Houston Parks Board, Riparian Restoration and Best Management Practices

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AUTHORS

Emily Manderson
Principal / Senior Environmental Designer

Michelle Bertelsen
Principal / Senior Ecologist

John Hart Asher II
Principal / Senior Environmental Designer

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This Riparian Restoration Best Management Practice is meant to provide a framework for restoration practices and principles. All BMPs created with this endeavor provide a foundation that will promote continuity for all staff and ensure a cohesive approach on future ecological restoration work. This serves as a land management document providing an initial restoration toolbox. The BMPs are broad recommendations and should be viewed as starting the process for landscape restoration, but they are by no means an exhaustive list of tasks. Every site is unique, and it will be up to the discretion of the conservation team to implement these BMPs in the most appropriate way given the conditions. Some work, like the incorporation of large woody debris, will require consultation with outside expertise. The Harris County Flood Control District's, *Stream Stabilization Handbook: A Guide for Harris County Landowners,* will serve as an invaluable resource when dealing with specific challenges of erosion and streambank stabilization. This BMP is a living document that will be updated overtime as the Houston Parks Board (HPB) learns more through implementation and management.

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I. Background

A. Riparian BMP topic overview

- Ecological context and definitions
- Value and ecosystem services
- Sustainable development
- Site assessment
- Long-term monitoring
- Design
- Installation
- Establishment & Maintenance
- References

B. Ecological Context and Definitions

Riparian areas are lands that occur along watercourses and water bodies. They are distinctly different from surrounding lands because of unique soil and vegetation characteristics that are strongly influenced by the presence of water. Riparian areas play several critical ecological roles. Riparian areas provide streambank stabilization and filter water, removing excess nutrients and sediment from surface runoff and shallow groundwater, thus protecting waterways. Riparian areas provide unique terrestrial habitats, often acting as wildlife corridors and improve in-stream habitat by cooling the water and providing organic matter. Riparian areas are defined by suites of indicator species of vegetation, characteristic soils, and the presence of plant-available surfaces and subsurface water.[1]

Riparian Buffer

Riparian buffers are vegetated zones adjacent to streams and wetlands that represent a best management practice (BMP) for controlling nutrients entering water bodies[2]. Buffer width is positively related to effectiveness in cleansing water. Proper design, placement, and protection of buffers is also critical to effectiveness.

Bottomland Hardwood

Bottomland hardwood is an important community type often occupying first and second terraces of river floodplains, low areas, seepages, and areas along river or creek channels. Hydrology is primarily responsible for development of these bottomland forests. Bottomland forests require presence of water; floodwater periodically or permanently inundates the soil and can create anaerobic conditions. Due to their high productivity, high diversity, and location near water resources, bottomland hardwood forest are important wildlife resources[3].

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[1] USDA NRCS. https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/technical/?cid=nrcs143_014199

[2] EPA. 2005. Riparian buffer width, vegetative cover, and nitrogen removal effectiveness. https://www.epa.gov/sites/default/files/2019-02/documents/riparian-buffer-width-2005.pdf

[3] Liui et al. An analysis of bottomland hardwood areas at three proposed reservoir sites in Northeast Texas. Final Report to Texas Water Development Board for the fulfillment of interagency agreement No. 97-483-211. https://tpwd.texas.gov/publications/pwdpubs/pwd_rp_t3200_1057a/index.phtml

Wetlands

"Wetlands are areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas."[4]

Vernal Pools

Microtopographic depressions that possess seasonal shallow water. These ephemeral wetlands can contain water from fall to spring but become dry during the driest and hottest parts of the year or during drought conditions. These pools can be found in grasslands or within floodplains. Moreover, several vernal pools can be connected to one another by swales. Depending upon the climate, vernal pools can empty and fill several times a year or remain dry for many years. "The unique environment of vernal pools provides habitat for numerous rare plants and animals that are able to survive and thrive in these harsh conditions."[5] This information is particularly important when restoring both riparian and upland communities because we often think of these communities as separate and distinct, but vernal pools act as hybrid entities that can support dry and wet species. Incorporating minimal changes into soil elevations in upland components and along riparian buffers creates the opportunity for habitat restoration that promotes greater diversity of gulf coast plain upland (UPL), facultative upland (FACU), facultative (FAC), and facultative wetland (FACW) communities.

C. Texas Riparian Ecosystems

Twenty percent of riparian bottomland forest ecosystems have been lost in the southern states since 1950 (Kellison and Young 1997 as cited in Holcomb 2001), and by 1986, over one-half million acres have been inundated by reservoirs in Texas (McMahan 1986 as cited in Holcomb 2001). The diversity of plant and animal species found in functioning bottomland forests is unparalleled among other ecosystem types throughout the lower 48 United States (Kellison and Young 1997 as cited in Holcomb 2001). It is important to understand that this species richness and diversity resulted from the convergence of wetland and upland associations. In fact, the U.S. Army Corps of Engineers (USACE), the Environmental Protection Agency (EPA), the U.S. Fish and Wildlife Service (USFWS), and the Natural Resources Conservation Service (NCRS) have expanded their wetland definition criteria to include bottomland hardwood forests (Kellison and Young 1997 as cited in Holcomb 2001).

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[4] Definition as utilized by United States Army Corps of Engineers (USACE) and the United States Environmental Protection Agency (EPA)

[5] Definition provided by United States Environmental Protection Agency (EPA)

Riparian Vegetation

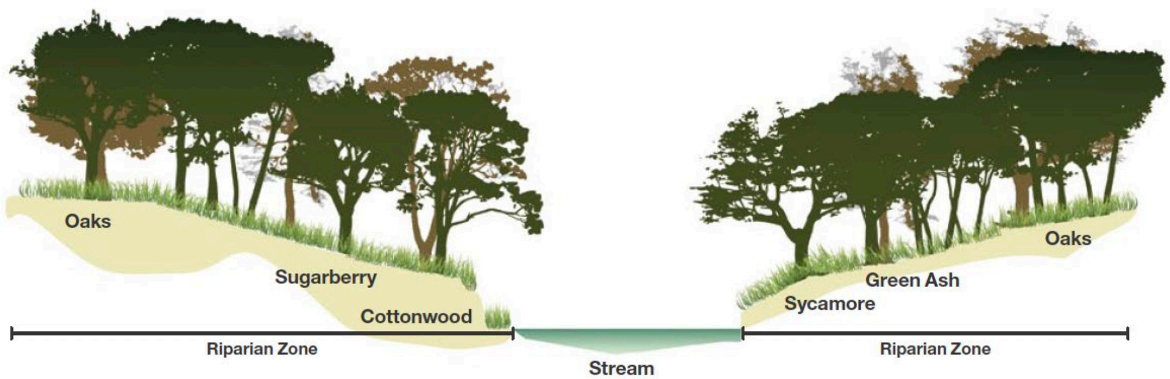

Figure 1. Houston Riparian Habitat Communities
Source: Harris County Flood Control District, *Streambank Stabilization Handbook: A Guide for Harris County Landowners, 2015*. This image above shows the various plant communities that are responsible for streambank stability and water quality. Streambank stabilization is maintained by riparian vegetation and this vegetation also provides organic input into the stream. Native vegetation improves water quality by intercepting runoff, retaining sediment, removing pollutants, and promoting groundwater recharge. Flood control is created by the floodplain's ability to intercept water and reduce peak flows. Riparian buffers support diverse vegetation and provide food and shelter for riparian and aquatic wildlife.

The health of Texas' rivers, streams, and creeks are important contributors to the overall environmental and human health of urban areas. Many of these ecosystems are threatened by non-point pollution, invasive plant growth, degraded/paved watersheds, and the channelization of streams, thus impacting or eliminating beneficial ecosystem services (Allan et al. 1997, Strayer et al. 2003, Townsend et al. 2003). Riparian areas perform essential hydrological and biological functions, including flood control, surface water storage, ground water supply recharge, and biological diversity (Dickson 1989, Gregory 1991, Williams et al. 1997). Vegetation in riparian corridors act as a filter, trapping sediment, organics, excess nutrients, and pollutants from parking lots, roads, residences, and commercial lot surface runoff, thus improving water quality (Lowrance et al. 1984, Henley et al. 2000).

Riparian areas are complex ecosystems that contain vital habitat for numerous species. The vegetation not only prevents erosion, but also provides food (Halls 1973), cover (Burk et al. 1990, Halls 1973), and breeding habitat for bird, amphibian, mammal (Dickson and Huntley 1987), fish, and reptile species (Rudolph and Dickson 1990, Brode and Bury 1984). Live trees, dead trees (large woody debris), branches, and leaves falling from riparian edges into the water provide habitat for aquatic organisms (Maser and Sedell 1994) and help build soil by slowing water flows. Removal of this cover results in a reduction in biodiversity and ecosystem services.

D. Houston Riparian Trees and Canopy Conditions

Texas has recorded some of the most intense rainfall in the world with some singular events depositing over 40" – 50". However, the state also experiences extended periods of drought. This climatic dichotomy results in a unique topographical system that includes floodplain and terraces formed from older floodplains (Wharton et al., 1982 as cited in Holcomb 2001). Forests in the floodplain are subject to flooding and the accompanying sediment deposition (Hodges, 1997 as cited in Holcomb 2001). The profile of these areas is characterized by a series of small ridges, flats, and sloughs, which influence water retention, sediment deposition, and soil texture (Hodges, 1997 as cited in Holcomb 2001). Species composition also varies with the topography as you move from mid-river to upland (Holcomb 2001). The key to the resilience and bank stability provided by riparian vegetation is that the community consists of a diverse mix of overstory, understory, and herbaceous species. Together, these three layers create a remarkably strong, interlocking matrix, not unlike bones and connective tissue. Typical dominant riparian woody species in the Houston area include:

- Pecan
- Little Walnut
- Black Willow
- Bald Cypress
- Ash species
- Gum species
- Hickory
- Cottonwood
- Oak
- Elm species
- Sycamore

Upland components include less water-tolerant species (e.g., loblolly pine, elm, hackberry, and live oak) growing on the ridges; facultative wetland species (e.g., bald cypress, American sycamore, cottonwood, water tupelo) in the sloughs; and mixtures of both types, as well as facultative upland species (e.g., green ash) on the flats (Hodges, 1997 as cited in Holcomb 2001).

Houston's forests tended to occur in riparian habitat lining the bayous or in the eastern portion of the city where soils and microtopography created residual soil moisture. The greatest diversity of woody species occurred within this riparian habitat. Most of the historic riparian edges and buffers have been degraded or completely destroyed due to logging, urbanization, and stream channelization. Most riparian zones that have not been destroyed are heavily impacted by invasive species or native vegetation which exists in thickets, minimizing overall biodiversity. Riparian restoration involves either completely recreating historical reference canopy conditions from scratch or by enhancing existing, less diverse wooded sites by removing invasive species and replanting a diverse mix of overstory, understory, and herbaceous components. Site specific conditions will ultimately drive the Houston Parks Board staff's approach to achieve desired outcomes.

E. Riparian Upland Associations

Even though the focus of this section is bottomland areas immediately adjacent to bayous and creeks, the upland areas are linked to and extremely important to, riparian health. Many times, these zones are thought as distinct components that are unrelated to one another, but this is a mistake. Upland components contribute organic matter that is essential to riparian health. Additionally, Houston Parks Board staff could have a project where upland, riparian, and wetland components are present as a heterogenous patch mosaic assemblage. In this case, staff should think of these projects/properties as a singular system and design the plant communities to strengthen overall habitat potential and ecosystem function. Soil analysis and historic soil survey data will help define specific zones and species choices.

Historically, much of the Houston area was covered in coastal prairie habitat with little or no woody growth due to the same wildfire and high intensity/low frequency grazing with other natural disturbances that occurred over approximately 129,000,000 acres of Texas grasslands. Houston uplands that did feature trees possessed sparse woody components, 2-3 large canopy trees per acre, or a matrix of longleaf pine (*Pinus* palustris) or loblolly pine (*Pinus taeda*) positioned within a diverse grassland-dominant matrix. This matrix would likely include the following USDA ecological sites, all of which featured Coastal Prairie species[6]:

- Clayey flat
- Lowland
- Northern Blackland
- Sandy Prairie
- Seasonally Wet Loamy Upland
- Southern Blackland
- Northern Loamy Prairie
- Loamy Bottomland
- Well Drained Loamy Upland

While many of the prairie species are associated mainly with drier upland soils, and although they are not directly affected by the bayou flows, they do possess microtopographic vernal pools that are vital for facultative upland and even some wetland plant species. Therefore, in a broader sense, upland communities should be considered an important contributor to riparian health and function (Miller et. Al. 2009, Gregory et al. 1991). Grassland species also play an important role in controlling sheet flow runoff and into receiving waterways during intense rain events, reducing flood severity. Grass and broadleaf plants in these areas historically included species such as:

Grasses[7]

- Purpletop (*Tridens flavus*)
- Sideoats grama (*Bouteloua curtipendula*)
- Virginia wildrye (Elymus virginicus)
- Canada wildrye (Elymus canadensis)
- Eastern gamagrass (Tripsacum dactyloides)
- Longleaf wood oats (Chasmanthium sessiliflorum)
- Little bluestem (Schizachyrium scoparium)

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[6] Table with Ecological sites descriptors located at end of document.
[7] Source Texas Parks and Wildlife

- Indiangrass (Sorghastrum nutans)
- Brownseed paspalum (Paspalum plicatulum)
- Switchgrass (Panicum virgatum)
- Big bluestem (Andropogon gerardii)
- Tall dropseed (Sporobolus compositus)
- Thin paspalum (Paspalum setaceum)
- Hairy fimbry (Fimbristylis puberula)
- Fewflower panicgrass (Dichanthelium oligosanthes)
- Beaksedges (Rhynchospora spp.)
- Florida paspalum (Paspalum floridanum)
- Gulf muhly (Muhlenbergia capillaris)
- Longspike tridens (Tridens strictus)
- Bushy bluestem (Andropogon glomeratus)
- Carpetgrasses (Axonopus spp.)
- Rat-tail smutgrass (Sporobolus indicus)
- Broomsedge bluestem (Andropogon virginicus)
- Silver bluestem (Bothriochloa laguroides ssp. Torreyana)
- Texas wintergrass (Nassella leucotricha)

Forbs[8]

- wild onion (Allium canadense)
- Drummond's wild onion (Allium drummondii)
- black-eyed Susan (Rudbeckia hirta)
- Gayfeathers (Liatris spp.)
- Meadow pink (Sabatia campestris)
- Western ragweed (Ambrosia psilostachya)
- Snow-on-the-prairie (Euphorbia bicolor)
- Goldenrods (Solidago spp.)
- Green milkweed (Asclepias viridis)
- Partridge pea (Chamaecrista fasciculata)
- Narrowleaf sunflower (Helianthus angustifolius)
- Goldentops (Euthamia spp.)
- Mexican hat (Ratibida columnifera)
- Heath aster (Symphyotrichum ericoides)
- Compass plant (Silphium laciniatum)
- Wild indigos (Baptisia spp.)
- Narrowleaf sumpweed (Iva angustifolia)
- Rattlesnake master (Eryngium yuccifolium)
- Smallhead doll's daisy (Boltonia diffusa)

[8] Source Texas Parks and Wildlife

- Yellow neptunia (Neptunia lutea)
- pigeonberry (Rivina humilis)
- tropical sage (Salvia coccinea)

Soil surveys can contain a diverse range of soil types based on the presence of clay, loam, and sand with some associations featuring combined variations of these three main textural groups. Site soil conditions will determine the appropriate plant compositions for properties located along the bayous. However, current urban soils and urban stream sediment may have little to do with older survey data, and urban soils can include anthropogenic components (e.g., asphalt, concrete, plastic litter) that dramatically differs from USDA data. Houston Parks Board staff will need to verify existing soil conditions on each site.

Given that many bayous cannot be returned to historic woody conditions due to necessary flood conveyance capability, herbaceous-dominated channels can feature native coastal prairie grasses and wildflowers. Harris County Flood Control District supports the inclusion of native grasses and forbs to promote biodiversity, beauty, wildlife habitat, and sustainable maintenance practices. Grassland species anchor the soil during high flow events due to their extensive fibrous root systems and their ability to lie down and shield underlying soils during high flow flood events. In eroded areas soil depth, content, and compaction will be limiting factors for site recovery. Replanting efforts will likely require multiple seeding sessions as well as planting plugs of key species that usually do not appear until ecosystems have reached a stable state (USDA Soil Survey 1974).

Vegetation, especially on areas within the 100-yearfloodplain, should predominantly consist of the tall warm-season perennial bunchgrasses listed above. In areas where vegetation height is a concern, and frequent mowing is necessary, Houston Parks Board staff should consider central Texas midgrass species that might not represent historic coastal prairie. These species will still provide soil stability, can deal with drought deluge swings, and still provide good habitat value. Candidates for such areas could be:

- Little bluestem (Schizachyrium scoparium)
- Sideoats grama (Bouteloua curtipendula)
- Virginia wildrye (Elymus virginicus)
- Canada wildrye (Elymus canadensis)
- Vine mesquite (Panicum obtusum)
- Texas wintergrass (Nassella leucotricha)
- Texas cupgrass (Erichloa sericea),
- Green sprangletop (Leptochloa dubia)
- Dropseeds (Sporobolus spp.)
- White tridens (Triden albescens)
- Cutleaf daisy (Engelmannia peristenia)
- Pink evening primrose (Oenothera speciosa)
- Indian blanket (Gaillardia pulchella)

- Lemon mint (Monarda citriodora)
- Rattlesnake master (Eryngium yuccifolium)
- Prairie clover (Dalea spp.)
- Zizotes milkweed (Asclepias oenotheroides)
- Green milkweed (Asclepias viridis)
- Dotted gayfeather (Liatris punctata)
- Wild foxglove (Penstemon cobae)
- Gulf coast penstemon (Penstemon tenuis)
- Partridge pea (Chamaecrista fasciculata)

F. Value and Ecosystem services

Ecosystem Services

Ecosystem services are services that nature provides for free that humans rely on to live such as cleaning air and water, providing food, regulating temperatures, and improving mental health and wellness.

Riparian areas provide multiple benefits including:

- Help control nonpoint source pollution by holding and using nutrients, and reducing sediment load
- Supply food, cover, and water for a large diversity of wildlife
- Serve as migration routes and stopping points between habitats
- Stabilize streambanks and reduce floodwater velocity with mixed vegetation resulting in reduced downstream flood peaks
- Maintain base flow by means of alluvial aquifers in many rivers within humid areas because of high water tables.

G. Sustainable Development

Sustainable development protects and enhances ecological function while integrating it with human use. The following process (Figure 2) illustrates sustainable development and ecological restoration principles as pertains to riparian restoration and integration into Houston Park Board projects. Success requires a holistic approach. The timeline below outlines the general progression of activities for a project from consideration for acquisition through the initial stages of maintenance.

H. Project Sequencing

Restoration as a practice is a trajectory, which lacks a defined end point since the restoration process revolves around restoring ecosystem function and natural systems that have cycles of activity. In urban areas, it is always possible to experience vegetative failure no matter how long it has been established. This is due to the suppression of fire and grazing regimes, as well as the constant pressure from invasive species. Maintenance begins with site preparation and never ends; it evolves from establishment to an iterative process of adaptive management. Establishing the monitoring program as early as possible will also benefit the project flow and capacity to gather valuable information that will inform management decisions.

Adaptive management

Adaptive management is the process of incorporating new scientific and programmatic information into the implementation of a project or plan to ensure that the goals of the activity are being reached efficiently. It promotes flexible decision-making to modify existing activities or create new activities if new circumstances arise (e.g., new scientific information) or if projects are not meeting their goals.

- *Congressional Research Service Report R41671*

Adaptive management is a management approach that acknowledges uncertainty in ecological systems and reduces uncertainty by using a problem-solving management approach. The focus is on learning about the system and how to best change the system. The process for adaptive management is circular in nature starting with assessment, design, implementation, monitoring, evaluation, and adjusting. Adaptive management is a hybrid of management and research (Murrary and Marmorek 2003).

