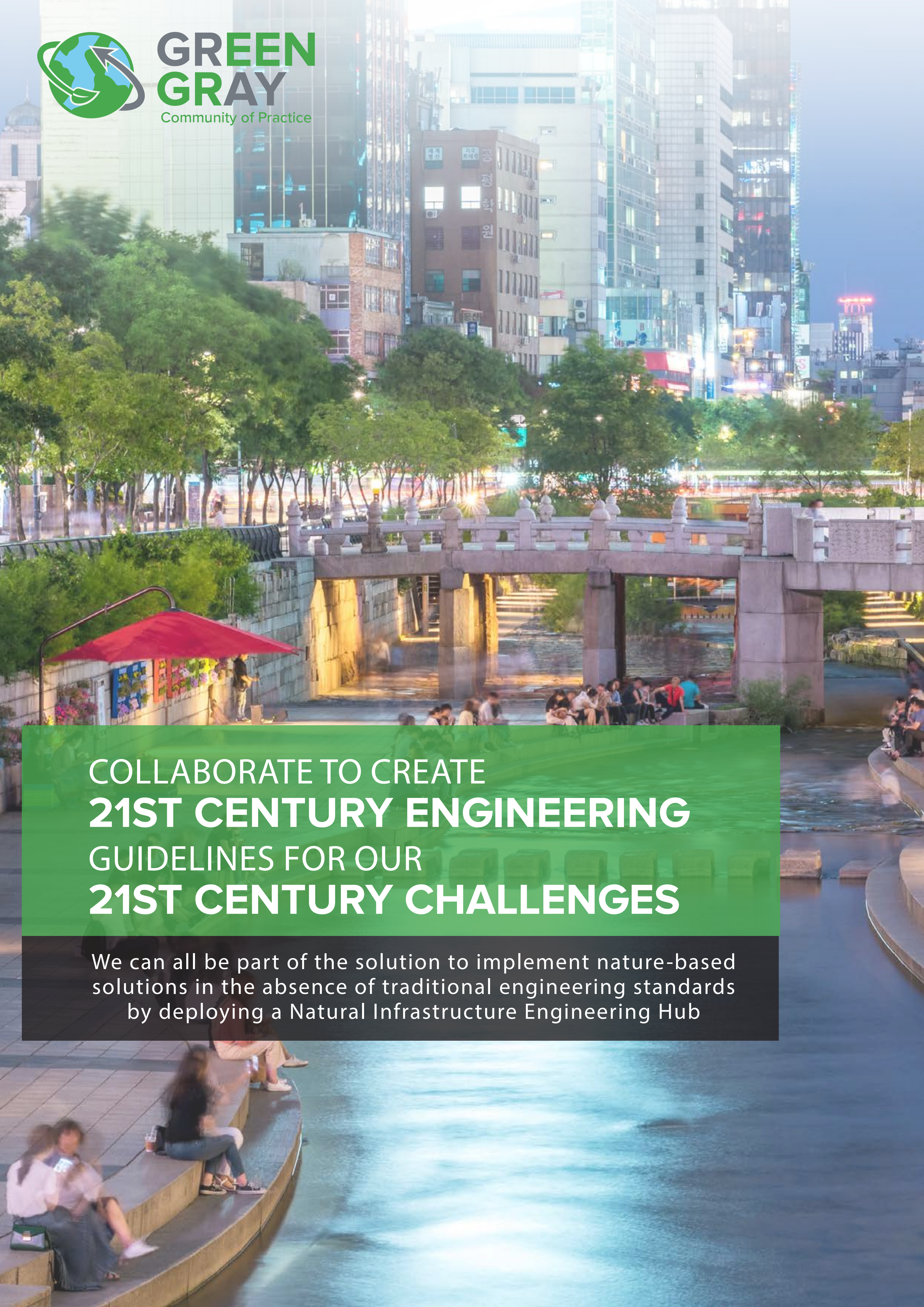


GREEN GRAY
Community of Practice

COLLABORATE TO CREATE **21ST CENTURY ENGINEERING** GUIDELINES FOR OUR **21ST CENTURY CHALLENGES**

We can all be part of the solution to implement nature-based solutions in the absence of traditional engineering standards by deploying a Natural Infrastructure Engineering Hub

ABSTRACT

In this era of ever-increasing weather and climate disasters nature-based solutions, like hybrid green-gray infrastructure, hold incredible promise as a climate adaptation solution, but accepted norms and engineering standards are a key barrier limiting applications.

Creating the next generation of climate resilient infrastructure will require the engineering and construction industry to design and build with nature. We need to continue **learning by doing** and accept that the complexity of nature-based solutions requires flexible design approaches– versus rigid standards.

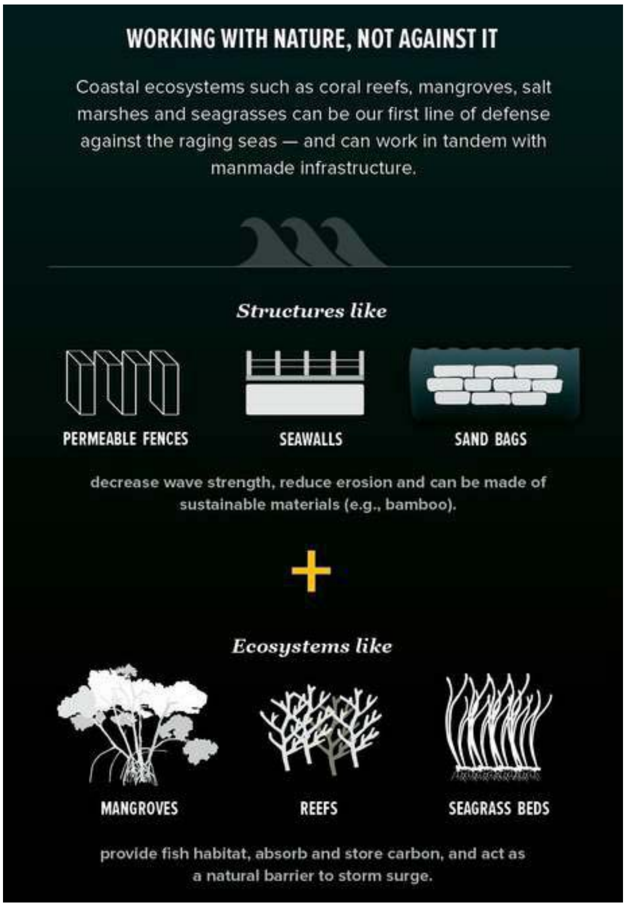
The increasing pace and intensity of climate threats means we do not have time to develop accepted engineering standards for nature-based solutions the way we have in the previous millennia.

The current approach to evidence-based decision making for nature-based solutions is at best – project, region, or problem specific. At worst, it is non-existent or proprietary. Regular monitoring of infrastructure performance and impacts is necessary to **generate data, which should be available to all stakeholders.**

The future is now – we won't have all the answers before it is time to act. **There are many existing guides and resources that give trained engineers enough information to innovate nature-based solutions now.**

We can collaborate across disciplines and geographies to design a modern data sharing platform for users to input technical knowledge and data about nature-based solutions projects. The platform would be open-access – making data and resources broadly and equitably available – while providing a real-time feedback loop from practitioners to designers, planners, and financiers.

The **resulting Natural Infrastructure Engineering Hub** would become a resource internationally for how to design, build, monitor, measure, maintain and adaptively manage nature-based engineering solutions.



SUGGESTED CITATION: Global Green-Gray Community of Practice. 2022. Collaborate to create 21st century engineering guidelines for our 21st century challenges.

COVER PHOTO CREDITS: Luke Porter / Unsplash

NATURAL INFRASTRUCTURE ENGINEERING HUB

With data inputs and outputs translated into multiple language

PORTALS TO SPECIFIC NATURE-BASED INFRASTRUCTURE SOLUTIONS

- MANGROVES & SEAWALLS
- LIVING SHORELINES
- HORIZONTAL LEVEES
- BIOENGINEERING FOR ROAD STABILIZATION
- AND MORE ...

Identify specific hazards for which each nature-based solution in the Hub can increase resilience.

EACH NBS PORTAL INCLUDES ...

CURATED LIBRARY
Assemble and disseminate annotated resources.

Engineering Guidance
including project plans and specifications to increase confidence in outcomes

Case Study Narratives
to communicate the intrinsic value of projects to sustainable development

Key Performance Indicators
to create consistency within the platform and efficient monitoring and evaluation programs

Cost-Benefit-Analysis Input Data and Outputs
to build a database of social, economic, and environmental costs and benefits

INVESTOR MARKETPLACE
Transparant and consolidated information for investors and funders.

Pipeline of Projects
to connect project developers with financiers in a type of project "match-making" service

Defined Financial Metrics
to measure asset performance and benchmark projects against each other

MONITORING & EVALUATION DATA
Publicly accessible data managment and storage repository enabling citizen science inputs

Data Accessibility
to address climate justice with data and resources broadly and equitably available with open-access to all

Project Performance Data
to collect monitoring data linked to key performance indicators, and environmental, social, and economic costs and benefits

Project Finance Data
to collect data about project deals, costs, and savings

REAL-TIME FEEDBACK LOOP
Regularly aggregated data enabling powerful interdependency assessments so we can learn from and share successes - and failures - widely.

Project Performance
to identify common themes, outcomes, findings, and update best practice guidance for design and implementation

Market Trends
to make information about project business models, market size and growth publicly available

Proposed Natural Infrastructure Engineering Hub portals and information gateways.

ABOUT CONSERVATION INTERNATIONAL

Founded in 1987, Conservation International works to spotlight and secure the critical benefits that nature provides to humanity. Since our inception, we have helped to protect more than 6 million square kilometers of land and sea across more than 70 countries. Currently with more than 1,000 staff working through offices in 29 countries, and with 2,000 partner organizations worldwide, our reach is truly global, as shown in Figure 1. Our careful stewardship of contributions and our emphasis on programmatic impact have allowed us to consistently earn the highest ratings for efficiency, effectiveness, and transparency from watchdog groups such as Charity Navigator.

CI's green-gray infrastructure program incorporates ecosystem restoration and conservation into climate adaptation-focused infrastructure projects to maximize benefits to nature for the well-being of humanity. CI's unique and valuable experience with ecosystem conservation and restoration, community co-design, and stakeholder leadership allows us to advise and lead green-gray initiatives around the world in collaboration with local, regional and national governments and engineering partners.

In addition to our leadership of the Global Green-Gray Infrastructure Community of Practice, CI is a leader in green-gray infrastructure design and implementation in vulnerable coastal communities. In 2015, CI-Philippines initiated a Green-Gray Infrastructure program providing disaster risk reduction and climate change adaptation strategies and solutions to five vulnerable coastal communities, with approximately 13,500 people. CI has also developed an innovative Climate Smart Shrimp model to access shrimp aquaculture as a sustained revenue stream for green-gray mangrove restoration initiatives. In 2022, we will construct a pilot of the model in Indonesia and are identifying barriers and opportunities to scale the model globally.

CONSERVATION INTERNATIONAL

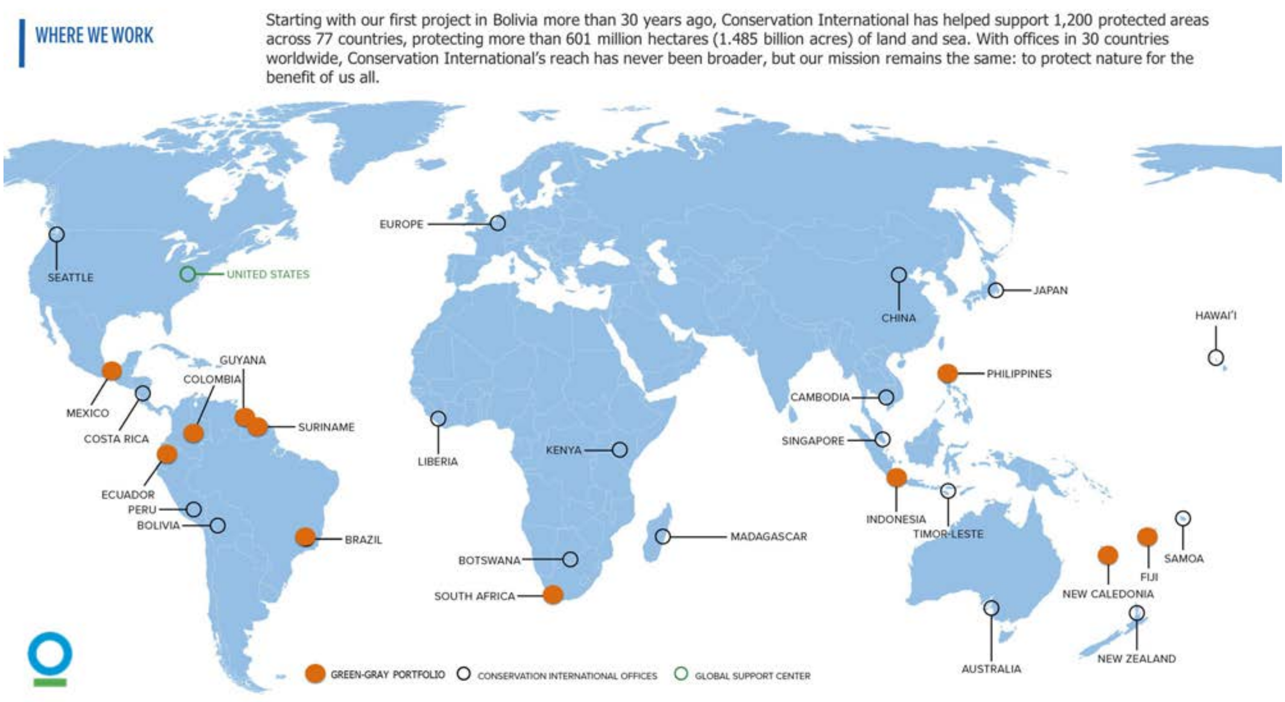


Figure 1. This map shows Conservation International country offices. Orange circles designate country programs in different stages of developing or implementing green-gray projects, programs, or policies.

PROBLEM STATEMENT

We live in an era of ever-increasing weather and climate disasters. By 2050, nearly 20% of the world's population will be at risk of floods and up to 5.7 billion people will live in water-scarce areas.[1] Simultaneously, biodiversity is declining at unprecedented rates and species extinctions continue to accelerate - threatening the functioning of ecosystems – that human livelihoods, economies, food security, and much more depend upon.

As the pressure to adapt increases, infrastructure costs are expected to equal 80% of total climate change adaptation spending globally – estimated at 150 to 450 billion USD per year in 2050.[2] And there is increasing demand for engineers and contractors to deliver sustainable and resilient infrastructure.

In a review of hundreds of 'nature-based infrastructure' (NBI) projects, the International Institute for Sustainable Development (IISD) calculated that NBI can be up to 50% cheaper than traditional gray infrastructure and provide 28% better value for money. Replacing just 11% of current global infrastructure needs with NBI could save 248 billion USD each year.[3]

There are a range of potential solutions that we can use to address our climate challenges. In our most built environments a gray-only solution, like sea walls, may be most appropriate – and on the other end of the spectrum, a purely green solution, like mangrove restoration, may be best. Green-gray infrastructure is a nature-based solution that draws upon the best of our engineering achievements to create hybrid solutions along this spectrum (Figure 2).

