The Ecosystem Services Primer For Greater Gulf-Houston Region

Second Edition | 2019

Six-Step Guide for Making Nature-Based Infrastructure Decisions Comparing the Benefits of Multiple Ecosystem Services

Credits

Houston Wilderness - authored and researched by Deborah January-Bevers, Lindsey Roche, MSc and Lauren Harper, MPA, 1st Edition (2016) and 2nd Edition (2019)

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Preface

This Ecosystem Services (ES) Primer for Greater Gulf-Houston Region, 2nd Edition, *a Six-Step guide for making nature-based infrastructure decisions based on the benefits of multiple ecosystem services* (**HW ES Primer**) is the result of over five years' of presentations, discussions and case study reviews based on the first edition of this HW ES Primer. Since 2014, over 50 presentations have been given on the HW ES Primer at environmental-based conferences and forums around the U.S. and in Europe with strong interest from a wide variety of interested stakeholders, decision-makers and supporters of enhancing various types of ecosystem services for community - residential and corporate sustainability and wildlife habitat improvements.[1] Along the way, the authors of the HW ES Primer have learned much more about how, why and to what extent policy and decision-makers, as well as governmental entities and scientists, can use this Primer for comparisons, ideas and options for enhancing/creating various ES in respective communities, often as a viable, cost-effective alternative to more structural, gray infrastructure.

In addition to information, comparisons and case studies provided in the first edition of the HW ES Primer, this 2nd edition adds more information on 1) the definition and use of nature-based infrastructure (NBI), 2) different ways to measure nature-based infrastructure options, particularly when targeting major planning and/or changes in air and water quality, carbon sequestration, erosion control (including biostabilization techniques) and stormwater control, 3) use of Benefit Relevant Indicators (BRI) as a valuation option in addition to monetary ES values, 4) ways in which use of nature-based infrastructure projects can be used to enhance/increase/maintain ES in high risk communities that have been subject to large storm events - such as hurricanes and repeated flooding - as well as sea level rise, and 5) a few new statewide/regional and local policy case studies based on actions taken in the aftermath of large-scale natural disasters. The eight-county area around the Gulf-Houston region is the basis for the various ES reviews, related case studies and nature-based infrastructure options.

Targeted uses of the HW ES Primer include: 1) determining how to best value an ecosystem service(s) depending on the goal of the decision-maker (e.g., making a land-use change, needing to improve air and/or water quality, providing erosion control or increasing carbon sequestration, providing more outdoor recreation in an area, lowering energy costs, etc); 2) determining how many ecosystem services an area of land provides to humans and wildlife; 3) comparing the ecosystem services of different areas of the region; and 4) accessing the options available to a decision-maker when looking at land-use changes). For example, this Primer has been used by various local, state and federal agencies to 1) consider ways to quantify multiple impacts to parks systems - due to both nature and man-made events, and 2) cumulatively value the ES impacts from temporary or permanent land-use disturbances, such as new installation of oil and gas pipeline running through public lands, disaster-fund residential home buyouts, enlargements in existing riparian corridors and increased use of nature-based stabilization techniques on developed lands. The HW ES Primer is

[1] One HW ES Primer presentation example: https://conference.ifas.ufl.edu/NCER2018/presentations/Salon%20C/Wednesday/1640%20January-Bevers.pdf.

also used by governmental officials and residential/commercial developers considering nature-based infrastructure projects for large storm-water detention areas and riparian nature-based stabilization techniques, including low impact development, bioswales and carbon sequestration.

In **Six Steps** designed to aid decision-makers in infrastructure options, this Primer looks at how the framework for comparison and valuation of the natural environment can be improved by laying out a comprehensive and systematic means to ensuring that ecosystems, and the critical services that they provide, are taken into account in policy decisions.

Throughout this Primer, the authors promote consideration of nature-based solutions to regional/community infrastructure needs, including aiming for a healthy urban environment for all citizens through inter-connected improvements in the various types of possible ecosystem services, improving access to green spaces, providing sustainable solutions to regional risks and stressers in air pollution, frequent flooding, non-point source pollution, low organic carbon sequestration, and reductions in ecological connectivity within urban spaces. Native grass and tree species are encouraged in all types of nature-based infrastructure options.

On a global scale, Houston Wilderness supports the UN Global Assessment Report on Disaster Risk Reduction, produced by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), that highlights the critical need to integrate biodiversity considerations in global decision-making on any sector or challenge, whether its water or agriculture, infrastructure or business. Healthy biodiversity is the essential infrastructure that supports all forms of life on earth, including human life. It also provides nature-based solutions on many of the most critical environmental, economic, and social challenges that we face as human society, including climate change, sustainable development, health, and water and food security.

This Primer recognises that there is considerable complexity in understanding and assessing the causal links between infrastructure policy, its effects on ecosystems and related services and then valuing the effects in economic terms. Integrating policy, science and economics disciplines is important when going through these Six Steps. The critical importance of the links to scientific analysis, which form the basis for valuing ecosystem services, is also stressed in this Primer. Also, there may not be a ‘perfect’ ecosystem service valuation for many decision-making purposes. Practical ES appraisals need to be able compare the relative magnitude of changes in the provision of ecosystem services across different options, and this can be possible even with limited availability and precision of scientific and economic information. In most cases, it should be possible to present a robust assessment, with suitable sensitivity analysis, highlighting the key uncertainties and exploring their implications.

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Abstract of HW ES Primer

Natural landscapes serve our well-being in a variety of ways including water purification, flood protection, hurricane protection, carbon capture, recreation and wildlife enhancement. Identifying and understanding the benefits of services provided by local ecosystems can lead to cost-effective solutions to infrastructural and environmental problems while also creating enhanced biodiversity in urban/suburban areas. For the storm-prone Greater Houston region, the critical need to better connect the ecosystem services (ES) provided by the diverse assemblages of forests, prairies, wetlands, riparian waterways and estuaries to long-term resilience and disaster protection is taking shape following four years of increased rain events, severe hurricane destruction and sea level rise. Adding to these challenges are the region's unique, clay-rich soil composition, made up largely of vertisols and alfisols which greatly influence infiltration and runoff, especially during heavy rain events. These same soils affect environmental enhancement and recovery efforts in the region's bays and estuaries, where the dynamics of various commercial industries intersect with fisheries, coastal wetlands and marine life. Greater knowledge and understanding of the region's soil composition, by both scientists and decision-makers, can help guide the discussion and implementation of billions of dollars in post-disaster projects targeting improvements in critical ecosystem services.

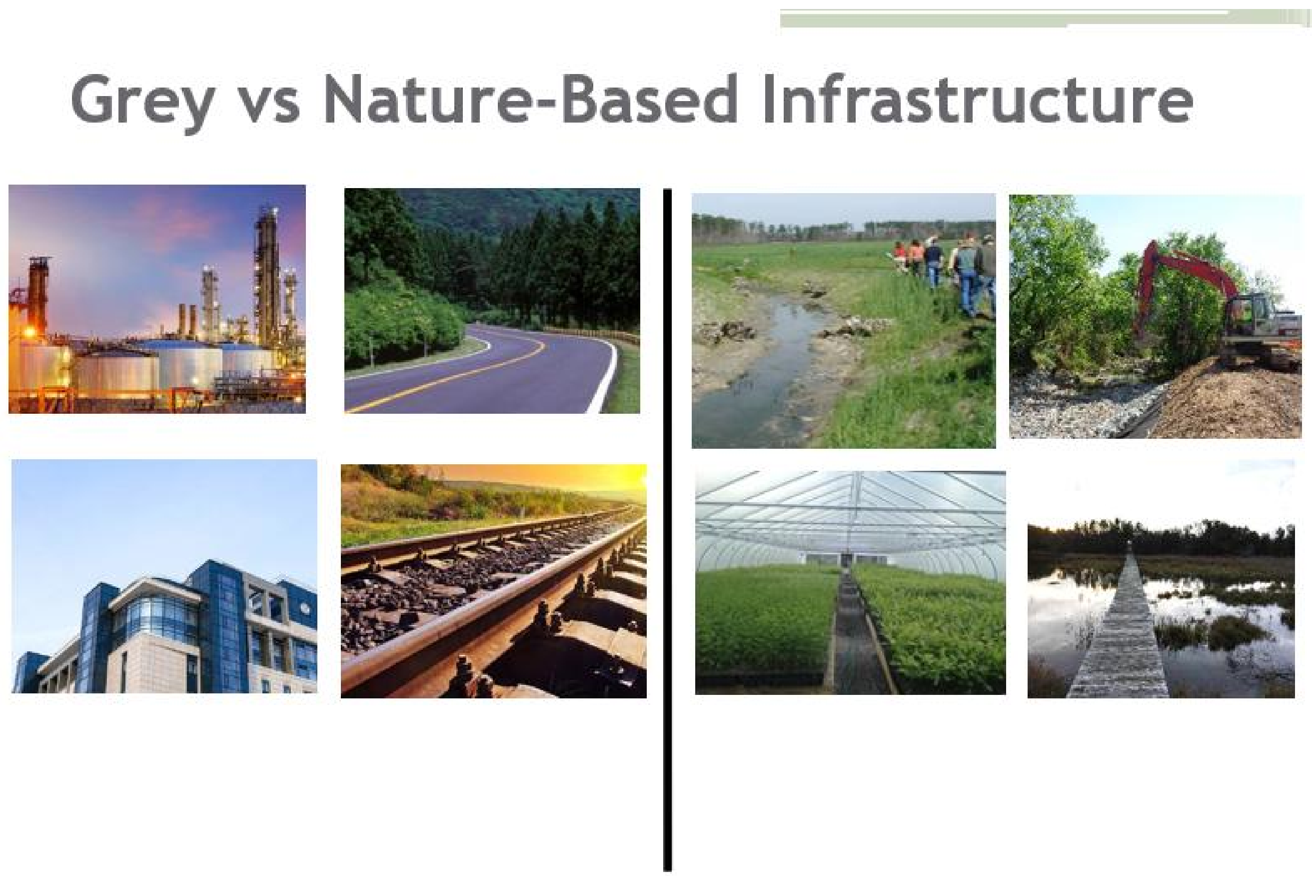
This Houston Wilderness' *Ecosystem Services Primer, 2nd Edition*, and related slide presentation, discusses ways for determining ecosystem services (ES) benefits and values using different established study/valuation methods depending on targeted infrastructure/project goals. In **Six Steps** designed to aid decision-makers in infrastructure options, this Primer looks at how the framework for comparison and valuation of the natural environment can be improved by laying out a comprehensive and systematic means to ensuring that ecosystems, and the critical services that they provide, are taken into account in policy decisions. The Six Steps include: determining the nature-based infrastructure goals, understanding the role of various ES in decision making, establishing an ES baseline for the targeted area(s), evaluating benefit relevant indicators, considering regional/local challenges, and using optimal ES valuation methods. In this way, the HW ES Primer considers the environment as a whole – bringing together land, water, air, soil and biodiversity, recognising that their linkages provide a wide variety of services and benefits.

This broader framework allows a shift in emphasis from a focus mainly on valuing environmental damage to highlighting the value of changes in the services provided by the natural environment through use of nature-based infrastructure. Ecosystem services contribute to economic welfare in two ways – through contributions to the economy of a region and long-term resilience, and through the prevention of significant damages that inflict costs on society. With a broader focus on valuing the benefits provided by ecosystems, policy options that enhance the natural environment are also more likely to be considered that demonstrate that investing in natural capital can make economic sense. Local and regional case examples are discussed, where science-based ES benefits and valuation options were analyzed and practical nature-based solutions were implemented, often as alternatives to more structural, gray infrastructure options.

Definitions

- **Benefit Relevant Indicators (BRIs)** - "indicator that explicitly reflects an ecosystem's capacity to provide benefits to society, ensuring that ecosystem services assessments measure outcomes that are demonstrably and directly relevant to human welfare." BRI's are used through "causal chains that link management decisions through ecological responses to effects on human well-being" (Olander et al. 2018)
- **Ecosystem Functions** - Ecosystem functions are the biological, geochemical and physical processes that are constantly occurring within ecosystems. These can also be thought of as components, processes, and actions that must occur within an ecosystem to maintain a healthy balance. Put another way, ecosystem functions are the capacity of natural processes and components to provide goods and services that satisfy human needs, directly or indirectly (de Groot et al., 2002).
- **Ecosystem Services (ES)** - The multiple, valuable benefits that humans and wildlife receive from the functioning of various ecosystems" (MEA, 2005).
- **Ecosystem Services Capital Asset Classification System** - "an agreed classification of natural capital assets is required to standardise their identification, description and measurement, and support action to reduce and mitigate the pressures they are under" (Leach et al., 2019).
- **ES valuations** - quantifying and assigning a value to an ecosystem service, in monetary terms or other, using a variety of methods
- **Infrastructure Goals of various Decision-makers** - the aim/goal of a policy or decision maker and which ES are of interest influences which method of ES assessment should be applied for ES valuation
- **Millennium Ecosystem Assessment (MEA)** - "From 2001 to 2005, the MA involved the work of more than 1,360 experts worldwide and assessed the consequences of ecosystem change for human well-being. Their findings provide a state-of-the-art scientific appraisal of the condition and trends in the world's ecosystems and the services they provide, as well as the scientific basis for action to conserve and use them sustainably" (MEA, 2005).
- **Natural Capital** - A similar term"the world's stocks of natural assets which include geology, soil, air, water and all living things. It is from this natural capital that humans derive a wide range of services, often called ecosystem services, which make human life possible" (World Forum on Natural Capital, n.d)
- **Nature-Based Infrastructure (NBI)** (also called Green Infrastructure) - Generally, NBI includes all undeveloped lands that are protected/preserved in some long term capacity (public or private) and provide a variety of ecosystem functions and services, even if not in a pristine or restored state. For flood mitigation and resilience purposes in Texas under the *Statewide Flood Infrastructure Plan*, NBI is defined as "non-structural flood mitigation including but not limited to conservation and restoration of land, wetlands, grasslands, forests, and riparian areas."

- **Nature-Based Stabilization Techniques** (also called Green Stormwater Infrastructure Techniques or Tools) - Innovative approaches to shoreline and stormwater infrastructure including living shorelines are "necessary as our coastal communities and shorelines are facing escalating risks from more powerful storms, accelerated sea-level rise, and changing precipitation patterns that can result in dramatic economic losses" (SAGE, NOAA, and USACE, 2015)
- **Resilience Plans and Projects around the region, the U.S. and the world** - "ecosystem resilience is the inherent ability to absorb various disturbances and reorganize while undergoing state changes to maintain critical functions" (Sasaki et al. 2015). Projects and planning are underway to optimize and maintain ecosystem resilience



Quick One-Page Reference for *Six Steps Guide for Making Infrastructure Decisions Based on the Benefits & Values of Multiple Ecosystem Services*

STEP 1 - Determine the goal(s) of the decision maker in the area(s) of infrastructure interest

- ❑ Ecological function monitoring
- ❑ Spatial-scale impact on function
- ❑ Outright losses
- ❑ Substitute Equivalency
- ❑ Building something new
- ❑ Energy savings
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STEP 2 - Understand the Ecosystem Services (ES) of a particular area of interest

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STEP 4 - Consider regional challenges & opportunities where ES can be applied

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Ecology ⇒⇒⇒ Ecosystem Services ⇒⇒⇒ Social Benefits

STEP 6 - Decide the best method(s) in determining the value of the ES in area(s) of interest

- ❑ On-site ecological function analysis
- ❑ Avoided cost
- ❑ Replacement cost
- ❑ Mitigation and restoration cost
- ❑ Direct market price
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I. How Ecosystem Services Work (Ecosystem Functions vs Services)

By living alongside natural ecology and allowing ecosystems the space to perform their self-sustaining functions and services, humans and wildlife are able to enjoy the myriad goods and services these functions yield. In doing so we save time, effort and precious resources that might have otherwise been expended to build a gray infrastructure option. Moreover, natural systems will continue to produce these same ES results year after year, season after season - with enhancements possible through various means of land/water conservation and/or restoration efforts. Human ways of life have utilized ecosystem services for generations, long before the recognition of placing a value on these ES was recognized as a contributing economic tool —a fact visibly reflected in commodities markets established for tangibly useful goods and services, such as purchase of fresh oysters, public "waterfront" property, tree-lined enjoyment along nearby trails and use of water quality filtering streams in place of gray infrastructure options.

There are many ways to discuss ecosystem functions versus services. One way is to illustrate the difference between the function of the Starbucks employee who can make different kinds of coffee recipes (the barista) versus the value of a particular coffee type. Starbucks does not base the value of the coffee on the functions of the employee but on the benefit value to the consumer. Much the same way, the functions performed by an ecosystem does not itself have a specific value but the ecosystem services provided to humans and wildlife through those vital functions - services such as improved air and water quality, enhancement flood and erosion control, carbon sequestration, outdoor recreation and enjoyment, increased property values and market commodities - have an economic or social benefit value.

Moveover, when ordering a particular kind of coffee - such as a Frappuccino - the consumer (i.e. "decision-maker") is often less concerned with the technical operations that produce their goods and service than with the substance of the goods and service itself - the specific coffee order requested. The consumer pays a price (value of the service) based on the expectation of the taste and quality of the item purchases, choosing between otherwise indistinguishably serviceable, or substitutional, products.

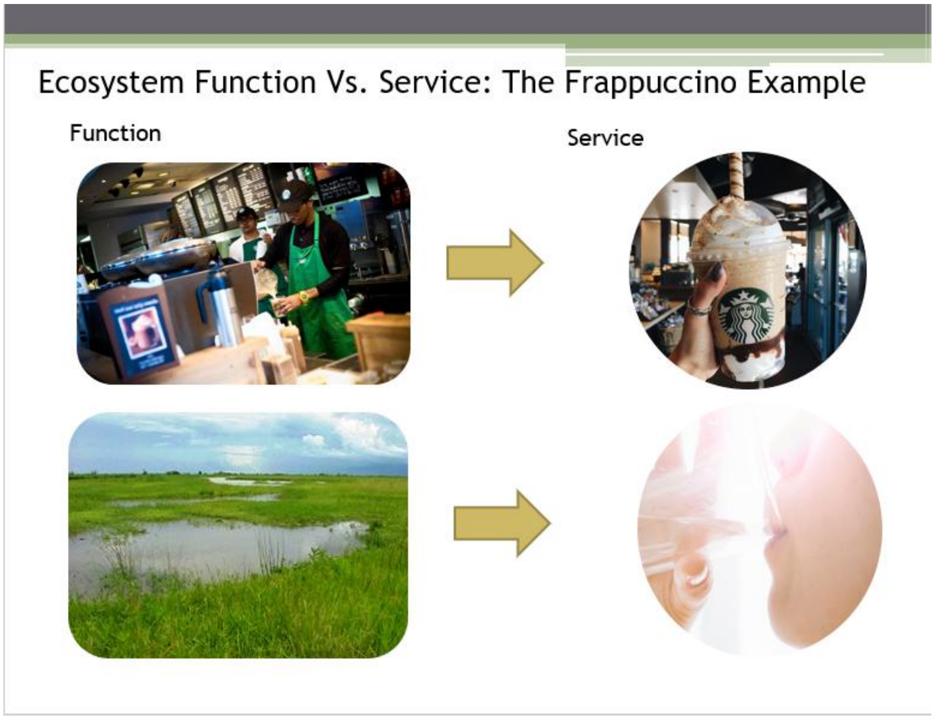


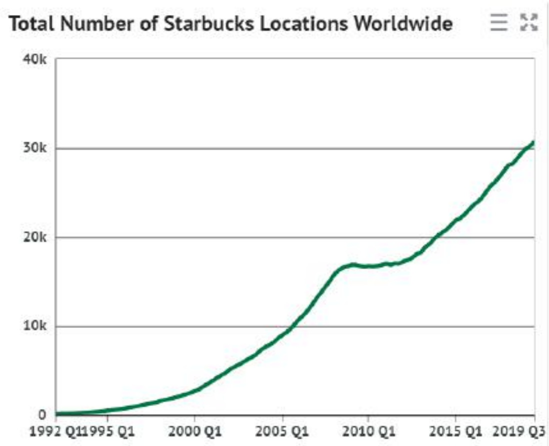
Illustration 1: Economic example of function vs service

Comparatively, when a decision-maker is reviewing options for providing its residents with clean drinking water, it may consider options with no functional difference (i.e. taste and safety) through conventional industrial (gray infrastructure) means or through natural filtration processes performed by engineered filtering through wetland plants (nature-based infrastructure). The value of the ecosystem service is the same - clean drinking water. There is however a huge difference between the two options - in that additional benefits are derived from the nature-based infrastructure that are not derived from the gray infrastructure - including added green space, improved air quality, increased water and soil carbon absorption and aesthetic enhancements. These added benefits (values) are an important component of a decision-makers comparison of gray vs nature-based infrastructure options, and when looked at from a cost-benefit analysis, often provided substantial cost savings to the decision-maker.

