nova Scotia, east of the Bay of Fundy. A new dike along the Onslow-North River was built and the existing dikes along the tidally influenced Salmon and North Rivers were breached to restore the tidal marsh habitat.

The area around Truro has been identified as being particularly vulnerable to climate change-related floods, storm surges and erosion hazards, and has already been experiencing annual flooding, causing damage to nearby properties and infrastructure, including roads and schools (CBCL 2017). Area flooding, creating impetus to address the problem, has occurred after heavy rainstorms, high tides and ice jams in the river, resulting in overtopping the existing dike; as well as severe flooding that impacted Truro in 2012, following Tropical Storm Leslie (Sherren et al. 2019).

Many stakeholders collaborated during all stages of the project (TCA 2022). The Joint Flood Advisory Committee was created which included representation from community members, local and provincial governments, and First Nations. An innovative, trust-built network between government, academia and private sector was key to successful implementation (Rahman et al. 2021). The monitoring stage is a shared responsibility between scientists at CB Wetlands and Environmental Specialists (CBWES) and Saint Mary's University (SMU) and will be carried out over a five-year period. The program will monitor habitat recovery by measuring sediment accretion, elevations, hydrology, water and soil quality, carbon sequestration, vegetation cover, and the presence of fish and other fauna (TCA 2022). In addition to these monitoring efforts, a research program is being applied under the new Canadian research network Natural Sciences and Engineering Research Council (NSERC) ResNET (NSERC ResNet 2022). Questions being explored include:

> "1. What services are delivered by Bay of Fundy dykelands, and how sustainable are those under sea-level rise?
>
> 2. What services are delivered by Bay of Funday tidal marshes, and what is the lag time to their delivery after restoration?
>
> 3. How do stakeholders trade off different categories of services over space and time?
>
> 4. What are the implications of the above for dyke reinforcement, realignment and removal decisions?"

Figure 8. Onslow-North River project site design



Source: TCA 2022

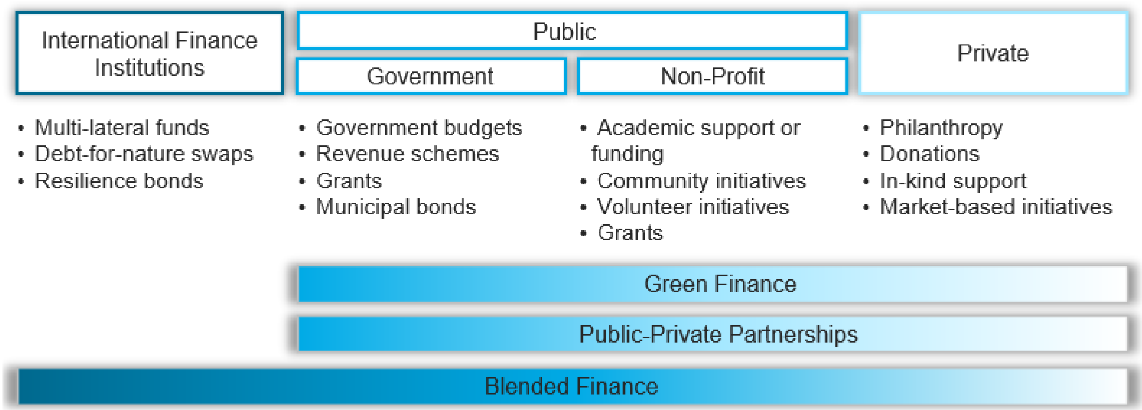
Additional Information may be found at TransCoastal Adaptations – Centre for Nature-Based Solutions (TCA 2022): <https://www.transcoastaladaptations.com/onslow-north-river>

3.3 Funding

During the CEC workshop series on NBS (DHI 2022), insufficient funding was identified as the primary challenge for monitoring NBS (as discussed in Section 1.3). To ensure a successful project, it is crucial to identify funding needs (for monitoring, evaluation, and subsequent adaptive actions) and to develop funding strategies (including assessing potential funding sources and opportunities) at the start of the project. It is also important to consider cost-effective monitoring solutions (as will be discussed in Section 4) to help alleviate budget requirements.

Potential funding sources include international finance institutions, public institutions, and private sources (de Looff et al. 2021; Silva Zuniga et al. 2020). Figure 9 summarizes potential funding sources for NBS projects (including monitoring). Currently, many of the most common funding sources for NBS projects come via government initiatives, such as the Natural Climate Solutions Fund in Canada, or directly through nonprofit organizations and academic institutions.

Figure 9. Examples of potential funding sources for monitoring and implementing NBS



Source: modified from Silva Zuniga et al. 2020, 23

Insurance of natural infrastructure provides an additional option to secure funds, generally to support adaptive management actions. Parametric insurance policies provide a payout of a certain amount when a triggering event occurs (for instance, when shoreline erosion exceeds a trigger threshold). Albeit novel, this concept has been applied successfully in the State of Quintana Roo, Mexico, where the Mesoamerican Coral Reef has been repaired using insurance payout (see Case Study 4).

