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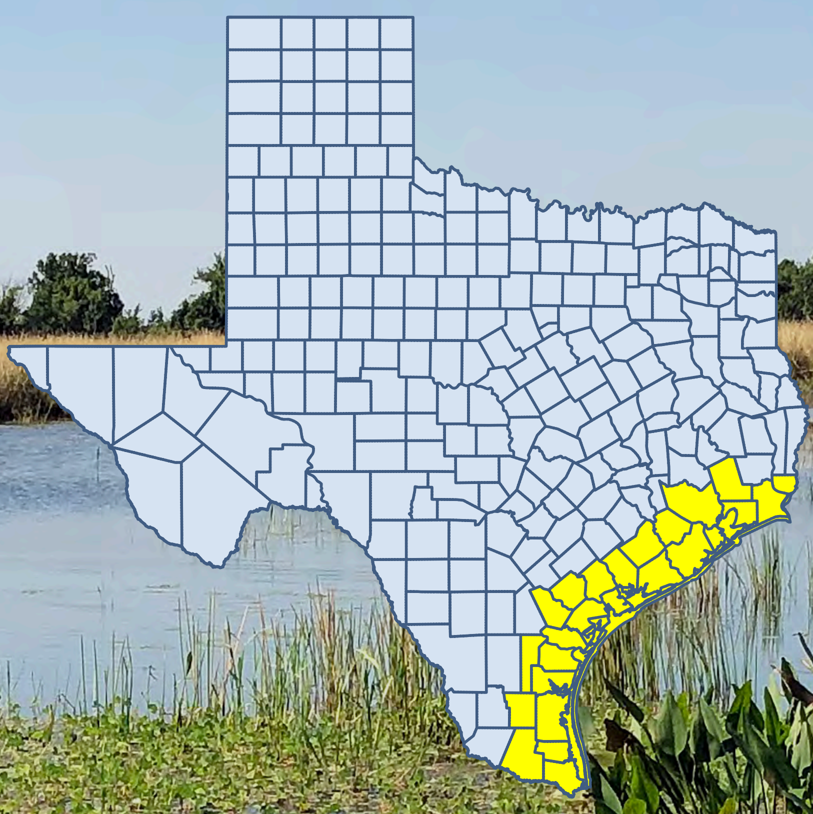
Regional Stormwater Wetland Manual



Gulf Coast Region

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Purpose Statement

This manual can help implement stormwater wetlands as a valuable green infrastructure (GI) method to manage and mitigate stormwater issues in communities through sharing case studies and lessons learned with community leaders, land managers and developers, project managers, contractors, and maintenance staff. These projects depend on effective communication to various groups of stakeholders. This includes partners, funding agencies, local citizen groups, contractors, and volunteers. No project can be completed without cooperation.

Economics of Stormwater Wetlands

There are many factors to consider when looking at the economic feasibility of a stormwater wetland project. Factors include the cost of design, engineering, materials, construction, maintenance, training, timelines, labor, and qualified labor sources. Then there are the monetary and non-monetary benefits of the project such as reduced flood risk, improved water quality and habitat, increased local jobs as well as climate and health benefits. These costs and benefits should always be compared to the cost of a similar project or maintaining current conditions. Section 4 of this manual begins to demonstrate how to make these comparisons but there is some time and effort needed to find comparable data for each location, as we are finding data is limited on the long-term maintenance and benefits of this type of project and not as easy to compare as initial construction costs. Not having the full analysis and cost ratios can deter new installations.

Funding a stormwater wetland project uses a multitude of mechanisms in various combinations, including local bonds, stormwater fees, capital improvement campaigns, grants, donations, and loans.

Stormwater Wetland Installation

Factors to consider when determining the location of a constructed or floating stormwater wetland.

Table A: Checklist for Stormwater Wetland Site Selection

STORMWATER WETLAND SITE SELECTION CHECKLIST		
Site Condition	**Yes**	**No**
1. Adequate Area Available		
2. Identified Wetlands Absent		
3. Hydrologic Flowpath Identified		
4. Depressional Storage Present		
5. Critical Habitat Absent		
6. Water Table Close to Surface		
7. Vegetation Identified FAC or Wetter		
8. Soil Infiltration Rate 0.04–0.4 in./hr.		
9. Soil Has Low Sand Content		
10. Site Accessible For Construction and Maintenance		

Table B: Checklist for Floating Wetland Site Selection

CONDITIONS FOR FLOATING WETLAND INSTALLATION CHECKLIST		
Site Condition	**Yes**	**No**
Slide slopes steeper than 3:1		
Water depth deeper than 18”		
Concrete sidewalls or liner		

Once a location is decided, the project needs to be designed and budgeted before construction can begin. We suggest following a project development process similar to the chart provided to successfully complete a stormwater wetland project. Recognize that this is just a sample timeline and will vary by the size and complexity of individual projects. However, this is a good starting point for planning and stakeholder discussions to promote understanding and communication.

As the charts below show, communication is an ongoing part of the project. Communicating with stakeholders, contractors, and partners is vital to keeping the project moving; construction and planting are the most time-consuming and expensive parts of the project. This is also the most variable area depending on size and methods used for construction. Construction is the most visible part of the process and often gets the most notice and comments from the stakeholders. Reminding them of the process and that this is just a temporary part of the long-term goals will help with a smooth transition. Construction is also the most weather-dependent and variable part of the project. Finally, ongoing maintenance involves staff time, coordination, evaluation, replanting if necessary, and all the things that keep the project looking and functioning at the top level. We suggest mowing at least twice yearly, controlling nuisance flora and fauna species, and regular litter or debris cleanup. Maintenance efforts will vary based on the time of the year and the number of stormwater runoff events. Again, these are just suggested maintenance timelines for the sake of planning and discussion; each site will vary in the level of maintenance required.

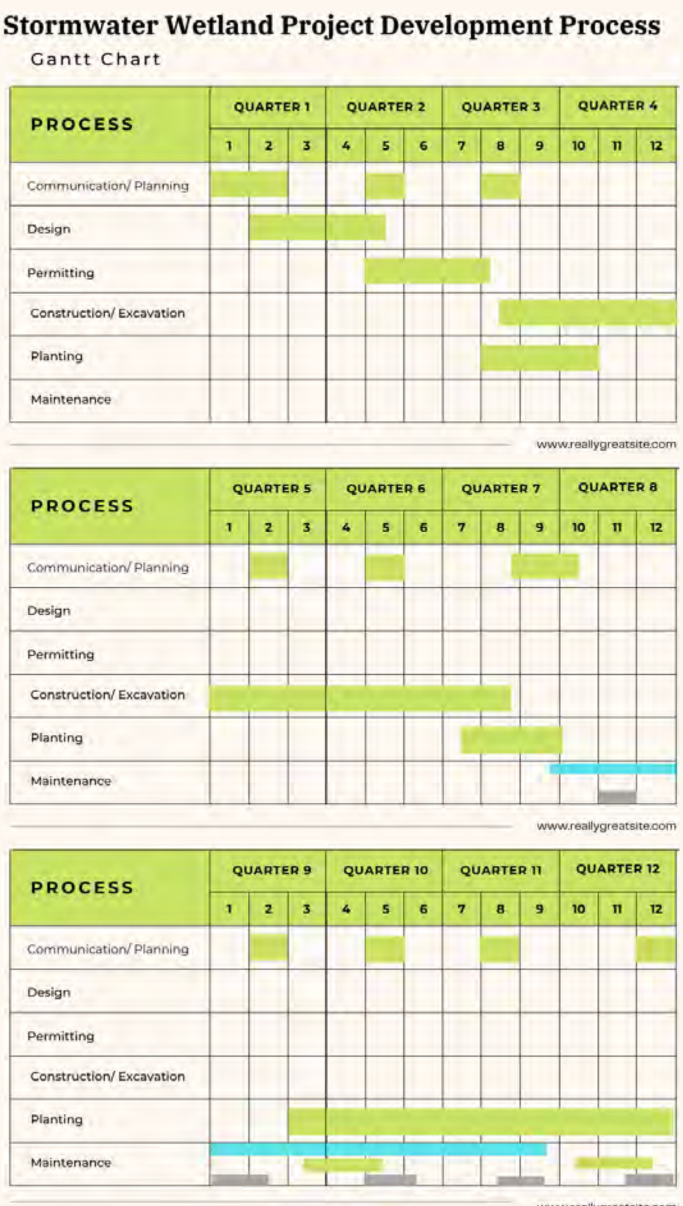


Figure 1: Chart depicting suggessted timline for Stormwater Wetland project completion.

Figure 2: Design plans for Exploration Green Stormwater Wetland Park in Clear Lake, Texas. Image provided by CLCWA https://www.clcwa.org/_files/ugd/6e2815_68f51ebb41a0477eae78400083d27b9d.pdf

Figure 3: Photo of completed stormwater wetland at Mason Park adjacent to Brays Bayou in Houston, Texas. Photo credited to Harris County Flood Control District Project Brays.

SECTION 2

Introduction

Section 2, Introduction

Stormwater wetlands are emerging as one of the best ways to manage stormwater quantity and quality on the Texas Gulf Coast. The Texas coast is comprised of wide, flat land features located at the mouth of several waterways *(depicted in Figure 4)*; this leads to inundation by contributing waterways upstream as well as localized stormwater events each year. This connection has led to the creation of a vast system of stormwater detention and conveyance features along the coast to which wetlands can be easily incorporated allowing the natural environment to work in conjunction with the engineered systems to benefit the community as a whole.[1] The purpose of this manual is to inform communities, land developers, and watershed groups about this stormwater management method and how it can work in their area of the state; to equip leaders to begin conversations within their communities that will lead to the implementation of nature-based solutions or green infrastructure to meet stormwater management goals.

Figure 4: River and Coastal Basins of Texas courtesy of the Texas Water Development Board, found here: twdb.texas.gov/surfacewater/rivers/river_basins/index.asp

What is a Stormwater Wetland?

A stormwater wetland is a created wetland in a new basin or added to an existing detention or retention basin for the express purpose of mitigating flood water levels and cleaning polluted waters to improve water quality in the downstream receiving waterways. [2, 3]

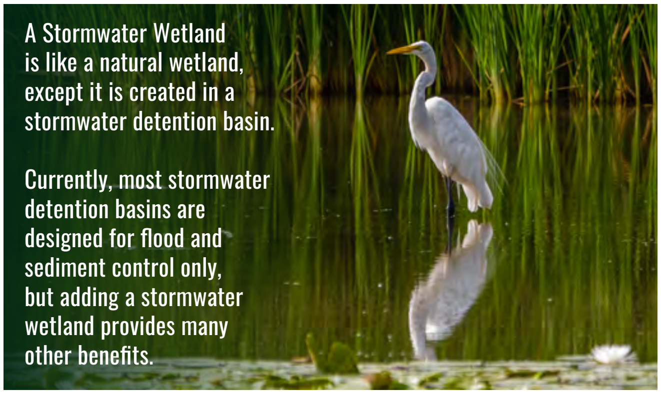


Figure 5: City of Houston Mason Park Stormwater Wetland

Figure 6: Floating wetland mats added to Mary's Creek detention facility at the City of Pearland Delores Fenwick Nature Center.