Similarly, if a decision maker wants to consider nature-based infrastructure options to increase air pollution absorption on its property, it may consider the differences in air pollution absorption rates (ecosystem function) between different native tree species to choose large-scale tree planting of high absorptive trees as a nature-based infrastructure option over a more gray infrastructure option (see example below). Native trees capture CO_2 during their ecosystem function of photosynthesis providing people with cleaner air as the resulting ecosystem services. To measure the impact of these and other services in the Greater Houston region we will discuss the benefits of local ecosystem services in Step 2 below, the *Impacts on People and Wildlife in the Greater Houston Area Section*

II. Valuing ES - Benefit Relevant Indicators vs Economic Value

Sometimes, there may be a corollary to the specific value placed on ecosystem service that can provide a valuable and quantifiable benefit all by itself. And, this type of benefit can be just as useful in looking at nature-based infrastructure options as a specific economic/monetary value. For example, to use the Starbucks example again, the function of making a specific coffee recipe may not change, but sometimes items are introduced by Starbucks that increases the interest in ordering a specific type of coffee or in ordering the item more frequently (see examples below in Illustration 2). Substantial increases in sales after introduction of these new/additional items are indicators that there is a benefit derived from them. When quantifying the benefits of ecosystem services, the results of increases/decreases in these types of new/additional items are called Benefit Relevant Indicators (BRIs). The values of ES may or may not be known, but the BRIs can provide a substantial basis for improved/enhanced value for a decision-maker to weigh options in cost/benefit analysis.



https://knoema.com/infographics/kchdsge/number-of-starbucks-stores-globally-1992-2019 https://www.bigcommerce.com/blog/starbucks-red-cups-holiday-campaign/

Illustration 2: Starbucks examples of Benefit Relevant Indicators on improved sales without change in function

The type of valuation technique chosen will depend on the type of ecosystem service to be valued, as well as the quantity and quality of data available. Some valuation methods may be more suited to capturing the values of particular ecosystem services than others.

III. Global Classifications of Ecosystem Services

Various types of decision makers need to understand how environmental changes - (e.g., land degradation, land/water enhancements, land development, climate impacts to land/water, etc.) can lead to improvements, disruption or unintended impacts on ecosystem services (ES) assets used by or associated with a private or public operation or environmental feature - such as a riparian corridor, a reservoir, a coastal estuary, beachfront property, etc. There are standardised ES classifications for the various types of ES supported by ecological functions provide decision makers with “first step” tools to evaluate the status and trends of ES assets and to subsequently estimate the improvements, or risk of disruption or unintended impacts in the benefits of ES.

For example, a bank, developer or governmental entity investing in an infrastructure project in a low-lying region subject to coastal or riparian erosion, will be dependent on erosion control as an ecosystem service if their investment is to be viable. This ES can be delivered through a combination of vegetated habitats, well-structured soils and sediments, and stable land geomorphology. As discussed with the two respective classification systems below, identifying and categorizing these ES assets enables a consistent approach to risk assessment.

Millennium Ecosystem Assessment (MEA) As we continue to think about capitalizing on ES, this ES Primer uses the guiding framework provided by the U.N.’s Millennium Ecosystem Assessment (MEA) of ES categorized by **provisioning, regulating, cultural and supporting**. These can be thought of in terms of raw goods (provisioning) and services (regulating and cultural) while supporting services act to keep the system as a whole in functional equilibrium. As ES has grown in popularity and interest, additional ES categorizations have been created (See Appendix A). This Primer continues to use the MEA framework and charts providing a uniform set of icons for various ES benefits and one providing a breakdown of ES capital based on scale of the ES asset (see below).

The MEA Classification List above illustrates the different ecosystem service classifications and their types of services.

Source:
https://www.iucn.org/news/commission-environmental-economic-and-social-policy/201702/step-sustainability-maes-mapping-and-assessment-ecosystem-services-european-cities-and-italy

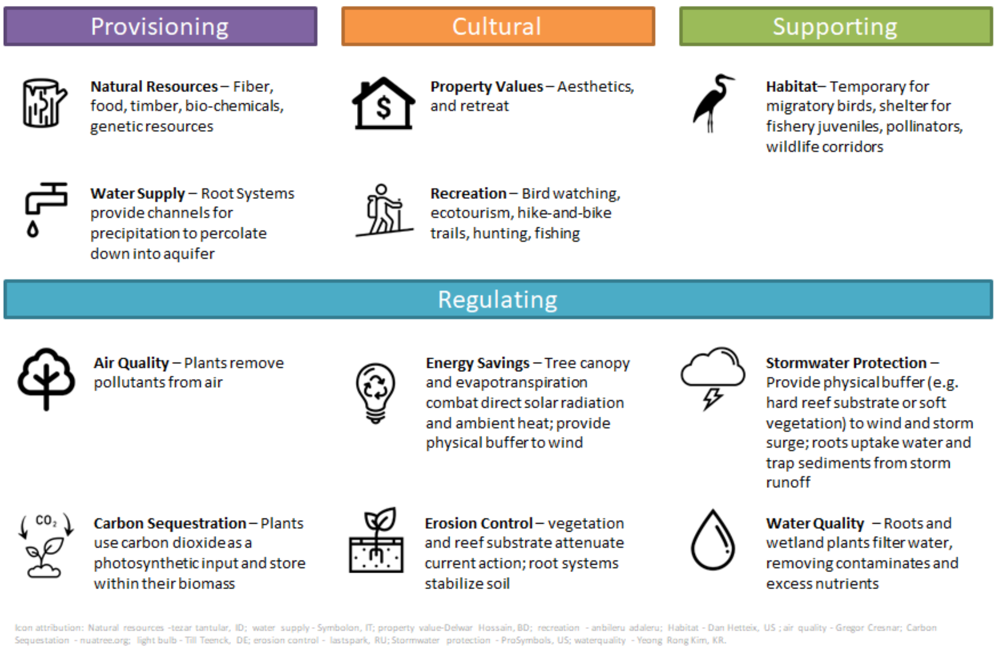


Illustration 3: ES icon legend for those services provided within the Gulf Houston region (Houston Wilderness, 2018). There are various levels of description, including oft-used icons, when discussing the ES classifications but they all begin with the basis classifications shown above. Throughout this primer you will find the oft-used icons below in case studies examples where these types of ecosystem services were beneficial or measured.

IV. Infrastructure Decisions Based on the Benefits and Economic Value of Multiple Ecosystem Services

As discussed above, ecosystems can provide us with useful goods and services. In addition to providing a targeted project objective, such as improved air and/or water quality, natural functions also produce a bundle of other ecosystem services that may not be targeted but are still beneficial to the surrounding community, such as erosion control, water absorption, added recreation, higher property values, and bigger seafood yields, to name a few. In pursuit of a particular project objective, sometimes other auxiliary ES are not taken into account and their associated values not included in decision-making. This section explores data analytics in ecosystem services' benefits.

Ecosystem services are also the final product received by people and wildlife from a healthy biome and ecologically rich environment. These results are directly connected to the biodiversity of that environment. Although there is a need for more robust frameworks to illustrate the links between biodiversity and ecosystem services, as well as how those services are valued by people and wildlife, it is generally understood that the more biodiversity that exists within an ecosystem, the more stable and prosperous ecosystem is and can then provide more ecosystem services.

EXISTING SOLUTIONS and UNMET NEEDS

As illustrated in the various case studies below, regional decision-makers can imagine their land-use activities as existing within a continuum of conservation efforts. Public infrastructure projects—like *Project Brays* or the *Bayou Greenways Initiative*—represent a share of the regional land cover controlled by the public sector. The public landowner can enlist additional funding from the private market through the sale of green bonds.

Government activity is further exercised through its political authority to regulate private entities. Commitment from policymakers can influence the long-term vision by fixing the available supply of land conversion acres (e.g. mitigation banking or in-lieu fee programs) and upholding ES integrity in the commons (e.g. Watershed Protection Plans). Private interests will respond to government regulation by asking "Is it still cost-effective to convert given the true price of my impacts (as exposed in the addition of regulatory costs)?" Within a business, efforts to minimize operational costs will leverage determinants of market health (i.e. sustainable supply chains, steady demand for certified products and/or more efficient outlays to green infrastructure technology) before pursuing land conversion activity, thereby imparting a more indirect effect on the region's landscapes. Finally, the Gulf-Houston Regional Conservation Plan (RCP) attempts to fill the gaps between public and private conservation by leveraging the collective efforts of our region's land trusts, other not-for-profit entities and private landowners. Covered in more depth below, the RCP's 3 key goals can be strengthened through partnership with the other efforts listed above—including mitigation banks and in-lieu fee sites—and in a sense acting as a database of large-scale acquisition and restoration projects across the public and private sectors.

The options for wetland mitigation can be expanded to create a workable in-lieu fee program, perhaps even using the RCP as a tool for market players to locate their projects within the ecological boundaries of the "watershed approach". And though companies like Dow Chemical have already implemented on-site NBI projects, further education of business leaders on the subject could be helpful in strengthening the voluntary private effort.

V. Regional Case Studies

The following case studies illustrate one of more of the ecosystem services opportunities that were chosen by public and/or private entities after making Nature-Based Infrastructure decisions comparing the benefits of multiple Ecosystem Services

A. *Gulf-Houston Regional Conservation Plan (Gulf-Houston RCP)*

One way to assist decision-makers and other stakeholders in a large region (such as the 8-county Greater Houston Region) is to develop and implement a large-scale, multi-partner conservation/restoration initiative that highlights the ES in the region and works toward specific goals to improve and enhance those ES. In the Greater Houston Region, an 8-county *Gulf-Houston Regional Conservation Plan* (GulfHoustonRCP.org) has been established as a long-term collaborative of environmental, business, and governmental entities working together to implement an ecosystem continuity and connectivity plan for the region. In addition to providing an online interactive database of all targeted environment-based projects taking place in the region (called the *Working List of Projects*), the three key goals of the Gulf-Houston RCP include:

(1) 24% by 2040: Increasing the current 12.3% in protected/preserved land in the eight-county region to 24% of land coverage by 2040,

Land Cover by County

County	Total Land Cover (acres)	Total Developed Land % (with Acres)	Land Currently Protected in 8-county region % (with acres)	Available Undeveloped Land % (with acres)	EXAMPLE of Annual Land % Increase to reach 24% by 2040 (with acres)
Harris	1,103,836	62% (679,088)	14.3% (158,145)	24.2% (266,604)	1.46% (72,693)
Montgomery	689,220	29% (199,167)	10.7% (73,439)	60.4% (416,614)	1.46% (72,693)
Fort Bend	558,738	26% (145,142)	5.5% (30,715)	68.5% (382,882)	1.46% (72,693)
Liberty	752,809	7% (53,100)	6.7% (50,071)	86.3% (649,638)	1.46% (72,693)
Waller	327,852	11% (37,116)	7.1% (23,336)	81.6% (267,400)	1.46% (72,693)
Galveston	247,594	36% (88,405)	18.3% (45,341)	46% (113,847)	1.46% (72,693)
Brazoria	893,083	15% (137,976)	16.8% (149,594)	67.8% (605,514)	1.46% (72,693)
Chambers	385,724	7% (28,183)	20.2% (77,939)	72.5% (279,602)	1.46% (72,693)
Total	**4,958,857**	**27.6%**	**12.3% (608,580)**	**60.1% (2,982,100)**	**11.7% (581546)**

8 County Region Total Acreage: 4,958,857 Acres

Current Protected Land: 608,580 Acres

Target Acres to reach 24% by 2040 581,546 Acres or 11.7% increase in Protected/Preserved land

Illustration 4. Gulf-Houston RCP Land-Use Data for 8 County Region - by County

(2) 50% by 2040: Increasing and supporting the region-wide land management efforts to install nature-based stabilization techniques, such as low-impact development, living shorelines, and bioswales, to 50% of land coverage by 2040, and

(3) 0.4% Annually: Providing research and advocacy for an increase of 0.4% annually in air quality offsets through carbon sequestration in native soils, plants, trees, and oyster reefs throughout the 8-county region.

The third key goal of the Gulf-Houston RCP supports a 0.4% annual increase in nature-based carbon offsets on private and public lands through substantially enhanced native soils, plants, and trees throughout the region. Most of the region's current soil carbon content is only 28-33 tons/acre. But, these soils have the capacity to absorb 64-77 tons/acre. By planting native trees and grasses with high levels of carbon absorption capabilities, the region can achieve this goal of an annual 0.4% increase in organic carbon sequestration. For example, if 2,000 Loblolly Pine trees are planted in 2019, in ten years, each of the pine trees will absorb as much as 479 pounds of carbon each year for a total of 958,000 lbs – a 0.17% increase in carbon sequestration in the soil around those trees. Multiple initiatives are beginning around the region, including the City of Houston and Harris County, to plant millions of trees over the next decade.

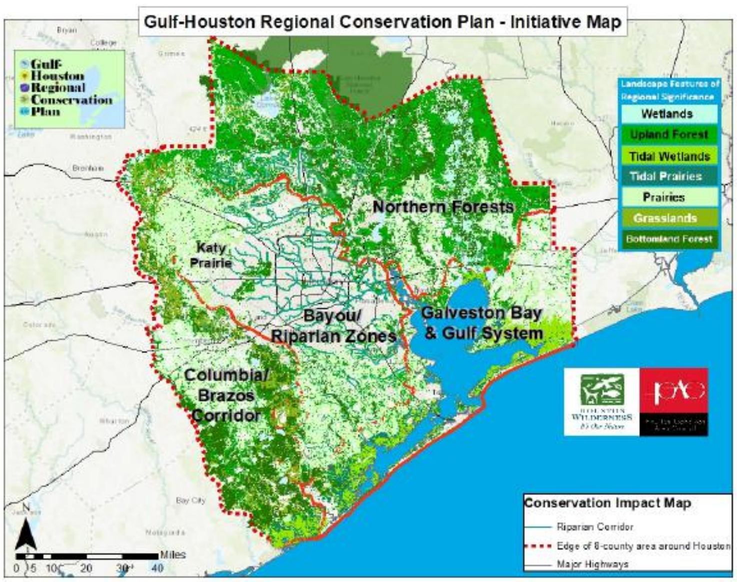


Illustration 5**.** Gulf-Houston Regional Conservation Plan (RCP) Initiative map.

The completion of the RCP is crucial to protect the remaining forests and wetlands of the area, as 40% of these habitats have already been lost to development. The Greater Houston Region is home to nearly 10% of the nation's remaining coastal wetlands. The ES in this region would be greatly enhanced by the protection of the Phase 1 project areas in the *Working List of Projects*, which include land acquisition and conservation easements in various parts of the region. Communities around the Phase 1 project areas will benefit from the preservation and continued supply of services such as increased flood water retention, improved water quality, and enhanced recreation opportunities. The RCP-supported projects will provide economic value through the increased ecosystem services in the region.

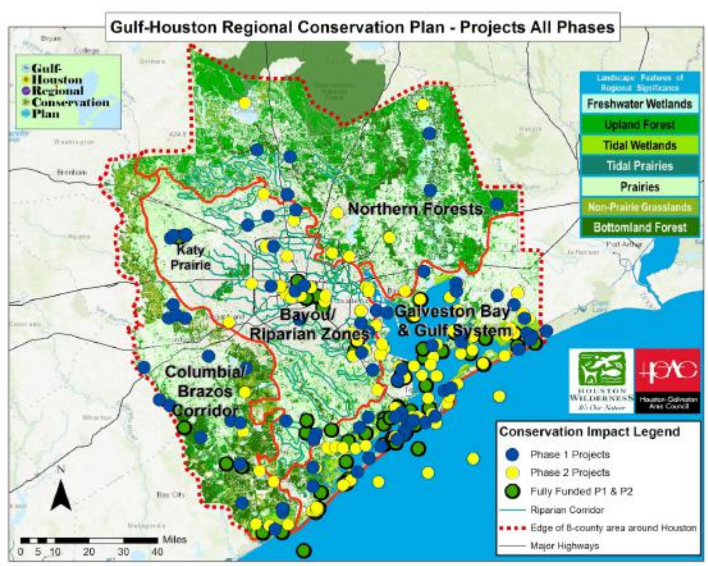


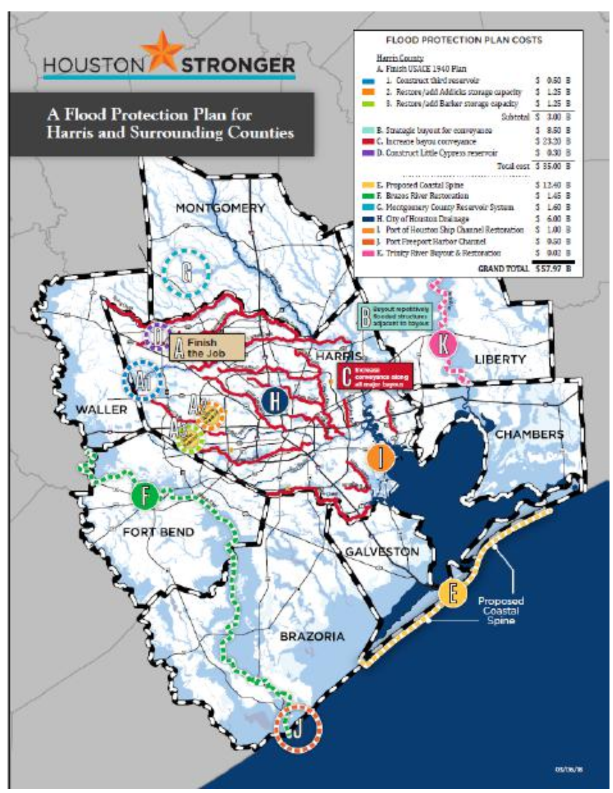
Illustration 6. *Gulf-Houston Regional Conservation Plan* (RCP) map of projects - all phases.
(See interactive map at www.GulfHoustonRCP.org)

B. Texas Monarch Flyway Strategy program

By facilitating collaborative funding from various federal, state and regional sources, Houston Wilderness is working with federal and state agencies, biologists, multiple municipalities, private and public land owners, schools and nonprofits to enhance or restore thousands of acres of habitat for monarch butterflies and other pollinators throughout Texas. With multiple completed and ongoing projects along the Texas MFS, partners are currently collecting various native milkweed and pollinator plant seeds and plugs for distribution to collaborative partners around the state. Current and future partners are also focused in increasing the supply of milkweed seeds and the variety of native pollinator species across all types of property in the state, resulting in a significant increase in pollinator sources and then result in an increased Monarch and other insect population in key migratory flyway areas (see more at http://houstonwilderness.org/mfs)

C. *Houston Stronger* Collaborative

After Hurricane Harvey, Houston Stronger formed to work with federal, state and local officials on increasing funding for flood mitigation and flood-related infrastructure improvements. Houston Stronger worked with County Judge Ed Emmett to create the Fight Flooding PAC, a group of Harris County businesses, organizations, and individuals who came together to support the successful August 25th, 2019 passage of Proposition A. The bond proposed $2.5 billion in investment to equitably reduce Harris County's flood risk by executing over 230 regional flood control projects in all of Harris County's 23 watersheds.



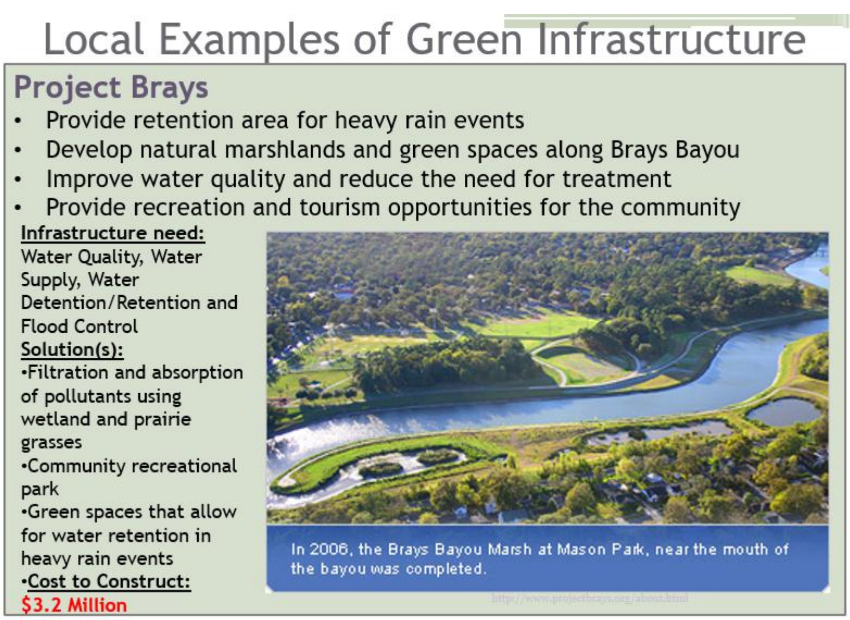
Houston Stronger partners worked together with members of the Texas Legislature, like Senator Brandon Creighton and House Representative Dade Phelan, to pass Senate Bills 6, 7, and 8 during the 86th legislative session. Thanks to leadership from the Lieutenant Governor Dan Patrick and Governor Greg Abbott, the bills passed overwhelmingly in both houses and provided over $2 billion in funding for flood control, recovery, and resilience across Texas.

Houston Stronger continues to work with area elected officials and with officials at Harris County Flood Control and the City of Houston on flood recovery and mitigation. See more at https://houstonstronger.net/.

Illustration 7. Flood Protection Plan developed by Houston Stronger for Harris and surrounding counties.