Additional funding for monitoring (and NBS, in general) may also become available through market-based initiatives. Notably, as carbon prices rise, private investments may be expected to take advantage of the carbon credits generated by NBS (Drever et al. 2021). Additionally, insurance companies have a special interest in supporting communities in becoming climate resilient, as reducing coastal flood risk would lead to a reduction in insurance payouts. In Canada, the Intact Foundation (backed by its mother insurance company, Intact Financial Corporation) launched the Municipal Climate Resiliency Grant Program to support cities and towns in developing practical and effective solutions to protect communities from floods and wildfires (Intact 2022). This grant helped to develop a "living shoreline" pilot project in the city of Mahone Bay, Nova Scotia. The project was built in 2022 and, although it is too early to present results, it is expected to be fully functional in protecting part of the town against flooding and erosion in approximately three years. This pilot project survived the impact of large waves during Hurricane Fiona in 2022 and is being continuously monitored by TCA. Establishing partnerships and synergies with other NBS projects, or between funding organizations, can also help reduce the financial burden of long-term programs. Additional information on funding opportunities is detailed in the Inter-American Development Banks report on *Increasing Infrastructure Resilience with Nature-based Solutions (NbS)* (Silva Zuniga et al. 2020).

Case Study 4. Mesoamerican Reef

Mesoamerican Reef:
Securing Long-Term Funding through Insurance

Quintana Roo, Mexico

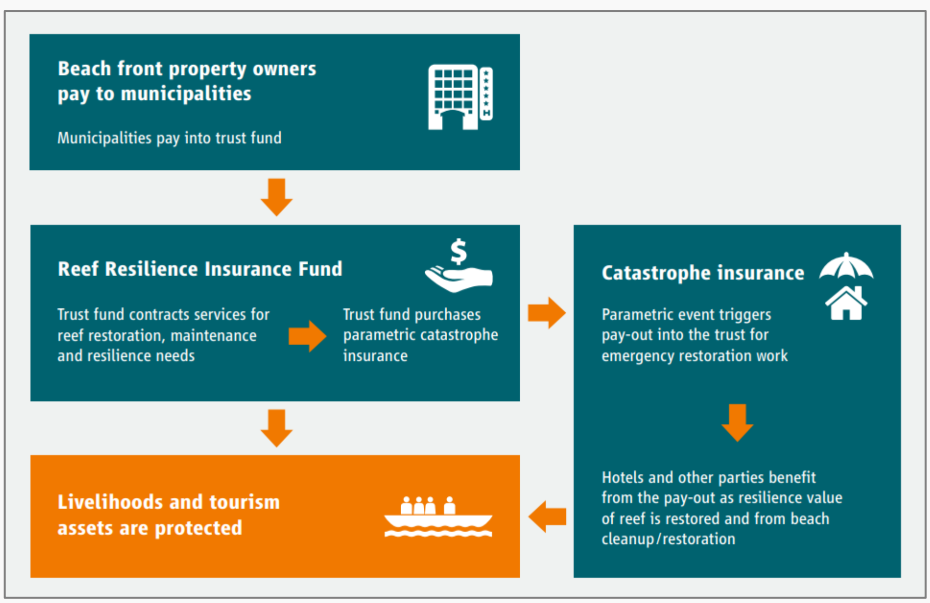
The Mesoamerican Reef in the Caribbean Sea is the second-largest coral reef in the world, spanning across Mexico, Guatemala, Belize, and Honduras. The local economy of the State of Quintana Roo is heavily dependent on tourism associated with the coastline and reef, and many of the hotels built along the coast are vulnerable to flooding from tropical storms. The reef has been shown to effectively reduce the risks of flooding and erosion associated with the frequent tropical storms experienced along Mexico's Caribbean coastline, estimated as an annual benefit of US$42 million in damage prevention to build infrastructure (Reguero et al. 2019).

The Government of the State of Quintana Roo, in collaboration with the tourism industry, the Nature Conservancy (TNC), the National Parks Commission, local researchers, community members and the insurance industry, created the Coastal Management Trust insurance scheme (TNC 2019). This is a parametric insurance scheme into which beachfront property owners and the local tourism industry pay a premium, and insurance payouts occur when wind speeds reach more than 100 knots (approx. 185 km/h) (Beck et al. 2019; TNC 2019).

The insurance scheme funds a highly trained team of community members, known as the Reef Brigades, to conduct the assessment and repair of reef damage following storm events (TNC 2019). Although the intended function of this scheme is to repair an existing natural reef following damage, a similar insurance approach could be adapted for NBS projects to provide funding for monitoring and adaptive management.

In October 2020, Hurricane Delta triggered a payout of US$850,000 (TNC 2021) to be used in a restoration effort spanning two to three years. A drawback to the scheme is the time taken for the insurance payout to be put into action, which delays the assessment and repair of the reef following a storm. The longer the time between the storm event and recovery actions, the less effective the repair of the reef.

Figure 10. Structure of the insurance trust scheme



Source: Beck et al. 2019

3.4 Data Access, Storage and Dissemination

Disseminating the results of the monitoring program and the progress of the NBS has immense benefits, such as increasing public knowledge on NBS and local government activities, promoting business opportunities for private companies within the context of NBS and allowing the scientific community and decision makers to build knowledge on existing projects (Dumitru and Wendling 2021). Making data—as well as the collection methods and analyses performed—publicly available and easy to access in a centralized database with standardized formats, is extremely valuable for future NBS monitoring programs. Building a collaborative monitoring and data dissemination network is an important step toward accumulating knowledge and evidence on NBS. Another benefit of disseminating data is increasing public interest and community engagement, which could result in additional sources of data collection from community science. Case Study 5 describes a community-based monitoring initiative, CoastSnap, that has expanded globally.