How can we fund a Stormwater Wetland project?

When assessing the cost-benefit of a project, green infrastructure (GI) offers many more benefits than gray infrastructure, despite a similar cost of installation. The long-term benefits of GI projects exceed those of gray infrastructure projects-hazard mitigation grants are available both pre and post-disaster which can fund actions identified through the planning process, including GI practices. Additionally, local funds can be dedicated if GI is part of a community's Capital Improvement Plan. Also, if required for new development, through local ordinances, the cost of installation of on the ground GI practices falls on the developer, not the taxpayer.

Where would we want to use Stormwater Wetlands?

Stormwater wetlands are often located in areas that naturally collect water and have some ties to a receiving waterway such as a bayou or creek.

Stormwater wetlands can also be used in conjunction with other forms of stormwater conveyance to add increased water quality improvements. Several smaller connected practices can multiply benefits.

How are Stormwater Wetlands Maintained?

The long-term performance of a stormwater wetland depends on best practices to support operation and maintenance during the projects operational life. This involves a written plan to share with maintenance crews and volunteers on issues of aeration, debris, sedimentation, vegetation, and wildlife.

Debris and trash can be removed as part of a voluntary clean-up event or managed by the landowner.

Figure 7: Volunteer trash cleanup event at Exploration Green. Photograph courtesy of Christie Taylor, AgriLife Extension

Figure 8: Aerator fountains in Phase 3A of Exploration Green. Photograph provided by Jason Miles.

Are Stormwater Wetlands considered jurisdictional waters and how do we find out?

Stormwater wetlands are created in areas that are not already identified wetlands and are not part of a compensatory mitigation requirement. Stormwater wetlands are designed with a maintenance plan in place to remove excess sediment. Only the United States Army Corps of Engineers (USACE) has the authority to determine the jurisdiction of any wetland.

What are the keys to successful project implementation?

As with any type of project, the key to success is communication that expresses an understanding of the problem to be mitigated, the need for the project, a clear understanding of the goals, and a clearly defined cost and benefit analysis.

The goal of this manual is to answer many of the common questions about how to start and complete a stormwater wetland project by providing some real on the ground examples and the lessons learned.

SECTION 3

Communication

Section 3, Communication

When preparing for a stormwater wetland project or any watershed improvement project you should start by communicating with a large and varied group of people. Partners can come from a variety of sources that include government agencies at multiple levels, nonprofit organizations including civic groups and churches, professional societies, businesses and corporations, local citizens and landowners, and youth serving organizations. Forming partnerships early is integral to achieving success. A team approach allows your community to bring in experts to better communicate with area residents.[4]

When people are invited to be part of the process, to help define and understand the problem, they can then contribute to the solution. Participants are more likely to take ownership and help implement that project.[4] At this stage you may want to work with the subject matter experts you have partnered with to host meetings or workshops for the community to share information and collect input.

Figure 9: AgriLife staff speaking at a Local Town Hall Meeting on the importance and function of wetlands in Green Infrastructure projects.

Stakeholders

Early in the project, you will need to determine a list of potential partners and begin reaching out to them through multiple methods.[4] A varied approach will help garner support for your project. You will also need to establish how and when you will continue to update the stakeholders and partners during the project. Communication should take multiple forms to reach a diversity of audiences:

Figure 10: Local officials explain the project and future steps to give clear details of the plans and expected timeline.

- **Digital**
  - Social media announcements on multiple platforms.
  - Project specific webpages or announcements on your existing websites.
  - Emails, electronic newsletters.
- **Meetings**
  - Public meetings and town hall events.
  - Electronic access to these events through Zoom, Teams, Facebook Live, or other webhosting platforms.
- **Print**
  - Announcements in newspapers, fliers, posters, signs, and mail outs.
- **Phone Calls & Text Messaging**

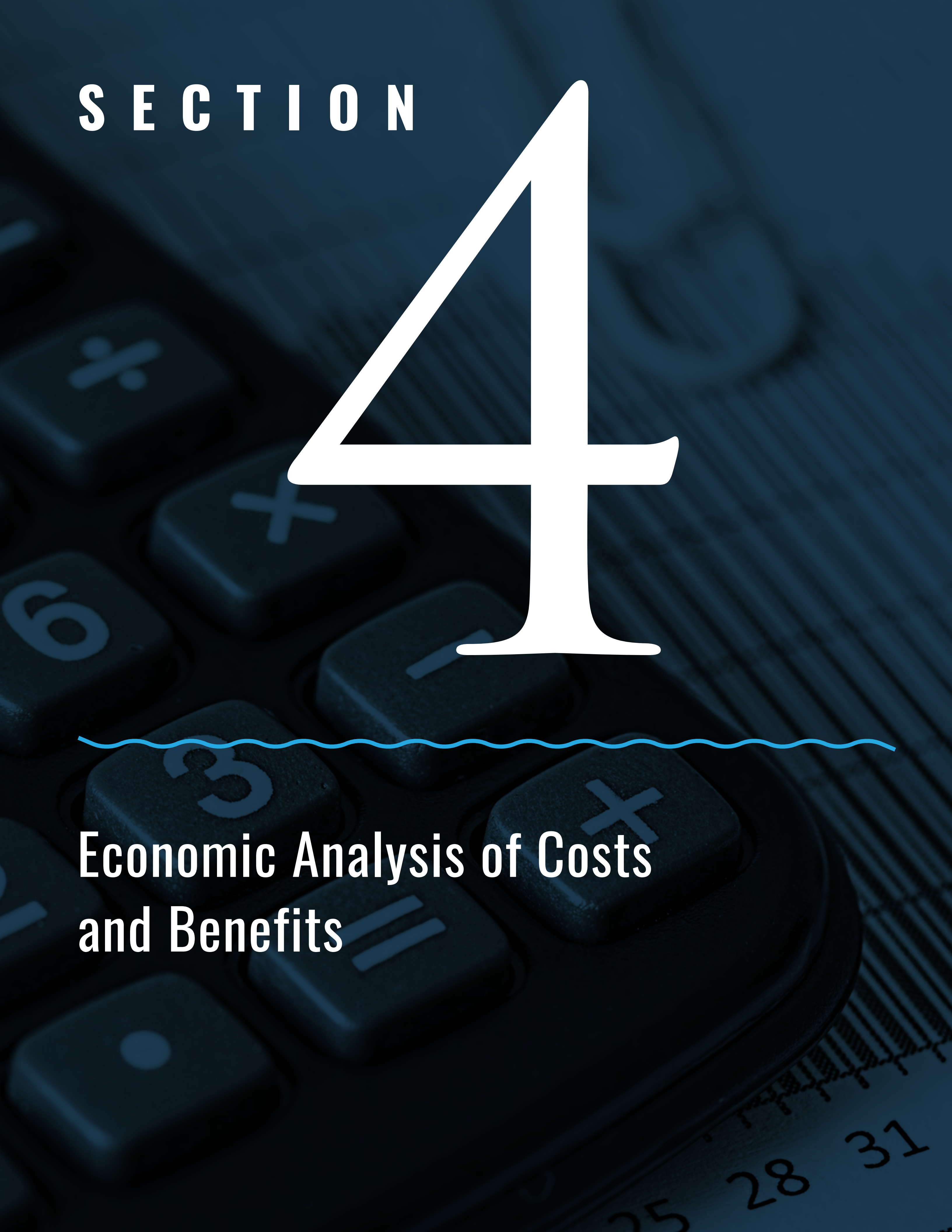
Designating a single point of contact, who is to be the first contact for public questions and concerns will help ease confusion and duplication of effort. This can be through a dedicated email, website or phone number but have one central location and person responsible for locating answers and providing information.

Project Team

Open and thorough communication on project specific goals with both designers and contractors onsite will help to smooth construction of the stormwater wetland and set the standard for a successful project. Outline the specifics of construction in a guidance document for the project that includes design plans, construction guidelines, existing infrastructure, required construction materials, equipment needs, and task sequences. Providing this document to potential contractors and construction staff, coupled with a site meeting to discuss the details of the project, can be very beneficial. Communication between all the partners with the end goal in mind helps everyone understand the importance of required tasks, techniques, and sequencing to overall project success and cost-effectiveness.[5]

Communication with the project team should be ongoing through the project scope, especially to pass along support and feedback from partner groups and stakeholders. You will need to communicate the need for changes and new directions to designers, architects, and contractors. You should arrange for them to visit the site and see the space prior to and during construction of the project.

Open and continued communication is essential for community support of your project, as well as successful project management and completion. Taking time at the beginning of a project to outline goals and set up a communications plan will pay dividends throughout the life of the project.



SECTION 4

Economic Analysis of Costs and Benefits

There is limited information on economic costs and benefits for these types of GSI practices. As more projects are being completed, more data will be available and the cost-benefit ratios will become better understood. The following section of this manual will help to give you a basic understanding of how to start making the connection between cost of the project to the longer term benefits and project effectiveness.

Estimating Stormwater Wetland Costs

Developing the benefits and costs to use in a cost-benefit analysis can be aided by researching other studies on stormwater management strategies. Sources for budget estimations include local case studies, project web searches, local engineering firms and construction companies with experience in stormwater wetland installation. All the costs considered below assume the stormwater wetland would be built or retrofitted into a stormwater detention facility therefore the costs per acre estimates do not include the initial excavation and disposal cost.

Table 4A: Table depicts estimates of cost per acre to create or retrofit stormwater wetlands into stormwater detention basins already being installed. Values taken from Stormwater Wetlands for the Texas Gulf Coast.[1]

	Basin Retrofit	New Construction Basin
Design & Engineering	$8,000 – $15,000 per acre	$8,000 – $15,000 per acre
Grading & Construction	—	Additional 5 – 10%
Vegetation Installation	$15,000 – $20,000 per acre	$15,000 – $20,000 per acre
Outlet Structure Construction	$5,000 – $10,000 per acre	$5,000 – $10,000 per acre
Total Cost per Acre	$28,000 – $45,000	$30,000 – $50,000

Cost-Benefit Analysis Considerations for Stormwater Management Strategies

Dr. Dean A. McCorkle and Daniel D. Hanselka

Stormwater management strategies provide a variety of benefits including economic, health and climate related. Some of these benefits are difficult to monetize making a true cost-benefit comparison difficult, however understanding the economics of new stormwater infrastructure can provide decision-makers with important insight needed for assessing tradeoffs involved with various stormwater management strategies.

