North Central Texas Council of Governments

Integrating Transportation and Stormwater Infrastructure

Economic Analysis Literature Review

July 2026

The Texas General Land Office provided guidance, oversight, and funding for this study.

This study was also funded by the Texas Water Development Board and Texas Department of Transportation.

integrating Transportation & Stormwater Infrastructure

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Economic Analysis

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1 Introduction

An economic analysis can be used to help agencies identify and prioritize adaptation strategies, according to the Federal Highway Administration (FHWA) Vulnerability Assessment and Adaptation Framework (Filosa et al., 2017). Several transportation resiliency studies did incorporate some element of economic analysis.

The Broward 2016 study (WSA et al., 2016) recommended a risk-based decision framework for incorporating climate change into facility design; the report stated this was in contrast with current frameworks for traditional facility design. The risk-based decision framework includes considering maintenance costs for climate events, agency costs related to damage and maintenance over the lifetime of the project, and quantified economic, social, and environmental costs for damage and loss of service. Finally, the framework recommends identifying the most cost-effective design solution using a benefit-cost analysis. The report itself did not conduct any economic analysis.

Resilient Tampa Bay (Kiselewski et al., 2020) evaluated the estimated costs of implementing adaptation strategies vs. the economic loss of not implementing adaptation strategies. The Tampa report reviewed six demonstration projects, potential climate impacts, the cost of adaptation strategies, and the regional economic impacts (gross regional product and lost personal income/wages) of those disruptions.

Cost estimates were developed as a planning-level effort using construction cost-per-mile models and the historical cost database from the Florida Department of Transportation. These amounts were supplemented to account for design, construction engineering and inspection, reconstruction of features such as box culverts and traffic signals, and right-of-way acquisition if detention/retention ponds were planned. The report provided a table describing the cost-per-mile of coastal protection strategies such as sea walls or vegetation; raised roadway profiles; drainage enhancements such as detention/retention ponds, swales/ditches, enhanced roadside drainage, and permeable pavements; and asset protection such as enhanced subbase and hardened shoulders. Costs per mile ranged from a low of $15,840 for installing vegetation to protect assets to a high of $16,127,000 for raising the profile of a six-lane urban roadway by 4 feet. Amounts were based on 2019 costs.

To estimate the economic consequences of transportation disruptions, the study team used TranSight, a software package from Regional Economic Models Inc., to analyze the economic impacts of transportation investments. TranSight provides information on the flow of goods and services based on changes in the transportation system's performance. The study used the model to estimate regional impacts, including changes in gross regional product and personal income, for scenarios in which transportation facilities were out of service for two days. These estimated losses were then compared with the costs of implementing adaptation strategies to evaluate their economic justification. The study found that adaptation investments for critical transportation corridors can be economically justified because the regional economic losses associated with climate-related transportation disruptions often equal or exceed the costs of implementing resilience measures. It also concluded that the greatest economic benefits are achieved by prioritizing resilience investments on transportation assets that are most important for regional mobility and economic activity.

The North Central Texas Council of Governments' (NCTCOG) study of green infrastructure ecosystem services (Highland Economics, LLC, 2018) included quantifications of the economic benefit of stormwater management. This was derived from residential stormwater fees in the cities of Fort Worth and Dallas. Stormwater management was valued at $1,000 to $1,100 per impervious acre per year (2018 dollars), based on stormwater management fees. The study also calculated capital costs, annual maintenance costs, and total annualized costs for mitigation measures. A comparison of the two allows for some benefit-cost comparisons for implementing green infrastructure solutions to mitigate the impacts of transportation projects.

A white paper developed on transportation system resilience explored the economic impacts of failing to address resiliency (Fletcher and Ekern, 2021). The paper noted flooding is the most likely cause of disruptions to transportation systems. The paper found that the cost to recover from flooding impacts is increasing, and flooding is occurring more frequently and affecting more people. The white paper noted the following factors that should be considered in economic analysis: deaths, injuries, and post-traumatic stress disorder; repair costs; loss of revenue and other business-interruption costs; loss of income to residents; loss of economic activity in the broader community; loss of transportation services; and costs for search and rescue.

While few studies incorporated economic analysis, the technique is a compelling one to demonstrate whether and where actions should be taken to reduce flooding impacts on transportation infrastructure. Economic considerations are required in Metropolitan Planning Organizations' (MPO) long-range transportation plans; stormwater infrastructure and adaptation strategies could be included in the construction cost of transportation facilities.

2 Overview: Economic Considerations and Approaches in Stormwater and Flood Risk Management

Stormwater runoff is produced when precipitation runs off impervious surfaces—like asphalt, concrete, and rooftops—rather than soaking into the soil. This runoff may transport pollutants like debris, chemicals, and sediment into groundwater and surface waters (EPA, 2025a). As areas urbanize, the resulting increase in impervious area thus increases stormwater runoff volumes and velocities. Higher stormwater runoff, in turn, can lead to higher water levels, more erosion and contaminants in rivers and streams during storm events, adversely affecting flood risk and water quality.

Grey and green infrastructure represent two approaches to managing stormwater. Conventional or grey infrastructure solutions (e.g., built infrastructure such as pipes, pumps, and storage tanks) typically are engineered to prioritize flood risk reduction and can also provide water quality benefits if water is conveyed to a water treatment facility. Grey infrastructure, however, can have adverse water quality consequences (degrading water quality and aquatic habitat if pollutants are conveyed directly into waterways) and can actually increase flooding if systems are overloaded or clogged during storm events and overflow (Akhter, et al., 2025; Jones, et al., 2015; Hoover & Hopton, 2020). Grey stormwater infrastructure can also be very costly.

Conversely, green infrastructure, which includes nature-based solutions (NBS) and green stormwater infrastructure (GSI), manages stormwater through preserving or using natural landscape features (vegetation, permeable surfaces, etc.) that slow down or store stormwater and filter contaminants from stormwater through processes like soil infiltration and evapotranspiration. While both grey and green approaches can provide stormwater benefits via avoided flood damages and improved water quality, as well as enhanced economic resilience and public safety (Kang, et al., 2024; Akhter, et al., 2025; Jones, et al., 2015), NBS and GSI solutions typically yield more diverse benefits across economic, social, and environmental systems. To appropriately capture the diverse benefits of NBS (and at times conventional) stormwater management, a comprehensive "triple bottom line" evaluation is necessary to properly capture the benefits provided.

The key types of economic and social values derived from the environmental benefits provided by NBS and GSI are summarized below. There are two main categories of economic and social benefits: 1) financial cost savings, and 2) quality of life improvements due to increased green space. Different types of benefits may be more important to different stakeholder groups, such as the public, local developers, and local governments. Further, different types of GSI and NBS may provide different types of benefits.

Potential Types of Cost Savings:

- Water Treatment/Management Cost Savings (stormwater and drinking water)
- Avoided Flood Damages and Public Safety Hazard to Transportation Infrastructure, Structures, and Property
- Energy Use (stormwater management and/or reduction in urban heat island)
- Infrastructure Investment Cost Savings (stormwater management and/or reduction in urban heat island)

Potential Types of Quality-of-Life Improvements:

- Habitat & Species Abundance (terrestrial and aquatic)
- Recreation Opportunity/Quality
- Aesthetic Quality

- Health Benefits from Improved Air Quality/Connection to Nature/Outdoor Exercise/Urban Heat Island Reduction

The following table categorizes the various types of potential effects and resulting socioeconomic values provided by stormwater management, highlighting the distinct benefits offered by NBS/GSI compared to traditional grey infrastructure.

Table 1. Potentially Relevant Economic and Social Benefits of Green vs. Grey Infrastructure

Project Effect / Socioeconomic Value	**Description of Benefits**	**Primary Associated Infrastructure Type**
Flood Hazard Reduction & Property Protection	Avoided physical damage to buildings, contents, and infrastructure. Reduced frequency and intensity of flooding. Property value increase due to reduction in flood exposure.	Both (Grey & NBS/GSI)
Transportation Costs & Safety	Avoided physical damage to transportation infrastructure and avoided costs (time, fuel, etc.) related to disruption or closure of travel routes. Reduced pavement maintenance costs (due to tree shade).	Both (Grey and NBS/GSI)
Social Disruption & Public Safety	Reduced loss of life, transportation disruption, access to public services, schools, and businesses. Avoided emergency response costs.	Both (Grey & NBS/GSI)
Water Quality Improvement	Reduced pollutant loads (e.g., nitrogen, phosphorus, sediment). Improved water clarity and ecological health. Avoided wastewater treatment costs.	Possibly both, but especially NBS/GSI
Climate Regulation & Greenhouse Gas Mitigation	Reduction of urban heat island (UHI) effects, shading, and evapotranspiration. Carbon sequestration and storage. Reduced energy use for cooling (avoided emissions).	NBS/GSI (primarily)
Human Health (Physical & Mental, Not Flood Related)	Improved air quality (pollutant removal). Avoided medical costs related to heat stress, respiratory illness, and waterborne disease. Improved mental health and psychological wellbeing.	NBS/GSI (primarily)
Water Supply / Water System Cost Reduction	Groundwater recharge from increased infiltration. Cost savings from reduced stormwater conveyance and/or treatment costs.	NBS/GSI
Recreation & Aesthetics (& Associated Property Value)	Increased quality of life resulting from improved aesthetics, green space proximity, or amenities; these improvements often result in increased property values.	NBS/GSI (especially)
Social & Community Cohesion	Sense of place, improved quality of life, community cohesion, and neighborhood appeal. Crime reduction from increased green space.	NBS/GSI
Ecosystem Function & Habitat	Restoration or enhancement of wetlands and wildlife habitat creation/connection. Increased biodiversity. Soil stabilization and nutrient cycling.	NBS/GSI
Economic Activity & Development	Economic resiliency and viability from reduced flood risk and reduced disruption to businesses and communities. Increased quality of life and community aesthetics translating to economic vibrancy and cohesion, potential commercial vitality, potential increased tourism and recreation revenue/value.	Both, greater potential for NBS/GSI
Social Equity & Vulnerability	Distributional effects and environmental justice based on who is affected by the project.	Both (with strategic siting)

Sources: (Akhter, et al., 2025; Braden & Johnston, 2004; CNT, 2020; Kang, et al., 2024; Symons, et al., 2015; TNC; AECOM, 2021; Sustainable Business Network, 2016; Lewis, 1997; NCTCOG, 2017; McPherson & Muchnick, Effects of Street Tree Shade on Asphalt Concrete Pavement Performance, 2005)

3 Available Data Sources on GSI/NBS Benefits

There are numerous sources of data on the benefits and costs of green infrastructure, including from federal agencies such as the Federal Emergency Management Agency (FEMA) and the U.S. Environmental Protection Agency (EPA), state and local agencies such as NCTCOG, nonprofit organizations such as The Nature Conservancy, and academic publications. Examples of these publications are provided below:

- Economic Benefit Values for Green Infrastructure - FEMA (2022)
- Green Stormwater Infrastructure for Urban Flood Resilience: Opportunity Analysis for Dallas, Texas - The Nature Conservancy / Texas A&M AgriLife (2022)
- The Value of Green Infrastructure: A Guide to Recognizing its Economic, Environmental, and Social Benefits - Center for Neighborhood Technology (2010)
- Valuation of Open Space and Conservation Features in Residential Subdivisions - (Bowman, et al., 2009)

However, the performance of GSI/NBS in providing the benefits listed in Table 1 can vary dramatically by GSI/NBS type and can also vary substantially with each GSI/NBS type, depending on site-specific factors. For this reason, the available data on the benefits of green space and GSI tends to be very generalized or very site-specific using a case study approach.