Data access and dissemination should be considered during the monitoring program's scoping and planning stages. This helps ensure that appropriate resources and funding are secured, appropriate tools for dissemination are identified, and the project intent is communicated to stakeholders early. Storage and servers to host data visualization portals have associated maintenance costs. Those costs should be considered during the project planning to ensure data are not lost and their access is reliable.

Considerations should also be given to data ownership and access for distribution rights, especially when dealing with personal information and socioeconomic indicators. For example, when collecting data in First Nations communities in Canada, data collection, storage and sharing protocols must respect the OCAP® principles,[1] ensuring that First Nations alone own and control how it is stored and used (FNIGC, 2022).

Both positive and negative outcomes are equally important to communicate. Lessons learned from what went wrong or what could be improved in the future are of utmost importance in avoiding repetition of mistakes or wasted resources due to implementing strategies and solutions that have been proven ineffective (Dumitru and Wendling 2021).

There are multiple ways of presenting and disseminating data and results, including scientific papers, reports, conference presentations, webinars, social media, data portals, and interviews. Regardless of the delivery method, it is helpful to create attractive and easy to interpret visual representations, such as infographics and GIS-based tools, which may support decision-making and increase stakeholder participation. Although many portals and atlases already exist describing NBS case studies (e.g., *the Engineering with Nature Atlas Series*, Bridges et al. 2018; Bridges et al. 2021a; *the Map of Adaptation Actions*, ECCC and NRCan 2021), there is still a need for an industry-wide, cross-border (i.e., international) database to host and disseminate monitoring data. Existing initiatives could serve as a basis for developing a centralized and recognized database of both projects and survey data.

[1] OCAP® is a registered trademark of the First Nations Information Governance Centre (FNIGC) - https://fnigc.ca/ocap-training/

Case Study 5. CoastSnap Community Beach Monitoring

CoastSnap Community Beach Monitoring:
Using community science to monitor coastlines

Canada, Mexico, and the United States

Figure 11. CoastSnap stations

Source: Harley and Kinsela 2022

CoastSnap is a platform that relies upon community members monitoring coastlines through taking photos and uploading them to social media (Harley and Kinsela 2022). The initiative consists of installing stainless-steel phone cradles at easy-to-access coastal locations and simple instructional signs that encourages the beach visitor to use the phone cradle to take a photo and share it using either the CoastSnap App or via any social media platform using a specific hashtag unique for each station (Harley and Kinsela 2022). In September 2022, more than 60 stations in the United States and 13 stations in Canada existed. In June 2022, the first CoastSnap station was installed in Mexico at San Bruno beach in Yucatán.

CoastSnap originated in Australia in 2017 but has since expanded worldwide via multiple partnerships and regional project initiatives, including the Coastie project in Canada (Parks Canada and the University of Windsor) and CoastSnap Delaware (Delaware Sea Grant College Program) and CoastSnap Woods Hole (Woods Hole Oceanographic Institution) in the United States.

In addition to serving as a centralized database for historical images, the technology behind CoastSnap can create time-lapse videos and track shoreline position. The backend system consists of intricate image-processing algorithms that align the images to a uniform angle and extract the shoreline position. The method has been validated at two pilot sites by comparing the photo-derived shoreline with local measurements and has proven to be a scientifically rigorous, cheaper alternative to traditional monitoring (Harley et al. 2019).

It is recognized that a high level of public participation is necessary for the success of the project. Overall, community engagement has been high (i.e., at least monthly, but often weekly, posts in the established stations in Canada and the United States).

Additional information is available at CoastSnap: <www.coastsnap.com/>

4 Technical Considerations for a Monitoring Plan

Several technical aspects should be considered when developing an NBS monitoring program, including selecting indicators and metrics, defining methods and techniques for data collection and analysis, and the extent of the monitoring (both in time and space). This section provides an overview of these key technical considerations. A case study is included in this section to illustrate the technical aspects of implementing a monitoring plan.

More in-depth technical guidance on developing and implementing monitoring plans is provided in the associated *Monitoring Efficacy: Proposed Methodology and Indicators* guidance document.

4.1 Indicators and Metrics

Monitoring programs for conventional FrM projects have generally focused on engineering performance. Given the potential for co-benefits of an NBS project, it is crucial to consider a wide range of indicators to measure impacts. In this context, an NBS project should be evaluated, not only with respect to its basic FrM functions, but also considering the various ecological and socio-economic co-benefits. Note that co-benefits of NBS are discussed in detail in the associated guidance document: *Co-Benefits.*

Performance may be defined as the degree to which NBS fulfills a specific objective by measuring changes toward certain targets or in relation to the baseline (Dumitru and Wendling 2021). Preferably, the baseline will be established using long-term historical data (see Section 2.3). To objectively assess performance, indicators and metrics must be established beforehand, preferably within the planning phase of the monitoring plan. NBS performance indicators may be classified into multiple interrelated and overlapping categories (Morris et al. 2019, Piercy et al., 2021):

- Engineering (FrM) performance, related both to the "function" of the project (i.e., flood protection capabilities) and to the "form" (i.e., if the NBS remains intact and functional through time).
- Ecological performance, related to the ecological success of the implementation, enhancement of biodiversity, reestablishment of a habitat, and improvement of ecosystem services (e.g., water quality, fisheries, etc.).
- Social performance, related to social benefits provided by the project, such as human health, well-being, recreational and cultural value, improvement of livelihoods, and job opportunities.
- Economic performance, related to monetary benefits resulting from the project, such as avoided damages, increased property prices, and increased economic activity through tourism and fisheries.