D. Project Brays Bayou & Bayou Greenway Initiative

Two examples of far reaching initiatives utilizing ecosystem services in the Greater Houston Area is Brays Bayou Flood Damage Reduction Project, or Project Brays, and the Bayou Greenway Initiative (also called the Bayou Greenways 2020 Project). Project Brays is cooperatively funded by Harris County Flood Control District (HCFCD) and the U.S. Army Corps of Engineers, with assistance from Texas A&M Sea Grant for the Mason Park wetland project, consists of combined flood control efforts and local initiatives to produce over 70 individual projects along and surrounding Brays Bayou. Sub-projects with substantial nature-based infrastructure components have been especially successful with their use of ecosystem services, including Arthur Storey Park Stormwater Detention Basin, Willow Waterhole and the Brays Bayou Marsh at Mason Park. These projects, which have recently reached completion, utilize marsh and wetland areas within the detention basins to remove pollutants from the stormwater runoff and redirected bayou water. The water, which has been drastically improved in quality, can then return back into the freshwater bayou system. These three innovative basin plans along Brays Bayou contribute to the overall vision of creating a significant flood damage reduction initiative while also utilizing natural areas and their ecosystem services. Project Brays is the largest flood control and water quality initiative to have been managed by the Harris County Flood Control District.



In 2015, the *Bayou Greenways Initiative* was created by a consortium of business, non-profit and governmental leaders, called the Quality of Life Coalition, to connect 77 miles of trails along 9 different bayous in the Greater Houston Region into one collective initiative for use in adding substantially more nature-based trails and green space. Originally built along the bayous by entities such as the City of Houston, Harris County, the Texas Department of Transportation, and Tax Increment Reinvestment Zones (TIRZs). By 2012, Houstonians showed overwhelming support for Bayou Greenways Initiative by approving $100 million in bond funding towards new trails and parks for the City of Houston. Since then, the Houston Parks Board has leveraged the commitment, support, and expertise of its private, civic, and philanthropic partners to raise another $120 million with an extraordinary lead gift of $50 million in 2013 from the Kinder Foundation. The following nature-based riparian trails are now connected together for residents and visitors alike to enjoy: Brays, Buffalo, Greens, Halls, Hunting, Sims, White Oak, Cypress Creek, Spring Creek and the West Fork of the San Jacinto River.

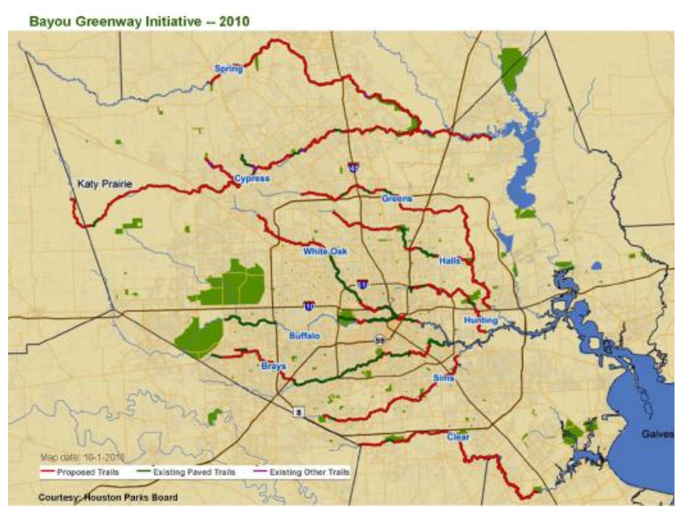
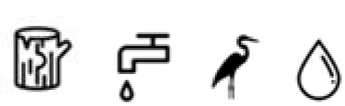


Illustration 8. GIS-based map of waterways in Greater Houston Region (with trails noted)

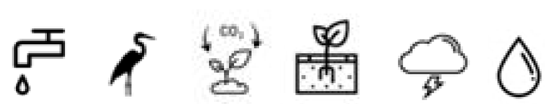
E. Dow Chemical nature-based wastewater treatment



The Dow Chemical Co. (Dow) is actively working to develop an approach to value ecosystem services and incorporate them in business decisions. The 110-acre tertiary treatment wetlands is located at the UCC plant in North Seadrift, Texas, USA. The Seadrift Facility is a large industrial complex containing several manufacturing units involved in the production of plastic resins and other organic chemicals. Wastewater from the facility and stormwater captured in containment areas are routed through the wastewater treatment system (WWTS). The original WWTS consisted of primary/secondary (anaerobic/aerobic biological) treatment ponds and a shallow tertiary pond of approximately 267 acres with water depth ranging from 1 to 4 feet. The tertiary pond was operated as a solar stabilization pond, with no active mixing. Lower organic loads and long retention time within the aerobic section and tertiary pond created ideal conditions for phytoplankton that can lead to algal bloom. This resulted in exceedance of the plant's discharge permit criteria for total suspended solids (TSS) and required extensive pH adjustments. To address this, UCC evaluated several design alternatives.

This case study investigates the use of replacement cost methodology (RCM) for financial analysis and life cycle assessment (LCA) for environmental assessment. The case study analyzes a business decision made in 1995, where a constructed wetland was built instead of a sequencing batch reactor to solve a regulatory compliance issue in meeting suspended solids requirements for a wastewater treatment system at the Union Carbide Corp. (a subsidiary of The Dow Chemical Co.) plant in Seadrift, Texas. The financial results indicate that the total net present value savings calculated for implementing the constructed wetland instead of the sequencing batch reactor is $282 million over the project's lifetime. The LCA demonstrates that the lower energy and material inputs to the constructed wetland resulted in lower potential impacts for fossil fuel use, acidification, smog formation, and ozone depletion, and likely lead to lower potential impacts for global warming and marine eutrophication. The result from the inventory of land use shows that both the upstream land burdens (for the sequencing batch reactor) and the on-site acreage of the constructed wetland are similar in magnitude and importance, contrary to the assumption that green infrastructure always requires greater land area. This case study illustrates how Dow considered both financial and environmental analyses in comparing gray and green infrastructure solutions and further understand the benefits of implementing green or nature-based infrastructure in an appropriate industrial application. See more at https://www.naturalinfrastructureforbusiness.org/wp-content/uploads/2015/11/DowUCC_NI4BizCaseStudy_ConstructedWetlands.pdf

F. Columbia Bottomlands Mitigation Bank



Established in 2017, the goal of Columbia Bottomlands Mitigation Bank is to provide appropriate compensatory mitigation for unavoidable impacts to wetlands authorized by the USACE within the Brazos/Oyster Creek watershed and adjacent areas. The objectives of the Bank are to rehabilitate degraded functions to 8.04 acres of existing jurisdictional wetlands, re-establish and sustain wetland functions to 323.9 acres as bottomland hardwoods wetlands, and re-establish and sustain wetland functions to 21.6 acres as coastal prairie emergent wetlands. The EPA and the Corps use the 1987

Corps of Engineers Wetlands Delineation Manual and Regional Supplements to define wetlands for the Clean Water Act Section 404 permit program. Section 404 requires a permit from the Corps or authorized state for the discharge of dredged or fill material into the waters of the United States, including wetlands.

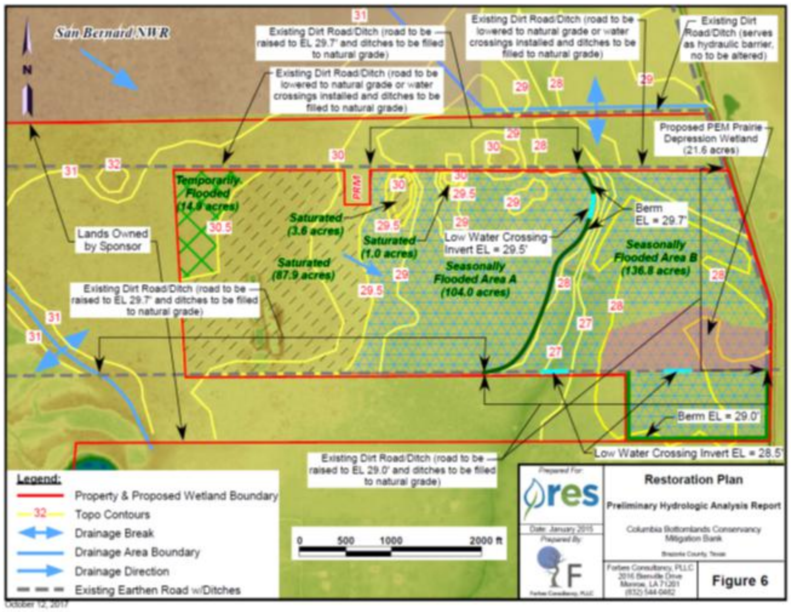


Illustration 9. Mitigation bank in Brazoria County, Texas

G. Port of Houston TREES Program

Fine particulate air pollution has serious health effects, including premature mortality, pulmonary inflammation, accelerated atherosclerosis, and altered cardiac functions. In a study published on-line by the journal Environmental Pollution, researchers David Nowak and Robert Hoehn of the U.S. Forest Service and Satoshi Hirabayashi and Allison Bodine of the Davey Institute in Syracuse, N.Y., estimated how much fine particulate matter is removed by trees in 10 cities, their impact on $PM_{2.5}$ concentrations and associated values and impacts on human health.

Port Houston Tree & Riparian Enhancement of Ecological Services (PoH TREES program) is a multi-year collaborative project by Houston Wilderness, Trees for Houston, Houston Health Department and the Port of Houston Authority focused on conducting a comprehensive tree inventory and replacement along Lower Buffalo Bayou, Lower Brays Bayou and 25 miles of the Houston Ship Channel, using tree species research, GIS-based data collection and on-site inspections over multiple years. Replacement native tree species are ranked in priority based on their respective levels of air pollution absorption (including CO_2, GHGs, PM2.5) as well as water absorption and erosion control. The removal and planting phases of the project provide a multitude of ecosystem services (increased air & water quality, increased nutrient cycling & oxygen production and improved aesthetic) for the area.

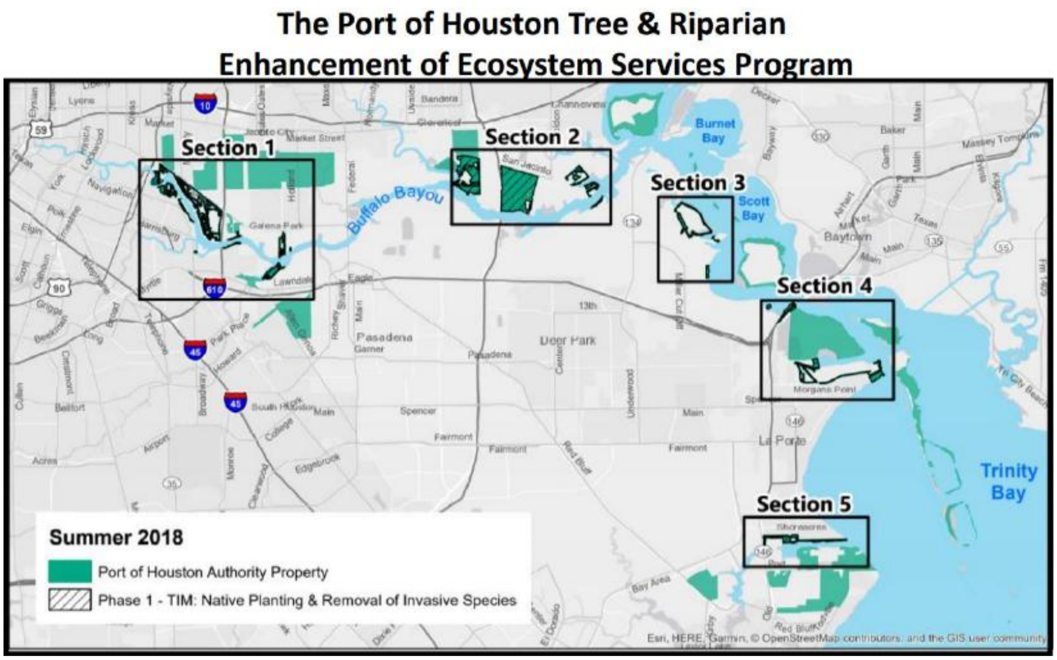


Illustration 10. Overview of Section in Phase 1 of PoH TREES Program.

Step One

STEP 1 - Determine the goal(s) of the decision maker in the area(s) of infrastructure interest

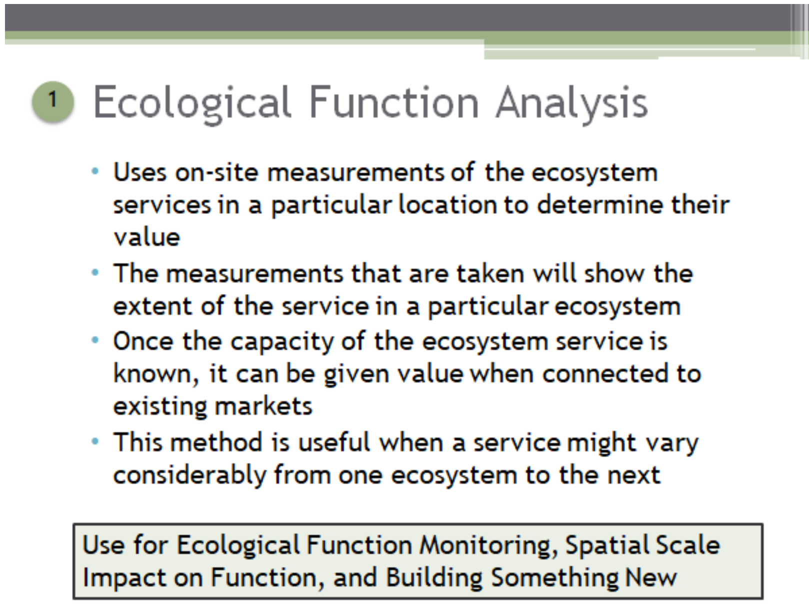
There are a variety of ways to assess ES values – depending on the goal(s) to be obtained in the ES analysis required to determine the relative ES value(s). Many such goals are based on development, infrastructure, in-house operations or other land-use needs. Below is (1) a list and explanation of many of these types of goals and (2) the ES methods of analysis that could be associated with them. Nine different goal options are referenced, along with eight different goal analysis methods. Sometimes a combination of analysis options can be used for one or more goals. Each goal analysis represents a perspective through which ES becomes "valuable." Paired with an evaluative method (see the following section), ecological or monetary value has added worth when defined in goal terms.

1. Ecological function monitoring

- ➢ Trying to determine how existing external and/or internal forces impact healthy ES
  - Non-point source pollution
  - Large rain events that overload bayous/creeks/rivers
- ➢ Trying to determine how changes to infrastructure can improve ES
  - Determine ES benefits of regional soil health
  - Adding parks/green space
  - Adding native plants along riparian corridors

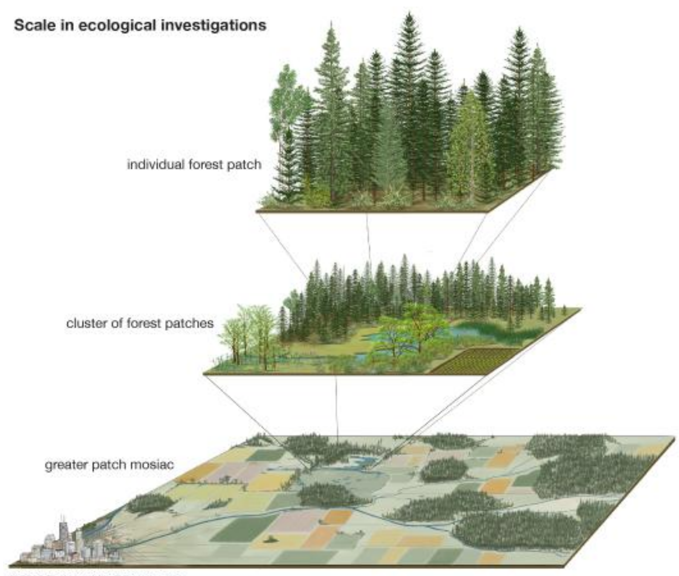
Each evaluation ought to begin by taking inventory of underlying ecological function. What if you wanted to know a project's impact on air or water quality? You could then use **Ecological Function Monitoring**, which uses statistics to determine the role that landscape and ecological functions play in regulating services. This goal analysis looks at data from water or air quality monitoring stations around areas with differing levels of development and existing ecosystems (e.g. a forested area vs. an industrial one, water quality before and after a natural filtering feature, etc.) to determine if the ecosystem is providing improvements in water or air quality that have economic value.

For example, a Texas university conducted an Ecological Function Monitoring study on coastal prairie wetlands in the Greater Houston region. They knew that runoff can contain high levels of inorganic nutrients which can end up in waterways to cause eutrophication--an excess of nutrients leading to algal blooms, decreased levels of dissolved oxygen and ultimately lower productivity overall. The coastal prairie wetlands sites were found to remove an average of 98% of inorganic nitrogen from water, with important implications for combating eutrophication downstream in Galveston Bay.



2. Spatial-scale impact on function

Does a change in spatial scale yield a difference in function? Analyzing Spatial-Scale Impact on Function would look at the services provided by an existing ecosystem and determine the amount the services could increase if the area of land devoted to the ecosystem were to expand. This would be useful in looking at how recreational values increase as the recreational space grows. Also a synergistic increase in some ecosystem services could be expected as the dollar per acre value of an ecosystem may not increase linearly with increasing ecosystem size.



- ➢ Large native prairie landscapes - adding acreage
- ➢ Large-scale native tree species plantings
- ➢ Nodes of water quality filtering features along waterway corridors

Illustration 11. Scale in ecological studies, a forest patch nested within a landscape mosaic.

3. Outright Losses

Development decisions may cast value within a framework that explicitly takes land-use change into consideration. What is the value of the ES I'm giving up to loss by developing the site? By analyzing the **Outright Losses** of ES to development, a decision-maker can measure the value of services that a landscape naturally provides plus how much it would cost to mitigate or replace the service loss equal to its current level. It could also look at the amount of money that can be saved when the service provided by the ecosystem is preserved. For example, the amount of stormwater that is absorbed by a prairie could be measured, and then the value of this absorption could be determined with an appropriate valuation method. An ecosystem service replacement cost study can be used to determine the value of both indirect and direct use ecosystem services.

4. Substitute Equivalency

Is it cheaper to add ES elements to existing operations? An analysis of **Substitute Equivalency** could compare the performance of existing gray infrastructure and determine the equivalent amount of green infrastructure that would be needed to achieve the same result. This goal analysis would be best suited for determining the value of regulating, indirect-use services. For example, a gray vs. green equivalency capacity analysis might be used to determine the acreage of wetland that would be needed to perform the same amount of water filtration as an existing gray water treatment facility.

- ➢ Example - Dow Chemical needed a solution for tertiary wastewater treatment. They compared the costs for an artificial wetland versus a sequencing batch reactor using the **Substitute Equivalency** approach in conjunction with the Replacement Cost method. By opting for a constructed wetland in lieu of a sequencing batch reactor, Dow projected an estimated $28M in savings over the project's lifetime. See more in Case Study, page 23)

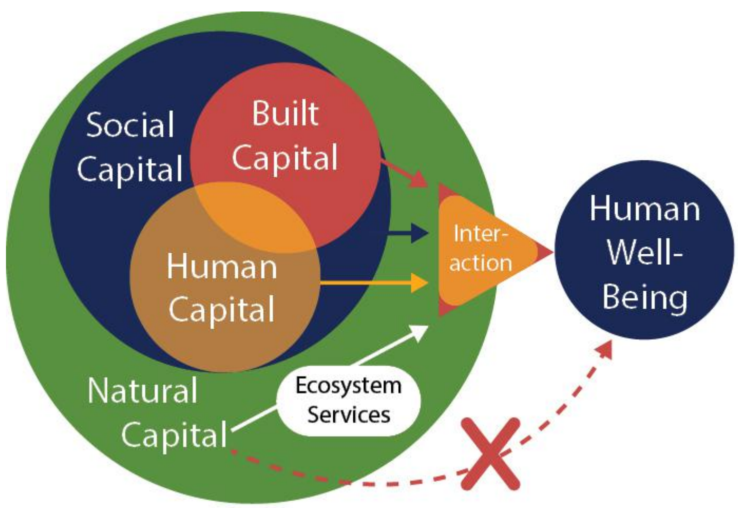


Illustration 12. Dependence of Human Wellbeing on Natural, Social, Built and Human capital. Source: Costanza et al. 2014.

5. Building Something New

Which type of infrastructure is cheaper? How can more nature-based infrastructure (protected/preserved land) be added to a project goal? A **Building Something New** analysis could be performed when there is the option to build either gray or green infrastructure to accomplish an infrastructure goal. This goal analysis would look at the ecosystem services provided by a green infrastructure solution and compare them with the outcomes of a gray infrastructure solution, while taking into consideration the cost of construction and maintenance that would be required in both situations.

- ➢ Example - Master Planned Communities (Where and How can MUDs create Recreation Facilities in Texas? Is there a financing cap on the bonds that MUDs can issue for Recreational Facilities?)

Illustration 13. R. G. Miller Engineers, Inc. and Asakura Robinson, Inc. / Feasibility study rendering of natural drainage residential development (or low impact development) with creek system and linear detention, infiltration, and stormwater quality features.

A Municipal Utility District (MUD) located in Bastrop County, Bexar County, Waller County, Travis County, Williamson County, Harris County, Galveston County, Brazoria County, Montgomery County (some restrictions apply), or Fort Bend County may issue bonds supported by ad valorem taxes to pay for the development and maintenance of recreational facilities but **they may not exceed 1%** of the taxable value of property in the district at the time of issuance of the debt or exceed the estimated cost provided in the park plan required under TWC, §49.4645(b), whichever is smaller.

6. Energy Savings

The following goals aim to calculate costs and revenues taken on over a project's lifetime, including operational costs and capital depreciation. *What factors impact my energy bill?* An **Energy Savings** goal analysis can be performed to determine the value of ecosystem services that result in lower energy costs for a building. For example, trees allow less solar heat to penetrate windows or a building’s surface. The value of trees providing shade to a building could be determined by calculating the amount of money saved on energy because of the trees.