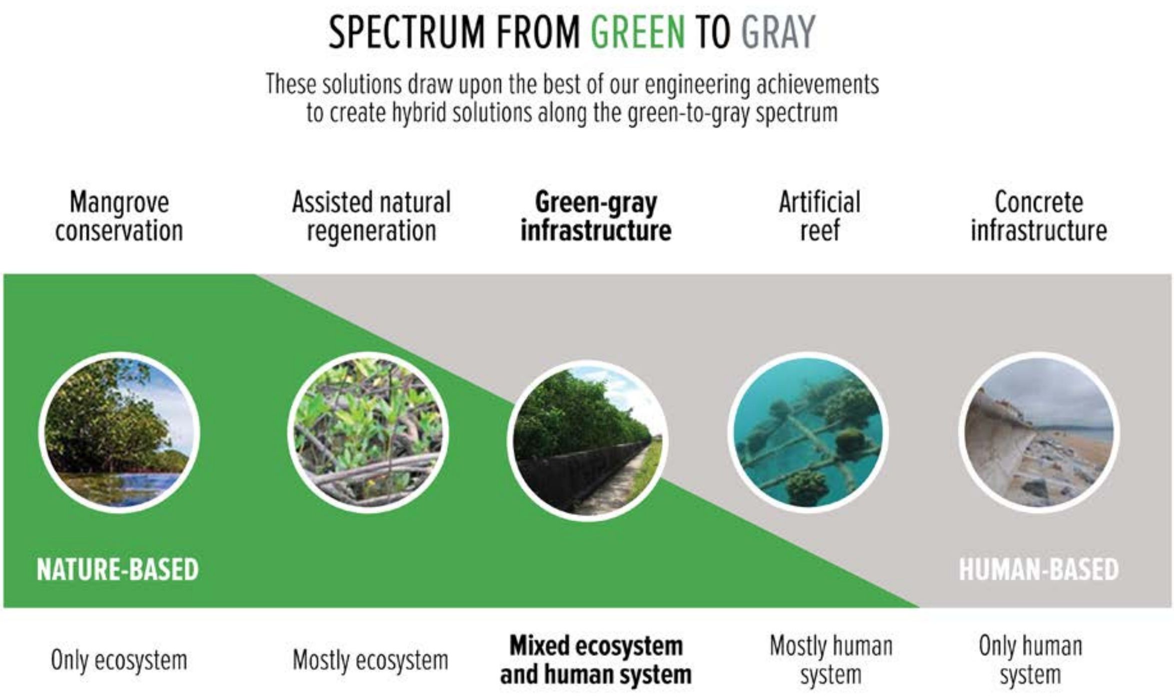


Figure 2. The combination of ecosystem restoration and conservation with built infrastructure (termed "green-gray infrastructure") is a type of nature-based solution that balances the challenges of investing in either separately while maximizing the positive effects on climate resilience, biodiversity conservation and human well-being.

1 World Bank and World Resources Institute (2019). Integrating Green and Gray: Creating Next Generation Infrastructure. Washington, DC.

2 United Nations Environment Programme. (2018) The Adaptation Gap Report 2018. Nairobi, Kenya.

3 Andrea M. Bassi, Ronja Bechauf, Liesbeth Casier, and Emma Cutler (2021). How Can Investment in Nature Close the Infrastructure Gap?

Conservation International's green-gray program is working to fundamentally transform the engineering and construction industry to design and build with nature – to create the next generation of climate resilient infrastructure.

Four key barriers to achieving this goal:

1. Engineers, developers, industry, and governments lack experience, familiarity and, consequently, confidence in the reliability and application of green-gray approaches which can limit the ability to get project approved or to recieve professional liability insurance;
2. Technical knowledge and data needed to standardize reliable green-gray solutions is not broadly or equitably available;
3. Most infrastructure policies and regulations do not currently incentivize green-gray solutions; and
4. Real and perceived risks constrain investments in developing economies despite significant opportunities for achieving social, economic, and climate mitigation and adaptation objectives at a competitive cost.

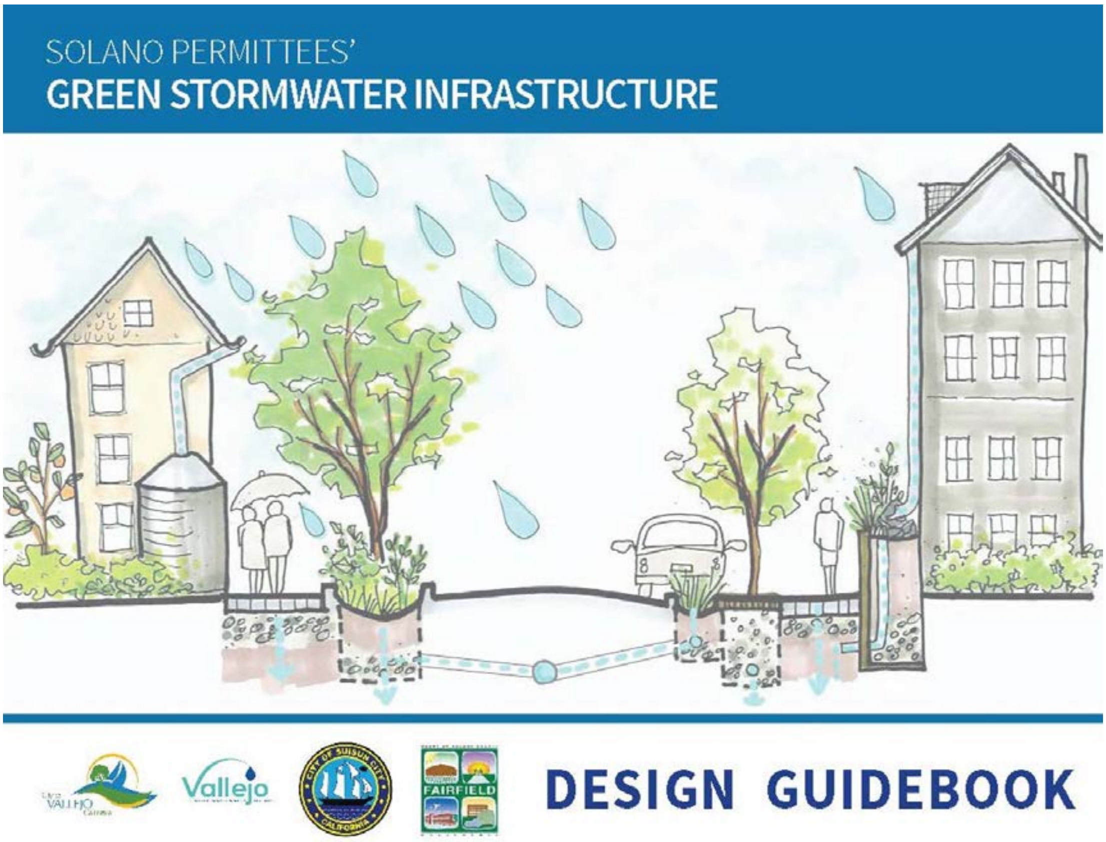
The purpose of this paper is to propose a strategy and solution to address the first two of these key barriers and accelerate the process of developing engineering standards for new and innovative nature-based solutions.

WHAT IS AN ENGINEERING DESIGN STANDARD?

Generically descriptive methods is a type of design guidance that includes a description of the approach (the purpose, benefits and constraints) and general design principles (about the sizing, operation and maintenance requirements, and costs) and engineering standards additionally include design details (usually drawn in AutoCAD) and design specifications (which are word document with detailed instructions for the builder). Engineering standards are a key component of decision-making, especially at the every-day level of practicing engineers.

Across geographies and project types there is flexibility in what level of detail is included in an engineering manual or a guidebook. Engineering practice – generally – is driven by codes and standards with prescriptive requirements where each component of a project is built to a certain standard. Compare that to a performance-based approach where all the elements in a project work together to perform to a certain standard.

This is an example design standard from a design guidebook for green stormwater infrastructure developed by an alliance of municipalities in the San Francisco Bay, California, USA.



#1. Started by defining typologies...

2. Green Stormwater Infrastructure Types

GREEN STORMWATER INFRASTRUCTURE CLASSIFICATIONS

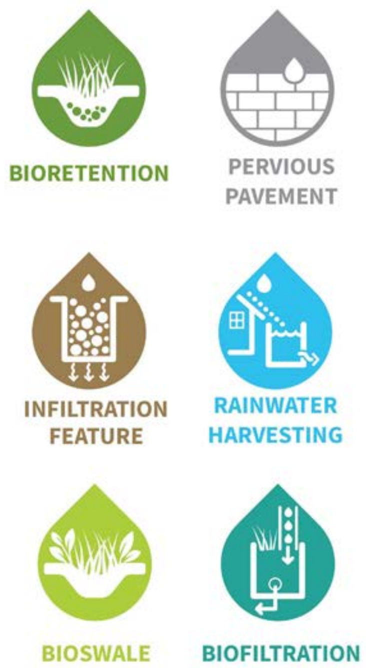
For the purposes of organizing and presenting information, this Design Guidebook classifies green stormwater infrastructure structures into six categories. Any existing or proposed green stormwater infrastructure feature can be identified as one of these six types: a bioretention feature, an infiltration feature, pervious pavement, rainwater harvesting, a bioswale or a biofiltration feature.

There are other common terms associated with green stormwater infrastructure, like "curb cuts", that are specific design elements that can be associated with many different green stormwater infrastructure types. Another example is the term "rain garden", which is a type of bioretention where stormwater can infiltrate into the subsurface soils. Biofiltration is another type of bioretention with an impermeable or concrete liner with an underdrain (pervious) pipe.

These definitions are consistent throughout the Solano Permittees' green stormwater infrastructure programs, including within the Green Infrastructure Plans and pollutant load models.

Several of these Green Stormwater Infrastructure strategies can be combined into a treatment train to meet stormwater requirements and project goals, depending on what is best suited for a particular project and site. In this context, treatment train refers to GSI in series so overflow, for example, from a biofiltration may flow into a bioretention which may flow into a bioswale. Throughout this Design Guidebook the icons to the right are used to identify different types of Green Stormwater Infrastructure as they are represented within right-of-way improvements or parking lots (Chapter 3) or specific design details (Chapter 4).

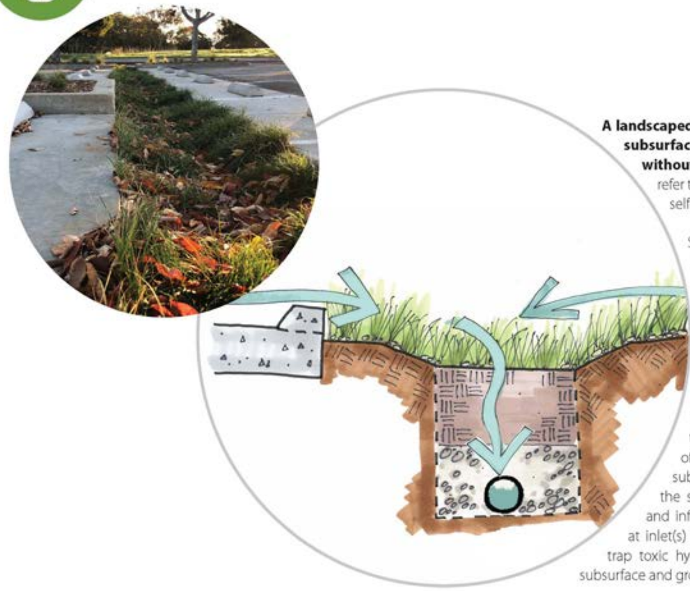
> Bioswales and pervious pavements will have limited applicability towards meeting a Regulated Project's stormwater requirements, and are recommended to "treat" impervious area at a 2:1 ratio of pervious to impervious surface..



#2. Then described the approaches...

2. Green Stormwater Infrastructure Types

BIORETENTION



A landscaped feature that allows for infiltration into subsurface soils and can be constructed with or without side walls. Other common terms used to refer to bioretention features include rain gardens, self-retaining areas, or biofilters.

Stormwater typically is designed to pond up to 6 inches prior to outflow via a surface outlet (e.g., curb cut) or a piped overflow (e.g., overflow inlet and/or underdrain). Bioretention features may or may not include a perforated underdrain. Bioretention structures are constructed with a specialized soil media ideally 18-24 inches in depth to enhance biogeochemical processes to retain and transform pollutants, and infiltrate at a rate of 5 inches per hour. A rock or aggregate subsurface reservoir can be included under the soil media to enhance stormwater storage and infiltration. A settling forebay can be located at inlet(s) to remove sediment. Bioretention features trap toxic hydrocarbons and asbestos before reaching subsurface and groundwater supplies.

#3. Provided general design principles...

3. Streetscape and Project Design Guidelines

Design Considerations

Stormwater curb extension sizing should allow for safe overflow during large storm events to minimize flooding into the roadway, which can create hazards for street users.

Plants in curb extensions should not grow taller than 24 inches above the sidewalk grade to maintain sight clearance in the right of way.

Curb extensions are typically recessed 1-2 feet from the outside edge of the right-most travel lane, though width may be adjusted based on site specific considerations.

The angle of the curb extension where it joins the original curb should be angled between 30 to 60 degrees to allow for mechanical street sweeping.

Inlets and outlets should be designed to avoid vehicle and bicycle wheels entering the openings.

A pre-settling zone, or energy dissipation area, should be incorporated at any locations where high energy flows are expected to enter the GSI.

While ensuring that emergency responders maintain adequate access, stormwater curb extensions can be located in areas where on-street parking is already prohibited, such as near fire hydrants or driveway setbacks.

#4. Typical Design details and notes...

4. Green Stormwater Infrastructure Standard Specification and Design Details

PURPOSE:

BIORETENTION BASINS CONTROL PEAK FLOWS AND VOLUMES OF STORMWATER RUNOFF BY PROVIDING SURFACE, SUBSURFACE STORAGE AND INFILTRATION INTO NATIVE SOIL. WATER IS ALSO TREATED AS IT FILTERS THROUGH THE BIORETENTION SOIL.

RELATED SPECIFICATIONS	CSI NO.
BIORETENTION: - BIORETENTION SOIL MIX - AGGREGATE STORAGE - MULCH - STREAMBED COBBLES	33 47 27

RELATED COMPONENTS	
UNDERDRAINS:	2.0 - 2.1
INLETS:	3.0 - 3.2
OUTLETS:	4.0 - 4.3

DESIGNER NOTES & GUIDELINES:

1. THE DESIGNER MUST ADAPT PLAN AND SECTION DRAWINGS TO ADDRESS SITE-SPECIFIC CONDITIONS.
2. FACILITY AREA, PONDING DEPTH, BIORETENTION SOIL DEPTH, AND AGGREGATE STORAGE DEPTH MUST BE SIZED TO MEET PROJECT HYDROLOGIC PERFORMANCE GOALS.
3. PONDING AND BIORETENTION SOIL DRAWDOWN TIME (I.E., TIME FOR MAXIMUM SURFACE PONDING TO DRAIN THROUGH THE BIORETENTION SOIL AFTER THE END OF A STORM) RECOMMENDATIONS:
   - 3 - 12 HOUR PONDING AND BIORETENTION SOIL DRAWDOWN (TYPICAL)
   - 24 HOUR MAXIMUM PONDING AND BIORETENTION SOIL DRAWDOWN
4. FACILITY DRAWDOWN TIME (I.E. TIME FOR SURFACE PONDING TO DRAIN THROUGH THE ENTIRE SECTION INCLUDING AGGREGATE STORAGE AFTER THE END OF A STORM) REQUIREMENTS:
   - 48 HOUR MAXIMUM FACILITY DRAWDOWN (I.E. ORFICE CONTROLLED SYSTEM OR EXTENDED STORAGE DEPTH WITHIN INFILTRATION SYSTEM).
5. THE FOLLOWING GUIDELINES APPLY TO RIGHT-OF-WAY APPLICATIONS:
   - BULB OUT CURB TRANSITIONS SHALL CONFORM TO CITY STANDARDS.
   - WHEN FACILITY CONSTRUCTION IMPACTS EXISTING SIDEWALK, ALL SAW CUTS MUST ADHERE TO CITY REQUIREMENTS. SAW CUTS SHOULD BE ALONG SCORE LINES AND ANY DISTURBED SIDEWALK FLAGS SHOULD BE REPLACED IN THEIR ENTIRETY.
   - DESIGNER TO SPECIFY TRANSITION OF PLANTER TO TOP OF CURB ELEVATION BETWEEN CURB CUTS OR CONTINUOUS 6 INCH REVEAL AT CURB EDGE.
6. UP TO TWO PLANTERS MAY BE CONNECTED IN SERIES, IN LIEU OF MULTIPLE INLETS, PROVIDED THE CONNECTION IS A TRENCH DRAIN OR EQUAL SURFACE CONVEYANCE AND IS ADEQUATELY SIZED TO CONVEY FLOWS.
7. MINIMUM UTILITY SETBACKS AND PROTECTION MEASURES MUST CONFORM TO CURRENT CITY ASSET PROTECTION STANDARDS AND OTHER UTILITY PROVIDERS REQUIREMENTS.