Economic Benefits – GSI promotes the creation of green jobs, or jobs that contribute to preserving or restoring the environment, be it in traditional sectors such as manufacturing and construction, or in new, emerging green sectors such as renewable energy and energy efficiency.[4]

Green Stormwater Infrastructure strategies can include planting trees, reactivating vacant or abandoned lots, green roofs, and incorporating stormwater wetlands and bioswales into an area – all of which can strengthen property values. A green stormwater infrastructure strategy can also help revitalize a neighborhood by making it more pedestrian friendly and walkable, which can lead to increase retail sales revenue, as well as increased recreation-related revenue if recreational aspects of the area have been enhanced.

Health Benefits – GSI can be incorporated as a component of a larger green environment, one that encourages increased physical activity and healthier lifestyles. Practices can also be designed to combat climate-related conditions that are known to create negative health impacts, such as air pollution, extreme heat, and noise.[3] *As illustrated in Figure 11*, Green Stormwater Infrastructure strategies can provide a variety of health benefits. For example, stormwater wetlands can improve outdoor air quality and indoor environmental quality, while reducing urban heat island effects and heat stress, improving the overall mental health of the community.

Climate Benefits – Green Stormwater Infrastructure can play a role in our communities adapting to the impacts of a changing climate by capturing rain, reducing climate heat impacts, reducing energy needs, and preventing urban flooding by preserving water through infiltration.[3]

Another type of climate benefit relates to the urban heat island effect. Many urban and suburban areas experience elevated temperatures compared to their outlying rural surroundings; this difference is what constitutes an urban heat island.[5] Relative to gray infrastructure, the use of street trees, green roofs, and other ground-infiltrating Green Stormwater Infrastructure fosters an environment for evapotranspiration and reduced ambient temperatures. Reducing the urban heat island effect can also lead to reduced energy use via reducing the cost of cooling a home.

Figure 11: Economic, Health and Climate Benefits Associated with Green Infrastructure.

*** High Benefit **Medium Benefit *Low Benefit

	Rain Garden	Bioswales	Rainwater Harvesting	Tree Filter Box/Street Trees	Green Roof	Stormwater Wetland	Pervious Pavement	Pervious Bike Lane
ECONOMIC BENEFITS								
Improved Job Creation		*		***	*	***	*	*
Improved Property Value	*	**		**	***	***		
Increased Sales Revenue	**	***		**				**
Increased Recreational Revenue						***		***
HEALTH BENEFITS								
Improved Outdoor Air Quality	**	*		**	*	*		
Improved Indoor Environmental Quality	*	*		***	*	***	**	**
Reduced Noise Pollution					***		**	**
Reduced Heat Stress	*	*		**	*	***		
Improved Community & Mental Health	*	*		**	*	***		
CLIMATE BENEFITS								
Reduced Flooding	**	**	*	***	**	***	***	**
Reduced Urban Heat Island Temperatures	*	*		***	***	***	*	*
Improved Water Quality	**	**	*	***	**	***	***	**
Reduced Greenhouse Gases	***	***		***	***	***	*	*
Reduced Energy/Fuel Use				***	***	**		

Source: Adapted from Green Values Strategy Guide: Linking Green Infrastructure Benefits to Community Priorities, Center for Neighborhood Technology (CNT), 2020.

The use of stormwater wetlands and other green stormwater infrastructure strategies capitalizes on the environment's natural carbon sequestration resources – plants, trees, and soil.

Cost-benefit Analysis

Cost-benefit analysis is a systematic method for measuring the costs and benefits (returns) associated with a project or investment to allow for more informed decision-making. The objective of cost-benefit analysis is to make sound estimates of expected costs and benefits that allow for measuring the net effect (benefits minus costs, or a ratio of costs/benefits).

When conducting a cost-benefit analysis, the scope and framework, projected life (number of years), and estimated costs and benefits of the project will need to be determined. For estimating costs of a project, the types of costs involved will depend on the type of infrastructure project. Some common ways to group or organize costs include direct and indirect; fixed and variable; and construction, operations, and maintenance.[6] Depending on the type of project, costs may include one-time construction costs at the beginning of the project, followed by several years of maintenance, operations, and/or other costs.

Net Present Value

Like many projects, stormwater infrastructure projects typically have a life that stretches over many years, on average 15-25 years according to most studies, which means there is a need to account for the time value of money, and risks. This can be accomplished with the net present value (NPV) method, which involves the discounting of the cash flows. The purpose of calculating the NPV of a project is to assess the cash inflows (benefits) and outflows (costs) of a project by converting all future cash flows to current dollars using a discount rate. Cash flows are discounted to account for the time value of money in the project timeline, i.e., a dollar today is worth more than a dollar in the future.

Figure 12: The formula for calculating the NPV of costs and benefits can be expressed as follows:

$$NPV = \frac{Cash\ Inflow_0}{1+r} + \frac{Cash\ Inflow_1}{(1+r)^1} + \dots - \frac{Cash\ Outflow_0}{(1+r)^0} - \dots$$

Where the numerator represents the cash inflows and outflows for each year (with year **0** representing the initial construction cost or investment amount), and ***r*** is the discount rate. It is important to note when conducting NPV analysis, benefits and costs reflect cash outflows and cash inflows (cash benefits) associated with the project.

It is important to note when conducting NPV analysis, benefits and costs reflect cash outflows and cash inflows (cash benefits) associated with the project.

For local government-funded stormwater projects, it is probably more appropriate to use a discount rate that represents the cost of debt, or a risk-free rate, such as the yield on U.S. Treasury bonds. The higher the discount rate is, the lower the NPV will be, and vice versa.

NPV can be calculated two ways. The first method, which is demonstrated below, involves estimating the effects of inflation on project costs and benefits, while using a “nominal” discount rate, meaning a discount rate that includes inflation. The second method is to use constant dollars for costs and benefits each year – thus not accounting for any projected inflation – and using a discount rate that does not include inflation. Either method, when done correctly, will yield the same result (NPV).

To illustrate the concept of NPV analysis, consider the following simplified, hypothetical example. A city is considering building a 3-acre stormwater wetland. The total costs for the design, engineering, construction, and installation of vegetation have been estimated at $152,100, which occurs at the beginning of the project (year 0). Thereafter, annual maintenance costs are estimated at 2% of the $152,100 each year, with a projected annual inflation rate of 2%. The discount rate used in this illustration is 3.2%, which is the 30-year U.S. Treasury bond rate (6/10/2022).[7]

Annual benefits for flood risk reduction, water quality and quantity, recreation and commercial fishing, and birdwatching and habitat have been estimated at $18,846 in total for year 1. Benefits are inflated each year by 2%.

Estimating project costs and benefits is the most time-consuming part of conducting the analysis. Once this step is complete, there are two methods for calculating NPV. One method is to calculate the discount factor for each year and apply it to the cash flows. The discount factor is calculated as $(1+r)^{-t}$, where ***r*** is the discount rate and ***t*** is the time period (note the negative sign preceding the time period). For example, for year 2, the discount factor of 0.939 was derived as follows: $(1+.032)^{-2}$, or 1.032^{-2} = 0.939 (Table 4B). An alternative method for calculating the discount factor for each year is: $1/(1+\boldsymbol{r})^{\boldsymbol{t}}$ where ***r*** is the discount rate and ***t*** is the time period. To calculate the discounted costs for each year, for example, the discount factor for each year is multiplied by the total cost for each year. The same applies for calculating the discounted cash inflows (benefits). For example, in year 3, the discounted costs (NPV of costs) are derived by multiplying estimated costs in year 3 ($3,165) by the discount factor for year 3 (0.910) by the; or $3,165 x 0.910 = $2,880.

Table 4B: Net Present Value Calculation of a Hypothetical Stormwater Wetland.

	Initial Costs								
Year	0	1	2	3	4	5	....	15	Total
Design, engineering, construction	$107,100								$107,100
Install vegetation	$45,000								$45,000
Maintenance		$3,042	$3,103	$3,165	$3,228	$3,293		$4,014	$52,607
Total	$152,100	$3,042	$3,103	$3,165	$3,228	$3,293		$4,014	$204,707
Benefits									
Flood		$3,102	$3,164	$3,227	$3,292	$3,358		$4,093	$53,644
Water quality and quantity		$2,676	$2,730	$2,784	$2,840	$2,897		$3,531	$46,277
Recreation and commercial fishing		$5,583	$5,695	$5,809	$5,925	$6,043		$7,367	$96,549
Bird watching and habitat		$7,485	$7,635	$7,787	$7,943	$8,102		$9,876	$129,441
Total		$18,846	$19,223	$19,607	$20,000	$20,400		$24,867	$325,912
Discount factor		0.969	0.939	0.910	0.882	0.854		0.623	
NPV of costs	$152,100	$2,948	$2,913	$2,880	$2,846	$2,813		$2,502	$192,891
NPV of benefits	$0	$18,262	$18,049	$17,839	$17,632	$17,427		$15,503	$252,713
NPV of project (benefits - costs)	-$152,100	$15,314	$15,136	$14,960	$14,786	$14,614		$13,001	$59,822

An alternative method for calculating the NPV of costs, for example, is to use the costs portion of the NPV formula noted above. To illustrate, the $2,880 NPV of cost in year 3 is calculated as follows: $\$3{,}165/(1+.032)^{3}$.

Once the estimated cash inflows and outflows have been discounted for each year of the 15-year life of the project, the sum of the discounted cash inflows and outflows is the NPV. In the illustration above, $192,891 is the sum of the discounted cash outflows (costs) over the life of the project and represents the NPV of estimated project costs. The same applies for the NPV of the cash inflows (benefits), which sums to $252,713. The NPV of the project (discounted benefits – discounted costs) is $59,822, which is the sum of the discounted benefits minus the discounted costs for each year.

Interpreting NPV Results

The interpretation rules for the results of a NPV analysis are rather simple. If the NPV of the project is positive, it would be interpreted as a worthwhile project from an NPV standpoint. If it's negative, it would not be considered a worthwhile project. A NPV of zero is a neutral result. In this case, a decision on whether to pursue the project would have to be made considering factors such as intangible benefits (if any) and other considerations that were not included in the analysis. However, given the limitations of NPV analysis (see below), and the fact that the person doing the analysis can make ill-guided assumptions and projections illustrates why there are many exceptions in which applying the rule would be wrong.[8] For this reason, the NPV results are one of several factors to take into consideration before making a decision about a project.

After a thorough NPV analysis, the results alone provide important insight into the worthiness of the project, but more perspective can be added if the results can be compared to the results of alternative action that is being considered. From a stormwater wetlands perspective, it could add insight if the same type of analysis could be undertaken on an alternative (and comparable) gray infrastructure alternative, just as an example.

Table 4C: Advantages and Disadvantages of NPV Analysis for Stormwater Wetlands.

