Create-NBS: A Decision Tool for Identifying Potential Nature-Based Solutions (NBS) to Reduce Flood Damages and Petrochemical Pollution in the Gulf of Mexico, based on an Evaluation of Galveston Bay

The aim of implementing Nature-Based Solutions (NBS) is to address the inherently dynamic aspects of flooding and provide multifunctional solutions (e.g., flood and contamination mitigation) for communities. There are two means to reduce the threat of chemical exposure from flooding: measures that lower the risk of flooding within a petrochemical facility and measures that restrain, redirect, and/or contain contaminated waters and sediment. Natural infrastructure and NBS have been shown to reduce flood heights, speed, and volume, assist in the sequestration and reduction of stormwater runoff as well as the natural filtration of contaminants associated with floodwaters (see Tables 1 and 2).

Identifying the appropriate NBS or combinations of NBS necessitates broad (a.k.a. systems) thinking to identify and consider hazards and their likelihood; assess the interplay of physical, ecological, social, and economic influences affecting damages and vulnerability; and evaluate opportunities and identify desirable outcomes. Consideration of these many systems will help reveal the root causes, changing conditions, and trends to identify plausible solutions that can address multiple issues.

Reduction in flood risk depends on several factors such as topography, sediment and vegetation characteristics, and the characteristics of the incoming events (e.g., precipitation intensity and duration, antecedent soil moisture, water level, wave height, and wave period, etc.) as well as sea level rise (and subsidence). NBS proposed for flood-risk reduction depend on raising the cross-shore profile, increasing the distance between water and structures, and offering greater frictional resistance to the movement of water to reduce waves, slow water speed, decrease erosion, lower water levels, and manage storm runoff. This is done via:

- creating space for less damaging flooding to occur (e.g., broadening floodplains);
- recreating topographic and bathymetric complexity (e.g., using features such as dunes, islands, strategically placed logs and sticks, and shellfish reefs) to store, restrain, or redirect flows;
- increasing pervious surfaces to encourage soil absorption of water;
- planting vegetation (whether submerged, emergent, or terrestrial) to reduce the speed of overland flow of water, dampen waves, and capture sediment, etc.; and/or
- planting terrestrial vegetation to improve soil porosity which aids passage of water into the ground and its retention (and later use) and to reduce the velocity of rain drops which reduces their erosive power.

The aim of the Create-NBS tool is to help communities and facility risk managers consider all this information in light of local circumstances (i.e., physical, social, economic, and ecological conditions) and ascertain whether and which types of NBS may be appropriate for reducing risk of exposure to petrochemical releases due to extreme precipitation and flood events. These solutions may be implemented alone or in conjunction with other nature-based features or, in concert with traditionally engineered approaches to flood risk reduction and chemical spill prevention. Note that while this tool is designed to identify NBS to address risks from chemical releases due to floods, it may also be helpful for identifying NBS solutions for flooding risks where chemical risks are not a driving issue.

How to Use This Tool

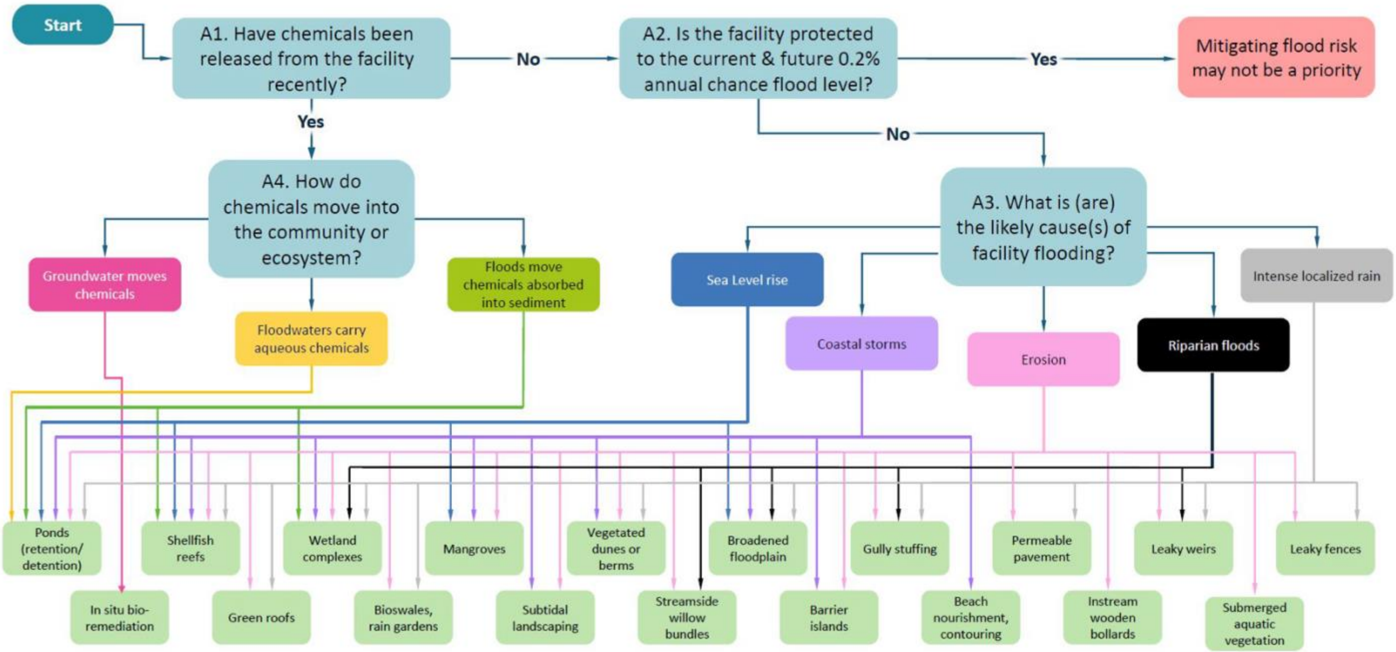
To use this tool, you[1] should answer the questions and follow the corresponding directions based on your answer. The tool is presented in four parts (Part A -- characterizing risks, B -- identifying community needs that can be addressed by NBS, Part C -- considering ecosystem needs, Part D -- selecting the best options, and Part E -- enabling a project). You may find that you do not know all the answers to questions. Call out boxes, denoted with an "i" in a circle, identify useful sources of information that can be explored to help answer questions. If after consulting useful sources of information, you still cannot answer a question, consider seeking input from local experts. Helpful resources to better understand this guide can be found here. Charts representing the steps in Parts A and B are provided as figures. In cases where more than one condition or answer applies, follow the corresponding directions applicable to each. After completing each of Parts A, B, and C insert the identified types of NBS that may be suitable into the top row of Table 3, found in Part D.

Likely two or more passes at completing Table 3 will be necessary as its purpose is to helps to refine understanding as well as guide decisions on what additional research is necessary to secure more definitive answers. Part E discuss other considerations important to project planning, evaluation, and funding.

——— **Go to Next Page** ———

[1] Throughout this document, "you" refers to the user. Users of this tool may be a chemical facility risk manager, a community planner, emergency manager, etc., or the community as a whole.

Figure 2: Schematic of Part A of Create-NBS



PART A. Characterizing and Reducing Risks with NBS

1. For the facility or area being examined:

   Does modeling indicate the potential for release or movement of toxics? For the Galveston Bay area refer to the **Toxic Flooding Vulnerability Map**.

   Is there evidence (e.g., reports, news coverage) that chemicals have been released from the facility (or facilities) in the past that may be present on the ground or in soils?

   Is there evidence (e.g., reports, news coverage) that past rainfall or flood events have resulted in toxic chemical releases into the area of interest?

   Does the area repetitively experience flooding or episodes of standing water?

   Is there evidence based on soil sampling and use of the Regional Screening Levels[2] (RSL) that indicates a Hazard Index greater than 1?

> ℹ In addition to information provided in this initiative, sources of information about chemical use, storage, and releases can be found by reviewing archives of local news as well as credible social media. Local facility records may also have access to chemical release and standing water histories.
>
> Detailed modeling of local conditions will usually be necessary to refine understanding of both flood and chemical exposure risks.

⟶ If YES to any of these questions, and no additional flood risk reduction measured have since been put in place, or if installed but thought to be insufficient, go to step A4.

⟶ If NO, go to step A2.

2. Is the facility, group of facilities, or specific portion of interest within a facility protected to the current 0.2%-annual-chance flood level[3] (i.e., is the area in a 500-year floodplain)?

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[2] United States Environmental Protection Agency. (2016). Regional screening levels (RSLs) Equations. https://19january2017snapshot.epa.gov/risk/regional-screening-levels-rsls-users-guide-may-2016_.html

Sansom, G. T., Fawkes, L. S., Thompson, C. M., Losa, L. M., McDonald, T. J., & Chiu, W. A. (2023). Cancer risk associated with soil distribution of polycyclic aromatic hydrocarbons within three environmental justice neighborhoods in Houston, Texas. Environmental geochemistry and health, 45(2), 333-342.

[3] A 0.2% annual chance of flooding is used because it is consistent with FEMA Executive Orders and floodplain management guidance that critical facilities be protected to the 0.2% chance flood level and a 500-year floodplain is the area with a 0.2%

Is it protected to a likely future 0.2% flood level, i.e., is the area *predicted to be* in a 500-year floodplain[4] by 2050?

⟶If NO to either of these questions, the risk of flooding is considered high given that it is critical infrastructure, continue to A3.

⟶If YES to both, the area may not be a priority to address and you may proceed to Part B; however, before doing so, you may want to consider the value of providing multiple layers of defense against flooding because risk of flooding still exists, and therefore you should continue to A3 to explore ideas.

> For the Galveston Bay area, information about the 500-year floodplain can be found on the **Toxic Flooding Vulnerability Map** In addition to information provided in this report, information on current and future flood risks can be obtained from state and local land use and flood control agencies as well as FEMA, NOAA Digital Coast, and USGS. Non-profit and commercial sources include the First Street Foundation and FloodFactor.com. Detailed modeling of local conditions will usually be necessary to refine understanding of flood risks.