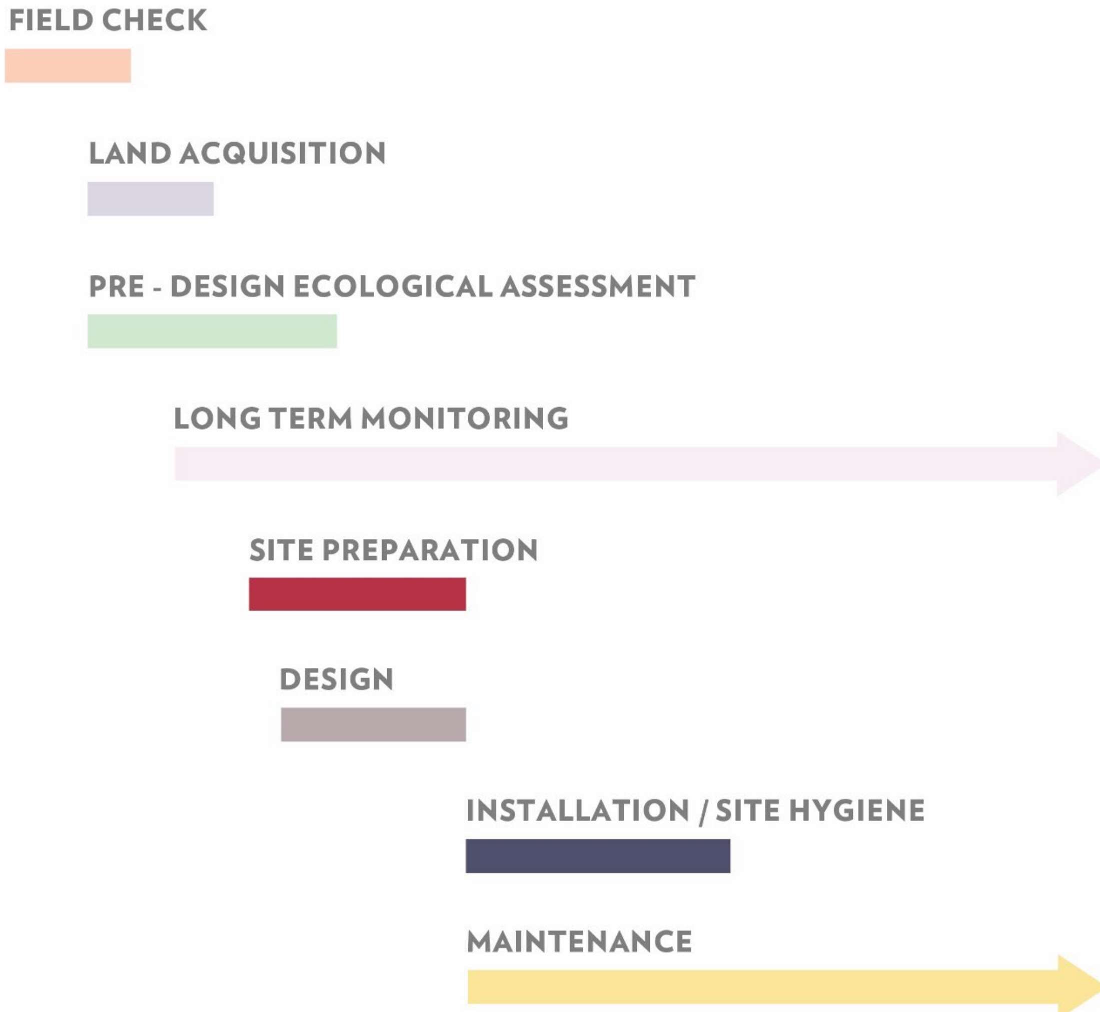

Figure 2. Project Sequencing and Major Milestones

Major questions and actions for each phase:

Pre-design

- What are the habitat and soil types and what condition is it in?
- What are the opportunities and performance goals?
- Are there special considerations/constraints for this site, social or ecological, that would shape planning?
- Identify nearby reference ecosystems that could be used for comparison

Metrics and Monitoring

- Set the program up early to get baseline data and have as thorough of data collection as possible.

Design

- Where is the optimal placement and layout for optimal ecosystem function and maintenance success?
- Understand potential permits necessary for work and permit approval timeline.

Site Preparation and Installation

- ***Scheduling enough time to prepare the site soils and gather plant materials***. Installing in an ideal sequence to vegetate as soon as possible.
- Maintain good site hygiene during installation.

Maintenance and Management

- Maintenance, especially controlling invasive species, start once site preparation begins and continues through maintenance and adaptive management.
- Monitoring of performance will inform management activities which is part of the adaptive management process.

I. Restoring landscapes

The restoration techniques mentioned in this BMP are designed to guide conservation staff in the process of repairing land or converting resource-intensive landscapes into areas that are both beautiful and best suited to perform ecosystem services. The species listed in this document evolved in disturbance-driven ecosystems that included wildfire and floods and are best adapted to contribute towards the recovery of ecosystem services. Houston Parks Board staff should note that the transition of a site from a degraded state dominated by invasive plant growth or severe erosion will be challenging and take a concerted effort that involves biotic and abiotic manipulation. Emphasis should be placed on the positive impacts from the restoration process rather than an end product. Minor disturbances in healthy, functioning ecosystems usually self-heal and return to a stable functioning state within a relatively small amount of time. However, such healthy systems are rare within or near urban and suburban areas because of significant alterations to natural processes, such as the water's movement through the landscape (hydrology), nutrient cycling (capture and utilization of soil nutrients), and soil health and organic matter production have resulted in an inability of the land to reset itself (Whisenant 2005).

During the restoration process. it is very likely that the best laid plans will face setbacks and that multiple efforts will be required to achieve success. Ecosystems are dynamic entities consisting of complicated networks of interconnected biotic and abiotic components. By slowing water and keeping it on site, incorporating native plantings in a system-based approach (not relegating plants to flower beds), and allowing tallgrass communities to thrive on parts of their property, conservation staff will make a major difference over time and help mitigate damage from future climatic events. This is not to say that restoration will completely prevent damage, but by embracing these measures, the residents of Houston will be able to enjoy a more diverse, healthy, and functional urban landscape and contribute towards an overall improvement of their urban habitats.

II. Site Assessment

When evaluating the site to determine the appropriate ecosystem, it is important to look at the historical ecological condition of the greater Houston area to use as a reference. Understanding the ecological condition at a regional scale informs the restoration target at a project level. The Houston region is one of the most diverse urban areas in the United States. Houston is also one of two cities in the United States to be classified as a "Hotspot" city that evaluates biodiversity and urban growth[9]. According to Houston Wilderness, ecological classifications in the Gulf-Houston Region are composed of ten ecoregions. Seven of the ecoregions are land-based and three are water-based (Figure 3). [Houston Wilderness] defines ecoregions as large areas of land or water that contain geographically distinct assemblages of species, natural communities, and environmental conditions.

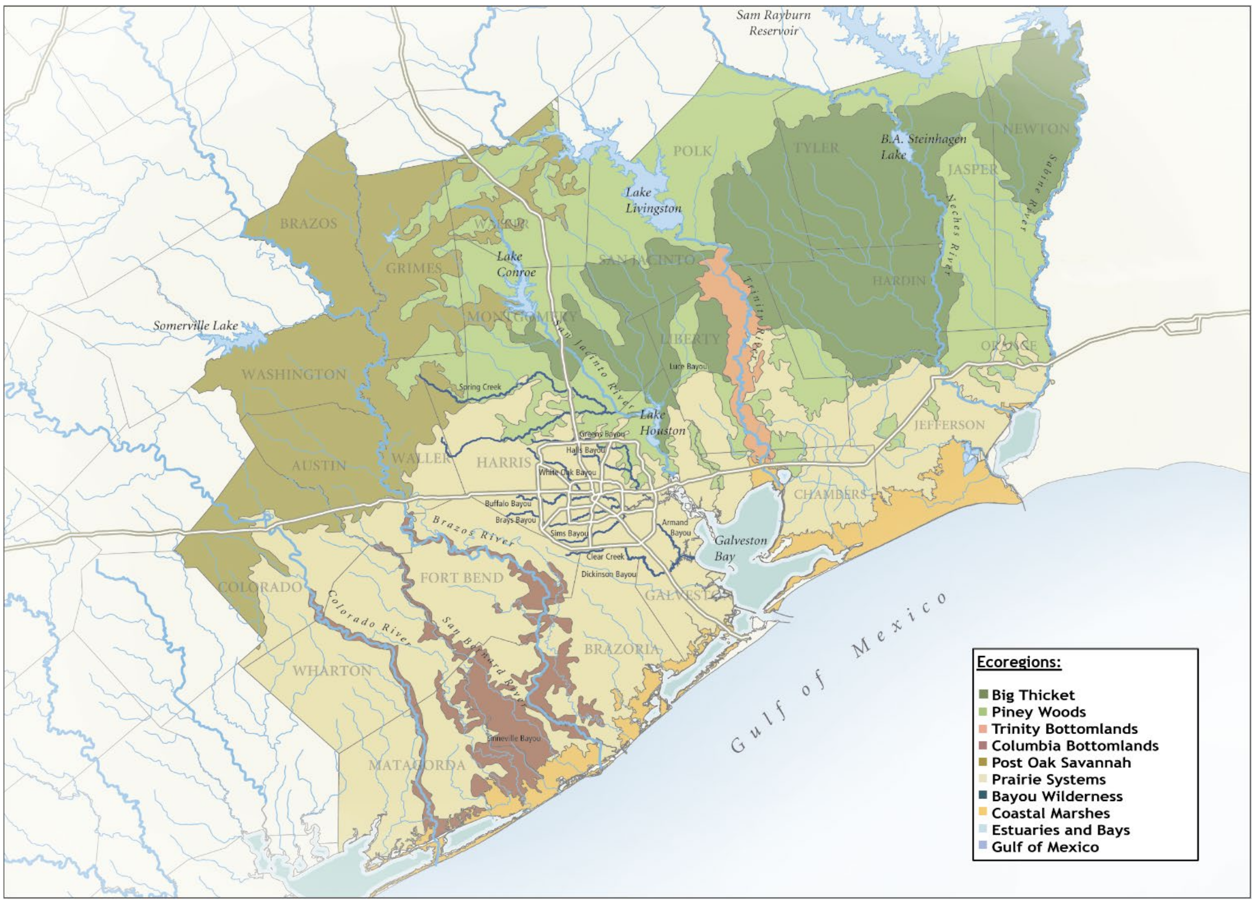

Figure 3. Houston area ecoregion map - Provided by Houston Wilderness

Based on the regional information, HPB conservation program is restoring and managing for 5 different habitat types that provide critical ecosystem services.*Ecosystem services are services that nature provides for free that we rely on to live such as cleaning air and water, providing food, regulating temperatures, and improving mental health and wellness.* These habitat types are prairie/savanna, forest, wetland, riparian, and native landscaping. Prairies were once the

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[9] https://hotspotcitiesproject.com/cities/houston

dominant ecosystem of the greater Houston region. Savanna and forest to the northeast, northwest, and along lower lying riparian areas is the second most significant ecosystem. Wetlands and riparian habitats (especially along the bayous) are dispersed throughout the landscape and play critical roles in mitigating flooding and improving water quality. Lastly, native landscapes are planted areas that are more horticulturally based but use native plant communities to help provide needed ecosystem services.

Protecting, restoring, and building ecological health requires a detailed understanding of the site's condition, its processes and how it is changing over time. Several types of site assessment are needed for different phases in a project from acquisition through maintenance. Three types of site assessment are needed for basic operations (field check, predesign ecological assessment, maintenance assessments). These assessments inform operational and maintenance decisions and track project status. Additionally, a long-term monitoring program is needed to track how the program is reaching conservation and HPB goals. The long-term monitoring program can also provide practical information to inform future restoration efforts within HPB and efforts of other conservation organizations. Table II.1 below summarizes the assessment types.

The field check, pre-design ecological assessment, and maintenance rapid assessment will be discussed in this section. The Monitoring Protocol will be discussed in its own section.

Table 1. Site assessment types

Type	Project Phase	Purpose	Data gathered
Field Check	Pre-acquisition	Gather preliminary data on habitat value to be considered during purchase decisions	Community type, basic structure, dominant species, presence/absence of ecological assets/liabilities
Pre-design ecological assessment	Pre-design	Evaluate current ecological condition and identify opportunities and issues to be considered during design	Ecological context, vegetation community structure and composition, soil condition, hydrologic/geomorphic condition.
Maintenance rapid assessment	Post installation, ongoing	Monitor project condition and identify maintenance needs	Plant health, invasive species presence/expansion, soil condition including erosional features
Monitoring protocol	Initiate prior to installation, repeat periodically for life of project	Evaluate contribution to Ecological goals, provide data on restoration evolution	Species use as habitat, soil condition, community complexity, species diversity, connectivity, heat mitigation.

A. Field Check

The Field Check occurs during the acquisition process. This is a high-level check intended to be performed during initial consideration of a property in coordination with Capital's initial assessment. The goal is to obtain a high-level understanding of the site's existing conditions, possible value, and liabilities from an ecological perspective. In addition to doing desk top analysis of the site with LiDAR data, aerial maps, and other sources to determine the sites natural history, it is important to assess the site on the ground. This is a quick fact-finding survey identifying the following parameters:

- Community Structure: Forest, Riparian, Savanna, Prairie, Wetland, Urban condition (% canopy)
- Dominant species in each layer
- Approximate percentage of invasive species, native species
- Presence of rare or valuable species/communities
- Presence of factors that will complicate restoration/management efforts such as severe erosion, substantial presence of invasive species, problematic adjacent properties etc.
- Presence of factors that will assist restoration/management efforts
- Presence/extent/severity of soil erosion

An example data sheet for a rapid assessment and erosion assessment is found in Appendix A: Data Sheets.

B. Pre-design Ecological Assessment

The predesign ecological assessment evaluates the site's current ecological condition and identifies opportunities for improving ecological health, sensitive features, and liabilities such as damaged soil and invasive species. It is important that this assessment occurs before design to ensure that planned restorations, as well as features such as paths and other amenities, are optimally placed within the landscape.

One of the main reasons for doing a Pre-Design Site Assessment is to assess the ecological condition of the site to determine challenges and opportunities. The diagram below illustrates how ecological function exists on a spectrum (Figure 4). To the left is a fully functional condition and to the right is a nonfunctional system such as a parking lot. Understanding where the project is on this spectrum during all phases of the project's life is valuable to informing management decisions. The goal is to continually move the project up the spectrum towards the left. However, a variety of scenarios could impact the site's function such as a delay in construction leaving areas unvegetated, an extreme weather event, or an insect infestation. Being able to assess where the project is on this spectrum pre-design through the life space of the project will help inform necessary steps for improving the site's ecological function through adaptive management.

ECOSYSTEM FUNCTION

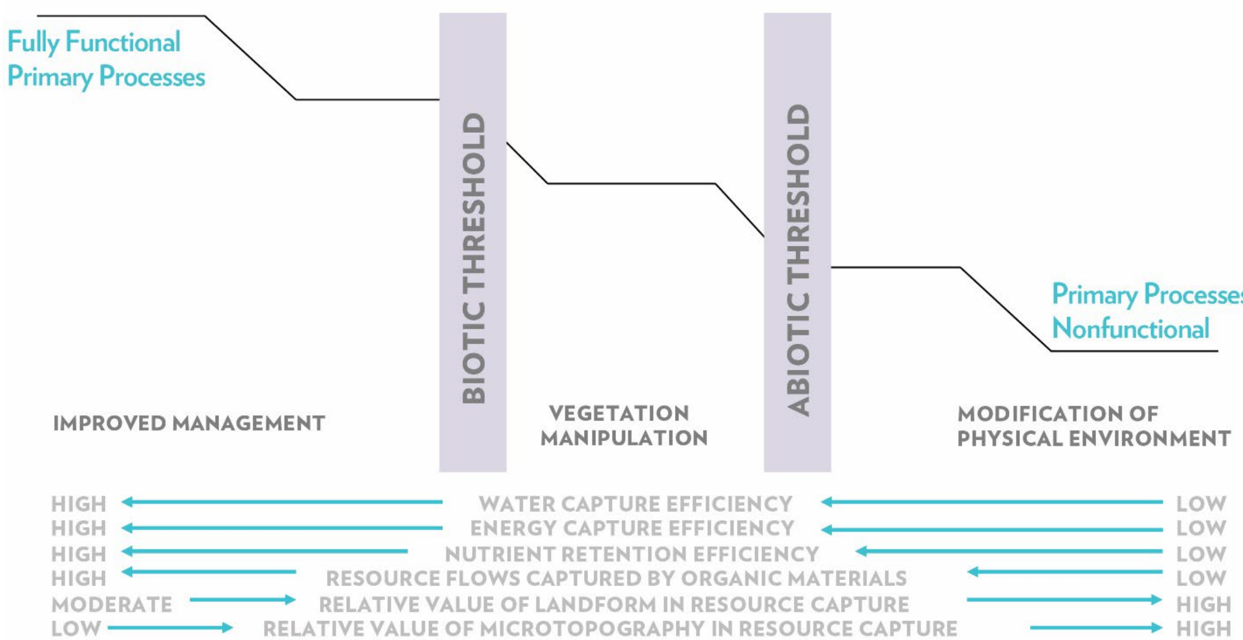

Figure 4. Ecological function. (Whisenant 2002)

Prior to the on-site portion of the assessment, the EPA Level III ecoregion, soils, ecological sites, updated 100 and 500 year floodplains, and stream network should be mapped. The Level III ecoregion provides an overview of the types of communities that would naturally occur for the area. Soils can be gathered from the USDA-NRCS soil survey. Soil information within the soil survey contains expected attributes for the soils on site. These include texture, erodibility, and several other classifications. One of the most important classifications from a restoration perspective is the Ecological Site. The ecological site description outlines the vegetative communities the site can support, including the historic or reference community, and provides a discussion of the ecological dynamics that shift composition between these communities. It is one of the few nationally available resources that discusses ecological dynamics for a particular site. Soil survey information is available online at the Web Soil Survey[10]. More information on referencing the Ecological Site for restoration and long-term management can be found in the **HPB Habitat Maintenance and Management Guidelines** document. Once these elements have been mapped, the on-site portion of the site assessment can begin. The on-site assessment can be divided into several parameters: Hydrology, Soils, Vegetation, and Site Context.

Hydrology

- Map stream, wetland, shoreline, (Desktop exercise/field confirmation)
- Geomorphic analysis (*See Houston County Flood Control District – Natural Stable Channel Design Guidelines)*
- Current overland flow direction (Desktop exercise/field confirmation)

[10] USDA-NRCS Web Soil Survey. https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

- Existing and potential pollution sources & and health hazards, on site and adjacent sites

Soils

Reference regional soil maps and the USDA-NRCS soil survey and compare to existing conditions. Map healthy soils and disturbed soils to allow development of a soil management plan. An interpretation of soil sample findings is included below in the Installation section.

- Take composite soil samples within each soil type and vegetative community type. Obtain agricultural soil analysis of organic matter, texture, macronutrients, and micronutrients. The Texas A&M AgriLife Extension Soil Lab can perform testing. Soil sampling methodology is found in Appendix A: Data sheets and linked here: http://soiltesting.tamu.edu/files/websoilunified2021.pdf
- Assess soil compaction through bulk density or soil cone penetrometer measurements. Penetrometer measurements are quick, but results will vary with soil moisture. Bulk density testing provides more robust measurements but takes a bit more processing.
- Bulk Density sampling methodology found in Appendix A: Data sheets, and is available here: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs143_019165.pdf
- Penetrometers test the pressure required to penetrate soil, providing quick, in situ information on soil compaction. Penetrometers are particularly useful during and after construction to assess compaction.
- Test soil infiltration. Infiltration testing methodology from NRCS USDA is found in Appendix A; Data sheets and is available here: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_052494.pdf
- Assess % bare ground and compare to acceptable amount for Ecological Site in the Soil Survey
- Erosion: Assess extent, severity, and type. Erosion evaluation datasheet found in Appendix A.

Vegetation

Map:

- Threatened or endangered species habitat[11]
- Zones of land cover/vegetation types. Note invasive species, native communities, special status plants and relative abundance classification (Abundant, common, frequent, occasional, rare[12]). Take diameter at breast height (DBH) for significant trees.
- Vegetative structure: % cover for overstory, mid-story, understory/herbaceous layer, litter cover, bare soil. Identify dominant species in each layer.
    - Riparian-specific considerations
    - Stream shading by riparian vegetation
    - Presence/absence of stabilizer vegetation
    - Width of riparian vegetation zone
- Natural history and land management changes (historic aerial photos and LiDAR data)

[11] https://tpwd.texas.gov/landwater/land/habitats/cross_timbers/endangered_species/

[12] https://tpwd.texas.gov/huntwild/wild/wildlife_diversity/nongame/tcap/sgcn.phtml

Site context
Take note of elements surrounding the site that will influence it. For example, a parking lot adjacent to the site that is channeling water into the site or a dense stand of invasive species. These elements will need to be considered during design and maintenance planning.

The following equipment can facilitate the necessary data collection and determinations:

- Infiltrometor or Amoozemeter
- Slide-hammer or rings for bulk density
- Soil sampling bags/equipment (permanent marker, plastic bags, shovels)
- GPS
- Camera
- DBF tape
- Meter tape

C. Maintenance Rapid Assessment
The Maintenance Rapid Assessment follows the protocols of the Existing Prairie and Wetland Habitat Assessment Protocol (updated Feb 2020) with the addition of these parameters: Bare patches, failing planted species, erosion, human or maintenance factors impacting the community (social trails, offroading etc).

HPB Maintenance Rapid Assessment is include in Appendix A: Data sheets

III. Long-term Monitoring

For an ecological monitoring program to be successful over the long term, the benefits of the information must justify the cost. The most value will be provided by a monitoring program that allows HPB to track progress toward organizational goals, allows improvements to restoration and maintenance operations over time, and that provides information to the larger conservation community that will improve efforts across the greater Houston area. The largest single cost is data collection. However, the cost of data management, quality assurance, and analysis are equally important and are often neglected during monitoring program design (Caughlan & Oakley 2001). The ideal monitoring protocol is often cost prohibitive, and the quality and depth of data collected must be balanced with the time and effort required to collect it. In some cases, easily measured parameters can be used as surrogates for more costly parameters.