Advantages	Disadvantages
It takes into account the time value of money.	Results are very sensitive to the discount rate.
Allows for more informed decision-making regarding the project(s) being evaluated.	Cash expenditures and benefits that occur 5 or more years in the future can be difficult to estimate.
Allows you to have a better understanding of the financial aspects of the project(s) being evaluated.	Cannot be used to compare projects of different sizes.
The process of conducting NPV analysis is relatively straightforward.	Selecting on an appropriate discount rate is not an exact science. There is no widely accepted method, or guidelines, for selecting a discount rate.
Allows for comparing (and ranking) multiple projects that are similar in size.	Can only be used to assess cash inflows and outflows. NPV analysis cannot be used to evaluate non-monetary benefits.
Risk can be incorporated into the NPV framework by way of probabilities.	

Cost-effectiveness Analysis

It may not always be possible to monetize project benefits in cash dollars, and some projects may have a mixture of monetary (cash dollars) and non-monetary benefits. When the discounted costs exceed the discounted benefits, it might be appropriate to support or approve a project with a negative NPV, provided it has additional non-monetary benefits that are deemed to be sufficient to more than make up the difference.[8] In either case, the NPV method would not be the best method of evaluating the costs and benefits.

Cost effectiveness analysis (CEA) is an alternative to cost-benefit analysis in which the benefits of a specified green stormwater infrastructure strategy are measured in non-monetary term, such as the amount of stormwater retention (gallons, acre-feet, etc), pounds of stormwater pollutants captured, etc. Costs are measured the same as in cost-benefit analysis.

To illustrate the concept of cost-effective analysis, consider the same hypothetical 3 acre wetland example. Annual maintenance cost of 2% of the total construction cost will be used, with an annual inflation rate of 2%. Since the project has a multi-year life, costs will be discounted in the same manner as with cost-benefit analysis previously discussed. The same discount rate of 3.2% will be used in this example.

Both the nominal and discounted construction and maintenance costs are presented in Table 4D. The value one places on costs or benefits may vary depending on when it occurs, reflecting an individual's time preference.[10] Even though the benefits are in gallons captured (non-monetary), the benefits are still discounted at the same discount rate. This results in a discounted number of stormwater gallons captured of 11.5 million gallons, or 768,813 gallons annualized, and a cost per 1,000 gallons captured of $16.73 (cost-effectiveness ratio). Again, when conducting cost-effectiveness ratios on more than one project, it is important to compare projects that are the same or similar in size, type, and intended objectives to facilitate a fair and equitable comparison. This includes comparing to the status quo (a "without" project alternative). In this scenario, if no wetland was installed and the lot remained as 3 acres of turf grass with an annual maintenance cost of $4200, to mow the area monthly. Stormwater captured would be reduced to 1/12th of the previous amount or 961 thousand gallons or 64,068 gallons annualized and a cost per 1,000 gallons captured of $51.56, as shown in Table 4D.

Table 4D: Table depicts cost effective analysis of stormwater captured from the same hypothetical stormwater wetland as our previous example compared to not doing the project and the value of stormwater captured by the existing turf grass.

YEAR	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
Design, Engineering, Construction	107,100																$107,100
Vegetation	45,000																$45,000
Maintenance		3,042	3,103	3,165	3,228	3,293	3,359	3,426	3,495	3,564	3,636	3,708	3,783	3,858	3,935	4,014	$52,610
Total	152,100	3,042	3,103	3,165	3,228	3,293	3,359	3,426	3,495	3,564	3,636	3,708	3,783	3,858	3,935	4,014	$204,710
Discount Factor		0.969	0.939	0.91	0.882	0.854	0.828	0.802	0.777	0.753	0.73	0.707	0.685	0.664	0.643	0.623	
NPV	$152,100	$2,948	$2,914	$2,880	$2,847	$2,812	$2,781	$2,748	$2,715	$2,684	$2,654	$2,622	$2,591	$2,562	$2,530	$2,501	$192,889
Annual Cost																	$12,859
NON-MONETARY BENEFITS																	
Stormwater Captured (gallons)		977,553	977,553	977,553	977,553	977,553	977,553	977,553	977,553	977,553	977,553	977,553	977,553	977,553	977,553	977,553	14,663,295
Discounted Stormwater Captured (gallons)		977,553	917,922	889,573	862,202	834,830	809,414	783,998	759,559	736,097	713,614	691,130	669,624	649,095	628,567	609,016	11,532,193
Annualized Gallons Captured																	768,813
Annualized Gallons (1,000/gal.)																	769
Cost/1,000/gal. of Stormwater																	$16.73
Cost/gal. of Stormwater																	$0.02
3 ACRES OF TURF GRASS																	
Discounted Maintenance (mowed 1/mo. for 12 mos.)		$4,200	$3,944	$3,822	$3,704	$3,587	$3,478	$3,368	$3,263	$3,163	$3,066	$2,969	$2,877	$2,789	$2,701	$2,617	$49,547
Discounted Stormwater Captured (gallons)		81,463	76,494	74,131	71,850	69,569	67,451	65,333	63,297	61,341	59,468	57,594	55,802	54,091	52,381	50,751	961,016
Annualized Cost																	$3,303
Annualized Water Capture																	64,068
Annualized Capture (1,000/gal.)																	64
Cost/1,000/gal.																	$51.56

Web-Based Stormwater Calculators and Data Support

The following publications and web sites contain useful information for developing stormwater management cost and benefit information:

Grand Valley State University, Integrated Valuation of Ecosystem Services Tool (INVEST)
Data sources for Economic value of West Michigan land uses.

https://www.gvsu.edu/wri/invest/regional-economic-valuation-11.htm

Green Values Stormwater Toolbox Calculator, Center for Neighborhood Technology (CNT)

http://greenvalues.cnt.org/index.php

The Water Research Foundation, Web Tools
Web Tools come in a variety of forms – ranging from spreadsheets and databases to risk calculators and planning guides.

https://www.waterrf.org/web-tools

Minnesota Stormwater Manual
Information includes costs-benefit analysis, data, and other useful stormwater management information.

https://stormwater.pca.state.mn.us/index.php?title=Main_Page

Environmental Protection Agency (EPA), Green Infrastructure Modeling Toolkit
Access to a suite of stormwater calculators and models.

https://www.epa.gov/water-research/green-infrastructure-modeling-toolkit

i-Tree
i-Tree is a state-of-the-art, peer-reviewed software suite from the USDA Forest Service that provides urban and rural forestry analysis and benefits assessment tools. The i-Tree tools can help strengthen forest management and advocacy efforts by quantifying forest structure and environmental benefits that trees provide.

https://www.itreetools.org/

Possible Sources of Funding for Green Infrastructure and Stormwater Management

Now you have run the calculations and decided to go forward with the project you need to plan your budget. There are several options to fund a project. Grants can help fund pilot or initial projects as well as new techniques. However, the best choice for ongoing support for maintenance and future projects is going to come from local sources such as bonds and capital improvement budgets.

Table 4E: Table of sources for reference to help you get started with stormwater wetland projects:

Source	Type	Notes	More Information
Gulf of Mexico Energy Securities Act (GOMESA)	Federal, dispersed through the State	Gulf oil and gas production revenues that are disbursed annually to Texas. A portion of the Funds are allocated directly to coastal counties. Additional funds are available through a TGLO grant program.	https://www.glo.texas.gov/coast/grant-projects/funding/index.html
Texas General Land Office – Coastal Management Program (CMP)	State	An annual competitive grant program from the TGLO. Pre-proposals are required and due in June. Full proposals are due in October.	https://www.glo.texas.gov/coast/grant-projects/funding/index.html
United State Environmental Protection Agency	Federal	A list of currently available Federal funding sources for Green Infrastructure projects including 319 and Urban Waters grants.	https://www.epa.gov/green-infrastructure/green-infrastructure-funding-opportunities
Gulf of Mexico Alliance	Federal	Includes a list of open funding opportunities. Some are from GOMA, and some from partner organizations such as NOAA.	https://gulfofmexicoalliance.org/announcements/funding-opportunities/
Capital Improvement Project Funds	Local	Each community has its own Capital Improvement Project mechanism. Stormwater wetlands should be included in this process for local funding.	N/A
Bonds	Local	Texas-backed bonds allow a local government to use future tax revenue to fund a current need such as stormwater infrastructure. These bonds frequently require voter approval in a general election.	N/A
Clean Water State Revolving Fund	Loan Program	Low-cost financial assistance for stormwater infrastructure.	https://www.twdb.texas.gov/financial/programs/CWSRF/index.asp
Hazard Mitigation Funds	Federal, managed by Texas Department of Emergency Management	Stormwater wetlands must be included in a community's Hazard Mitigation Action Plan to be eligible for HMGP funding.	Hazard Mitigation Grant Program (HMGP) – dependent upon your community Hazard Mitigation Action Plan
Texas State Soil and Water Conservation Board	Federal, dispersed through the State	Grant program to support projects that reduce non-point source pollution. Applications are accepted annually in September.	https://www.tsswcb.texas.gov/programs/texas-nonpoint-source-management-program
Building Resilient Infrastructure and Communities (BRIC)	Federal	Entities seeking funding must have a FEMA approved Hazard Mitigation Plan. Application open in the Fall of each year.	https://www.tdem.texas.gov/bric
Texas Commission on Environmental Quality	Federal, dispersed through the State	Grant program to support projects that reduce non-point source pollution. Applications are accepted annually in June or July.	Non-point Source Grant Program – https://www.tceq.texas.gov/waterquality/nonpoint-source/grants/

Another option is to pass the funding through to the developers through local ordinances that require GSI practices be associated with any new development.

SECTION 5

Site Selection

Section 5, Site Selection

There are many factors to consider when determining the location of a newly constructed stormwater wetland.

Volume

The overall detention goal of the project should be determined to ensure the site can provide an adequate detention volume for the size of the contributing watershed.

Existing Features

Consider the existing features of the area including landforms, vegetation, waterbodies and hydrology, riparian areas, depression storage, floodplain boundaries, buildings, roadways, and access points. Identify these areas and determine how they might inform later development, as sites should avoid sensitive resource areas such as floodplains, erodible soils, wetlands, mature forests, and critical habitat areas. Any new buildings, roadways, and parking areas should be located to fit the terrain and in areas have the least impact.[4]

Existing wetlands and any wetland area used as compensatory mitigation for wetland loss cannot be used for a stormwater wetland and should be avoided. Stormwater wetlands should be new construction in a favorable pathway. They should not change hydrologic flow to existing wetlands but can be located upstream and connected to wetlands or other riparian buffer areas, which would increase the benefits to water quality.[6]

Hydrology

A hydrology study, or a basic idea of how the stormwater flows across the site, is a good first step; this could use GIS options that determine flowpaths. The location of the stormwater detention basin and wetland should align with the flow of water across the site. To minimize engineering requirements and achieve the greatest success, the outlet of the wetland should be aligned with the drainage pathway of the detention basin and be in-line with the downstream receiving waterbody.[1]

The water table is another important factor. Ideally it should be relatively close to the ground surface, this improves survivability of the plantings with little to no need for irrigation.