Since gathering site specific data and using a case study approach can be time-consuming and costly, many studies of GSI/NBS benefits leverage existing data and valuation estimates. Applying the results of existing economic valuation studies to a new policy context is called benefits transfer. The key to ensuring a successful benefit transfer is to carefully assess the soundness and similarity of studies selected for benefits transfer. To be considered sound, a study should have high-quality data collection procedures, adhere to best practices for empirical methodology, and be consistent with economic theory. Further, the study should provide enough information about the research to fully evaluate the data, modeling, and results. Similarity refers to how closely the context of the proposed transfer study resembles the "new" context (current study). Some aspects of similarity that are important to consider include the type of GSI/NBS being analyzed, the climate/rainfall of the area, the amount of impervious surface, the size or design capacity of the GSI/NBS, and the socio-economic characteristics, demographics, and land uses of the local area.

4 National and State Guidance on Economic Analysis

Cost-benefit analysis (CBA) is the economic tool typically used to economically analyze flood mitigation projects. CBA aims to evaluate if a project maximizes overall societal welfare by comparing all costs and benefits to calculate the Net Present Value (NPV) or a BCR (BCR). The federal government considers CBA as universally appropriate for determining the economic efficiency of major public investments; hence it is frequently required for obtaining federal funding (TNC; AECOM, 2021; Cross, et al., 2024).

Historically, CBAs for flood mitigation have primarily focused on monetizing changes in expected property damages (Akhter, et al., 2025; Environmental Finance Center, 2019). Analyses with this narrow focus tend to overlook other positive and negative environmental and social effects. As outlined in the table above, stormwater management projects and other flood mitigation projects often have diverse environmental and public safety effects that should be considered to reflect the full economic value of a project.

Further, there are social and economic resiliency considerations that can be incorporated into socioeconomic analysis of stormwater and flood risk management. Conventional CBAs performed for state and national agencies typically do not include analysis of distributional consequences (i.e., who is affected where) and effects on social/economic vulnerability (i.e., consideration of the percentage of minorities, disabled, or low-income households in an affected area and the relative effects on their economic well-being and ability to survive and recover from a flood event). A CBA of a flood mitigation project that solely focuses on estimating property damage tends to prioritize projects that benefit wealthier populations since these populations tend to have higher valued property (Akhter, et al., 2025; McGee, 2021; van Hattum, et al., 2021). As such, a flood mitigation project protecting 100 homes flooded in a wealthy neighborhood with high value homes may have a higher BCR than a project protecting 200 homes in a low-income neighborhood.

To address these issues in a traditional CBA of flood mitigation projects, recent state and federal guidance has identified a need to address the full range of environmental, social, and economic values affected by flood mitigation and other water resource projects. Some guidance has also emphasized the importance of considering social equity and long-term resiliency. Equity weights can address concerns about distributional effects (van Hattum, et al., 2021).

4.1 Federal Principles, Requirements, and Guidelines for Water Resource Projects

In 2014, the federal Council on Environmental Quality published the Principles, Requirements, and Guidelines (PR&Gs), which govern how federal agencies (specifically the Departments of Interior, Agriculture, Commerce; EPA; the U.S. Army Corps of Engineers; FEMA, and the Tennessee Valley Authority) evaluate proposed water resource development projects. The PR&Gs supersede the 1983 Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies. The PR&Gs differ from the Principles and Guidelines (P&Gs) by moving from a primarily economic-based evaluation to a framework that encompasses a broader set of values affected by water resource projects, including: sustainable economic development, healthy and resilient ecosystems, public safety, and environmental justice (U.S. Department of Interior, 2015). The PR&Gs require that economic development, environmental, and social effects all be considered and evaluated to determine the net public benefit, including monetary and non-monetary effects and qualitative and quantitative metrics. To accomplish this, the PR&G framework is an ecosystem service and watershed-based approach.

In addition to PR&G, all federal cost-benefit analysis must conform to the Office of Management and Budget's (OMB) Circular A-94, recent versions of which have directed agencies to recognize distributional effects (McGee, 2021; Carey, 2024; Lockwood, et al., 2024).

4.2 FEMA and USACE

Two of the federal agencies that most frequently fund and analyze flood mitigation projects are the U.S. Army Corps of Engineers (USACE) and FEMA. This section describes agency-specific guidance and efforts for economic analysis of flood mitigation projects.

Each federal agency can issue specific guidance for implementing the federal PR&Gs and conducting CBA. For example, in April 2024 USACE issued guidance that emphasized consideration of long-term impacts, cumulative effects, climate adaptation, and social economic vulnerability (Akhter, et al., 2025). In line with this policy, USACE has embraced initiatives like "Engineering with Nature" and developed new frameworks to promote the use of non-monetary benefit indicators and multi-criteria analysis (MCA) to capture comprehensive project impacts.

FEMA relies on CBA to ensure that Hazard Mitigation Assistance (HMA) projects are cost-effective (FEMA, 2022b). The FEMA CBA Toolkit has evolved significantly over time. In 2013, FEMA incorporated into the toolkit per-acre estimates of the dollar value of ecosystem services by land cover type, such as riparian and green open space (FEMA, 2022b). Then, in 2020, FEMA removed the previous limitation that required projects to achieve at least a threshold of 0.75 BCR using only traditional risk reduction benefits before ecosystem service values could be included (FEMA, 2022b; TNC; AECOM, 2021). This policy change effectively recognizes that ecosystem service values alone can provide benefits that exceed costs. FEMA has also begun encouraging the inclusion of benefits such as reduced social vulnerability and mental health in applications for programs like Building Resilient Infrastructure and Communities (BRIC) (McGee, 2021). To help measure these benefits, FEMA has developed the National Risk Index (NRI), which integrates measures of social vulnerability, community resilience, and expected annual loss. In addition, FEMA has recently released new guidance for valuing essential public services (FEMA, 2023).

4.3 Texas Water Development Board

The Texas Water Development Board (TWDB) is in the final stages of preparing a CBA guidance document intended to identify scalable approaches to CBA and provide a set of new damage benefit tables to assist communities in preparing BCRs. This document will include standardization for green infrastructure projects called Green Infrastructure in Texas (GIFT) (Texas General Land Office, 2025). The most recent available guidance comes from the River Basin Flood Study (RBFS), initiated by the Texas General Land Office (GLO) with the purpose of collecting, analyzing, and communicating flood risk information to assist decision-makers in protecting Texas from future floods. The regional study teams conducting the RBFS are recommended to use the TWDB State Flood Plan CBA Input Tool in conjunction with FEMA's CBA Toolkit 6.0 (Texas General Land Office, 2025).

To compare alternatives, the RBFS's procedure recommends quantifying and ultimately monetizing, where possible, non-monetary benefits and costs, such as increased emergency access, reduced population at risk, and environmental equity. In addition, the evaluation expects a robust set of criteria that moves beyond simple economic calculations. While most criteria remain qualitative, actual values are requested for social vulnerability and cost/benefit estimates. These criteria evaluate factors like impact on water supply and quality (yes/no), social vulnerability (percent of area that is low on the social vulnerability index), and potential for ecological uplift (low/medium/high). The procedure also suggests considering other factors as tiebreakers if the performance (dollar-denominated net benefits or other criteria) is comparable. Additionally, teams are instructed to give priority to projects that make an impact sooner by including early implementation alternatives alongside more complex, large-scale projects.

5 Other Economic Analysis Approaches and Available Tools

Cost-benefit analysis has historically been the primary economic analysis approach to provide information to decision-makers on alternative approaches to stormwater management, transportation planning, and flood risk mitigation. This section summarizes alternative approaches that may provide additional insight and information to decision-makers.

5.1 Least-Cost Analysis and Cost-Effectiveness Analysis

Least-cost analysis (LCA) is a systematic framework to compare options that can all achieve the same objective. As such, this method does not require analysis and monetization of all relevant benefits or costs. This method is most useful when there is one main project goal (such as flood reduction) and there are a variety of options that achieve the project goal but differ only in their costs. LCA can be an appropriate tool when a regulatory body or statute has specified the level of benefits to be achieved or when a decision is based on expediency or policy, and the simplest, cheapest, or most effective option to achieve the specified outcome is sought (van der Pol, et al., 2017; Jones, et al., 2015; Isely P. , 2010).

Cost-effectiveness analysis, a related analysis, may be viewed as an intermediate form of CBA, where costs are fully counted, but benefits are expressed in physical, non-monetary terms. In cost-effectiveness analysis (CEA), the level of benefit (such as number of bridges not inundated) per unit of cost is examined. This is particularly useful when evaluating benefits that are not easily expressible in monetary terms. For example, CEA is valuable when comparing the costs required to achieve specific physical outcomes, such as "*x* CF of stormwater captured per $1,000 spent". Due to CBA often not being legally required for systems like urban drainage, cost-effectiveness approaches remain predominant in their design (van der Pol, et al., 2017). For example, the Capitol Region Watershed District (CRWD) in Minnesota used CEA to assess different Low Impact Development/GI practices, demonstrating its comparative simplicity and speed relative to a full CBA (EPA, 2013). Outcomes are often measured using preferred metrics like lives saved or life-years saved rather than monetary valuation.

However, LCA/CEA is inappropriate when the primary objective is to maximize societal welfare because the cheapest or most cost-effective option may not be the choice that maximizes net benefits. CEA is inherently limited because it cannot justify the overall economic viability of a project or evaluate trade-offs when multiple disparate outcomes are achieved unless complex weighting schemes are introduced (OMB, 2003). The simplest form, Capital Cost Assessment, is also unsuitable for long-term project viability as it ignores Operation & Maintenance (O&M) and replacement costs (EPA, 2013).