It is unrealistic to monitor everything of interest, so statistical sampling should be included as part of the design. The HPB properties should be seen as a system, and sampling points should be selected to represent the system, not necessarily individual sites. A stratified sampling design ensuring each habitat type has adequate coverage is recommended. Replication over time is equally important. The correct sampling interval will detect changes over time but avoid oversampling. The appropriate interval depends on the parameter being sampled. Long-term changes in vegetation can be detected with yearly or twice-yearly sampling. Soil changes occur more slowly and can be sampled every other year. Use of sites by target faunal species will be documented on a schedule timed to the life history of that species, or within an interval that will capture use by multiple species of interest. The framework for data collection is being created and established at this time. The earlier the framework is established the better the data will be overtime. Gathering baseline data is highly recommended whenever possible to have a comparison and reference point for ecosystem improvement.

In addition to formal observations and monitoring methods used by staff or partner organizations, less formal methods of citizen science data collection can be used to supplement these data.

- Photo monitoring points in which visitors take photos and link to a database can provide ongoing monitoring as well as help tell the story of the site. An example of a photo-point system can be found in found in the USGS Tidal Marsh Monitoring Program[13]. Another protocol example is the Photo-Point Standard Operating Procedures developed by USGS[14]. The Conservation Team should look at these examples in addition to other to create a photo monitoring program that suites their specific needs. More detailed information regarding the USGS method is included in the HPB BMP Management and Maintenance document.

[13] http://www.tidalmarshmonitoring.net/pdf/USGS_WERC_Photo-Point_SOP.pdf

[14] US Geological Survey. 2012.

- Creation of a project within an application like iNaturalist can provide an informal, but quite useful, index of species present. “Friends” groups of trained volunteers can assist in monitoring for invasive species and other maintenance concerns.

Turnover in personnel is a constraint to long-term monitoring that can be mediated by selection of techniques that are less sensitive to differences in observers and that are easily communicated to new staff/volunteers. Training observers is an important mechanism to reduce variability in observation.

Two critical components of a monitoring program are scientific oversight by a qualified person, ideally attached to the program for the long-term, and quality assessment (QA). For an ecological monitoring program, QA means that the data are of known quality and meet the program's needs. Quality controls (QCs) are an important part of QA and should be designed along with the monitoring protocol. This is especially true for HBP because multiple researchers, methodologies, and data types will be used. Using a QA plan can increase the cost effectiveness of the monitoring program.

Reporting of monitoring data is especially important. The audience for the HPB monitoring data is varied, including field staff making management decisions, managers reviewing budgets and making investment decisions, conservation organizations such as The Nature Conservancy looking to improve their own programs, as well as the general public. A basic reporting plan and budget should be developed during the creation of the monitoring program.

Possible models exist. One such model is the Waller Creek Biodiversity & Ecosystem Monitoring Project conducted by The Nature Conservancy (Belaire et al. 2018). This study demonstrates a straightforward way to monitor biodiversity and ecosystem services across a large area. The methods used could be modified to fit the needs of HPB.

A. Monitoring parameters

It is of utmost importance that each of the monitoring protocols outlined below support the Conservation Program’s vision as well as HPB’s conservation messaging and outreach. Also of significance is that the monitoring below aligns with the work and messaging of HPB’s partners. Partners can also benefit from HPB’s monitoring data as well as contribute to HPB’s data collection. Ultimately, the monitoring must feed into habitat conservation practices and inform adaptive management decisions.

Stormwater capture

<u>Summary and purpose</u>

The stormwater capture metric is about monitoring the site's capacity to slow down, hold, and infiltrate water. Since the majority of the Bayou Greenway locations are adjacent to bayou systems, having a performance goal focused on water movement and quality is a benefit to improving bayou ecosystem function. Furthermore, locating and designing all HPB’s restoration projects with a watershed approach that aims to slow and capture stormwater as much as possible could have a positive impact on the Houston region that has high rainfall, is prone to flooding, and continues to increase impervious cover. As identified as one of City of Houston's Resilient Houston goals to complete 100 new green stormwater infrastructure projects by 2025, HPB projects are being recorded to help meet this goal. To be able to contribute performance data to the City of Houston will help further inform future planning and initiatives to better improve ecosystem function in urban environments.

Measuring water quality most likely means following the City of Houston Code of Ordinances chapters 9 and 13[15] as well as Harris County's Low Impact Development and Green Infrastructure Design Criteria for Stormwater Management.

<u>How we measure</u>
Estimate the combined capacity of restored communities, green infrastructure practices such as rain gardens and infiltration basins, and traditional parkland. Tools are available such as the National Stormwater Calculator and the calculations available within the Sustainable Sites Initiative[16] to assist with this effort. Reasonable estimations of capture capacity for each habitat type will need to be assembled from existing literature or new experimental results[17].

<u>Potential issues with this metric</u>
These calculations are normally done by an engineer and sometimes with special software.

Biodiversity
<u>Summary and purpose</u>
In general, a more diverse ecosystem is a healthier ecosystem. Species diversity means more robust ecosystem services are provided and offered, and there is more resilience in the face of disaster.

The purpose of measuring biodiversity is to evaluate and hopefully show that HPB restoration projects are increasing wildlife and vegetation biodiversity, therefore creating a healthier urban habitat.

Formally sampling vegetation over time to represent flora and pollinators to represent fauna should be the priority. Organized bird observations with volunteers and other groups such as Houston Audubon and Master Naturalist to tally species are also high priority, though data collection will not be as formalized.

Other wildlife monitoring would be supplemental to vegetation, pollinators, and birds. Though important, it seems challenging to collect this data without partnerships or more staff. Wildlife cameras wherever possible would be extremely beneficial.

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[15] https://www.houstontx.gov/codes/
[16] https://sustainablesites.org/resources
[17] https://www.epa.gov/water-research/national-stormwater-calculator

<u>How we measure</u>

HPB conservation team is developing methods for assessing flora and fauna biodiversity, and those methods should be referenced once fully developed. Below is a working methodology.

- Vegetation- a suggested framework has been proposed
  - Use the 9 bayous and their watersheds to organize the data collection.
  - A bayou as a sample area. If a project is not right on the bayou it can be included in the sample area of the closest bayou.
  - 3 bayous per year on a 3-year rotation to capture all the bayous and associated greenspaces.
  - 6 points per habitat type (4) = 24 points per bayou = 108 collection points per year.
  - Data collection can be done at organized times throughout the year- i.e. fall and spring and with interns/volunteers.
  - If a site is big enough and distinct from the bayou system, use the same structure as above- The site itself becomes a sample area and then sampled by habitat type (six samples of 4 habitat types) within that area- i.e. Coolgreen.
  - As much as possible, wildlife, vegetation, and pollinators data collection should be in the same area.
  - Establishing a control would be beneficial to the analysis of the data and for telling the performance story. An example control site could be sampling turf areas to compare performance.
  - Before beginning, reference maps and assign habitat types on them, then establish sampling locations that you return to on a yearly basis.
  - Once the sample locations are established, put something physical in the ground to mark them such as orange forestry stake or metal markers such as rebar in addition to GPS points. We recommend locating the center of the sampling point in the middle of the habitat type- not randomly located.
  - Assign a central point and follow the radial methods defined in Houston Arboretum vegetation methods (Appendix B), which is based on the US Forestry methods. To get more data for the herbaceous layer, it is recommend to add more quadrats specifically either define 4 other quads based on that central point or do a random scatter of quads around the point each time.
- Birds and pollinators
  - Pollinator and wildlife data should be collected in the same locations, if possible.
  - A pollinator method could be layered on the radial/quadrat method. Blackland can assist with developing a method.
  - Another option is a pollinator- transect example titled Streamlined Bee Monitoring Protocol for Assessing Pollinator Habitat provided (Appendix B). Other organizations in Houston are following this method. It is easy and fast. Since the method was established not in Texas, it is recommended to go out earlier in the day than what is specified.

Potential Issues with this Metric

Data on flora and fauna changes over time is useful information for storytelling and reaching out to the public about restoration improvements. The data collection can take time and needs to be replicated consistently.

Habitat Connectivity

Summary and Purpose

Connectivity can be defined as the capacity of the landscape to facilitate movement of species, resources, seed etc. between larger habitat patches. Connectivity supports migration and allows some species to effectively increase their habitat area. To continue the example from above, most wild bees need a patch size of 48 to 198 acres to fully support a population. However, much smaller patches are valuable as long as they are close enough that the bees can move between them, steppingstone style. This metric is focused more on connectivity within the different projects rather than project wide.

The purpose of habitat connectivity metric is to increase connectivity within each HPB conservation project so that the layout, design, and maintenance considers wildlife movement through the different ecosystems.

How we Measure

- Pollinators - A body of research exists outlining the distances and floristic richness needed between patches of habitat to elevate the value of an area for pollinators. Key species can be selected and connectivity evaluated based on the requirements of those species.
- Other species such as bats, reptiles, and select bird species can be included over time if there is capacity.

Potential Issues with this Metric

Selecting the appropriate scale can be challenging. This metric would most likely be program-wide, and a summary would be done every few years. Partnering with professors would be the ideal way to do this.

Habitat Quality

Summary and Purpose

Habitat Quality is an important part of assessing ecological function.

Creating a habitat quality index for the greater Houston region, as mentioned in HPB high level metrics, is a need for multiple professionals to evaluate habitat function. Gathering habitat quality data at the project level could help contribute to this data need. Collaboration with other like-minded organizations and stakeholders is recommended to coordinate the collection of highest priority data and organization and distribution of the data. The Nature Conservancy Biodiversity and Ecosystem Monitoring program conducted in Austin (Belaire et al. 2017, provided in Appendix B: Resources) provides a possible model.

How we measure

- Species diversity
- Community diversity
- % native
- Structural diversity, when appropriate
- Utilization by target species
- Soil quality

Potential issues with this metric

Habitat quality is defined by species and settling on an overall metric is challenging.

Heat Island Mitigation

Summary and Purpose

Greenspaces help mitigate heat island effect by transpiration and reflecting more solar radiation than human made surfaces such as buildings and roads. Urban environments typically are warmer than surrounding rural areas. The number one weather related deaths are caused by heat.[18] Houston's temperatures on a whole are getting hotter and hotter as seen in the Houston Climate Impact assessment.[19]

How we measure

- Temperature measurements adjacent to and within project boundaries
- Can follow Houston-Harris Heat Team's mapping process [Houston Heat Mapping | The Nature Conservancy](https://www.nature.org/en-us/newsroom/houston-heat-mapping/) [20]

Potential issues with this metric

Finding the time to organize staff and volunteers to get enough data points.

[18] https://weather.com/safety/heat/news/2021-06-03-heat-america-fatalities
[19] https://www.houstontx.gov/mayor/Climate-Impact-Assessment-2020-August.pdf
[20] https://www.nature.org/en-us/newsroom/houston-heat-mapping/

IV. Design

Several elements during overall park design should be considered to increase the success of included conservation projects.

A. Placement and selection of elements

The results of the ecological site assessment should be used to help place both conservation projects as well as other elements such as trails. Focus on elements such as trails, ballfields, and parking lots in areas identified as damaged or low ecological health during the ecological site assessment. Restoration will be prioritized in more healthy areas, in areas in which the soils or existing vegetation would best support the planned restoration, and in areas damaged by construction. All elements should be coordinated to ensure optimum ecosystem services. For example, prairie restorations can be placed to help capture and clean water flowing from parking lots. Wetlands can be placed to help with flood mitigation and to reduce storm pulses to the bayou. Green infrastructure, native landscaping, and restoration areas can be placed in such a way that they create a series of refugia for pollinators making their way through the park, and all elements can be organized into a cohesive system for capturing and cleaning water.

B. Design for maintenance

Maintenance capacity and logistics should be a design parameter. Elements like pathways can be used to simplify maintenance and delineation of different types of areas.

C. Community assembly for restoration areas

Develop unified soil/plant communities that reflect historic or appropriate reference communities of the site, the site's current condition, and its intended purpose. Community assembly conditions change depending on the stage and condition of the project.

- Early condition/very disturbed sites will require a larger complement of early successional and generalist species, particularly in seed mixes. Early successional species can include annuals such as *Aristida spp.*, while later successional species could be perennials like little bluestem (*Schizachyrium scoparium*), Indiangrass (*Sorghastrum nutans*), or trees such as Southern Magnolia (*Magnolia grandilflora*), and Shagbark Hickory (*Carya ovata)*[21]. Houston Parks Board Staff will need to become familiar with successional status for specific ecotypes. However, even at the start of the project, late successional grasses should be encouraged. They can be included in seed mixes, but live planting them is often worth the expense. **The mycorrhizal fungi brought in with the live plantings' roots can help the soil progress more quickly toward a mature state**. Care should be taken before planting to scrape the top 1-3" of container soil off into a bag to eliminate weed species common in nursery environments.

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[21] Nowak, David J., et al. United States Forest Service. 2015. *Houston's Urban Forest, 2015.* Prepared by the United States Department of Agriculture, Asheville, North Carolina.

- Consider multiple plant introductions over time as the soil matures. Later successional and diversity species can often be supported once the soil and plant community has matured for a few years but will not thrive under earlier conditions. Additionally, small sites will continue to lose species and individuals over time that will need to be replaced. Most urban sites are not large enough to be completely self-sufficient.

- Riparian-specific community assembly considerations. Riparian communities must contain a complement of stabilizer species as well as a mix of woody and herbaceous species.

D. Soil Protection

Vegetation and soil protection zones (VSPZs) should be delineated early in the design, based on the results of the ecological site assessment and the design requirements of the site. These zones should be protected in the final design as well as during the installation process.

Results of soil testing, observations of existing plant communities, and desired final conditions should determine the final soil design for the restoration. It is generally preferential to repair existing soils rather than replacing them. However, if soils must be replaced, they should be closely matched to the native soils the linked to the restoration vegetative community. This requires working with soil suppliers well in advance, because native prairie soils differ from standard mixes available from vendors. Similarly, compost should be sourced very early in the design/installation process because quality static-piled compost is difficult to find and can be expensive. However, windrow produced compost can be static piled for 6 months to allow fungal growth. This is a quick fix for the lack of readily available static piled compost.

E. Opportunities to Restore Ecological Function

There are many opportunities to improve ecological function of our urban streams in addition to creating stunning landscape designs. To restore ecosystem function is not to simply replace plants but to use restoration principles to restore processes that allow natural systems to repair themselves and to remain relatively stable. In practice, the assessment and repair of natural processes begins with the soil. Healthy soil, and the healthy plant communities it can support, comprises the foundation for functional ecosystems. It is possible to increase urban ecology while enhancing park functions.

While the Houston Parks Board may not be restoring property areas to historical climax conditions, restoration principles, which are informed by historical plant communities, still apply and can allow a hybrid condition to exist that will foster greater ecological integrity than current conditions. As an overall strategy, it is often beneficial for restoration efforts to occur incrementally so that the challenges of climate (drought, excessive rain, freezes, etc.) do not overwhelm a significant investment or effort. This incremental approach will allow fine-tuning Houston Parks Board's restoration methods to adapt and employ strategies that work best on each site. Initial efforts should begin in high-priority areas.

It is important for conservation staff to understand that the creation of sustained, successful landscapes will only occur if their designs are based on measures of function rather than measures of structure (Grayson et al. 1998). Structure, or patterns of an ecosystem, describes the various physical and biological parts of that ecosystem, whereas function includes the interactions of organisms with one another and with their physical environment (Grayson et al. 1998). Many projects are designed with the assumption that if the structure (i.e., spatial characteristics) looks right, the system will also function correctly, but many restoration/habitat projects that have been deemed a success in terms of realized project goals were ultimately not successful because the measures of function were insufficient or absent (Grayson et al. 1998). It is unlikely that every stream can be returned to historical climax community conditions, but the design strategies can implement achievable functional goals by defining major design objectives during site assessments. For example, the project could aim to increase plant species diversity, reduce erosion, or mitigate the heat island effect (Grayson et al. 1998).

F. Riparian Edges

Riparian vegetation is a major source of energy and nutrients for stream communities. Overhanging riparian vegetation keeps streams cool, which is especially important for increasing the site's species diversity. The target community in many riparian areas is a properly functioning gallery forest, dominated by bottomland hardwood canopy and understory species with a diverse herbaceous layer beneath, composed primarily of species that will enhance bank stability. Gallery forests support the goals of enhanced water quality along stream channels by enhancing bank stability, removing nutrients and other pollutants such as sediments, helping to grade stream channels, and slowing water velocities.

G. Riparian Plant Community Considerations

For riparian restoration, a healthy, diverse native plant community adjacent to receiving water bodies and riparian zones helps control erosion, filter sediment and pollutants carried in stormwater, support the health of aquatic ecosystems, and provide flood control and habitat. The fibrous root systems of these vegetated areas are crucial for achieving stable conditions. Increased native diversity can be encouraged through selective removal of invasive species and seeding of native woody and herbaceous species. Primary goals guiding the staff's species selection in riparian areas should be enhanced bank stability and water quality. Many species found in central and southeast Texas have been given draft stability ratings based on their contribution to bank stability (Nelle 2009). Stability ratings range from 1 to 10, with 1 approximating a bare ground condition and 10 representing anchored rock. Ideally, riparian areas will be dominated by plants with stability ratings between 6 and 9. Stability ratings of 7 or higher are generally considered to be the minimum for acceptable bank stability. However, combinations of species, particularly woody species in association with grasses or sedges, will provide the highest achievable stability (Nelle 2009).

In addition to bank stability ratings, USFWS wetland indicator status should be considered in the planting design. Riparian areas should contain a mix of obligate wetland, facultative wetland, and facultative species, dependent on water availability. It is important that all riparian areas contain some species from the facultative groups to provide diversity of vegetative growth as water availability fluctuates.

Establishment of these species can be done passively or actively. Passive establishment is the regeneration of an existing vegetated buffer through the succession of native plants and natural seed dispersal. This method is facilitated through elimination of invasive species and selective vegetation thinning. Active establishment is a technique used with little or no existing riparian buffer. This technique involves the creation of a site-specific plan detailing the species and location of proposed vegetation. In some cases, a combination of the two approaches is ideal, and Houston Parks Board staff will need to assess each site to determine the best approach to ensure diversity, bank stability, and water quality.

The active approach requires several steps for effective buffer improvements and establishment. Re-establishing the riparian zone should take place after erosion control measures have been established in adjacent areas draining to the receiving bayous and along streambanks themselves. It is important to spend adequate time preparing each site by focusing on removing invasive species from the riparian zones and providing a buffer to adjacent areas that possess invasive vegetation. A general rule of thumb for site preparation is the longer the better, but Houston Parks Board Staff will need to define what constitutes an acceptable period of time within active drainages. Keeping soil disturbance to a minimum to reduce vegetation loss and erosion would be preferable, but in some cases invasive treatments might result in bare or disturbed soils. Staff will need to decide the best approach for each site based on flows and potential velocities of the bayous in consultation with a geomorphologist. Once the site is prepared, staff will need to establish vegetation planting zones: hydric, mesic, xeric zones (See Figure below). Houston Parks Board staff should follow the protocol for prairie restoration and incorporate live plantings along upland and riparian edges with seeding and intermittent live planting within the xeric zone. More about planting is discussed below in the **I. Live Planting section** of **V. Installation & Maintenance**.

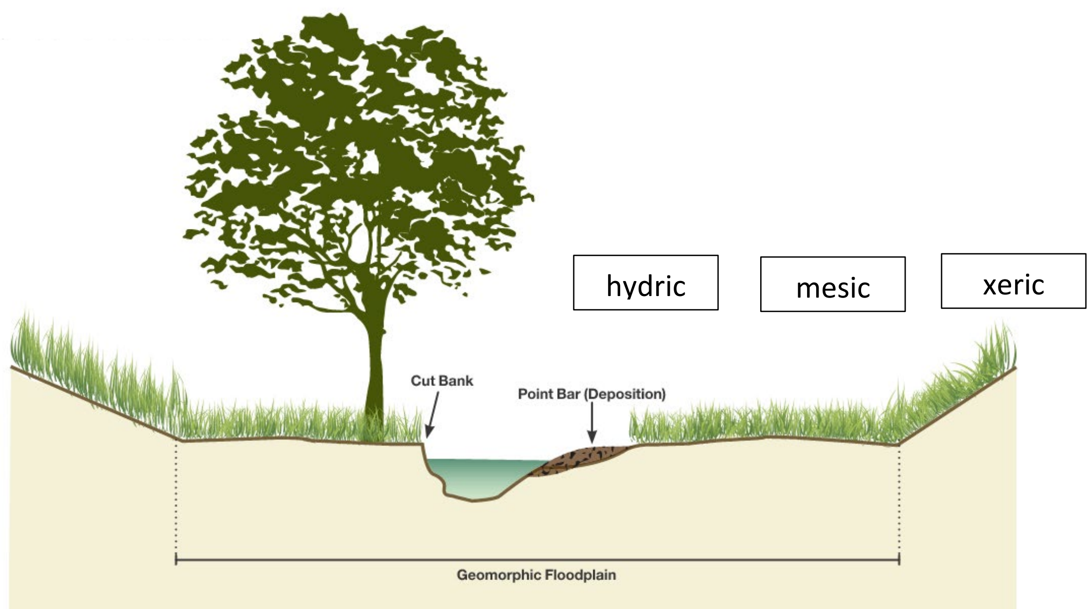

Figure 5. Cross section of a riparian pool with hydric, mesic, and xeric zones identified (HCFCD, 2015).