3. What are the known or likely sources of flood hazards?

Flood risk can be from coastal storm surge and wave action, be associated with rivers overtopping their banks, intense or lengthy periods of precipitation that overwhelms stormwater drainage systems, and sea level rise. Furthermore, erosion can be associated with all these hazards and will further increase risk of floods and damages. More than one source of flooding may apply. For the facility or area of interest, consult historic and predictive flood maps and then consider local topography and proximity to sources of flooding (e.g., rivers, bayous, streams, creeks, bays, or the ocean), consider documented causes of previous floods, if any, and community knowledge of causes of localized flooding events and erosion zones to reach reasonable conclusions about flood types. Finally consider the possibility of flood protective structures failing or being overtopped (e.g., levees, sea walls, dams, or retention basins). Table 1, below, lists types of sources of flood risk, functions that reduce flood risk, and potential NBS.

annual chance of flooding. A critical facility is "a structure or other improvement that, because of its function, size, service area, or uniqueness, has the potential to cause serious bodily harm, extensive property damage, or disruption of vital socioeconomic activities if it is destroyed or damaged or if its functionality is impaired" (https://www.fema.gov/glossary/critical-facility). Critical facilities include, among other places, hazardous materials facilities because when flooded they would make the flood problem and its impacts much worse.

[4] NOAA updated its sea level rise predictions in Feb 2022 and suggests that under the low - intermediate climate warming scenario that sea level rise in the Gulf may exceed one foot by 2050. (https://oceanservice.noaa.gov/hazards/sealevelrise/sealevelrise-tech-report-sections.html)

Numerous references explain NBS ability to address various flood, storm, and erosion hazards. Most provide photographs, case studies and many provide technical guidance for planning, site assessment, design, and construction, and trouble shooting. A few stand out sources include. See also the Resources Section of this initiative.

- International Guidelines on Natural and Nature-Based Features for Flood Risk Management
- Building with Nature
- EPA's Tools, Strategies and Lessons Learned from EPA Green Infrastructure Technical Assistance Projects and Green infrastructure design and implementation
- FEMA's Building Community Resilience with Nature-based Solutions: A guide for local communities
- Green Infrastructure Tool Kit
- Reconnecting Rivers to Floodplains
- NOAA's Guidance for Considering Use of Living Shorelines
- Climate Risk and Resilience Resources Library
- A Guild to Living Shorelines in Texas
- Galveston Bay Foundation
- Living Shoreline Academy

Many flood risk maps exist and from them one can generally intuit the sources of flood risk (i.e., whether it is from riverine flooding or storm surge). Less well documented are erosion zones (which can result in rapid change in flood risk) and surface flooding due to intense rainfall that overwhelms stormwater management systems. Sources of Information on flood risk include, but are not limited to:

- **Toxic Flooding Vulnerability Map**
- **Galveston Bay Shoreline Protection Map Viewer**
- FEMA's **Flood Map Service Center**
- NOAA's **Coastal Flood Exposure Mapper**
- NOAA's **Sea level Rise Viewer**
- Tools for researching the flood history of facility or property include:
  - **Realtor**
  - TNC **Coastal resilience**
  - **NRDC**
- NOAA **Storm Events Database** and **Risk Factor** provides maps and assessments of current and future flood risk

⟶ Using Table 1, for the facility or area of interest, identify each type of potential cause of flooding (column 1), and then identify the functions needed to reduce flooding (column 2). Insert answers from Table 1's column 3 into Table 3.

4. What waterborne paths could harmful chemicals released be reasonably predicted to follow, causing community or ecosystem exposure?" This question addresses what happens if the petrochemical facility is flooded and chemicals are moved by the flood. Table 2 lists means of chemical movement and NBS that can lessen exposure risks. More than one method may apply.

   ⟶If you are using a hard copy of this tool, for each type of potential path applicable to your situation, compile a list of possible NBS from Table 2 and insert them into Table 3.

   ⟶If you are using this tool online select from each of the applicable causes of flooding, and a list of possible NBS will be inserted automatically into Table 3 for you.

Table 1: Relationships between causes of flooding, functions to reduce flooding and NBS measures to mitigate flooding.			
Causes of Flooding	**Desirable Functions to Minimize Flooding Risk and Impact to Reduce Damage**	**NBS Performing these Functions**	
Coastal Storm (Surge/Waves):	Reduce inland penetration of water by increasing distance from water (e.g., width of beach or coastal floodplain), increasing elevation, physical barriers, and/or otherwise slowing the flow of water over land.	• Broadened coastal floodplains (accomplished through periodic beach nourishment or through permanent removal of infrastructure) • Maritime forests	• Salt marshes • Mangrove forests • Root mats • Vegetated dunes and/or berms • Bioretention or detention ponds
	Reduce wave energy and lower wave height.	• Offshore barrier islands • Shellfish reefs • Subtidal landscaping • Anchored systems of networked mats of emergent and submerged aquatic vegetation	
Riverine	Absorb water or otherwise slow overland flow	• Widened riverbeds • Broadened vegetated floodplains • Floodplain wetland complexes and ponds	• Bioretention or detention ponds • Stormwater parks
	Reduce tributary flows to reduce and delay peak stream discharge downstream	• Upland wetland complexes • Bioretention or detention ponds • Gully stuffing	• Leaky weirs • Stormwater parks
Intense localized rain (pluvial flooding or stormwater)	Enhance absorption of water and/or alter the timing of flow of water to community drainage systems so that their capacity is not exceeded.	• Rain gardens and bioswales • Green roofs • Replace impervious paving with impervious options • Bioretention and detention ponds	• "Low impact development"[5] features • Wetland complexes • Storm water parks

[5] Low impact development, or LID, refers to systems and practices that use or mimic natural processes that result in the infiltration, evapotranspiration or use of stormwater to protect water quality and associated aquatic habitat. More information on LID can be found here: https://www.epa.gov/nps/urban-runoff-low-impact-development.

Table 1: Relationships between causes of flooding, functions to reduce flooding and NBS measures to mitigate flooding.

Causes of Flooding	Desirable Functions to Minimize Flooding Risk and Impact to Reduce Damage	NBS Performing these Functions
Coastal Erosion (Chronic and episodic)	Dampen water speed and energy.	• Wetland complexes • Leaky stick fences • Oyster or other shellfish reefs • Submerged aquatic vegetation • Mangrove forests • Maritime forests • Subtidal landscaping • Offshore barrier islands • Broadened coastal floodplains • Anchored systems of networked mats of emergent and submerged aquatic vegetation may reduce erosion rates by dampening wave energy • Living Shorelines (Combinations of NBS that involve plantings of native coastal vegetation (often in combination with coil mats to stabilize substrates), placement of oyster castles (or balls) and strategic placement of large shells and rocks in ways that do not significantly disrupt natural coastal bio-physical processes but reduce erosion.)
	Slow overland flows.	• Vegetated dunes and/or berms
	Stabilize shorelines.	• Vegetated dunes and/or berms • Offshore islands • Thin layer applications of clean dredged material onto coastal wetlands.
	Direct and slow areas of water flow.	• Vegetated dunes and/or berms • Wetland complexes
Riparian & Upland Erosion	Redesign of stream channels and floodplains to cope with anticipated changes in hydrology and hydraulics.	• Strategic placement of rocks and boulders to create riffle and pool habitats. • Willow bundles • Wetland complexes
	Improve ability to allow and withstand occasional bank overtopping (that builds natural levees).	• Willow bundles
	Slow overland flows and tributary flows.	• Rain gardens and bioswales • Green roofs • Replacing impervious paving with pervious options • Wetland complexes • Gully stuffing • Leaky weirs

Table 1: Relationships between causes of flooding, functions to reduce flooding and NBS measures to mitigate flooding.		
Causes of Flooding	**Desirable Functions to Minimize Flooding Risk and Impact to Reduce Damage**	**NBS Performing these Functions**
	Stabilize shorelines.	• Strategic positioning of anchored woody material in or along streams (e.g., wooden bollards, willow bundles) • Strategic placement of boulders to protect infrastructure while allowing more natural stream flow
Sea Level Rise	Serve as barriers directing water away from infrastructure.	• Vegetated dunes and/or berms • Coastal wetlands • Bioretention or detention ponds
	Absorb tidal waters and have adequate hydrological connections to keep water away from housing, streets, and other infrastructure.	• Broadening coastal floodplain habitats • Coastal wetlands
	Reduce erosion Enhance sediment trapping and encourage nearshore sediment deposition	• Vegetated dunes and/or berms • Mangrove forest • Leaky stick fences • Oyster[6] and other shellfish reefs (i.e., balls or castle substrates)
	Elevate onshore portions of the beach profile.	• Vegetated dunes and/or berms

[6] Studies suggest that oyster reefs can grow at rates necessary to keep pace with sea level rise, which makes this NBS especially resilient. Ridge, JT, Rodriguez, AB, Fodrie, FJ. Evidence of exceptional oyster-reef resilience to fluctuations in sea level. Ecol. Evol. 2017; 7: 10409– 10420. https://doi.org/10.1002/ece3.3473

Table 2: NBS Measures Mitigating Chemical Releases due to Flooding.		
How Chemicals are Released Move Through the Environment due to Flooding Events	**Desirable Functions to Minimize Chemical Spread**	**NBS Performing these Functions**
Chemicals can dissolve in water	• Act as barriers to thwart water movement, slow water movement, and/or direct water flow away from neighborhoods and coastal ecosystems and facilitate containment and subsequent remediation. • Reduce the amount of water flowing through or left standing in a petrochemical facility also reduces the probability of chemical spread and exposure risk (these are discussed above in Table 1).	• Vegetated dunes or berms • Bioretention and detention ponds. (Note that bioretention and detention ponds can be designed and managed to remove chemical tainted water so that it can be treated and disposed of properly to reduce further contamination spread and/or exposure risks.)
Chemicals adsorb (stick) to sediment. • Released chemicals can be carried on sediment suspended in flood waters. • Erosion due to excessive rainfall and flooding can result in movement of previously contaminated sediment.	• Trap contaminated sediment at or near facilities. • Reduce erosion.	• Bioretention or detention ponds (Such ponds can be designed for periodic removal of sediment for proper disposal will reduce contamination spread and/or exposure to polluted water and soil.) • NBS measures reducing erosion (see Table 1). • Oyster reefs (Oyster reefs or other living barrier systems could be used to filter and sequester (store) toxic chemicals; however, such reefs must be off limit to commercial or recreational harvest and periodic removal and disposal of oysters would likely be necessary to ensure contaminants did not return to the ecosystem.)