In addition to the NBS performance evaluation, the monitoring program must also address uncertainties and help reduce risks related to the NBS. Critical uncertainties should be identified early in the design phase and appropriate metrics be defined to trigger adaptive management activities and inform whether the initiative is meeting project objectives. Climate change poses significant uncertainties, which may require additional monitoring activities to quantify effects and impacts.

For most NBS there are a core set of performance indicators, which should be included in all monitoring programs, such as extreme water levels and vegetation cover. The choice of additional performance indicators to include in the monitoring program will be project-specific, and will be influenced by project objectives, scale, associated risk, degree of innovation, budget, policy directives, and logistical factors. As budgets are often limited, indicators and metrics should be selected carefully to prioritize critical aspects of the project and, if possible, to inform multiple types of performance criteria using the same data or survey method (Piercy et al., 2021). It is also relevant to consider applying standardized methodologies (as exemplified in Case Study 6) and indicators to allow comparison between NBS projects and potential collaboration among various monitoring programs. Indicators should be measurable, simple, achievable, scalable, replicable, affordable, and within the constraints of available resources, such as time and personnel (Kumar et al., 2021; Piercy et al., 2021). Standardized methodology and indicators are proposed and outlined in the associated *Monitoring Efficacy: Proposed Methodology and Indicators* guidance document.

Metrics should be set to define project targets or goals. For example, a beach elevation indicator for FrM may include metrics that defines the minimum, intervention, and base-layer thicknesses and inform adaptive management decisions (as shown in 4).

Although this report focuses on monitoring new NBS projects (which have not yet been constructed), the performance concepts and analyses discussed herein are also directly applicable to the evaluation of existing natural features that provide flood protection. Performance monitoring of existing natural features may help to support cost-benefit analyses of proposed interventions and inform management strategies, especially if related to the preservation of natural areas and the realization of ecological services provided by natural assets (MNAI 2022).

Case Study 6. Statewide Shoreline Monitoring Framework

Statewide Shoreline Monitoring Framework:
A Standardized Approach to Monitoring Nature-based Solutions (NBS)

New York State, United States

Acknowledging the need for a standardized NBS monitoring framework and data collection protocols, the New York Department of State developed the Statewide Shoreline Monitoring Framework (Science + Resilience Institute 2020). The framework was developed by a multidisciplinary researcher/practitioner network through a collaborative process to facilitate the comparison of NBS with conventional shoreline approaches (Wijsman et al. 2021).

The framework was developed based on a high-level literature review, input from multidisciplinary expert working groups, regional stakeholder consultation, and regulatory and advisory council input. The framework was also adapted to reflect pilot monitoring data collection at 16 sites across the State of New York over the period of one season. The framework includes:

- A roadmap to develop a project-specific monitoring plan for both NBS and hard infrastructure
- List of 19 recommended indicators for New York State coastlines and guidance on how to narrow down the selection to each site
- Data collection (fieldwork) and data analysis protocols for each indicator
- Development of a centralized database to store and analyze data
- Lessons learned from the pilot program and suggestions for future application

Indicators spanned ecological, hazard mitigation, and socio-economic services. Additional information on indicators (and other project details) may be found through the NY Department of State website for the Statewide Shoreline Monitoring Framework: <https://dos.ny.gov/statewide-shoreline-monitoring-framework>.

This initiative is an important step towards building foundation and a growing database for comparison between NBS and conventional, hard infrastructure. The framework is envisioned to evolve continuously, based on user feedback and needs.

Figure 12. Monitoring framework

Source: Science + Resilience Institute 2020

4.2 Methods and Techniques

Performance indicators may require different metrics, data collection techniques, and data analysis methods. For example, measuring ecological success, frequency of flooding events and social co-benefits may involve a wide range of methodologies, techniques and data types, from visual surveys to in-situ water level sensors, remote satellite imagery, and interviews with community members.

Standard data collection methods include observations and sampling (acquired both in-situ and remotely), surveys and census (especially related to socioeconomic metrics) and laboratory experiments and numerical models, which are useful tools during planning phases and for pilot projects.

Measurements can be direct or indirect and provide qualitative, semi-quantitative or quantitative evaluation metrics. Direct measurements include on-the-ground observations or remotely obtained data, such as airborne or satellite imaging (Piercy et al., 2021). Examples of direct measurements include installation of water level data loggers to measure water levels, directly counting visitor numbers, or obtaining digitized drone imagery to define marsh areas. Direct measurements are not always feasible (often due to funding or access constraints), so indirect measurements may instead be used as proxies (Piercy et al., 2021). Examples of indirect measurements include using flood water marks on buildings to estimate inundation levels, or semi-quantitative index-based socioeconomic or ecological metrics.