DESIGNER CHECKLIST
(MUST SPECIFY, AS APPLICABLE):

- ☐ FACILITY WIDTH, LENGTH, SLOPES (INCLUDING SIDE, CROSS, AND LONGITUDINAL), AND SHAPE
- ☐ DEPTH OF BIORETENTION SOIL
- ☐ DEPTH AND TYPE OF GRAVEL STORAGE, IF ANY
- ☐ PLANTER SURFACE ELEVATION (TOP OF BIORETENTION SOIL) AT UPSLOPE AND DOWNSLOPE ENDS OF FACILITY
- ☐ CONTROL POINTS AT EVERY CORNER OF FACILITY AND POINT OF TANGENCY
- ☐ DIMENSIONS AND DISTANCE TO EVERY INLET, OUTLET, SIDEWALK NOTCH, ETC.
- ☐ ELEVATIONS OF EVERY INLET, OUTLET, STRUCTURE RIM AND INVERT, AND SIDEWALK NOTCH
- ☐ TYPE AND DESIGN OF FACILITY COMPONENTS (E.G., EDGE TREATMENTS, INLETS/GUTTER MODIFICATIONS, UTILITY CROSSINGS, LINER, AND PLANTING DETAILS)

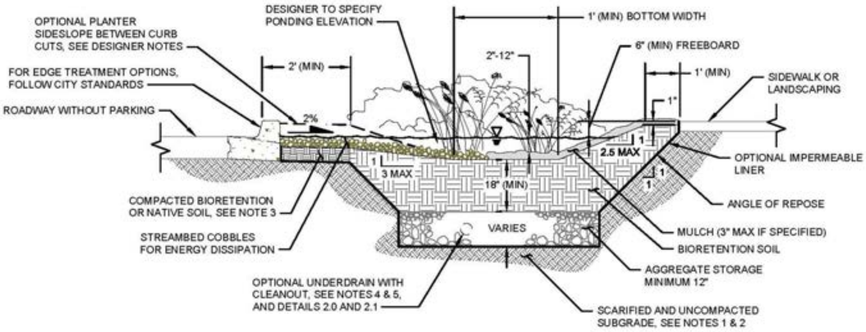
LAYOUT REQUIREMENTS:

1. FOR RIGHT-OF-WAY APPLICATIONS, REFER TO THE CITY STANDARD ACCESSIBILITY REQUIREMENTS FOR CONSTRUCTION OF COURTESY STRIP, THROUGHWAY, PARKING SPACE AND ACCESSIBLE PATH REQUIREMENTS.
2. LOCATE CURB CUTS AND GUTTER MODIFICATIONS TO AVOID CONFLICTS WITH ACCESSIBILITY REQUIREMENTS (E.G., LOCATE OUTSIDE OF CROSSWALKS).

NOT FOR CONSTRUCTION

BIORETENTION & BIOINFILTRATION BASINS DESIGNER NOTES	1.0

4. Green Stormwater Infrastructure Standard Specification and Design Details



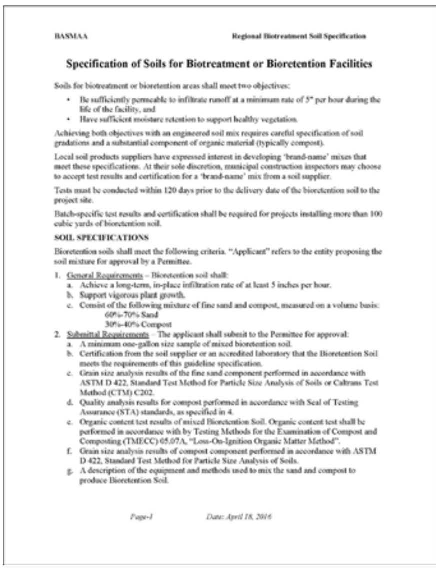
CONSTRUCTION NOTES:

1. AVOID COMPACTION OF EXISTING SUBGRADE BELOW BASIN.
2. SCARIFY SUBGRADE TO A DEPTH OF 3 INCHES (MIN) IMMEDIATELY PRIOR TO PLACEMENT OF AGGREGATE STORAGE AND BIORETENTION SOIL MATERIALS.
3. COMPACT BIORETENTION SOIL IMMEDIATELY BEHIND CURB TO 90% OF MAXIMUM DENSITY PER STANDARD PROCTOR TEST (ASTM D698).
4. UNDERDRAIN REQUIRED FOR ALL FACILITIES WITH IMPERMEABLE LINER.
5. PROVIDE ONE CLEANOUT PER PLANTER (MIN) FOR FACILITIES WITH UNDERDRAINS. CLEANOUT MUST CONSIST OF A VERTICAL, RIGID, NON-PERFORATED PVC PIPE, WITH A MINIMUM DIAMETER OF 4-INCHES AND A WATERTIGHT CAP.
6. MINIMUM UTILITY SETBACKS AND PROTECTION MEASURES MUST CONFORM TO CURRENT CITY STANDARDS. COORDINATE WITH ENGINEER IN THE EVENT OF UTILITY CROSSING AND UTILITY CONFLICTS.

NOT FOR CONSTRUCTION

BIORETENTION & BIOINFILTRATION BASINS ROADSIDE SECTION	1.1

#5. And finally, specifications



BASMAA Regional Biotreatment Soil Specification

Specification of Soils for Biotreatment or Bioretention Facilities

Soils for biotreatment or bioretention areas shall meet two objectives:

- Be sufficiently permeable to infiltrate runoff at a minimum rate of 5" per hour during the life of the facility, and
- Have sufficient moisture retention to support healthy vegetation.

Achieving both objectives with an engineered soil mix requires careful specification of soil gradations and a substantial component of organic material (typically compost).

Local soil products suppliers have expressed interest in developing 'brand-name' mixes that meet these specifications. At their sole discretion, municipal construction inspectors may choose to accept test results and certification for a 'brand-name' mix from a soil supplier.

Tests must be conducted within 120 days prior to the delivery date of the bioretention soil to the project site.

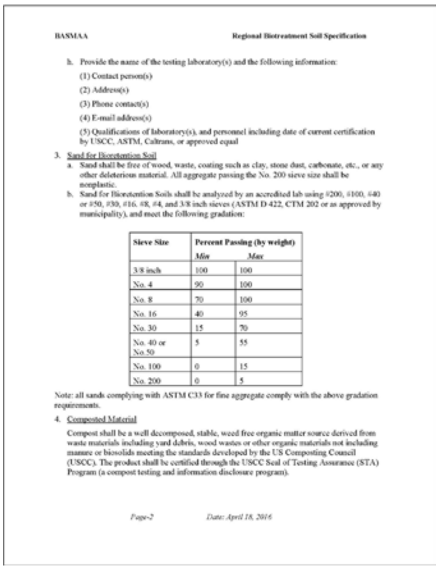
Batch-specific test results and certification shall be required for projects installing more than 100 cubic yards of bioretention soil.

SOIL SPECIFICATIONS

Bioretention soils shall meet the following criteria. "Applicant" refers to the entity proposing the soil mixture for approval by a Permittee.

1. General Requirements – Bioretention soil shall:
   a. Achieve a long-term, in-place infiltration rate of at least 5 inches per hour.
   b. Support vigorous plant growth.
   c. Consist of the following mixture of fine sand and compost, measured on a volume basis:
      60%-70% Sand
      30%-40% Compost
2. Submittal Requirements – The applicant shall submit to the Permittee for approval:
   a. A minimum one-gallon size sample of mixed bioretention soil.
   b. Certification from the soil supplier or an accredited laboratory that the Bioretention Soil meets the requirements of this guideline specification.
   c. Grain size analysis results of the fine sand component performed in accordance with ASTM D 422, Standard Test Method for Particle Size Analysis of Soils or Caltrans Test Method (CTM) C202.
   d. Quality analysis results for compost performed in accordance with Seal of Testing Assurance (STA) standards, as specified in 4.
   e. Organic content test results of mixed Bioretention Soil. Organic content test shall be performed in accordance with by Testing Methods for the Examination of Compost and Composting (TMECC) 05.07A, "Loss-On-Ignition Organic Matter Method".
   f. Grain size analysis results of compost component performed in accordance with ASTM D 422, Standard Test Method for Particle Size Analysis of Soils.
   g. A description of the equipment and methods used to mix the sand and compost to produce Bioretention Soil.

Page-1 Date: April 18, 2016



BASMAA Regional Biotreatment Soil Specification

   h. Provide the name of the testing laboratory(s) and the following information:
      (1) Contact person(s)
      (2) Address(s)
      (3) Phone contact(s)
      (4) E-mail address(s)
      (5) Qualifications of laboratory(s), and personnel including date of current certification by USCC, ASTM, Caltrans, or approved equal
3. Sand for Bioretention Soil
   a. Sand shall be free of wood, waste, coating such as clay, stone dust, carbonate, etc., or any other deleterious material. All aggregate passing the No. 200 sieve size shall be nonplastic.
   b. Sand for Bioretention Soils shall be analyzed by an accredited lab using #200, #100, #40 or #50, #30, #16, #8, #4, and 3/8 inch sieves (ASTM D 422, CTM 202 or as approved by municipality), and meet the following gradation:

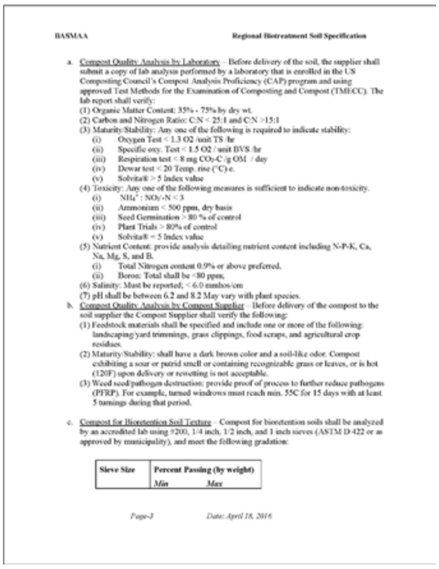
Sieve Size	Percent Passing (by weight)	
	Min	*Max*
3/8 inch	100	100
No. 4	90	100
No. 8	70	100
No. 16	40	95
No. 30	15	70
No. 40 or No. 50	5	55
No. 100	0	15
No. 200	0	5

Note: all sands complying with ASTM C33 for fine aggregate comply with the above gradation requirements.

4. Composted Material

   Compost shall be a well decomposed, stable, weed free organic matter source derived from waste materials including yard debris, wood wastes or other organic materials not including manure or biosolids meeting the standards developed by the US Composting Council (USCC). The product shall be certified through the USCC Seal of Testing Assurance (STA) Program (a compost testing and information disclosure program).

Page-2 Date: April 18, 2016

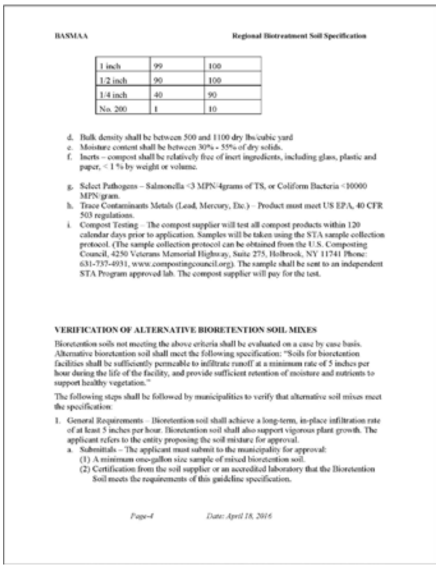


BASMAA Regional Biotreatment Soil Specification

   a. Compost Quality Analysis by Laboratory – Before delivery of the soil, the supplier shall submit a copy of lab analysis performed by a laboratory that is enrolled in the US Composting Council's Compost Analysis Proficiency (CAP) program and using approved Test Methods for the Examination of Composting and Compost (TMECC). The lab report shall verify:
      (1) Organic Matter Content: 35% - 75% by dry wt.
      (2) Carbon and Nitrogen Ratio: C:N < 25:1 and C:N >15:1
      (3) Maturity/Stability: Any one of the following is required to indicate stability:
         (i) Oxygen Test < 1.3 O2 /unit TS /hr
         (ii) Specific oxy. Test < 1.5 O2 / unit BVS /hr
         (iii) Respiration test < 8 mg CO_2-C /g OM / day
         (iv) Dewar test < 20 Temp. rise (°C) e.
         (v) Solvita® > 5 Index value
      (4) Toxicity: Any one of the following measures is sufficient to indicate non-toxicity.
         (i) NH_4^+ : NO_3^--N < 3
         (ii) Ammonium < 500 ppm, dry basis
         (iii) Seed Germination > 80 % of control
         (iv) Plant Trials > 80% of control
         (v) Solvita® = 5 Index value
      (5) Nutrient Content: provide analysis detailing nutrient content including N-P-K, Ca, Na, Mg, S, and B.
         (i) Total Nitrogen content 0.9% or above preferred.
         (ii) Boron: Total shall be <80 ppm;
      (6) Salinity: Must be reported; < 6.0 mmhos/cm
      (7) pH shall be between 6.2 and 8.2 May vary with plant species.
   b. Compost Quality Analysis by Compost Supplier – Before delivery of the compost to the soil supplier the Compost Supplier shall verify the following:
      (1) Feedstock materials shall be specified and include one or more of the following: landscaping/yard trimmings, grass clippings, food scraps, and agricultural crop residues.
      (2) Maturity/Stability: shall have a dark brown color and a soil-like odor. Compost exhibiting a sour or putrid smell or containing recognizable grass or leaves, or is hot (120F) upon delivery or rewetting is not acceptable.
      (3) Weed seed/pathogen destruction: provide proof of process to further reduce pathogens (PFRP). For example, turned windrows must reach min. 55C for 15 days with at least 5 turnings during that period.
   c. Compost for Bioretention Soil Texture – Compost for bioretention soils shall be analyzed by an accredited lab using #200, 1/4 inch, 1/2 inch, and 1 inch sieves (ASTM D 422 or as approved by municipality), and meet the following gradation:

Sieve Size	Percent Passing (by weight)	
	Min	*Max*

Page-3 Date: April 18, 2016



BASMAA Regional Biotreatment Soil Specification

1 inch	99	100
1/2 inch	90	100
1/4 inch	40	90
No. 200	1	10

   d. Bulk density shall be between 500 and 1100 dry lbs/cubic yard
   e. Moisture content shall be between 30% - 55% of dry solids.
   f. Inerts – compost shall be relatively free of inert ingredients, including glass, plastic and paper, < 1 % by weight or volume.
   g. Select Pathogens – Salmonella <3 MPN/4grams of TS, or Coliform Bacteria <10000 MPN/gram.
   h. Trace Contaminants Metals (Lead, Mercury, Etc.) – Product must meet US EPA, 40 CFR 503 regulations.
   i. Compost Testing – The compost supplier will test all compost products within 120 calendar days prior to application. Samples will be taken using the STA sample collection protocol. (The sample collection protocol can be obtained from the U.S. Composting Council, 4250 Veterans Memorial Highway, Suite 275, Holbrook, NY 11741 Phone: 631-737-4931, www.compostingcouncil.org). The sample shall be sent to an independent STA Program approved lab. The compost supplier will pay for the test.

VERIFICATION OF ALTERNATIVE BIORETENTION SOIL MIXES

Bioretention soils not meeting the above criteria shall be evaluated on a case by case basis. Alternative bioretention soil shall meet the following specification: "Soils for bioretention facilities shall be sufficiently permeable to infiltrate runoff at a minimum rate of 5 inches per hour during the life of the facility, and provide sufficient retention of moisture and nutrients to support healthy vegetation."

The following steps shall be followed by municipalities to verify that alternative soil mixes meet the specification:

1. General Requirements – Bioretention soil shall achieve a long-term, in-place infiltration rate of at least 5 inches per hour. Bioretention soil shall also support vigorous plant growth. The applicant refers to the entity proposing the soil mixture for approval.
   a. Submittals – The applicant must submit to the municipality for approval:
      (1) A minimum one-gallon size sample of mixed bioretention soil.
      (2) Certification from the soil supplier or an accredited laboratory that the Bioretention Soil meets the requirements of this guideline specification.