5.2 Comparative Analysis / Multi-Criteria Decision Analysis

Comparative analysis, including multi-criteria decision analysis (MCDA) or multi-criteria decision making (MCDM), is a systematic analysis framework for evaluating alternatives in complex policy fields like flood risk assessment (de Brito & Evers, 2016). This approach is an umbrella term for methods that structure and evaluate alternatives based on multiple criteria and objectives. MCDM criteria can be monetary and non-monetary, and quantitative and qualitative (Peck, et al., 2022; Environmental Finance Center, 2019). As such, for complex decisions involving numerous competing objectives, MCDA is a flexible and transparent framework that can integrate monetized, quantified, and qualitative factors simultaneously. MCDA is particularly suitable for planning activities that require broad stakeholder input and must explicitly consider non-monetary aspects like social vulnerability, cultural value, and quality of life alongside economic performance (Cross, et al., 2024).

Since many public flood mitigation projects generate benefits difficult to express in monetary terms (e.g., clean water, biodiversity, cultural heritage, and environmental justice benefits), MCDM can be a useful tool to objectively compare project alternatives. MCDM's use in flood risk management has grown quickly in recent years, with common applications including the ranking of alternatives for flood mitigation (the most frequent application) and conducting risk, hazard, and vulnerability assessments. MCDM is appropriate for flood risk assessment because flood decision-making is inherently complex and uncertain, involving multiple stakeholders and non-monetary values that traditional tools struggle to capture. Applications span project prioritization (e.g., Kirkland, WA, using quantitative ranking to integrate low impact development [LID]/GSI into Capital Improvement Projects) to broader strategy selection (e.g., Calgary, AB, using a Triple Bottom Line MCDA to compare 13 flood mitigation scenarios, including managed retreat) (EPA, 2013; OMB, 2003). While MCDA can help to foster political buy-in by explicitly valuing subjective criteria, it has challenges related to non-commensurability and the reliance on stakeholder or expert judgment for scoring and weighting criteria (Akhter, et al., 2025; Cross, et al., 2024). This process can be time-consuming, costly, and the resulting score aggregation often implies a potentially misleading "substitutability" where a strong score in one area offsets a critical failure in another.

Specific MCDM techniques commonly applied include the Analytic Hierarchy Process (AHP), often integrated with Geographic Information Systems (GIS) due to its simplicity in deriving criteria weights (de Brito & Evers, 2016). Other methods include TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution) and SAW (Simple Additive Weighting). TOPSIS ranks alternatives by comparing their distance to an ideal solution and a negative-ideal (worst) solution, while SAW ranks alternatives by calculating a total score as the sum of each criterion's performance value multiplied by an assigned weight (de Brito & Evers, 2016). The selection of the appropriate MCDM tool, however, depends on the problem type and decision makers' objectives.

5.3 Stakeholder/Community-Based Approaches

Stakeholder/community-based approaches for flood risk assessment and management prioritize the involvement of citizens, local officials, non-governmental organizations (NGOs), and other affected parties in the decision-making process, moving away from purely top-down, expert-dominated policy (Edelenbos, et al., 2017). This approach can be appropriate for flood risk management because flood decision-making involves multiple stakeholders with diverse and often competing objectives. Understanding resilience at the community level is often helpful because the direct and indirect impacts of disasters are acute at this scale, and effective action often originates locally (Chapagain, et al., 2024). For example, the Flood Resilience Measurement for Communities (FRMC) framework, which employs community surveys, focus groups, and interviews, is designed to provide a holistic approach to measuring community flood resilience across five "capitals" (physical, social, human, financial, and natural) (Chapagain, et al., 2024; Kim & Newman, 2020). Engaging stakeholders helps managers to identify and leverage co-benefits of projects (such as job creation, public health, or environmental enhancements) and tailor messaging to specific local needs and priorities (Smith, et al., 2022; Hoover & Hopton, 2020). Furthermore, community engagement is important for successful asset management and long-term funding strategies (Environmental Finance Center, 2019).

Stakeholder- and community-based approaches are particularly effective in dealing with challenges concerning equity and intangible value. Community and intrinsic values, such as social cohesion and sense of place (which can be lost during projects like managed retreat), are best assessed using deliberative democracy-type approaches rather than adapting market analysis methods (Jones, et al., 2015).

Stakeholder approaches address knowledge and data gaps inherent in flood-costing methodologies (Adeel, et al., 2020). The process of community engagement and field verification is an important component of flood risk assessment because it enables local officials and residents to validate risk assessment findings, verify data for modeling (like foundation type and first-floor height), and identify Areas of Mitigation Interest (AoMIs) (Donaldson & Sharma, 2021). This local knowledge ensures the information used is in sync with community standards and helps to strengthen the foundation for indicator development that better reflects the context in which vulnerability occurs (Rufat, et al., 2015).

In summary, stakeholder- and community-based approaches can serve to ground technical assessments in local values and priorities. These approaches ensure transparency, equity, and local acceptance, which enable the long-term success of projects involving significant community impacts, such as managed retreat or changes in neighborhood characteristics. These approaches are appropriate when defining criteria (as seen in a flood hazard assessment in Pakistan where community input helped weigh criteria using the Analytic Hierarchy Process, [AHP]) and when managing inter-agency and jurisdictional coordination (necessary for large GSI projects in NYC) (Ibrahim, et al., 2025; EPA, 2013). Although community-based planning ensures that assessments reflect the full range of social and cultural benefits and harms, its main drawbacks are the substantial time and resource commitments required and the challenge of translating diverse qualitative input into a structured, quantitative framework usable by government agencies (Akhter, et al., 2025; Cross, et al., 2024; de Brito & Evers, 2016).

5.4 Scenario Planning

Scenario planning is a flexible and strategic decision-making process that identifies and prepares for various plausible future options, rather than relying on the traditional "predict-and-plan" approach which only considers singular growth trajectories and does not address future complexities (Kim & Newman, 2020). This method helps stakeholders, including agencies and local officials, to make better decisions for possible future conditions by comparing and assessing different and plausible scenarios, such as "business as usual" and "resilient growth" urban development scenarios, combined with various sea level rise projections (Johnson, et al., 2019; Loch, et al., 2020). Scenario planning is appropriate for flood risk assessment because the field is dominated by high uncertainty about future conditions, especially climate change, sea level rise, and urbanization.

Economically efficient flood risk management strategies in the face of future climate change requires methods that integrate hydrological uncertainty about changes in weather extremes and sea levels. Scenario planning handles this challenge by introducing uncertainty through probability-weighted climate scenarios. For instance, the analysis of a specific adaptation strategy can evaluate costs and benefits across four or more sea level rise scenarios to determine the optimal mix of measures (de Ruig, et al., 2020). By using multiple scenarios, the process encourages consideration of extreme change possibilities and avoids reliance on only conservative outputs, which can help to build resilience against rare, high-consequence flooding events (Kim & Newman, 2020; van der Pol, et al., 2017).

The strength of scenario planning is explicit preparation and planning for future uncertainty, including climate change and changing flood hazards. Applications include developing flood mitigation strategies that remain effective under various hydrologic or growth projections, or by sequencing adaptive actions over time using Dynamic Adaptive Policy Pathways (DAPP) based on trigger points (Cross, et al., 2024). The primary benefit of scenario planning is the resultant flexibility and robustness of the chosen strategies, enabling decision-makers to test options against extreme events (Cross, et al., 2024; Kim & Newman, 2020). However, scenario planning introduces uncertainty that is difficult to translate into conventional expected value calculations required by standard CBA, and requires high-quality, spatially detailed data, sometimes necessitating complex land change models (LCM) (Akhter, et al., 2025; Cross, et al., 2024; Kim & Newman, 2020).

Overall, the assessment of flood risk and stormwater management is shifting from a narrow focus on traditional CBA to more comprehensive and inclusive frameworks. Historically, CBAs for flood mitigation primarily monetized changes in expected property damages, a practice that inadvertently favors wealthier populations and overlooks critical social, environmental, and resilience-based impacts. To address these gaps, alternative methods have been developed. These methods can help regional planners make decisions about flood risk that involve complex tradeoffs.

6 Literature Review: Economic Considerations for Integrating Transportation and Stormwater Infrastructure Planning

Transportation networks and stormwater management have a reciprocal relationship. Impervious surfaces, such as roads, parking lots, and sidewalks, are a primary contributor to stormwater runoff (EPA, 2021d). Likewise, in storm events, flooding can inhibit movement along transportation networks. During Hurricane Harvey in 2017, sections of Houston's highway network became impassable when depressed freeways and frontage roads filled with stormwater, because the drainage grid was designed for past conditions and could not handle the volume and intensity of rainfall (Borenstein & Bajak, 2017; Kelman, 2017). Houston's drainage system, much of it based on Depression-era bayous and reservoirs, had not been updated in step with rapid highway expansion and paving, so runoff from transportation infrastructure quickly overwhelmed it.

As floods become more frequent and intense, and development pressure increases in one of the fastest-growing areas in the U.S., the integration of stormwater infrastructure with transportation planning presents a possible solution (EPA, 2017; Oberoi, 2025). Some communities are shifting from traditional gray infrastructure to GSI. GSI utilizes a suite of techniques, often called Best Management Practices (BMPs), that mimic natural hydrologic processes to filter, infiltrate, and detain stormwater where it falls (EPA, 2015b; National Academies of Sciences, Engineering, & Medicine, 2012). This approach is not only a mitigation tactic but an opportunity to increase efficiency, reduce costs, and create multi-functional corridors that enhance environmental health, foster community well-being, and build economic resilience. This review synthesizes key findings from the literature on the multifaceted benefits of integrating GSI with transportation infrastructure, including site-specific design.

7 Economic Benefits of Integrated Planning

The core benefit of an integrated infrastructure management approach is cost savings (Araya & Vasquez, 2022). According to water resource experts, integrating green infrastructure planning with planned infrastructure improvements can result in cost savings of 30 to 60 percent compared with implementing GSI projects in isolation (Water Environment Federation, 2015).

A case study from the City of Lancaster, Pennsylvania, illustrates how integrated planning can save money. Faced with a mandate to reduce sewer overflows, the city's traditional grey infrastructure solution was to build massive underground storage tanks at an estimated cost of $419 million (EPA, 2015b). As an alternative, the city instead implemented a series of GSI projects, including transforming city-owned parking lots with permeable pavement, rain gardens, and tree plantings. These proactive GSI renovations were estimated to cost about $224,000 each, demonstrating a total savings of 45 percent compared to the conventional grey alternative (EPA, 2015b; Detwiler, 2015).[1] The projects met two objectives: replacing and restoring transportation infrastructure, and reducing runoff. Similarly, the Milwaukee Metropolitan Sewerage District estimated that planning for GSI to coincide with other capital projects would result in savings of nearly 40 percent compared to stand-alone construction (CH2M Hill, 2013). Another study in Lenexa, Kansas, found that application of GSI in different kinds of developments saved tens to hundreds of thousands of dollars in infrastructure costs and site work (EPA, 2013). This approach of integrating infrastructure planning with stormwater planning helps to maximize the value of every dollar spent by leveraging existing budgets, mobilization, and construction activities for multiple infrastructure goals.