In terms of maintenance, the shallow hydric (wetland) zones can contain unmanaged vegetation while the mesic (drainage) and xeric (upland) areas can contain managed vegetation. When establishing these zones, it is best to plant herbaceous seeding/plantings first before woody species. For tree establishment, it is recommended to plant a mix of smaller gallon trees and whips so that future forest will possess a diversified age class as it matures. In general, 30% of the riparian area to be reforested should be planted with 3” caliper trees at 6-7’ intervals and 60% of the area with whips at 15’ intervals. These densities and amounts are flexible dependent upon restoration goals and will need to be approved by any agencies that need to review roughness coefficients to ensure that the woody species don’t impede bayou flood conveyance. For the best results, restoration areas should include temporary irrigation for establishment. The riparian zone will need to be monitored regularly for signs of erosion, sedimentation, debris, establishment, or invasive species. Irrigation and monitoring requirements should be detailed in restoration and maintenance plans.

A final consideration is the determination of the riparian buffer width. As mentioned in the site assessment, the current buffer varies regarding both width and ecological health. When possible, the riparian buffer area shall be as large as possible, or a minimum width of 20 feet on either side of the water body. A wider buffer is more effective at filtering and reducing runoff pollutant levels, specifically nitrogen (Mayer et al, 2005). Having a larger buffer zone will also allow for greater potential of improved bank conditions.

H. Natural Channel Design

When possible, Houston Parks Board should employ and be familiar with bioengineering practices such as Natural Channel Design (NCD) utilized in contemporary stream restoration and ensuring that plantings will not impede fluvial geomorphological priorities. In cities such as Houston, many conservation projects are restricted to restore riparian systems by passive measures such as installing coir log strips several feet out from a channel to promote passive sediment accrual or erosion and limit work to outside of the channel. However, there might be some properties that will allow Houston Parks Board staff to explore the potential for a stabilization strategy that will provide streambank stabilization by utilizing NCD techniques such as using live stakes, buried rip rap, creating bankfull benches, or using large woody debris (LWD) that promotes passive sediment accrual while simultaneously creating much needed habitat for many species. Such work, depending upon location, would be coordinated with Harris County Flood Control District. NCD creates optimal habitat for flora and fauna, protects newly installed vegetation, and features natural materials that break down over time allowing a diverse plant species palette to become the main aesthetic feature. Other NCD are compared below in a table from the Harris County Flood Control District Streambank Stabilization Handbook.

Comparison of Bioengineered Streambank Stabilization Techniques*

STABILIZATION TECHNIQUE	APPLICATION	INSTALLATION METHOD	CONSTRUCTION COST	MAINTENANCE COST	COMMENTS
Coir Matting	Gently sloping banks	Hand	Low	Low	Used by itself or as part of many other techniques.
Live Stakes	Moderately steep banks	Hand	Low	Medium	Works best at base of streambank when bottom of stake can intersect the water table.
Joint Planting	Moderately steep banks	Hand	High	Low	Rip rap will provide immediate protection while vegetation becomes established.
Live Fascine	Moderately steep banks, at toe of bank	Hand	Medium	Low	Fascine can help trap sediment
Brush Mattress	Moderately steep banks	Hand	Medium	High	Works well when banks are only 2 to 4 feet in height.
Coir Fiber Rolls	Moderately steep banks, at toe of bank	Hand	Medium	Medium	The fiber rolls can also be planted with vegetation.
Buried Rip Rap	Moderately steep banks	Heavy Equipment	Medium	Low	Typically used in conjunction with other techniques.
Bankfull Bench	Moderately steep banks	Heavy Equipment	High	Low	Helps relieve stress on the bank.
Branch Packing	Steep banks, localized erosion	Hand/Equipment	Medium	High	Rapidly establishes vegetation.
Live Cribwall	Steep banks	Heavy Equipment	High	Low	Useful where space is limited.
Vegetated Geogrids	Steep banks	Heavy Equipment	High	High	Useful on the outside of meander bends.
Rootwad Revetment	Steep banks	Heavy Equipment	High	Low	Provides in stream habitat for fish.

* Landowner should consult with an experienced design engineer to determine appropriate application.

Figure 6. Comparison of Bioengineered Streambank Stabilization Techniques – Harris County Flood Control District – *Streambank Stabilization Handbook*

Large Woody Debris

Large woody debris is defined as logs 4” to 6’ in diameter with a minimum length of 6’ that protrudes or lies within a stream channel or shoreline. LWD is often removed from waterways to “beautify” or make areas safe for recreation or to prevent flooding. LWD will not impact on water levels unless it is blocking more than 10% of the cross-sectional area of a river and removal of large wood debris results in only minimal improvement in channel capacity and reduction of flooding in lowland rivers because most material accumulates adjacent to the edge[22]. Approximately 70 percent of stream channel structural diversity is derived from root wads, trees, debris from bank erosion, storm damage, or tree mortality.[23] However, the removal of LWD is detrimental to stream health and well-being, destroying fish habitat, undermining stream channel and streambank stability, and adversely impacting diversity of

[22]Sanger, Dr. Andrew. Fisheries Scientific Committee. *Recommendation: Removal of Large Woody Debris*. Fisheries Management Act. 1994. File No. FSC 01/02. Ref No. FR18.

[23] Knutson and Naef 1997.

species along the shoreline. Removal of LWD results in the complete degradation of riparian systems.[24]

Recently, state and federal agencies have begun to increase incorporation of LWD into stream and shoreline restoration projects because to restore ecosystem function is not simply to replace and focus on components but, rather, to use restoration principles to restore processes which allow natural systems to repair themselves and to remain relatively stable.

Houston Parks Board staff should review the Washington State Department of Fish and Wildlife's study, *Compiled White Papers for Hydraulic Project Approval Habitat Conservation Plan (HCP),* that was created in March 2009. Section 7.5 *Direct and Indirect Effects: Riparian Vegetation and LWD Modifications* is a great resource for further information.

Integrating LWD into appropriate projects will require engineering and hydrologic expertise to ensure that placement does not impeded drainage or is installed in a way that can compromise bank stability.

LWD Strategy

- Maximize habitat potential
- Absorb excessive energy
- Temporarily harbor plants from excessive herbivory (LWD breaks down over time)
- Promote passive sediment accrual
- Promote diverse plant species palette
- Potentially utilize COH downed invasive material for LWD
- Keep strategy simple

"Construction costs per unit channel length were 23–58% of costs for recent stone bank stabilization projects… Application of this approach on a regional basis could trigger unprecedented recovery of stream corridor ecosystems at much lower cost than other practices."[25]

[24] Washington Department of Fish and Wildlife. *Compiled White Papers For Hydraulic Project Approval Habitat Conservation Plan (HCP). Chapter 7.5 Direct and Indirect Effects: Riparian Vegetation and LWD Modifications*. March 2009.

[25] Shields et al., 2004.

Figure 7. Streambank stabilization via rootwad. Harris County Flood Control District – *Streambank Stabilization Handbook*

Rootwad Revetment

- Consists of trees buried in a streambank with the root mass exposed to the flow.
- Root mass is generally greater than 3 feet in diameter.
- Often placed in clusters along the outside bank of a meander bend to form a protective layer against high flows impacting the streambank.
- Used in conjunction with logs or boulders to create an integrated revetment.
- Boulders are often placed between the rootwads to minimize erosion or scour around the rootwad, and to anchor the rootwads.
- Plantings, brush layers, or matting around the rootwad help stabilize the upper streambank.
- When properly installed, rootwads can provide a high level of stability in or near high stress bends.

Applications: Outside meanders of channels; for protection of fill slopes.

Pros: Provides a strong and stable solution for protecting the toe of a streambank.

Cons: Can be expensive relative to other bioengineering techniques. May not be suitable on steep fill slopes.

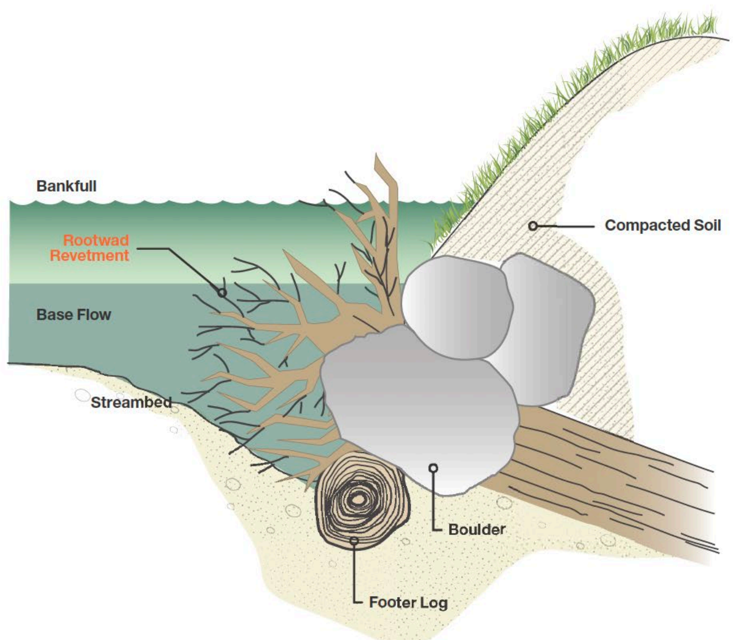

Figure 8. Streambank armoring via rootwad revetment – Harris County Flood Control District – *Streambank Stabilization Handbook*

I. Low Impact Development (LID)

Beyond providing a healthy buffer to enhance water quality and reduce erosion, properties should be evaluated for opportunities to restore and improve hydrological function. Because upland areas contribute and drain to Houston's bayous, slowing surface flow from locations such as parking lots, turf areas, and buildings through dispersed vegetated systems are integral to the larger riparian health and function of the river. *Low Impact Development (LID), or Green Infrastructure, is a comprehensive hydrological approach to site planning, design and pollution prevention strategies that creates a more economically sustainable and ecologically functional landscape. As such, the LID approach provides many benefits to a community's water resources and overall quality of life. It is a comprehensive approach to land development or re-development to manage stormwater runoff.* The LID methodology works with nature to manage stormwater as close to its source as possible, treating runoff as a resource rather than a waste product. Using LID techniques can help:

- Emphasize conservation and the use of on-site features to protect water quality
- Create functional and appealing site drainage
- Keep water on the site and allow infiltration into soils
- Recharge groundwater and the aquifer (where appropriate)
- Installation techniques
- The ability to infiltrate the runoff (or if they will be filtration features)
- The desired performance goals of the LID feature

Before implementing any LID techniques on site, it will be important to determine the volume of the annual runoff to be managed. This may be specified in existing local regulations. Or, it is possible to analyze historical rainfall data in the region to determine the relationship between the water quality volume and the amount of the annual runoff to be treated. It will also be important to conduct a thorough analysis of the following, at the minimum:

- Soil type and whether modifications are needed
- The storage needed to capture and treat the runoff (based on local conditions)
- The sensitivity of the receiving body
- Future maintenance
- Installation techniques
- The ability to infiltrate the runoff (or if there will be filtration features)
- The desired performance goals of the LID feature

Rain gardens
Rain gardens (or bioretention) function as a soil and plant-based filtration device that removes pollutants through a variety of physical land biological processes. These depressed areas allow water to be retained in a basin-shaped landscape area with plants and soil where the water is allowed to pass through the plant roots and the soil column. These facilities normally consist of a basin or ponding area, organic or mulch layer, and plants. Constructed rain gardens provide stormwater treatment that enhances the quality of downstream water bodies by infiltrating runoff, or when designed with liner or underdrain, temporarily storing runoff and releasing it over a period of days to the receiving water. The vegetation within the constructed rain gardens can provide shade and wind breaks and help absorb noise. Rain gardens are easily integrated into site landscaping, and their design can be formal or informal in character.

Bioswales

Swales are vegetated channels that convey stormwater and remove pollutants by sedimentation and infiltration through soil. Unlike rain gardens that capture, retain, and infiltrate stormwater, swales are primarily stormwater conveyance systems. They can provide sufficient control under light to moderate runoff conditions, but their ability to control large storms is limited. Therefore, they are most applicable in low to moderately sloped areas or along roadsides as an alternative to ditches and curb and gutter drainage. Swales can be more aesthetically pleasing than concrete or rock-lined drainage systems and are generally less expensive to construct and maintain. With this technology, it is important that the swale maintain 100% cover with short grasses to be effective.

More on LID design and implementation can be found in the HPB Wetland Restoration Best Management Practice.

V. Installation & Maintenance

A. Soil Sampling

Before starting any work, it will be imperative to understand the basic conditions of the soils to see if they align with soil survey data or have been altered significantly as drastic changes might necessitate a plant mix that is not representative of the historical climax plant community.

Houston Parks Board will submit soil samples for each restoration site to the Texas A&M Agrilife Extension office. Samples should follow these steps as laid out by Texas A&M's T.L. Provin and J.L. Pratt in their document, *Testing Your Soil: How to Collect and Send Samples*. The conservation department will utilize the *Urban Homeowner Soil Sample Information Form SU12* (this form also has sampling guidelines at the end of the document for guidance). Sample information is as follows:

- Sample ID (name of specific restoration site)
- Square footage
- Last time fertilized (not applicable)
- Previously used fertilizers/organics (not applicable)
- I am growing -> Enter J. Buffalograss (or other native species if this category changes)
- Choose test 12 – Routine (R) + Micro + B + Org. Matter + Detailed Sal. + Texture

TEXAS A&M AGRILIFE EXTENSION

Soil, Water and Forage Testing Laboratory
Department of Soil and Crop Sciences
Texas AgriLife Extension Service

SU 21

Urban and Homeowner Soil Sample Information Form

Please submit this completed form and payment with samples. Mark each sample bag with your sample identification and ensure that It corresponds with the sample identification written on this form. *See sampling and mailing instructions on the back of this form.

(PLEASE DO NOT SEND CASH)

SUBMITTAL AND INVOICE INFORMATION: This information will be used for all official invoicing and communication. **Sheet ___ of ____**

Name ______________________________ County where sampled ____________________

Mailing Address ______________________________ Phone ____________________

City ____________________ State______ Zip ______ Email* ____________________

Payment (DO NOT SEND CASH)
☐ Check/ Money Order (keep your M.O. receipt)
Amount Paid $____________________
Make Checks Payable to: **Soil Testing Laboratory**
☐ Prepayment on Aggie Marketplace Payment
Order Number____________________ $ amount _____
☐ Extension of Credit-Bill, AG-257 on file
Samples will not be processed if payment is not received or a valid AG-257 is not on file with Texas A&M AgriLife Extension Service. See website for more information on Form AG-257

CLIENT NAME: Client name will only be included with information above on result reports.

Name ______________________________

Lab Use only

SAMPLE INFORMATION (Required) **(see options listed below)**

Laboratory # For Lab Use)	My Sample ID	Square feet of sampled area	Last Time Fertilized	I previously used fertilizers/organics	I am growing (see below*)	Requested Analyses
Example	Front Yard	2000	5/30/14	5 lbs 21-0-5 per 1000 sqft	F	Select only one box
						☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8 ☐9 ☐10 ☐11 ☐12
						☐1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8 ☐9 ☐10 ☐11 ☐12

***A $2.00 mail fee will be charged for all invoice and sample results mailed via USPS. Results and invoice can be emailed in PDF form for free.**
☐email results ☐Charge $2 for mailing

We strongly suggest emailing the laboratory at soiltesting@tamu.edu prior to shipping your samples. This will provide the laboratory a valid email address for returning your results and invoice. Bounced emails will be billed $2 and a hardcopy will be mailed to the address listed above.

Annual, Flowers and Gardens
A. Azaleas and Camelias
B. Roses
C. Annuals
D. Vegetable Garden
E. Other

Turfgrass
F. Common Bermudagrass
G. Hybrid Bermudagrass
H. St. Augustinegrass
I. Centipedegrass
J. Buffalograss
K. Tall Fescue
L. Kentucky Bluegrass
M. Zoysiagrass

Trees and Woody Ornamentals
N. Pecan trees
O. Fruit trees
P. Shrubs and Ornamentals
Q. Shade trees
R. Other trees

1. Routine Analysis (R) (1) — **$12 per sample**
(pH, NO_3-N, P, K, Ca, Mg, Na, S and Conductivity)
(This test is a base test for basic fertilizer recommendations.)

2. R + Micronutrients (Micro) (2) — **$19 per sample**
(Adds Zn, Fe, Cu, and Mn to test 1.)

3. R + Micro + Boron (B) (3) — **$26 per sample**
(Includes Test 2 plus boron)
(Recommended for individuals applying compost and manures.)

4. R + Detailed Salinity (4) — **$34 per sample**
(Includes Test 1 plus detailed salinity analysis)
(Recommended for individuals using lower quality irrigation water.)

5. R + Micro + Detailed Salinity (5) — **$41 per sample**
(Includes Test 2 plus detailed salinity analysis)

6. Routine Analysis + Organic Matter (8) — **$32 per sample**
(Includes Test 1 plus organic matter analysis)

7. R + Micro + Organic Matter (10) — **$39 per sample**
(Includes Test 2 plus organic matter analysis)

8. R + Micro + B + Organic Matter (13) — **$46 per sample**
(Includes Test 3 plus organic matter analysis)

9. R + Texture (determines % sand, silt, and clay)(7) — **$32 per sample**
(Includes Test 1 plus textural analysis)

10. R + Micro + Texture (11) — **$39 per sample**
(Includes Test 2 plus textural analysis)

11. R + Micro + B + Organic Matter + Detailed Salinity(14) — **$68 per sample**
(Includes Test 8 plus detailed salinity)

12. R + Micro + B + Org. Matter + Detailed Sal. + Texture (15) — **$88 per sample**
(Includes Test 8 plus textural analysis and detailed salinity and provides the most comprehensive data needed for troubleshooting most plant/soil growing issues {does not address pathogen, pesticide or hydrocarbon issues}).

Hardcopy mailed to address listed above — **$2 per invoice**

Pricing valid until 12-31-2021.

The latest form can be downloaded at the laboratory's website: soiltesting.tamu.edu

Form S4-21

Figure 9. Soil sample information form

The key to understanding this test is that the lab is using the soil sample results to provide macro level amendments for a crop. Herbaceous and woody components in riparian restoration projects do not require a robust fertilization regime. This is mainly because many native species evolved in what agronomists would call “nutrient poor” conditions. If you treat restorations as crops and apply large, or even agronomist recommended nutrients as per your soil sample recommendations, you will only succeed in encouraging a bumper weed/invasive crop. If you choose a non-native crop, the recommended fertilization regime will be even higher and take you down the wrong path.

The main objective of carrying out these soil tests is to:

- Understand if soil web results align with actual soil conditions
- Understand current textural condition
- Understand if any macro (Nitrogen-N, Phosphorus-P, Potassium-K) levels are at 0
- Understand current organic matter (OM) levels

Understanding these four factors will allow conservation staff to 1) design appropriate plant communities, 2) recognize if any specific macronutrients need to be added to adjust for complete absence, and 3) anticipate how much organic matter might need to be brought in for amendment to help improve soil condition and provide food source and environment for establishing/increasing soil food web.

TEXAS A&M AGRILIFE EXTENSION

Soil Analysis Report

Soil, Water and Forage Testing Laboratory
Department of Soil and Crop Sciences
2478 TAMU
College Station, TX 77843-2478
979-845-4816 (phone)
979-845-5958 (FAX)
Visit our website: http://soiltesting.tamu.edu

Report generated for:

Sample received on: 1/4/2021
Printed on: 1/14/2021
Area Represented: 17800 acres
SWFTL recommends <40 acres/sample

Travis County
Laboratory Number:
Customer Sample ID: Middle West
Crop Grown: MINIMUM REQUIREMENT: WARM SEASON PERENNIAL GRASS

Analysis	Results	CL*	Units	ExLow VLow Low Mod High VHigh Excess.	Fertilizer Recommended
pH	7.5	(5.8)	-	Slightly Alkaline	
Conductivity	144	(-)	umho/cm	None	
Nitrate-N	14	(-)	ppm**		10 lbs N/acre
Phosphorus	17	(50)	ppm		35 lbs P2O5/acre
Potassium	100	(130)	ppm		5 lbs K20/acre
Calcium	17,603	(180)	ppm		0 lbs Ca/acre
Magnesium	148	(50)	ppm		0 lbs Mg/acre
Sulfur	18	(13)	ppm		0 lbs S/acre
Sodium	8	(-)	ppm		
Iron	4.51	(4.25)	ppm		
Zinc	3.71	(0.27)	ppm		0 lbs Zn/acre
Manganese	8.63	(1.00)	ppm		0 lbs Mn/acre
Copper	0.19	(0.16)	ppm		0 lbs Cu/acre
Boron	0.43	(0.60)	ppm		0.5 lbs B/acre
Limestone Requirement					0.00 tons 100ECCE/acre
Limestone Requirement (Chemical Test)					0.0 tons 100ECCE/acre

Organic Matter	2.43	%

Detailed Salinity Test (Saturated Paste Extract)		
pH	7.5	
Conductivity	0.53 mmhos/cm	
Sodium	18 ppm	0.786 meq/L
Potassium	16 ppm	0.410 meq/L
Calcium	124 ppm	6.200 meq/L
Magnesium	8 ppm	0.636 meq/L
SAR	0.43	
SSP	9.78	

*CL=Critical level is the point which no additional nutrient (excluding nitrate-N, sodium and conductivity) is recommended. **ppm=mg/kg

pH - Important to know what plant community you need to aim for. Houston will have acidic and alkaline communities.

N/P/K (Macros) - vital for plant growth. If applying fertilizer make sure you can reference "available" N,P,K as they are immediately availabe to plants. Regarding soil report, you are mainly determining if there is no available macro. Native plants DO NOT NEED excessive nutrients. Many evolved on soils that agronomists would consider nutrient poor soils. Adding excessive nutrients will result in invasive plant explosion.