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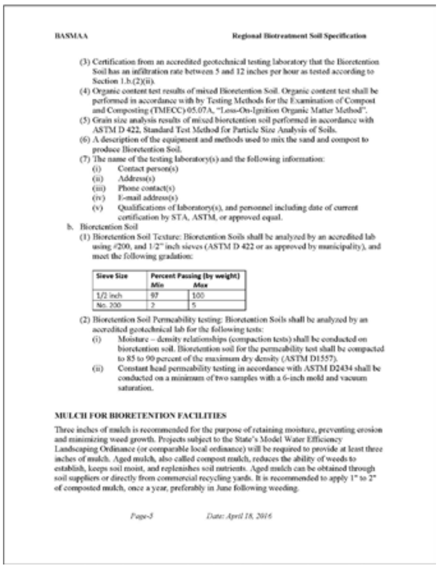

BASMAA Regional Biotreatment Soil Specification

      (3) Certification from an accredited geotechnical testing laboratory that the Bioretention Soil has an infiltration rate between 5 and 12 inches per hour as tested according to Section 1.b.(2)(ii).
      (4) Organic content test results of mixed Bioretention Soil. Organic content test shall be performed in accordance with by Testing Methods for the Examination of Compost and Composting (TMECC) 05.07A, "Loss-On-Ignition Organic Matter Method".
      (5) Grain size analysis results of mixed bioretention soil performed in accordance with ASTM D 422, Standard Test Method for Particle Size Analysis of Soils.
      (6) A description of the equipment and methods used to mix the sand and compost to produce Bioretention Soil.
      (7) The name of the testing laboratory(s) and the following information:
         (i) Contact person(s)
         (ii) Address(s)
         (iii) Phone contact(s)
         (iv) E-mail address(s)
         (v) Qualifications of laboratory(s), and personnel including date of current certification by STA, ASTM, or approved equal.
   b. Bioretention Soil
      (1) Bioretention Soil Texture: Bioretention Soils shall be analyzed by an accredited lab using #200, and 1/2" inch sieves (ASTM D 422 or as approved by municipality), and meet the following gradation:

Sieve Size	Percent Passing (by weight)	
	Min	*Max*
1/2 inch	97	100
No. 200	2	5

      (2) Bioretention Soil Permeability testing: Bioretention Soils shall be analyzed by an accredited geotechnical lab for the following tests:
         (i) Moisture – density relationships (compaction tests) shall be conducted on bioretention soil. Bioretention soil for the permeability test shall be compacted to 85 to 90 percent of the maximum dry density (ASTM D1557).
         (ii) Constant head permeability testing in accordance with ASTM D2434 shall be conducted on a minimum of two samples with a 6-inch mold and vacuum saturation.

MULCH FOR BIORETENTION FACILITIES

Three inches of mulch is recommended for the purpose of retaining moisture, preventing erosion and minimizing weed growth. Projects subject to the State's Model Water Efficiency Landscaping Ordinance (or comparable local ordinance) will be required to provide at least three inches of mulch. Aged mulch, also called compost mulch, reduces the ability of weeds to establish, keeps soil moist, and replenishes soil nutrients. Aged mulch can be obtained through soil suppliers or directly from commercial recycling yards. It is recommended to apply 1" to 2" of composted mulch, once a year, preferably in June following weeding.

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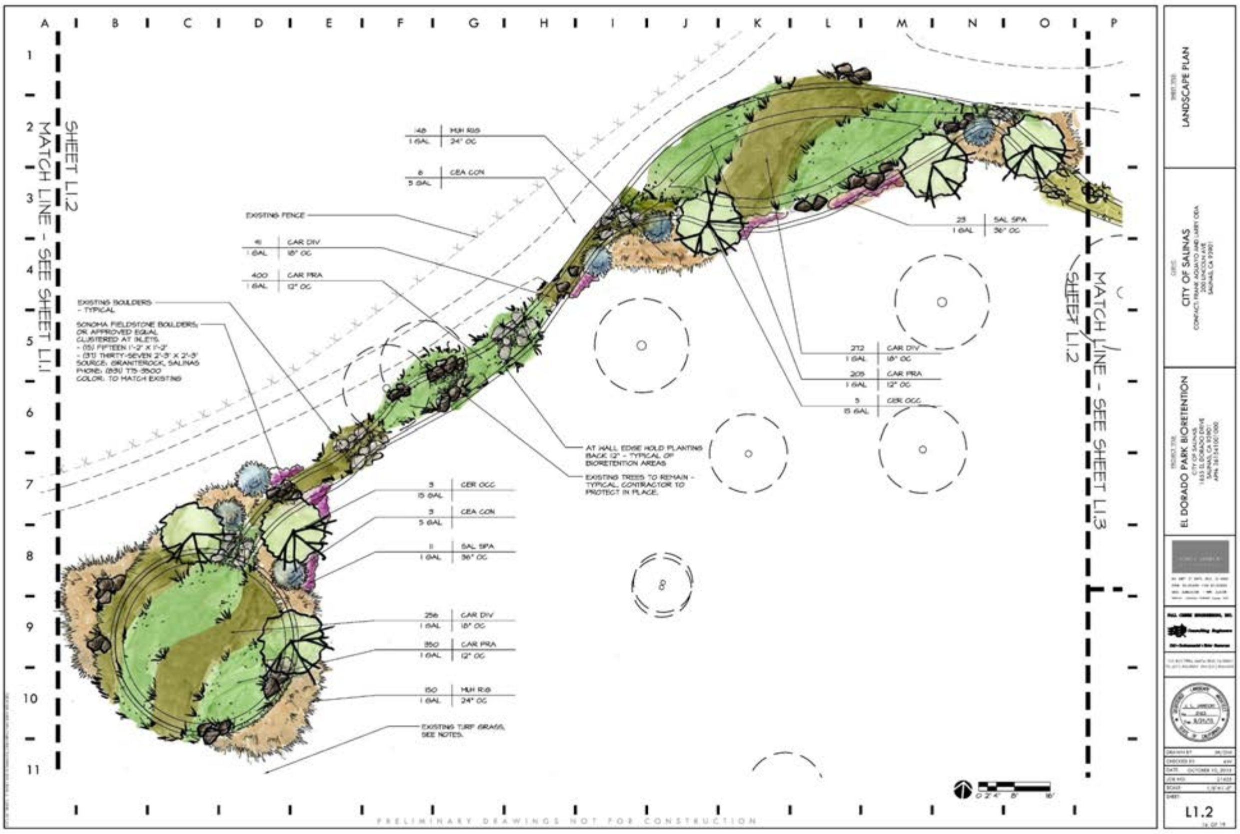
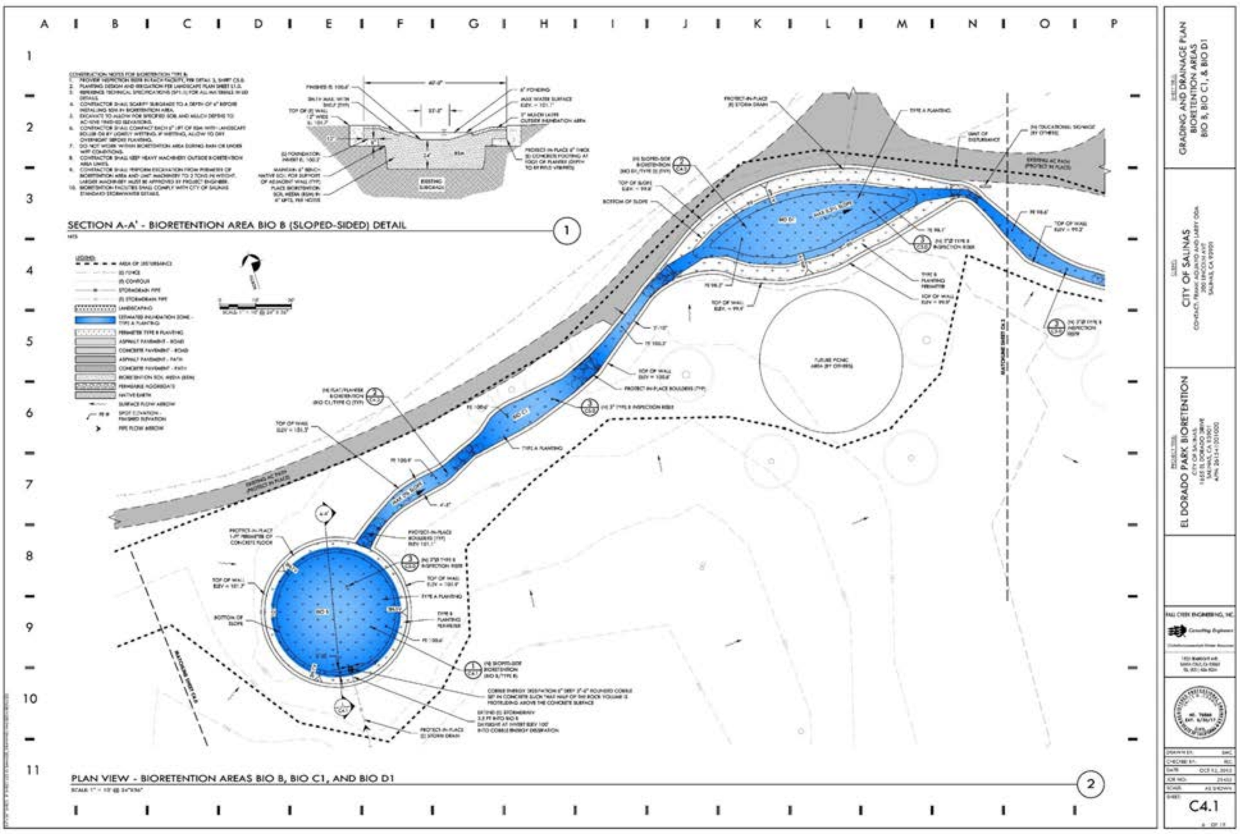
And this is an example from a project – using resources in the guidebook to design and build a green stormwater infrastructure project.





WHAT LEVEL OF GUIDANCE DO ENGINEERS NEED?

Figure 3 depicts the amount of engineering guidance available on the x-axis and the % of engineers capable of designing natural infrastructure on the y-axis. Our goal is to reach 100% of engineers around the world with the information they need to design natural infrastructure projects. Generally speaking the early adopters are those willing to take risks and try new approaches. Next come those comfortable applying best practices and principles, then those that need engineering standards and specifications – and finally the group that will only apply natural infrastructure if code, regulators, or clients demand it.

Right now engineers in the first two categories are designing nature-based solutions. For green stormwater infrastructure in the United States, it took approximately 30 years to move towards the end of this curve – and given our climate crisis – we have 5 years to move through this process for other types of natural infrastructure. So how can we compress – or shorten – this adoption curve?

To continue moving along this curve – and quickly – we need to continue learning by doing knowing that:

- Often the complexity of nature-based solutions requires flexible design approaches– versus rigid standards, and
- Competent engineers – will take risks and innovate and apply and improve upon best practices and principles.

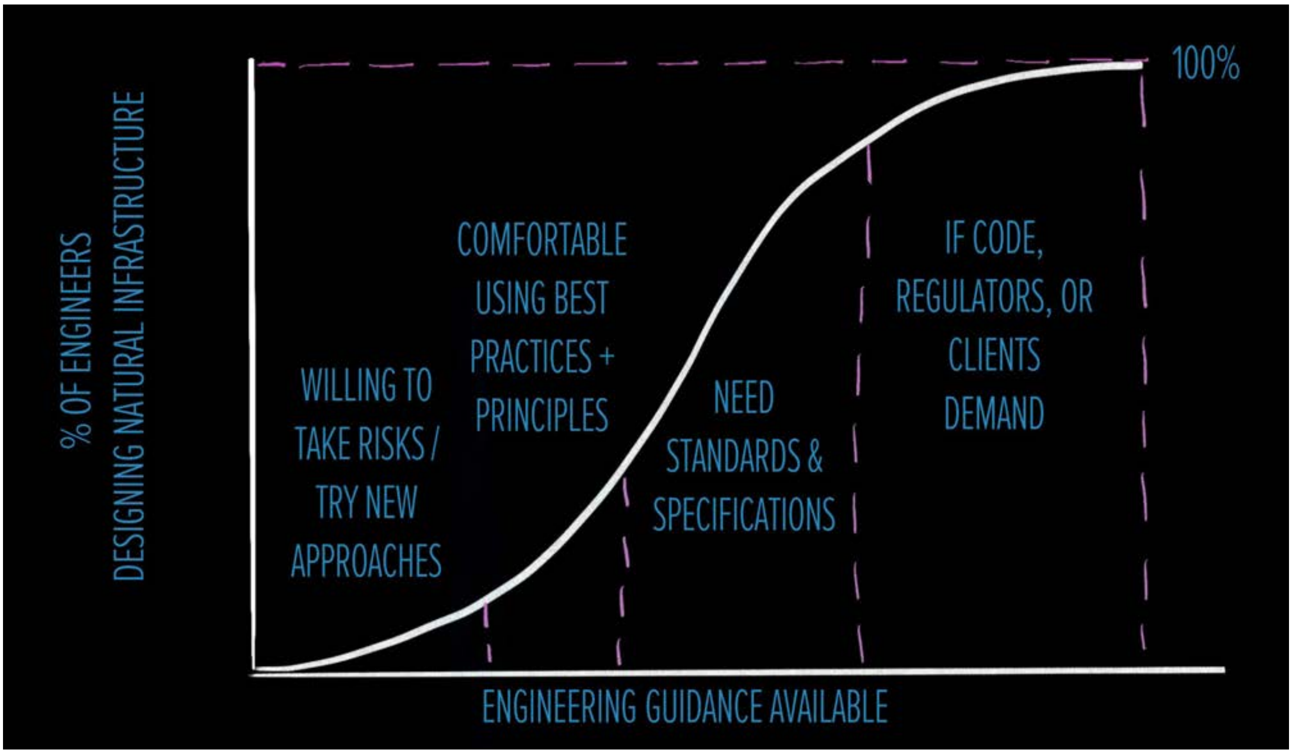


Figure 3. Engineers' willingness to innovate nature-based solutions based on available engineering guidance.

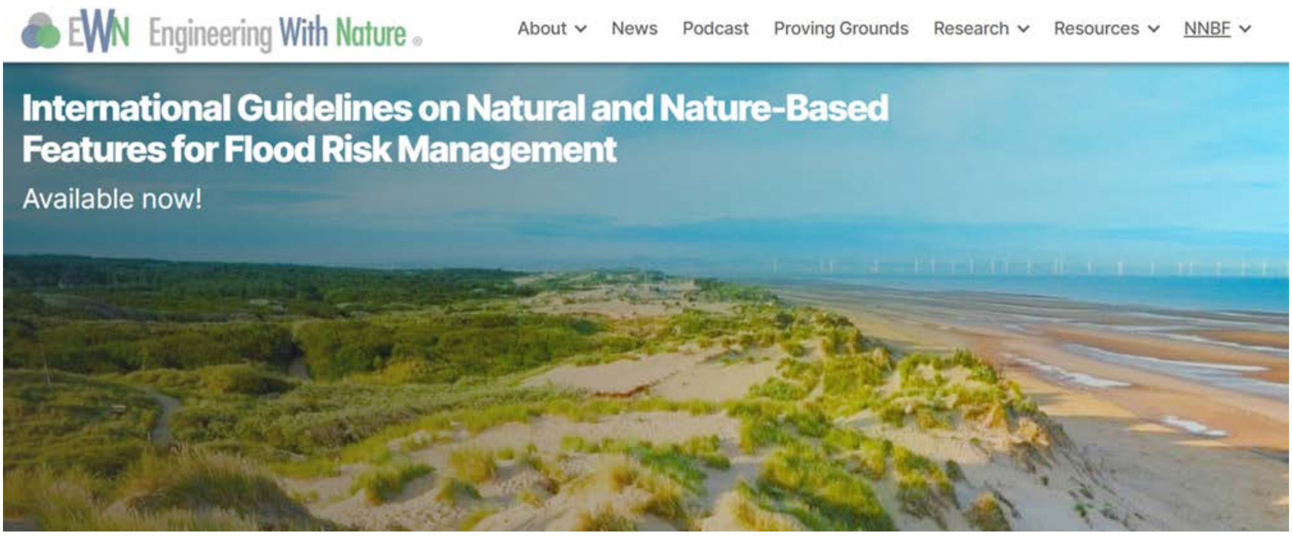
WE HAVE ENOUGH GUIDANCE TO BEGIN ...