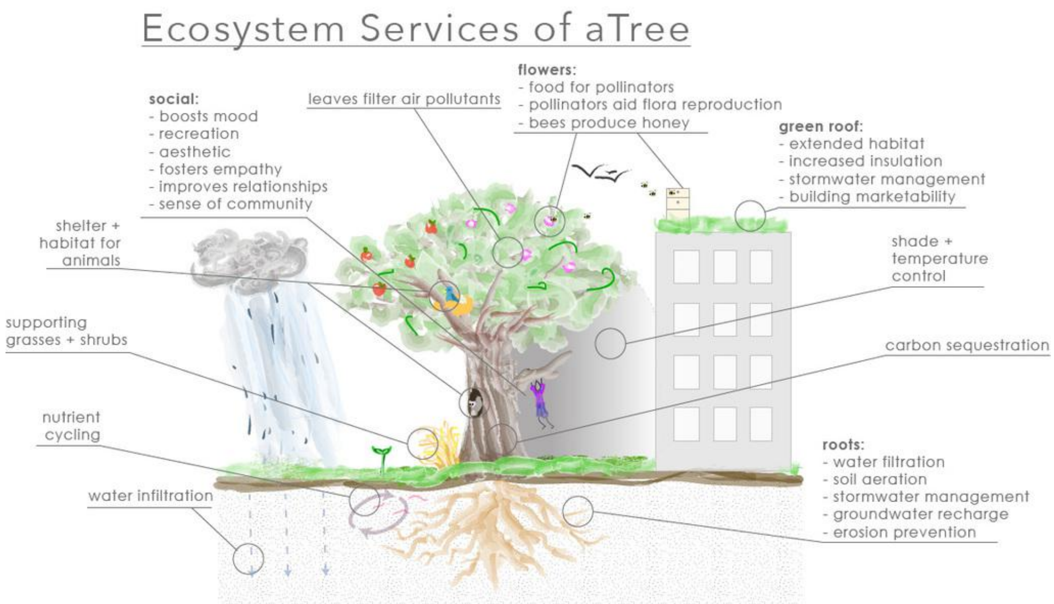


Illustration 14. Trees provide many important services for humans, living organisms, and the environment, including energy savings

7. Insurance Savings

How can I reduce exposure to flooding and other climate-related risks? A goal analysis of **Insurance Savings** could be used to determine the value of regulating services such as water retention and flood regulation through the amount of insurance costs that were avoided due to an ecosystem service. This goal analysis might look at historical damages to property and determine how much current or proposed ecosystem services would reduce these costs.

Coastal wetlands can be evaluated in terms of their efficacy in lowering costs for damages incurred during hurricanes. Insurance Savings for coastal wetlands has been studied across the Atlantic and Gulf coasts, concluding that the loss of one hectare of wetland corresponded to a national average of $33,000 for incurred damages (both direct, physical damages and indirect loss of revenues, employment and market stability). Additionally, the most valuable wetlands were large in area and located in states that have high coastal GDP (i.e. heavy reliance on industries like fishing, ecotourism or port activity) like Texas, Louisiana, or Florida.

Insurance class/ line of business	Risks (from climate impacts, policy implementation, or policy failure)	Opportunities (from proactive policy or climate impact)
Property	◆ Unprecedented accumulation of extreme events threaten solvency/liquidity. ◆ Getting cover may become harder. ◆ Lack of capital/reinsurance. ◆ Inaccurate risk pricing. ◆ Misinformed response from public sector. ◆ More costly repair work.	◆ More demand for insurance and alternative risk transfer. ◆ Risk differentials can be priced. ◆ Insurance of "Kyoto" projects. ◆ Administration of disaster recovery. ◆ Prototype equipment can be insured.
Casuality	◆ Unexpected claims for duty of care. ◆ Product failures in new conditions. ◆ Disruption to transport (extreme events).	◆ Cover for professional services to carbon markets. ◆ "Green" transport products such as low-mileage motor policies.
Life/health/savings	◆ Episodic impacts on human health. ◆ Underestimating human life expectancy due to warmer winter in northern hemisphere transfer. ◆ Reduced disposable income due to disasters.	◆ More demand for health cover savings. ◆ Growing wealth in developing markets due to technology tranfer.
Other under-writing	◆ Increased losses from business interruption, e.g. due to failure of public utilities. ◆ Disruption to leisure events. ◆ Increased losses in agrobusiness. ◆ Novel technology in energy sector.	◆ Alternative risk transfer (catastrophe bonds, etc.). ◆ R&D risks for low carbon technology. ◆ Consulting/advisory services. ◆ Insurance for emissions trading. ◆ Trade risks for technology exports. ◆ Carbon becomes an insurable asset.

Source: Allianz (2005, p. 26).

Illustration 15. Important climate change-related risks and opportunities for insurers

8. Property Value

What is the value added of quality-of-life improvements? A **Property Value** goal analysis can be used to evaluate the increase in property values that is associated with natural aesthetics, improved air quality, or improved quality of life in an area. Proximity to an ecosystem that is providing these services generally enhances the desirability of a property for buyers, and this increased desirability gets reflected in increased prices for a property that has access to these ecosystem services. Studies of different properties that are comparable except for different levels of naturally aesthetic spaces around them can reveal the economic impact that these cultural, non-use services have on the value of associated goods.

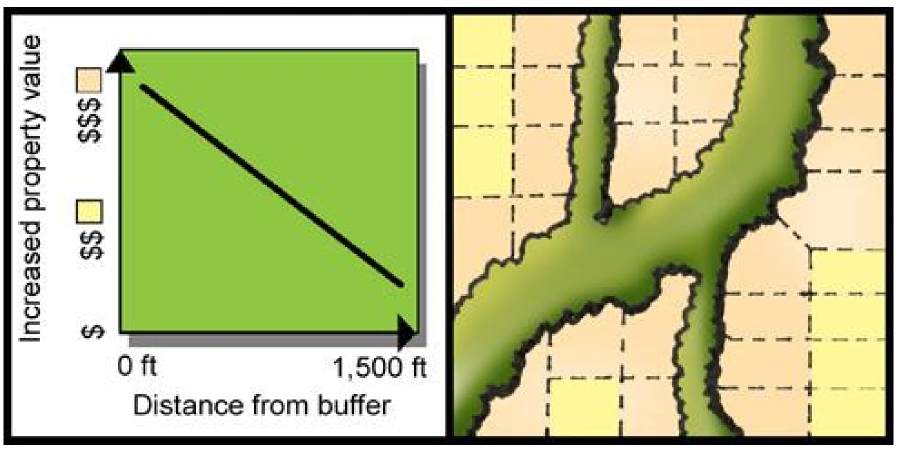


Illustration 15. Greenways can increase property values of nearby parcels by 5 to 32 percent. Greenways with desirable visual characteristics and recreational opportunities correspond to higher property values

9. Cost of Illness

What is the value of the avoided health care costs? A **Cost of Illness** goal analysis can be used to evaluate the health care costs that are associated with increased air and water pollution. When an ecosystem such as a forest or a wetland is removed, the ecosystem services of air and water quality improvements are also lost. This goal analysis might look at the health impacts and costs associated with poor air and water quality as a "value" of the missing ecosystem services. Additionally, the value of added improvements to water and air quality associated with increasing an area's ecosystem services could also be determined through a Cost of Illness analysis. Both the direct market cost and avoided cost method can be used with this goal consideration.

Fine particulate air pollution has serious health effects, including premature mortality, pulmonary inflammation, accelerated atherosclerosis, and altered cardiac functions. In a study published on-line by the journal Environmental Pollution, researchers David Nowak and Robert Hoehn of the U.S. Forest Service and Satoshi Hirabayashi and Allison Bodine of the Davey Institute in Syracuse, N.Y., estimated how much fine particulate matter is removed by trees in 10 cities, their impact on $PM_{2.5}$ concentrations and associated values and impacts on human health. The study used the EPA's tool BenMap to examine tree data from ten U.S. cities (no cities in Texas were evaluated). BenMap was used to obtain an estimate of the health-related costs saved by the removal of $PM_{2.5}$. The results indicated that trees in New York City removed 37.4 tons of $PM_{2.5}$ per year, resulting in a benefit of $60.1 M per year related to avoided health care costs and reduced mortality rates.

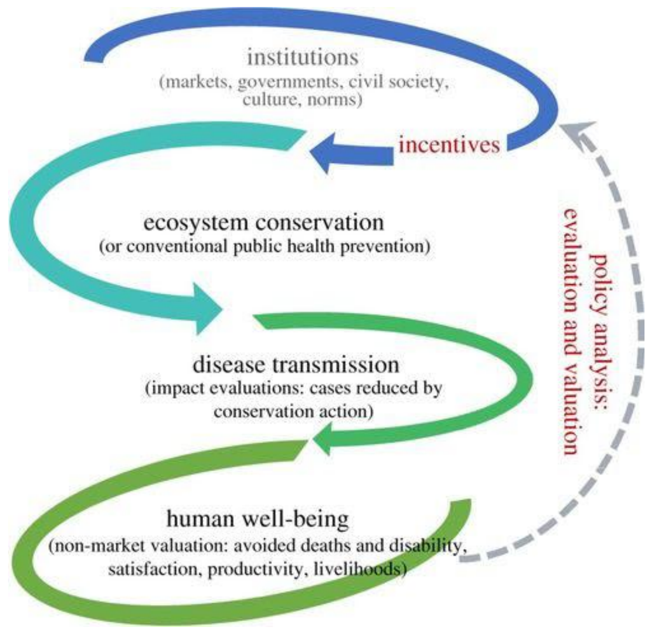


Illustration 16. Policy analysis framework to evaluate how ecosystem conservation improves human health and well-being. As dotted arrow suggests, analyses can guide the design of appropriate incentives for conservation by using the long-term joint pay-offs—i.e. costs and benefits.

Step Two

STEP 2 - Understand the Ecosystem Services (ES) of a particular area of interest

1. Ways to define Nature-based Infrastructure (NBI)
2. Types of NBI
3. The Role Texas' Unique Soils Play in Ecosystem Services
4. ES Issues in Greater Gulf-Houston Region - Eight County area
   - Local ES Benefits
   - Impacts on people and wildlife in Greater Gulf-Houston area
     - Residential and corporate changes to adapt to extreme events
     - Wildlife changes/adaptations as extreme events continue

1. Ways to Define Nature-Based Infrastructure - Infrastructure that relies primarily on ES for its performance goals is often referred to as Nature-Based Infrastructure or Green Infrastructure. Nature-based Infrastructure (NBI) represents the most direct way to include ES into development decisions. Conversely, "gray infrastructure" is composed of synthetic/concrete materials and processes. Agencies and industries are increasingly making use of NBI with great monetary and social success—and at a variety of scales—to solve environmental regulatory issues as well as provide more services beyond a targeted project objective, such as cleaner drinking water, erosion control along riparian banks, etc. NBI can utilize the functions of existing natural areas or a natural system can be enhanced or engineered for high ES abilities. Finally, "green" and "gray" represent a palette of materials within a spectrum of hybrid design approaches rather than mutually-exclusive alternatives.

2. Types of NBI - Recent large flood events around the State of Texas devastated the Texas Coast, Hill Country, and Rio Grande Valley and raised interest in greater investments in **Nature-Based Infrastructure (NBI)** projects. NBI projects integrate, add, or replace built infrastructure with natural landscape features to sustain and restore ecosystem functions and services, particularly related to stormwater management, flood prevention, erosion control, wastewater treatment, and drinking water conservation and delivery. NBI projects can provide cost-effective flood risk reduction with lower initial capital costs and lower long-term maintenance costs. These projects can also provide water conservation and water quality benefits as well as recreational opportunities, including hunting, fishing, and hiking.

NBI needs across the State of Texas include: (1) protecting/ preserving land to naturally hold water necessary to mitigate downstream flooding, (2) maintaining additional detention basins, dams and levees throughout targeted parts of the state to store water as needed, (3) increasing use of native plants and trees through low-impact development techniques, and (4) planning for stormwater infrastructure needs, water quality and water retention.

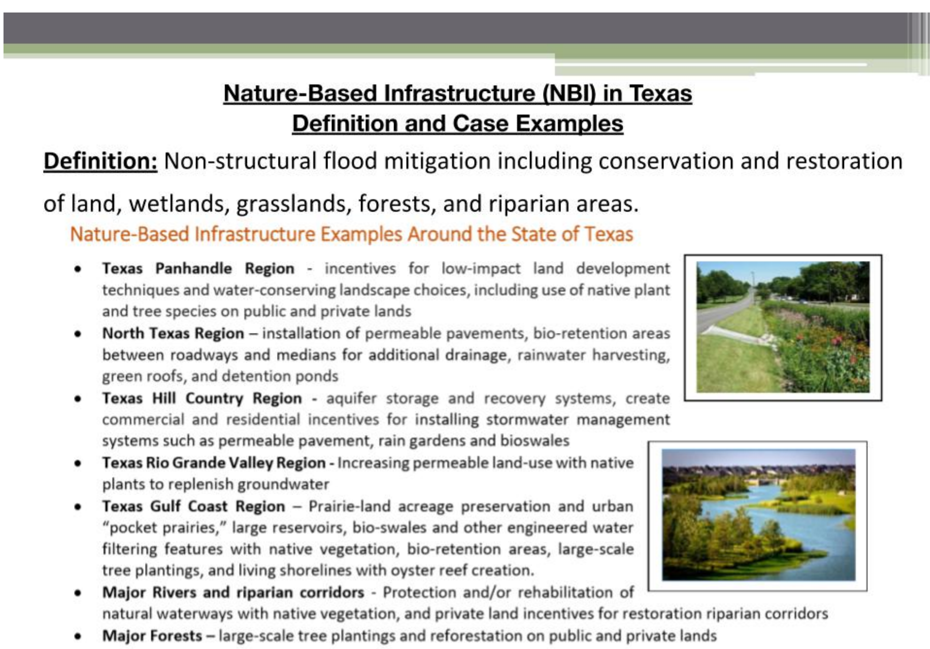


Illustration 17. Houston Wilderness, distributed to Texas Legislature, 2019.

NBI has applications in important coastal protection efforts. Using a combination of gray and green infrastructure for coastal protection is the most effective strategy. It provides multiple lines of protection against hurricanes and tropical storms. This type of green infrastructure includes oyster reef creation, dune restoration, living shorelines, tidal marsh and wetland restoration and preservation, and other vegetative features. The gray infrastructure for coastal protection includes shoreline stabilization using riprap, levee or seawall construction, drainage improvements, and building elevation. By using a combination of these methods on our coast, the Houston-Galveston Area will be provided with the best protection from future storms.

3. The Role Texas' Unique Soils Play in Ecosystem Services

In working to enhance protected/preserved land (nature-based infrastructure) from 10% to 24% by 2040, our region's unique soils play a critical role. The National Resources Conservation Service (NRCS) classifies dominant soil types for the 8-County region as Gulf Coast Prairie Soils. The U.S. Dept. of Agriculture (USDA) identifies twelve soil orders, with Texas containing nine of those twelve orders (see below). From those nine orders, four major urban regions of Texas all contain either Vertisols or Alfisols as their dominant soil orders.

Vertisols are very unique soils and only occupy less than 3 percent of the continental land area on Earth, mainly in the Deccan Plateau of India, the Al-Jazīrah region of Africa, eastern Australia, Texas in the United States, Paraná basin of South America, and Mexico/Central America. Estimated global vertisols soil coverage area totals 300 million hectares (mh), equaling 741,316,144 acres or just 2.7% of continental land.

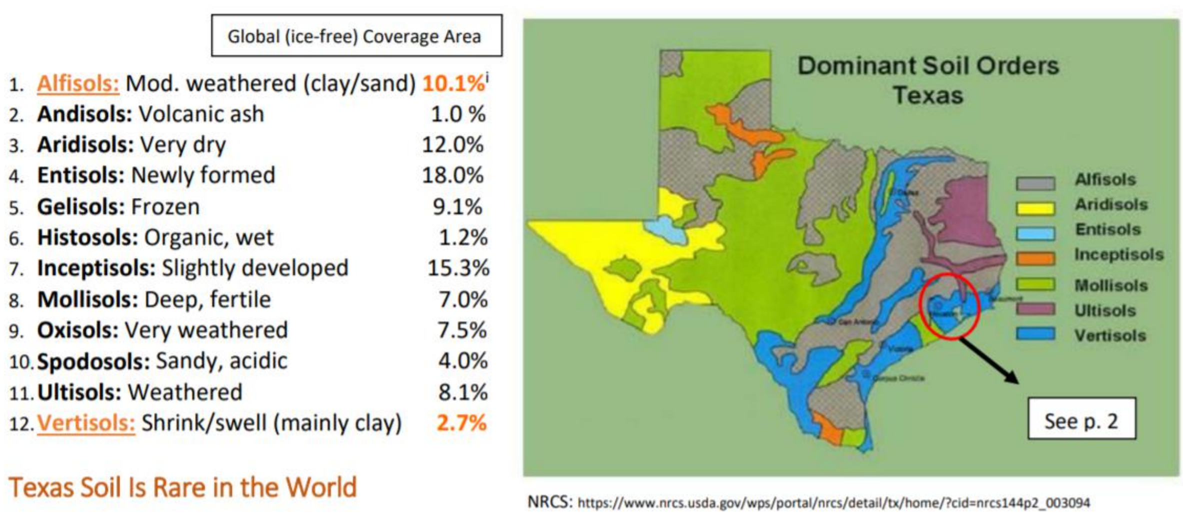
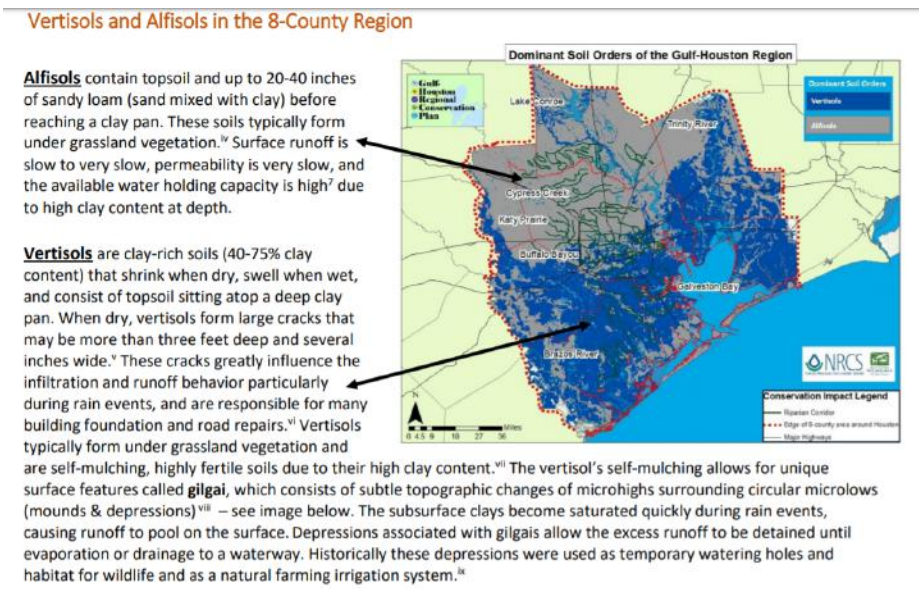


Illustration 18. Chart of Dominant Soil Orders in Texas with emphasis on Greater Houston Region soils (Houston Wilderness, 2018).

Soil considerations for 24% by 2040 Strategy as thousands of local and regional projects continue to be funded to increase ecosystem services, particularly related to storm-resilience, the Gulf-Houston Regional Conservation Plan (RCP) 24% by 2040 Strategy can be reached by preserving and restoring the region's nature-based infrastructure, including riparian corridors, coastal prairies and wetlands, forests and coastal areas (See Working List of Projects here: www.gulfhoustonrcp.org). Knowledge and understanding of our region's unique Vertisols and Alfisols can help guide the discussion on the importance of (1) the need to "spread out" protected land to naturally hold water necessary to mitigate downstream flooding, (2) create and maintain additional detention basins throughout targeted parts of our region that allow for additional storage of water during large rain events, (3) encourage increased native plants and trees on all available lands in our region, and (4) target measureable carbon sequestration as a major factor in restoration/enhancement efforts. Houston Wilderness works with the 8-county region to facilitate the Gulf-Houston RCP and the 24% by 2040 Strategy. For more information, see www.houstonwilderness.org.


Vertisols and Alfisols in the 8-County Region

Alfisols contain topsoil and up to 20-40 inches of sandy loam (sand mixed with clay) before reaching a clay pan. These soils typically form under grassland vegetation.[iv] Surface runoff is slow to very slow, permeability is very slow, and the available water holding capacity is high[7] due to high clay content at depth.