CL - "Critical Level" is the amount that agronomists aim for, but is not as important for native plants. Again, you can add organic fertilizer if chlorosis becomes an issue, but the soil report should verify that there is no lack of any macro.

Fertilizer Recommended - these recommendations are from a crop perspective. No need to follow the recommendation. HPB staff just need to understand if there is a complete lack of a major nutrient.

Conductivity - Indicates the amount of salts present in the soil. (K,Ca, Mg, Na, CL, HCO3). Excessive salts will hinder or prevent plant growth and can affect infiltration. 1 mmhos/cm = 1 dS/m. Adverse impacts will start at .75 dS/m.

Organic Matter - prairie soil organic matter varied upon the specific soil type, but acceptable percentage range is 2-5% with 2-3% being common. Even if OM falls within acceptable ranges, compost should be added as a soil amendment to help address soil structure and inoculate with beneficial microorganisms.

Figure 10. Soil sample results and interpretation

B. Site Preparation

Ecological restoration is a trajectory, not an intervention. The amount of time you place on site preparation will determine your rate of success. While it is true that conservation staff could take a minimalist approach in site prep and save money up front, it is very likely that species diversity and richness will never be achieved, and a massive amount of sweat equity will be involved trying to "right the ship" by dueling with invasive species within the interior space of the restoration plots over the life of the plot. It cannot be overstated how much work will be saved if the Houston Parks Board understands that each step of the process of identifying acquisitions, prepping chosen sites once acquired, and installing during the optimal installation windows must be given adequate time to ensure success. Trying to flip a portion of land in a limited amount of time will yield poor results.

Any site improvements will most likely consist of some disturbances to the site. Therefore, a preliminary item to consider regarding restoration is how the design will be implemented. Before construction begins, it will be crucial to stabilize the site and set up protection measures so that the exposed soil does not run off into the adjacent bayous. It is anticipated that the installation/construction processes could result in a lot of fine sediment, and topsoil being washed into the river. Construction Best Management Practices (water pollution control) should be established and explored to protect these riparian zones.

The first part of this BMP reviews all the steps recommended for site selection and assessment. This portion will focus on ensuring a solid foundation, installing sites correctly, and establishing these plots:

- Invasive removal
- Soil preparation
- Compaction rates
- Soil amendments
- Seeding
- Live planting
- Establishment
- Post-installation monitoring first year

C. Vegetation and Soil Protection

A vegetation and soil management plan is needed at this phase. The plan should identify areas of healthy vegetation and soils to protect with vegetation and soil protection zones (VSPZ). Healthy soils are identified through a combination of vegetation community assessment, agricultural soil testing, and comparison to reference soils either in the soil survey or from identified reference sites nearby. These areas should be clearly marked for contractors and communicated through maps and in the field to reduce damage and compaction. In addition, laydown areas and construction access and circulation should be identified. Limits of construction should be well defined to reduce site disturbance as much as possible. Though the site is a greenspace and seems like it has ample space for moving around, it should be treated as an urban downtown project with tight constraints. Protecting healthy areas will reduce work in the future and increase project success.

D. Site Hygiene

Once site activity begins, the site should be considered a construction zone and maintenance begins. Site hygiene should be a high priority as much as possible for HPB and its contractors. Maintaining site hygiene practices, means protecting the site from invasive species encroachment or preventing damage such as soil loss or compaction. Site hygiene practices include:

- Washing equipment
- Properly stockpiling soils
- Managing invasive species during construction
- Stormwater protection measures such as silt fences and erosion control mats

Timing between site preparation and installation is critical to sequencing in the most effective and efficient manner. Communication between all involved parties should occur regularly so that the project is well coordinated, and adjustments do not significantly alter the forward process.

E. Invasive removal

It is highly likely that most urban sites will be dominated by undesirable invasive vegetation. Each site should be evaluated during the site assessment to determine appropriate restoration activities. While the focus of long-term pest management should focus on least toxic means, often the best option when starting on invasive-dominated sites is to completely start over with the goal of eliminating all vegetative growth. Site preparation should include herbicides, tillage, adequate depth mulching, and, depending upon timeline/approval, prescribed fire. Sites with pre-existing stands of competitive or dominant invasive plants such as

- Bermudagrass (*Cynodon dactylon*)
- Johnsongrass (*Sorghum halepense*)
- Brome (*Bromus* spp.)
- chinaberry (*Melia azedarach*)
- Brazilian pepper tree (*Schinus terebinthifolia*)
- Japanese honeysuckle (*Lonicera japonica*)
- Chinese Tallow (*Triadica sebifera*)
- Castor bean (*Ricinus communis*)
- Ligustrum (*Ligustrum* spp.)
- Catclaw vine (*Macfadyena unguis-cati*)
- Vasey Grass (*Paspalum urvillei*)

will require multiple treatments with herbicide to knock back vigorous stands. Houston Parks Board staff will need to ascertain the best sequence to eliminate woody invasives, grasses, forbs, vines, and shrubs. Depending upon the site, staff might consider wicking the herbaceous components first, removing thatch after multiple treatments, and then cutting and painting stumps of invasive woody and vine species. **Houston Parks Board staff should wear personal protective equipment and follow manufacturer's directions as posted on labels and materials safety and data sheet (MSDS) sets**.

Multiple treatments of herbicide help deplete carbohydrate reserves in rhizomes and minimize regrowth potential in these invasives. However, these species have likely been present for years and have established seed banks that can remain viable in the soil for over a decade. Another complicating factor is there will be a mix of warm and cool season invasive species, so if sites are not prepared over a minimum of a year, Houston Parks Board conservation staff might only knock back one type of invasive growth and not address the other. **Therefore, if possible, initial herbicide treatments to "start over" should be followed by multiple applications on invasive herbaceous components and woody and vine species.** Large-scale treatments of grasses and forbs might not be necessary in thick stands of woody vegetation, which means Houston Parks Board staff can focus on cutting and painting stumps. For the first application of herbicide on woody species, staff should cut the tree and leave at least 3' of stump and paint immediately. This will allow conservation staff to return to the site to check for any resprouts and then cut and repaint with herbicide if necessary. Once the woody species is confirmed dead, the stump can then be flush cut to the ground. There are a number of conservation organizations that advocate for two years of treatment before planning. Application timing is crucial. All efforts should be made to eliminate invasive species before they flower. Conservation staff must realize that the invasive seed bank will never be completely exhausted. Subsequent seeding and planting post-site preparation will bring up invasive seed from lower soil horizons no matter how clean the field may seem after site has been treated, even after multiple attempts.

Invasive presence does not prevent native growth through vegetative competition alone. Many of the common invasive species hijack the soil and alter the biogeochemical conditions preventing certain native species from establishing. While allelopathy is a well-known mechanism by which invasive species control or eliminate competition from other plants[26], increasing data demonstrates that they also cultivate specific microbes through root exudates[27] and prevent development of the soil food web, excluding important drivers of later successional growth such as mycorrhizae.

[26] "Leachates from johnsongrass inhibited vegetative and sexual growth of the dominant Texas prairie grass in the United States." (Rout et al., 2013a)

[27] "Endophytic bacteria were transmitted horizontally along [johnsongrass] rhizomes and vertically into seeds. When bacteria were suppressed with tetracycline, plant growth slowed, supporting the importance of these bacteria to plant growth." (Rout et al., 2013b).

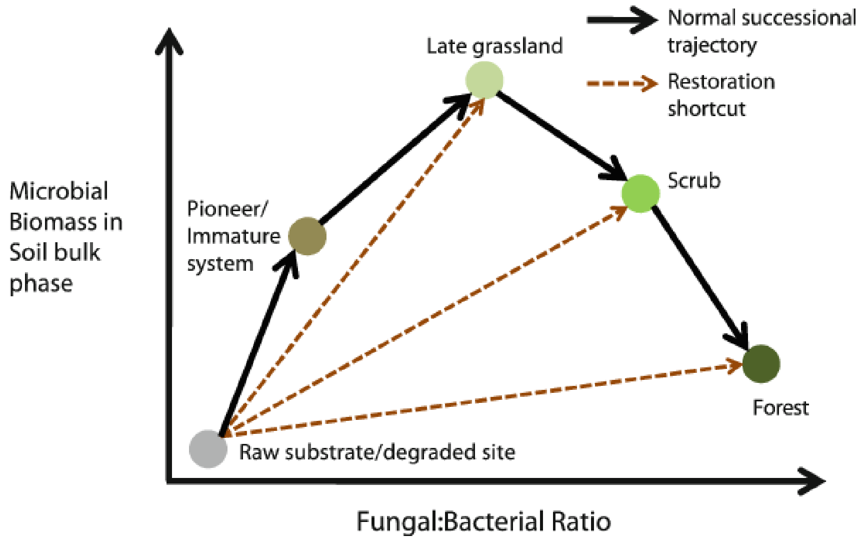

Figure 11. Facilitators or Followers graph. Relationship between ecosystem successional state and microbial community size and composition. Copyright: JA Harris. From (Harris 2009)

<u>It is recommended that the conservation team should develop an Integrated Pest Management (IPM) plan specifically for the Conservation Program's invasive species needs.</u> Best Management Practices for control of problematic vegetation are based on IPM principles that will maintain the desired site conditions using a combination of available methods (cultural, manual, mechanical, chemical), while minimizing risk to people, property, and the environment. Employing the least toxic, yet effective, treatment is desired. Managers use current information on pest life cycles and control methods to select the least toxic control method that is effective and economical. IPM principles identify current infestations, set action thresholds for treatment, and prescribe control and prevention methods.

All pesticide applicators must follow all label requirements and read the material safety data sheets (MSDS), including dilution, application and disposal of containers. Equipment must be maintained to ensure cost effectiveness and safety. Do not apply herbicide when rain is expected within 48 hours. Use directed or individual plant treatment, rather than broadcast, application methods.

Table 2. Common invasive species and treatment. Be sure to read labels and follow HPB established IPM guidelines.

Target Species	Herbicides, Rates, and Notes
Broad spectrum complete site clearing - Both forbs and grasses - Herbaceous species to be removed in areas without standing water, saturated soils, or frequent flooding	48% glyphosate – 3.0-3.3 quarts per acre of chemical mixed with water carrier. Comes in 2.5 gallon jugs, 2 jugs per box = gallons 1 box sprayed at 3 quarts per acre treats 6.67 acres Plan no less than 4 applications for the summer. One early and then one at least 4 weeks before first frost date. Will not control weeds such as crabgrass. Not recommended for aquatic areas.
Bermudagrass (Cynodon dactylon) - Similar to site clearing due to invasive potential. Herbaceous species to be removed in areas without standing water, saturated soils, or frequent flooding	48% glyphosate - 1.5-2 quarts per acre (heavier rates for heavier infestation and more mature plants) 1, 5 gallon box will treat 10 acres if sprayed at 2 quart per acre rate Plan multiple applications for the growing season (no less than 4-5). Spray no later than 4 weeks before first frost date or when nighttime temperatures routinely drop below 50 degrees Plan at least 2 applications for the summer. One early and then one at least 4 weeks before first frost date. Follow up in early spring with application of Fluazifop-P-butyl (Fusilade II) and nonionic surfactant at rate recommended by manufacturer and within temperature range approved by manufacturer. Fusilade II will kill grasses without affecting forbs. Once spring seeding occurs, Fusilade II will not be an option due to inclusion of native grasses in mix. If Bermudagrass is still present before seeding, team may need to discuss omitting grasses in this mix so we can continue Fusilade II treatments to eliminate Bermudagrass. Glyphosate will not control weeds such as crabgrass. Not recommended for aquatic areas.

Broad spectrum complete site clearing - Both forbs and grasses - Herbaceous species to be removed in areas adjacent to rivers and creeks, with some standing water, saturated soils, or frequent flooding, and wetlands	0.25 to 0.5 lb ae/A (acid equivalent per acre) of imazapyr (Habitat) for grass, broadleaf, brush, and vine species. Herbicide should be applied when vegetation is weeds are “growing vigorously at the time of application.” Chlorosis and tissue damage may take up to 2 weeks after application, with plant mortality occurring up to several weeks later. *DO NOT apply to water ½ mile upstream of active potable water intake in flowing water or within ½ mile of an active potable water intake in a standing body of water such as a lake, pond, or reservoir. To apply within these intake areas, water intake MUST be turned off during application and for a minimum of 48 hours after application. * In Lakes and Rivers DO NOT apply within 1 mile of an active irrigation water intake during the irrigation season. Applications less than one mile of active irrigation intake may be made during off season, provide the intake is inactive for 120 after application.
Broadleaf invasives – broad application	1.5% triclopyr (Remedy Ultra) - 1.5 pints per acre with the addition of 0.5% aminopyralid (Milestone) 3 -7 ounces per acre. This mix will knock back most broadleaf invasive species and younger woody material. It is not recommended to try and hand pull species such as dewberry (Rubus trivialis) due to the persistent rhizomatous root growth habit. Staff should be sure that high temperatures aren’t present or volatilization could occur and damage non target plants. *This method should only be used in areas where large stands of non-desirable species (vines, woody shrubs) exist, and no desirable species are nearby.
Grassland near riparian and wetland habitat (broad spectrum control)	1.5% Isopropylamine salt of Imazapyr (Habitat) - 1.9 oz to 6 pints mixed with appropriate corresponding gallons of water and nonionic surfactant. Habitat has very specific conditions where it can be applied in regards to irrigation canals/ditches, quiescent or slow moving waters, or moving water in close proximity to active irrigation water intake.

Cut tree stumps -	Tripclopyr (Remedy Ultra or similar) with 8% active ingredient. Some products might require mixing with penetrant oil, be sure to check product label. Staff can carry jar with pre-mixed herbicide and paint herbicide onto cambium immediately after tree is cut. Dye can be mixed with herbicide to ensure which trees have been treated. Cut stump to 3' apply and watch for resprouts. If they occur, reapply and monitor. Flush cut stump to ground once dead.

Other species HPB is treating are listed below with treatments:

Target Species	Herbicides, Rates, and Notes
McCartney Rose (Rosa bracteate) 4 out of 10	Preferred control method is herbicide applied in the spring/summer. Use 2oz/gal Glyphosate (Ranger Pro) and 1 oz/gal Triclopyr (Triclopyr 3). Foliar spray is preferred but it varies from location to location
Chinese Privet (Ligustrum sinense)5 out of 10	Preferred control method is mechanical removal and herbicide in the spring/summer. 2, 4-D Amine, Triclopyr 4, and MSO* recipe came from TPWD and mixed in large batches. Cutting the stump is the application method.
Yaupon (Ilex vomitoria). 4 out of 10	Preferred control method is mechanical removal and herbicide applied in the spring/summer. 2, 4-D Amine, Triclopyr 4, and MSO* recipe came from TPWD and mixed in large batches. Cutting the stump is the application method.
Chinese Tallow (Triadica sebifera)6 out of 10	Preferred control method is mechanical removal and herbicide applied in the summer. 2, 4-D Amine, Triclopyr 4, and MSO* recipe came from TPWD and mixed in large batches. Cutting the stump is the application method.
McCartney Rose (Rosa bracteate) 4 out of 10	Preferred control method is herbicide applied in the spring/summer.

	Use 2oz/gal Glyphosate (Ranger Pro) and 1 oz/gal Triclopyr (Triclopyr 3). Foliar spray is preferred but it varies from location to location
Deep Rooted Sedge (Cyperus enterianus) 9 out of 10	Preferred control method is herbicide applied in the spring/summer. Halosulfuron-methyl 5% 1 packet covers 1000 sq. ft.
Guinea Grass (Megathyrsus maximus) 5 out of 10	Preferred control method is herbicide applied in the spring/summer with young vegetative growth and actively growing. 1.5% glyphosate can be used to kill individual plants with perfect coverage. Use 2% of a 41% solution + surfactant formulation if you don't think you will have perfect coverage. If you have good funding or resources, 3% gives a quicker kill, but not a more thorough kill.
Itchgrass. (Rottboellia chochinchinensis) 5 out of 10	Preferred control method is herbicide applied in the spring/summer with young vegetative growth and actively growing. Fluazifop applied at 6 to 12 oz/A to achieve mortality. This will affect othre grasses as well.
Castor Bean (Ricinus communis) 5 out of 10	Preferred control method is hand removal for individual plants or small infestations. Be sure to wear gloves as this species is poisonous. For larger infestations, apply foliar spot treatment of triclopyr 1% v/v solution (Garlon3A) or for cut stump treatement use 100% v/v solution (Garlon 3A).

F. Soil preparation

After herbicide treatments mulching, and follow-up spot treatments, the site's soil will be ready to be worked in preparation to receive seed and live planting. Sites that have been treated and mulched will be devoid of vegetation, but the soil will need to be made loose and friable to ensure good seed/soil contact and to eliminate compaction that exceeds ranges that allow root penetration into lower soil horizons. This is especially important to ensure plant resilience to drought conditions, allow infiltration of stormwater down into the soil horizon rather than promoting surface sheet flow off the site, and replicate hydrographic conditions that would have existed prior to impacts from site development or overuse.

However, in canopy conditions, loosening soil by traditional tilling won't be an option due to extensive critical root zones. It is recommended that these are to be lightly roughened and organic matter be incorporated into the soil but never deeply tilled. If seeding is desired or necessary, staff will need to investigate air spading areas to loosen soils to create friable base. If properties have steep slopes, placing brush along contours will enhance natural recovery processes by slowing rainwater runoff, initiating passive soil building, and helping prevent erosion. Leaving downed wood in place will help the system start to recover and act as a nursery for new trees and germinating vegetation. Large woody debris should not be removed unless it threatens infrastructure in the immediate vicinity, completely blocks access, or contributes to erosion, be sure to consult with partners such as Harris County Flood Control District. Large woody debris is typically defined as material greater than 4" diameter and 6' in length. Clean-up of this material can be detrimental to river health as it is an essential component of river ecosystems. Large woody debris helps stabilize the stream bank and stream channel, promotes new vegetation growth, and provides habitat for fish and other important riparian animal species. Increasing soil roughness focuses on reducing runoff and erosion by retaining precipitation through roughness, vegetative cover, and reducing distance of unobstructed soil. Soil roughness strategies, such as micro-catchments, pits, basins, ripping, and chiseling, affect soil roughness and accompanying infiltration rates.

Surface obstructions promote the retention of water by reducing the amount and velocity of surface and channel flows. Surface obstructions, including organic matter (compost), mulch, and woody debris, improve soil aggregation and provide initial stability to establish vegetation.

These obstructions reduce the flow rates of water and wind, capture and concentrate resources, and increase infiltration rates. All of this leads to an increase in plant establishment and accelerated vegetative development. Onsite sources of logs, felled trees, brush piles, contoured rock rows, or purchased burlap wattles are all examples of surface obstructions that impeded increasing water velocity and improve resource retention (Whisenant 2002).

Conservation staff will need to use a cone scale penetrometer (Figure 12) to gauge the level of compaction to assess how much manipulation will be required to address compaction conditions. A general guide to acceptable compaction ranges for multiple soil types comes from James Urban's Up by Roots: Healthy Soils and Trees in the Built Environment. Soil scientists and ecologists tend to describe soil compaction by using bulk density, while engineers utilize

Standard Proctor Density. There was no good translation correlating these two metrics until Urban's text. His table below shows that regardless of soil type (albeit with some variation), Standard Proctor Density should not exceed 80 – 85% to ensure deep root penetration (Figure 13). This language will allow conservation staff to communicate with HPB Capital projects on desired finished compaction levels once projects are handed over to conservation. Conservation should know that these levels are well below the typical compaction levels specified by engineers because they use compaction as a means to prevent erosion. However, this strategy is problematic because vegetation is the most effective means of erosion control, and if soils are compacted beyond optimal ranges, vegetation will be limited to taproot plants and annuals that are able to take hold under extreme compaction. Often, these intentional over-compacted sites will require erosion matting that remains until invasive plants can get a hold and start to spread over several years. This approach is fundamentally opposed to restoration work goals of vegetation quality, focusing instead on total coverage with no assessment of species or growth type (e.g., annual, tap root, invasive). Monitoring compaction on construction sites also inhibits contractors' abilities to drive heavy equipment all over the site. This restriction might not be a factor for work occurring in existing greenways but will need to be considered for HPB Capital projects where major grading and construction occurs.