Large-scale projects, like those described above, result in savings because multiple priorities are addressed at once, and GSI is incorporated into the entire planning process, reducing the need for

[1] Adjusted from $300 million and $160,000 in 2011 dollars using the GDP Deflator Index.

retrofitting down the road. In contrast, retrofitting established, dense transportation corridors may involve constraints that drive up expenses (Ando & Netusil, 2013; EPA, 2013). Limited right-of-way is a primary challenge, since it sometimes requires the costly purchase of additional land to accommodate GSI practices (AASHTO, 2012). The presence of buried utilities, the need for complex traffic control to manage lane closures, and unforeseen geotechnical issues further complicate design and construction (National Academies of Sciences, Engineering, & Medicine, 2012).

While retrofitting can be costlier than proactive BMP establishment, GSI projects often pay for themselves over time (Applied Research Associates Inc., 2018). For example, another analysis in West Union, Iowa, found that while a permeable paver system in a downtown project would be more expensive than traditional materials, the lower maintenance and repair costs would result in cost savings by year 15, and total $3.6 million after 57 years.[2] In addition, GSI often provides other quantifiable benefits that, when included, increase their net benefit.

7.1 Co-Benefits of Integrated Design

While the primary drivers for GSI implementation are often stormwater management and cost savings, a growing body of research indicates that roadway greening provides significant co-benefits. GSI can support the creation of green jobs in landscape design, construction, and maintenance (CH2M Hill, 2013). It also delivers quantifiable environmental improvements by capturing stormwater where it falls, which can reduce pollutant loads to local waterways, increase the recharge of groundwater aquifers, and enhance aquatic habitat (Shaneyfelt, et al., 2017; Ando & Netusil, 2013). One study demonstrated that GSI implementation resulted in major reductions in freshwater eutrophication, marine eutrophication, climate change, terrestrial acidification, and terrestrial ecotoxicity compared with conventional infrastructure (Hengen, et al., 2016).

Trees can be especially beneficial, since they can also help to improve air quality, both by trapping and absorbing pollutants, and by providing shade, which reduces energy needs and therefore fuel burning (Shaneyfelt, et al., 2017; Nowak, et al., 2017; Nowak, et al., 2013; Nowak, et al., 2006). The strategic placement of trees can provide shade, and vegetation cools the ambient air through evapotranspiration, which mitigates the urban heat island effect (Detwiler, 2015; EPA, 2021d). Trees can also extend the life of asphalt pavement by providing shade. For example, in Modesto, California, a street shaded by large Hackberry trees was projected to require fewer slurry seal applications over 30 years compared to an unshaded street, reducing repaving costs by 58 percent (McPherson & Muchnick, Effects of Street Tree Shade on Asphalt Concrete Pavement Performance, 2005).

The social benefits of GSI integration can enhance community well-being and quality of life. The addition of green spaces, trees, and landscaped features improves neighborhood aesthetics and has been linked to tangible positive outcomes. For instance, some evidence suggests greening can decrease crime incidence (Kuo & Sullivan, 2001; Bogar & Beyer, 2016; Du & Law, 2016). Other research has demonstrated that office workers who can see nature from their

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[2] Adjusted from $2.5 million in 2008 dollars using the GDP Deflator Index.

desks report greater job satisfaction, lower rates of sickness, increased engagement, lower burnout rates, and increased work ability (Popov, et al., 2023; Lottrup, et al., 2015; Dravigne, et al., 2008; Kaplan, 1993). GSI integration could also provide safety benefits: research suggests a positive impact of roadside greening on driver performance. A driving simulator study found that roads with greener landscapes resulted in diminished anger, boredom, anxiety, stress, and mental fatigue among drivers compared with barren landscapes (Jiang, et al., 2021). Another study found that increased greening was directly linked to greater driver attention and quicker driver reactions to emergencies (Chiang, et al., 2022).

This evidence runs counter to the long-standing "clear zone" concept in transportation engineering, which seeks to minimize fixed-object hazards like trees along the roadside (Marshall, et al., 2019; Wolf K. , 2018). While this principle is valid for high-speed rural highways, its application in urban contexts is being questioned. Multiple recent studies have found an association between the presence of street trees and a *decrease* in crash rates in urban settings by up to 46 percent (Zhu, et al., 2022; Marshall, et al., 2018; Mok, et al., 2003; Wolf K. , 2018).

The aesthetic enhancements and other benefits provided by GSI can also lead to increases in property values. A study in Athens-Clarke County, GA, found that homes with more trees in their yards sold for 3.5 to 4.5 percent more than homes with no or fewer trees in their yards (Anderson & Cordell, 1988). Another study of home sales in Seattle and Philadelphia found that doubling the square footage of small, distributed GSI like rain gardens, swales, planters, or pervious pavement, is associated with an average 0.28 to 0.78 percent higher residential sale value of homes within 250 feet (SB Friedman; CNT, 2020). Evidence from North Central Texas, in Tarrant County, showed that increased urban tree cover reduced the adverse effect on house prices of proximity to chemical facilities (Lee, et al., 2008). These property value increases are often maximized when basins are designed as multi-use community resources, incorporating recreational amenities (Nordman, et al., 2018; EPA, 1995). Illustrating this point, a redesign of a mall complex in Florida which involved water gardens, native plantings, and improved pedestrian access resulted in an 85 percent increase in property values nearby (Zhu, et al., 2024). This increase in property values likewise contributes to increased property tax revenues.

7.2 Integrated Transportation and Stormwater Management Strategies

Presented below are descriptions of several common BMPs and suggestions of optimal siting in transportation features.

7.2.1 Detention and Retention Systems

Retention or detention BMPs are primarily designed to manage stormwater volume and settle out particulates by gathering runoff in basins (wet ponds, dry basins) or subsurface vaults and slowly releasing the water to drainage systems or receiving waters (AASHTO, 2009). Dry detention basins, for example, function to control peak runoff typically associated with 2-year and 10-year storms, reducing overall stormwater volume through natural processes like infiltration and evapotranspiration (Central Massachusetts Metropolitan Planning Organization, 2018). Since these facilities generally require land, planners must budget and acquire sufficient right-of-way (ROW) not only for construction but also for long-term maintenance access (AASHTO, 2012). Dry detention basins should be carefully sited, as they may offer negligible groundwater recharge and total suspended solids (TSS) removal benefits (Central Massachusetts Metropolitan Planning Organization, 2018).

Regional planners in North Central Texas have developed a specialized form of retention system for integration with transportation. It involves increasing impoundment of water behind bridge infrastructure to increase water storage during storm events and reduce downstream flood risk. In many cases, this modified retention system requires modifying local bridges and culverts to adjust flow and increase water retention upstream of the bridge or road, increasing infiltration and possibly creating wetland-like conditions. The flow rate downstream will decrease, which will reduce flood likelihood.

The concept is similar to road retention systems popular in some parts of the Midwest. These are projects that modify existing roads or crossings to temporarily store excess stormwater upstream, acting like controlled reservoirs to manage floodwaters (Area 2, 2025). These projects often involve securing easements from upstream landowners to allow water ponding behind the road for short periods, such as 24 to 72 hours, while structures meter out the flow at a controlled rate (Area 2, 2025). Simulations of flooding at the Hydrologic Unit Code-12 (HUC-12) level in Iowa showed that building between 19 and 71 on-road structures (ORS) per watershed reduced peak flows by between 14.3 percent and 23.6 percent for a 50-year storm event (Weber, et al., 2024). By ponding water behind the road, this type of project can reduce peak flood flows, slow water velocity, and lower downstream water elevations, preventing overwhelming of rivers and streams (Area 2, 2025). This "metering" mimics natural drainage, which helps to avoid erosion and infrastructure damage that is caused by rapid runoff (Behm, 1995; Area 2, 2025). It can also help to improve water quality and provide recreation and irrigation opportunities (Behm, 1995).

These projects are also similar to road-impounded wetlands (Barnard, et al., 2013). These projects can occur in freshwater marshes and similar low-lying wetlands when a highway fill or causeway interrupts sheet flow, leading to ponded zones on one or both sides of the road (Shuldiner & Cope, 1979). Blocking the flow of water will cause changes in drainage, which will shift plant and animal communities. Fish movement can also be a concern (Barnard, et al., 2013). Depending on the subsurface soil composition, such embankments can reduce groundwater flow, which can affect the health of plants upstream that are not adapted to growing in standing water (Shuldiner & Cope, 1979). Slowed water can also trap pollutants and sediments. However, there are also opportunities to create wetland habitat through practices such as borrow pit construction, disposal of dredge material, and use of ditches and culverts. Impoundment can contribute to changes in plant communities downstream as well, since some plants are dependent on annual flood cycles, while others benefit from an absence of flooding (National Research Council, 2002). Additionally, sediment trapped upstream means a reduction in sediment downstream.

While studies evaluating siting for these projects are scant, a simulation study from Iowa State University found that the percentage of a watershed regulated by ORS is correlated with the peak flow reduction for the 50-year storm (Weber, et al., 2024). In other words, additional structures generally help to reduce peak flow in the 50-year storm. The authors suggest that ORS can be especially beneficial just upstream of infrastructure that floods frequently by providing peak flood reduction. In Minnesota, siting considerations for these structures include available flood storage volume, drainage area, flood pool size, percent reduction in peak flood discharge for the

10-year and 100-year floods, and project costs (Behm, 1995). From this information, several ratios can be developed that aid with site selection, including volume of flood storage to area, cost per acre-foot of storage, and cost per reduction in peak runoff. A higher ratio of storage volume to area provides greater volume for short-duration events and helps meet peak-flow reduction targets, and a smaller area will reduce land costs (ADS, 2009). Although there is little literature available on the possible costs of this kind of project, it is similar in structure to a retention basin and some kinds of low dams. Maintenance costs would likely include checking for seepage, erosion, animal burrows, and deep-rooted vegetation, and sediment and debris removal (U.S. FHA, 1997).