Vertisols are clay-rich soils (40-75% clay content) that shrink when dry, swell when wet, and consist of topsoil sitting atop a deep clay pan. When dry, vertisols form large cracks that may be more than three feet deep and several inches wide.[v] These cracks greatly influence the infiltration and runoff behavior particularly during rain events, and are responsible for many building foundation and road repairs.[vi] Vertisols typically form under grassland vegetation and are self-mulching, highly fertile soils due to their high clay content.[vii] The vertisol's self-mulching allows for unique surface features called **gilgai**, which consists of subtle topographic changes of microhighs surrounding circular microlows (mounds & depressions)[viii] – see image below. The subsurface clays become saturated quickly during rain events, causing runoff to pool on the surface. Depressions associated with gilgais allow the excess runoff to be detained until evaporation or drainage to a waterway. Historically these depressions were used as temporary watering holes and habitat for wildlife and as a natural farming irrigation system.[ix]

Illustration 19. Houston Wilderness, Soil Two-Pager on Regional Soil Orders, 2018

4. ES Issues in Greater Gulf-Houston Region - Eight County area

➢ **Local ES Benefits**

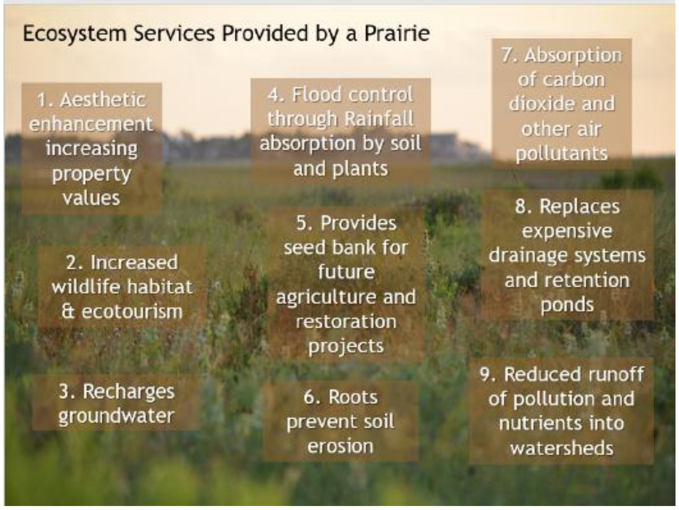
Contrary to the prevailing image of concrete expanses and glass towers, the expansive Greater Houston Region has 10 distinct ecoregions, including three major rivers—the Trinity, San Jacinto and Brazos—as well as over 20 major bayous and creeks that run like fingers from west to east through the region and into Galveston Bay and the Gulf of Mexico.

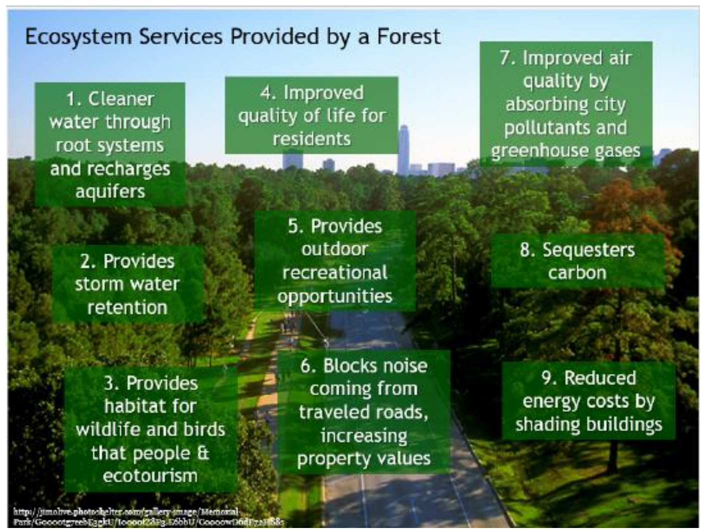
Whether standing in more pedestrian urban settings or in the expanses of the surrounding rural areas, the forests are perhaps the most immediate landscape available to urban citizens - the energy savings afforded to buildings that enjoy the shade from neighboring tree canopies and/or the volume of airborne pollutants— including carbon—removed and sequestered within a tree's biomass.

The once extensive Texas tall grass prairies have been reduced to 1% of their historical range, and the loss of their vast root systems have had devastating consequences on the soil's ability to hold together and to capture and store stormwater. Fertilizer use and pollutant runoff from agriculture and other land use changes further upsets the necessary water filter prairies provide to our watersheds.

For coastal communities and energy pipelines (a significant number of these are sited in the coastal zone with great implications for our nation's energy security), wetlands and estuaries provide a "soft edge" of vegetation which attenuate the force of storm surges and high-powered hurricane winds. The types of habitat provided by wetlands are most useful to migratory birds and commercial fish species. Additionally, wetlands grasses improve water quality by filtering out contaminants and lowering nutrient loads in inflow waters, while also acting as a carbon sink to alleviate atmospheric CO_2 levels.

Below provides a description of the three major areas in which the 10 ecoregions fall: wetlands & estuaries, coastal prairies, and forests (upland and riparian) and the ecosystem services overlap but are distinct for each ecological area.





Illustrations 20, 21 & 22. Three main types of ecoregions in Greater Houston Region

➢ **Impacts on people and wildlife in Greater Gulf-Houston area**

Wilderness areas act as a buffer against species loss. Retaining these remaining wilderness areas is essential. (Di Marco M, Ferrier S, Harwood T, Sept. 18 2019, Wilderness areas halve the extinction risk of terrestrial biodiversity, Nature, Vol. 573, pgs 582-585)

The various ecoregions in the Houston area support different species and the habitats they need within an intricate food web of turtles, small fish, squirrels, alligators, bobcats and hawks—to name just a few. Such a food web gives rise to high levels of biodiversity and is the result of well-functioning plant life responding to proper water and nutrient levels in the surrounding habitat. In this way, complex biodiversity symptomizes overall ecosystem health and can be used as a proxy indicator of functional integrity.

Oysters. One area of wide-spread interest is the effect that large rain events have on oysters, particularly after Ike's damaging impacts to the oyster population in 2008 when many of the bay's beds were covered in sediment and suffered die-offs. Oysters are a commercially important species in Texas with over 6.1 million pounds of meat harvested in 2000. Oyster reefs also provide shelter, food, and habitat to over 300 aquatic species. Finally, oysters contribute to the overall health of the bay by filtering the water that flows over them: one oyster can filter up to fifty gallons of water in one day, making them important contributors to water quality. To that end, Texas Parks and Wildlife (TPWD) is surveying all kinds of shellfish with a particular interest in oyster populations and the effect that the massive freshwater inundation from Harvey had on oyster beds throughout the bay. While it is too early to publish even initial findings, TPWD is committed to collecting data for future analysis.

Wildlife along Waterways & Wetlands. The Texas Coastal Watershed Program has been collecting data on stormwater wetlands at places like Exploration Green, their floating wetlands in Pearland, Texas, and the wetland nursery at the Gulf Coast Bird Observatory in Lake Jackson, Texas. An understanding of how large rain events impact constructed wetlands can help with design and plant selection in the future, to sustain and increase native wildlife. For example, plants that were selected to tolerate times of lesser rainfall did not fare as well as those conditioned for constant moisture. Constructed wetlands play a critical role in habitat creation and restoration, so the analyses of data such as this will assist with planning and implementing projects in the future.

Shorelines. Another restoration technique used in both large and small-scale applications is "living shorelines." Living shorelines are erosion control and habitat restoration techniques that mimic natural coastal processes. These are in contrast to the all-too-familiar bulkheads – constructed walls of concrete, wood, or vinyl – placed at the water's edge to protect property. While effective in the short- to mid-term, bulkheads eliminate any existing marsh habitat, do not provide any replacement habitat value, and are prone to structural wear and failure over time.

Nesting birds. Many birds use islands to make their nests and raise their young. These rookery islands are generally low-lying and subject to flooding during massive rain events or high tide events. Audubon Texas has been sampling rookery islands in the bay complex, looking for damage that might prevent birds from nesting during the coming season and thereby potentially impacting the number of offspring successfully hatched or the location of breeding birds.

- **Residential and corporate changes to adapt to extreme events**

National news articles that followed Hurricane Harvey provide a good synopsis of the residential and corporate changes to adapt to extreme weather events in Greater Houston:

- Los Angeles Times (Nov. 8 2017) https://www.latimes.com/projects/la-na-houston-harvey-home-survivors/
- Architect Magazine (May 31, 2018) https://www.architectmagazine.com/design/houstons-post-harvey-reckoning_o
- New York Times (March 22, 2018) https://www.nytimes.com/interactive/2018/03/22/us/houston-harvey-flooding-reservoir.html

- **Wildlife changes/adaptations as extreme events continue**

The above-described wildlife aspects of the Greater Houston Region touches on some efforts being expended to assess damage done to wildlife habitat by various large storms, such as Hurricane

Harvey. It is heartening to know that professionals from many disciplines are doing what they can to collect data, assess damage, and publish results so that plans can be made to restore habitat, and restore what is lost when possible. In addition to learning what was lost in the storm, it will be equally interesting to understand what was undamaged or what will recover on its own. By understanding the natural processes at play that keep ecosystems in balance, we can better plan human activity so that it diminishes negative impacts on native wildlife.

Step Three

STEP 3 - Establish a baseline evaluation for measurement

1. Identify the health (quality and quantity) of each ecosystem service in the area of interest
   - ➢ Are there specific studies on the state of the ES?
   - ➢ Are there Benefit Relevant Indicators (BRIs) that can be determined?
2. Determine the current use and appreciation of the ES in each ecoregion
3. Determine the level (state of) human well-being associated with each ES
   - ➢ Does it need to be enhanced?
   - ➢ What is needed to maintain a healthy state?

Once the ecosystem services are known in the area of interest, the next step for a decision maker in making infrastructure decisions based on the benefits and/or economic value(s) of multiple ES is to determine a baseline of the measurable benefits of the ES in the targeted area. For example, as illustrated in the diagram below, the ecosystem of a well-functioning river will likely include vegetation and clean upstream water sources that allow for the river to provide appropriate levels of nutrients and oxygen allowing for the proliferation of various types of fish. The ES provided by the river include: good water quality, healthy fish, erosion control, water absorption and recreational fishing, among other possible ES. It is easy to identify use and appreciation of the ES in this river as well as the human well-being associated with it - fishing, recreation, relaxation. If the baseline of this same river included degraded levels of ES - perhaps poor nutrient and oxygen sources and erosion problems, then the ES provided by the river would be significantly reduced and planning would need to be made on how to best improve the river's functions to allow for ES enhancements.

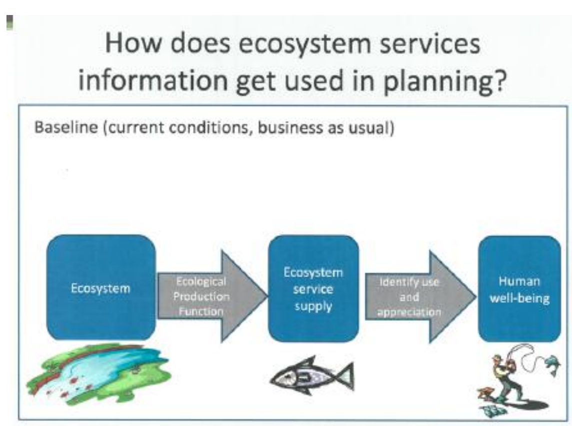
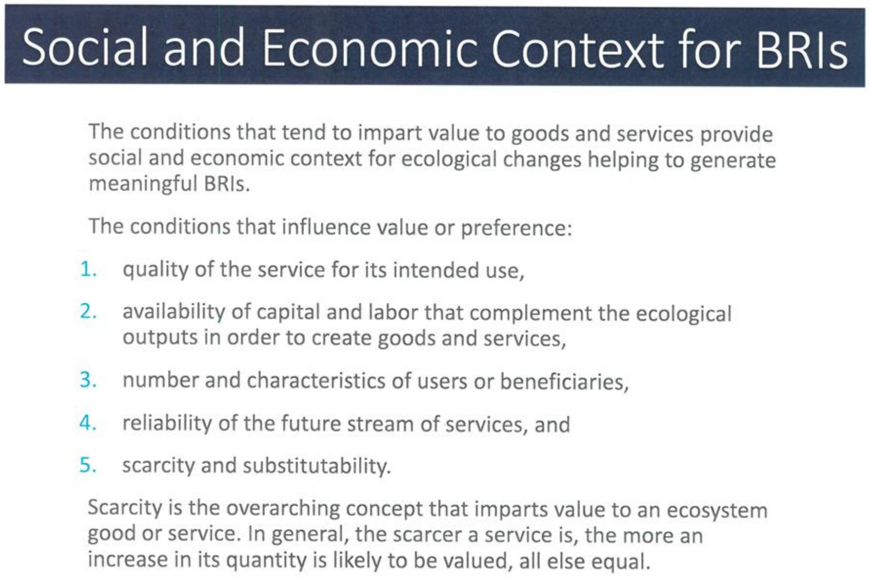


Illustration 23. Before determining how much an increase in ecosystem services (ES) may benefit a nature-based infrastructure goal, it often helps to first determine what the baseline of current ES of the targeted area provides to land use and/or human well-being



Similar approaches can be taken for decision-makers looking at infrastructure planning at various scales. For example, when looking at different lines of protection from coastal storm (hurricane) surge or other types of large rain events, the ES provided by the various ecoregions along protection lines will have different levels of ES - some providing higher quality than others. The key is to identify the baseline state of each ES, to the extent possible, then determine the current use and appreciation of the ES in each ecoregion and then determine the human well-being associated with each one. Larger scale examples of this process were performed for the *Houston Resilience Strategy* (http://www.greenhoustontx.gov/) and *Houston Stronger* Plan (https://houstonstronger.net/) and the *Gulf-Houston Regional Conservation Plan* (http://www.gulfhoustonrcp.org/).

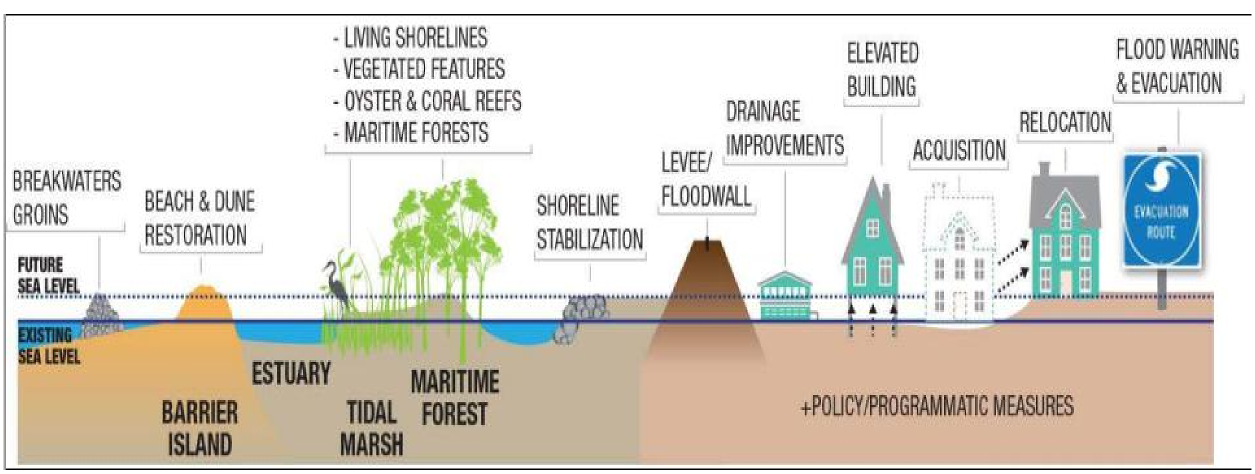
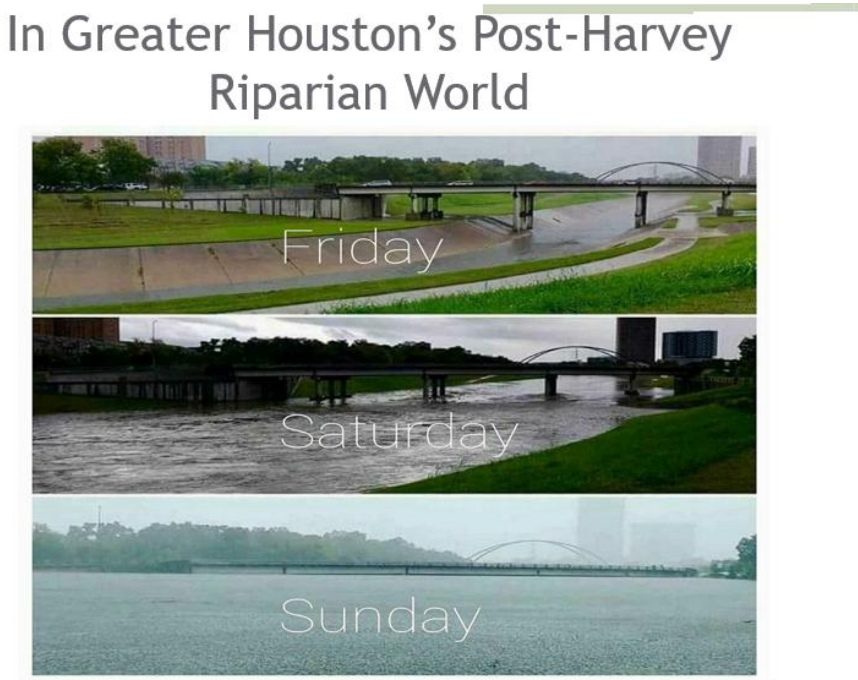


Illustration 24. An approach to integrating green and gray infrastructure for coastal protection (U.S. Army Corps of Engineers - Galveston District, 2018)



Houston Chronicle, August 2017 - Brays Bayou in three sequential days during Hurricane Harvey

The Houston region received more rain from Hurricane Harvey than any other American city has received from any storm in recorded history. Some areas experienced a 1,000–year flood, meaning there is a 0.1 percent chance of such a flood happening in any given year. For the past 40 years, the Gulf-Houston Region design standards have been calibrated for 100-year events. Even if all of our drainage systems were built to this standard, Harvey would have caused massive flooding across the entire area.

Illustration 25. NASA Photo of sediment days after Hurricane Harvey (September 2017)

Step Four

STEP 4 - Consider regional challenges & opportunities where ES can be applied

- **Oil & Gas Capital - pipelines and plants**

Like oil and gas, wind energy requires a network of roads, transmission lines, and associated infrastructure to capture and transport the power. Information on the current and projected impacts of oil, gas, and wind energy land-uses on habitat for biodiversity and land-based ecosystem services is scarce and warrants further investigation, given the potential of energy development to transform natural and human-dominated landscapes. Understanding the characteristics of the landscape that increase or decrease the severity of disturbances will aid in the responsible design of projects at a regional scale and will result in more comprehensive impact estimates. This type of analysis is relatively inexpensive and allows investigators to draw inferences over a larger geographic scale and for a wide selection of predictor variables. For example, aerial imagery can be used to obtain accurate measurements of the habitat loss and fragmentation resulting from energy development across a diversity of landscapes (Jones and Pejchar, 2015).

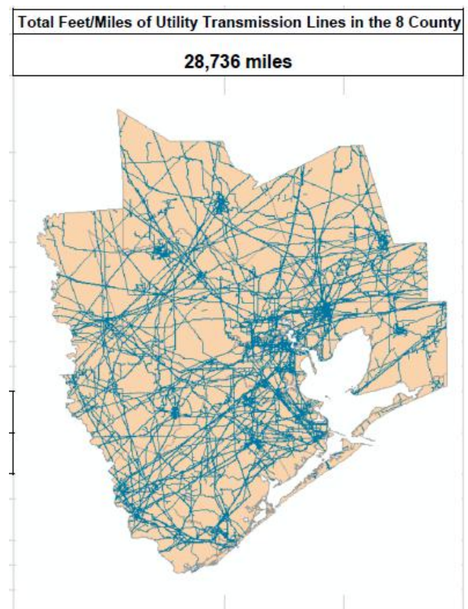


Illustration 26. Total Feet/Miles of utility transmission lines in the 8-County Gulf-Houston Region

- **Air Quality and Urban Heat Island Effect on Communities in the Region**

Houston has experienced a significant loss of tree cover over the last few decades. One study estimated the value of lost tree canopy in Houston from 1972 to 1999 (Anthony et al. 2009) was \$38 million per year during that time period – resulting in significant loss of ecoservice benefits to the City's residents and businesses. This study found that the loss of tree canopy reduced the amount of CO, SO2, and O3 that would have otherwise been removed from the air. Moreover, there are Urban Heat Island areas in communities around the City of Houston and Harris County and these areas tend to disproportionately affect lower income areas. The urban forest is critical to Greater Houston's landscape and community/bayou/regional stormwater recovery and resilience.

Planting thousands (1-4 million) additional native tree species in strategic locations on both private and public protected/preserved lands as well as other public/private locations in the Greater Houston Region will increase resilience and recovery from shocks and stressors by (1) protecting, restoring, and improving the water and air quality, water and carbon absorption, riparian erosion rates and habitat of multiple watersheds in the City of Houston and its ETJ, and (2) reducing Urban Heat Islands around the CoH.