Soils

Become familiar with the soil types in the project area, using either electronic or paper soil maps. Testing soil core samples from the area of the detention basin is highly recommended. This way you can avoid highly permeable soils such as sand or sandy loams that will inhibit wetland formation.[1] Projects can work around small concentrations or pockets of sandy soil by modifying the design shape or bringing in clay to cap or encase the pockets, preventing erosion into the basin.

Additional Benefits and Functions

Finally, does/can the site provide for multiple benefits and functions such as maintenance accessibility, increased mobility, and passive or active recreation (e.g., bird watching, wildlife habitat, walking trails)? These additional benefits may not typically be considered for a detention project but can play a role in the site you select for a wetland. A constructed wetland can also be strictly for improved drainage, flood control, and water quality benefits with no additional amenities added.

Table 5A: Checklist for Stormwater Wetland Site Selection

STORMWATER WETLAND SITE SELECTION CHECKLIST		
Site Condition	**Yes**	**No**
1. Adequate Area Available		
2. Identified Wetlands Absent		
3. Hydrologic Flowpath Identified		
4. Depressional Storage Present		
5. Critical Habitat Absent		
6. Water Table Close to Surface		
7. Vegetation Identified FAC or Wetter		
8. Soil Infiltration Rate 0.04–0.4 in./hr.		
9. Soil Has Low Sand Content		
10. Site Accessible For Construction and Maintenance		

Table 5B: Checklist for Floating Stormwater or Treatment Wetland Installation

CONDITIONS FOR FLOATING WETLAND INSTALLATION CHECKLIST		
Site Condition	**Yes**	**No**
Slide slopes steeper than 3:1		
Water depth deeper than 18”		
Concrete sidewalls or liner		

SECTION 6

Design

Section 6, Design

The stormwater wetland design process should begin with the project goals and vision. Focusing on the needs and wants of your community will help direct the design process and provide context for decisions along the way.

Functions

The design stage is the best time to discuss which functions of the stormwater wetlands matter most to the stakeholders. Projects will differ in design to meet the functions or goals that are selected.

Primary Functions Include:

- Flood control through stormwater detention.
- Peak flow reduction by slowly releasing water back to the receiving bodies.
- Water quality improvements.

Secondary Functions Include:

- Enhance and reduce maintenance on already existing engineered storm drain systems.
- Habitat creation.
- Green space or park space.
- Improved pedestrian mobility.

Amenities such as benches, exercise and play equipment can be added to stormwater basins above the wetland shelf area. Whatever amenities you add need to be designed to handle temporary inundation during large storm events. They also need to be well anchored with the smallest impervious footprint possible to not negate the effectiveness of the proposed green infrastructure.

It is necessary to recognize that a fully functional wetland cannot be established spontaneously. Time is required for vegetation to establish and for nutrient retention and wildlife enhancement to function efficiently. Therefore, take the time during the design phase to set a target construction completion date that will maximize plant growth at the site during the first growing season.[2]

Size

Stormwater wetlands are ideal for drainage areas greater than 10 acres[3] and the factor that most impacts the effectiveness of the wetland is its size relative to the contributing watershed. To determine the size of wetland needed for an area, first identify the total area for the catchment basin then calculate the amount of wetland needed for the size of the watershed to design the fringe or shelf size proportionately. The size of a fully effective stormwater wetland should be 5-10% of the total area of the contributing watershed. For example, a catchment area of 100 acres should drain through 5-10 acres of wetland. The wetland size is the amount of vegetated shallow water shelf or fringe excluding the open water area. The wetland is essential to removing pollutants from the water and a larger system is more effective at removing pollutants.[1]

Volume

In addition to the size of the watershed, the volume of water running off the land and into the wetland should be considered. The wetland should be sized to retain and treat runoff from a 90th percentile storm for 48–96 hours after a storm event. A 90th percentile storm for the Upper Gulf Coast of Texas is equal to a 2–3 inch rainfall event.[1]

The length of hold time varies by the design of the outfall, and is regulated by local ordinances, check these to determine the maximum allowable time. Retaining water is essential for wetland function, the longer the water is interacting with the plants and the soil the more treatment will occur.

It is important to note the ideal size ratio above is difficult to meet if you are converting or adding stormwater wetlands to an existing detention or retention basin. However, any additional wetland area added to the basin will still provide some level of pollutant removal and increased infiltration.[1]

Features

To be the most effective, constructed wetlands need to simulate natural wetland features as close as possible. These include:

Forebay: Simulates deep pools often found in natural wetlands; 13–30 inches deep; located at the inflow to dissipate the runoff energy and collects large particles of sediment and debris in the runoff; 10–15% of the total area; easily accessible for periodic cleanout

Channel: Open water section that connects the deeper pools to the forebay and outfall. Permanent water except in drought situations.

Deep Pools: Distributed along the main channel. 18–30 inches deep; 20–25% of the total area. Help maintain aquatic species populations in drier seasons open water areas of the detention.

Shallow water vegetated shelf the main course of the water; 2–6 inches deep; 40% of the total wetland area.

Temporary Inundation Zone: This area is sometimes referred to as the shallow planting shelf. A temporary inundation zone is an area that holds a shallow amount of water, usually 6 - 18 inches of rainwater just after the rain event for up to three days. This is the area with the greatest amount of water quality and infiltration treatment capacity because it is allowed to drain off and dry temporarily between events. This is where the majority of the wetland plants will be planted in the stormwater wetland.

Side Slopes: Part of the upper banks; slope no steeper than 3:1; and should be vegetated to stabilize soil; can survive under dry conditions.[1]

Figure 13: Feature and shape schematic variations proposed for the Kost Street retention stormwater wetland in Alvin, Texas.

Shape

Basins can be many different shapes, but the most aesthetic designs follow natural curves and sinuous flow paths; the entire basin can be curved, sinuous, oval, or rectangular as long as the flowpath or channel in the bottom of the basin can shift like a natural channel. Unnatural shapes like straight sided channels and rectangular basins should be avoided whenever possible. Variation in shape adds to the visual appeal of the wetland feature and will allow for less maintenance on the channel and deep pockets by providing them the ability to adjust within the design as a natural channel.

A retrofit design in an existing shallow dry basin will most likely need to follow the shape already constructed, but some variations within the confines of the basin can be added to provide a natural look to the wetlands.

Floating Wetland Options

A retrofit project with steep sides can limit your wetland design, installing floating wetlands mats is an option. You will want to determine the size and shape of the mats you plan to install. Also, you need to know how the mats will be secured to the bottom of the basin. There are different anchoring options available. Then you will need to select the brand of mat, make sure it will stand up in the weather conditions of the area. Then you will create a planting plan using plants that will cover the surface quickly to prevent the UV rays from the sun from deteriorating the mat. You will want to vary the height of the plants to create and interesting habitat and visual display.

Figure 14: Floating wetland design plan for stormwater treatment or water quality improvement.

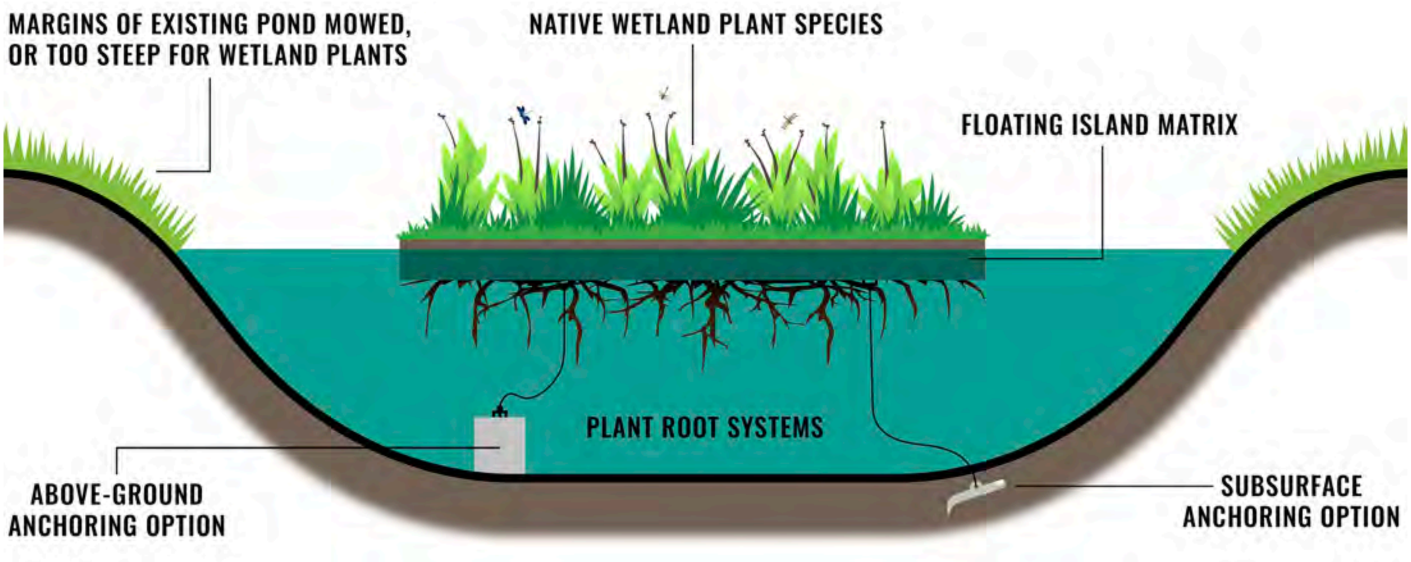
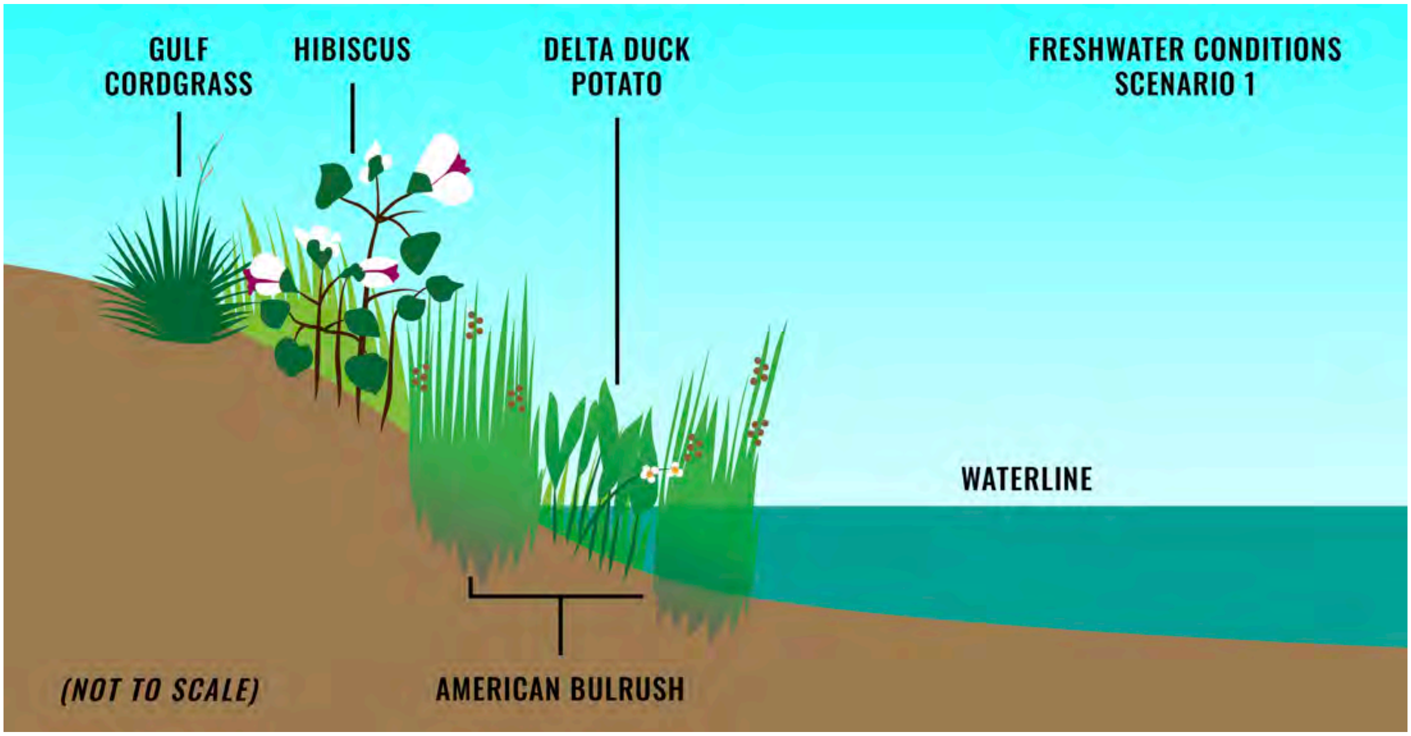