Given that funding is recognized as one of the biggest constraints to monitoring NBS, it is generally necessary to design a program that has a cost-efficient solution to data collection, and that may include employing existing (maintained) datasets, such as earth observation and remote sensing programs, establishing a collaborative measurement approach across multiple projects and stakeholders, and making use of community science project results or community participant-collected data. New technological, research and innovation advancements are expected to improve how the effectiveness of NBS is monitored, reduce costs, and enhance the knowledge and evidence base for future NBS projects (Somarakis et al. 2019).

Regardless, the long-lasting value of the monitoring program depends dramatically on achieving consistent, comparable results that can be reproduced (Altman et al. 2021). When defining monitoring methods and techniques, it is therefore beneficial to involve subject matter experts early in the planning process and consult with them to ensure compliance with scientific standards so the results are defensible, and the data can be used to meet project requirements and inform future projects and research of NBS. It is often beneficial to apply standardized methodologies and indicators (as described in Section 4.1).

Proposed methodology and indicators for NBS are outlined in the associated document *Monitoring Efficacy: Proposed Methodology and Indicators.* Additional discussion on methods to measure and evaluate co-benefits are described in the *Co-Benefits* report. Additionally, Kumar et al. (2021) provide a review of available methodologies and equipment used to evaluate NBS engineering performance with respect to flood risk, and Raymond et al. (2017) propose a framework to assess NBS socioeconomic co-benefits.

4.3 Physical Scale and Locations

Monitoring can take place at various spatial scales, from a local level (e.g., property, road, or park), to community-wide, city-wide, or even regional scales. Defining an appropriate spatial domain for monitoring is critical for data representativeness and adequacy (Dumitru and Wendling 2021). The scale of the overall monitoring program should be adjusted on a project-specific basis, depending on the size of the intervention, the project objectives and uncertainties, the expected impact scale, and availability of funding for monitoring. In addition, it is often appropriate to consider multiple spatial scales within the monitoring program to appropriately define different performance indicators. For example, economic indicators will often require monitoring at a city-wide or regional scale, whereas FrM indicators can often be limited to the project footprint.

Although the scales of NBS are typically relatively small, acquiring and analyzing data at larger scales can also be beneficial in assessing the upscaling and replication potential of specific NBS interventions.

When developing a monitoring program, it is also important to consider site-specific conditions that may impact monitoring feasibility, such as physical characteristics, accessibility constraints, weather constraints, daylight limitations, tidal windows, permitting windows and safety. This is especially important for in-situ instrument deployment. Areas chosen for instrument installation should be carefully selected, considering, among other things, navigational and swimmer safety, social nuisance, maintenance access restrictions, and potential for vandalism or theft.

4.4 Temporal Scale and Frequency

Defining the temporal scale and periodicity of the monitoring program is important for an adequate performance evaluation and to inform adaptive management. When designing a monitoring program and establishing indicators and metrics, considerations should be given for when, with what frequency, and for how long monitoring should be conducted.

Monitoring frequency (or acquisition regime, as described in Dumitru and Wendling 2021) can be broken into four broad categories:

1. Continuous data, such as in-situ instruments (e.g., tide gauges, cameras)
2. Demand-driven data, such as monitoring responses to extreme storms or other relevant events (as described in Section 2.3)
3. Once-off data, referring to data that are generated only once in this configuration (e.g., construction monitoring data, which represents a snapshot in time that cannot be replicated)
4. Periodic data collection, such as seasonal beach profiles

Ideally, the choice of a particular acquisition regime should be determined based on the expected temporal dynamics of a given process or performance indicator. Monitoring should also be of sufficient frequency to inform adaptive management (as shown in Figure 4). In practice, however, the monitoring interval is a compromise between several factors, such as technological constraints, project timeline, and funding and resource availability (Dumitru and Wendling 2021).

In addition to the monitoring frequency, the duration and temporal scale of monitoring, data analysis, and performance evaluation should be defined for each selected performance indicator, considering expected and unlikely outcomes, as well as the natural scale and variability of each indicator. It should be noted that some NBS can take years to fully develop and achieve full FrM and co-benefit performance (e.g., extensively restored or newly created wetlands). It is, therefore, sometimes necessary to wait until the system has matured to fully evaluate performance indicators and avoid early "lack of performance" results and unnecessary adaptive actions (de Looff et al. 2021). Nevertheless, short-term monitoring can help to confirm if the theory of change for the project was correct and may still trigger adaptive management actions. For example, loss of juvenile vegetation during an unexpected storm event or from intensive foraging by herbivores may trigger the need for re-planting (see Case Study 1).

Establishing an adequate monitoring program timeline is crucial to avoid data gaps, poor data suitability, and lack of essential information in evaluating NBS performance and establishing a baseline. Monitoring timelines should therefore be evaluated early in the planning and design phase of the project and revised as part of adaptive management.

Additional discussion on the temporal scale and frequency of monitoring is provided in the report *Monitoring Efficacy: Proposed Methodology and Indicators.*

4.5 Data Analysis

Raw data collected during the monitoring program needs to be processed and interpreted according to the selected indicators and metrics to provide meaningful information for measuring NBS performance and supporting adaptive management.