Table 2: NBS Measures Mitigating Chemical Releases due to Flooding.		
How Chemicals are Released Move Through the Environment due to Flooding Events	**Desirable Functions to Minimize Chemical Spread**	**NBS Performing these Functions**
Chemicals that move through groundwater.	• In situ bioremediation options (e.g., biostimulation and bioaugmentation[7]) may be possible. However, methods are chemical specific and beyond the scope of this initiative and tool.	
Chemicals are released to the air.	• Reduce the likelihood of floods or should floods occur, lessen the depth, speed, or duration of flood water will decrease the likelihood of accidental releases to air. (Such releases can occur due to loss of power to facilities.)	• See Table 1

——— **Continue to Part B** ———

[7] Bioremediation involves creating optimal environmental conditions to encourage microbial break down of contaminants. The two strategies employed are biostimulation, which involves the addition of limiting nutrients to support microbial growth, and bioaugmentation, which involves the addition of living cells capable of degrading a substance.

PART B. Characterizing Community Needs Considering Some NBS Benefits

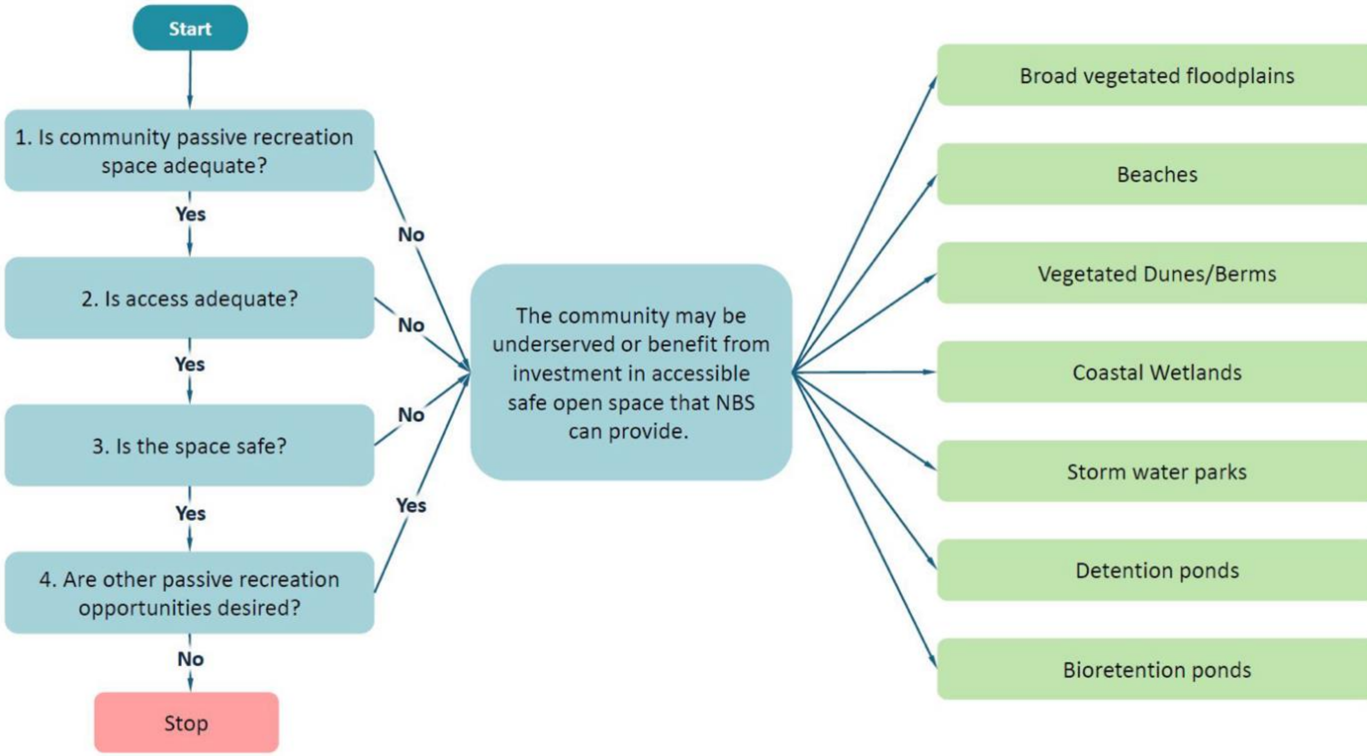
Communities vulnerable to flooding and pollution are often also prone to economic and environmental shocks and may also suffer from other afflictions including neglect, disinvestment, and lack of resources. Part B's three sections reflect benefits that NBS can provide to communities in addition to flood and chemical exposure risk reduction. These co-benefits can be important for broadening community support and securing diverse funding for projects sources. Many grants require a Benefit-Cost Analysis and integration of co-benefits is often allowed; inclusion of co-benefits can mean the difference between a project being approved for funding or rejected. Office of Management and Budget guidance[8] to federal agencies states that benefits must always be counted from the perspective of the affected community, not from the perspective of the federal government; therefore, for a benefit-cost analysis of NBS for flood hazard mitigation, a broad range of benefits may legitimately be counted, even when Federal programs do not compensate for that kind of damage when it occurs. The Federal Emergency Management Agency (FEMA) has funds for projects that mitigate flood (and other) hazards and requires projects to have positive benefit to cost ratios; under certain circumstances FEMA allows consideration of social and environmental co-benefits (in addition to avoided costs)[9]. Co-benefits closely associated with NBS are described in each Co-Benefit section below.

FEMA provides several resources guiding communities' Benefit-Cost Analysis. See FEMA's Resources for Benefit-Cost Analysis web page.

[8] OMB Circular 94.

[9] See FEMA's Benefit-Cost Model and related resources

Figure 3: Schematic of Create-NBS Part B1, Passive Recreation



Co-Benefit B1. Passive Recreation

Passive recreation includes open space areas for non-organized and non-competitive activities that do not need significant built facilities (such as pavilions or arenas or other features involving extensive land clearing), but may include site amenities such as picnic tables, boardwalks, pathways, pedestrian bridges, and more. Common passive recreation examples are walking, jogging, biking, swimming, canoeing, birdwatching, kite flying, beachcombing, etc. Besides providing recreational opportunities and promoting healthier communities[10], passive recreation may improve community cohesion, boost tourism, and create new business opportunities.

> In 2022 a new evidenced-based guideline for urban forestry, known as the 3-30-300 rule, was created to help planners and communities identify whether access to trees and green spaces, and their benefits, was adequate. The rule is that every home, school and place of work should have at least 3 well-established trees in view, no less than a 30% tree canopy in every neighborhood; and every residence should be no more than 300 m (984 feet) to the nearest public green space. (Note 30% tree canopy may not be achievable in semi-dry and arid areas, so it may be appropriate to compare to other communities in the region.) The American Planning Association suggested Standards for Outdoor Recreation are: 10 acres of recreation per 1,000 of the population of the municipality and, for each 1,000 people in the region, 10 acres of park land in stream valley parks and parkways, large scenic parks and forest preserves under municipal, county, state, federal or other authorities; and in addition, in urban areas, the recreation acreage should be at least 10 acres of area left in their natural state for each 1,000 persons. Nevertheless, the question of adequacy is one each community should answer for itself.

1. Does the community have adequate passive recreational green open space?[11],[12]

    ⟶ If YES, go to B1.2.

    ⟶ If NO, go to B1.5.

2. Is access to the green space adequate?[13] Is formal access available by the public to waterfront (coastal or riverine) features?

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[10] See for example, Caoimhe Twohig-Bennett and Andy Jones. 2018. The health benefits of the great outdoors: A systematic review and meta-analysis of greenspace exposure and health outcomes. Environmental Research 166, 628-637, doi.org/10.1016/j.envres.2018.06.030.

[11] The American Planning Association suggested Standards for Outdoor Recreation can be found at https://www.planning.org/pas/reports/report194.htm

[12] Konijnendijk, C.C. Evidence-based guidelines for greener, healthier, more resilient neighbourhoods: Introducing the 3–30–300 rule. *J. For. Res.* (2022). https://doi.org/10.1007/s11676-022-01523-z

[13] A review of several papers shows that accessibility to recreational green space is generally considered adequate if community members can walk via sidewalks, without insurmountable barriers (e.g., a fenced factory), between 0.2 miles to 0.5 mile to access it. Longer distances will typically involve travel by car. Meghann Mears and Paul Brindley. 2019. Measuring Urban Greenspace

⟶ If any answer is YES, go to B1.3.

⟶ If NO, go to B1.5.

> ℹ Accessibility to recreational green space is generally considered adequate if community members can walk via sidewalks, without insurmountable barriers (e.g., a fenced factory), between 0.2 miles to 0.5 mile to access it. Longer distances will typically involve travel by car. Community input in addition to online maps to measure distances will help determine the answer.
> For the Galveston Bay area, information to help determine an answer can be found on the **Toxic Flooding Vulnerability Map** in the Parks and Greenspace layer of the map.

3. Do existing green spaces have sufficient features to make them attractive for safe use by community members (e.g., recreation centers, bike paths, trails, landscaping, lighting, and litter management)?

⟶ If YES, the community may have adequate safe access to green/open spaces; go to B1.4. See list of NBS options under B1.4.

⟶ If NO, go to B1.5.

> ℹ Tapping into community knowledge and using online maps to identify some features will aid answering this question.

Distribution Equity: The Importance of Appropriate Methodological Approaches. International Journal of GeoInformation 8, 286; doi:10.3390/ijgi8060286 https://www.mdpi.com/2220-9964/8/6/286

4. Does the community desire additional or more diverse passive recreational opportunities?

⟶ If YES, go to B1.5.