There are few accepted engineering standards for nature-based infrastructure solutions - but there are many guides and resources that give us enough information to begin. For example:

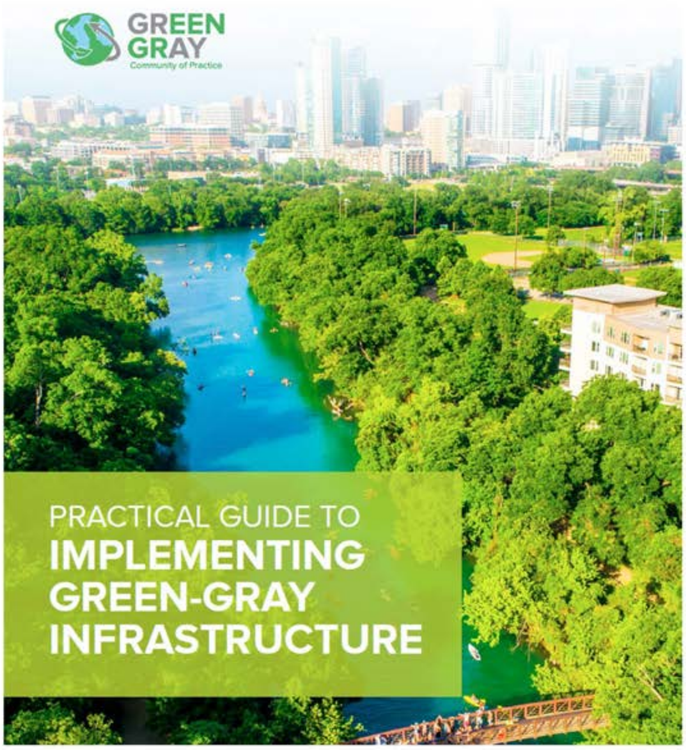
The International Guidelines on Natural and Nature-Based Features for Flood Risk Management - That provide practitioners with the best available information to conceive of - plan, design, engineer, construct, and maintain Natural and Nature-based Features to support resilience and flood risk reduction for coastlines, bays, and estuaries, river and freshwater systems.

The Practical Guide to Implementing Green-Gray Infrastructure, a crowdsourced product of the Green-Gray Community of Practice, highlights 36 case studies from around the globe, with 10 chapters on how to select, design, build, and monitor green-gray projects – influence policy and engage stakeholders.

The Green-Gray Community of Practice is also setting out to develop concise, scientific green-gray engineering guidance – starting with mangroves and seawalls. A Guyana specific version is available – and we are working to make a globally applicable version in 2022. We also have made available on our green-gray community website a database that reviews engineering resources from around the world – based on their level of detail, topical focus, and applicability to nature-based infrastructure



Examples of existing engineering guidance available for green-gray practitioners.


GREEN
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Community of Practice
PRACTICAL GUIDE TO
IMPLEMENTING
GREEN-GRAY
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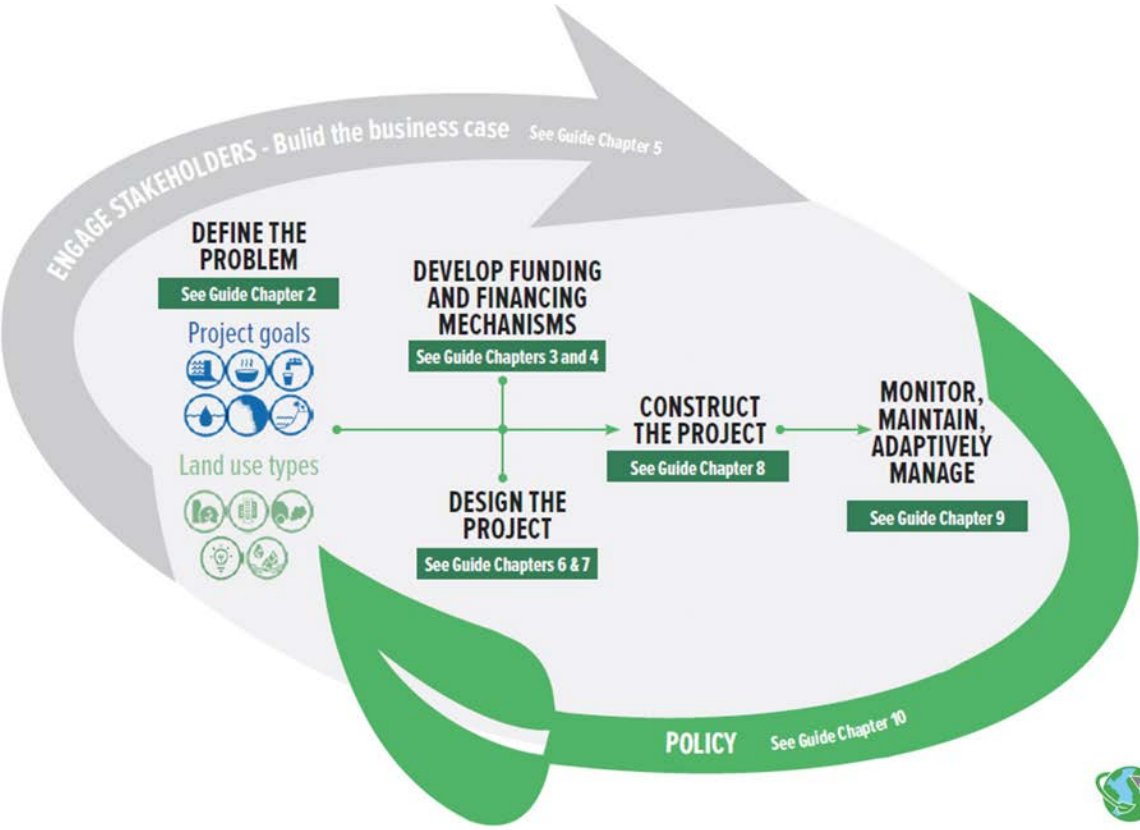

ENGAGE STAKEHOLDERS - Bulid the business case
See Guide Chapter 5
DEFINE THE PROBLEM
See Guide Chapter 2
Project goals
Land use types
DEVELOP FUNDING AND FINANCING MECHANISMS
See Guide Chapters 3 and 4
DESIGN THE PROJECT
See Guide Chapters 6 & 7
CONSTRUCT THE PROJECT
See Guide Chapter 8
MONITOR, MAINTAIN, ADAPTIVELY MANAGE
See Guide Chapter 9
POLICY
See Guide Chapter 10

THE NEED FOR EVIDENCE-BASED DECISION-MAKING

Collecting, sharing, and using data is needed to make rational and defensible decisions related to the planning and operation of infrastructure. Unfortunately, the current approach to evidence-based decision making for nature-based solutions is at best – project, region, or problem specific. At worst it is non-existent or proprietary.

In 2021-2022 a consortium of partners completed a year-long monthly webinar series called 'Sustainable Infrastructure: Putting Principles into Practice'[4] based on UNEP's International Good Practice Principles for Sustainable Infrastructure.[5] The 10th principle is on evidence-based decision making – and it describes best practice for project monitoring and data sharing. The principle is aspirational and worth reflecting on as we strive to address key barriers for engineering nature-based solutions.

"The planning and management of infrastructure throughout the lifecycle should be informed by key performance indicators that should promote the collection of data, including data that is disaggregated by stakeholder groups. Regular monitoring of infrastructure performance and impacts is necessary to generate data, which should be made available to all stakeholders."

The principle describes best practices for monitoring and data sharing:

1. "Monitoring the performance and impacts of infrastructure enables continuous improvement in service delivery and sustainability.

2. Pre- and post-project data on all stages of the lifecycle should be identified and defined, collected, managed, analysed and fed back to decision makers and stakeholders.

3. In addition to economic and financial data, adequate resources should be allocated to collection of data relating to environmental and social sustainability factors, including spatial and disaggregated data - at international, national, local and project levels.

4. Effective monitoring requires data management and storage capacity that allows for continuity of data gathering, storage and sharing across different project and lifecycle phases and with different stakeholder groups.

5. Governments should engage in partnerships with the private sector, academia and civil society to ensure that relevant data are defined, measured, collected, analysed and synthesised in ways that are useful for decision makers and the public.

6. Regular monitoring of infrastructure performance and impacts is necessary to generate data, which should be available to all stakeholders."[5]

PROBLEM STATEMENT

Given the lack of accepted norms and standards for Natural Infrastructure Design and Engineering, how might we increase the experience, familiarity and, consequently, confidence of engineers, developers, industry, financiers, and governments so they can design, fund, and build natural infrastructure projects that protect, manage, and restore nature for communities and future generations.

The solution relies upon strengthening evidence-based decision-making abilities for teams designing nature-based solutions with a sustainable and scalable framework.

> "Ensuring long-term social-ecological integrity of NbS requires an improved evidence base, informed by science, practitioner and local and indigenous knowledges. There is urgent need for better understanding of where, when, how and for whom NbS can support mitigation and adaptation, especially in marine and non-forest ecosystems, low-income nations in general and their cities in particular and in comparison to technological solutions."[6]

4 Led by Duke Nicholas Institute for Environmental and Policy Solutions, in partnership with the Green-Gray Community of Practice, Sustainable Infrastructure Partnership, Conservation International, Project ECHO, UN Environment Program, ITTECOP, and the International Coalition for Sustainable Infrastructure. Recordings and case studies available online.

5 United Nations Environment Programme (2022). International Good Practice Principles for Sustainable Infrastructure. Nairobi

6 Seddon, N. (2022). Harnessing the potential of nature-based solutions for mitigating and adapting to climate change. Science

NATURAL INFRASTRUCTURE ENGINEERING HUB PROPOSAL

To address the problem and systematically learn by doing we propose creating a nature-based solutions evidence-based decision-making feedback loop to collaborate across disciplines and geographies. This trusted modern data sharing platform would leverage modern computing and data collection technology using an online, open-source, database structure. The system would be built and implemented by-and-for users to input knowledge and data, with a focus on crowd sourcing information about natural infrastructure technology, performance, and cost to inform descriptive methods and engineering standards.

The Natural Infrastructure Engineering Hub is proposed as a voluntary, collaborative effort focused on providing science-based information to advance the state of the practice for nature-based solutions.

The project's long-term purpose is to provide scientifically sound information that improves design, selection, implementation, cost-effectiveness and ultimately performance of nature-based solutions.

The Hub would include voluntarily shared performance monitoring data and study site metadata in a consolidated, publicly accessible repository to support selection and design of nature-based solutions to achieve climate adaptation goals. Performance data, data entry spreadsheets, performance summary reports and monitoring guidance would be accessible through the Hub website.

Figure 4 summarizes the main elements of the proposed Natural Infrastructure Engineering Hub, which would include portals to specific types of nature-based solutions, such as mangroves and seawalls, living shorelines, horizontal levees, and bioengineering for road stablization. Each nature-based solution portal woudl include a curated library of resources, and investor marketplace and project monitoring and evlauation data. A real-time feedback loop from practitioners to designers, planners, and financiers would enable data aggregation so we can learn from and share successes - and failures - widely.

The Curated Libary would assemble and disseminate annotated resources, including:

1. Engineering Guidance and typical design details, plans, and specifications to increase confidence in outcomes;
2. Case Study Narratives to communicate the intrinsic value of projects to sustainable development;
3. Key Performance Indicators to create consistency within the platform and efficient monitoring and evaluation programs; and
4. Cost-Benefit-Analysis Input Data and Outputs to build a database of social, economic, and environmental costs and benefits.

The Investor Marketplace would create access to transparant and consolidated information for investors and funders, including to a:

1. Project Pipeline to connect project developers with financiers in a type of project "match-making" service; and
2. Defined Financial Metrics to measure asset performance and benchmark projects against each other.

The Monitoring and Evaluation Data portal would provide data management and storage capacity that allows for continuity of data gathering, storage and sharing across different project and lifecycle phases and with different stakeholder groups, including:

1. Data Accessibility to address climate justice with data and resources broadly and equitably available with open-access to all;
2. Project Performance Data to collect monitoring data linked to key performance indicators, and environmental, social, and economic costs and benefits; and
3. Project Finance Data to collect data about project deals, costs, and savings.

The Real-Time Feedback Loop would include:

1. Project Performance to identify common themes, outcomes, findings, and update best practice guidance for design and implementation and
2. Market Trends to make information about project business models, market size and growth publicly available

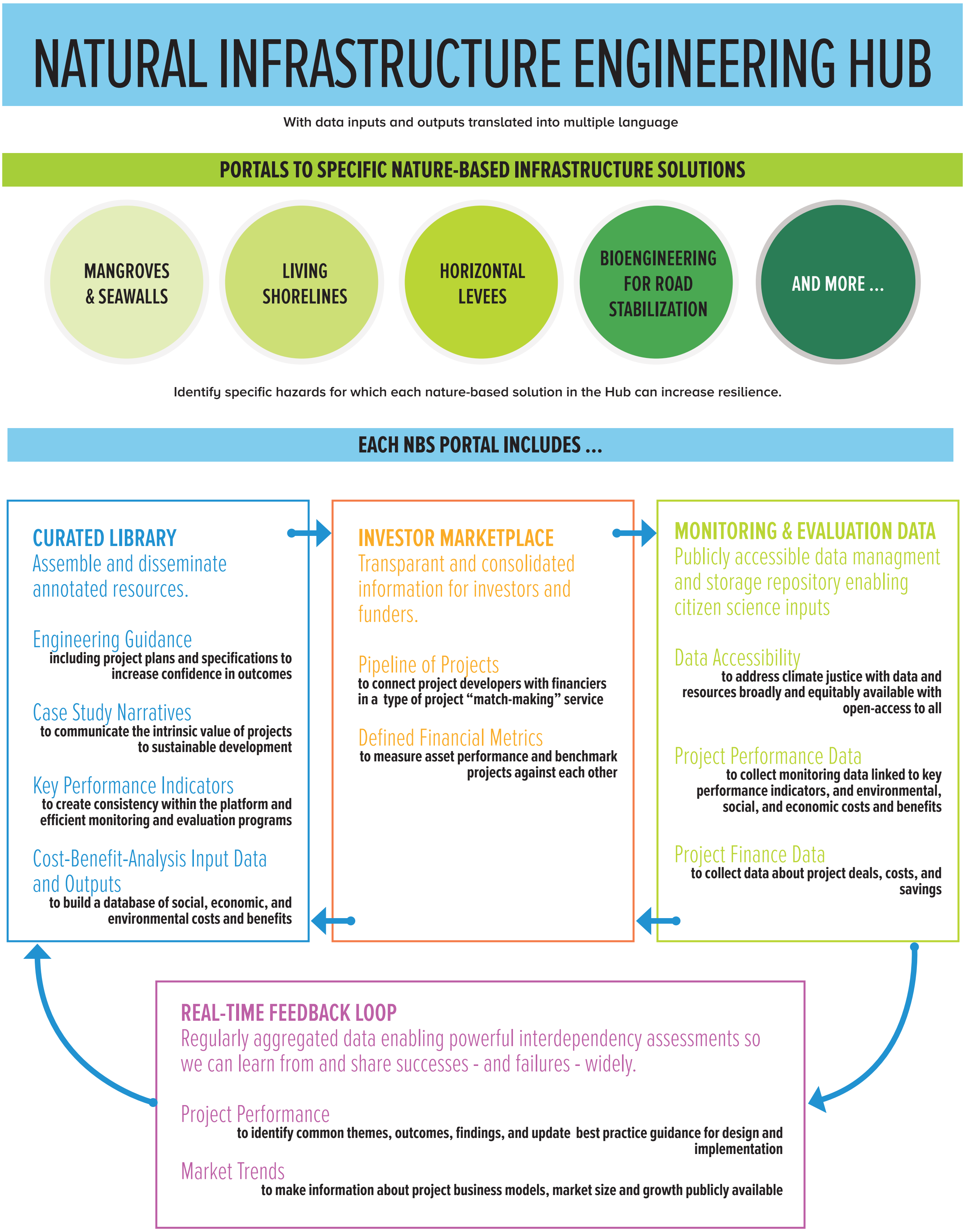


FIgure 4. Proposed Natural Infrastructure Engineering Hub portals and information gateways.