Various data analysis and manipulation types are possible, ranging from basic statistics and spatial/temporal aggregation to more sophisticated techniques, compiling a set of different metrics and measurements to estimate complex indicators. It is also crucial to set quality assurance and quality control procedures early in the process of developing the monitoring plan and using standardized techniques and methodologies, if possible. This includes storing all relevant information and metadata, documenting all forms of data manipulation, and ensuring that the data accurately represent the conditions observed. Transparency and reproducibility are essential for results to be trusted by the project team for adaptive management and by other stakeholders (including regulators and the public), and for expanding the usage and value of the data collected beyond the specific project. In particular, detailed metadata are important in order to capture important details (e.g., location, instrumentation, maintenance, processing methods, etc.) that may affect data reliability and future usage.

Considerations on spatial and temporal scales (as discussed in Section 4.3 and 4.4) also apply to the data analysis. It is important to check the quality of the data to ensure that results are not affected by either short-term or long-term temporal variability or by natural spatial patterns.

Guaranteeing data access and dissemination are key to promoting NBS and to encourage collaboration and knowledge growth. As discussed in Section 3.4, providing easy-to-interpret results and focusing on key messages when publicizing information is beneficial. It is recommended to use popular (i.e., widely available) data analysis tools and standardized methodologies that allow for ease of replication, knowledge sharing, and continuity of analytical procedures.

5 The Efficacy of Monitoring

Monitoring has the potential to provide significant benefits to FrM projects and is an essential component of NBS projects. Despite the potential benefits of monitoring, there is a practical need to tie the scope and scale of monitoring initiatives to the overall project needs, project risks, and funding limitations, which can impact the monitoring initiatives' overall efficacy (as discussed in Section 3). In addition, variable environmental and site conditions, as well as changing climatic conditions, may impact the quality and reliability of monitoring results. The potential impact of these factors on monitoring results are described briefly herein. In addition, the efficacy of monitoring NBS in comparison to monitoring conventional, hard infrastructure is discussed.

5.1 Impact of Site Setting

For monitoring to be effective, it is important to tailor the monitoring program to each site and the specific type of NBS. Variable site settings across North America may pose limitations on the quality, quantity, or type of monitoring data that may be collected and impact the efficacy of the monitoring initiative should methods not be chosen carefully. Potential site characteristics that may impact the efficacy of monitoring may include the following:

- Limited tidal windows
- Limited daylight hours
- Excess vegetation growth or coverage
- Ice coverage
- Debris and sediment accumulation
- Intense storm conditions
- Vandalism of equipment by humans and animals
- Limited proximity to equipment and personnel
- Limited site accessibility for maintenance

Thus it is important to consider site setting when selecting performance indicators (see Section 4.1) and monitoring methods (see Section 4.2), as well as when planning adaptive management strategies (see Section 2.4).

5.2 Impact of Changing Climate Conditions

The design of the monitoring program, as with the design of the NBS itself, should consider climate change impacts. Climate change may impact the efficacy of monitoring through two primary mechanisms:

1. <u>Impacts to function:</u> where the changing climate and fluctuating site conditions impact the functioning of monitoring equipment and techniques.
2. <u>Impacts to baseline conditions:</u> where the changing climate (rather than the NBS) shifts baseline conditions related to selected performance indicators.

To avoid changes in monitoring function, allowances for sea-level rise and other impacts of climate change (e.g., increased rainfall, ocean acidity, etc.) may be included in the monitoring plan. However, given the uncertainties surrounding climate change projections and the subsequent ecosystem effects, it is advised to plan for adapting the monitoring plan, rather than to account fully for potential changes directly in the design.

Changing baseline conditions due to climate change may influence impact assessment and performance evaluation metrics developed for the NBS monitoring program. Conventional evaluation approaches that compare monitoring results to static baseline conditions might not be adequate and consequently, a moving baseline must be considered (NCCARF 2018). The *Monitoring Efficacy: Proposed Methodology and Indicators* companion report proposes best practices for monitoring to identify and accommodate shifting baseline conditions due to climate change.

In addition to moving baselines, climate change may also impact the definitions of performance and success for a given system. As a result, the project's perceived success or failure (as defined through performance metrics) may need to be adjusted according to the context of climate change. Intervention thresholds and maintenance requirements may also require adjusting (as shown in Figure 4).

Within this context, a long-term adaptive management approach to monitoring is recommended. This long-term plan should focus on establishing milestones and identifying tipping points when the monitoring plan may need to be revisited and modified. A changing climate may serve as the impetus for additional monitoring.

Monitoring also plays an important role in developing a better understanding of the impacts of climate change. Monitoring initiatives should seek to continually identify, assess, and manage the consequences of current and future climate conditions.

5.3 Comparisons with Conventional Infrastructure

Monitoring efforts for evaluating the efficacy of NBS versus conventional, hard infrastructure (e.g., seawalls, breakwaters, and dikes) differ significantly, depending on the methodology as well as the type of indicators and metrics used. Experts from the CEC workshop series (DHI 2022) indicated that monitoring was meaningful for all FrM projects; however, they also determined that it was more important for NBS than for conventional infrastructure solutions.