Figure 15: Sample freshwater planting plan profile based on water depth.



Planting Plan

This is the time to discuss the types of plants you want in your design. Both for the wetland and the upland bank areas. You will need to have an idea of the area needing to be covered to plan for the appropriate coverage amounts and budget. Knowing when construction will be complete will also help with plant selection; you will be able to better identify which plants will be available at the time and can be planted.

Plants that are in the area already provide a good starting point for plant selection. You always want to use plants that are native to your region to give them a better chance at survival. Many natural wetlands go through wet and dry cycles; therefore, these native plants can adapt to the changes in water depth of stormwater wetlands. Established plants with good root systems have an increased ability to reach moist soil, increasing survival even during drought conditions.[4]

It is good to create a list of prioritized primary and secondary plants. The list should include name, description, depth zone or favorable growing zone, and quantity desired. See sample plant list provided in Table 6A. The most versatile genera for pollutant removal are Carex, Scirpus, Juncus, and Lemna. (Mass. Stormwater Handbook mega manual) Give priority to perennial species that establish themselves rapidly. Give priority to species that have already been used successfully in constructed stormwater wetlands and that are commercially available in the local area.

Being intentional in plant selection can help manage budgets, provide an aesthetically pleasing look year-round, increase diversity, and attract a desirable mix of pollinators, birds and other animals to the habitat.

Table 6A: TCWP Preferred Wetland Plant list for stormwater wetlands.

TCWP Stormwater Wetland Plant List

Plant Species	Common Name	Nutria Resistance	Colonizing Speed	Water Depth	Notes
Bacopa caroliniana	Blue water hyssop/ lemon bacopa	yes	fast	0-6"	easy establishment, blue-purple flowers, lemon scent
Bacopa monerii	Coastal water hyssop	yes	fast	0-3"	easy establishment
Brasenia schreberi	Watershield		fast	18"+	
Carex hyalinolepsis	Thinscale sedge		medium	0-3"	blue-green foliage
Crinum americanum	Swamp Lily		medium	0-6"	showy white flowers
Cyperus articulatus	Jointed Flatsedge		medium	0-3"	foliage
Echinodorus cordifolium	Creeping Burhead		fast	0-6"	part shade tolerant, white flowers
Echinodorus rostratus	Upright Burhead		medium	0-6"	white flowers/dormant in winter
Eleocharis macrostaycha	Pale spikerush		fast	0-3"	easy establishment
Eleocharis montana	Spikerush		medium	0-3"	easy establishment
Eleocharis quadrangulata	Square-stem spikerush		fast	0-6"	easy establishment
Hibiscus coccineus	Texas star hibiscus		slow	0	shade tolerant/showy red flowers
Hibiscus lasiocarpus	Wooly swamp mallow		slow	0	showy white/pink flowers
Hydrolea ovata	Blue waterleaf	yes	medium	0-3"	drought tolerant/blue flowers
Hymenocallis liriosme	Spider lily		slow	0-6"	showy white flowers
Iris brevicaulis	Zigzag iris	possibly	medium	0-3"	showy blue flowers
Iris hexagona	Dixie iris	yes	medium	0-3"	showy blue flowers
Iris virginica	Southern blue flag iris	yes	medium	0-3"	showy blue flowers
Juncus effusus	Soft rush	yes	medium	0-3"	evergreen
Kostelezkya virginica	Saltmarsh mallow		medium	0	Showy pink flowers
Nelumbo lutea	American lotus	yes	medium	18"+	large/deep wetlands

Nuphar lutea	Spatterdock		medium	18"+	part shade tolerant
Nymphaea mexicana	Yellow water lily		medium	18"+	showy yellow flowers, aggressive in small areas
Nymphea odorata	White water lily		fast	18"+	showy white flowers
Panicum hemitomon	Maidencane	yes--in fall	fast	0-6"	foliage
Panicum virgatum	Switchgrass		medium	0-3"	clumping grass
Pontederia cordata	Pickerel weed		medium	0-12"	showy purple flowers
Potamogeton nodosus	Longleaf pondweed		medium	18"+	
Rynchospora corniculata	Horned beakrush		medium	0-3"	
Sagittaria lancifolia	Bulltongue		medium	0-6"	white flowers/dormant in winter
Sagittaria longiloba	Longlobed arrowhead		medium	0-6"	white flowers/dormant in winter
Sagittaria papillosa	Nipplebract arrowhead		medium	0-6"	white flowers/dormant in winter
Sagittaria platyphylla	Delta arrowhead		fast	0-3"	white flowers/dormant in winter
Saururus cernuus	Lizard tail	yes	medium	0-3"	part shade tolerant, flowering stalks, drought tolerant
Schoenoplectus pungens	American bulrush		fast	6-12"	foliage
Spartina patens	Marsh hay cordgrass		medium	0-3"	folaige
Spartina spartinae	Gulf Cordgrass		slow	0	clumping grass
Thalia dealbata	Powdery alligator flag		medium	0-6"	purple flower stalks
Tradenscantia ohiensis	Spiderwort		medium	0"	part shade tolerant

Table 6B: Table of TCWP native wetland plants least preferred for stormwater wetlands.

Native wetland plants less preferred for TCWP stormwater wetlands

Plant Species	Common Name	Nutria resistance	Colonizing speed	Water depth	Notes
Cyperus virens	Green Flatsedge		medium	0-3"	Indistinguishable from nuisance sedges to the
Fimbristylis annua	Fimbry		fast	0-3"	seasonal/weedy/volunteers
Juncus diffusisimus	Slimpod rush		medium	0-3"	seasonal/weedy/volunteers
Juncus nodatus	Stout Rush		medium	0-3"	seasonal/weedy/volunteers
Juncus validus	Roundhead Rush		medium	0-3"	seasonal/weedy/volunteers
Leersia hexandra	southern cutgrass		fast	0-3"	seasonal/weedy/volunteers
Polygonum hydropiperoides	Swamp Smartweed	yes	medium	0-6"	seasonal/weedy/volunteers
Rhynchospora colorata	White-topped Sedge		medium	0	volunteers preferred
Rhynchospora indianolensis	Indianola beaksedge		medium	0	seasonal/weedy/volunteers
Tripsacum dactyloides	Gamma Grass		medium	0	large scale projects only
Zizaniopsis miliacea	Giant cutgrass	yes	fast	0-6"	nutria resistance indicated
Utricularia radiata	Bladderwort		medium	(floats)	volunteers preferred
Cladium jamaicense	Jamaica Sawgrass		slow	0-6"	large scale projects only
Ludwigia spp	Water primrose	yes	fast	0-6"	seasonal/weedy/volunteers
Sagittaria graminea	Grassy arrowhead		slow	0-3"	seasonal/volunteers

Once plant lists are selected you will need to create a planting plan diagramming where each species will be installed. Planting plans generally include the general area for planting and a rough estimate of the number of plants in each section. Often you will plan to plant a mixture of 2–3 plant species in a specific ratio per section to provide greater diversity. Most plants can be planted on 24" centers. Denser plantings provide impact sooner and crowd out the invasive or weedy species.

When selecting plants consult with your maintenance team to help develop a schedule of mowing and no mow areas.

Maintenance

Prepare a maintenance plan before beginning the project. Involve staff that will oversee maintenance at the newly created wetland area in the design phase. They often have actual field insight that is valuable in planning. They can plan to add this to their future scheduling and budget needs. Be sure the maintenance team knows which plants are desired.

Schedule monitoring for plant survival quarterly the first year and at least biannually the next 2–3 years. Regular monitoring also helps to know where plants need to be added or thinned out. This period of monitoring and maintenance limits the amount of aggressive or invasive species establishment.

Floating wetlands also need a maintenance plan. In the event the plant material needs to be supplemented or replaced due to bird activity or storms.

Figure 16: Volunteer Planting at a Wetland Basin for the Houston Botanic Garden.

Health and Safety

When designing the project, it is important to consider all the risks. This will help to alleviate any health or safety concerns that may arise. The most common concerns are wildlife encounters, pests, and water safety.

If the proper design is used, including a diverse planting plan, mosquitoes should not be a problem in a stormwater wetland. Care should be taken to avoid using an abundance of certain plants where mosquitoes can breed. With more diversity there are a greater number of predators that can prevent any one species from overpopulating an area. In deeper water zones or pockets designed to hold water during drier times you can stock *Gambusia affinis* (Mosquito Fish) to help control mosquitoes by eating the larva in the water.[5]

Snakes and other wildlife are going to be a part of any natural setting. They are present in the areas already but making people aware of their surroundings with signage helps reduce accidental encounters.

The inclusion of shallow water planting shelves in stormwater wetlands and gradual water depth changes help to avoid accidental drownings. Drownings become a hazard with deep water and steep side slopes; neither of these are common practices in stormwater wetland design.