⟶ If NO, Stop Part B1; continue to Part B2.

> ℹ Review community masterplans and recreation plans. Seek community input to aid determination of the answer.

5. The community may be underserved in terms of availability and safe access to open green space and passive recreation. NBS for flood risk reduction simultaneously offer green space that provide passive recreation opportunities. Such NBS can include beaches, dunes and vegetated berms, coastal and freshwater wetlands, and broad vegetated floodplains.

⟶ In Table 3, list all the NBS options on the top row and make note of the expected open space benefits for each in the body of the table.

Figure 4. Schematic of Create-NBS, Part B2, Tree Coverage/Natural Cooling

Co-Benefit B2: Tree Cover/Natural Cooling

Urban tree cover counteracts the urban heat island effect, which is caused by the built environment absorbing more solar energy than natural surfaces and releasing this energy in the form of heat. Studies have shown urban trees enhance cognition and attention, improve mental health, and even have positive health effects such as better birth outcomes, immune functioning, active living, cardiovascular function, weight status, and social cohesion.[14]

1. Does the community have less tree coverage than the region's high income census blocks?

   Similarly, does the area demonstrate higher temperatures due to increased light reflection on paved surfaces than other communities in the region?

   ⟶ If YES to either of these questions, go to B2.3.

   ⟶ If NO, go to B2.2.

> ℹ Look for locally relevant analyses or online maps showing tree cover or surface temperatures. Other tools, like i-Tree Landscape and i-Tree Canopy, exist to help assess tree coverage (as well as identify carbon dioxide, air pollution, and stormwater reduction benefits). i-Tree Canopy will allow you to prioritize areas for planting using information about population, density, minorities, and poverty levels.

2. Does the community desire additional trees?

   ⟶ If YES go to B.2.3.

   ⟶ If NO, stop.

> ℹ Review community masterplans. Seek community input to aid determination of the answer.

3. The community appears to be underserved in terms of tree cover and the natural cooling and protection such provides. NBS the community may wish to consider include broadening undeveloped floodplains and planting native trees and other landscaping (e.g., storm water parks) to attenuate (slow) overland flow of flood waters and enhance absorption of flood waters into the ground. Stable berms and dunes can also support growth of

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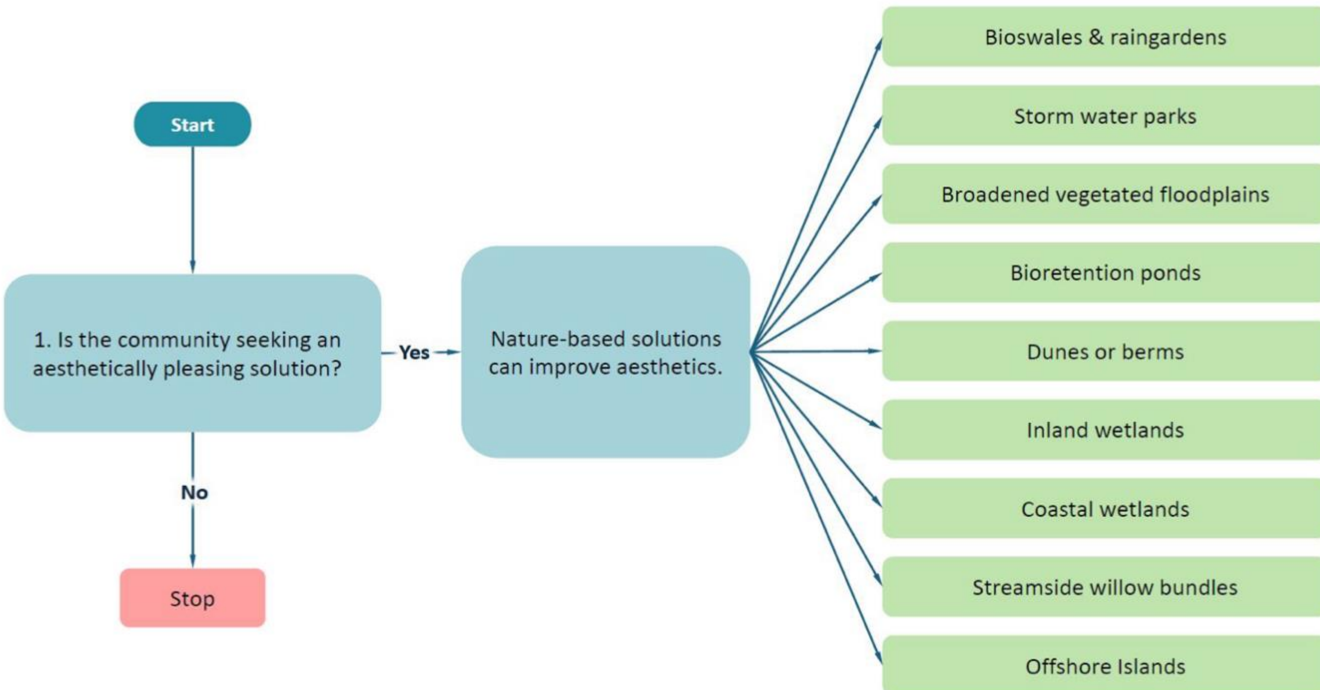
[14] McDonald R.I., Biswas T., Sachar C., Housman I., Boucher T.M., Balk D., et al. (2021) The tree cover and temperature disparity in US urbanized areas: Quantifying the association with income across 5,723 communities. PLoS ONE 16(4): e0249715. https://doi.org/10.1371/journal.pone.0249715. Wolf KL, Lam ST, McKeen JK, Richardson GR, van den Bosch M, Bardekjian AC. Urban trees and human health: A scoping review. International journal of environmental research and public health. 2020;17(12):4371. pmid:32570770)

tall shrubs and trees. Replacing impermeable sidewalks with pervious materials and adding trees at ground level (not in planters) or in bioswales can enhance groundwater percolation to reduce some runoff.

⟶ List all NBS the community may desire for addressing shade interests (i.e., listed in B2.3) in Table 3.

Figure 5: Schematic of Create-NBS, Part B3, Aesthetics



Co-Benefit B3. Aesthetics

The aesthetic character of a location has a "positive and significant effect on perceived community satisfaction" and "one of the most significant factors, alongside economic security, good schools, and the perceived capacity for social interaction" for community satisfaction.[15]

1. Has the community been working on improving its aesthetic character?

> ℹ Review community masterplans. Seek community input to aid determination of the answer.

Does the community seek to improve the aesthetic experience for residents?

⟶ If YES, go to B3.2.

⟶ If NO, stop.

2. Several NBS offer aesthetic advantages by softening and greening industrial or urbanized landscapes. Rain gardens, bioswales, bio-retention basins, detention ponds, and other "low impact development" can transform bare areas with attractive blooms and evergreen plants. These various bioretention systems can simultaneously reduce the visual impact of parking lots or other unsightly infrastructure as well as enhance community safety.[16] Coastal and inland wetlands and broadened vegetated floodplains also provide visual diversity to urban, suburban, and industrialized landscapes. Dunes and berms can provide topographic interest, and if planted with tall native grasses can provide reduce the visual impact of industrial areas. Even offshore islands planted with native vegetation can moderate industrial landscapes from some perspectives. Note that NBS used in combination with traditionally engineered approaches relying on concrete, steel and large stone -- like levees, sea walls, and revetment -- can lessen their visual impact to improve the overall aesthetic quality of shoreline resilience measures. (All of these options can be combined with educational signage to provide outdoor education opportunities.)

⟶ Note the anticipated changes in aesthetic quality in the Gulf Coast Decision Tool Table 3 for each NBS under consideration.

——— **Continue to Part C** ———

[15] Florida, R., Mellander, C., & Stolarick, K. (2011). Beautiful places: The role of perceived aesthetic beauty in community satisfaction. *Regional studies*, *45*(1), 33-48. https://www.tandfonline.com/doi/abs/10.1080/00343404.2010.486784

[16] See https://dirt.asla.org/2018/11/08/book-review-resilience-for-all/ which has an example of them being creatively paired to direct citizens to safe paths to parks and schools in the Denby neighborhood of Detroit.

PART C. Considering the Best NBS for Local and Regional Ecosystem Needs

Part C provides a quick proxy for important bio-physical factors important for habitat sustainability by placing coastal NBS into a regional and historical context. Considering historic conditions and current ecosystem needs helps in selection of solutions in two fundamental ways. Historic conditions provide clues about what types of natural flood infrastructure have been diminished and, thus, what ecosystem services have been lost and could be recovered through NBS. Using natural features and native species adapted to the area is more likely to yield viable projects and successful long-term results.

> ℹ An analysis of pre-development natural features on or around the facility and community could suggest what and where nature-based features might work in the landscape. Look to low-lying areas that tend to experience recurrent flooding, often these are locations where bayous, creeks, and wetlands historically existed. Elevated areas may have been berms or dunes, i.e., natural levees.

1. Do any remnant natural features exist that might be restored or expanded to provide flood or pollution risk reduction services (refer to Tables 1 and 2)?

   ⟶ List any not already included on Table 3.

2. What habitats and topographic features used to exist in the area that might be restored to provide flood or pollution risk reduction services?

   ⟶ List those not already included in Table 3.

   ⟶ Review environmental status reports, habitat management and fishery plans, and water quality reports prepared by state and federal government agencies and local conservation or other organizations. These will often identify habitat changes as well as regional habitat types, quantity, and quality needs for the area. This information can be used to inform selection of NBS. Where selected NBS fit with plans to protect and restore habitat quantity and quality, there may be additional sources of funding — beyond flood control or flood hazard mitigation funds — and partners available with which to plan, design, and implement projects.

   ⟶ For each NBS option, note in appropriate section of the body of Table 3, whether and what plan it supports.