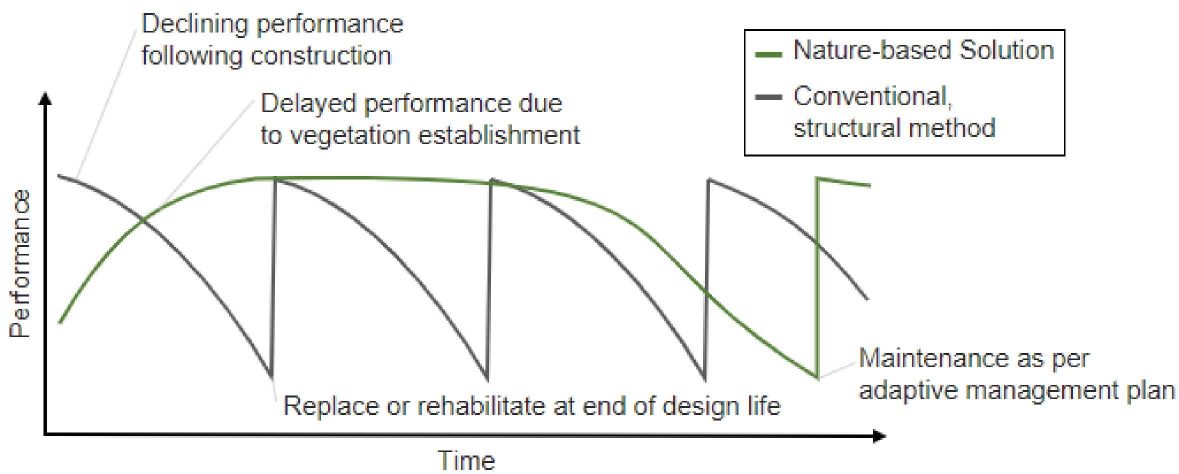
Monitoring conventional, hard infrastructure tends to focus primarily on FrM performance indicators and, to a lesser degree, environmental indicators. In addition, conventional infrastructure monitoring generally focuses on pre-construction, construction, and short-term post-construction monitoring to inform payment and compliance with design. For more high-risk infrastructure, such as elevated dikes or levees protecting high-density urban communities, long-term FrM performance-related monitoring is also regularly scheduled.

In contrast, long-term monitoring and adaptive management are fundamental for NBS. Monitoring should focus on co-benefits in addition to FrM performance. Identifying all potential co-benefits and selecting appropriate metrics for evaluation at early stages of the project are essential to better assess the value of NBS. A discussion on co-benefits of NBS is provided in the associated *Co-Benefits* guidance document.

Furthermore, when evaluating options for flood-risk management, there is often a tendency to focus primarily on a direct cost-benefit comparison based solely on FrM performance (van Zanten et al. 2021). Instead, to compare NBS with conventional, hard infrastructure, there must be a broader understanding of co-benefits and unintended impacts of the potential solutions. Because of a general lack of monitoring data for conventional infrastructure—particularly related to co-benefits—it is difficult to adequately compare the overall function of NBS with conventional infrastructure. In light of increasing pressure from climate change on urban FrM programs, it is recommended that decision makers place equal emphasis on the funding and collection of standardized monitoring data for both conventional and NBS FrM infrastructure, including their co-benefits. Such an approach will enable better comparative analysis of infrastructure performance and impacts, thereby improving adaptive management capacity and future understanding of their respective effectiveness and applicability.

It is also important to highlight that the benefits and value of NBS change over time, often improving as the project matures (Bridges et al. 2021b). As discussed in Section 4.4, project scoping, planning, design, and implementation should consider the natural variability of the solution. Life-cycle cost analysis is a critical step in this process. This kind of analysis defines both capital and maintenance costs (i.e., whole-life costs) projected over the life of the full FrM system (Piercy et al. 2021). Figure 13 provides a conceptual model of how the performance of conventional infrastructure and NBS may change over time, leading to substantially different life-cycle costs for each type of solution. The performance of conventional, hard infrastructure declines following construction, requiring replacement or rehabilitation of the infrastructure at the end of its design life. In contrast, the performance of NBS may be delayed at the outset and increase over time, with maintenance requirements informed by the monitoring and adaptive management plans. Consideration of these whole-life costs over a longer period allows for a better comparison between nature-based solutions and conventional infrastructure.

Figure 13. Conceptual model of varying performance over the design life of two FrM alternatives



Source: adapted from Piercy et al. 2021, 194

6 Opportunities and Future Directions

Monitoring is essential to the effective implementation of NBS, supporting performance evaluation, informing adaptive management, supporting future projects, and giving confidence to NBS project proponents and funders (Vouk et al. 2021). However, several known challenges and knowledge gaps exist related to monitoring that impedes the implementation and uptake of NBS. Section 1.3 outlines key data gaps and barriers, which include social, technical, environmental, and institutional barriers. A high-level list of opportunities and future initiatives that decision makers may implement to help alleviate known data gaps and barriers is provided in Box 4.

Most social (or attitudinal) barriers may be overcome, or at least reduced, by improving communication, cooperation, and knowledge-sharing. For example, developing workshops and seminars on NBS monitoring, as well as training sessions on frequently used monitoring techniques and equipment, would help to alleviate social and technical barriers.

Knowledge-sharing from previous projects is also essential for faster progress on the technical understanding of NBS and on the overall uptake of NBS. Fundamental, is documenting and broadly disseminating information on projects, regardless of the level of success. Developing a centralized and recognized (industry-wide) database of projects and their monitoring data are important first steps in improving data access and building knowledge. Similarly, research and guidance are needed to determine which methodologies and performance indicators are appropriate for different types of NBS in different regions (Vouk et al. 2021). The associated *Monitoring Efficacy: Proposed Methodology and Indicators* report, which proposes standard monitoring methodologies and indicators for NBS, is a step in this direction. Encouraging formal training of engineers, scientists, and decision makers for monitoring and adaptive management within academic institutions, as well as bridging the gap across disciplines, would also help to fill the technical knowledge gaps and reduce hesitancy toward implementing NBS.