7.2.2 Vegetated BMPs

Vegetated BMPs, which include grassy swales, filter strips, and bioretention areas (rain gardens), utilize landscaping and beneficial soil conditions to remove pollutants and facilitate the percolation of runoff, thereby helping to maintain natural site hydrology (AASHTO, 2009; EPA, 2021d). Filter strips and grassy swales are typically linear features that integrate naturally with roadside infrastructure, effectively functioning as initial treatment controls to reduce sediment loads from impervious surfaces (Central Massachusetts Metropolitan Planning Organization, 2018). In terms of siting, vegetated BMPs generally function best for smaller drainage areas characterized by gentle slopes (Central Massachusetts Metropolitan Planning Organization, 2018). For those installed along major arteries, transportation planners must ensure the design keeps vegetation low enough to avoid compromising sight distance and roadway visibility for safety. In addition, since winter maintenance may call for deicing in North Central Texas, planners should consider vegetation that is salt-tolerant to ensure long-term viability (Central Massachusetts Metropolitan Planning Organization, 2018; Webner, 2025).

Bioretention systems demonstrate strong performance in removing TSS, metals, oil, and grease, offering great flexibility in size, shape, and placement, making them suitable for both large and small drainage areas, highly impervious sites, and retrofit projects (EPA, 2021d). Bioretention systems can enhance parking lots (islands and perimeters), sidewalks, street frontages, intersections, and road medians (EPA, 2021d). Possible constraints include high pedestrian activity (which can be addressed with bridges over large bioretention systems), proximity to utilities and the water table, and underlying soil conditions that affect design (EPA, 2021d). For instance, steep slopes may require terracing or check dams, while low-permeability native soils (Hydrologic Soil Groups C and D) may necessitate soil amendments or the inclusion of an underdrain to ensure adequate drainage within the required drawdown period (Ou, et al., 2023; EPA, 2021d). Furthermore, if the bioretention system is planned near heavy traffic or pollution areas, planners may need to incorporate extensive pretreatment and/or an impermeable liner to prevent groundwater contamination from runoff (EPA, 2021d).

The stormwater benefits of these vegetated features can be amplified by placing them in stormwater curb extensions or “bump-outs”, which are modified traffic-calming devices that extend the curb into the roadway to reduce traffic speed (EPA, 2021d). These features work well in neighborhood streets and some collector roads, especially at intersections and mid-block crossings, because they offer dual benefits of stormwater treatment and traffic calming/pedestrian safety enhancement (EPA, 2021d). Specifically, curb extensions narrow the pedestrian crossing distance and increase visibility (EPA, 2021d). Planners should ensure that vegetation selected for curb extensions is low-profile (typically 36 inches or less at maturity) to maintain clear sightlines for both pedestrians and motorists (EPA, 2021d). In addition, while curb extensions typically require minimal disturbance and present flexibility for placement along a street, they must be carefully designed to minimize the impact on parking availability (EPA, 2021d).

7.2.3 Infiltration and Pavement Systems

Infiltration BMPs are engineered to maximize the percolation of runoff through soil into groundwater, reducing the quantity and flow of stormwater while simultaneously removing pollutants (AASHTO, 2009). One example of infiltration BMP types is permeable pavement systems, such as porous asphalt, pervious concrete, and interlocking concrete pavers, which treats, detains, and infiltrates stormwater by allowing surface runoff to pass through the paved material into an underlying stone bed for storage and subsequent infiltration into the ground (Central Massachusetts Metropolitan Planning Organization, 2018). These porous systems integrate optimally with low-volume traffic features such as parking stalls, bicycle lanes, and sidewalks (EPA, 2015b). Permeable pavement can be highly effective when integrated into alleys, where alternative vegetated practices may be limited by constraints like low sunlight exposure (EPA, 2021d). These systems require a level subbase; for slopes greater than 3 percent to 5 percent, check dams or terraces in the subgrade may be necessary to maintain storage capacity (EPA, 2021d). Additionally, permeable pavements may be less suited to areas where there may be substantial sediment-laden runoff or leaf-fall, since these materials may clog the pavement and require additional maintenance or pretreatment upstream (EPA, 2021d).

Infiltration trenches are shallow trenches backfilled with a coarse stone aggregate. They store runoff within the void space created by this aggregate material (Barr Engineering Company, 2011). Like swales, they are compatible with new residential road features, where they can be incorporated along the perimeter or perpendicular to the road contour (Central Massachusetts Metropolitan Planning Organization, 2018). They require highly permeable soils with an infiltration rate greater than 0.5 inches per hour to reduce the likelihood of clogging and ensure proper drainage (Morrison & Mikulencak, 2012). Generally, planners should keep in mind that these systems rely heavily on favorable soil conditions and must include pretreatment methods for sediment and pollution removal prior to water entry (Central Massachusetts Metropolitan Planning Organization, 2018).

7.2.4 Street Trees

Stormwater tree systems involve planting a tree or shrub with bioretention soil media and a gravel reservoir to intercept and capture stormwater (Philadelphia Water Department, 2023; EPA, 2021d). They are ideal for ultra-urban and urban environments where space is limited, making them compatible with sidewalks, medians, parking lots, and the buffer zone between the sidewalk and street (EPA, 2021d). When siting these systems, planners should prioritize providing sufficient uncompacted soil volume for root growth, as trees require at least 1,000 cubic feet of uncompacted soil for mature growth (i.e., about the size of a typical bedroom) (EPA, 2021d). If sidewalk space is constrained, root paths or structural soil cells can be utilized beneath the pavement to support tree growth and prevent sidewalk upheaval (EPA, 2021d). Again, planners must ensure appropriate setbacks from the road to maintain line-of-sight requirements, especially at intersections and curb cuts.

Trees can reduce air pollution due to the turbulence in air flow they cause and their large leaf size, but they can also increase it in street canyons (where buildings on each side of the street concentrate pollutants in the street area) (Shaneyfelt, et al., 2017). Hence, trees will be more successful at improving air quality in places with wider streets and shorter buildings (with a width-to-height ratio greater than two). In addition, a prevailing wind that is parallel to the street axis can reduce the canyon effect and resulting pollution. Additional considerations for optimal street tree placement include species, arrangement, and local climate (Shaneyfelt, et al., 2017).

7.3 Conclusions on Integrated Planning Strategies

An integrated GSI-transportation strategy is a core component of fiscally responsible infrastructure management for North Central Texas. Transportation planners can maximize cost savings by adopting a proactive, data-driven approach that prioritizes land acquisition and preservation before development occurs. Return on investment can be maximized by siting GSI in locations where it generates significant ancillary benefits, such as increased property values. A proactive, strategic approach can result in more efficient public investment and enhance community resilience to future growth risks. By treating transportation corridors as opportunities for sharing resources, the region can achieve cleaner water, create more attractive public spaces, and ensure more efficient use of public funds.

8 Literature Review: The Economics and Return on Investment of Nature-Based Stormwater Solutions

NBS for stormwater management, including preserving floodplain areas and conserving riparian corridors, can be cost-effective strategies for managing stormwater, conveying flood waters, and reducing flood risk in flood-prone areas. In the face of increasing frequency and severity of flood events and rapid development across North Central Texas, this review provides information on the long-term value and return on investment (ROI) associated with preserving floodplain areas and conserving riparian corridors as nature-based approaches to stormwater management and flood risk reduction as well as a pathway to enhance habitat, recreation opportunity, and environmental quality. In essence, wise investments today in conserving natural areas can provide future payoffs both in terms of avoided future flood damages and enhanced quality of life, property values, and environmental quality.

Rapid urbanization in regions like North Central Texas leads to an increase in impervious surfaces like roads and parking lots. This, in turn, intensifies stormwater challenges by increasing runoff volume, which can overwhelm traditional drainage systems and lead to flooding and the transport of nonpoint source pollution into local waterways (Kim & Park, 2016; Middleton & Barrett, 2008). Floodplain preservation and riparian corridor conservation are two key NBS strategies that can be effective solutions to these challenges that also provide a high ROI. Riparian corridor conservation refers to the preservation, management, and restoration of the vegetated transition zones between terrestrial (land) and aquatic (water) ecosystems, such as the margins of streams, rivers, lakes, and wetlands. Floodplain preservation projects can take many forms, including the following types, as categorized by the Harris County Flood Control District (Harris County Flood Control District, 2025).

- Floodplain preservation and conservation involve acquiring floodplain properties to achieve two primary goals: maintaining natural flood storage benefits and preventing future development that would increase flood risk. This approach is often most suitable for ex-urban or rural locations that still possess large amounts of open space.

- Home buyouts involve purchasing residential properties that have been, or are likely to be, severely damaged by flooding. This strategy is employed to reduce future flood damages in areas where structural projects (such as levees or dams) are not cost-effective or feasible.
- Flooding easements are easements acquired for private properties that flood frequently. They involve contracts that legally restrict or prohibit future development on those properties, ensuring they remain available to convey or store floodwaters.
- Wetland mitigation banks are properties acquired specifically to create or enhance wetlands. This solution is intended mitigate unavoidable losses of existing wetlands caused by the construction of flood damage reduction projects elsewhere.
- Regional detention basins are excavated stormwater detention areas, which might be better categorized as a type of GSI than as NBS, and are discussed at length in the section on GSI.

9 Benefits of Preserving Natural Floodplains and Riparian Corridors

In this section, we will discuss some of the benefits of preserving natural areas, including flood damage reduction, aesthetic benefits, and others. Because many ecological benefits are inter- and context-dependent and cannot be bought or sold in regular markets, putting values on nature faces several methodological challenges. Translating complex ecosystem functions and relational or spiritual connections to nature into a single metric, typically money, risks ignoring intrinsic and culturally specific values that are not easily expressed as preferences or prices. Furthermore, economic models can struggle with long time horizons, irreversibility, and thresholds in ecological systems, so estimates can be highly sensitive to assumptions about future scarcity, income growth, and discount rates. Finally, these models are inherently anthropocentric, since they are dependent on human preferences and input. Despite these limitations, valuation models make nature visible within economic decision processes that would otherwise treat it as having a zero price and hence zero weight. A discussion including approximate economic worth of nature-based solutions will help compare conservation with alternative investments.

To enable ease of comparison, all monetary values have been converted to 2025 dollars from original values using the Gross Domestic Product (GDP) Implicit Price Deflator.

9.1 Flood Risk Reduction

The principal economic benefit of floodplain and riparian corridor preservation is the avoidance of future flood damages to buildings and infrastructure that would otherwise have been built in the floodplain. Riparian zones and floodplains slow, absorb, and divert floodwaters, reducing their force, height, velocity, and volume (Siefert, 2019). These effects help protect downstream developments from flood damage. Preserving floodplains reduces exposure to flooding by restricting development in areas that are now, or will in the future be, prone to flooding.

Additionally, preserving floodplains and riparian corridors can mitigate flood risk in downstream areas (Atkinson, et al., 2010).