Figure 12. Cone scale penetrometer image

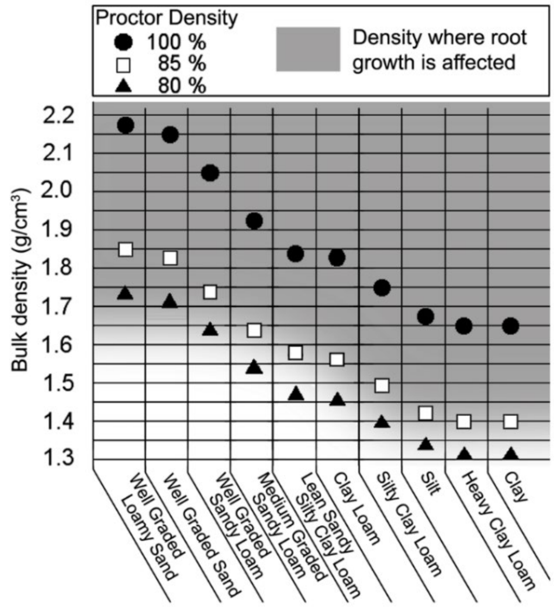

Figure 13. Standard Proctor Density to Bulk Density graph – James Urban, *Up By Roots.*

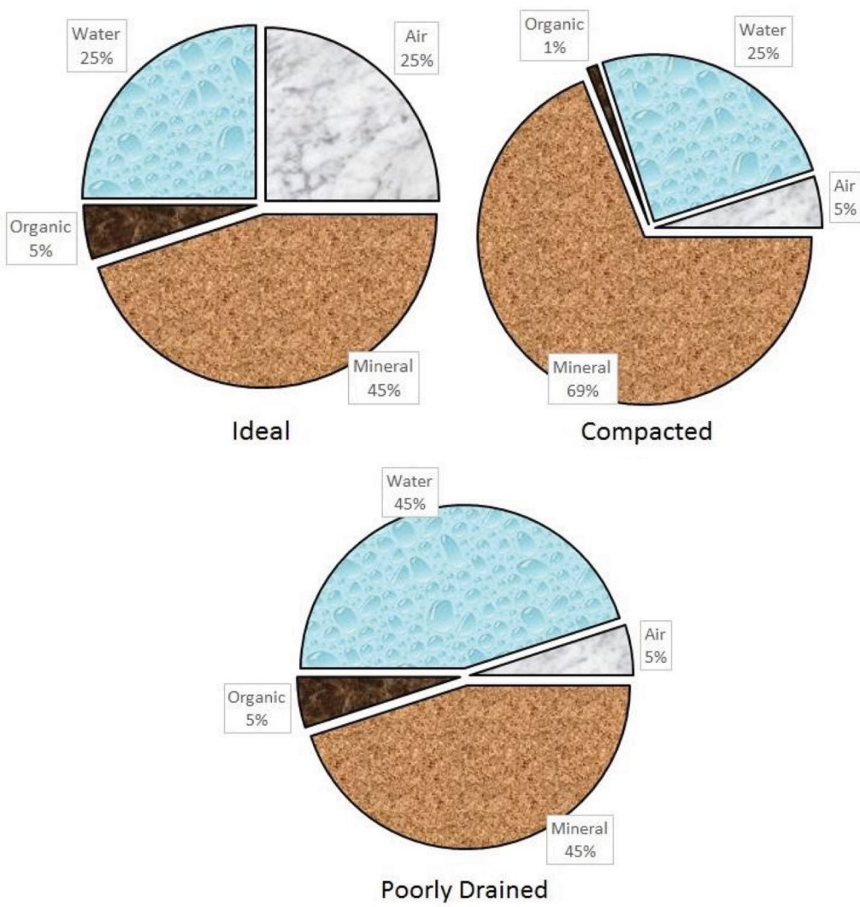

Figure 14. Image of soil particles with and without void space – NC State Extension Publications

The cone scale penetrometer will not provide hyper-accurate data, though it will provide conservation staff with an immediate answer as to whether the soil compaction rates are suitable, bordering compacted, or beyond acceptable compaction ranges. It is a very useful tool when dealing with contractors and helps provide instant feedback so that unsatisfactory work can be controlled and corrected.

Only utilize deep tilling to loosen soil if it is absolutely necessary based on compaction test results (e.g., cone scale penetrometer, bulk density testing) and if the site has no trees. As mentioned before, deep tilling or cultivation will pull up dormant invasive seed bank.

To address soil compaction, it is recommended to rototill or airspade on a low level if near tree root systems and finances allow. Rototilling at least 2' in depth and integrating 2" of high quality compost. Nature's Way Resources has the best product available. Then a 1' layer of compost should be added on top. Enforcement of VSPZ will help reduce unnecessary compaction. Once a soil is compacted it is generally not going to perform as well as an undisturbed area for quite some time even if amended.

G. Soil amendments

Besides being excessively compacted, urban soils lack important components that drive soil food web development. Historically, riparian soils possessed rich organic matter (OM) built up over millennia and also featured charcoal from reoccurring wildfires that occurred quite frequently based on historical fire return interval data. As with uplands, wildfires would often burn up to rivers with embers jumping the water and fires continuing onto other sides. Areas with high levels of shade and relative humidity, or with saturated soils might escape this disturbance. OM helps provide food for beneficial microbes (i.e., bacteria, fungi, protozoa, and nematodes), contributes towards optimal soil structure, promotes moisture retention, provides nutrients (macro and micro), drives pH levels to optimum ranges, promotes greater soil biodiversity over time (many microbes cannot be grown in labs), helps prevent runoff (a 5% increase in soil OM can quadruple soil water holding capacity), and reduces plant pathogens.

Houston Parks Board should look to acquire or self-produce static-piled compost as this method is low-tech and results in OM that is well balanced with all the aforementioned key soil food web species. Most compost is now produced via the windrow method that involves long rows of parent material that is repeatedly turned via machinery. This method allows compost manufacturers to make a product that meets all the U.S. Composting Council and TXDOT definitions of compost (e.g., does not resemble parent material, meets weak maturity and stability standards, contains no heavy metals and no E. coli or similar pathogens) within a short time span, but also results in a bacteria-dominant microbe profile with minimal protozoa and no mycorrhizae. Additionally, various manufacturers use different types of feedstocks that can produce dramatic ranges of macro and micronutrients, meaning that when applying windrow compost, conservation staff won't be sure if they are dousing new plots with high levels of N|P|K, which can result in explosive weed growth. Excessive nutrient runoff from riparian areas will contribute to degraded water quality in receiving waterways. Ensure that any fertilizer regime within riparian areas is slow-release organic component and does not possess high N | P

| K values. Many Texas native prairie and riparian species evolved in nutrient-poor conditions and do not require the fertilization regime that crops or non-native transplants need. Furthermore, in Texas, compost providers cannot provide nutrient information regarding their product, or their business will be regulated as a fertilizer manufacturer and they will be subjected to much stricter environmental review. Houston Parks Board conservation staff will have to request tests per certain batch amounts (e.g., every 1000 cubic yards) if they want to know more information, and such testing adds cost and coordination. Nature's Way Resources makes the best compost product in the Houston area, and Houston Parks Board staff could be sure that they are using compost that provides all of the aforementioned benefits, but their product costs more than typical compost, and demand is high. Because HPB has a good relationship with Nature Way Resources it is recommended to make this the priority compost source. Conservation staff should incorporate 1-3" of compost into the soil.

Though the benefits of charcoal, or biochar, are still being analyzed, we can be sure that this component was a part of historical grassland and riparian soils given the role of wildfire. There is an increasing understanding of the importance of adequate carbon-nitrogen (C:N) ratios in soil, though there is no definitive prescription for replicating conditions that best promotes grassland restoration, nor is there a definitive list of what specific C:N ratios existed for the soil orders where grasslands dominated (e.g., Alfisols, Vertisols, Mollisols). However, an important insight into the benefits provided by soil charcoal is demonstrated by archaeological research into the prehistorical and historical amendment of tropical sandy and loamy soils with charcoal, or *Terra Preta*. These amended agricultural soils have maintained fertility and other desirable performance traits for over 2000 years, and researchers found that charcoal makes it possible to "convert infertile soils' insufficient physical and hydrological properties to sustainable, fertile soils with good physical and hydrological properties."[28] Further examination of the amended soils provided a definitive correlation between improved soil function with charcoal particle size, stating, "The reduction of particle size causes an increase in water retention and total porosity and a decrease in available water content and bulk hydrological and chemical properties of soil."[29] Smaller particles were demonstrated to be the most effective. To be clear, de Jesus Duarte et. al. did focus on tropical sandy and loamy soils, but the purpose of the inclusion of this study is to provide an accurate, non-industry assessment of the potential beneficial effects of charcoal when integrated into soil horizons.

Given the documented presence of charcoal with soil matrices in fire ecologies, Houston Parks Board conservation should endeavor to not only recreate above ground conditions, but also mimic below ground components when practical and economically feasible. When looking to restore ecosystems it will be important to must embrace systems-based design, a strategy that acknowledges the drivers, components, complex relationships, and functional processes of ecosystems rather than static reactionary responses. Blackland Collaborative currently uses a product out of Washington State by Biochar Supreme called Black Owl™ Premium Organic

[28] "Effect of Biochar Particle Size on Physical, Hydrological and Chemical Properties of Loamy and Sandy Tropical Soils." (de Jesus Duarte et al. 2019).
[29] Ibid., (de Jesus Duarte et al. 2019).

BIOCHAR and integrates ½” – 1” into the soil. Shipping costs are expensive for this product, but if Houston Parks Board conservation staff purchases bulk amounts, they could potentially negotiate product cost to negate some of the shipping fees.

In addition to compost and charcoal, Houston Parks Board conservation staff can further improve soil conditions by adding amendments that contain low level N|P|K, organic fertilizer, humic acid, horticultural molasses, beneficial microbe inoculant, and micronutrients. Organic fertilizer feeds the soil life as well as boosting vegetative growth. Humic acid serves as food for mycorrhizae while horticultural molasses serves as food for beneficial bacteria. There are products that can be applied to the soil before seeding and planting as well as after the native growth has started. Products with organic fertilizer should aim for low levels such as 2,3,2. The object is to feed the soil more so than the plants. Organic fertilizer should only be applied 2-3 times per season or more frequently if in response to chlorosis, but increased frequency should be driven by ***soil sample nutrient data*** if chlorosis does occur.

H. Seeding

Seeding is the most cost-effective means of achieving diversity and richness within a grassland restoration. The key to seeding successfully is ensuring that seeding is done with appropriate species and rates, with correct method, and within appropriate seasonal windows. Blackland Collaborative has provided Houston Parks Board conservation staff with a starter seed mix to reference that they can incorporate (Table V). It is strongly recommended that recommended seed rates are doubled or tripled. This will provide the projects with an instant native seed bank and help combat competition and has proven successful in a number of restoration projects.

In addition to commercially purchased seed, wild collected seed from remnant riparian areas and prairies and other local conservation groups should be incorporated into the seed mix or spread separately on projects. This is important for genetic diversity and to have the most local sources available. Commercially purchased seed should be well researched and the origin of the seed should be discussed with the supplier. Seasonal seed collection outings should be part of the conservation team’s regular duties for yearly supplemental diversity seedings.

Table 3. Starter Seed Mix Type 1

SEED MIX TYPE 1: UPLAND/SAVANNA MIX			
Habit	**Scientific Name**	**Common Name**	**Ideal lbs Per Acre Needed**
grass	*Andropogon gerardii*	Big bluestem	3
grass	*Andropogon glomeratus*	Bushy bluestem	1
grass	*Bouteloua curtipendula*	Sideoats grama	3
grass	*Elymus canadensis*	Prairie Wildrye	1
grass	*Chasmanthium latifolium*	Inland sea oats	1
grass	*Paspalum floridanum*	Florida paspalum	2
grass	*Leptochloa dubia*	Green sprangletop	1
grass	*Schizachyrium scoparium*	Little bluestem (Gulf)	4
grass	*Sorghastrum nutans*	Indiangrass	3
grass	*Tridens flavus*	Purpletop tridens	1
grass	*Tripsacum dactyloides*	Eastern gamagrass	2
forb	*Coreopsis lanceolata*	Lanceleaf coreopsis	2
forb	*Coreopsis tinctoria*	Plains coreopsis	1.5
forb	*Dracopis amplexicaulis*	Clasping coneflower	1.5
forb	*Gaillardia pulchella*	Indian Blanket	4
forb	*Ipomopsis rubra*	Standing Cypress	3
forb	*Lobelia cardinalis*	Cardinal flower	(pkt 50 ct)
forb	*Monarda citriodora*	Lemon beebalm	2
forb	*Phlox drummondii*	Drummond Phlox	2
forb	*Rudbeckia hirta*	Black-eyed Susan	2
forb	*Asclepias virids*	Green Milkweed	.15
forb	*Asclepias tuberosa*	Butterflyweed	.15
forb	*Asclepias syriaca*	Common Milkweed	.15
		Total	39.45

Table 4. Starter Seed Mix Type 2

SEED MIX TYPE 2: SHADE RIPARIAN SHADE MIX			
Habit	**Scientific Name**	**Common Name**	**Ideal lbs Per Acre Needed**
grass	*Andropogon gerardii*	Big bluestem	3
grass	*Andropogon glomeratus*	Bushy bluestem	1
grass	*Bouteloua curtipendula*	Sideoats grama	3
grass	*Elymus canadensis*	Prairie Wildrye	1
grass	*Paspalum floridanum*	Florida paspalum	2
grass	*Leptochloa dubia*	Green sprangletop	1.5
grass	*Schizachyrium scoparium*	Little bluestem (Gulf)	4
grass	*Sorghastrum nutans*	Indiangrass	3
grass	*Tridens flavus*	Purpletop tridens	1
grass	*Tripsacum dactyloides*	Eastern gamagrass	2
grass	*Chasmanthium latifolium*	Inland sea oats	3
forb	*Coreopsis lanceolata*	Lanceleaf coreopsis	2.5
forb	*Coreopsis tinctoria*	Plains coreopsis	1.5
forb	*Dracopis amplexicaulis*	Clasping coneflower	1.5
forb	*Echinacea purpurea*	Purple coneflower	5
forb	*Gaillardia pulchella*	Indian Blanket	4
forb	*Lobelia cardinalis*	Cardinal flower	(pkt 50 ct)
forb	*Phlox drummondii*	Drummond Phlox	2
forb	*Rudbeckia hirta*	Black-eyed Susan	2
		Total	43

Table 5. Starter Seed Mix Type 3

SEED MIX TYPE 3: RIPARIAN PRAIRIE MIX			
Habit	**Scientific Name**	**Common Name**	**Ideal lbs Per Acre Needed**
grass	*Andropogon glomeratus*	Bushy bluestem	1.5
grass	*Chasmanthium latifolium*	Inland sea oats	1
grass	*Leptochloa dubia*	Green sprangletop	1.2
grass	*Panicum obtusum*	Vine Mesquite	2
grass	*Panicum virgatum*	Switchgrass	6
grass	*Paspalum floridanum*	Florida paspalum	2
grass	*Schizacyrium scoparium*	Little Bluestem	2
grass	*Tridens albescens*	White Tridens	2.2
grass	*Tidens flavus*	Purpletop	6.5
grass	*Tripsacum dactyloides*	Eastern gamagrass	3.5
forb	*Coreopsis lanceolata*	Lanceleaf coreopsis	2.5
forb	*Coreopsis tinctoria*	Plains coreopsis	1.5
forb	*Dracopis amplexicaulis*	Clasping coneflower	1.5
forb	*Echinacea purpurea*	Purple coneflower	5
forb	*Helianthus maximiliani*	Maximillian Sunflower	2
forb	*Lobelia cardinalis*	Cardinal flower	(pkt 50 ct)
forb	*Rudbeckia hirta*	Black-eyed Susan	1
forb	*Salvia farinacea*	Mealy Blue Sage	1.5
forb mix	*Asclepias incarnata, Asclepias viridis*	Roundstone Seed Southern Monarch Milkweed Seed Mix	1
		Total	44

Table 6. Starter Seed Mix Type 4

SEED MIX TYPE 4: DIVERSITY MIX			
Habit	**Scientific Name**	**Common Name**	**Apply**
grass	*Andropogon virginicus*	Broomsedge bluestem	Spring
grass	*Carex cherokeensis*	Cherokee Sedge	Spring
grass	*Dichanthelium acuminatum var. fasciculatum*	Western Panicgrass	Spring
grass	*Dichanthelium clandestinum*	Deertongue	Spring
grass	*Dichanthelium dichotomum*	Cypress Panicgrass	Spring
grass	*Eragrostis spectabilis*	Purple Lovegrass	Spring
grass	*Paspalum denticulatum*	Longtom	Spring
grass	*Paspalum plicatulum*	Brownseed Paspalum	Spring
forb	*Arnoglossum ovatum*	Ovateleaf Cacalia	Fall
forb	*Arnoglossum plantagineum*	Prairie Plantain	Fall
forb	*Asclepias linearis*	Slim Milkweed	Fall
forb	*Asclepias oenotheroides*	Zizotes Milkweed	Fall
forb	*Asclepias verticillata*	Whorled Milkweed	Fall
forb	*Asclepias viridis*	Green Milkweed	Fall
forb	*Baptisia alba*	White Wild Indigo	Fall
forb	*Baptisia australis*	Blue Wild Indigo	Fall
forb	*Baptisia sphaerocarpa*	Yellow Wild Indigo	Fall
forb	*Callirhoe involucrate*	Winecup	Fall
forb	*Desmanthus illinoensis*	Illinois Bundleflower	Fall
forb	*Eryngium yuccifolium L.*	Rattlesnake Master	Fall
forb	*Euthamia leptocephali*	Bushy Goldentop	Fall
forb	*Helianthus angustifolius*	Swamp Sunflower	Fall
forb	*Helianthus maximiliani*	Maximilian Sunflower	Fall
forb	*Lobelia puberula*	Downy Lobelia	Fall
forb	*Polytaenia nuttallii*	Prairie Parsley	Fall
forb	*Rudbeckia texana*	Texas Coneflower	Fall
forb	*Silphium gracile*	Slender Rosinweed	Fall
forb	*Sisyrinchium angustifolium*	Narrowleaf Blue-eyed Grass	Fall
forb	*Solidago sempervirens*	Seaside Goldenrod	Fall
forb	*Vernonia missurica*	Missouri Ironweed	Fall
	*Harvest Seed When Possible or Transplant		

Seeding method will have a big impact on project success. No-till drill is by far the best means of incorporating seed into the soil at the proper depth without causing problems arising from deep cultivation. The Dew Drop Drill is a great piece of equipment that will allow you to seed areas ¼ acre and above with ease and can be pulled by an ATV (Figure 15). Like most no till drills, it has a bin with auger for fluffy seed and another bin? for dense seed. the benefit of this piece of equipment can not be overstated, and Houston Parks Board conservation staff should look to acquire one when able. When no till drilling, best results are achieved by making a first pass along the entire plot and then following up with a second pass that runs perpendicular to the path of initial coverage.

Hand seeding or broadcast seeding is acceptable for smaller plots, but this method can skew success and favor certain species over others (Figures 16-18). If this is the only option, follow the same strategy as with no till drilling where staff seeds in one direction to cover entire plot, and then finish out seeding by making a second pass perpendicular to the first pass. After seeding is complete, staff will need to brush the seed in with a rake or branch from a tree. The idea is to ensure good seed/soil contact without burying the seed too deeply. This can be very tricky as the seed mix will incorporate many types of seed of varying size. The rule of thumb guides that seed should not buried deeper than twice its width. Burying seed deeper than this depth will eliminate the potential of germination. This method is not recommended for large scale seeding.

A third option for Houston Parks Board staff where slope is an issue is hydraulically applying seed mixed with the product similar to Proganics Biotic Soil Media (BSM). Staff or contractor should follow manufacturer's installation instructions and recommendations. Proganics is mixed at a rate of 75 to 100 pounds per 100 gallons of water. Proganics should be applied at 3,500 to 5,000 lbs/A. Contractor should be able to mix custom seed mix as required, but staff will need to coordinate with contractor to ensure that equipment can handle the required amounts. Proganics is an expensive product with many benefits and HPB will need to determine if this is justified on a per project basis.

A cheaper option for hydroseeding would be to use the typical cellulose/tackifier/seed mix. This method typically consists of applying a mixture of wood fiber, seed, and stabilizing emulsion with hydro-mulch equipment, which temporarily protects exposed soils from erosion by water and wind. The practice may also be called hydro mulching, hydraulic planting, hydraulic mulch seeding, hydraseeding.

Hydroseeding isn't as preferred as no till drill seeding and Blackland Collaborative has had mixed results with this method. Other researchers have also documented skewed species results (legumes tend to be favored) and restoration companies also report that hydroseeding is generally not recommended. Having said that, if this option is needed for steep slopes or other access issues the following steps should be followed:

Materials

- Seed

- Wood Mulch
- A guar based tackifier (organic plant based thickening and binding agent) can be used, though the BC has had issues with germination rates with the application of tackifier. It is recommended that HPB omit the tackifier if the hydroseeding is not being used for slopes or to reduce soil erosion.

Seed Mix:
Utilize appropriate mix of choice

Wood mulch:
1850 lbs per acre (about 45 lbs. per 1,000 square feet), HPB should not exceed that number as wood (brown) material will begin to break down and impede germination due to loss of macronutrients.