ENGINEERING HUB USERS

The primary users of this platform include infrastructure practitioners, designers, and engineers who depend upon project data, details, designs, and specifications to design and build natural infrastructure projects. These users will trust the Hub to capture the best available scientific and technical information about performance, costs and benefits, and technology and in exchange input technical knowledge and data about the natural infrastructure projects they design, build, and monitor.

Pre-competitive collaboration is the cornerstone about which the hub would depend, and specifically the willingness of researchers to voluntarily share their performance monitoring research.

OUR COMMITMENT TO PRE-COMPETITIVE COLLABORATION

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

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

The Global Green-Gray Infrastructure Community of Practice is a forum for collaboration across the conservation, engineering, finance, and construction sectors to generate and scale-up green-gray climate adaptation solutions. The multi-disciplinary Community of Practice has grown to over 140 member organizations spanning the globe, representing non-profit, academic, government and private organizations.

We are working to:

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

In this Global Green-Gray Community of Practice, the private sector, non-government organizations, and academics share their needs and experiences, learning from one another about what works, what does not and what has not worked yet.

Pre-competitive consortiums – such as this community of practice – create an opportunity to bring diverse stakeholders together and exchange perspectives that are integral to ensuring project success. By drawing on multidisciplinary expertise, collaborative outputs can ensure the inclusion of diverse perspectives on ecological, social, economic, financial, policy, site assessment, design, engineering, construction, monitoring, and management considerations. In addition, pooling resources generates buy-in from contributors, reduces costs, creates more universal and accessible tools, and can bolster the credibility of outputs and the communication of key messages and recommendations.

As the green-gray community of practice continues to build the knowledge base about how to implement green-gray infrastructure solutions, we are committed to pre-competitive collaboration to create fertile ground for innovation and new partnerships within and across sectors.

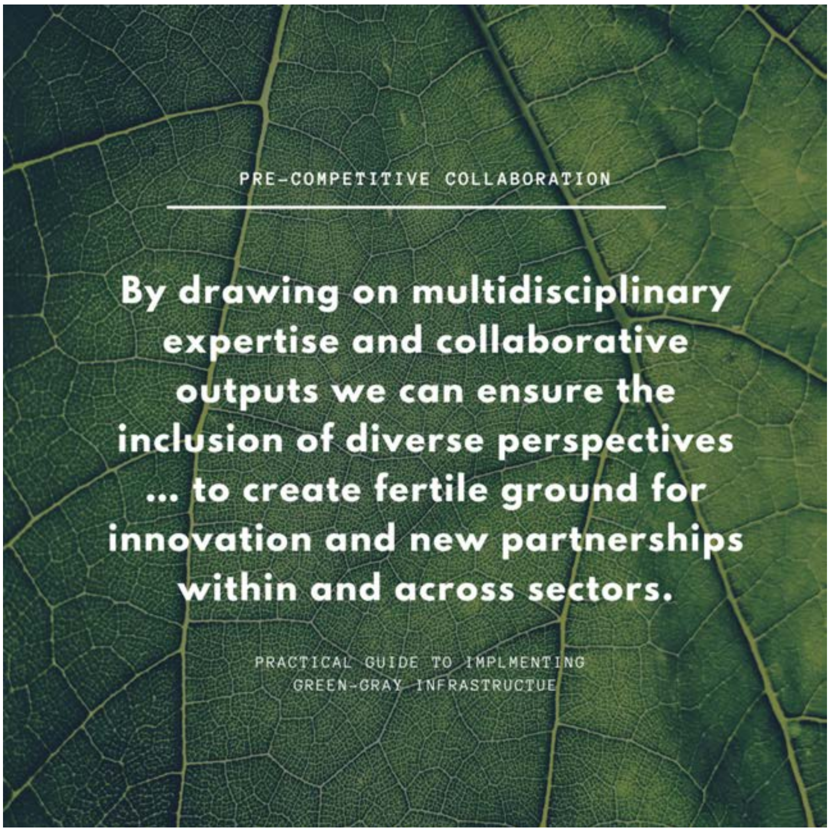
WHAT DO POTENTIAL USERS THINK OF THE PROPOSAL?

The Natural Infrastructure Engineering Hub would be an international resource for how to design, build, monitor, measure, maintain, and adaptively manage nature-based engineering solutions closing and shortening the feedback loop between discovery, application, and advancing practice.

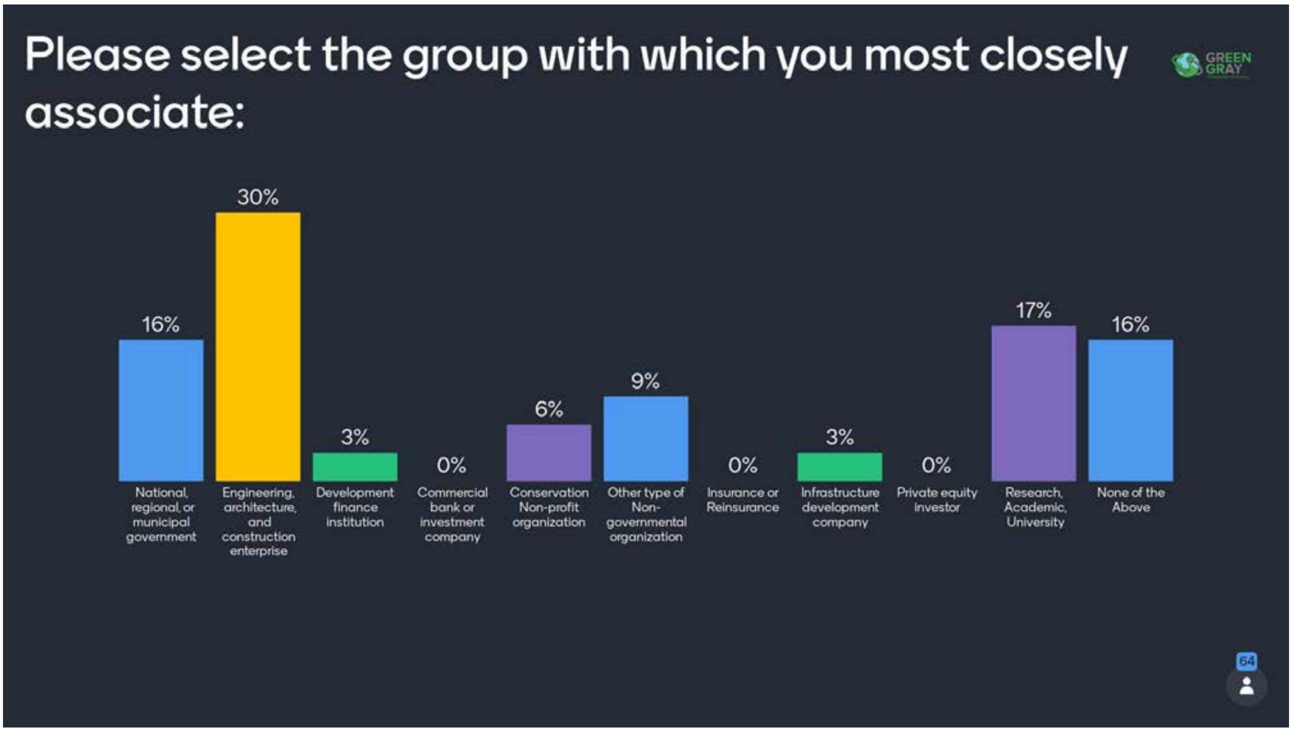
Since June 2022 the concept for the proposed Hub has been shared with over 100 infrastructure practitioners from around the world, over half of whom responded to questions about the perceived usefulness and effectiveness of the Hub as a solution to address barriers to implementing nature-based solutions.

"We need frameworks to be inspirational ....
To help people imagine what it is they can do"[7]

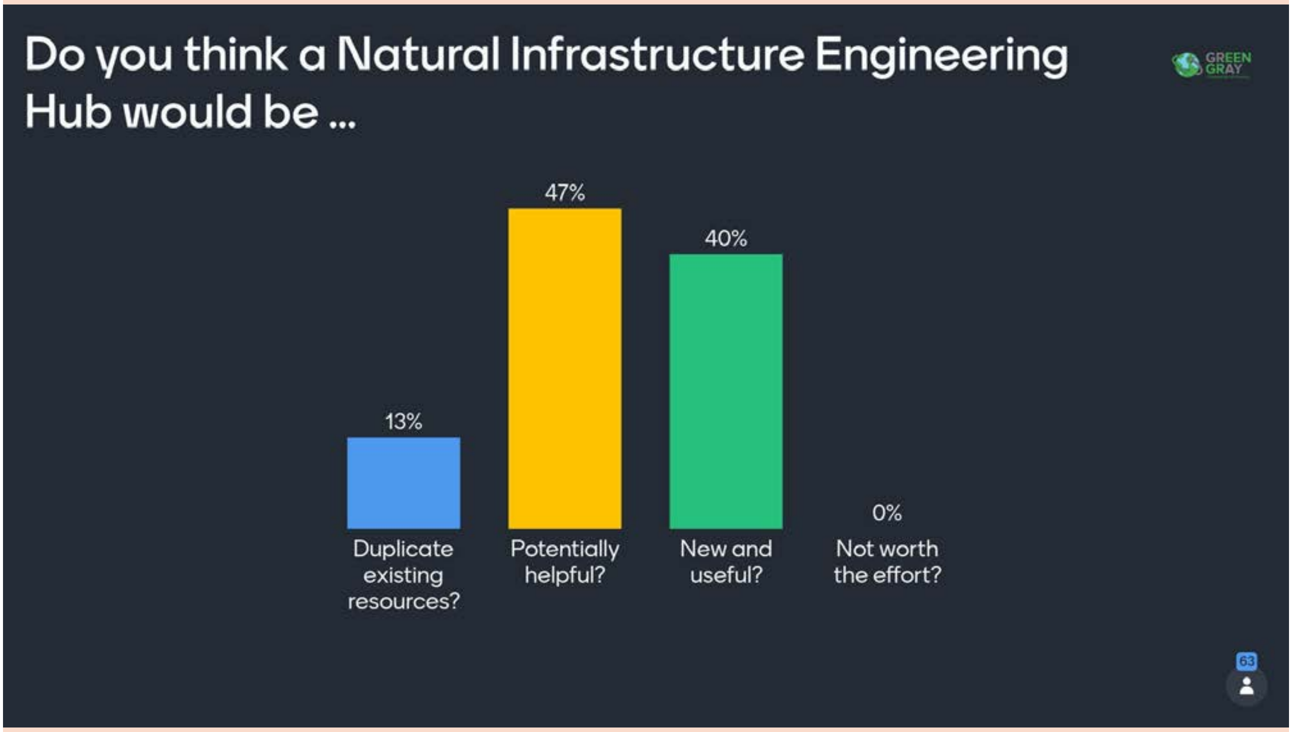
7 Participant quotes during a National Academy of Sciences Workshop exploring the Benefits, Applications and Opportunities of Natural Infrastructure



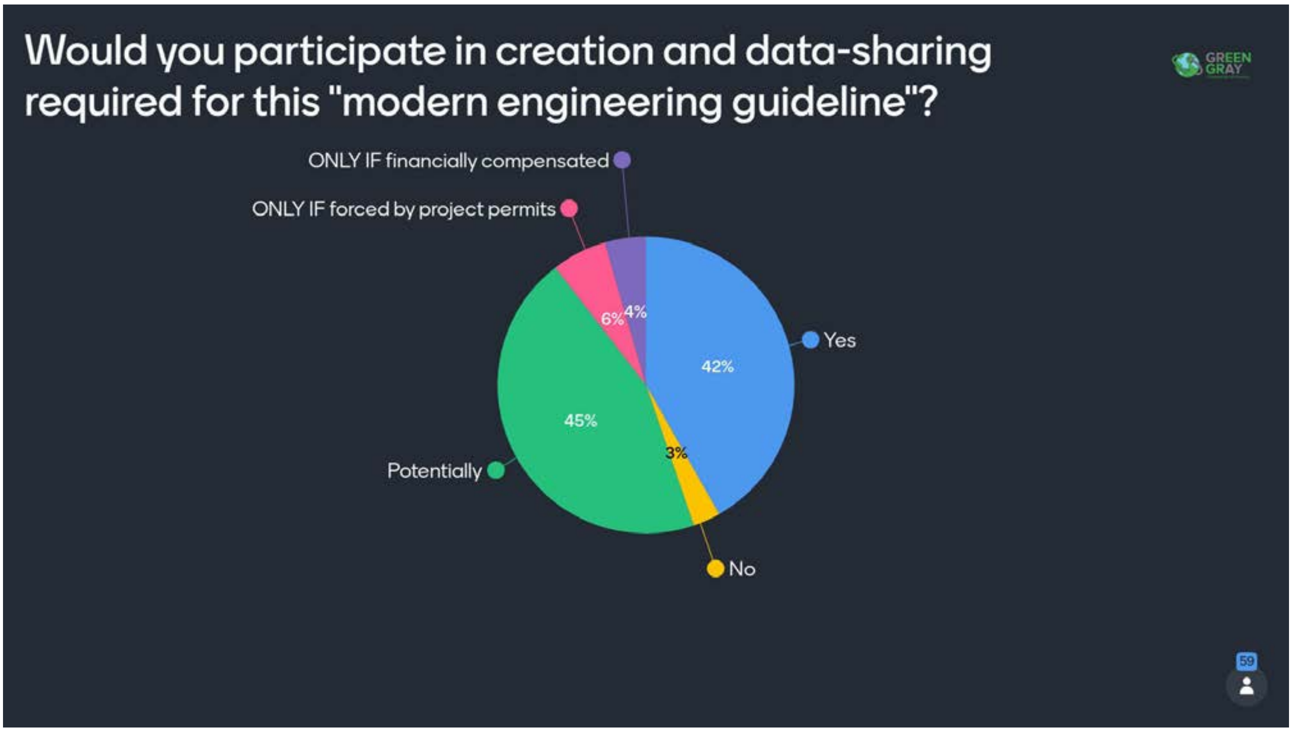
Most responses are from professionals associated with engineering, architect, and/or construction enterprises (30%) and national, regional, or municipal governments (16%), the principal users of the proposed Hub.



Most respondents (87%) consider the proposed Hub would be new and useful (40%) or potentially helpful (47%). Considering the wealth of information and web portals available about nature-based solutions, 13% respondents indicated the potential for the Hub to duplicate existing resources.



Most respondents (87%) also indicated they would consider participating in data-sharing and creation of the Hub.



DISCUSSION

To move forward and achieve the ambitious vision for the Natural Infrastructure Engineering Hub, numerous questions for discussion exist. For example,

- How could we require or incentivize inputs back into this type of "modern engineering guideline"? Through permits, reimbursements, or rewards?
- Would it be possible to enable citizen science inputs?
- Collecting and managing evidence-supporting data takes effort. How do we fund implementation and long-term maintenance of such a Hub? Who leads the design and implementation? Who hosts – monitors and maintains - the platform?

EXISTING PLATFORM REVIEW

To inform the discussion and responses to these questions a review of ten existing pre-competitive technical data knowledge exchange platforms was conducted to identify trends and lessons learned to inform development of a Natural Infrastructure Engineering Hub. Each platform was reviewed based on a common set of questions:

Who hosts the platform?

- Who led design and implementation of the platform?
- Who monitors?
- Who maintains?

How is the platform funded?

- Who funded initial design of the platform?
- For what period of time is funding secured?
- Who pays for monitoring and maintenance of the platform?

What is the type of data collected?

- What is the geographic scope/scale across which the platform applies?
- What level of detail?
- What types of projects?