In economic terms, avoided flood risk is usually calculated as the difference between the expected monetary damages "with" and "without" a given protection measure, averaged over time. Conceptually, this involves three steps: estimating the probability distribution of different flood events, linking flood depth or extent to physical damage for assets and people (e.g., depth–damage curves), and monetizing those expected losses (property damage, business interruption, health impacts) to obtain an expected annual damage figure. The economic benefit of preserving or restoring natural areas is then the reduction in expected annual damage relative to the baseline, often discounted over the project lifetime and compared to the cost of the measure in a cost–benefit framework. Other methods include estimating the replacement cost of a given natural protection and preference-based methods, in which human participants indicate how much they would be willing to pay for a given service, or choose among different cost-amenity combinations. In a global meta-analysis of 20 studies of different methodologies, Brader et al. (2024) estimated a mean value of avoided flooding and storm protection of $2,444 per acre of inland wetland.[3] Using only the nine U.S. studies, this value falls to $1,762 per acre.[4] However, because the studies in this analysis were mainly based on rural or remote wetlands, the value of avoided flood risk may be much higher in more populated areas, where structural, health, and displacement losses would be much higher. The value of benefits provided by natural areas is often dependent on its specific site context.

Floodplain preservation can be either proactive (i.e., protecting natural floodplains prior to development) or reactive (i.e., managed retreat or buyout programs where governments purchase properties in the floodplain and restore the land to natural open space to reduce future flood damages, emergency response, and increase natural function and storage of floodwaters). Proactively conserving floodplains and riparian corridors before they are developed is generally much more cost-effective than restoring already developed or damaged areas. By preventing development in high-risk areas, communities can avert the costs associated with property damage, disaster recovery, and the need for expensive structural flood controls. For example, allowing development in frequently flooded parts of the floodplain in Pierce County, Washington, resulted in a cycle of reactive investment, including millions of dollars in costly infrastructure repairs (Earth Economics, 2013). Preserving this frequently flooded land would have avoided these damages. A study of direct flood mitigation benefits provided by the Meramec Greenway, in St. Louis County, Missouri, illustrates this point (Kousky & Walls, 2014; Kousky, et al., 2014). The authors employed the FEMA Hazus-MH model to estimate and compare flood damages under two scenarios: the current, conserved condition of the greenway, and a hypothetical scenario where the greenway lands had been developed. The study found that the annual avoided flood damages provided by the conserved land are about $8,245 per acre.[5]

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[3] Adjusted to 2025 dollars from $8,077 per hectare per year in 2020 International dollars using the GDP Deflator Index, then divided by 2.47 acres per hectare.
[4] Adjusted to 2025 dollars from $3,583 per hectare per year in 2020 International dollars using the GDP Deflator Index, then divided by 2.47 acres per hectare.
[5] Adjusted to 2025 dollars from $6,000 per acre per year in 2012 USD using the GDP Deflator Index.

Under future conditions, including 30 to 50 percent increases in peak discharge, the value provided by the conserved land also increased by 30 to 50 percent (Kousky, et al., 2014).

Another study looked at the value of upstream wetlands for downstream flood mitigation across the continental U.S. by linking high-resolution land cover data with National Flood Insurance Program (NFIP) claims (Taylor & Druckenmiller, 2021). The researchers isolated the protective effects of upstream wetlands, and found that wetlands located 500 to 750 meters from the nearest stream or river provided flood mitigation benefits valued at $12,394 per acre per year. However, wetlands located less than 500 meters or further than 750 meters from a water source did not provide measurable benefits. The pattern was heightened for wetlands in developed areas, with an estimated benefit of $37,030 per acre per year.[6] The authors suggest that this pattern may be the result of wetlands close to a water source being fully saturated, without the capacity to absorb additional floodwaters. On the other hand, wetlands located too far from the surface water network are less likely to intercept floodwaters before those waters reach and damage residential properties. Ultimately, the researchers concluded that the societal benefits of reduced flooding outweigh the costs of wetland conservation within just six years on average. Importantly, the researchers found no effect of wetland gains (such as through compensatory mitigation requirements) on flood insurance claims (Taylor & Druckenmiller, 2021). The authors suggest this indicates that created or restored wetlands may not provide the same flood mitigation services as mature, naturally occurring ecosystems, or that they are being placed in areas where they do not effectively protect assets.

A similar, more recent study, replicated the result that wetland gains had no effect on flood insurance claims, but showed that upstream wetland loss resulted in increases in flood insurance claims of between 0.01 and 0.03 percent per hectare for individual properties between 1985 and 2023 (Gourevitch, et al., 2026). This resulted in an estimated total $10.1 billion dollar increase in flood claims nationwide (a nine-percent increase). These costs are concentrated in areas of the southeastern United States, such as metropolitan areas of Houston, where there is high wetland loss. The researchers used claims data to calculate the marginal Net Present Value (NPV) of one hectare of wetland based on flood insurance claim data. The NPV is the present value of all future cash inflows (benefits) minus the initial investment. The marginal NPV is then the change in total NPV that results from producing or investing in one additional unit of a project, good, or service. The researchers found a median value of $76 per acre and an average value per acre of $6,574 of wetland in reducing riverine flood losses.[7] The median and average value are different because there are many acres of wetland without much expected flood damage or development downstream, while some acres of wetland are upstream of high-risk and/or highly-developed areas, and valued at hundreds of thousands of dollars of avoided flood risk. A figure in the study (3c) shows that the North Central Texas region is on this end of the spectrum, with marginal

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[6] Based on NFIP claims between 2001 and 2016, reported in a nominal value. Adjusted to 2025 dollars from $21,178 and $63,276 per hectare per year in 2009 USD using the GDP Deflator Index, then divided by 2.47 acres per hectare.

[7] Adjusted to 2025 dollars from $181 and $15,738 per hectare per year in 2024 USD using the GDP Deflator Index, then divided by 2.47 acres per hectare.

NPVs per hectare in the thousands to hundreds of thousands. Evidence from these two studies further supports the case for preventative acquisitions.

Although proactive buyouts have the greatest potential for savings, retroactive buyout projects can also provide benefits under favorable circumstances. A proposed floodplain restoration in Waterbury, Vermont, was estimated to reduce expected flood damages by 20 percent (Parsons, et al., 2020). By lowering a field at a river chokepoint (where a narrow channel constricts water flow), the project would protect homes and businesses downstream; however, it was unable to move forward due to a lack of interest from the owners of the field in question (Elder-Conners, 2023). A similar project in Napa, California, was expected to save $1.4 billion in flood damage savings over the life of the project, or about $35 million per year (Parsons, et al., 2020; Kershner & Gregg, 2021).[8] This project involved reconnecting the Napa River to its historic floodplain. The project allowed for commercial development, such as hotels and office space, in areas that would otherwise have been at high risk of flooding. The Greenway Foundation estimated that another project in Denver resulted in billions of dollars' worth of new development (Parsons, et al., 2020). Other projects in Cleveland, Ohio, and Peoria, Illinois also led to new development (Parsons, 2020).

There are diverse means of funding buyout and preservation programs. FEMA has historically provided grants for flood prevention efforts (Elder-Conners, 2023). On a more local level, Tulsa, Oklahoma was an early adopter of progressive, proactive approach to floodplain management (Conrad, et al., 1998). Following a devastating flood in 1984, the city established a dedicated stormwater utility fee to fund its program, allowing it to strategically acquire and remove at-risk properties over time. Charlotte, North Carolina follows a similar model (Salvesen, et al., 2018). In contrast, Harris County relies primarily on voter-approved bonds specifically allocated toward flood reduction (Vilay & Pollman, 2020).

In addition to flood risk reduction, both floodplain preservation and riparian corridor conservation also deliver other benefits, including improved water quality from pollutant filtration, habitat provision for wildlife, carbon sequestration, and recreational opportunities. Some of these values are estimated in a Texas Land Trust study of Texas conservation land (Siglo Group, 2019). The researchers estimated the per-acre value of these services by county, drawing on studies from across the U.S. and other countries. These values are reproduced here, updated from dollar-year 2018 to dollar-year 2025 using the GDP Deflator Index. These types of benefits are discussed in more detail in the sections below, with more detail provided on values derived from a range of available studies.

Table 2. Ecosystem Service Value by County, Texas

County	Inland Flooding Prevention ($/acre)	Water Quality ($/acre)	Water Quantity ($/acre)	Timber, Ag, Ranch Products ($/acre)	Wildlife, Hunting $/acre)	Total ($/acre)

[8] Adjusted to 2025 dollars from $25M and $1B in 2011 USD using the GDP Deflator Index.

Dallas	$227	$226	$1,031	$134	$9	$1,627
Ellis	$199	$215	$979	$196	$9	$1,598
Hood	$134	$55	$251	$120	$9	$568
Johnson	$112	$59	$269	$120	$9	$569
Parker	$126	$197	$899	$109	$9	$1,340
Tarrant	$198	$212	$965	$117	$9	$1,501
Wise	$24	$210	$956	$78	$13	$1,281

Source: (Siglo Group, 2019)
Note: Values may not add to total due to rounding.

9.2 Water Quality and Quantity

Wetlands and vegetated riparian buffers are effective natural filters. They can remove sediment and associated pollutants, such as nutrients and pesticides, from runoff before it enters a stream, protecting downstream water quality (Atkinson, et al., 2010). Restored riparian areas can often filter pollutants with greater cost savings compared with other GSI strategies. A cost-effectiveness analysis focused on water quality benefits of BMPs in the Hickory Creek sub-watershed in Denton, Texas, found that for urban land, riparian buffers were the most cost-effective among nine GSI strategies for sediment, phosphorus, and nitrogen removal (Olivera, et al., 2013). Additionally, Charlotte-Mecklenburg Storm Water Services (CMSWS) in North Carolina observed that local waterways had become polluted with a sole reliance on traditional stormwater infrastructure (EPA, 2013). In response, CMSWS undertook future conditions modeling to compare effectiveness of stormwater management approaches, and found that stream restoration was by far the most cost-effective means of controlling sediment pollution in a local reservoir, at between $0.91 and $1.55 per pound of sediment removed.[9]

Another study used actual federal program dollars spent on conservation practices as a proxy for the value placed on maintaining or enhancing specific ecosystem services (Putman, et al., 2022). The researchers present a Texas-specific model for estimating the economic value of various ecosystem services provided by working lands, such as ranches. They developed a willingness-to-pay model by analyzing expenditures from the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) landowner incentive programs in Texas between 2015 and 2020. The study estimated that the value of water quality improvements provided by Texas working lands would be about $36 per acre per year, based on past NRCS investments (Putman, et al., 2022).[10] Relatedly, the value of erosion control was estimated to be $33 per acre.[11] However, the study combines all Texas working lands, not only wetlands or riparian areas, which would be expected to provide greater benefits. Based on 18 estimates from global studies of inland wetlands, a meta-analysis reported a waste treatment mean value of $1,280 per acre (Brander, et al., 2024).[12] This estimate may be higher due to isolation of a habitat type which is especially effective at improving water quality, or it may be related to the use of differing methodologies, such as willingness-to-pay or preference-based methods.