With growing knowledge and expanded research, new insights into the performance of NBS (such as the relative performance of different vegetative species in attenuating waves) may help to identify more appropriate metrics and indicators for monitoring.

Seasonal and long-term variability of natural environmental systems also pose a significant barrier for monitoring NBS. Encouraging and highlighting case studies with long-term monitoring results (to avoid focusing on potentially misleading results indicative of short-term variability) may help to reduce this barrier. In addition, remote monitoring techniques may provide relatively cost- and time-efficient methods to capture seasonal and long-term variability of systems.

Emerging technologies, such as advances in remote sensing, earth observation systems, machine learning and big data, as well as low-cost instruments for community monitoring, may help us realize more opportunities for monitoring. Developing additional capacity related to new technology may also be beneficial.

Notably, amongst experts polled as part of the CEC workshop series on NBS (DHI 2022), a lack of funding for long-term monitoring and adaptive management was repeatedly highlighted as the major barrier to implementing NBS. Developing strategic, regional-level funding streams may help alleviate funding-related barriers to monitoring, as well as improving learning and promoting NBS uptake. Another alternative is for decision makers to make permitting, approvals, or funding contingent on the development and implementation of a monitoring program (Vouk et al. 2021). Additional institutional opportunities outlined in Box 4 relate to adjusting project requirements to include the development of monitoring plans and the dissemination of data, and to simplify the permitting process for NBS by creating streamlined pathways.

Box 4. Opportunities and future directions related to monitoring NBS, and the type of barrier that the opportunities address

Opportunities and Future Directions	Type of Barrier Addressed: Social	Technical	Environ.	Institut.
1. Host or fund sessions, workshops, and seminars on monitoring NBS, particularly highlighting the use of qualitative or participatory data.	✓	✓		✓
2. Develop short training programs (with easily accessible materials) for standard monitoring techniques, to build capacity within communities.	✓	✓		
3. Develop a centralized (industry-wide) database to host and disseminate monitoring data.	✓	✓		
4. Work to make existing/historical monitoring data publicly available.	✓	✓		
5. Develop and/or recognize specific technical standards and guidelines on monitoring NBS.		✓		✓
6. Include (and advocate for the inclusion of) training on monitoring and adaptive management within academic programs/degrees.		✓		
7. Develop a community of practice with experts spanning multiple disciplines, across multiple regions.		✓		
8. Encourage and highlight case-studies with negative outcomes.		✓		
9. Encourage and highlight case-studies with long-term monitoring results.		✓	✓	
10. Develop capacities around emerging technologies, such as remote monitoring (to reduce physical assess and logistics constraints).		✓	✓	
11. Emphasize adaptive management practices for long-term monitoring (within guidelines, applications, funding requirements, etc.).			✓	✓
12. Request consideration of monitoring and adaptive management within early project phases (i.e., within Requests for Proposals).				✓
13. Require project teams to commit to data distribution (regardless of project outcomes) within early project phases.				✓
14. Simplify permitting processes (i.e., provide expedited processes) for NBS construction, monitoring, and adaptive management.				✓
15. Develop regional-level funding streams for (long-term) monitoring, data analysis, and data dissemination, and adaptive management.				✓
16. Create funding streams for NBS pilot projects and projects with a high degree of adaptive management.				✓
17. Make permitting and approvals of all FrM projects contingent on proponents developing and implementing a monitoring program.	✓			✓
18. Develop specific funding opportunities that are contingent on proponents developing and implementing a monitoring program.	✓			✓

7 Conclusions

This document provides a synthesis of the monitoring process to evaluate the efficacy of projects featuring NBS within the context of FrM in Canada, Mexico, and the United States. Its focus is on the various administrative and technical considerations for developing a monitoring plan and on potential opportunities to alleviate information gaps and barriers to monitoring.

Monitoring is an essential component of the effective implementation of NBS, allowing for the assessment of project performance, co-benefits, and unintended impacts. It is also crucial to inform adaptive management strategies, provide a basis for future research and promote the uptake of NBS. Given the relevance of co-benefits in this case, the performance of NBS should be assessed from a wide perspective, by an interdisciplinary project team.

The monitoring process should start at the early stages of a project and continue long after its construction. Although the use of standardized methodologies and indicators and centralized knowledge bases and guidelines is recommended, the development of a monitoring plan should be tailored to each project considering the scale of the solution, the physical, social, and environmental settings, available funding, and how innovative or novel the solution is.

One of the main takeaways from this report is that collaboration and communication are key for advancing monitoring efforts for NBS. Expanding data access and dissemination is essential to build a strong foundation for future NBS and to promote them to the public at large. Collaboration both within a project and between various monitoring initiatives is key to reducing data collection costs and providing more meaningful information to NBS research and development projects.

Finally, there are numerous opportunities to advance NBS by removing barriers and data gaps related to monitoring. Expanding funding opportunities—such as creating additional funding streams for projects involving long-term monitoring, data analysis, data dissemination, and adaptive management—is essential to removing barriers to implementation of NBS.

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