State and local coastal management plans, climate resilience plans, conservation plans, and species recovery plans are good sources of information. For Galveston Bay, good sources of information include:

- Texas General Land Offices' Texas Coastal Resiliency Master Plan, it's data viewers, technical report, and updates:
- Galveston Bay Comprehensive Conservation and Management Plan. (2018)
- Seagrass Conservation Plan for Texas: Ten-year review and update. (2012).
- Texas Commission on Environmental Quality Galveston Bay Estuary Program, State of the Bay, 4th Edition.
- Texas Coastal Management Program Section 309 Assessment and Strategies Report: 2021-2025.
- Gulf of Mexico Fishery Management Council, Red Drum.
- Gulf States Marine Fisheries Commission. Black Drum Regional Management Plan. (1993)
- Gulf States Marine Fisheries Commission. Spotted Seatrout Regional Management Plan. (2001)
- Texas Oyster Fishery Management Plan. (1988)

See also the Resources Section of this initiative.

——— **Continue to Part D** ———

PART D. Selecting from Among the Possible NBS

Table 3 Instructions:
Having completed Parts A, B, and C, you should have an idea of which NBS could be further explored. To help narrow down the suitable choices of NBS you should now complete Table 3. Table 3, which expands on methods presented in Bridges, et al. 2021 and Bridges et al. 2015, facilitates comparison of the various benefits NBS can provide your community in terms of meeting its social, economic, and ecological objectives. Completing Table 3 serves dual purposes, it helps your scoping process while also serving as a guide for development of information necessary for detailed planning and design modeling. Completing the table with the involvement of community members and subject matter experts will aid building community consensus, and initial decision-making regarding which NBS to pursue. Before filling out the table, it will be helpful to have available information drawn from citizen experiences as well as mapped data, such as provided by this initiative, to aid its completion. Table 3 is designed to be flexible and adaptable.

Table 3 is organized around 3 overarching goals: 1) improving resilience to coastal storms, sea level rise, and/or intense rainfall events, 2) increasing ecological resilience, and 3) increasing economic and social resilience. Table 3 presents specific objectives for each goal as well as ideas for qualitative and quantitative measures of performance for comparing NBS attributes. Table 3 poses some project analysis questions to help particulate why an objective and performance measure is suggested; you may wish to consider some of these issues in addition to the metrics provided.

Table 3 is adaptable and flexible. While the table suggests scales and metrics to assess how NBS meets your objectives, you can choose different scales and metrics to reflect community interests and priorities. You may choose to weight certain objectives based on community priorities. However, it is important that for each given objective you apply the same method to each NBS being considered. While Table 3 is designed around comparing NBS, a similar methodology could be employed to compare NBS to eco-enhanced traditional solutions (i.e., traditionally engineers solutions that employ designs and materials to improve environmental benefits) and traditionally engineered approaches (e.g., sea walls).

Step 1: Complete set up of Table 3. Insert the NBS identified in Parts A and B into the column heads in Table 3's top row (this will be done automatically if working on line; additional columns may be necessary if working offline). You may wish to review the listed NBS options to:

- Eliminate any NBS solution that appears in multiple columns (while recognizing this may be an indication that NBS is an especially good one to explore further) or consider distinguish duplicative NBSs by size or location to more fully explore options.

- Combine into an additional column several NBS ideas to create suites of solutions; and
- Eliminate NBS options if they appear to be inappropriate (e.g., a type of habitat that never existed in the area and is unlikely to thrive or where topography or bathymetry would clearly be unsuited for the NBS).

> Be aware that the size (i.e., areal extent, height or depth, and width) of the proposed NBS will greatly affect assessment of effects; you may wish to evaluate smaller and larger versions of the same NBS to assist evaluations and comparisons.

Step 2: Make some initial assumptions about size and location of the NBS options you are considering.

Step 3: Seek community input to decide about priority objectives (e.g., top 10).

Step 4: Fill in body of Table 3. Address each objective (row). Place information you gathered and used in Parts A, B, and C to complete initial estimations or calculations and/or valuations and gather additional information to complete as much of the table as possible. It is important to compare conditions expected when the NBS project is in place (i.e., a with-project future) to that of a flood-prone future without the NBS project (i.e., without-project future).

> Plan on completing Table 3 multiple times with each iteration being increasingly detailed and the answers increasingly data driven and quantitative. Start with estimates and qualitative assessment; this initial attempt should be performed early and quickly to reveal questions and issues needing further examination to bring greater clarity to options and community interests, as well as the expertise you may need to secure to address important information. For the initial development of the table, you may wish to simply reflect likelihood and scope of impact by assessing and assigning a relative value (e.g., a number 1-10; Not Likely, Likely, Very Likely; or $, $$, $$$) for each NBS option and you should keep notes summarizing your rational. Table 3 suggests metrics both for a quick assessment (listed first) and a more quantified assessment. Table 3 provides links to sources and methods to develop quantitative data.
>
> Data from this initiative, including information from the **Adaptive Stormbox for Green Infrastructure Selection"**, may also be helpful for completing criteria presented in Table 3; for Texas applications, the Texas General Land Office Ecosystem Service Benefits Tool for Hazard Mitigation will likewise be helpful. See also Chapter 6 of Bridges et al. (2021) which presents methods valuing risk reduction and co-benefits of NBS. FEMA, a potentially good source of funds for projects using NBS to mitigate flood hazards, has a BCA Tool Kit available for download to make benefit and cost analysis much easier for potential FEMA-funded projects.
>
> Subsequent iterations should increasingly include answers gathered from scientific evidence, case studies, expert knowledge that move from using generalized notions to computational data based on simple representations of measures and then onto more detailed site-specific hydrodynamic, engineering, ecological, social, and economic modeling scaled to the size and location of the project.

Step 5: Review and discuss. Review the answers to identify the most promising NBS solutions for the community and ecosystem, in terms of community priorities and in total. Determine the questions and issues that need further examination and detail to bring greater clarity as well as the expertise that is needed to secure important data. Note that colorizing responses (e.g., where green means NBS meets an objective well, yellow means NBS has promise, red means the NBS may not be best at addressing an objective) can help more rapidly conduct screening (see hypothetical example in Table 4) by more clearly showing which NBS generated the most greens and yellows and which generated the most reds. Discuss findings with stakeholders.

Step 6: Refine and quantify answers. Eliminate some NBS if warranted, refine initially preferred NBS locations and sizes, compose additional suites of NBS if desired. Refine the table using additional expertise, data, and community input to secure more quantitative and definitive assessments. After a few iterations of Table 3, you should be ready to proceed to initial design where you begin evaluating more deeply the local biophysical factors influencing river and floodplain hydrology and/or coastal dynamics and economic outcomes and developing a more quantified and data driven analysis.

As with any project, you will eventually have to compare life-cycle (planning, design, construction, maintenance, and repair) costs, as well as assess and document environmental impacts and the various funding sources to select a feasible sustainable solution that is widely supportable because it improves quality of life and reduces risk for a community. If you are seeking Federal support, you will eventually need to complete a benefit-cost analysis (BCA); federal and state agencies have various prescribed methods to follow. Now you should be ready to do that.

> Bio-physical and economic factors will need to be carefully considered in both a regional and setting-specific context of systems that interact with each other. These factors include, but aren't limited to, current and expected tidal range, foreshore gradients (slope and topography of beach and foreshore) or river channel dimensions and floodplain topography, sediment size and supply, erosion rates and causes, temperatures, salinity, and water quality. Such factors are important not only for selecting the appropriate NBS for the problem, but also for aiding recovery after a storm (or other disturbance) and for considering sea level rise implications (Sea levels have been rising in the Galveston Bay area for decades) and future changes in stream dynamics where and when weather may be intensifying. For example, appropriate sediment supplies and sufficient space (e.g., for features like dunes or wetlands to maintain their integrity in a dynamic coastal environment and to move landward); furthermore, measures to capture sediment supplies need to look at down current or downstream effects. This information will be necessary to fully determine the design requirements and constraints of the preferred NBS option.

Table 3: Create-NBS Decision Tool, Part D, methodology for comparing performance of various NBS.

					Potential NBS identified from Parts A, B, and C:					
	Objective	**Project Analysis Questions**	**Performance Metric**	**Example Methods**						
Improve resilience to coastal storms, sea level rise, and/or intense rainfall events.	**Increases safety of population.**	Does the NBS increase the size of the population benefitting from flood reduction, by how much? Can the NBS be expected to alter flood depth or duration?	Extent reduces population at risk from flooding.	Estimate or calculate population effected based on reduced area of chemical risk exposure and changes in land use.						
	Benefits vulnerable populations.	Does the NBS prioritize socioeconomic or otherwise disadvantaged communities?	Enhances protection of disadvantaged populations.	Estimate or calculate disadvantaged population that would benefit from reduced flood and chemical risk exposure.						
	Improves runoff management.	Does the NBS reduce storm water quantity? Does the NBS change flood frequency, depths, or duration?	Improves management of stormwater quantity and drainage through capture, slowing, or redirecting runoff.	Calculate potential increase in amount of pervious surface area -- input either area or assign a value from 0 -10 (none to most). Estimate expected decrease in area covered by pooled water during rainfall events; Calculate improvements via L-THIA model or EPA green infrastructure models						

	Objective	Project Analysis Questions	Performance Metric	Example Methods	Potential NBS identified from Parts A, B, and C:					
	Reduces erosion.	Does the NBS slow erosion or help accumulate sediment in ways that reduce flood impacts? Does the NBS aim to address or reverse changes in natural processes?	Reduces erosion rates.	Evaluate vegetation coverage, height, and bathymetry changes effects on erosion. Assign a value from 0-10, 10 being best at reducing erosion rates. Calculate changes in erosion rates.						
	Mitigates multiple flood hazards.	Does the NBS address more than one flood related hazard?	Reduces multiple flood hazards such as flood height, wave height/energy, surge distance, erosion, duration of standing water, etc.	Assign 1 point per hazard addressed.						
	Complements other flood risk reduction solutions.	Does the NBS work well with other existing, planned projects, including other NBS?	The extent the NBS will provide synergies or otherwise complement flood and chemical risk exposure reduction strategies to provide additional lines of defense.	Does the NBS provide another line of defense or otherwise work well with other flood/chemical risk reduction measures under consideration? Yes/No. Assign Value 0 - 10, 10 being best. Calculate and note incremental increase in level of risk reduction.						