[9] Adjusted to 2025 dollars from $0.60 and $1.02 per pound in 2006 USD using the GDP Deflator.
[10] Adjusted to 2025 dollars from $30 per acre per year in 2020 USD using the GDP Deflator Index.
[11] Adjusted to 2025 dollars from $27 per acre per year in 2020 USD using the GDP Deflator Index.
[12] Adjusted to 2025 dollars from $2,603 per hectare per year in 2020 International dollars using the GDP Deflator Index, then divided by 2.47 acres per hectare.

The value of water provision and groundwater recharge appears more consistent. The same meta-analysis estimated a water provision value of $429 per acre of inland wetland, based on eight estimates (Brander, et al., 2024).[13] Similarly, Putman et al. (2022) estimate the value of water quantity provided by working lands in Texas at about $423 per acre. This value represents the potential water capture of the land (calculated using average annual rainfall and a 50 percent infiltration rate) and the associated cost to replace that captured water if the land were developed (Putman, et al., 2022). In addition to the value of water captured, the average annual payments made to improve or conserve water capture on working lands were about $35 per acre, for a total of $458 per acre per year. [14] Another study used water management costs to calculate values associated with water quantity and quality in Texas conservation areas. The authors allocated each budgetary item to either water quality or quantity, and calculated the percentage of the total budget for each item (Siglo Group, 2019). Then the cumulative percentage of budget for each category was multiplied by the cost per acre-foot for the given region. The value per acre-foot, updated to dollar-year 2025, is reported in Table 3.[15] North Central Texas's water management area is mostly within Region C, with some counties in Region G, so only values for these regions are reproduced (Texas Water Development Board, 2025).

Table 3. Water Value of Texas Conservation Lands Water Value of Texas Conservation Lands

Texas Water Development Board Region	Total Water Value (2025$/AF)	Water Quality (2025$$/AF)	Water Quantity (2025$/AF)
C	$744	$134	$610
G	$211	$38	$173

Source: (Siglo Group, 2019)

9.3 Recreation, Aesthetics, and Property Values

FEMA-funded voluntary buyouts must revert permanently to open space, recreational use, or natural floodplains. This requirement ensures that the land serves a public benefit in perpetuity. In accordance with this standard, Ann Arbor, Michigan, planned its riverfront for golf courses, ball fields, public parks, arboretums, and greenways (Conrad, et al., 1998). Recreational use of these lands is a quantifiable benefit. Non-consumptive recreational use (such as bird-watching) in Texas has been valued at about $15 per acre per year, based on NRCS payments for conservation programs, while consumptive recreation use, such as hunting and fishing, has been valued at about $11 per acre per year based on Texas hunting lease data (Putman, et al., 2022).[16] On the high end, a meta-analysis of 26 studies estimated a mean global value of $6,344 per acre

[13] Adjusted to 2025 dollars from $873 per hectare per year in 2020 International dollars using the GDP Deflator Index, then divided by 2.47 acres per hectare.
[14] Adjusted to 2025 dollars from $348 per acre per year in 2020 USD using the GDP Deflator.
[15] Original values in 2018 dollars, top row: $594.34, $106.98, $487.36, bottom row: $168.46, $30.32, $148.13, have been adjusted to 2025 USD using the GDP Deflator Index.
[16] Adjusted to 2025 dollars from $12 and $9 per acre per year in 2020 USD using the GDP Deflator.

for recreation and tourism opportunities at inland wetlands.[17] The gap between these values is wide, partly because the Texas study is based on actual current funding serving recreation in areas with lower visitation, while many of the underlying sites used to produce estimates for the meta-analysis are high-profile or tourism-oriented wetlands with substantial visitation and spending (Brander, et al., 2025).

A third approach to measuring aesthetic and recreational benefits provided by greenspace is known as the hedonic method. The hedonic method (hedonic pricing) is a way to infer the value of non-market attributes—like environmental quality or proximity to wetlands—from the prices of market goods, most commonly houses. In a buyout where land is converted to open space, that open space results in a new positive attribute for nearby homes, which is reflected in changes in property value, and this change can be calculated statistically. An analysis in Alachua County, Florida, used this method, and found that proximity to open space increased parcel value, resulting in additional property tax revenue of several million dollars per year compared to not having the open space (EPA, 2013). This increase in revenue more than offset property tax losses from acquiring the open space (however, this is partly because most of the open-space land acquired was zoned for agriculture, which has a lower tax rate). Properties near open space were worth between $13,000 and $16,000 more than homes not near open space, and homes directly adjacent to open space were worth over $40,000 more.[18]

Putting the impact of green space amenities in percentage terms, one study in Santa Cruz, California, found that residential homes next to restored streams were valued at between 3 to 13 percent more than those near unrestored streams (Streiner & Loomis, 1995). Similarly, after floodplain restoration projects in Denver, Colorado, properties within a half mile of the water and greenways became valued at 36 percent more than properties elsewhere in the city; prior to the projects, these same properties had been valued at 17 percent less than similar properties in Denver (Parsons, et al., 2020). A more modest change in property values resulted from projects in the Portland, Oregon metropolitan area, with properties within 250 meters of the projects showing a 10.79 percent increase in value six years after project completion. On the low end, a study of the same watershed showed a 7-percent increase in property values post-project, while a Washington State combined levee setback and greenspace project in resulted in approximately a 5-percent increase in property values (Netusil, et al., 2019; Jarrad, et al., 2018). Importantly for public decision-makers, these increases in property values lead to increases in property tax revenues. For example, the Denver project resulted in an increase in annual property tax revenue of $82 million (Parsons, 2020).[19] Similarly, after completion of the Santa Cruz project, property tax revenues per household increased by $672 (Streiner & Loomis, 1995).[20]

9.4 Habitat

Land bought out for the purposes of flood prevention can also provide habitat for wildlife and native plants. Wetlands and riparian areas act as highly productive transition zones between

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[17] Adjusted to 2025 dollars from $12,899 per hectare per year in 2020 International dollars using the GDP Deflator Index, then divided by 2.47 acres per hectare.
[18] Adjusted to 2025 dollars from $8,000, $10,000, and $25,000 in 2004 USD using the GDP Deflator Index.
[19] Adjusted to 2025 dollars from $64 million in 2017 USD using the GDP Deflator Index.
[20] Adjusted to 2025 dollars from $240 per household in 1982 USD using the GDP Deflator Index.

aquatic and terrestrial environments, providing essential life-support systems for a disproportionately large number of species relative to the small land area they occupy (Wentzel & Hull, 2021; Wagner, 2004). These ecosystems function as critical sources of food, shelter, and migration corridors (Atkinson & Lake, 2020). Economists assign existence value to these habitats that is different from the value provided by recreation. This existence value represents the benefit people derive simply from knowing that a natural resource or species exists, even if they never actively use it (Office of Management and Budget, 2024; Saraev, 2012). Similarly, bequest values quantify the desire to preserve these resources for future generations. Various studies have attempted to quantify the economic value of habitat services.

For instance, a recent meta-analysis frames the value of habitat and biodiversity support as "maintenance of life cycles" (Brander, et al., 2024). The mean maintenance of life cycles value provided by wetlands globally is estimated to be $2,340 per acre per year; however, this estimate was based on only two available studies.[21] The study from the U.S. used in this analysis put the value at $567 per acre, which is substantially lower (Brander, et al., 2025).[22] It is also based on Nebraska flyways, which might have a different value than wetlands in the Study Area. An earlier meta-analysis by Woodward and Wui (2001) estimated the value of habitat services specifically at a mean of $445 per acre, though they noted a wide confidence interval ranging from $205 to $2,118 per acre, which indicates high variability and uncertainty.[23] This range is still well above the general value of Texas working lands estimated by Putman et al. (2022), at about $20 per acre, which is not based on wetlands or riparian areas specifically.

In contrast to other values like recreation or aesthetics, which might be expected to increase with increasing population density, habitat-related values may not scale linearly with human density, because they depend on species' ecological requirements, such as patch size, connectivity, and disturbance regimes, rather than on the number of people who can enjoy them directly. Some species may benefit from landscape heterogeneity and access to multiple habitat types, and others are area-sensitive and require large, continuous, low-disturbance habitats to reduce predation risk and physiological stress, so greater human presence does not translate into higher habitat value and can even reduce it past certain disturbance thresholds.

9.5 Air Quality

Riparian ecosystems also contribute to air quality, primarily via trees, which absorb and capture pollutants. One national study used maps of tree cover, air pollution and meteorological data, and research on the health costs of pollution to estimate the economic benefit of tree cover as it affects air quality and human health (Nowak, et al., 2014). Researchers estimated the amount of pollution removed by trees, the resulting change in ambient air quality, and the subsequent number of avoided adverse health incidents and their associated economic value by state. They estimated that in Texas, tree cover provides $57 of air quality benefits per acre in urban areas,

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[21] Adjusted to 2025 dollars from $4,759 per hectare per year in 2020 International dollars using the GDP Deflator Index, then divided by 2.47 acres per hectare.
[22] Adjusted to 2025 dollars from $1,153 per hectare per year in 2020 International dollars using the GDP Deflator Index, then divided by 2.47 acres per hectare.
[23] Adjusted to 2025 dollars from $306, $95, and $981 in 1990 dollars using the GDP Deflator.

and $2 per acre of air quality benefits in rural areas.[24] Air quality improvements have greater economic values in cities because of the greater population benefiting from the improved area. It is possible that these values are high estimates, since they do not account for possible negative impacts on air quality from trees, such as the emission of biogenic volatile organic compounds (VOCs), which can be precursors to ozone formation. However, the Texas working lands air quality improvement estimate of $23 per acre per year falls within this range, based on funding for current NRCS conservation practices meant to improve air quality (Putman, et al., 2022).[25]

On the high end, the value of air quality regulation provided by inland wetlands was quantified in a 2024 meta-analysis at approximately $1,222 per acre based on nine estimates (Brander, et al., 2024).[26] The same study reported that temperate forests (like the Great Trinity Forest) produce air quality benefits of $553 per acre, based on 302 study estimates.[27] The estimated value for wetlands may be higher due to a smaller number of estimates containing some large outliers (Brander, et al., 2025). Overall, air quality benefits will tend to be greatest in locations with high tree and vegetive cover and high population.