Guar tackifier:
30 lbs./acre prepared in mechanically agitated hydro-seeder slurry

Construction Guidelines

1. Prior to application, roughen embankment and work so soil surface is even, but friable and ready to receive seed

2. Hydroseeding can be accomplished using a multiple-step or one-step process:

- The multiple-step process ensures maximum direct contact of the seeds to soil
- When the one-step process is used to apply the mixture of seed, fiber, etc., the seed rate shall be doubled to compensate for all seeds not having direct contact with the soil
- Follow-up applications shall be made as needed to cover weak spots
- The time allowed between placement of seed in the hydraulic mulcher and the emptying of the hydraulic mulcher tank should not exceed 30 minutes
- Application of the slurry should proceed until a uniform cover is achieved. The applicator should not be directed at one location for too long a period of time or the applied water will cause erosion

***It is extremely important that Houston Parks Board staff ensures contractors have washed out all tanks meticulously before application. Failure to do so could result in a dirty tank contaminated with invasive seed such as bermudagrass.**

Figure 15. Image of Dew Drop Drill

Figure 16. Image of No till Drill vs hand seeding Headwaters at the Comal

Figure 17. No-till drill example, Headwaters at the Comal bioswale edge

Figure 18. Image of eastern gamagrass – Carolina Biological Supply Company

Figure 19. Indian Paintbrush seed – Missouri Wildflowers Nursery

Seeding windows are extremely important to ensure success. There are two seasons for installing seed, fall and spring. Forbs and cool season grasses have the best success if planted in the fall while warm season grasses and annual forbs prefer going in during the spring. Often projects can only have one seeding so conservation staff will have to decide if they want to seed a plot only once or if they can incorporate two seasons of seeding to provide warm and cool season grasses and forbs the best chance to become established. Possessing a no till drill makes the two-season approach very easy and only requires that the site is prepped by removing thatch and growth by prescribed fire or mowing and hand removal. The seed can then be drilled into the “cleared” area. If conservation staff only seeds once, you will need to be very patient with the evolution of the prairie to see if there is reduced presence of any species that were planted outside their optimal installation window. The planting window times can contract and expand depending upon El Niño Sothern Oscillation (ENSO) trends and weather patterns. For the Houston area, the fall window could likely be October – December and spring March – June. Conservation staff will need to ascertain the best windows based on climate data and weather forecasts. While water is an extremely important factor, the main concern is excessive heat. If the temps are above 80°F or below 60° F the seed will not grow very well and there is the chance that if there are any excessive swings within the first 6 weeks of growth, seedlings will be lost.

I. Live planting

Live planting is a great way to boost the seeding effort, establish plants in areas that are too wet for seed, and shortcut the site’s herbaceous evolution by incorporating later successional species such as little bluestem (*Schizachyrium scoparium*), switchgrass (*Panicum virgatum*), and big bluestem (*Andropogon gerardii*) for part shade areas and Indian grass (*Sorghastrum nutans*) part shade/shade for grass components or woody species such as shagbark hickory (*Carya ovata*) or magnolia (*Magnolia grandiflora*).

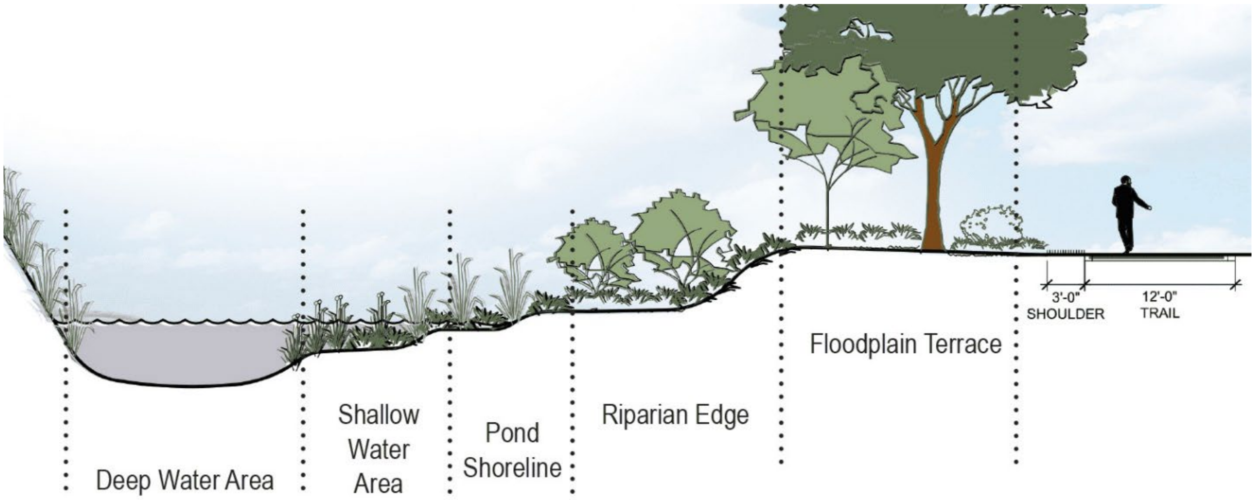

Figure 20. Recommendations for Streambank Planting. Source: Great Rivers Greenway. This image above shows a breakdown of zone components that should be considered when planting.

Plantings in shallow water to shoreline should follow wetland BMP measures for establishment procedures. Planting in the riparian edge and floodplain terrace can be challenging due to fluctuating water levels and high flow events. These dynamic processes can create variability that dramatically affect planting success. Because of this, planting within the riparian edge as demonstrated above should focus on stream stabilization rather than aesthetics.[30] Rivers and streams react to the volume and speed of runoff from adjacent contributing upland zones. If there is adequate canopy and herbaceous coverage within upland and riparian components, runoff is dramatically reduced creating manageable above ground sheet flow and subsurface flow that results in a stable channel. Urban streams usually demonstrate many qualities that hydrologists consider representative of a dysfunctional system, such as downcutting, wide channels with shallow water, increased flood flows, large scale erosion, turbid water, and absence of large woody debris in and along the bank.[31]

Houston Parks Board staff should consider using a diversity of trees, shrubs, grasses, and forbs to shade water and ensure bank stability. Wider buffers provide better habitat. Select species best suited to stream flow and the water table. Aquatic species should be planted in the shallow water area and shoreline. Along the shoreline and riparian edge, areas with regular high and intense flows will benefit from plantings of grass species such as switchgrass and eastern gamagrass. These species protect the bank via extensive root systems and their ability to lie down during high flows, protecting the surface as well. Plants with flexible stems and rhizomatous root spread should be located from the shoreline into the top of the riparian shoreline. Small to medium shrubs should also be included along the bank and into the riparian edge. Large tree species, shrubs and upland herbaceous species should be planted on the top of the riparian edge and in the floodplain terrace. Care should be taken to exclude larger trees

[30] Great Rivers Greenway, "Recommendations for Streambank Planting."
[31] Nueces River Authority, *Your Remarkable Riparian: A Field Guide to Riparian Plants Within the Nueces River Basin of Texas*, 4.

within areas that can experience high velocity events because there is a high probability of damage/mortality, as well as, causing buildup of debris or contributing to erosion. Trees also produce resistance to flow and can exacerbate flooding if there are concentrated swaths that possess large trunk diameter.

Currently for grasslands in the upland areas, conservation staff is utilizing live plantings as a buffer on the outer edges of the grassland areas to help prevent infiltration of invasive species from the exterior. This is a great strategy, but conservation staff should also incorporate swaths of later successional species and diversity plantings within the interior (Figure 21) When installed, there is no definitive formula for scale, but depending upon project size, staff should incorporate drifts of plants spaced 1'- 2' on center in grid. The number of plants incorporated per site should vary according to the site's scale, but for example a 16' x 16' space could incorporate 81 1-gallon plants at 2' on center grid spacing. Live planting in this manner allows conservation staff densely pack desired species into a small area. It is important to remember that later successional species can only grow and thrive if they have established a symbiotic relationship with certain microbes, so by planting these desired live plants into the prairie, the conservation team will inoculate the interior component of the restoration areas. See Prairie BMP for more information.

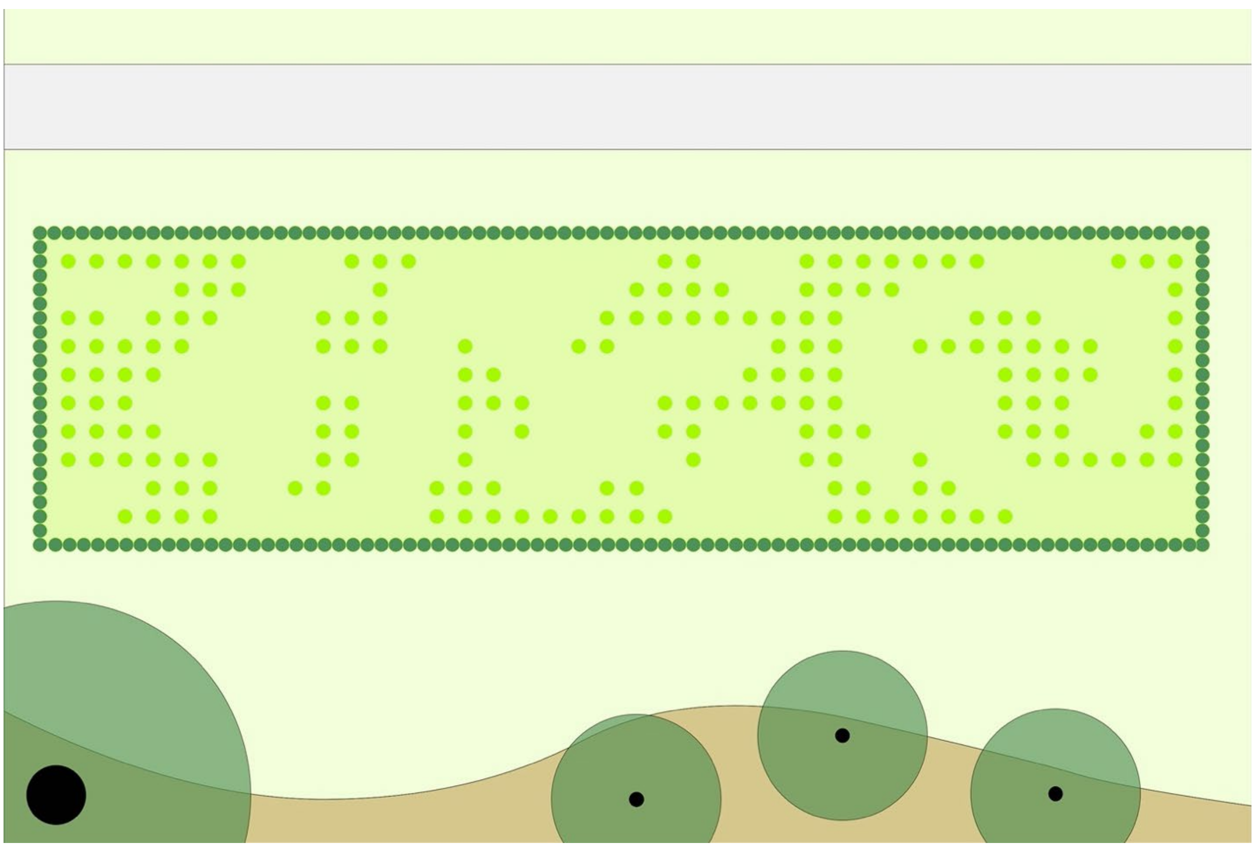

Figure 21 – Planting strategy diagram. Dark green circles are exterior edge of diversified native plantings that HPB currently uses, interior space would be seeded and drifts of later successional species such as little bluestem are plugged to help inoculate soils and introduce older growth.

When installing live plants, the hole should be similar to the size of the planting (e.g., 4”, 1 gallon, 3, gallon, etc.). The hole should not be too deep so that the base of the plant is lower than the surrounding ground level. The excavated soil should then be used to fill any air spaces, but the soil should not be over-compacted.

Live plantings are also beneficial for shady and/or wet areas where seed has difficulty establishing. Also, species that are difficult to purchase by seed such as sedges, diversity plants, and other cool season species should be planted as plugs or gallon material.

Rescuing valuable plant material from projects pre-construction is an excellent way to then replant the site with conserved material. The conservation team needs to have the capacity to pot and maintain the plants until they are ready to be planted. Salvaging plants from other sites beyond HPB in areas that will be disturbed due to construction or other impacts is another best management practice to preserve plant material and provide benefits to the soil biology. Plant salvage events should also be a regular practice.

Planting tree recommendations

Container grown trees:

Prep and Storage

Before beginning any planting, it is very important to remove any extra growth or invasive species from the pots. This should be done before plants arrive to the restoration site, but it is important to always double check before planting. If trees are being stored before planting, make sure to keep the plants in the shade and water frequently depending upon the weather conditions to keep the soil moist in the pots as they will dry out frequently.

Tree hole and placement

Container grown trees should ideally be planted in a hole three times the diameter of the container. Majority of the HPB holes will be excavated using a tree auger. Shovels are also options for larger volunteer/staff plantings. Try to not overly compact the soil on the side of the holes. If the sides look too slick, you can scuff the sides with your hands. This will allow for easier root penetration.

Tree height

It is important to not plant a tree too low. The hole should be shallow enough to allow the top of the root ball or root flare to sit just above ground (or even a bit higher as nursery soil is lighter than native soil and will compact causing the tree to sink over time). If a tree is planted too low, it is susceptible to rot. This is a common error in tree planting. It is preferable to err on planting a tree too high rather than too low. If the tree is planted a bit too high this can be accounted for with mulch.

Root assessment

When removing the tree from the pot, the roots should be inspected for root binding and the soil should be lightly loosened from compaction. It is recommended to “tickle the roots” to get them ready for growth. It is not necessary to be more aggressive with decompaction of the roots. If roots are girdling or root bound there may be a need to cut some roots to help them grow in a straighter direction for the health of the tree.

<u>Backfilling</u>

Before placing the tree in a hole, root hormone should be placed in the hole. When backfilling the soil, with native soil don't compress too much, add soil in stages, and make sure there are no air pockets. Break up the large clumps and heavily water the soil between rounds. Watering requirements depends on the soil and weather conditions. Generally, generous watering is recommended unless the conditions are very wet. It is not ideal to plant in too wet conditions as the soil will become compacted and will be hard for the tree to establish its roots. Filling the hole with water can be done if planting is occurring in dry conditions. Tree planting should be done in the tree planting windows. These are outlined below in this document. Planting outside of the ideal planting windows greatly increases tree mortality chances. Only fill the hole up to just below the root flare.

<u>Mulching</u>

Adding a high-quality mulch to the top of the plantings is recommended with 50/50 compost from Natural Resources. Again, be careful to not place the mulch up against the tree trunk. This is a common mistake when planting trees and can also cause rot and disease. Mulch in a radius of 2 to 3 feet from the trunk. Spread about 3 to 4 inches deep of mulch. Leave a space of at least 3" between the mulch and the trunk itself. **Do not pile mulch up against the tree.** Tree rings around the outside edge of the planting area are recommended to keep moisture concentrated in the new tree planting zone. If the weather is wet for an extended period, then rings are most likely not necessary.

Trees should be planted in winter during full dormancy to increase survivability. This will by no means guarantee success and a potential mortality rate of up to 70% should be acceptable to team. Young transplants will likely have much higher survivability rates if no extreme weather events occur and there is no pressure from herbivores.

For more information on planting trees please refer to the **HPB Woodland BMP I. Live plantings- Tree planting**s section. In addition, another in-depth resource on best management practices for planting trees in urban environments Houston Parks Board should purchase James Urban's *Up By Roots: Healthy Soils and Trees in the Built Environment* and the International Society of Arboriculture's *Best Management Practices – Tree Planting, Second Edition.*

Table 7. Riparian Live Plantings

LIVE PLANTING: RIPARIAN MOIST SOIL PRAIRIE LIVE PLANTINGS		
Habit	**Scientific Name**	**Common Name**
grass	*Andropogon glomeratus*	Bushy bluestem
grass	*Carex blanda*	Creek Sedge
grass	*Carex emoryi*	Emory Sedge
grass	*Carex texensis*	Texas Sedge
grass	*Eleocharis ssp.*	Spikerush
grass	*Juncus effusus*	Soft rush
grass	*Juncus tenuis*	Path rush
grass	*Scirpus validus*	Bulrush
grass	*Tripsacum dactyloides*	Eastern gamagrass
forb	*Eryngium yuccifolium*	Rattlesnake Master
forb	*Justicia americana*	American Water Willow
forb	*Physostegia intermedia*	Obedient plant
forb	*Pontedaria cordata*	Pickerel Weed
forb	*Sagittaria lancifolia*	Bulltongue arrowhead
forb	*Veronia baldwinii*	Western Ironweed

Trees/Shrubs	
Bald cypress	Taxodium distichum
Cedar elm	Ulmus crassifolia
Eastern swampprivet	Forestiera acuminata
Green ash	Fraxinus pennsylvanica
Hawthorn	Crataegus spp.
Planertree	Planera aquatica
Possumhaw	Ilex decidua
Sugar hackberry	Celtis laevigata
Sycamore	Platanus occidentalis

Water hickory	Carya aquatica
Water locust	Gleditsia aquatica
Black willow	Salix nigra
Sandbar willow	Salix exigua
Eastern cottonwood	Populus deltoides
Pecan	Carya illinoinensis
Little walnut	Juglans microcarpa
Black walnut	Juglans nigra
Roughleaf dogwood	Cornus drummondii
Flame-leaf sumac	Rhus lanceolata
Water tupelo	Nyssa aquatica

Planting Windows

Depending upon current climatic conditions, ideal planting/sowing windows for each type of plant are listed below:

Table 8. Planting Windows

Plants	Season
Spring forbs and grass mixes	March - May
Warm season grasses	October - May*
Cool season grasses	October - mid November
Perennial forbs	October - May**
Annual Forbs	March - April
Shrubs	October - Early November and March - June
Trees	November - February***

*Best results when planted in spring.

**Best results when planted in fall.

***Best to plant trees when they are dormant during the winter to avoid transplant shock. However, they can also be planted, depending on climatic conditions, in late fall and early spring if necessary. These trees will require more attention.

J. Watering for Establishment

Watering trees

Trees should be planted in the winter and watered the day they are planted. Then they should be watered weekly depending upon the weather for two years. Watering needs will typically decrease in the winter and increase in the summer months. After the two-year establishment period the trees should be watered as needed. It will be important to regularly inspect for stress especially during the summer months.

Drench all trees and shrubs with water twice, during the first 24 hours after installation. This will ensure the root zone is well saturated. Maintenance of soil moisture at or greater than 6" below grade during early (3-6) months is critical for tree establishment. Young saplings should be watered twice a week (saturating the critical root zone) for 2-3 months. At each watering, thoroughly saturate the soil around each tree and ensure proper soil moisture at least 6" below grade. Over the next four months, the root depth should not be allowed to dry out, watering every other week or as necessary depending on local weather conditions. After this initial establishment period, stormwater runoff should provide sufficient irrigation needs. However, if there is a long drought period or no significant precipitation for any 4-6 week period over the first two growing seasons, the trees will need supplemental watering. Trees should be maintained for two years and inspected at least once a month during this two-year establishment period.

Tree Establishment Watering Schedule

- Trees generally will require anywhere between 5-10 gallons of water per inch of diameter. The lower value of this range is for trees planted in optimal conditions, with the latter needed by trees planted in stressed conditions (urban street trees, trees planted under turf or competing with other herbaceous components, trees surrounded by compacted soils). Ideally, the root zone will remain moist, but not soggy to a depth of 12 to 18 inches.

- For the first 18 months trees must receive water in addition to any water supplied via other sources (e.g. rain, lawn sprinkler, adjacent irrigation zones) if not permanently irrigated.

- Minimum watering:
  January, February, March, November, and December once per week
  April, May, and October 3 days per week
  June, July, August, and September every other day

Caliper	Requirement
Inches	Gallons Per Week
0-5	1-5
6-10	10-20
11-15	30-45
16-20	60-80
21-25	100-125
26-30	150-180
31-35	210-245
36-40	280-320
41-45	360-345
46+	450+

Watering seeds

Houston Park Board might not be able to provide water for establishment for every project, but the presence of available moisture is vital for seed and newly planted species. Currently, all new sites enter a 1-year minimum contract with the contractor to water the projects for regular weekly or biweekly watering. It is critical for the site to be watered for the first 6 weeks after seeding- especially for large-scale projects. While Houston receives an average of 49” per year, staff should anticipate swings in precipitation stemming from climate change. Having the ability to water as needed will ensure that projects will not need to be reworked should dramatic dry spells occur. Houston Parks Board should also consider possibly establishing irrigation for “showpiece prairies” that might be located in important areas if financially feasible.

Establishment Watering Schedule

- First 10 days seed is not allowed to dry out – watering event replicating 1” rain event every day
- Next 3 weeks – watering event replicating 1” event every other day
- Next 2 weeks - watering event replicating 1” event twice a week

  *This schedule can be adjusted, and days skipped if rainfall occurs

Ideally watering should occur during times when water loss from evaporation is lowest (dawn and/or dusk) but without potentially creating a disease-prone environment. Watering should not occur after a sufficient rain event or when otherwise unnecessary.

K. Monitoring for establishment

Each project will establish differently over time, but if done right, conservation staff should see verdant seedling growth within the first three weeks. Staff will need to become familiar with each native species seedling and seedlings of invasive plants. They will also need to know each of these plants as they advance in their life cycle. Each project should have regular establishment monitoring for the first two years with the first year having a minimum of a site visit every two weeks. Woody species will be easier to monitor, though 100% survivability is not a reasonable expectation. On prior restoration projects with the Texas A&M Forest Service, Blackland Collaborative was informed that a 30% establishment rate is acceptable. That also means that 70% mortality is acceptable. Houston Parks Board staff will need to establish what is acceptable for woody species in terms of survivability.

Spot treatment of invasive species should occur if rhizomatous or stoloniferous species such as bermudagrass or johnsongrass pop up. Hand removal can occur for woody species, and regular sweeps should be made during inspections to make sure undesired plants are not allowed to go to seed. Any plants that are setting seed or sprouting should be treated or pulled, seedheads or plants bagged, and then bags discarded. If invasive spot treatment occurs and results in dead patches, conservation staff should remove dead material and then reseed with bare patch mix (Table 9). This will involve lightly roughening the soil and hand seeding into the site. While the seed can be ordered as needed, most projects find it helpful to have some seed on-hand so they can seed as soon as needed. It is imperative to not leave the void unattended because urban areas are vectors for invasive species and could potentially fill the space if native seed or live plugs are not planted as soon as possible.