As always for the safety of small children they should always be accompanied by an adult whenever exploring in nature.

Figure 17: Example of Safety Signage

SECTION 7

Construction

Section 7, Construction

Unlike some other commonly engineered projects, stormwater wetlands are both physical and biological systems. Envisioning wetlands in this way will help designers and construction managers make informed decisions and build effective projects. Creating stormwater wetlands as thriving ecosystems will translate into improved downstream water quality for streams, rivers, and estuaries. Think of wetland construction as building a large garden, and coordinate construction with planting in mind.[2] Completing construction during the early fall can be an advantage in coastal areas with shallow water tables. Additionally, winter to early spring construction completion can be managed for more complex sites where extra time may be needed to complete earthwork or outlet construction, or both. Planting early in the growing season will help to protect the new wetland plants from periods of extreme heat and drought and allow for a full season of growth. Being able to schedule late winter to early spring planting times would be optimal for plant success. With stormwater wetland projects it is important to cover all the processes for the projects to be successful. These processes include permitting, site layout, materials, excavation, inlet and outlet installation, erosion control and bank stability, and wetland planting and establishment.

Permits

Permitting will vary by municipality and area. For the sake of providing planning assistance, we are including an example from the Houston Botanic Garden and the City of Houston. Permitting will not take place until you have your design packet finalized from your selected engineering firm.

Figure 18: The above listed information was provided by Chong Ooi from Walter P Moore to Houston Botanic Garden who gave permission to include as a guide for future projects using this manual.

Permitting Process for Houston Botanic Garden Stormwater Wetland	
STEP 1	The City of Houston Stormwater information form that summarized the project development information including the total impervious area of the development, flood zone, and point of stormwater discharge was submitted with the civil design package.
STEP 2	The drawing package was reviewed by the City of Houston Public Works Department and the Code Enforcement Department. The city review was mainly focusing on the storm water conveyance, stormwater detention volume and storm water quality improvement of the development.
STEP 3	The total permitting process took around 10 weeks that included a couple rounds of public comments/responses. After the plan review approval by the city, the contractor picked up the permits from the city prior to the start of construction.

Site Layout

Once the permitting is completed the site layout will begin. Site layout usually includes a walk through with the selected contractor to mark the site. Then the contractor will take over the site and fence off the work zone. They will arrange for traffic flow around the site. Site layout will include things like silt fences, temporary channel dams, filter socks to block inlet flow into the construction site from existing drainage, pumps to remove excess rainfall if needed during construction.

Figure 19: Photo depicts construction at Exploration Green note the grade stakes in the foreground. Photo courtesy of Jason Miles.

Materials

Once the construction timeline is established it is time to start planning for the biologic components. If you have a longer timeline and space to create a small nursery area with grow out ponds it may be cost effective to propagate plants for the project onsite; This way you can manage the supply and ensure native or adapted plant stock for the project. **Simple grow out tanks can be set up using tarps on a 2x4 frame for up to 3" water, or pond liners on a 2x12" frame for more depth.**

Figure 20: Pond liners on a 2 x 12" frame that are 16' x 40' can hold up to 1000 1-gallon size potted plants.

Figure 21: Plastic pools used to store plants temporarily.

Plastic pools can also be used as temporary storage for wetland plants as they grow out for local projects. Other materials to consider when deciding to grow plants onsite include space and storage for soil, pots, garden tools, worktables, signage, labels, planting equipment, water supply and staffing needs to manage grow out of plant material. Alternative grow out options include working with local partners such as Native Plant Society chapters, schools, garden clubs or Master Naturalists Chapters for assistance. Plant materials can come from local collection sites (50–150 miles of the site) collected as bare root plants, cuttings, or seeds. Always use ecologically sensitive collecting methods, 10% or less of the total population, to protect the collection source. Rescue sites where development or excavation is slated are exceptions to the rule. Be sure to get permission from landowners before collecting any materials.

Potential Collection Sites include:

- Roadside ditches or transportation easements.
- Utility Easements.
- Other Constructed Wetlands.
- Private Property.

ECOLOGICALLY SENSITIVE COLLECTING METHODS:

10% or less of populations, more than 100 parent plants per population, Seed > Cuttings > Divisions > Whole Plant removed.

Alternatively, you can plan to purchase the plants from local distributors to be delivered when excavation is complete. When using the purchase method, you may need to use multiple nurseries or suppliers to get the number of plants you need. Contract with growers early in construction to ensure supply. Realize that native populations will be collected in a greater area and may not be adapted to your specific climate. Be prepared for limited selection and sources; Many regionally important wetland species are not widely grown commercially and their horticultural requirements are not yet well-understood.

Excavation

Depending on the size and depth of the excavation this process could take anywhere from 6–18 months. There are many considerations when excavating including:

- The time work is allowed in and around neighborhoods.
- Access to get equipment on and off site.
- Are you using the soil onsite or are you removing it from the site.
- Traffic patterns for trucks and equipment, especially if you are moving materials off site.
- How to handle excess rainwater once construction is underway.

Figure 22: Excavation of Phase 5 of Exploration Green. Construction photos courtesy of Jason Miles.

Figure 23: Hauling excess topsoil from excavation off property. Photo courtesy of Jason Miles.

The primary things that effect timelines are weather delays and equipment delays.

Outflows

If the proposed wetland has been designed to be "in-line" with stormwater flow, outlet structures should be installed before any other major excavation. Establishing the outlet will give the structure more time to stabilize, and contractors will be able to control site drainage if groundwater seepage or rainfall occurs during construction.

A stormwater wetland outlet has three functions: Detain the water quality volume for treatment inside the wetland, safely pass large events that exceed the water quality storm, and allow for maintenance by lowering the pool elevation inside the wetland.

To achieve these functions the outflow structure will consist of a weir or a drawdown hole, or orifice used to slowly release captured runoff. For stormwater wetlands serving watersheds of 50 acres or less the typical orifice is quite small, with a diameter often measuring less than 2 inches, leaving it prone to clog. To prevent clogging of the orifice many preventive structural design methods often include:

1. A trash rack or grate.

2. Draw water from lower portions of the deep pool by submerging the orifice inlet. This keeps floating debris from clogging.

3. Incorporate elements of a flashboard riser, a technology borrowed from controlled drainage systems in eastern North Carolina.

Figure 24: Outfall structure at Houston Botanic Garden Stormwater wetland at low water level. showing clean out ladder.

Inflows

Inflow points of the stormwater wetland should be protected from erosion by using erosion control fabrics and closely planted vegetation to slow the speed of the water entering the forebay and wetland areas and protect these points from erosion. Many areas around the inlets are lined with rock substrate to prevent erosion.

Erosion Control / Bank Stability

Slopes

Slopes of the wetland banks should ideally be no more than 3:1 to minimize erosion issues and provide for maintenance such as mowing and pruning. In some cases with limited land surface available or increased detention needs, slopes can be increased if a bench shelf is added to the site to plant the wetland plants or other floating wetlands can be arranged for deeper water areas to maximize the amount of vegetated area.

Seeding

Banks above the wetland area will be seeded to protect banks from erosion. These seed mixtures should ideally consider native vegetation from local suppliers. These seed mixes should contain higher concentrations of forbs or wildflower seeds that tend to have a lower growth height than prairie grasses. Also select grass species that are only 2–3 feet tall at maturity to reduce the need for mowing, especially for wetland projects in urban and suburban areas.

Planting

Aquatic vegetation plays an important role in pollutant removal in both stormwater ponds and wetlands. In addition, vegetation can enhance the appearance of a pond or wetland, stabilize side slopes, serve as wildlife habitat, and can temporarily conceal unsightly trash and debris.[2]

Establishing and maintaining wetland vegetation is important when creating a constructed stormwater wetland. Horner et al. (1994) recommend the following actions when constructing stormwater wetlands:

- Match site conditions to the environmental requirements of plant selections. **Plant in large patches of the same species, mimicking the swaths one sees in established natural wetlands.**

- Plants will develop best when soils are enriched with plant roots, rhizomes, and seed banks from existing wetland soils. However, this could also introduce aggressive or invasive seed, that will need to be monitored closely during the establishment period.

- **Take into account hydroperiod and light conditions when selecting plants and planting the wetland.**

- **Plant on the "high side". Transplants that become established in shallow water may gradually send shoots into deeper water, even though they wouldn't thrive at that depth if they were planted there initially.**

- Planting on 24-inch centers is recommended, although coverage in 1 year can be ensured if the wetland is planted on 12-inch centers.[2] Skimping on plants will certainly result in a stormwater wetland that will not perform as designed, particularly in the early years. If the budget for your stormwater wetland project allows, planting at higher densities will improve wetland appearance and performance.

- **Select fast colonizing species as a foundation and mix in slower diversity species/floral displays**
- **Drying cycles enhance a wetland's ability to treat many pollutants effectively.**

Planting Plans / Density

Balance spacing, budget, and invasive species. Tighter spacing is more costly but provides more competition to crowd out invasive species. Planting on 24” centers spacing is ideal for most herbaceous species.

Fast colonizing species can generally go on wider spacing, up to 36”. For immediate lush look, plant closer.

Majority of species prefer less than 3” of water. Make sure the standing water depths are well understood in a new or modified basin. Over-inundation will cause thinning or die-back.

Planting

Larger sites that may require longer timetables or a phased planting approach should be planned with greater consideration. Wetland plants should be planted within 24 hours of delivery. Depending on the supplier, some plant species may arrive in flats, while others may be delivered as bare-root seedlings. Make sure that the plants remain moist and cool between arrival and planting. If the plants are kept on site for longer than 1 day, they will need to be watered.

The zones for each wetland plant species should be identified before the volunteer or professional planters arrive. Mark these areas with flagging. Use dibble bars or sharpshooter spades to plant bare roots or small rootballs in water or mud. Shovels for 1 gallon pots. A crew of 10 to 15 volunteer planters can plant a 1⁄4- to 1⁄2-acre stormwater wetland over the course of a day with proper oversight and direction. It is a good idea to supply the volunteers with planting tools (shovels, sharp-shooter shovels, dibbles) and disposable work gloves, and have plenty of drinking water on hand. Orient the volunteers to the location and target spacing requirements for the different species of wetland plants. Stagger plants rather than rows. Plant during the growing season, since dormant plants can drown. Start planting deepest species first, then higher elevations. Filling (or refilling) the basin so that species are in water immediately after they are planted is ideal.

Establishment Timeframe

Set benchmarks for establishment, such as 70% coverage within 1 year is ideal. The wetland needs to be managed as it is developing. It is particularly vulnerable in its early stages to drought, large storms, and herbivory. Because of these factors, it’s a good idea to budget for revegetation or repairs during the project’s first year. Weather following construction will often dictate plant success and site stability.