How is data input back into the platform?

- Who are the primary users inputting data?
- What incentives?
- If regulatory, through which permits and at what level of governance?
- Is citizen science included? If so, how and at what level?
- Is there a peer review process for the data?

How is the data compiled and communicated back to users?

- Who are the primary users of the consolidated data?
- Are there regular reports? Documentation of results?

What was the timeline for developing the platform?

What is the future of the platform?

Following is a summary of each of the ten reviewed platforms and potential relevancy to the proposed Hub.

Public Infrastructure Engineering Vulnerability Committee (PIEVC) (https://pievc.ca/)

PIEVC Engineering Protocol is a qualitative process to predict the likelihood of individual infrastructure projects to be impacted (e.g., deterioration, damage, or destruction) by current and future climate, and to inform structural and non-structural adaptation strategies (e.g., design, operation & maintenance, policy) to reduce risk and increase climate resilience. The PIEVC is a "Made in Canada" tool developed between 2005 and 2012. Between 2008 and January 2021 over 100 infrastructure risk assessments have been completed.

Relevancy & Lessons Learned for Natural Infrastructure Engineering Hub:

Effective March 30, 2020, ownership and control of the PIEVC Program transferred to the PIEVC Program Partnership consisting of the Institute for Catastrophic Loss Reduction (ICLR), the Climate Risk Institute (CRI) and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.

The guiding principles and objectives have overlap and transferability to the proposed Hub and include:

- Providing freely accessible, open, credible resources to support improved understanding of the impacts of climate change on Canada's infrastructure and buildings.
- Providing a Community of Practice to engage and work directly with infrastructure policy and decision-makers from the public and private sectors.
- Improving the understanding, capacity and expertise of policy makers, decision makers, infrastructure professionals and practitioners to adapt infrastructure based on current and future climate risks and vulnerabilities.
- Providing ongoing advice to, and engagement with, governments, and other regulatory authorities on reviews and adjustments to infrastructure codes standards and related instruments to account for and mitigate climate risks and vulnerabilities.

To access the PIEVC Protocol users are asked to complete a Non-Disclosure and Release Agreement, which includes a condition that a final assessment report is submitted to the PIEVC Program Partnership. PIEVC Protocol users will be requested to submit a final PIEVC Protocol Assessment Report that can be placed on the PIEVC.ca website for public access. "The primary public good of the PIEVC Program is publication of final PIEVC Protocol assessment reports whenever possible. Users are granted free access to the Protocol to facilitate its use, and to ensure that valuable information concerning methods, data, and approaches to climate change vulnerability assessments remain in the public arena, all project users are requested to submit a publishable, final report." (PIEVC.ca)

PIEVC Protocol assessment reports remain publicly accessible via the www.pievc.ca website and are searchable by category (e.g., buildings or roads), province/territory, and report completion status.

Training for PIEVC Protocol practitioners is available as part of a parallel program to the PIEVC Program - the Infrastructure Resilience Professional (IRP) program. This program includes a series of courses that lead to an "IRP" credential, and includes a course focused on the PIEVC Protocol.[8] (Sandink et al, 2021)

No summary reports or meta-analysis available.

8 Sandink et al, 2021. The PIEVC Protocol For Assessing Public Infrastructure Vulnerability to Climate Change Impacts: National And International Application

[Global Infrastructure Hub (https://www.gihub.org/)](https://www.gihub.org/)

Established by the G20 in 2014 as a mandate to work between governments, the private sector, development banks, and other international organizations to implement the G20's infrastructure agenda. The Global Infrastructure Hub (GI Hub) is a not-for-profit organization that advances the delivery of sustainable, resilient, and inclusive infrastructure. It acts as a global knowledge sharing hub, to produce data, insights, knowledge tools, and programs that inform both policy and infrastructure delivery. The Knowldege Hub is searchable by resource type (e.g., news, articles, case studies), sector (e.g., energy, transport, water), and sub-sector, lifecycle stage (e.g., planning and strategy, project preparation, design, O&M), region, and topic (e.g., G20, PPP, technology). Case studies are searchable by contracting model (e.g., design-bid-build, design-build, PPP) and infrastructure value ($).

Relevancy & Lessons Learned for Natural Infrastructure Engineering Hub:

The GI Hub currently focuses on conventional infrastructure projects, energy, technology with low to no emphasis on nature-based solutions.

The GI Hub secretariat staff and/or collaborators identify, develop, and curate information in the Knowledge Hub.

Regular summaries of data and trends are published through Data Insights from the Secretariat.

Technical data (e.g., dimensions or design thresholds) are not included in platform.

All resources are freely available and accessible.

The GI Hub has a sustainable funding and hosting model through the G20. The GI Hub's mandates extended from 2014-2018 and in 2021 the G20 again extended the mandate (https://www.gihub.org/news/g20-fmcbg/) until the end of 2024 (Finance Ministers and Central Bank Governors Meeting).

It could be possible to integrate the Natural Infrastructure Engineering Hub into Global Infrastructure Hub, and at a minimum propose as a new topic area in the Knowledge Hub.

Surface Water Ambient Monitoring Program (SWAMP) (https://www.waterboards.ca.gov/water_issues/programs/swamp/)

The SWAMP is a unifying program created in 2000 as a result of legislation that coordinates all water quality monitoring conducted by the California State and Regional Water Boards. "The SWAMP mission is to provide resource managers, decision makers, and the public with timely, high-quality information to evaluate the condition of all waters throughout California. SWAMP accomplishes this through carefully designed, externally reviewed monitoring programs, and by assisting other entities state-wide in the generation of comparable data that can be brought together in integrated assessments"

Relevancy & Lessons Learned for Natural Infrastructure Engineering Hub:

There are numerous SWAMP partners, but the central staff responsible for day-to-day maintenance of the program are funded through the annual state budget process and State Water Resource Control Board staff.

Permits require data monitoring and for permittees to input data back into the Program. Permittees are incentivized to comply so as to avoid fines from State and Regional Water Quality Boards for failure to submit self-reported data.

SWAMP is an excellent example of integrating Citizen Monitoring (Citizen Science + Volunteer Monitoring) through a 'Clean Water Team' program. Citizen monitoring is any water quality monitoring activity that relies in whole or in part on participation by volunteers, students or non-paid staff. A variety of organizations may be involved in citizen monitoring projects, including but not limited to non-profit groups, Resource Conservation Districts (RCDs), Coordinated Resource Management and Planning (CRMP) groups, local government agencies, and colleges.

Clean Water Team Citizen Monitoring Coordinator(s) provide technical assistance and guidance documents, training, QA/QC support, temporary loans of equipment and communication to citizen monitoring programs and watershed stewardship organizations.

Data is freely available through multiple platforms (e.g., California Environmental Data Exchange Network (http://www.ceden.org/), SWAMP Data Dashboard (https://gispublic.waterboards.ca.gov/swamp-data/), and California Open Data (https://data.ca.gov/).

Equator Initiative Online Best Practice Database (https://www.equatorinitiative.org/knowledge-center/e-library/case-studies/)

Hosted by the UNDP, the Equator Initiative Knowledge Center includes a global E-Library for Case Studies and Publications. The Case Studies catalog is a best practice database with detailed case studies on Equator Prize winners – a growing network of local sustainable development solutions for people, nature, and resilient communities. The case studies describe vetted and peer-reviewed best practices to inspire policy dialogue to scale NbS essential for achieving the SDGs. There is an accompanying searchable 'Nature-based Solutions Database'.

Relevancy & Lessons Learned for Natural Infrastructure Engineering Hub:

Equator Initiative prize winners are awarded a cash prize of US$10,000 each and case studies available from the website are co-written with prize winners and UNDP staff.

Technical data (e.g., dimensions or design thresholds) not included in platform.

International Institute for Sustainable Development (IISD) Nature-based Infrastructure Global Resource Centre (https://nbi.iisd.org/)

"The leading global hub for nature-based infrastructure" to build the business case for nature-based infrastructure, providing data, training and sector-specific valuations based on systems thinking and financial modeling. The Centre makes available information about Nature-based Infrastructure performance and costs; "the environmental, social and governance-related externalities of infrastructure; as well as direct costs and climate risks". It includes the outputs of SAVi assessments (40 funded Sustainable Asset Valuations through GEF and MAVA).

Relevancy & Lessons Learned for Natural Infrastructure Engineering Hub:

IISD staff support project developers to complete the economic valuation using the IISD tool SAVi, then reports, summaries, and data are available on the website and in the database.

Free consulting services are available to conduct customized economic valuations for 40 projects.

The online database is an excel file that can be downloaded by users (https://nbi.iisd.org/database/) and identifies Value type (added benefit, avoided cost or direct cost), Category (e.g., sectoral or biophysical groupings), SubCategory (e.g., avoided cost, water filtering, carbon storage), Unit ("most costs and benefits are presented as both an absolute and an intensity value. The absolute value is equal to the value given int eh SAVi integrated cost-benefit analysis. The intensity value is normalized by a factor such as area or quantity" (https://nbi.iisd.org/wp-content/uploads/2021/11/nbi-database-user-guide.pdf), Climate Scenario (e.g., IPCC RCP scenario), Policy Scenario (e.g., BAU, green infra, gray infra), Value (of the cost or benefit), Country, SAVi Assessment.

Training is available through a Massive Open Online Course and customized training.

[Green Growth Knowledge Platform (https://www.greengrowthknowledge.org/)](https://www.greengrowthknowledge.org/)

Established in 2012, the Green Growth Knowledge Partnership (GGKP) is a global community of policy, business, and finance professionals and organisations committed to collaboratively generating, managing, and sharing knowledge on the transition to an inclusive green economy. The GGKP's three knowledge platforms - the Green Policy Platform, Green Industry Platform, and Green Finance Platform – offer quick and easy access to the latest research, case studies, guidance, and tools."

Relevancy & Lessons Learned for Natural Infrastructure Engineering Hub:

The Knowledge Platform is led by a Steering Committee comprised of senior representatives from the Global Green Growth Institute (GGGI), Organisation for Economic Co-operation and Development (OECD), United Nations Environment Programme (UNEP), United Nations Industrial Development Organization (UNIDO), and the World Bank. The GGKP draws together more than 75 partner organisations.

The Platform uplifts reports, case studies, tools, research, webinars from partners

The GGKP Secretariat is hosted by GGGI and UN Environment. The Secretariat manages the initiative's operational activities.

Technical data (e.g., dimensions or design thresholds) is not included in platform.

[APEX (Advanced Practices for Environmental Excellence in Cities) (https://www.apexcities.com/)](https://www.apexcities.com/)

An investment planning application from the International Finance Corporation (IFC) for Cities to identify Investments for suitable green financing, develop long-term strategies to meet greenhouse gas emission reduction targets (e.g., climate action plans), and track performance towards meeting emission reduction targets (%). APEX harnesses the knowledge about green practices from around the world to show what these practices mean for specific cities, based on a users local context - estimating environmental impact and cost - and explore policies and investments to drive implementation.

Relevancy & Lessons Learned for Natural Infrastructure Engineering Hub:

In-application calculations are conducted based on user-input data.

Provides City-scale planners with a tool to attract finance for implementation of identified measures

To access the free App users submit a simple 2-page application, including a sentence describing how you will use the App - and create a username and password.

International BMP Database (https://bmpdatabase.org/)

Starting in 1996, through a cooperative agreement between the American Society of Civil Engineers and the United States Environmental Protection Agency the International Stormwater Best Management Practices (BMP) Database is a publicly accessible repository for BMP performance monitoring study, design, and cost information. The project began to provide scientifically sound information to improve the design, selection and performance of urban stormwater BMPs, and is a repository of BMP field studies and related web tools, performance summaries and monitoring guidance. Continued population of the database and assessment of its data, primarily from North America, supports improved understanding of the factors influencing BMP performance and supports improvements in BMP design, selection and implementation. The performance, design, and cost data have also supported and will continue to support the development of science-based stormwater regulations, policies, and programs that seek to balance receiving water protection, technical feasibility, and cost.

Relevancy & Lessons Learned for Natural Infrastructure Engineering Hub:

This 25 year old project is made possible through the financial support of multiple organizations and the willingness of researchers to voluntarily share their performance monitoring research.

Technical data about project design, performance and costs are submitted by practitioners following a Data Entry User's Guide and Spreadsheets which identify required data necessary for inclusion into the Database. Completed spreadsheet packages, project photos, and relevant associated publications are emailed to a Clearinghouse. Practitioners are encouraged to contact the Clearinghouse in advance of submittal, and with any questions before or during the submittal process.

Since the BMP Database project's inception in 1996, a key purpose of project has been to provide better guidance on urban stormwater BMP monitoring, reporting protocols and performance analysis methods. These protocols have been released in various BMP Database reports over time and are updated to incorporate lessons learned and address new stormwater management approaches.

The most current and comprehensive information is provided in the 2009 Urban Stormwater BMP Performance Monitoring Guidance. This manual provides both monitoring guidance and recommended performance analysis approaches, including approaches to evaluating volume reduction.[9]

Some public agencies, including state departments of environmental protection, flood control districts and departments of transportation, have adopted the database format to track their ongoing studies.

Use of the database format is free and publicly available, if Terms of Use are followed.

"Performance monitoring data stored in the Urban Stormwater BMP database can be accessed several ways depending on the type of performance information desired by the user. These options include:

- Summary Reports statistically analyzing BMP performance for common pollutants for common BMP categories updated approximately biennially.
- BMP Mapping Tool allows users to view the geographic distribution of BMPs, filter to individual study sites and generate statistical analysis for BMP-pollutant combinations of interest for individual sites. This tool also enables users to access PDF summaries of BMP design characteristics and precipitation and flow summaries for a site. A corresponding CSV performance data file is also provided.
- BMP Statistical Analysis Tool allows user to dynamically generate statistical summaries for user-defined queries of BMPs by BMP category, location, pollutant and other criteria. A corresponding CSV data file is also provided.
- Request Access Database allows users to request a full copy of the BMP Database in Microsoft Access, enabling independent user queries and full access to site metadata and performance data. The 40 MB zipped file is provided upon request.
- API access to the BMP Database is under development and is not currently publicly accessible." (https://bmpdatabase.org/get-data)

The BMP Database project is an excellent example of how to collaborate to collect technical data to inform project design and implementation to improve performance.

9 https://static1.squarespace.com/static/5f8dbde10268ab224c895ad7/t/604926dae8a36b0ee128f8ac/1615406817379/2009MonitoringManualSingleFile.pdf

Infrastructure Pathways (https://infrastructure-pathways.org/)

Developed by the International Coalition for Sustainable Infrastructure, The Resilience Shift and delivered by Arup this resource provides infrastructure practitioners with clear, easy-to-navigate guidance on climate-resilient infrastructure, compiled from hundreds of leading resources, and organized by the 9 phases of the infrastructure lifecycle. The curated guidance is relevant to resilience experts and non-experts alike, and includes a specific Use Case Pathway for nature-based solutions, with specific recommended guidance and tools for each infrastructure lifecycle phase.[10]

Relevancy & Lessons Learned for Natural Infrastructure Engineering Hub:

Resource materials are curated with input from a Steering Committee, Technical Team, and User Panel and includes descriptions and definitions of Climate Resilient Infrastructure.[11]

Technical data (e.g., dimensions or design thresholds) not included in platform.

The proposed Natural Infrastructure Engineering Hub would support Delivery and Management of Climate Resilient Infrastructure as defined in Infrastructure Pathways - specifically Lifecycle Phases 5, 6, 7, and 8 - Design, Procurement, Construction, and Operations and Maintenance.

The Natural Infrastructure Engineering Hub could be organized with resources relevant to each of the 9 phases to specific natural infrastructure solutions.

NbS Evidence Platform (https://www.naturebasedsolutionsevidence.info/)

Part of the University of Oxford Nature-based Solutions Initiative, this global map-based portal links nature-based solutions to climate change adaptation outcomes based on a systematic review of peer-reviewed literature. The platform allows researchers, practitioners, and policy makers to compare the effectiveness of nature-based solutions intervention types including "created habitats, restoration, management, combination, protection, mixed created/non-created habitats". Peer reviewed literature on NbS is organized and sort-able based on ecosystem type, intervention type, effect of NbS on climate change impact, social outcomes, ecological outcomes, and climate change impact addressed with ability to generate maps, graphs, and download data.