Table 9. Bare Patch Mix

SEED MIX TYPE 2: BARE PATCH MIX			
Habit	**Scientific Name**	**Common Name**	**1 Acre coverage**
grass	*Bouteloua curtipendula*	Sideoats grama	1
grass	*Leptochloa dubia*	Green sprangletop	1
grass	*Paspalum floridanum*	Florida paspalum	0.5
grass	*Tridens flavus*	Purpletop	1
grass	*Tripsacum dactyloides*	Eastern gamagrass	1
forb	*Monarda citriodora*	Lemon beebalm	1
forb	*Rudbeckia hirta*	Black-eyed Susan	1
		Total	6.5

Undesired woody growth should be removed as it pops up with a weed wrench in areas of herbaceous communities or due to conveyance needs (Figure 22). Nature prevented sapling establishment with wildfire and high intensity grazing. The absence of these disturbance events means that conservation staff will have to take up that function and serve as bison surrogates where appropriate.

Figure 22. Image of weed wrench

L. Management and Maintenance

The goal of restoration is to restore ecosystem process, not simply to replace components. Ecosystem processes allow natural systems to repair themselves and to remain relatively stable. The restoration principles help make connections between site context and site-specific information and help relate to future restoration projects and maintenance. Developing a restoration and maintenance plan that incorporates a well-supported interpretive plan reinforces a successful implementation, maintenance, and education impact.

The restoration invasive species toolbox is composed primarily of prescribe fire, mowing, physical removal, and chemical treatments. Often, it is not one tool or another, it is a combined use of these tools and practices. Mowing will most likely be the main disturbance tool for HPB's prairies and savannas.

Mowing can be substituted for other treatments, such as fire, though the effects are not equivalent. Mowing leaves a thatch on the ground that will, over time, begin to choke prairie species (grasses and forbs). Raking thatch after mowing is recommended. However, mowing will retard woody invasion. Combining select spot treatments of herbicide on woody species will reduce the need for frequent mowing. During the first year of establishment, it would be beneficial to mow 1-3 times at 8" to let in sunlight and allow germination. This is especially recommended in areas where native aggressive plants might be present such as sumpweed (*Iva annua*) or aggressive plants that could quickly dominate a restoration. However, grasses can tolerate annual mowing in winter if desired while most grasses are dormant. Mowing at other times of the year may result in loss of that year's seed and competitively favor undesired species. Mowing may be undertaken any time after grass seeds have ripened (December) or alternatively may be delayed until very early spring (February), just before the plants begin to green up. Bunch grasses grow from the crown, so mowing height should be at least 4 to 6 inches. Mowing in the Houston area may require mowing more than once a year due to invasive species pressure. If invasive species are an issue, mowing in mid-June to mid-July can help maintain plant diversity.

Management of new habitat types requires frequent monitoring and recording of management activities and performance results. Adaptive management practices should be applied following an adaptive management framework.

Adaptive management

Adaptive management is a management approach that acknowledges uncertainty in ecological systems and reduces uncertainty by using a problem-solving management approach. The focus is on learning about the system and how to best change the system. The process for adaptive management is circular in nature starting with assessment, design, implementation, monitoring, evaluation, and adjusting. Adaptive management is a hybrid of management and research (Murrary and Marmorek 2003).

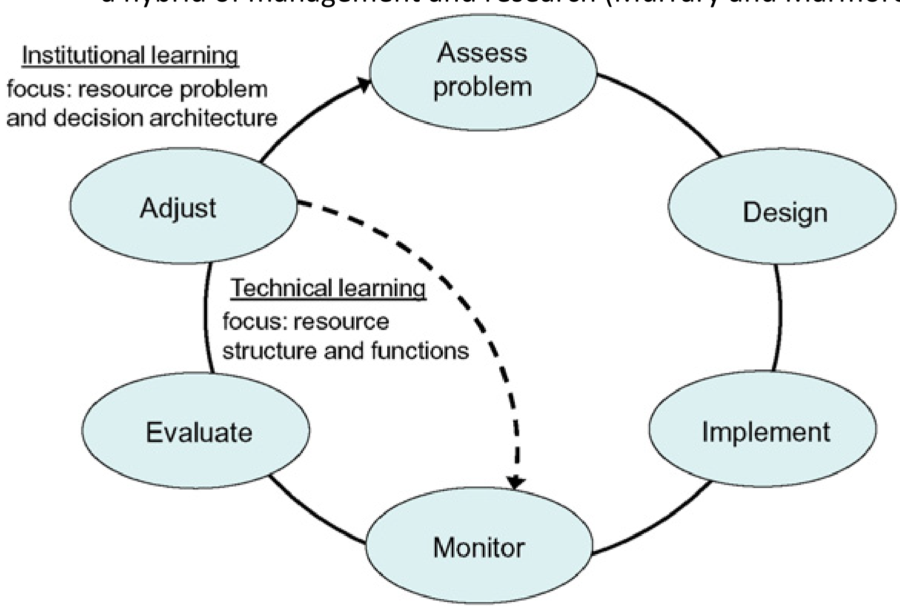

Figure 23. Diagram of the Adaptive Management process. (Williams and Brown 2016).

Figure 23 provides a diagram of adaptive management's circular process starting with assessing the problem and then moving from there to design, implement, monitor, evaluate, and adjust. The diagram also highlights that there is a smaller circle within the larger framework where learning regarding the methods can be adjusted while maintaining the larger process. Managing complex living systems in urban environments with relatively new science requires flexibility, adaptability, as well as a method and process. More information regarding adaptive management and maintenance recommendations are included in the associated *HPB BMP Management and Maintenance Guidelines.*

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VII. Appendix

Appendix A. Data Sheets (also provided as an excel document)

1. Field Check

Date: Surveyor: Rapid assessment-vegetation

Point/ location	Dominant communities	Soil surface condition overall (1-5)	Erosion class (1-5)	Erosion extent (% cover)	Invasive (% cover)	Valuable species (% cover)	Invasives - other	High value - other
					total	total		
					Dominant spp.	heritage tree (>60.96 cm)		
					Ligustrum sp.	protected tree (>48.26 cm)		
Overall diversity	Woody age diversity	Dominants overstory	Dominants midstory	Dominants Herb	bermudagrass	Reference community spp.		
Riparian buffer (width-ft)	Connection to floodplain (high/med/low)	Bottomland/ riparian diversity (high/med/low)			Challenges	Assets	Additioaal challenge/ asset	Boundary/ adjacent property
Comments					Social trails	Reference species		
					Damaged soil	Healthy soil		
					Boundary influences	Microtopography		
					Poor access	Water availability		
					Invasive dominance	Existing work		

Cover classes	Soil surface condition	Erosion classes
Class 1: None Class 2: trace Class 3: 1-25% Class 4: 26-50% Class 5: 51-75% Class 6: 75-100%	Class 5-**High**: developed organic layer, good structure, low/no disturbance **Class 3: Medium** Class 1-**Low**: thin, damaged, rocky, construction debirs present	**Class 1: severe**, subsoil exposed, most rocks/plants pedestaled and roots exposed **Class 3: moderate** movement of soil, surface rock/ or litter, pedestalling in flow patterns **Class 5**: no visual evidence of soil movement

2. Pre-design assessment

Date: Surveyor: Rapid assessment-vegetation

Point/ location	Ecological site / Community name	Overstory (% cover / diversity (1-5))	Midstory (% cover / diversity (1-5))	Ground (% cover / diversity (1-5))	Invasive (% cover)	Valuable species (% cover)	Invasives - other	High value - other
		% cover	% cover	% cover	total	total		
		Diversity	Diversity	Diversity	Dominant spp.	heritage tree (>60.96 cm)		
		Dominants	Dominants	Dominants	Ligustrum sp.	protected tree (>48.26 cm)		
Overall diversity	**Woody age** diversity				bermudagrass	Reference community spp.		

Soil surface condition	Erosion severity	Erosion extent	Connection to floodplain (high/med/low)	Bottomland/ riparian diversity (high/med/low)	Challenges	Assets	Additioaal challenge/ asset	Boundary/ adjacent property
Comments					Social trails	Reference species		
					Damaged soil	Healthy soil		
					Boundary influences	Microtopography		
					Poor access	Water availability		
					Invasive dominance	Existing work		

Cover classes	Soil surface condition	Erosion classes
Class 1: None Class 2: trace Class 3: 1-25% Class 4: 26-50% Class 5: 51-75% Class 6: 75-100%	Class 5-**High**: developed organic layer, good structure, low/no disturbance **Class 3: Medium** Class 1-**Low**: thin, damaged, rocky, construction debirs present	**Class 1: severe**, subsoil exposed, most rocks/plants pedestaled and roots exposed **Class 3: moderate** movement of soil, surface rock/ or litter, pedestalling in flow patterns **Class 5**: no visual evidence of soil movement

3. Soil condition classes

Characteristic	Class 1	Class 2	Class 3	Class 4	Class 5
Soil movement	Subsoil exposed on much of the area; may have embryonic dunes an/or wind scoured depressions	Soil and debris deposited against minor obstructions	Moderate movement of soil particles has occurred	Some movement of soil particles has occurred	No visual evidence of soil movement
Surface rock and/or litter	Very little remaining; if present, surface rock or fragments exhibit some movement and accumulation of smaller fragments behind obstacles	Extreme movement; many large deposits against obstacles; surface rocks exhibit movement; smaller fragments accumulate behind obstacles	Moderate movement; fragments deposited against obstacles, fragments have a poorly developed distribution pattern	May show slight movement; if present, coarse fragments have truncated appearance or spotty distribution caused by wind or water	Accumulation in place; if present, the distribution of fragments shows no movement caused by wind or water
Pedestaling	Most rocks and plants pedestaled and roots are exposed	Many rocks and plants pedestaled and roots are exposed	Rocks and plants pedestaled in flow patterns	Slight pedestalling in flow patterns	No visual evidence of pedestaling
Flow patterns	Flow patterns numerous, readily noticeable; may have large barren fan deposits	Flow patterns contain silt, sand deposits and alluvial fans	Well defined, small and few with intermittent deposits	Deposition of particles may be in evidence	No visual evidence of flow patterns
Rills and gullies	May be present at depths of 8--15 cm and at intervals of less than 13 cm; sharply incised gullies cover most of the area, with 50% actively eroding	Rills 1-15 cm deep at 150 cm intervals; gullies numerous and well developed; active erosion on 10-50% of their lengths or a few well-developed gullies with active erosion along more than 50% of their length	Rills 1-15 cm deep in exposed places at about 300 cm intervals; gullies well developed, with active erosion along less than 10% of their length with vegetation present	Few infrequent rills in evidence at distances of over 300 cm; evidence of gullies with little bed or slope erosion; some vegetation is present on slopes	No visual evidence of rills; may be present in stable condition, but with vegetation on channel bed and side slopes

Appendix B. Methods

1. Vegetation Monitoring

Houston Arboretum & Nature Center's Vegetation Monitoring Plots

Chris Garza

Introduction

In 2015, a total of 88 permanent vegetation monitoring plots were created across the property of the Houston Arboretum & Nature Center. ArcMap software was used to generate these plots by placing a two acre grid across the site and randomly placing a plot center within each cell (Figure 1). When located with a Garmin GPS (each plot center is entered in the GPS as "RP##' with #'s denoting the plot number), each plot center is permanently established in the field with a stake. Vegetation monitoring consists of assessing trees, shrubs, and herbaceous plants (Figure 2). All trees with a diameter at breast height (dbh) greater than 6 inches within a circular 0.1 acre plot around the plot center have their dbh measured and the species are recorded. All trees and shrubs with a dbh between 3 and 6 inches are recorded the same way within a 0.05 acre subplot. All trees and shrubs with a dbh less than 3 inches are counted by species within the same 0.05 acre subplot. Grasses, forbs, vines, and tree/shrub seedlings are measured within a square meter quadrat around the plot center. Percent cover is recorded for each species. The percent cover of bare soil and leaf litter is also noted. Each year, a variable number of plots are sampled so that all 88 plots are sampled within 5 years. Plots can then be resampled and compared 5 years from when they were previously sampled. Refer to Figure 3 to see the plots when plots are to be sampled.

Methods

Materials used included a ½ meter by ½ meter square pipe, a compass, a GPS, eight pin flags, a DBH tape measure, and the data sheets. The location of each vegetation plot was determined with a GPS and a compass. An orange stake was placed in the ground at the center of the plot. Starting from the orange stake, two pin flags were placed in each cardinal direction, one 26 feet away and one 37 feet away from the orange stake. A DBH tape was used to measure the distance from the orange stake to the 26 and 37 feet marks in each direction. This effectively makes a big circle with a radius of 37 feet, and a smaller circle with a radius of 26 feet, both with the orange stake serving as the central point. One person stood at the orange stake holding the end of the tape measure while the other person measured and placed the pin flags. Once all of the pin flags were set up, a 1 meter vegetation sampling with the orange stake as the center point was completed. A compass was utilized to determine the northwest direction, and the ½ meter by ½ meter square pipe was placed in the northwest quadrant. Percentage of leaf litter and bare ground were recorded, as well as the species of any plant growing in the quadrant. This was repeated for the northeast, southeast, and southwest directions, effectively making a 1 meter square plot with the orange stake in the middle.

After the 1 meter square plot survey, trees were measured and counted. The DBH and species of any trees with a DBH over 6 inches and located within the bigger circle (radius of

37 inches) were recorded. Any trees with a DBH between 3 and 6 inches and located only within the smaller circle (radius of 26 inches) were measured. The DBH and species were recorded. After that, any trees with a DBH below 3 inches and taller than hip height (around 3 feet) in the smaller circle were simply counted. The species and number of individuals of each tree were recorded.

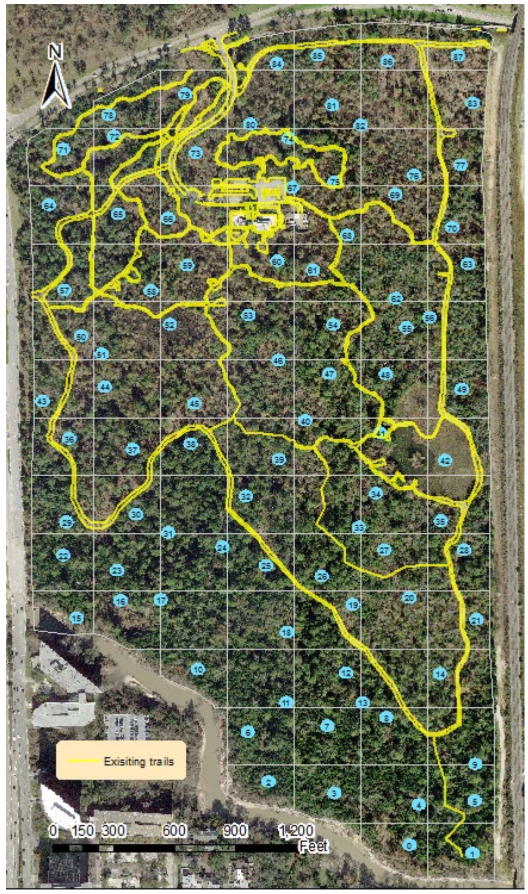

Figure 1: In 2015, the 88 permanent vegetation monitoring plots were placed randomly within a two acre grid. Trees, shrubs, and herbaceous plants are monitored in these plots.

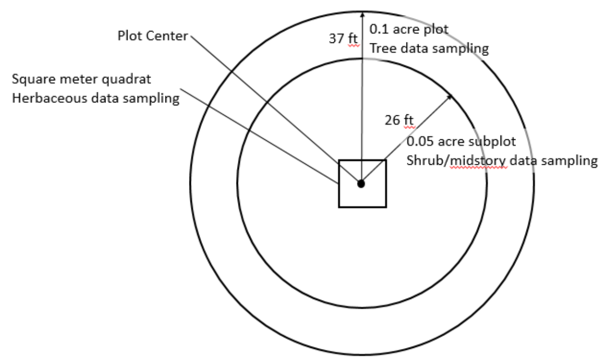

Figure 2: The vegetation monitoring plots were designed to sample trees, shrubs, and herbaceous plants.

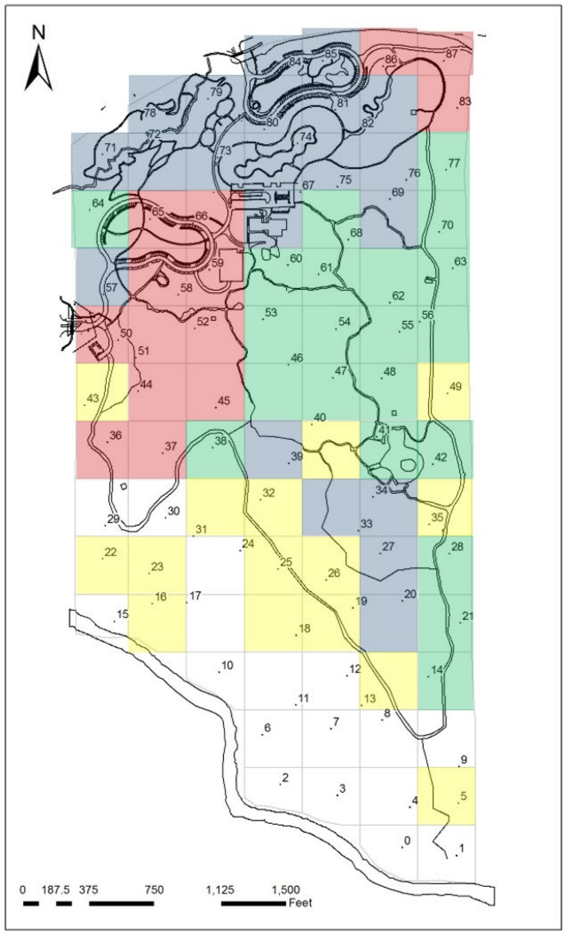

Figure 3: The staggered plot sampling system over five years. Red plots (14 total) were sampled in 2015 and will be resampled in 2020. Yellow plots (15 total) were sampled in 2016 and will be resampled in 2021. Blue plots (21 total) were sampled in 2018 and will be resampled in 2023. Green plots (21 total) are to be sampled in 2019 and will be resampled in 2024. Note that no plots were sampled in 2017. The uncolored plots (17 total) can be sampled for the first time in 2022.

Plot #		Date		%Canopy cover	

Overstory trees with dbh > 6" within 1/10th acre plot (37' radius)

Species	*Dbh*	*Height*	*Notes*

Midstory trees with 3-6" dbh within 1/20th acre plot (26' radius)

Species	*Dbh*	*Height*	*Notes*

Understory trees with dbh < 3" within 1/20th acre plot (26' radius)

Species	*Count*	*Notes*

Herbaceous - NW

Species	*%Cov*	*Notes*	*Species*	*%Cov*	*Notes*
Bare					
Litter					

Herbaceous - NE

Species	*%Cov*	*Notes*	*Species*	*%Cov*	*Notes*
Bare					
Litter					

Herbaceous - SE

Species	*%Cov*	*Notes*	*Species*	*%Cov*	*Notes*
Bare					
Litter					

Herbaceous - SW

Species	*%Cov*	*Notes*	*Species*	*%Cov*	*Notes*
Bare					
Litter					

Figure 4: The template of the data sheets to be used in the field

2. Pollinator Monitoring

Houston Arboretum Pollinator Methods- Chris Garza

In 2015, 88 vegetation monitoring sites were chosen across the 155-acre HANC using ArcMap software, located with GPS coordinates, and permanently marked with a stake. 30 of these sites were randomly selected for pollinator community monitoring in addition to vegetation surveys to record changes in pollinator diversity with vegetation changes as the site undergoes continued restoration and development.

Materials used included a ½ meter by ½ meter square pipe, a compass, a GPS, a pin flag, a DBH tape measure, and the data sheets. A GPS device and compass were used to locate the pollinator plot locations marked with an orange stake. Once at the orange stake, the cardinal directions were determined with a compass. Then, one person stood over the orange stake holding one end of the tape measure while the other person walked with the tape measure in one cardinal direction until a distance of 26 feet was reached. A pin flag was placed in the ground at the 26 feet mark, and vegetation sampling around the flag was completed. With the pin flag serving as the center of a 1 meter square plot, the square pipe was placed in the northwest direction first, which was determined with a compass. The percentage of bare ground versus percentage of ground covered in leaf litter was recorded on the data sheets. Then any vegetation found within the square pipe was classified and its species and percent cover were recorded. The square pipe was then moved to the northeast quadrant of the 1 meter square plot and the percent cover and species present were again recorded. This was repeated for the southeast and southwest quadrants. If any flowers were present in or directly above the 1 meter square plot, the flowers were observed for 15 minutes and any pollinator activity was recorded along with the species of the pollinator. Then, the pin flag was taken back to the orange stake, the center of the big plot. Once a second cardinal direction was determined, one person held the end of the tape measure and the other walked 26 feet in the cardinal direction. As before, the pin flag was placed at the 26 feet mark and a 1 square meter vegetation survey was performed around the pin flag. This whole process was repeated for the two remaining cardinal directions. The relative humidity, temperature, and wind speed were determined with an iPhone and recorded on the data sheets as well.