Waterfowl and burrowing animals can damage plants and berms. If a dense vegetative community is established in the first growing season, plant growth will typically outpace losses from wildlife browsing. Establish woody species after herbaceous species. Where applicable, add vegetation that will achieve other objectives, in addition to pollution control.

Wetland soils are also available commercially. The upper 5.9 inches of donor soil should be obtained at the end of the growing season and kept moist until installation. Wetland plants are commercially available through wetland plant nurseries.

SECTION 8

Maintenance

Debris

Debris and trash can be removed as part of a voluntary clean-up event or managed by the landowner. This needs to be done periodically, especially after large storm events. Community members with an interest in the project or local scout organization will often volunteer to lead these events. Some areas may employ a staff member who can direct these clean-up or maintenance events.

Sedimentation

Sedimentation in the forebay and outfall areas need to be monitored to remove excess sediment. This type of maintenance is generally completed in 5–10-year intervals, depending on the depth of the forebay feature. Other instances could arise after large storm events. Periodic removal of sediments that naturally accumulate maintains the depth and storage capacity of your project.

Vegetation

Mowing

Clearly marking areas that are not to be mowed gives maintenance crews and the public boundaries for safety and the success of the project. Banks can be mowed a couple of times a year to manage grasses and prevent shrub encroachment in the area. Make sure you provide the maintenance crews and mowing contractors with a list and description of desirable and undesirable species and an appropriate mowing schedule that allows desirable native species to go to seed before mowing.

Invasive or Aggressive Species Management

The site should be checked periodically throughout the year to determine if invasive species are present or multiplying. Despite being a native species, cattails are well adapted to develop monocultures that crowd out other natives and limit species diversity. The vegetative form of the cattail leaves shelter mosquitoes from their predators. For stormwater wetlands located near population centers, such as a commercial center parking lot or a residential neighborhood, it is best to limit the cattail population to less than 10% of the total vegetative population. The best or least harmful way to manage invasives and cattails is to manually remove them, however this is also the most labor-intensive method and requires a dedicated crew or volunteer base. Another intermediate method of control would be to remove seed heads of invasive or aggressive species to limit the amount of spread until either physical removal or spot herbicide treatments can be completed. Spot treatment application of herbicide is the final method to control for these types of species and should only be applied by licensed trained professionals to limit chemicals from getting into the waterways and limit the exposure of desirable plants to the harmful effects of the chemicals.

Irrigation or Watering

It is okay for stormwater wetlands to dry out occasionally during periods of drought and low water. This is a natural system and these periods of drought and inundation occur naturally. Even in drought situations wetland soils will remain moist to about a foot below the surface.

After initial plantings you will want to hold water depth to let the plants establish. The first growing season is also the most important for the native species on the banks to establish and they should be watered frequently that year. If the plants have time to establish in the first year of growth, native species will be able to tolerate dry periods.

Wildlife

A healthy wetland system can control nuisance populations, such as mosquitoes and biting insects, using natural predators. Healthy systems also provide habitat for other types of pollinators such as wasps, of which visitors should be aware. This can be done by posting pollinator garden signs or letting people know about the native plants in the area.

If you find that wildlife control is necessary, contact your local wildlife control agencies to discuss management of burrowing animals, such as trapping and relocation. Animal control can also relocate the occasional alligator or other reptile. All trapping and relocation should be done by professionals contacted through your local wildlife control agency.

Other wildlife that could need to be managed would be the introduction of other invasive species, such as nutria, channel apple snails, or armored catfish. These types of animals should be monitored and removed when possible.

It is a good idea to remind people wetlands are natural areas and to be aware of their surroundings and signage at the entrance should accomplish this purpose.

For other tips on maintenance issues you can consult design guides like HGAC's Designing for Impact: https://www.h-gac.com/getmedia/52972b6c-f53b-41ac-a1ea-dc6f64c106d5/Designing-For-Impact-Guide-for-Governments.pdf for reference guides and maintenance ideas.

Section 2: Introduction

1. *Stormwater Wetlands for the Texas Gulf Coast Ecology and Beauty for Improved Runoff Water Quality,* 2nd edition. – Texas Sea Grant, TAMU-SG-12-501, August 2012.

2. *NPDES: Stormwater Best Management Practices.* – Stormwater Wetland. EPA, EPA-832-F-21-03/AA, December 2021.

3. *2004 Connecticut Stormwater Quality Manual.* – University of Connecticut, 2004. Chapter 11.

Section 3: Communication

4. *National Coastal Ecosystem Restoration Manual.* – Oregon Sea Grant, 2002. pp. 3–11.

5. *Stormwater Wetland Construction Guidance.* – Urban Waterways. NC State Extension, AG-588-13, November 2010.

Section 4: Economic Analysis of Costs and Benefits

1. *Stormwater Wetlands for the Texas Gulf Coast Ecology and Beauty for Improved Runoff Water Quality,* 2nd edition. – Texas Sea Grant, TAMU-SG-12-501, August 2012.

3. *Green Values Strategy Guide: Linking Green Infrastructure Benefits to Community Priorities.* Center for Neighborhood Technology, Chicago, IL, 2020.

4. International Labor Organization (Available at: https://www.ilo.org/global/topics/green-jobs/news/WCMS_220248/lang--en/index.htm). Retrieved on May 30, 2022.

5. *Reducing Urban Heat Islands: Compendium of Strategies.* U.S. Environmental Protection Agency, undated.

6. *Estimating Benefits and Costs of Stormwater Management: Part I: Methods and Challenges.* Environmental Finance Center, Sacramento State University, July 2019.

7. 30 Year Treasury Rate – 39 Year Historical Chart, macrotrends.net, retrieved on June 14, 2022.

8. *Limitations of NPV*, Martin Hopkinson, Risk Management Capability, Ltd. Retrieved on June 16, 2022 from: http://www.projectnpv.com/9.html (undated web site).

10. *Discounting of Life-Saving and Other Non-Monetary Effects.* Emmett B. Keeler and Shan Cretin. Management Science, Vol. 29 (3), p. 300-306, March 1983.

11. *Economic Analysis of Investment Operations: Analytical Tools and Practical Applications.* Pedro Belli, Jock R. Anderson, Howard N. Barnum, John A. Dixon, and Je-Peng Tan, World Bank Institute, Washington, DC. 2001.

Section 5: Site Selection

1. *Stormwater Wetlands for the Texas Gulf Coast Ecology and Beauty for Improved Runoff Water Quality,* 2nd edition. – Texas Sea Grant, TAMU-SG-12-501, August 2012.

4. Hunt, Bill , et al. *Stormwater Wetland Design Update: Zones, Vegetation, Soil, and Outlet Guidance Urban Waterways.* – North Carolina Cooperative Extension, AG-588-12, December 2007.

6. Schueler, Thomas R. *Design of Stormwater Wetland Systems: Guidelines for Creating Diverse and Effective Stormwater Wetlands in the Mid- Atlantic Region.* – Anacostia Restoration Team Department of Environmental Programs Metropolitan Washington Council of Governments, 1992.

Section 6: Design

1. *Stormwater Wetlands for the Texas Gulf Coast Ecology and Beauty for Improved Runoff Water Quality,* 2nd edition. – Texas Sea Grant, TAMU-SG-12-501, August 2012.

2. *Stormwater Wetland Construction Guidance-Urban Waterways.* – NC State Extension, AG-588-13, November 2010.

3. Barrett, Michael E. *Permanent Structural Best Management Practices.* Complying with the Edwards Aquifer Rules: Technical Guidance on Best Management Practices – Texas Commission on Environmental Quality, Field Operations Division, RG-348, July 2005, https://www.tceq.texas.gov/downloads/publications/rg/chapter-3-rg-348.pdf

4. "Landscape." *iSWM Technical Manual.* – Integrated Stormwater Management, April 2010, https://iswm.nctcog.org/Documents/technical_manual/Landscape_9-2014.pdf

5. Hunt, Bill. *Mosquito Control for Stormwater Facilities.* – NC State Extension, 9 July 2020, https://content.ces.ncsu.edu/mosquito-control-for-stormwater-facilities

Section 7: Construction

1. *Stormwater Wetlands for the Texas Gulf Coast Ecology and Beauty for Improved Runoff Water Quality,* 2nd edition. – Texas Sea Grant, TAMU-SG-12-501, August 2012.

2. *Stormwater Wetland Construction Guidance-Urban Waterways.* – NC State Extension, AG-588-13, November 2010.

3. Constructed Stormwater Wetlands From the Massachusetts Storm Water Handbook, https://megamanual.geosyntec.com/npsmanual/constructedstormwaterwetlands.aspx

4. "Landscape." *iSWM Technical Manual.* – Integrated Stormwater Management, April 2010, https://iswm.nctcog.org/Documents/technical_manual/Landscape_9-2014.pdf

Section 8: Maintenance

5. Hunt, Bill. *Mosquito Control for Stormwater Facilities.* – NC State Extension, 9 July 2020, https://content.ces.ncsu.edu/mosquito-control-for-stormwater-facilities

Appendix: Estimating Benefits & Costs

The following publications have been identified as being a good resource for estimating costs and benefits:

The Value of Green Infrastructure: A Guide to Recognizing its Economic, Environmental and Social Benefits, Center for Neighborhood Technology, 2010.

https://cnt.org/publications/the-value-of-green-infrastructure-a-guide-to-recognizing-its-economic-environmental-and

Green Stormwater Infrastructure Impact on Property Values, Center for Neighborhood Technology and SB Friedman Development Advisors, November 2020.

https://cnt.org/publications/green-stormwater-infrastructure-impact-on-property-values

Green Values Strategy Guide: Linking Green Infrastructure Benefits to Community Priorities, Center for Neighborhood Technology, March 2020.

https://cnt.org/publications/green-values-strategy-guide-linking-green-infrastructure-benefits-to-community

Title of Paper	Authors / Year Published	Discount Rate	Life of Project (Years)
Case Studies Analyzing the Economic Benefits of Low Impact Development and Green Infrastructure to Reduce Localized Flooding *(Sun Valley Watershed, Los Angeles County Department of Public Works, Los Angeles County (LACDPW), California)*	U.S. EPA, Office of Wetlands, Oceans and Watersheds Nonpoint Source Control Branch, August 2013	4.0%	50
A Benefit-cost Analysis of Combined Sewer Overflow Control Options *(Philadelphia Water Department (PWD) Philadelphia, Pennsylvania)*		4.875%	40
Economics Benefits of Green Infrastructure – Great Lakes Region *(Case Study – Milwaukee, Wisconsin)*	Mark Buckley, Tom Souhlas, and Ann Hollingshead, December 2011	3.0%	50
Economics Benefits of Green Infrastructure – Great Lakes Region *(Case Study – Ann Arbor, Michigan)*	Mark Buckley, Tom Souhlas, and Ann Hollingshead, December 2011	3.0%	50