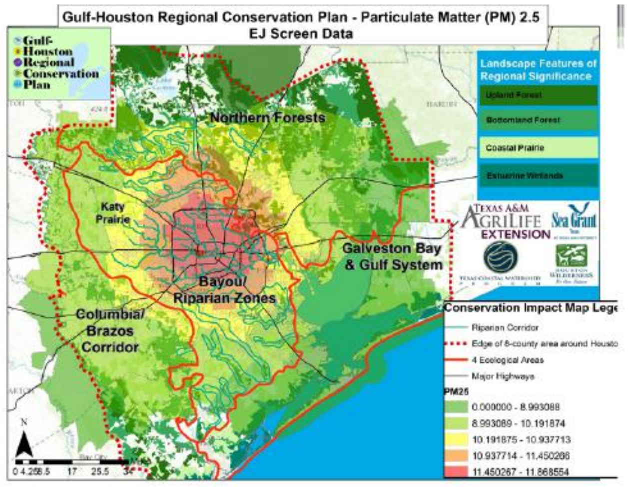


Illustration 27. Particulate Matter 2.5 levels in 8-County Gulf-Houston Region

- **Impacts of Sea Level Rise on Texas Coast**

In 2019, the three locations that saw the highest rates of sea level rise were all on the Gulf: Grand Isle, Louisiana at 7.93 millimeters per year (mm/yr), Rockport, Texas at 6.95 mm/yr and Galveston, Texas at 6.41 mm/yr. There is increasing evidence from the tide-gauge records that these higher sea-level curves need to be seriously considered in resilience-planning efforts (William & Mary's Virginia Institute of Marine Science (VIMS), Sea-level report cards: 2019 data adds to trend in acceleration**,** February 2020).

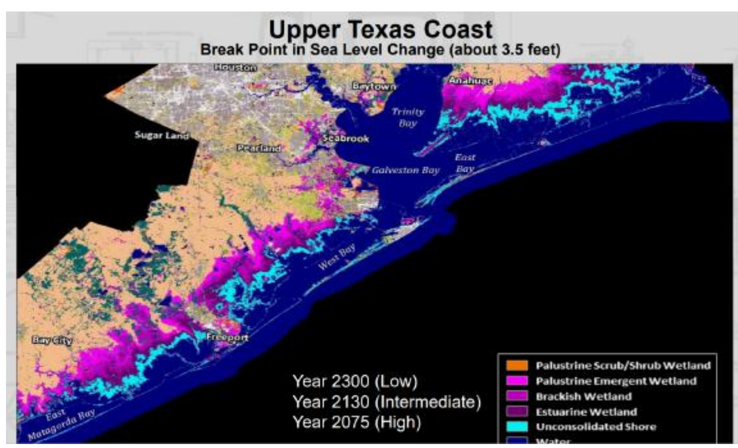


Illustration 28. Break Point in Sea Level Change along Gulf-Houston Coast

- **Funding Responses to High Risk factors and areas of concern in the region**

Harris County Flood Control District's post-Harvey bond projects and home buyouts - On August 25, 2018, Harris County voters approved $2.5 billion in bonds to finance flood damage reduction projects in Harris County. Going forward, the Harris County Flood Control District will prioritize, plan and build projects with bond funding – and will provide transparent tracking of progress on those projects along the way. The bonds are sold in increments over at least 10-15 years, as needed for multiple projects and the multiple phases of each project.

Projects also are phased in, as appropriate. The actual timing of individual projects depend on a variety of factors including any needed environmental permitting, right-of-way acquisition and utility relocation. Some projects are already underway or nearing construction; others are still in very preliminary stages, or require further investigation. Projects will be authorized individually for funding by Harris County Commissioners Court, based on recommendations by the Flood Control District.

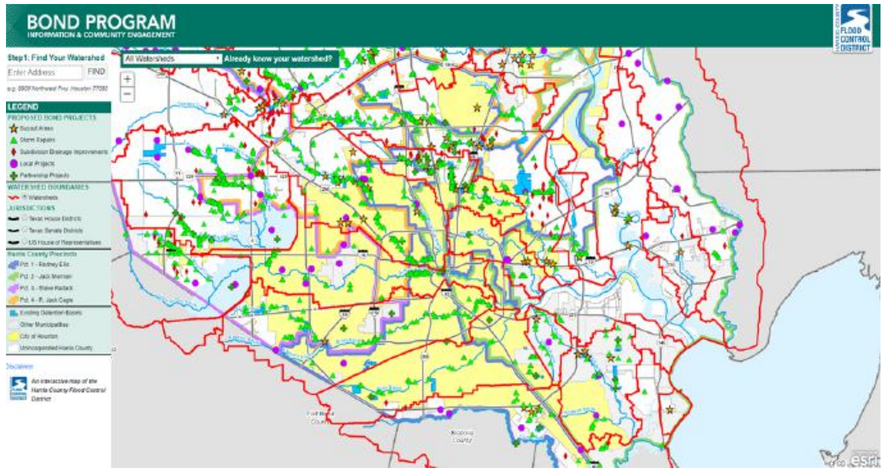


Illustration 29. Harris County Flood Control District $2.5 Bond Project Interactive Map

Step Five

STEP 5 - Create flow chart of Ecosystem Services' Benefits and Economic Valuations

Ecology ⇒⇒⇒ Ecosystem Services ⇒⇒⇒ Social Benefits

As decision makers aim to improve their cities, data and statistical information are becoming ever more essential to understanding the current and future needs of a city. In order for decision makers to make informed choices about their cities infrastructure, they require the most current and credible data. This information enables them to realize the multiple factors and ways their decisions will impact their communities.

Regardless of the processes or units used for quantifying such values, the ability to map them and relate them to the ecosystem services to which they are attributed is necessary for effective assessments.

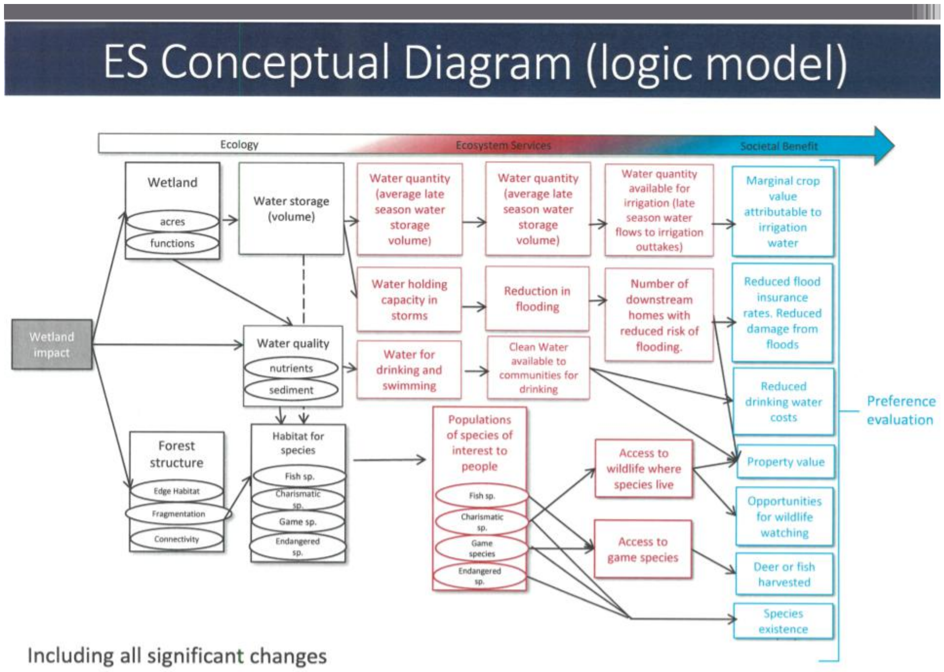


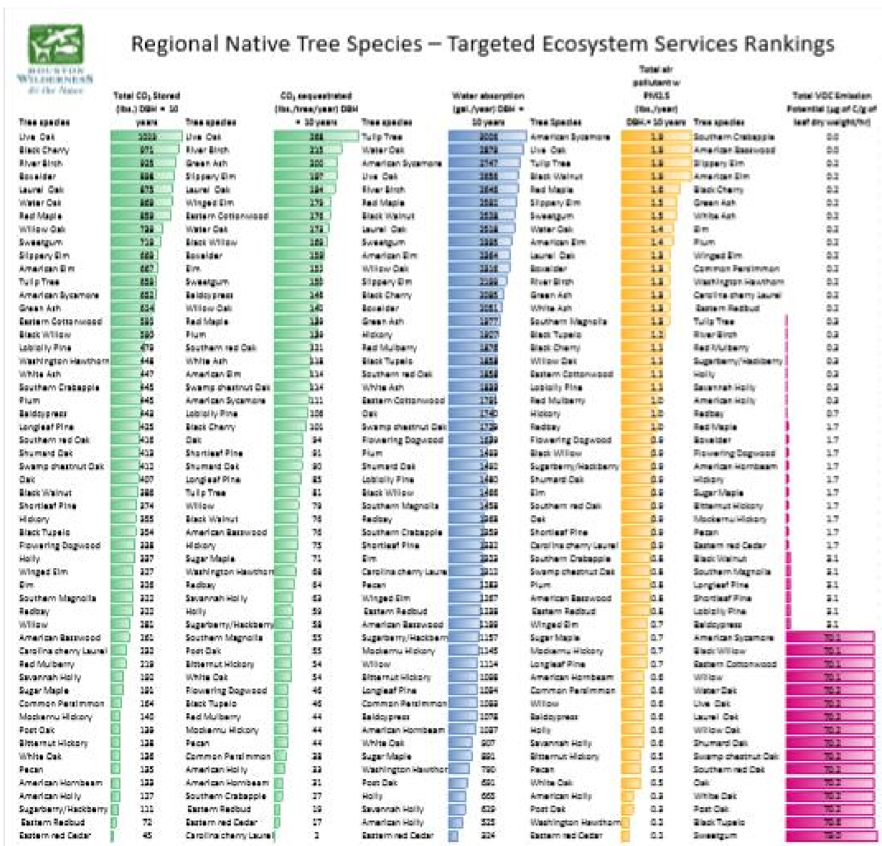
Illustration 30. Example of Logic Model Diagram showing impacts of ecosystem services increases after wetland mitigation is performed

Properly integrated NBI can maintain connectivity between habitats, thereby providing a safe corridor for wildlife and otherwise reducing edge effects.

- Flood protection can use gray materials to evacuate stormwater runoff into vegetation buffers or green reservoirs and can ultimately facilitate stormwater infiltration into the soil—replenishing groundwater reserves.
- Designing for storm surge protection can combine riprap and other "hard" materials with vegetation buffers, oyster reefs, or tidal marshes to ensure a robust coastline of defense against storm impacts.
- An artificial wetland can be built to improve water quality while also attracting birds and birdwatchers. Improvements made to water and air quality can affect improved health in neighboring residents.
- Progress made in developing green infrastructure is a positive step towards creating environmentally conscious and ecosystem service-oriented communities.

Example: When native tree species are planted in an area, the trees begin absorbing organic carbon from the air into the trees and the surrounding soil right away, with increases in carbon sequestration every year. So, for example, (1) If 2,000 Live Oak trees are planted in 2020, by 2030 each of the Live Oak trees will be absorbing as much as 268 pounds of carbon each year, and all 2,000 trees are absorbing 536,000 lbs each year; and (2) Those same 2,000 Live Oak trees planted in 2020, by 2030 each of the Live Oak trees will be absorbing as much as 2,656 gallons of water each year, and all 2,000 trees are absorbing 5,312,000 gallons of water each year. If mulch and/or organic compost is added to the base of the trees, the carbon absorption is up to 4 times higher in the soils annually.

Large-scale tree planting on nature-based infrastructure



Regional Native Tree Species – Targeted Ecosystem Services Rankings

Tree species	Total CO_2 Stored (lbs.) DBH + 10 years	Tree species	CO_2 sequestrated (lbs./tree/year) DBH + 10 years	Tree species	Water absorption (gal./year) DBH + 10 years	Tree Species	Total air pollutant w PM2.5 (lbs./year) DBH + 10 years	Tree species	Total VOC Emission Potential (μg of C/g of leaf dry weight/hr)
Live Oak	1010	Live Oak	266	Tulip Tree	3006	American Sycamore	1.9	Southern Crabapple	0.0
Black Cherry	971	River Birch	215	Water Oak	2879	Live Oak	1.9	American Basswood	0.0
River Birch	925	Green Ash	200	American Sycamore	2747	Tulip Tree	1.9	Slippery Elm	0.2
Boxelder	886	Slippery Elm	197	Live Oak	2656	Black Walnut	1.9	American Elm	0.2
Laurel Oak	875	Laurel Oak	184	River Birch	2646	Red Maple	1.6	Black Cherry	0.2
Water Oak	869	Winged Elm	175	Red Maple	2582	Slippery Elm	1.5	Green Ash	0.2
Red Maple	859	Eastern Cottonwood	175	Black Walnut	2536	Sweetgum	1.5	White Ash	0.2
Willow Oak	736	Water Oak	172	Laurel Oak	2516	Water Oak	1.4	Elm	0.2
Sweetgum	719	Black Willow	169	Sweetgum	2395	American Elm	1.4	Plum	0.2
Slippery Elm	689	Boxelder	159	American Elm	2384	Laurel Oak	1.3	Winged Elm	0.2
American Elm	667	Elm	153	Willow Oak	2316	Boxelder	1.3	Common Persimmon	0.2
Tulip Tree	659	Sweetgum	150	Slippery Elm	2199	River Birch	1.3	Washington Hawthorn	0.2
American Sycamore	652	Baldcypress	148	Black Cherry	2095	Green Ash	1.3	Carolina cherry Laurel	0.2
Green Ash	614	Willow Oak	140	Boxelder	2081	White Ash	1.3	Eastern Redbud	0.2
Eastern Cottonwood	593	Red Maple	139	Green Ash	1977	Southern Magnolia	1.3	Tulip Tree	0.2
Black Willow	590	Plum	139	Hickory	1927	Black Tupelo	1.2	River Birch	0.2
Loblolly Pine	479	Southern red Oak	131	Red Mulberry	1878	Black Cherry	1.1	Red Mulberry	0.2
Washington Hawthorn	448	White Ash	118	Black Tupelo	1858	Willow Oak	1.1	Sugarberry/Hackberry	0.2
White Ash	447	American Elm	114	Southern red Oak	1858	Eastern Cottonwood	1.1	Holly	0.2
Southern Crabapple	445	Swamp chestnut Oak	114	White Ash	1822	Loblolly Pine	1.1	Savannah Holly	0.2
Plum	445	American Sycamore	111	Eastern Cottonwood	1791	Red Mulberry	1.0	American Holly	0.2
Baldcypress	442	Loblolly Pine	108	Oak	1740	Hickory	1.0	Redbay	0.7
Longleaf Pine	425	Black Cherry	101	Swamp chestnut Oak	1729	Redbay	1.0	Red Maple	1.7
Southern red Oak	418	Oak	94	Flowering Dogwood	1639	Flowering Dogwood	0.9	Boxelder	1.7
Shumard Oak	412	Shortleaf Pine	91	Plum	1493	Black Willow	0.9	Flowering Dogwood	1.7
Swamp chestnut Oak	412	Shumard Oak	90	Shumard Oak	1492	Sugarberry/Hackberry	0.9	American Hornbeam	1.7
Oak	407	Longleaf Pine	85	Loblolly Pine	1480	Shumard Oak	0.9	Hickory	1.7
Black Walnut	388	Tulip Tree	81	Black Willow	1466	Elm	0.9	Sugar Maple	1.7
Shortleaf Pine	374	Willow	79	Southern Magnolia	1458	Southern red Oak	0.9	Bitternut Hickory	1.7
Hickory	355	Black Walnut	76	Redbay	1368	Oak	0.9	Mockernut Hickory	1.7
Black Tupelo	354	American Basswood	76	Southern Crabapple	1359	Shortleaf Pine	0.9	Pecan	1.7
Flowering Dogwood	338	Hickory	75	Shortleaf Pine	1332	Carolina cherry Laurel	0.9	Eastern red Cedar	1.7
Holly	337	Sugar Maple	71	Elm	1332	Southern Crabapple	0.8	Black Walnut	2.1
Winged Elm	327	Washington Hawthorn	68	Carolina cherry Laurel	1312	Swamp chestnut Oak	0.8	Southern Magnolia	2.1
Elm	326	Redbay	64	Pecan	1282	Plum	0.8	Longleaf Pine	2.1
Southern Magnolia	322	Savannah Holly	63	Winged Elm	1267	American Basswood	0.8	Shortleaf Pine	2.1
Redbay	322	Holly	59	Eastern Redbud	1238	Eastern Redbud	0.8	Loblolly Pine	2.1
Willow	281	Sugarberry/Hackberry	58	American Basswood	1189	Winged Elm	0.7	Baldcypress	2.1
American Basswood	261	Southern Magnolia	55	Sugarberry/Hackberry	1157	Sugar Maple	0.7	American Sycamore	70.1
Carolina cherry Laurel	232	Post Oak	55	Mockernut Hickory	1145	Mockernut Hickory	0.7	Black Willow	70.1
Red Mulberry	219	Bitternut Hickory	54	Willow	1114	Longleaf Pine	0.7	Eastern Cottonwood	70.1
Savannah Holly	190	White Oak	54	Bitternut Hickory	1098	American Hornbeam	0.6	Willow	70.1
Sugar Maple	181	Flowering Dogwood	46	Longleaf Pine	1094	Common Persimmon	0.6	Water Oak	70.2
Common Persimmon	164	Black Tupelo	46	Common Persimmon	1088	Willow	0.6	Live Oak	70.2
Mockernut Hickory	140	Red Mulberry	44	Baldcypress	1076	Baldcypress	0.6	Laurel Oak	70.2
Post Oak	139	Mockernut Hickory	44	American Hornbeam	1037	Holly	0.6	Willow Oak	70.2
Bitternut Hickory	138	Pecan	44	White Oak	907	Savannah Holly	0.6	Shumard Oak	70.2
White Oak	136	Common Persimmon	38	Sugar Maple	891	Bitternut Hickory	0.5	Swamp chestnut Oak	70.2
Pecan	135	American Holly	33	Washington Hawthorn	790	Pecan	0.5	Southern red Oak	70.2
American Hornbeam	133	American Hornbeam	31	Post Oak	691	White Oak	0.5	Oak	70.2
American Holly	127	Southern Crabapple	27	Holly	665	American Holly	0.3	White Oak	70.2
Sugarberry/Hackberry	111	Eastern Redbud	19	Savannah Holly	629	Post Oak	0.3	Post Oak	70.2
Eastern Redbud	72	Eastern red Cedar	17	American Holly	535	Washington Hawthorn	0.2	Black Tupelo	70.8
Eastern red Cedar	45	Carolina cherry Laurel	3	Eastern red Cedar	324	Eastern red Cedar	0.2	Sweetgum	78.0

Illustration 31. Regional Native Tree Species - Targeted ES Rankings

Using Data Analytics on Ecosystem Services' Economic Valuations

The growing appreciation that ecosystem services allows for a better understanding and interest in quantifying the flow of nature's goods and services so that decision-makers can better evaluate trade-offs when making complex decisions that affect the environment. This quantification can come in many forms -

1) Fact-based analysis of the ES provided by different land uses,
2) Valuation of those healthy
3) Functioning ES that provide fresh water to downstream users,
4) Sequestration of atmospheric carbon dioxide,
5) Pollination of agricultural crops
6) Erosion and flood control
7) Placing monetary worth on ES using primary valuation methods or value transfer
8) Conducting dynamic spatial modeling of ES flows to beneficiaries (i.e., people)
9) Detailing forest carbon storage capacity and defining accounting systems
10) Developing geospatial technology and remote sensing data to enhance quantification and spatial visualization of ES
11) Performing scenario analysis of ES flows under alternative conditions

Case Example: The *Our Great Region 2040 Strategy Playbook*, facilitated by the Houston-Galveston Area Council (H-GAC) recognized that the 13-county region around Greater Houston contained forests, wetlands, prairies, water bodies, and other natural ecosystems that provide the region with a variety of services, which could be quantified in dollars and cents. In creating a Strategy Playbook to increase awareness of the economic benefits of environmental systems as a tool for decision-makers, they noted: “These ecologically-rich landscapes clean the air, filter and cool water, store and recycle nutrients, conserve and enhance soils, pollinate crops, regulate climate, sequester carbon, protect areas against storm and flood damage, and maintain water supplies. They also provide marketable goods and services, like forest products, fish, and recreational opportunities. Many citizens do not realize that Our Region’s unique ecosystems provide valuable services that enhance our quality of life. Educational programs, science-based analyses, and other initiatives can increase awareness of these benefits, highlighting the important role natural processes play in our everyday lives. Recognizing these benefits will help policymakers and citizens calculate the full costs of their decisions.”

Goals	Objectives
• Our Region values and preserves its unique ecosystems, working landscapes, parks, open spaces, and the ecological benefits they provide • Our Region embraces its rich multicultural, historical and natural assets to ensure its communities retain their unique character • Our Region is resilient and adaptive to economic downturns and environmental or natural disasters	• Preserve, protect and restore green infrastructure, vital ecosystems and prime agricultural land • Promote low impact development and community planning that incorporates conservation • Capitalize on the region's reputation as a place of diversity, opportunity and unique historical, cultural and natural assets • Create a built environment that is resilient and adaptive to changes in the natural environment • Encourage development in locations that are more resilient to environmental and natural disasters
Metrics	**Livability Principles**
• Acres of high value environmental resources by category • Percentage of population that resides within 1 mile of a park or open space for rural or 1/2 mile for urban space • Acres of impervious surface • Dollar value of ecological services in environmentally sensitive areas • Dollar value of environmental service losses from vegetative changes in long term drought conditions of region	• Enhance economic competitiveness • Coordinate policies and leverage investment

Illustration 32. Using flow chart and data analytics to determine goals, objectives, metrics and principles for increasing nature-based infrastructure awareness

Step Six

STEP 6 - Based on Goal(s) Analysis, determine the best method(s) to use in looking at ES valuation

The methods for eliciting the value of ecosystem services can be divided into two categories: economic (also known as dollar based methods) and non-economic valuation. The former include the market price method, productivity method, hedonic price method, travel cost method, damage cost avoided, replacement cost, substitute cost method, contingent valuation method, contingent choice method and benefit transfer method.