	Objective	Project Analysis Questions	Performance Metric	Example Methods	Potential NBS identified from Parts A, B, and C:					
	Reduces chemical exposure.	Could the NBS reduce chemical exposure risks to the community?	Reduces risk of human exposure to industrial releases.	Assess decreased potential for flood water moving from a facility into a community or ecosystem using hydrodynamic and hydraulic models (e.g., DELFT-3D Flow and SWAT). Assign value 0 - 10, 10 being highest confidence in most reductions or containment. Use Long-Term Hydrologic Impact Analysis (L-THIA) together with Toxic Equivalency Factors (TEF) to predict the reduction in heavy metals exposures.[17]						
	Reduces storm damage.	How much would the NBS reduce storm damage? Would the NBS change flood height, duration, and/or areal extent?	Incremental decrease in average annual damages avoided.	Estimate changes in storm damages relative to current and likely future conditions and assign points or symbol: Much lower as 0 or <; about the same as 5 or ~; much higher as 10 or >. Calculate expected reduction in storm damages using USACE Flood Damage Reduction Analysis.						

[17] Newman, Galen, Garett T. Sansom, Siyu Yu, Katie R. Kirsch, Dongying Li, Youjung Kim, Jennifer A. Horney, Gunwoo Kim, and Saima Musharrat. 2022. "A Framework for Evaluating the Effects of Green Infrastructure in Mitigating Pollutant Transferal and Flood Events in Sunnyside, Houston, TX" Sustainability 14, no. 7: 4247. https://doi.org/10.3390/su14074247

	Objective	Project Analysis Questions	Performance Metric	Example Methods	Potential NBS identified from Parts A, B, and C:					
	Reduces emergency management costs.	By reducing flood risk, would the NBS reduce emergency response costs and by how much?	Incremental decrease in average annual emergency response costs.	Consult with emergency responders to obtain estimates in changes in response costs relative to likely future conditions. Assign value: Much lower = 0, about the same = 5, much higher = 10. Estimate reductions.						
	Aids protection of critical infra-structure[18].	Does the NBS enhance protection to critical infrastructure? Does the NBS reduce exposure of critical infrastructure to flooding. Are expected interruptions and annual damages reduced?	Enhances protection of infrastructure considered vital to the nation, region, or the community such that their incapacity or destruction would have a significant adverse effect on public health, safety, or physical or economic security.	Value low to high in terms of likelihood (e.g., NL=not likely, L=Likely, VL=Very Likely). Calculate area receiving enhanced protection compared to without project. Calculate the savings/benefits from avoided interruptions of service, days of closure, etc.						
	Aids in protecting commercial and industrial infrastructure including marinas.	Does the NBS reduce the amount of commercial and industrial infrastructure exposed to flooding?	Enhances protection of local commercial and industrial Infrastructure (i.e., reduces economic impacts of disruptive flood or chemical release events.)	Determine number of structures and/or industrial acreage that would benefit from enhanced protection.						

[18] Critical infrastructure are assets, systems, facilities, and networks that provide vital services and must reliably function during a severe flood event (or other disaster). Critical infrastructure is typically grouped into one of four main functions: transportation, water, energy, and communications. Critical infrastructure can be defined in terms of national significance, but communities wishing to improve their resilience to flooding may wish to define what features are significant to their well-being and recovery speed. Some examples of critical infrastructure are petrochemical facilities and critical manufacturing; power plants, water and wastewater facilities and systems and other facilities important for public health; fire stations, hospitals and other healthcare and emergency services; and transportation systems.

	Objective	Project Analysis Questions	Performance Metric	Example Methods	Potential NBS identified from Parts A, B, and C:					
	Sequesters carbon.	Would the project aid in offsetting climate change?	Measure of carbon sequestration potential.	Assign value 0-10, 10 being most promising. Estimate tons of carbon stored in plants, shells, and soil (kt/ha/yr)[19].						
Increase Ecological Resilience	**Restores lost habitat.**	Does the NBS recreate, restore, expand feature(s) historically occurring in this area? Does the project address multiple habitat types? Does the project address an identified stressor to native species? Does the project aim to install, create, restore or enhance natural processes by mimicking them?	Extent to which NBS reflects conditions/ features lost in the last 100 years.	Assign a value: Does not reflect past habitat type(s), does not restore degraded habitats = 0; Re-creates some aspects of past habitats or improves some degraded habitat(s) = 5; recreates habitat(s) in acreage equivalent to past amounts; restores lost habitat quality = 10 points.						
	Addresses highly valued habitat.	Does the NBS support formally recognized high-value habitats?	The NBS supports regional restoration plans or priorities.	Review local habitat recovery plans. Assign points as follows: Does not support regional habitat plans or priorities = 0, Addresses more than one habitat, assign 5 points for each plan the habitat restoration supports.						

[19] The USDA Climate Resource Center has a calculator for determining carbon storage for trees; for others habitats, a literature specific to your site conditions may be required.

	Objective	Project Analysis Questions	Performance Metric	Example Methods	Potential NBS identified from Parts A, B, and C:					
	Reduces chemical contamination	Will the NBS reduce risk of releases of contaminants reaching bayous, river, or estuarine waters?	Extent to which the NBS could reduce risk of ecosystem exposure from contaminant releases (e.g., by redirection or containment).	Assign value based on likelihood. None = 0; Low = 1, Medium = 5, High = 10						
	Improves stormwater runoff quality or coastal or riverine water quality.	Will the NBS project improve runoff water quality? Will the NBS improve water quality in rivers, estuaries or the ocean?	Improves discharge quality or reduces suspended solids via capture, infiltration, treatment.	Initially, predict whether NBS will improve water quality (N: Not likely, L: Likely; VL: Very likely.) To calculate storm-water runoff, use screening tools like L-THIA to calculate expected reduction total suspended solids average concentration in stormwater runoff. For oyster reefs, use the Oyster Calculator to assess water filtration capability (as a % of estuary volume)						
	Increases native plants.	Will the NBS increase native plants?	The NBS improves habitat quality by increasing native plant habitats.	Estimate percentage of project area covered by native terrestrial, aquatic, or submerged plants (i.e., foliar cover).[20]						
	Helps protected species.	Does the NBS provide habitat for protected, or other species of concern? Does the project address identified stressors to species?	Extent to which NBS will provide habitat or otherwise support state or federally listed threatened, endangered species or other species of concern.	Assign one point per species.						

[20] Tools like i-Tree Landscape and i-Tree Canopy classify land and tree cover across a given area using random sampling of aerial imagery.

					Potential NBS identified from Parts A, B, and C:					
	Objective	**Project Analysis Questions**	**Performance Metric**	**Example Methods**						
Improve Social and Economic Resilience (Quality of Life)	**Reduces disaster recovery time**.	Will the NBS increase the speed of recovery from a flood? Will the NBS improve community members access to jobs and supplies after a disaster strikes?	Expected reduction in time to recover from floods due to additional protection afforded by NBS.	Consult with community members and emergency management experts, based on changed flood elevation, extent and duration, estimate the change in expected length of time areas will be inundated; and/or Estimate the change in number of days major roadways stay inaccessible; and/or, Estimate the change in length of time businesses are closed due to flooding or chemical releases.						
	Protects historic properties/ tribally/ culturally significant areas.	Does the project enhance protection for historic properties or culturally significant structures or properties? Does the NBS project effect or incorporate community anchor points?	Historic properties or culturally significant areas (a.k.a. anchor points) protected by implementation of NBS.	Rate in terms of the number of anchor points/properties protected. 0-10, 10 is high.						
	Improves waterfront access.	Does the plan for NBS include improved community access to water bodies (i.e., ponds, bayous, streams, estuaries, or ocean)?	Increases community's opportunity to safely access waterbodies.	Location of access points decreases distance traveled from key community population spots. Assign for No improvement = 0, Low improvement = 4, Moderate improvement = 7, Significant increase in access for local population = 10.						

	Objective	Project Analysis Questions	Performance Metric	Example Methods	Potential NBS identified from Parts A, B, and C:					
	Creates recreational opportunity.	Does the plan for NBS allow for diverse passive recreation opportunities?	NBS diversifies passive recreation opportunities.	Project the number of new recreational opportunities provided by boat launches, miles of walking/biking paths, picnic areas, open fields, etc).						
	Creates economic growth opportunity.	Would the NBS help to establish, support, or expand a recreation or ecotourism businesses?	NBS potential to support establishment/expansion of recreational or ecotourism businesses and jobs.	Indicate likelihood or Assign: No, Very Low to High Estimate economic growth. One tool is the Downtown Toolbox.						
	Sustains commercial fisheries.	Will the NBS provide habitat important to commercial fish?	The NBS increases habitat important to supporting commercial fisheries.	Estimate acreage of improved commercial fishery habitat due to NBS; Use the Seagrass and Salt Marsh Calculator[21] and the Oyster Calculator.						
	Enhances employment opportunity.	Does the project support continued economic development and jobs that do not put infrastructure or people at risk?	Due to maintenance requirements, recreation, and eco-tourism opportunities, NBS provides local employment opportunities.	Estimate the number of jobs[22] potentially created.						

[21] The Nature Conservancy developed these models and notes that fish production data are currently only available for the Northern Gulf of Mexico, Floridian, Carolinian, and Virginian ecoregions.

[22] Consider jobs that could be associated with creation of the NBS project (e.g., designers, construction, and maintenance), indirect jobs could be new positions at material suppliers, and induced jobs could be those such those associated with recreation and tourism.