Relevancy & Lessons Learned for Natural Infrastructure Engineering Hub:

The platform interface is easy to use and navigate .

The organization of papers enables meta-analysis to identify trends.

The portal only categorizes peer-reviewed literature, which limits access to projects, or aspects of projects, not in peer-reviewed literature.

Technical data (e.g., dimensions or design thresholds) not included in platform.

10 https://infrastructure-pathways.org/use-case/nbs/

11 https://infrastructure-pathways.org/key-concepts/

LESSON #1: DATA SHOULD BE FREELY AVAILABLE AND ACCESSIBLE TO ALL

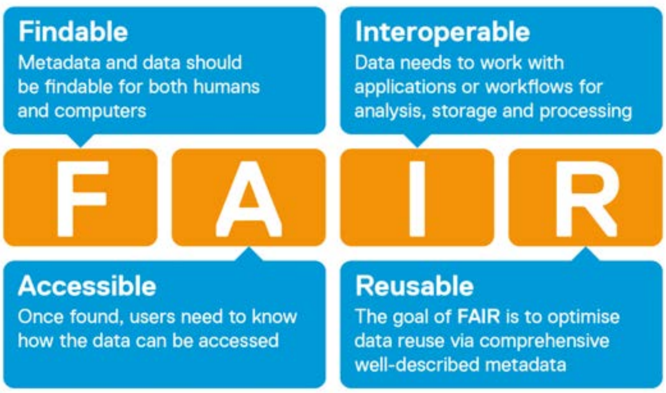
All the reviewed platforms, with isolated exceptions[12], prioritized providing free and accessible information to advance practice and improve environmental outcomes.

Good data management is not a goal in itself, but rather is the key conduit leading to knowledge discovery and innovation.[13] The Natural Infrastructure Engineering Hub could use FAIR guiding principles for open data sharing and management include being findable, accessible, interoperable, and reusable.

The term FAIR was first coined at a Lorentz workshop in 2014, and the resulting FAIR data principles published in 2016 as The FAIR Guiding Principles for Scientific Data Management and Stewardship by Mark D. Wilkinson et al., 2016.[14]

Other resources to review to inform best Data Sharing practices within the Natural Infrastructure Engineering Hub include:

- Open Data for Resilience Initiative
- The World Bank Open Government Data Toolkit
- Geospatial Risk and Resilience Assessment Platform
- Analysis of the cascade effects in supply networks – software tool CAESAR



LESSON #2: INVESTOR MARKETPLACE COULD INCENTIVIZE DATA INPUTS

Survey respondents (Figure 5) indicated project permits, regulations, and finance institutions have the greatest potential to incentivize inputs back into the Natural Infrastructure Engineering Hub. Involving finance and funding stakeholders in design and implementation of the Hub, and specifically the Investor Marketplace, could motiviate project developers to participate in the Hub data development and delivery.

The platform review identified other data input models with high potential to integrate into to the Natural Infrastructure Engineering Hub:

- Similar to the Nature-based Infrastructure Global Resource Centre model, the Natural Infrastructure Engineering Hub could invite projects from around the world to apply to receive funding for long term monitoring of natural infrastructure projects. Selected projects would receive (1) consultant support to develop a Monitoring and Evaluation plan, identify Key Performance Indicators and (2) five years of monitoring funding that requires annual inputs of data back into the Natural Infrastructure Engineering Hub.
- Similar to SWAMP, regulators could require self-reporting to the Natural Infrastructure Engineering Hub as a condition of project approvals and permits.
- Similar to the Equator Initiative prize winners, the Natural Infrastructure Engineering Hub could award a cash prize to winning projects with data entered into the Hub to promote community projects as best practices and instructive examples.

12 The Agricultural Best Management Practices Database (AgBMPDB) is behind a Water Research Foundation paywall

13 Wilkinson, M. D. et al. The FAIR Guiding Principles for scientific data management and stewardship. Sci. Data 3:160018 doi: 10.1038/sdata.2016.18 (2016). https://www.nature.com/articles/sdata201618.pdf

14 Source: scibite (https://www.scibite.com/solutions/enterprise-fair-data-mdm/), accessed October 2022.

LESSON #3: INTEGRATION OF CITIZEN SCIENCE INPUTS IS POSSIBLE AND GENERATES COMMUNITY CO-BENEFITS

Establishing the platform as a trusted data source is essential for long-term success. To be successful, survey respondents (Figure 6) indicated the importance of linking citizen science efforts to specific data needs and addressing bias amongst science and engineers about the value and accuracy of data collected through citizen science efforts.

SWAMP is a good model of integrating citizen science, and the Natural Infrastructure Engineering Hub could adopt their method for providing data templates to standardize data inputs, summarizing data for users, and creating Citizen Monitoring Coordinator(s) to provide technical assistance and guidance documents, training, QA/QC support, temporary loans of equipment and communication to citizen monitoring programs and organizations.

Other resources to review to inform integrating citizen science within the Natural Infrastructure Engineering Hub include recent successful examples leveraging technology (i.e., smart phones):

- 'Catch the King' sea level rise mapping
- Citizen Stormwater Infrastructure Assessments (Dr. Marcus Hendricks)
- Citizen Journalism
- Seed Pile Project (Miridae Living Labs)

LESSON #4: COLLABORATIVE FUNDING AND OWNERSHIP ARE ESSENTIAL FOR LONG-TERM SUCCESS

A collaborative funding and ownership model is important for long-term success, beyond the design and initial launch and start-up phase of a technical platform.

A diversity of infrastructure practitioners stands to benefit from the Natural Infrastructure Engineering Hub, and their participation in design, launch, start-up, and long-term maintenance should be required. The practitioner categories include - Government, Owners and Operators, Investors, Designers, Contractors, Civil Society, and the Direct Users of Infrastructure.

Often the team involved in the design, launch, and start-up of a platform is different than the long-term host. During the initial design the Natural Infrastructure Engineering Hub team should identify long-term host and funding strategy.

There are existing platforms into which a Natural Infrastructure Engineering Hub could be integrated – like the Green Growth Knowledge Platform, Infrastructure Pathways, International BMP Database, and the Global Infrastructure Hub.

- Consider integrating the Natural Infrastructure Engineering Hub into the Global Infrastructure Hub, and at a minimum propose as a new topic area in the Knowledge Hub. In this way the resource could secure a global collaborative commitment from the G20 for use and funding of the Natural Infrastructure Engineering Hub.
- The Natural Infrastructure Engineering Hub shares with the Green Growth Knowledge Platform the goal of – "collaboratively generating, managing, and sharing knowledge".[15]
- The International BMP Database is already a trusted data clearinghouse – pivotal in building confidence and comfort for green stormwater infrastructure implementation – especially in the design and regulatory communities.
- Infrastructure Pathways provides the benefit of taking a lifecycle view to encourage collective action and

15 Green Growth Knowledge Platform Impact Report 2020

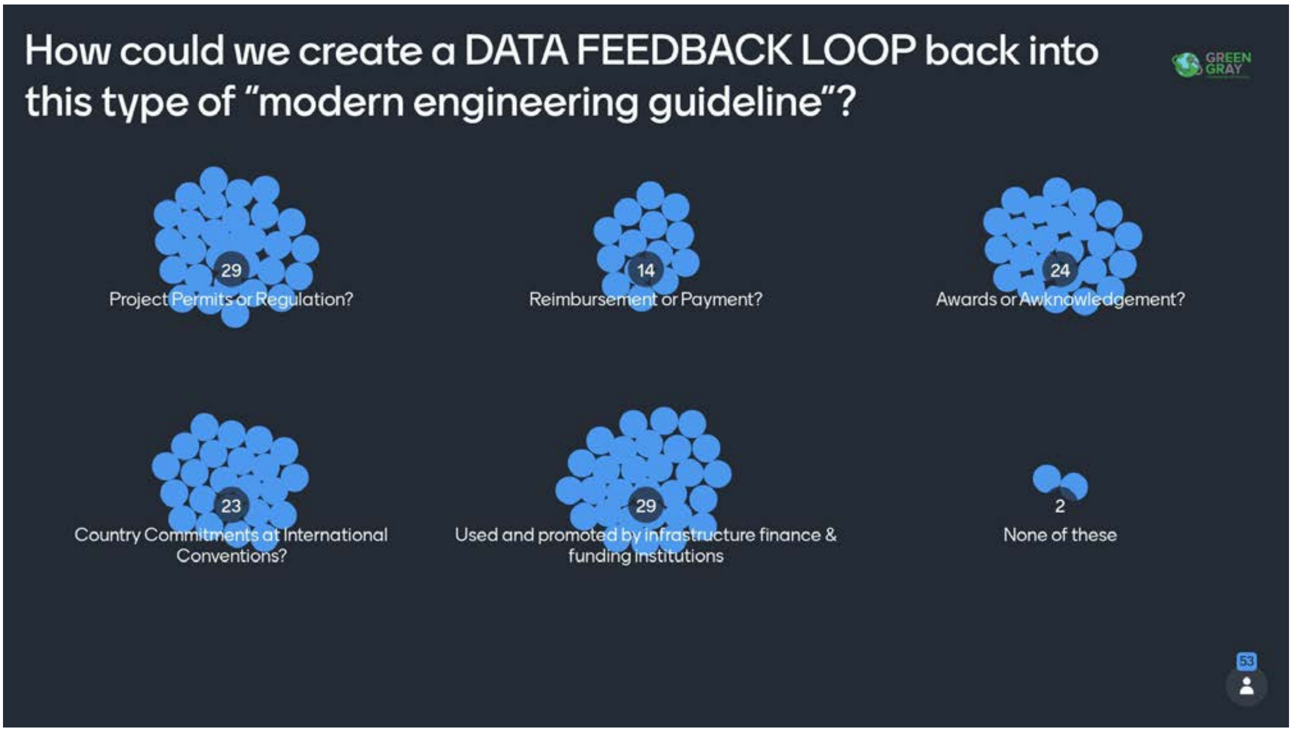


Figure 5. Project permits, regulations, and finance institutions have the greatest potential to incentivize inputs back into the Natural Infrastructure Engineering Hub.

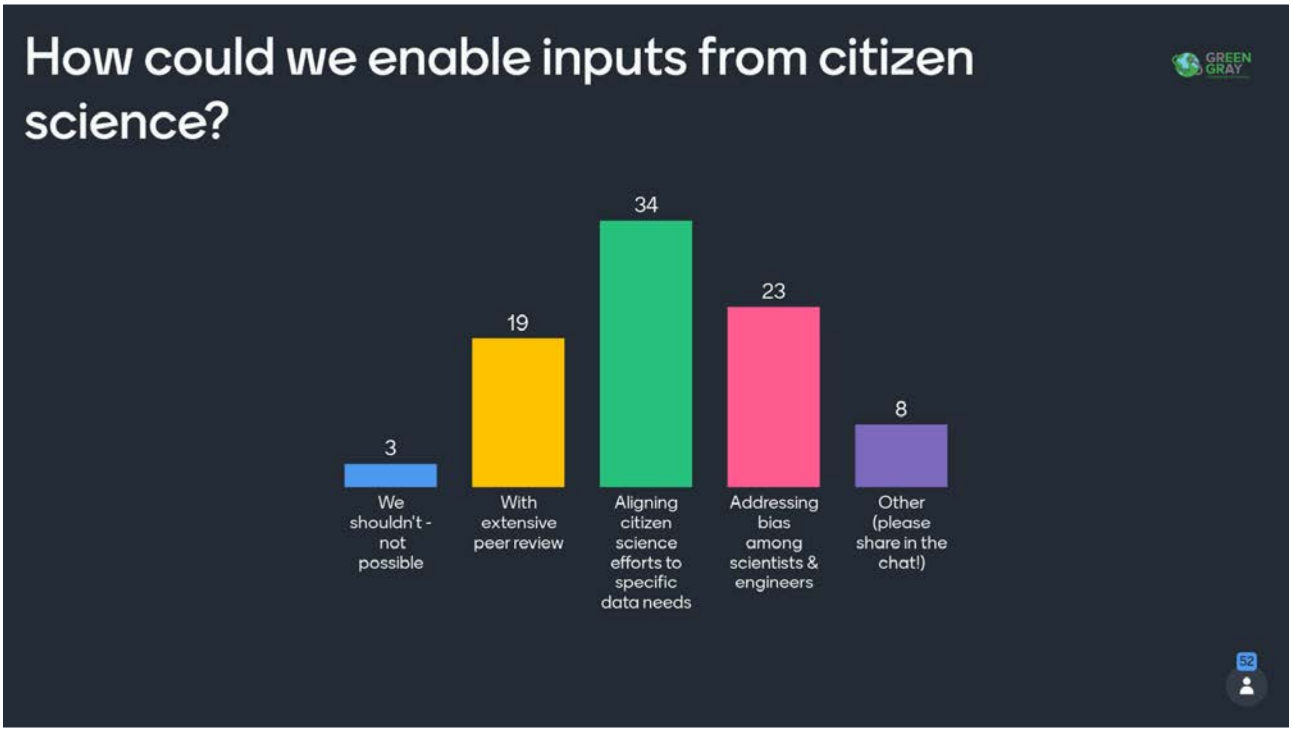


Figure 6. To be successful,citizen science efforts to align with specific data needs and the hub will need to address bias amongst science and engineers about the value and accuracy of data collected through citizen science efforts.

CONCLUSION & NEXT STEPS

Given the lack of accepted norms and standards for Natural Infrastructure Design and Engineering, we propose COLLABORATING to create 21st century engineering guidelines for our 21st century challenges – and advance new strategies to develop engineering guidance for practitioners. The solution relies upon strengthening evidence-based decision-making abilities for teams designing nature-based solutions with a sustainable and scalable framework.

To systematically learn by doing we propose creating a Natural Infrastructure Engineering Hub as a nature-based solutions evidence-based decision-making feedback loop to collaborate across disciplines and geographies. This trusted modern data sharing platform would leverage modern computing and data collection technology using an online, open-source, database structure.

The system would be built and implemented by-and-for users to input knowledge and data, with a focus on crowdsourcing information about natural infrastructure technology, performance, and cost to inform descriptive methods and engineering standards.

Based on a review of existing data and information sharing platforms:

1. Data should be freely available and accessible to all.

2. Permits, funding, and/or cash prizes can incentivize data inputs.

3. Integration of citizen science inputs is possible and generates community co-benefits

4. Collaborative funding and ownership of a shared data platform are essential for long-term success

Nature-based solutions practitioners have a deep understanding of the challenge, have articulated the problem to solve, and have started brainstorming potential solutions. As next steps we can:

1. CONVENE an international panel of cross disciplinary nature-based solutions experts - representing engineers, developers, industry, governments and financiers, to

2. BRAINSTORM together to develop a knowledge sharing framework to outline what we need to understand – as an infrastructure pathway with inputs for end-to-end information

3. PROTOTYPE a set of three types – or combinations – of nature-based engineering solutions. For example, mangroves and seawalls, living shorelines, and ecotone levees.

4. Test and ITERATE with patience and intellectual humility between practice, policy, and partnership in a knowledge generation loop.

Which of course all takes time, money, and VERY HARD collaboration. Numerous existing collaborative efforts share the scale and ambition of the proposed Natural Infrastructure Engineering Hub and could be approached to gauge interest as potential hosts and partners - like the Green Growth Knowledge Platform, Infrastructure Pathways, International BMP Database, and the Global Infrastructure Hub.

A Natural Infrastructure Engineering Hub is ONE pathway to upscaling natural infrastructure for disaster and climate resilience and to safeguard – stop or reverse – global biodiversity and species declines. One pathway is not enough. We need many different pathways to address our challenges. This is one – arguably a no-regrets approach - with the potential to provide practitioners and financiers around the world with access to up-to-date data about performance and costs, engineering design resources and tools. As a result designers will have increased confidence and the tools to design projects as experiments with integrated key performance indicators – upon which measure and monitor performance - and share their data back to the Hub.

We can all be part of the solution to implement nature-based solutions in the absence of traditional engineering standards.