1. On-Site Ecological Function Analysis

An *On-Site Ecological Function Analysis* goal analysis uses on-site measurements of the ecosystem functions in a particular location to determine the value of the service they provide. Data collected from the site would be geared towards understanding how much of a particular service the natural ecosystem function provides, so that the measurements that are taken will show the extent of the service in a particular ecosystem. This could be accomplished using a variety of different tools, depending on what type of service is being valued. Once the capacity of the ecosystem functions are known, they can be given value when connected to existing markets. An ecological function analysis can be combined with a cost-based study (direct market price, avoided cost, replacement cost, or mitigation and restoration cost) to give the ecosystem's capacity a monetary value. For example, on-site water absorption studies could be used to determine the capacity of water that a prairie holds, and an avoided cost study could then give an economic value to the water absorption in terms of flood damage avoided.

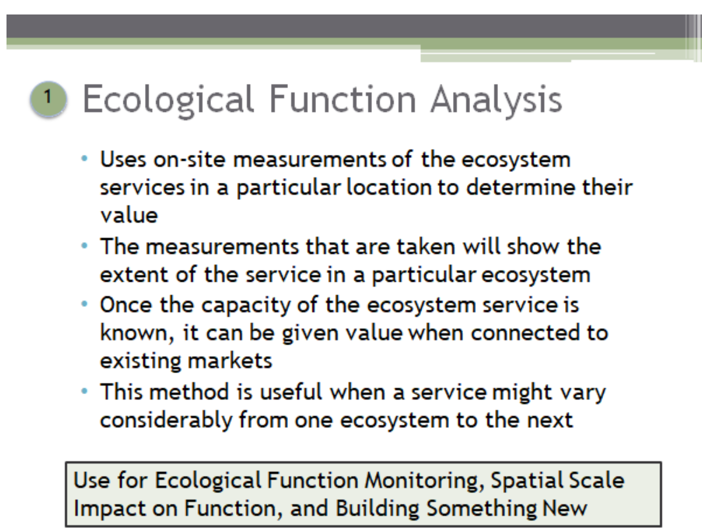
NOAA conducted a study of blue crab, brown and white shrimp juvenile production in various habitat types across Galveston Bay. Using On-Site Ecological Function Analysis they concluded that juvenile production for all three species was highest where wetland vegetation met open water.

When it is not possible to conduct on-site measurements and obtain data directly from the ecosystem that targeted for valuing, it may be possible to perform a Benefit Transfer analysis (which is not covered in this Primer) or a Literature Review. In a benefit transfer analysis, values for ecosystem functions can be taken from studies of one ecosystem and applied to a different ecosystem, which is likely to have different soil and ecological considerations. The accuracy of benefit transfer studies depends heavily on the design of the original study from which values are obtained. The original studies should be carefully reviewed to ensure that sound methodology was used throughout the studies, as a benefit transfer can amplify any errors or inaccuracies from an original study and give skewed values.

In a literature review, values for ecosystem services are taken from many studies of similar ecosystem types and compiled to obtain an average value for the ecosystem services measured. Ecosystem functions depend on a wide array of variables and can vary drastically from one location to the next. Both of these studies carry the risk of under or over valuing the ecosystem services you want to measure, since there is no way to verify the level of service being provided with on-site measurements. However, benefit transfer and literature review can be useful when a precise value is not necessary or on-site measurements are not possible. They can also be a good starting point to justify a further analysis of the ecosystem in question.

Hydrological models such as the Soil and Water Assessment Tool (SWAT) or Soil and Water Integrated Model (SWIM) can provide valuable outputs simulating streamflow, water quality, and erosion that can be used to assess the supply of an ecosystem service. If a model has been created or the time and resources to build a model for your region are available, it can be an extremely useful tool in assessing ES. However, it is a time consuming and extensive process to develop a reliable model so there are limitations on the usage of this method.

Researchers working with hydrological models have developed a set of equations to calculate five **ES Indices** to quantify the supply of an ES (Logsdon and Chaubey, 2013). The indices can be used for quantifying fresh water provisioning, food provisioning, fuel provisioning, flood regulation, and erosion regulation. The equations can be used with model outputs, if time and resources permit model development, or with observed data if it is available. There is planned work for utilizing observed USGS streamflow and water quality data to quantify the current state of freshwater provisioning and flood regulation supply in the Greater Houston Region.

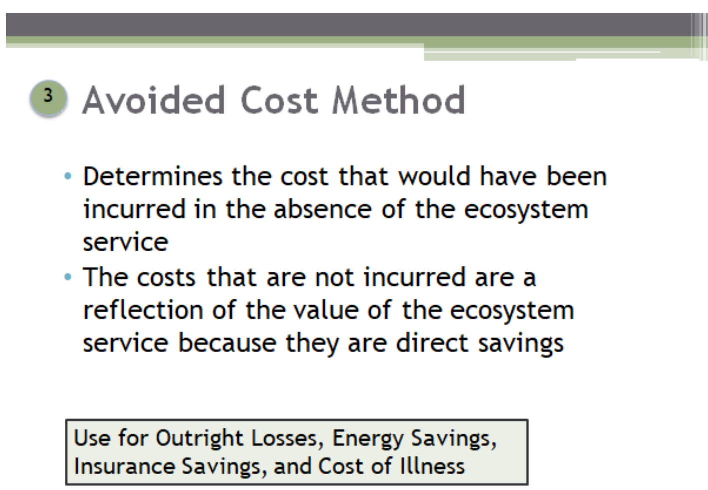


On-Site Ecological Function Analysis measures a specific ecosystem's productive output. This analysis provides a baseline inventory for use in conjunction with a cost-based or market price method.

2. Avoided Cost

There are several cost-based approaches to determine the value of an ecosystem service. Overall, cost-based approaches determine value by looking at the costs that would be incurred if existing ecosystem services were to be interrupted. The *Avoided Cost* method determines the cost that would have been incurred in the absence of the ecosystem service. The economically valuable service that is currently being provided "for free" by the ecosystem would be studied to determine an appropriate value for the ecosystem's services. For example, looking at the cost to repair damages that would have occurred if stormwater had not been retained by a wetland in a flood event would give a value for the stormwater retention that is provided by the wetland. The costs that are not incurred are a reflection of the value of the ecosystem service because they are direct savings made possible by the ecosystem's function.

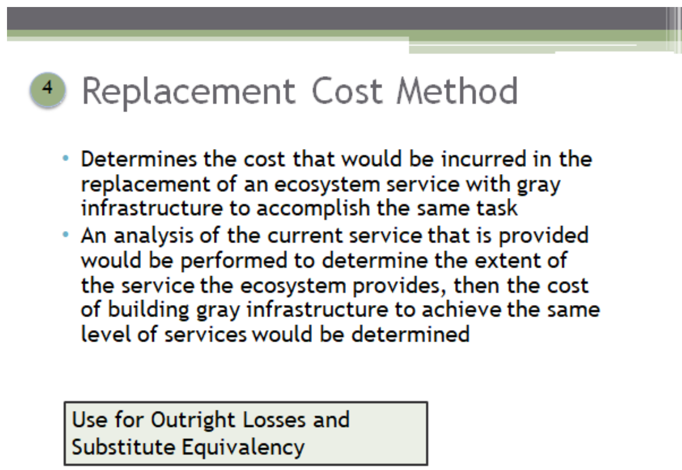
New York City's water supply was threatened by agricultural runoff in the Catskill-Delaware watershed. Rather than construct a water treatment facility for $6B, they worked with local farmers to conserve 108,000 ac. of land as part of the Whole Farm Program. The Whole Farm Program recruited local buy-in on a voluntary basis through farmer education of environmentally friendly best management practices and PES compensation. These practices could be integrated into the farmer's current practices in an effort to mutually improve runoff water quality and the farmer's business. In total, the Whole Farm Program cost the city $1.5B for $4.5B of Avoided Costs to taxpayers.



The Avoided Cost method uses damages incurred by neighbors or historical data to evaluate the target ES equal to the costs of these damages. This value represents savings generated by ES to avoid having to pay these costs to damages.

3. Replacement Cost

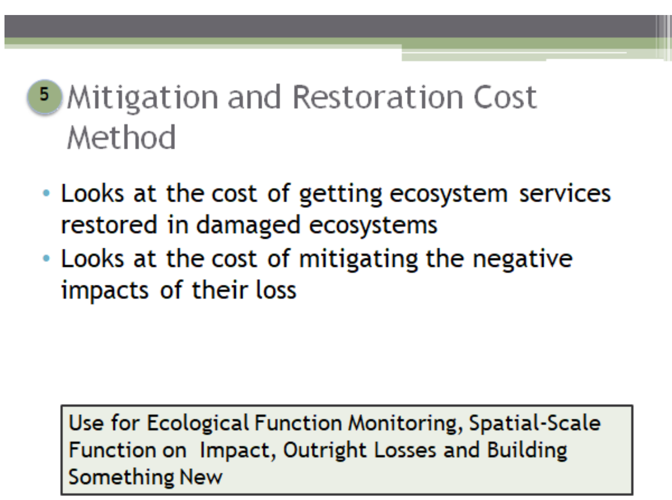
The *Replacement Cost* method determines the costs that would be incurred in the replacement of an ecosystem service with gray infrastructure to accomplish the same task. An analysis of the current service that is provided (eg. amount of water that is naturally filtered or retained, amount of air pollutants that are removed by trees, etc.) would be performed to determine the extent of the service the ecosystem provides (see ecological function method). Then the cost of building gray infrastructure to achieve the same level of services (e.g. water treatment facility that filters the same amount of water as the wetland does naturally) would be determined and that cost would be used to show the monetary value of the services currently provided by the ecosystem.



The Replacement Cost method evaluates ES equal to the cost of installing an alternative with equivalent performance to the current infrastructure solution.

4. Mitigation/Restoration Cost

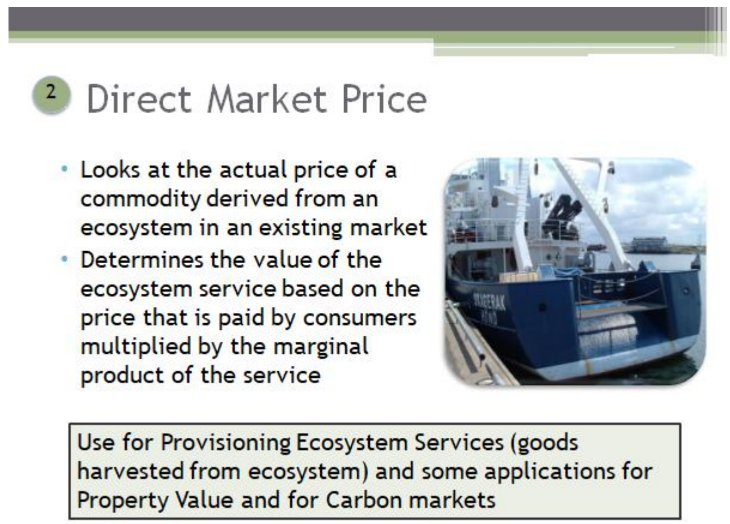
The *Mitigation/Restoration Cost* method looks at the cost of getting ecosystem services restored or the cost of mitigating the negative impacts of their loss. This method could use the cost of restoring the ecosystem in the future in the event of the loss of the ecosystem's current functions. For example, if a particular wetland that is providing ecosystem services such as flood protection is being filled, the cost of restoring the wetland at a later date to provide the same level of ecosystem functions and services can determine the value of the service that the ecosystem provides. The other option with this method would be to look at how much it would cost to mitigate the flood damage through the restoration or creation of an alternative wetland that would provide an equivalent level of ecosystem services. All of the direct market and cost based studies require some knowledge about the ecosystem's capacity to provide the service, and an ecological function analysis or other data collection will most likely be the starting point for these studies. This ensures that the



ecosystem can be valued accurately based on the extent of the service it is providing in the specific location targeted by the study.

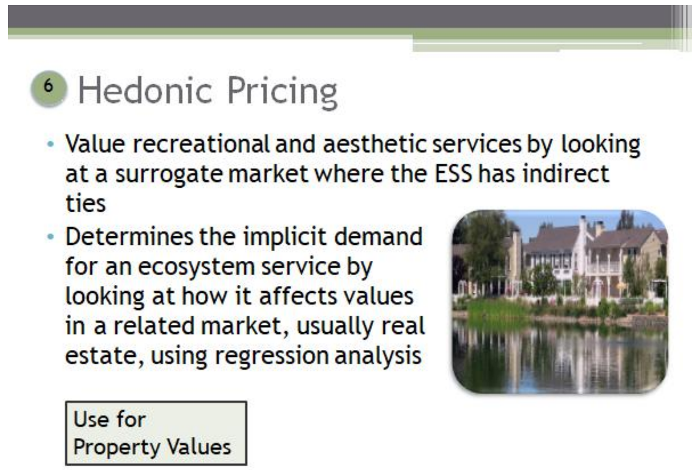
5. Direct Market Price

A subset of cost-based methods, market value looks at consumer spending to derive ES value. The *Direct Market Price* approach looks at the actual price of a commodity derived from an ecosystem (considered a provisioning ecosystem service or ecosystem good) in an existing market and determines the value of the ecosystem service based on the price that is paid by consumers multiplied by the marginal product of the service. This gives the economic value of the ecosystem service. For example, the pounds of shrimp per year harvested from Galveston Bay could be multiplied by the price per pound consumers pay for them, and this result would be multiplied by the marginal product of the shrimp to give a value for the bay in terms of how much shrimp is harvested from it each year. This method does not take into account any of the other ecosystem services being provided by the ecosystem, but it is a good way to obtain a partial valuation of an ecosystem because it uses an economically accurate marker. Sometimes it is not possible to value an ecosystem service using a method that relies on direct market ties. Recreational and aesthetic values can be determined by using a surrogate market where the ecosystem service has indirect ties to activities like fishing, birding, leaf peeping, or spring bloom.



6. Hedonic Pricing

One method that uses a surrogate market is *Hedonic Pricing*, which determines the implicit demand for an ecosystem service by looking at how it affects a related market. For example, a real estate market can be examined using regression analysis to determine how the proximity of properties to a natural forest affects property values. The increase in property value that is associated with an ecosystem gives a monetary value to the aesthetic or recreational benefits that the ecosystem provides, which otherwise do not have a direct place in the market. There are other methods that use a simulated market to determine ecosystem service values. These methods primarily use surveys to determine how much value people place on ecosystem services by giving them hypothetical situations where they choose dollar amounts for how much they would be willing to pay to preserve an ecosystem service or how much they would accept as compensation if the service was lost.



7. Stated Preference

Stated Preference approaches simulate a market for ecosystem services through surveys. These methods can be used when no market or surrogate market exists for the ecosystem service. The Contingent Valuation method uses questionnaires that ask how much people are willing to pay to protect or enhance the ecosystem service, or how much they would be willing to accept to compensate for its loss.

In some cases, the best approach capable of generating estimates of value are scientifically-based survey (stated preference) methods. The most commonly used stated preference method is contingent valuation, in which respondents are asked whether they would be willing to pay a specified amount for some environmental amenity. By varying the size of the payment amount across different respondents, one can trace out the demand curve for the environmental amenity and estimate the mean willingness to pay of people in the sample for that amenity.

Other valuation methods include the Revealed Preference approaches to ES valuation which use observations of individual choices in existing markets that are related to the ecosystem service being valued similar to Hedonic Pricing. The Travel Cost Method determines monetary values of biodiversity and ecosystem services based on the amount of money and time people spend on recreational experiences in an ecosystem.

VI. Frequently Asked Questions

1. If I know what ES goal that I want to measure, then do I need to follow all the steps?

The Steps are designed for as much or as little analysis the Primer user (decision maker) is interested in considering while looking at ES benefits for various nature-based infrastructure opportunities.

2. Where do cultural ES fit into the analysis?

Cultural ecosystem services are the non-material benefits that people obtain from ecosystems through recreation, tourism, intellectual development, spiritual enrichment, reflection and creative and aesthetic experiences. These ES benefits fit into all goals analysis that involve public access to nature-based infrastructure.

3. **How do you introduce ecosystem services and green infrastructure alternatives to decision makers and municipal leadership?**

Various communication sources and education through workshops/forums/presentations that provide information and case studies, such as this Primer, are good ways to inform leaders on ES benefits and goals analysis.

4. **Are there market trends that are associated with the incorporation of ecosystem services into infrastructure decisions?**

There are a growing number of market trends associated with ES improvements in nature-based infrastructure decision-making. The GreenBiz article, *The market for payment for ecosystems services is growing up*, by Anne Thiel, Friday, June 15, 2018 provides a good synopsis of current market trends: https://www.greenbiz.com/article/market-payment-ecosystems-services-growing

REFERENCES

Alan Plummer Associates, Inc. 2013. George W. Shannon Wetland Water Reuse Facility. Retrieved July 20, 2015 from http://www.apaienv.com/?post_type=portfolio&p=873.

American Forests. Dec 2012. Urban Ecosystem Analysis for the Houston Gulf Coast Region: Calculating the Value of Nature. Retrieved 27 July, 2015 from http://www.systemecology.com/4_Past_Projects/AF_Houston.pdf.

Biltonen E., G. Biddinger, R. Bernknopf, J. Lester, D. Saah, D. Yoskowitz, K. Bagstad, M. Russell, J. Woodrow. J. Taebel, and J. Jacob. December 2011. White Paper The Valuation of Ecosystem Services with Relevance to the Lower Galveston Bay Watershed. HARC, TCEQ.

Burkhard B, Maes J (Eds) (2017) Mapping Ecosystem Services. Advanced Books. https://doi.org/10.3897/ab.e12837.

Campbell, E. T. and Tilley, D. R. Oct. 2013. Valuing Ecosystem Services from Maryland Forests Using Environmental Accounting. Elsevier: Ecosystem Services 7 (2014) 141-151. Retrieved from http://www.cep.ees.ufl.edu/emergy/documents/conferences/ERC07_2012/11_CampbellE.pdf.

Climate Science Special Report: NCA4 Volume I, published in 2017, at science2017.globalchange.gov.

Costanza R, de Groot RS, Sutton P, van der Ploeg S, Anderson SJ, Kubiszewski I, Farber S, Turner RK (2014) Changes in the global value of ecosystem services. Global Environmental Change 26: 152-158.

Costanza, R., O. Pérez-Maqueo, M. Luisa Martinez, P. Sutton, S.J. Anderson, and K. Mulder. June 2008. The Value of Coastal Wetlands for Hurricane Protection. Royal Swedish Academy of Sciences, Vol 37, No. 4. Retrieved July 1, 2015 from http://seagrant.noaa.gov/portals/0/documents/what_we_do/social_science/ss_tools_reports/value_hurricane_protection.pdf.

Davis, A., J. Blackburn, E. Jones. February 2014. The Texas Coastal Exchange. Severe Storm Prediction, Education, and Evacuation from Disasters (SSPEED) Center. Rice University. Retrieved from http://sspeed.rice.edu/sspeed/downloads/The_Texas_Coastal_Exchange_2014.pdf.

DiMuro, J. L., F. M. Guertin, R. K. Helling, J. L. Perkins, and S. Romer. 2014. A Financial and Environmental Analysis of Constructed Wetlands for Industrial Wastewater Treatment. Yale University. Journal of Industrial Ecology. 18:5. DOI: 10.1111/jiec.12129 Retrieved July 1, 2015 from http://onlinelibrary.wiley.com/doi/10.1111/jiec.12129/full.

Environmental Protection Agency (EPA). June 2007. National Estuary Program Coastal Condition Report Chapter 5: Gulf of Mexico National Estuary Program Coastal Condition, Galveston Bay Estuary Program. Retrieved from http://water.epa.gov/type/oceb/nep/upload/2007_05_09_oceans_nepccr_pdf_nepccr_nepccr_gom_partg.pdf.

Environmental Protection Agency (EPA). 20 March 2014. Mitigation Banking Factsheet. Retrieved

July 15, 2015 from http://water.epa.gov/lawsregs/guidance/wetlands/mitbanking.cfm.

Environmental Protection Agency (EPA). 13 March 2015. Summary of Clean Water Act. Retrieved May 20, 2015 from http://www2.epa.gov/laws-regulations/summary-clean-water-act.

Forbes, M., R. Doyle, A. Clapp, J. Yelderman, N. Enwright, and B. Hunter. May 2010. Final Report: Freshwater Wetland Functional Assessment Study. Baylor University and TCEQ. TCEQ Contract 582-7-77820. Retrieved July 7, 2105 from http://www.baylor.edu/content/services/document.php/119417.pdf.

Forest Trends, the Katoomba Group and UNEP. Payments for Ecosystem Services: Getting Started, A Primer. Nairobi: Publishing Services Section, UNON. 2008. Web. http://www.unep.org/pdf/PaymentsForEcosystemServices_en.pdf.

Harris County Flood Control District (HCFCD). 2010. Project Brays Overview. Retrieved July 22, 2015 from http://www.projectbrays.org/about.html.

Houston Chronicle, Sept. 6, 2017 - D. Wayne Klotz - water resources engineer, RPS Klotz Associates and former president of the American Society of Civil Engineers.

Houston-Galveston Area Council (H-GAC), *Our Great Region 2040*, 2010, http://www.ourregion.org/download/OurGreatRegion2040-FINAL.pdf.