	Objective	Project Analysis Questions	Performance Metric	Example Methods	Potential NBS identified from Parts A, B, and C:					
		Could implementation of the NBS contribute to local employment (i.e., would the NBS contribute to a growing workforce, tax base, or other development?								
	Enhances education opportunities.	Does implementation of the NBS afford opportunities for education and outreach?	Extent to which valuable educational opportunities can be built into the NBS to inform the public about flood risks, NBS solutions, and community benefits.	Assign value 1 - 5, based on the ability to support learning kiosks, field visits, etc.						
	Minimizes industrial operations impact.	Does the NBS reduce the daily impacts of petrochemical industrial operations on community health and well-being?	Extent to which NBS can reduce the daily impacts of operations, e.g., noise, dust, visual impacts.	Assign value, Low to High, 0 - 10; Use I-Tree Landscape to calculate air pollution reduction benefits						
	Lessens urban heat.	Does the NBS reduce urban heat?	Extent NBS could contribute to urban cooling due to increased shading or evaporative cooling.	Assign potential value, Low to High, 1-10						
	Aligns with community goals.	Does the NBS solution aid achievement of other community goals?	Extent to which NBS aligns with community desires for health, wellbeing, and other factors relevant to quality of life as determined by an existing plan, public meetings, or a survey.	Assign value, 0-10, 10 being best						

	Objective	Project Analysis Questions	Performance Metric	Example Methods	Potential NBS identified from Parts A, B, and C:					
	Reduces mental stress.	How much would the NBS be expected to reduce stress and lost productivity due to changes in flooding?	Population no longer likely to experience flooding.	Calculate the benefits to be derived by assigning[23]: $2,443/person for mental stress reduction and $8,736/person for lost productivity.						
	Property Value.	Is there a change in property values (as compared to without project) due to the project?	Expected changes in property values due to intervention[24].	Compare current property values trend to that of without NBS project. Assign, based on percent change: Small: 0.5% Med: 0.5-1% Large 1-1.5% Very Large more than 1.5%						
	Implement-ability.	To what degree does the project have foreseeable funding? What permits be required?	Ability of the project providing benefits within 10 years.	Assign value low to high, 1 - 10, the likelihood design, permitting, and funding issues could be addressed in the next 5 years.						

[23] These are the benefits FEMA's Benefit-Cost Tool allows.

[24] It is best to compare to look at least three conditions: What would property value be without any intervention, what would it be with an NBS project, and without an NBS project. Flood prone properties in coastal zones are predicted to lose value relative to those not effected by flooding (see for example, McAlpine SA, Porter JR. (2018) Estimating Recent Local Impacts of Sea-Level Rise on Current Real-Estate Losses: A Housing Market Case Study in Miami-Dade, Florida. Popul Res Policy Rev. 2018;37(6):871-895. doi: 10.1007/s11113-018-9473-5. Epub 2018 Jun 26. PMID: 30546178; PMCID: PMC6267259; and Hino, M, Belanger ST, Field, CB, Davies, AR, and Mach, KJ. High-tide flooding disrupts local economic activity. Science Advances 5(2) https://doi.org/10.1126/sciadv.aau2736.) Aspects that can influence property values include: flooding frequency, areal extent, duration, impact, business interruption, inconvenience, cost of flood insurance, etc.

					Potential NBS identified from Parts A, B, and C:					
	Objective	**Project Analysis Questions**	**Performance Metric**	**Example Methods**						
	Afford-ability.	Is the NBS cost effective considering its various benefits? Does the project have a positive cost-benefit ratio? Are there funding sources the community could access to help offset its costs?	Ability of the community to afford the project.	Extent to which community feels total benefits outweigh costs. Assign value 1-10, 10 being best Conduct a cost - benefit analysis that includes consideration of co-benefits using FEMA's BCA Tool Kit Calculator or Texas GLO's Hazard Mitigation Funding Opportunity Approach for Coastal Resilience Projects with Ecosystem Services Methodology.						

Tables 4a & 4b: Hypothetical examples of initial development of Table 3 (NBS Comparison Table) based on Texas City case study conditions. Both versions of the table omit the questions, metrics, and example methods listed in Table 3 and include color coding to assist review of the totality of the information. Version 4b is an abbreviated version of 4a as it reflects only those objectives that a hypothetical community identified as their top 10 priorities. NBS with more green boxes may be both more promising in terms of flood and chemical risk reduction benefits (such as riparian buffers, urban forests, and freshwater wetlands) as well as more attractive in terms of co-benefits and other community concerns (e.g., stormwater runoff reduction, storm water sequestration, storm surge protection, etc.). Conversely alternatives with more red boxes (such as shellfish reefs or barrier islands) may on their own be insufficient but when integrated into an assemblage of other NBS, may provide added value. (Please do not assume the ratings here apply to your project.)

Table 4a. Example table with full suite of objectives

			Possible Nature Based Solution (s)							
Goal	Objective	Top 10 (*)	Increase pervious surfaces	Riparian buffer/Urban forest	Shellfish Reef	Park lands	Retention pond/water director	Bioswales/Filter strips	Freshwater wetlands	Offshore barrier islands
Improves resilience to coastal storms, sea level rise, and/or intense rainfall events	Increase safety of population		2	3	1	3	5	3	4	5
	Benefits vulnerable populations	*	1	5	1	5	5	3	3	3
	Improves runoff management		5	5	1	4	5	5	5	1
	Reduces erosion		3	4	1	3	5	5	4	3
	Mitigates multiple flood hazards	*	1	5	1	3	4	1	3	1
	Complements other flood risk reduction solutions	*	Y	Y	Y	Y	Y	Y	Y	Y
	Reduces chemical exposure	*	1	3	3	1	5	3	4	3
	Reduces storm damage	*	3	4	3	4	4	3	5	4
	Reduces emergency management costs		2	5	3	4	5	2	4	3
	Aids protection of critical infrastructure		2	5	5	3	5	2	4	4
	Aids in protecting commercial and industrial infrastructure, including marinas		1	3	5	3	5	2	4	4
	Sequesters carbon		1	5	3	2	1	1	5	1
Increases ecological resilience	Restores lost habitat		N	Y	Y	Y	N	N	Y	N
	Addresses highly valued habitat		N	Y	Y	N	N	N	Y	N
	Reduces chemical contamination		Y	Y	Y	N	Y	Y	Y	Y
	Improves stormwater runoff quality or coastal/riverine water quality	*	Y	Y	Y	Y	Y	Y	Y	N
	Increases native plants		N	Y	N	N	N	N	Y	Y
	Helps protected species		N	Y	Y	N	N	N	Y	N
Im pr ov	Reduces disaster recovery time		1	5	3	4	4	2	4	4

Goal	Objective	Top 10 (*)	Increase pervious surfaces	Riparian buffer/Urban forest	Shellfish Reef	Park lands	Retention pond/water director	Bioswales/Filter strips	Freshwater wetlands	Offshore barrier islands
			Possible Nature Based Solution (s)							
	Protects historic properties/tribally/culturally significant areas		1	4	3	4	5	4	4	4
	Improves waterfront access		N	N	N	N	N	N	N	N
	Creates recreational opportunity	*	N	Y	N	Y	N	N	Y	Y
	Creates economic growth opportunity		L	H	L	H	H	L	M	L
	Sustains commercial fisheries		L	H	H	L	L	L	H	L
	Enhances employment opportunity		L	M	L	M	H	M	L	L
	Enhances education opportunities		L	M	L	M	M	H	H	M
	Minimized industrial operations impact	*	L	H	L	M	L	L	M	L
	Lessens urban heat		L	H	L	M	L	M	M	L
	Aligns with community goals	*	Y	Y	N	Y	Y	Y	Y	N
	Reduces mental stress		N	Y	N	Y	Y	Y	Y	N
	Property value		L	H	L	H	H	M	M	L
	Implementability		H	M	H	H	H	H	M	L
	Affordability	*	M	M	H	M	L	M	L	L

Sample Grading Criteria	N, L, 1, 2	M, 3	H, Y, 4, 5
	Least Promising →		*Most Promising*

Table 4b. Example showing only top 10 community priorities.

Goal	Objective	Top 10 (*)	Possible Nature Based Solution (s): Increase pervious surfaces	Riparian buffer/Urban forest	Shellfish Reef	Park lands	Retention pond/water director	Bioswales/Filter strips	Freshwater wetlands	Offshore barrier islands
Improves resilience to coastal storms, sea level rise,	Benefits vulnerable populations	*	1	5	1	5	5	3	3	3
	Mitigates multiple flood hazards	*	1	5	1	3	4	1	3	1
	Complements other flood risk reduction solutions	*	Y	Y	Y	Y	Y	Y	Y	Y
	Reduces chemical exposure	*	1	3	3	1	5	3	4	3
	Reduces storm damage	*	3	4	3	4	4	3	5	4
Increases ecological resilience	Improves stormwater runoff quality or coastal/riverine water quality	*	Y	Y	Y	Y	Y	Y	Y	N
Improves social and economic	Creates recreational opportunity	*	N	Y	N	Y	N	N	Y	Y
	Minimized industrial operations impact	*	L	H	L	M	L	L	M	L
	Aligns with community goals	*	Y	Y	N	Y	Y	Y	Y	N
	Affordability	*	M	M	H	M	L	M	L	L

——— **Continue to Part E** ———

PART E. Enabling a Project

Numerous other factors effect project selection, planning and design, and community acceptance. First and foremost, projects need broad support and limited opposition, therefore, it is critical that multiple stakeholders be involved throughout project exploration and planning phases. You should first identify likely stakeholders, such as local industry, property owners, community groups, and business interests as well as local, state, and federal agencies and nongovernmental institutions. Involving academic or research institutions and technical experts can help develop necessary new information as well as provide broader context and experience that should help build trust as well as build local capacity. Successful projects will approach stakeholder engagement carefully, looking for multiple means to secure input in a variety of ways to ensure adequate community representation. Numerous guides have been developed on community engagement. Documenting co-benefits of alternatives is an excellent way to attract stakeholders that otherwise might not be particularly interested in flood and chemical risk reduction and secure their engagement with and, ideally, eventual support of the project.