Houston Public Media, Bayou Greenway Initiative Gets Grant to Complete Gaps in Trail, October 13, 2010, https://www.houstonpublicmedia.org/articles/news/newslab/2010/10/13/23552/bayou-greenway-initiative-gets-grant-to-complete-gaps-in-trail/.

Houston Wilderness. July 2015. Gulf-Houston Regional Conservation Plan Packet. Retrieved July 29, 2015 from http://houstonwilderness.org/gulf-houston-regional-conservation-plan/.

Houston Wilderness. 2015. Ecoregions. Retrieved August 17, 2015 from http://houstonwilderness.org/about-ecoregions/.

Houston Wilderness. 2015. Ecosystem services. Presentation. Retrieved August 17, 2015 from http://houstonwilderness.org/ecosystem-services/ .

Nathan F. Jones, Liba Pejchar, Joseph M. Kiesecker, The Energy Footprint: How Oil, Natural Gas, and Wind Energy Affect Land for Biodiversity and the Flow of Ecosystem Services, *BioScience*, Volume 65, Issue 3, March 2015, Pages 290–301, https://doi.org/10.1093/biosci/biu224.

Leach K, Grigg A, O'Connor B, April 2019, Common framework of natural capital assets for use in public and private sector decision making, Ecosystem Services, Vol. 36, 100899.

Logsdon, R.A. and Chaubey, I. (2013) A Quantitative Approach to Evaluating Ecosystem Services. Ecological Modelling, 257, 57-65, http://dx.doi.org/10.1016/j.ecolmodel.2013.02.009.

McDonald, E. T., A. H. Plummer, and J. M. Parks. (n.d.). East Fork Raw Water Supply Project: A Natural Success Story. 2012 Guidelines for Water Reuse. Retrieved from http://www.reclaimedwater.net/data/files/206.pdf.

Millennium Ecosystem Assessment. 2005. Ecosystems and Human Well-being: Synthesis. Island Press, Washington, DC. Retrieved June 1, 2015 from http://www.millenniumassessment.org/documents/document.356.aspx.pdf.

Minello, T. J., G. Matthews, P. A. Caldwell, and L.P. Rozas. Jan. 2008. Population and Production Estimates for Decapod Crustaceans in Wetlands of Galveston Bay, Texas. Transactions of the American Fisheries Society 137:129-146. DOI: 10.1577/T06-276.1 Retrieved June 29, 2015 from http://www.galvestonlab.sefsc.noaa.gov/publications/pdf/880.pdf.

Mohammad, B. A., Dietrich, E., & Beaudoin, F. (n.d.). Ecosystem Services Case Study: Clean Water Services Tualatin River, Washington. Retrieved July 7, 2015, from http://www.pdx.edu/sustainability/sites/www.pdx.edu.sustainability/files/CleanWaterServices_CaseStudy.pdf.

Muller, M. (n.d.). The New York City Watershed Whole Farm Program. Retrieved July 7, 2015 from http://www.iatp.org/files/New_York_City_Watershed_Whole_Farm_Program.htm.

National Agroforestry Center, https://www.fs.usda.gov/nac/buffers/guidelines/4_opportunities/11.html.

The New York City Watershed Whole Farm Program, Catskill Region, New York, https://www.iatp.org/sites/default/files/New_York_City_Watershed_Whole_Farm_Program.htm.

NYC Watershed Agricultural Council. Small Farms (Catskill/Delaware). Retrieved August 17, 2015 from http://www.nycwatershed.org/ag_smfarmscd.html.

Opaluch, J., T. Grigalunas, J. Diamantides, M. Mazzota, and R. Johnston. 1999. Recreational and Economic Values for the Pecionic Estuary System. Economic Analysis Inc. Retrieved June 15, 2015 from http://www.peconicestuary.org/reports/f53c82ee382e1c988058ee2ae8e47db855b1517e.pdf.

Pascual, U. and R. Mulradian et al. March 2010. The economics of valuing ecosystem services and biodiversity. The Economics of Ecosystems and Biodiversity: The Ecological and Economic Foundations. Retrieved June 1, 2015 from http://www.teebweb.org/wp-content/uploads/2013/04/D0-Chapter-5-The-economics-of-valuing-ecosystem-services-and-biodiversity.pdf.

Perrot-Maitre, D. Sept. 2006. The Vittel payments for ecosystem services: a “perfect” PES case? International Institute for Environment and Development. Retrieved 28 July, 2015 from http://pubs.iied.org/pdfs/G00388.pdf .

S. K. Pattanayak S.K,, Kramer R.A., Vincent J.R., April 24, 2017, Ecosystem change and human health: implementation economics and policy, The Royal Society, Volume 372Issue 1722. https://doi.org/10.1098/rstb.2016.0130.

Donatella Porrini (2011). The (potential) role of insurance sector in climate change economic policies. Environmental Economics, 2(1).

M, Frantzeskaki N, Kabisch N, Nov. 2017, A Framework for assessing and implementing the co-benefits of nature-based solutions in urban areas, Environmental Science & Policy, pgs 15-24.

Sifleet S, Pendleton L, Murray BC. 2011. State of the Science on Coastal Blue Carbon: A Summary for Policy Makers. Durham, NC: Nicholas Institute for Environmental Policy Solutions. Retrieved June 15, 2015 from https://nicholasinstitute.duke.edu/sites/default/files/publications/state-of-science-coastal-blue-carbon-paper.pdf.

Nowak, David J.; Hirabayashi, Satoshi; Bodine, Allison; Hoehn, Robert, 2013, Modeled $PM_{2.5}$ Removal by Trees in Ten U.S. Cities and Associated Health Effects, Environmental Pollution. 178: 395-402; http://www.nrs.fs.fed.us/pubs/43676 (doi:10.1016/j.envpol.2013.03.050).

Texas A&M Galveston Campus. 2010. Galveston Bay Facts. Retrieved on May 15, 2015 from http://www.tamug.edu/gbic/gbicresources/bayfacts.html.

Texas Administrative Code, Title 30, Part 1 TCEQ, Chapter 293.41., Subchapter E

Texas Parks & Wildlife, Lance Robinson, Coastal Region 1 Director, Dickinson TX, Oysters in Texas Coastal Waters, https://tpwd.texas.gov/fishboat/fish/didyouknow/coastal/oysterarticle.phtml.

Texas Water Code, Sec. 49.4645. DISTRICT IN CERTAIN COUNTIES: BONDS FOR RECREATIONAL FACILITIES.

Tirpak, S., S. Willey, and J. Stokes. Coastal Texas Protection and Restoration Project. U.S. Corps of Engineers-Galveston. August 2014. Retrieved from http://www.swg.usace.army.mil/Portals/26/docs/PAO/0827%20Hou-Galv%20Coastal%20TX%20Public%20mtg%20August%2027%202014.pdf.

U.S. Army Corps of Engineers, Department of the Army, Department of Defense, and Environmental Protection Agency (EPA). 29 June 2015. Federal Register Vol. 80, No. 124. 80 FR 37053. Retrieved from http://www.gpo.gov/fdsys/pkg/FR-2015-06-29/pdf/2015-13435.pdf.

U.S. Fish & Wildlife Service (USFWS). 26 January 2015. The Migratory Bird Program-Conserving America's Birds. Retrieved from http://www.fws.gov/migratorybirds/newreportspublications/Flyways.html.

United Nations Environment Programme (UNEP). Millennium Ecosystem Assessment (MEA). 2005. Chapter 2: Ecosystems and their Services. Page 57. Retrieved from http://www.unep.org/maweb/documents/document.300.aspx.pdf.

Walls, M. and Riddle A. Feb. 2012. Biodiversity, Ecosystem Services, and Land Use: Comparing Three Federal Policies. Resources for the Future: RFF DP 12-08. Retrieved from http://www.rff.org/RFF/Documents/RFF-DP-12-08.pdf.

William & Mary's Virginia Institute of Marine Science (VIMS), Sea-level report cards: 2019 data adds to trend in acceleration, February 2020, https://www.vims.edu/newsandevents/topstories/2020/slrc_2019.php.

Wilson, M. A. and J. P. Hoehn. Aug. 2006. Valuing environmental goods and services using benefit transfer: The state of the art and science. Elsevier: Ecological Economics (60) 335-342. Retrieved 27 July, 2015 from https://doi.org/10.1016/j.ecolecon.2006.08.015.

Wu Jianguo, Encyclopedia Britannica, Dec. 17, 2019, Patch dynamics, ECOLOGY.

Zarate Barrera TG, Maldonado JH. 2015. Valuing Blue Carbon: Carbon Sequestration Benefits Provided by the Marine Protected Areas in Colombia. PLoS ONE 10(5): e0126627. DOI:10.1371/journal.pone.0126627 Retrieved June 15, 2015 from http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0126627.

APPENDIX A

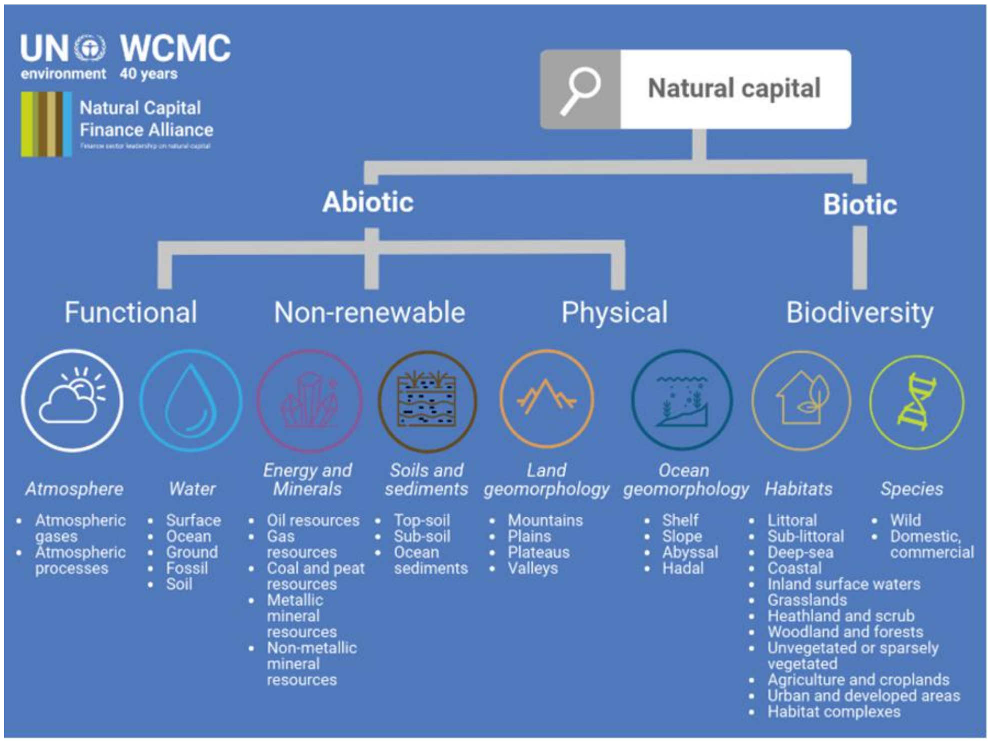
The tables below show the overall structure of CICES V5.1 for the upper three tiers in the part of the classification that covers **biotic and abiotic ecosystem outputs** (i.e. those dependent on living organisms):

BIOTIC ecosystem outputs		
Section	Division	Group
Provisioning (Biotic)	Biomass	Cultivated terrestrial plants for nutrition, materials or energy
Provisioning (Biotic)	Biomass	Cultivated aquatic plants for nutrition, materials or energy
Provisioning (Biotic)	Biomass	Reared animals for nutrition, materials or energy
Provisioning (Biotic)	Biomass	Reared aquatic animals for nutrition, materials or energy
Provisioning (Biotic)	Biomass	Wild plants (terrestrial and aquatic) for nutrition, materials or energy
Provisioning (Biotic)	Biomass	Wild animals (terrestrial and aquatic) for nutrition, materials or energy
Provisioning (Biotic)	Genetic material from all biota (including seed, spore or gamete production)	Genetic material from plants, algae or fungi
Provisioning (Biotic)	Genetic material from all biota (including seed, spore or gamete production)	Genetic material from animals
Provisioning (Biotic)	Other types of provisioning service from biotic sources	Other
Provisioning (Abiotic)	Water	Surface water used for nutrition, materials or energy
Provisioning (Abiotic)	Water	Ground water for used for nutrition, materials or energy
Provisioning (Abiotic)	Water	Other aqueous ecosystem outputs
Regulation & Maintenance (Biotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of wastes or toxic substances of anthropogenic origin by living processes
Regulation & Maintenance (Biotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of nuisances of anthropogenic origin
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Pest and disease control
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Regulation of soil quality
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Water conditions
Regulation & Maintenance (Biotic)	Regulation of physical, chemical, biological conditions	Atmospheric composition and conditions
Regulation & Maintenance (Biotic)	Other types of regulation and maintenance service by living processes	Other
Cultural (Biotic)	Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	Physical and experiential interactions with natural environment
Cultural (Biotic)	Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	Intellectual and representative interactions with natural environment
Cultural (Biotic)	Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting	Spiritual, symbolic and other interactions with natural environment
Cultural (Biotic)	Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting	Other biotic characteristics that have a non-use value
Cultural (Biotic)	Other characteristics of living systems that have cultural significance	Other

ABIOTIC ecosystem outputs		
Section	Division	Group
Provisioning (Abiotic)	Water	Surface water used for nutrition, materials or energy
Provisioning (Abiotic)	Water	Ground water for used for nutrition, materials or energy
Provisioning (Abiotic)	Water	Other aqueous ecosystem outputs
Provisioning (Abiotic)	Non-aqueous natural abiotic ecosystem outputs	Mineral substances used for nutrition, materials or energy
Provisioning (Abiotic)	Non-aqueous natural abiotic ecosystem outputs	Non-mineral substances or ecosystem properties used for nutrition, materials or energy
Provisioning (Abiotic)	Non-aqueous natural abiotic ecosystem outputs	Other mineral or non-mineral substances or ecosystem properties used for nutrition, materials or energy
Regulation & Maintenance (Abiotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of waste, toxics and other nuisances by non-living processes
Regulation & Maintenance (Abiotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of nuisances of anthropogenic origin
Regulation & Maintenance (Abiotic)	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events
Regulation & Maintenance (Abiotic)	Regulation of physical, chemical, biological conditions	Maintenance of physical, chemical, abiotic conditions
Regulation & Maintenance (Abiotic)	Other type of regulation and maintenance service by abiotic processes	Other
Cultural (Abiotic)	Direct, in-situ and outdoor interactions with natural physical systems that depend on presence in the environmental setting	Physical and experiential interactions with natural abiotic components of the environment
Cultural (Abiotic)	Direct, in-situ and outdoor interactions with natural physical systems that depend on presence in the environmental setting	Intellectual and representative interactions with abiotic components of the natural environment
Cultural (Abiotic)	Indirect, remote, often indoor interactions with physical systems that do not require presence in the environmental setting	Spiritual, symbolic and other interactions with the abiotic components of the natural environment
Cultural (Abiotic)	Indirect, remote, often indoor interactions with physical systems that do not require presence in the environmental setting	Other abiotic characteristics that have a non-use value
Cultural (Abiotic)	Other abiotic characteristics of nature that have cultural significance	Other

https://cices.eu/cices-structure/

The table below illustrates the recent updates to the Ecosystem Services Capital Asset Classification System that streamlines existing ES classification approaches to create a system that is practical for decision makers across public and private sectors. Leach K, Grigg A, O'Connor B, April 2019, Common framework of natural capital assets for use in public and private sector decision making, Ecosystem Services, Vol. 36, 100899, https://www.sciencedirect.com/science/article/pii/S221204161730815X.



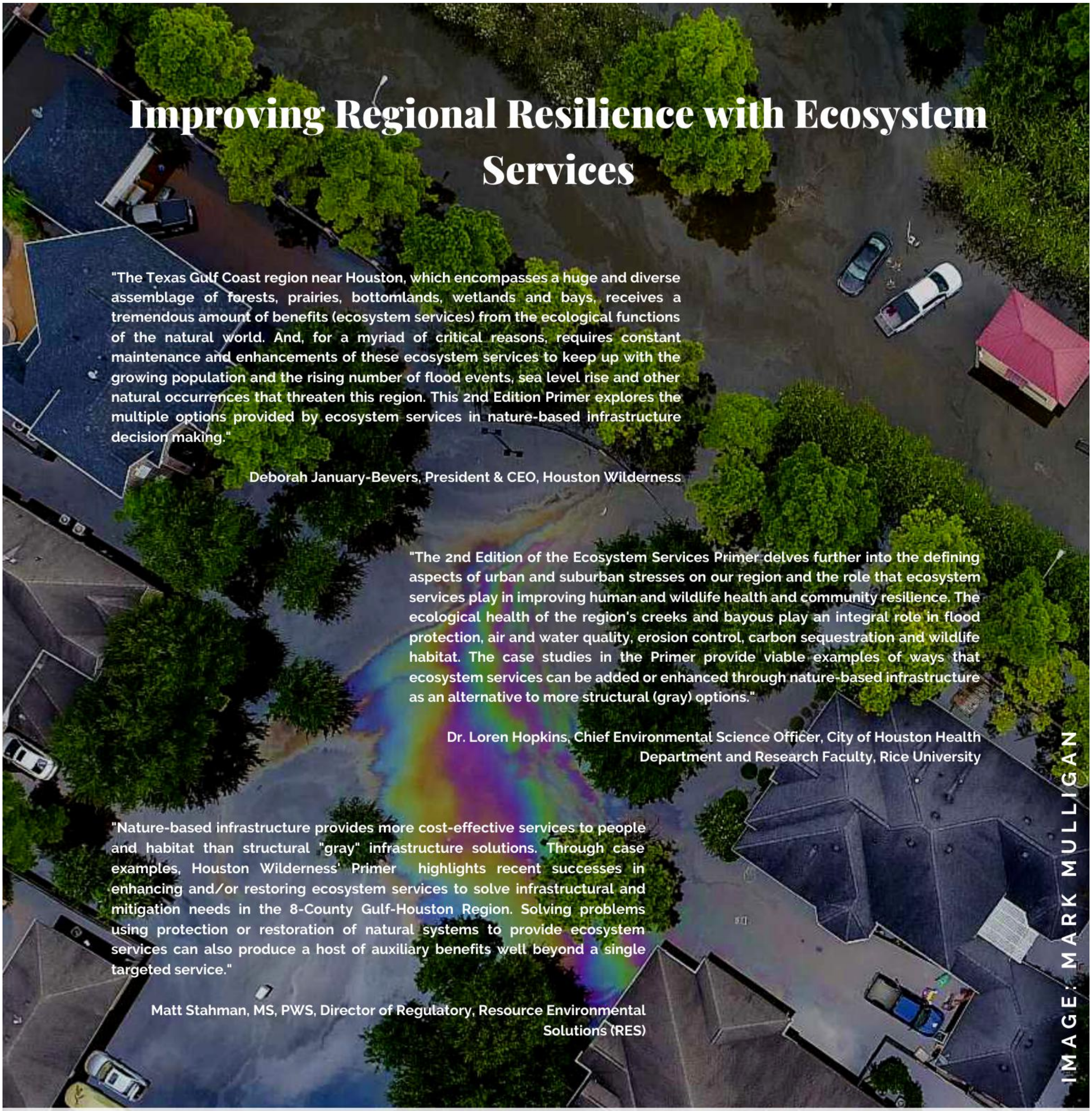


IMAGE: MARK MULLIGAN

Improving Regional Resilience with Ecosystem Services

"The Texas Gulf Coast region near Houston, which encompasses a huge and diverse assemblage of forests, prairies, bottomlands, wetlands and bays, receives a tremendous amount of benefits (ecosystem services) from the ecological functions of the natural world. And, for a myriad of critical reasons, requires constant maintenance and enhancements of these ecosystem services to keep up with the growing population and the rising number of flood events, sea level rise and other natural occurrences that threaten this region. This 2nd Edition Primer explores the multiple options provided by ecosystem services in nature-based infrastructure decision making."

Deborah January-Bevers, President & CEO, Houston Wilderness

"The 2nd Edition of the Ecosystem Services Primer delves further into the defining aspects of urban and suburban stresses on our region and the role that ecosystem services play in improving human and wildlife health and community resilience. The ecological health of the region's creeks and bayous play an integral role in flood protection, air and water quality, erosion control, carbon sequestration and wildlife habitat. The case studies in the Primer provide viable examples of ways that ecosystem services can be added or enhanced through nature-based infrastructure as an alternative to more structural (gray) options."

Dr. Loren Hopkins, Chief Environmental Science Officer, City of Houston Health Department and Research Faculty, Rice University

"Nature-based infrastructure provides more cost-effective services to people and habitat than structural "gray" infrastructure solutions. Through case examples, Houston Wilderness' Primer highlights recent successes in enhancing and/or restoring ecosystem services to solve infrastructural and mitigation needs in the 8-County Gulf-Houston Region. Solving problems using protection or restoration of natural systems to provide ecosystem services can also produce a host of auxiliary benefits well beyond a single targeted service."

Matt Stahman, MS, PWS, Director of Regulatory, Resource Environmental Solutions (RES)

Key Ecosystem Services

- **Natural Resources**
- **Water Supply**
- **Property values**
- **Habitat**
- **Air Quality & Urban Heat Island**
- **Stormwater Protection**
- **Carbon Sequestration**
- **Recreation**
- **Energy Savings**
- **Erosion Control**
- **Water Quality**