Numerous publications on outreach and community planning exist that now focus on building resilience and provide tools to help assess risks and plan for them. A few sources include:

- Chapters 3 and 4 of the 2021 International Guidelines on Natural and Nature Based Features for Flood Risk Management
- NIST Community Resilience Planning Guide for Buildings and Infrastructure Systems.
- The River Network's Essential Learning Series: Building Community and Climate Resilience
- ICLEI's Temperate Adaptation Planner
- The Center for Planning Excellence's Guides

You will want stakeholder input to help address important considerations:

What levels of uncertainty the community will accept?

The level of risk a community can tolerate can depend to a great extent on socio-economic factors effecting both community-wide and personal vulnerability. Flood prone socio-economically challenged communities often have fewer resources, less flood insurance, and less access to government programs consequently they often take longer to recover from floods. Even, reducing the frequency of relatively small flooding events can realize significant improvement in quality of life in these communities.

It is important to build stakeholder understanding of flood probabilities and how changing environmental conditions -- from habitat loss to climate change -- effects flood probability and the impact of floods. Similarly, it is important that stakeholders gain an understanding that neither NBS nor traditional hardscaped engineering solutions will not work for every conceivable storm event and condition. Beyond what level of uncertainty will the community accept, corollary questions should include: what level of protection is expected from the NBS and will it be considered the principal hazard reduction measure to achieve that level of protection?

Some natural infrastructure and NBS have been used for decades as the principal flood hazard reduction measure. For example, The Netherlands employs dune complexes along its coast to provide protection against major storm events. In the United States, beach-dune systems are widely accepted as principal measures and standardized means exist to design them to deliver a given sustained level protection (e.g., the U.S. Army Corps of Engineers Coastal Design Manual). Similarly oyster reefs function as submerged breakwaters — structures for which the US Army Corps of Engineers also has design parameters.

Loss of wetlands and offshore reefs are widely considered contributors to increasing flood damages. The flood reduction benefits of wetlands (both coastal and riparian) and reefs have been increasingly quantified with models and in terms of damage reduction or damage avoided.[25] Modeling can quantify their contribution to flood risk and damage reduction. However, while numerous technical guides for wetland, coral reef, shellfish reef restoration exist, widely accepted standardized practices for designing wetlands and reefs for flood protection do not. Further methods for evaluating the level of flood protection they provide have not yet been standardized. Nevertheless, sophisticated, widely accepted, publicly available models, like Delft-3D Flow and SWAT, can provide necessary details to inform changes in flood risk brought about by NBS.

You may prefer to start with NBS deployed as "interim" measures that provide some protection while waiting for completion of major large-scale flood and storm protection infrastructure projects which that often take decades in planning and construction. Moreover, you may wish to consider NBS as “supporting measures” that provide additional layers of flood protection or aid in extending the life of traditionally built flood infrastructure. Often the approach is to place a NBS on the waterside (threat side) of the structure can combine to deliver more flood risk reduction and provide additional co-benefits. For example, broad floodplains combined with setback levees have been deployed on the Missouri River for over 70 years to reduce flood damages. Oyster reefs, wetlands and wide foreshores have been proposed to sit in front of a levee in a hybrid NBS design called the “horizontal levee”[26]. When retaining berms, levees, or seawalls are already in use for chemical spill prevention, NBS may be added to one side to help increase the level of protection, reduce erosion that can undercut a structure, and even increase the longevity of its performance. Increasing the diversity of measures employed to reduce risk of flood damages, together with measures that mitigate the negative effects of floods, is known as a “multiple lines of defense” approach. By employing multiple tactics, a facility or a community is better prepared for changing conditions that can lead to catastrophic events and cascading system failures.

Whether primary or supportive, all flood risk and chemical risk reduction approaches will still need to be complemented with nonstructural measures (e.g., zoning to set back development from flood hazards, building codes, insurance, evacuation and readiness plans, and facility contingency plans) to lessen impacts and reduce damages.

How can potential spatial limitations be overcome?

Nature-based solutions may require more space than stone or concrete barriers to floods. Therefore, it’s essential to consider whether sufficient space exists and how might additional space be created. Rehabilitating water fronts

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[25] See for example, Narayan, S., Beck, M.W., Wilson, P. *et al.* The Value of Coastal Wetlands for Flood Damage Reduction in the Northeastern USA. *Sci Rep* **7**, 9463 (2017). https://doi.org/10.1038/s41598-017-09269-z

[26] See https://www.cityofpaloalto.org/files/assets/public/public-works/environmental-compliance/source-control/factsheets/horizontal-levee-factsheet_revised.pdf

through removal of obsolete structures, changing zoning and in land use and targeted buyouts can provide room for solutions to reduce flood damages. It's also likely that community interest in the co-benefits to be derived from the nature-based solution could increase acceptance of means to create new open spaces. The desired level of flood protection and limits to available space may require a hybrid solution (i.e., involving more conventional structure measure such as a levee in combination with NBS).

Is the project costly and is it cost-effective?

As with any project, a life-cycle assessment of costs including planning, construction, maintenance, and repair considering the benefits (flood risk reduction, chemical risk reduction, as well as other community benefits) will be needed. This initiative as well as Chapter 6[27] of Bridges et al. (2021) presents several methods valuing flood risk reduction and co-benefits of NBS.

How committed is the community to management and maintenance?

Periodic maintenance, especially in the initial years after installation, will likely be needed. Ideally NBS will become self-sustaining as well as resilient to storms, given the correct physical and biological settings (e.g., sediment supplies); however, there is always the possibility of needing major repairs after large events to boost recovery speed. Beach nourishment is an NBS that typically requires periodic renourishment due to normal erosion. Furthermore, if conditions change more or differently than planned, adaptive management may be necessary.

Properly constructed NBS should not require extensive repairs after major storms but it is reasonable to plan for the potential for major repair costs if a storm occurs in the initial years after NBS construction. One advantage of NBS is that they tend to grow more stable with age as plants and roots get larger. However where beaches and dune projects provide distance and physical protection to property during major storms, more extensive and costly repair efforts may be required.

Local public works or recreational department's staff likely will need training on proper management and maintenance of NBS.

Areas used for passive recreation will need additional management and maintenance (e.g., garbage removal, security, walkway repairs, etc.). Therefore, it is important to consider funding needs for maintenance as well as job creation benefits.

Explore ways to build community commitment to protect NBS. Community based volunteer groups may be able to take responsibility for some management and monitoring tasks. Often academic and research institutions can be encouraged to monitor and report on site conditions and performance.

How can the project be funded?

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[27] van Zanten, B., K. Arkema, T. Swannack, R. Griffin, S. Narayan, K. Penn, B. G. Reguero, G. Samonte, S. Scyphers, E. Codner-Smith, S. IJff, M. Kress, and M. Lemay. 2021. "Chapter 6: Benefits and Costs of NNBF." In *International Guidelines on Natural and Nature-Based Features for Flood Risk Management*. Edited by T. S. Bridges, J. K. King, J. D. Simm, M. W. Beck, G. Collins, Q. Lodder, and R. K. Mohan. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Finding and dedicating revenue is a challenge for any project from its first idea exploration or feasibility phase, to detained modeling and design, to implementation, and lastly sustained management, monitoring, and potential amendments. Building partnerships will expand funding opportunities. Fortunately, projects involving NBS can benefit by tapping and combining multiple sources of funds such as FEMA flood hazard mitigation grants, NOAA/National Fish and Wildlife Foundation coastal resilience grants, EPA sewer overflow and storm water reuse municipal grants, and many other programs that target habitat and species recovery. Innovative financing options, such as resilience bonds, environmental impact bonds, and parametric insurance are also expanding.

Two sources of information relevant to funding NBS projects include: Financing Natural Infrastructure for Coastal Flood Damage Reduction and Local Funding for Coastal Projects: An Overview of Practices, Policies, and Considerations. The latter presents options for raising revenue and discusses emerging financial tools as well as considerations communities to determine which may be most appropriate for funding a beach or coastal restoration project and

Conclusion

Once you have answered the questions in Parts A and B, and completed a comparison of options, as suggested in Table 3, you will have a better idea of which NBS merit further exploration. Even if you can not answer all questions initially, working through this material will provide you with a better appreciation of what data should be gathered to address questions of feasibility and sustainability as well as what information could be developed to build community support for the project. As more site-specific information becomes available, preliminary designs can be developed and co-benefits and costs further refined. At that time, it may be appropriate to again revisit the questions and the table.

While designing aspects of your project, it may be helpful to also consider the Waterfront Alliance's Waterfront Edge Development Guidelines (WEDG) as this relatively new process aims to help communities design waterfront developments or redevelopments using high standards of resilient design and risk reduction. By using the questions and the Table, here, and consulting these WEDG guidelines, you will be well positioned to seek WEDG verification which indicates leadership in resilient design and risk reduction. Working through this information will also aid completion of environmental compliance documentation that will likely be needed for permits, grants, or other federal or state support.

RESOURCES

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Tools, Strategies and Lessons Learned from EPA Green Infrastructure Technical Assistance Projects. 2015. EPA 832-R-15-016. Washington, DC: U.S. Environmental Protection Agency. https://www.epa.gov/sites/production/files/2016-01/documents/gi_tech_asst_summary_508final010515_3.pdf and USEPA's website on green infrastructure design and implementation: https://www.epa.gov/green-infrastructure/green-infrastructure-design-and-implementation

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Reconnecting Rivers to Floodplains. 2016. American Rivers. http://s3.amazonaws.com/american-rivers-website/wp-content/uploads/2016/06/17194413/ReconnectingFloodplains_WP_Final.pdf

Guidance for Considering Use of Living Shorelines. 2015. NOAA. https://www.habitatblueprint.noaa.gov/wp-content/uploads/2018/01/NOAA-Guidance-for-Considering-the-Use-of-Living-Shorelines_2015.pdf

Climate Risk and Resilience Resources Library. Conservation gateway.org/ConservationPractices/Marine/err/library/Pages/default.aspx#habitats.

A Guild to Living Shorelines in Texas. https://www.glo.texas.gov/coast/coastal-management/forms/files/living-shoreline/living-shorelines-in-texas.pdf

Galveston Bay Foundation: https://galvbay.org/work/habitat-restoration/

Living Shoreline Academy: https://www.livingshorelinesacademy.org/