9.6 Climate Regulation

GSI, particularly tree cover, has the ability to regulate local temperature, thereby reducing energy costs for heating and cooling buildings. It does so through two primary mechanisms: providing direct shade and releasing water vapor through evapotranspiration (CNT, 2020; Wolf K. L., 2014). Trees modify local microclimates by altering solar radiation, wind speed, and air temperature, creating an "oasis effect" (CNT, 2020). Shaded surfaces can be 20°F to 45°F cooler than unshaded surfaces during peak summer temperatures (CNT, 2020; Wolf K. L., 2014). Additionally, trees and vegetation within riparian corridors shade streams, preventing wide fluctuations in water temperature and protecting aquatic life from climatic extremes (Vogt, et al., 2015; Wagner, 2004). The economic benefit of reduced temperature depends on multiple factors, such as the placement and orientation of the tree and nearby buildings. It can be measured by estimating the reduced health care costs from reduced incidence of heat stroke or other heat-related maladies, and by calculating the reduced energy use of buildings in the shade of the tree.

Additionally, on a global level, natural areas have the ability to absorb and store greenhouse gases, reducing the impacts of climate change. A meta-analysis put the value of global climate regulation in inland wetlands and temperate forests at $91 and $368 per acre, respectively, based on 14 and 42 studies (Brander, et al., 2024).[28] Putman et al. (2022) estimated an additional benefit of $15 per acre of Texas working lands for carbon storage, based on NRCS payments.

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[24] Adjusted to 2025 dollars from $97.80 and $1.40 per hectare per year in 2010 USD using the GDP Deflator Index, then divided by 2.47 acres per hectare.

[25] Adjusted to 2025 dollars from $19 per acre in 2020 dollars using the GDP Deflator.

[26] Adjusted to 2025 dollars from $2,485 per hectare in 2020 International dollars using the GDP Deflator Index, and divided by 2.47 acres per hectare.

[27] Adjusted to 2025 dollars from $1,124 per hectare in 2020 International dollars using the GDP Deflator Index, and divided by 2.47 acres per hectare.

[28] Adjusted to 2025 dollars from $185 and $748 per hectare in 2020 International dollars using the GDP Deflator Index, and divided by 2.47 acres per hectare.

10 Tools

Overall, the return on investment of NBS is likely to be maximized if they are sited in areas where multiple of these benefits can be realized, but there are many priorities to track. One tool that can help identify and rank these opportunities is the Trinity Floodplain Prioritization Tool (FPPT) (Trinity River Floodplain Tool, 2024). Developed in partnership with The Nature Conservancy and Freshwater Network, it supports planning by allowing users to apply multiple criteria and view geographies that meet the selected priorities. Users can visualize unprotected floodplain area for their watershed of interest at the HUC-8, HUC-12, and catchment scales, and filter floodplain units by many dimensions of pollutant yield, impairment status, habitat, carbon storage, flood risk, and development pressure. Priority Conservation Areas are identified based on the Texas Water Explorer, and reflect high-quality freshwater habitats where freshwater species of concern persist (The Nature Conservancy, 2015). This tool could be valuable to identify sites with the greatest returns based on planners' goals.

11 Costs of Floodplain and Riparian Corridor Conservation

The primary costs of floodplain preservation and riparian corridor conservation are to acquire land or conservation easements (which restrict future development while allowing the land to remain in private ownership and productive use). Easements represent the opportunity cost of forgone development, and may cost about 35 percent of the land value (Smith, et al., 2023). State programs such as the Texas Farm and Ranch Lands Conservation Program (TFRLCP) provide incentive funds to assist qualified entities in acquiring these easements (Lund, et al., 2019). Land costs in North Central Texas are summarized Table 4 below, updated from 2022 U.S. dollars to 2025 U.S. dollars using the GDP Deflator Index.

Table 4. Average Land Values per Acre by Land Use and County in North Central Texas

County	Cropland	Grazing Land	Other*	Wildlife Management	Average
Dallas	$24,178	$17,871	$11,519	$8,976	$20,162
Denton	$21,557	$26,365	$75,867	$34,953	$25,830
Ellis	$9,163	$8,341	$11,083	$7,285	$8,534
Johnson	$8,190	$5,790	$17,427	$7,789	$6,251
Parker	$14,544	$14,494	$20,267	$11,949	$14,546
Tarrant	$22,122	$15,227	$73,751	$17,420	$16,246
Wise	$7,522	$10,035	$5,320	$8,510	$9,976

Source: (Texas A&M Natural Resources Institute, 2025)
*Land use: "Orchard Other" as identified by the Texas Comptroller of Public Accounts' appraisal categories

The costs of conserving riparian corridors and floodplain areas depend on their current condition. For degraded areas, costs involve active restoration, which can include planting trees, shrubs, and seed mixes, as well as installing and operating temporary irrigation systems to ensure plant establishment (Asher, et al., 2015; Hill Country Alliance, 2025). A restoration of more than a half-mile of riparian corridor damaged by cattle in Oklahoma reported a planned budget of

$74,554 (Oklahoma Conservation Commission, 2008).[29] Early revegetation of the degraded Las Vegas Wash cost about $21,600 per acre, but in other areas of the Lower Colorado Basin, restoration costs ranged between $740 to $4,300 per acre, including revegetation costs of $630 to $1,700 per acre (Ralston & Sarr, 2017).[30] The Central Texas Floodplain Reforestation Program, whose services include planting native saplings, reports a cost of $5,000 per acre (TreeFolks, 2023).

A buyout project in Elm Grove, Wisconsin, cost about $8.9 million to acquire 52 properties, including a 99-unit apartment building and four commercial buildings (Siders & Gerber-Chavez, 2021; Association of State Floodplain Managers, 2020).[31] Additional costs included about $200,000 for relocation, and $16,000 to $24,000 for park establishment (Siders & Gerber-Chavez, 2021).[32] This project would amount to a total capital cost per site of about $175,000. On the lower end, the average acquisition cost of buyout properties in Lumberton, North Carolina, was about $29,000 (Salvesen, et al., 2018).[33] Without acquisition costs, Schiff et al. (2015) assumed a cost of $40,000 per site to remove the associated building and replant vegetation in New York and Vermont.[34] Relocation may cost between $17,000 and $34,000 per property (Siders & Gerber-Chavez, 2021).[35] Finally, in a Harris County (Houston) program, 400 properties were acquired and 185 acres restored; with a reported project budget of about $97.5 million, this implies on the order of $527,000 per acre when all costs are included, in a relatively low-cost market (Patterson, 2017).[36]

A relevant case study from Arlington, Texas demonstrates a locally-funded property buyout program implemented in direct response to a major flooding event (Naturally Resilient Communities, 2017). The Rush Creek corridor experienced repetitive and severe flooding, which culminated in more than 250 structures being flooded during Tropical Storm Hermine in 2010. Fifty of these structures were located in the particularly vulnerable Woodland Park area. With no other cost-effective way to alleviate the flooding, the City of Arlington created a phased, locally-funded buyout program for 50 residential properties and condominium complexes in the Woodland Park area. The city successfully acquired and demolished 49 of the 50 targeted properties. This created 23 acres of new parkland, which was combined with three existing city parks to form a large, 82-acre contiguous park and open space area. The total project cost was $23 million.[37] The acquisition was funded entirely by a 20-year stormwater bond program, repaid by local stormwater utility revenues. Based on these estimates, costs of floodplain or riparian corridor conservation acquisition may vary from $1,800 per acre per year, plus a one-

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[29] Adjusted to 2025 dollars from $21,600 per acre per year in 1999 USD, and $575, $3,370, $490, and $1,334 per acre per year in 2017 USD using the GDP Deflator Index.
[30] Adjusted to 2025 dollars from $51,240 per acre per year in 2008 USD using the GDP Deflator Index
[31] Adjusted to 2025 dollars from $5.5 million in 2004 USD using the GDP Deflator Index.
[32] Adjusted to 2025 dollars from $125,000, $10,000, and $15,000 in 2004 USD using the GDP Deflator Index.
[33] Adjusted to 2025 dollars from $16,180 in 1999 USD using the GDP Deflator Index.
[34] Adjusted to 2025 dollars from $30,000 in 2014 USD using the GDP Deflator Index.
[35] Adjusted to 2025 dollars from $15,000 and $30,000 in 2021 USD using the GDP Deflator Index.
[36] Based on cumulative costs between 1999 and 2017. Adjusted from 2008 dollars to 2025 USD using the GDP Deflator Index.
[37] Adjusted to 2025 dollars from $17 million in 2014 USD using the GDP Deflator Index.

time restoration cost of $1,700 in a low-density area, to upwards of $1 million per acre for an urban buyout and restoration scenario, depending on the neighborhood in question.

Fiscal impacts on local governments extend beyond the immediate cost of acquisition. One concern for municipalities is the potential loss of property tax revenue when homes are removed or land is taken off the development market (Salvesen, et al., 2018). If buyout participants relocate within the community, the tax base will be preserved, but if they do not, that revenue will be lost. A study of buyouts in Waterbury, Vermont and Willsboro, New York, showed that removing buildings from the floodplain is only sustainable from a municipal finance perspective if the lost tax base is preserved through proactive planning that encourages relocation *within* the community (Schiff, et al., 2015). However, as in a preservation scenario, this loss can be offset by the creation of parks, greenways, and open spaces, which can increase the value of adjacent residential properties, thereby boosting the remaining tax base (Jarrod et al., 2018; Kousky & Walls, 2014; Parsons et al., 2020).

For properties acquired through floodplain buyouts that are maintained as open space (often mowed grass), the primary maintenance cost is mowing. Research in North Carolina found that annual maintenance costs for staff, equipment, and fuel to mow vacant lots ranged from $250 to $1,800 per acre, depending on the frequency of mowing and the equipment available (Salvesen, et al., 2018).[38] In contrast, other communities have successfully used contiguous buyout properties to create new public amenities, directly converting them into an asset (Salvesen, et al., 2018). These properties now include a 9-hole disc golf course in Windsor and a disc golf course and dog park in Rocky Mount. Other municipalities lease vacant buyout lots to adjacent property owners for a nominal fee (e.g., $1/year) (Siders & Gerber-Chavez, 2021). The neighbors gain extra yard space (for gardens or parking) in exchange for maintaining the land, greatly reducing municipal costs. Additionally, restoring land to a natural state (e.g., forest or wetland) rather than maintaining it as a manicured lawn can eventually reduce annual maintenance costs, though it requires upfront investment for restoration (Salvesen, et al., 2018). The way that acquired properties are managed and maintained over the long term can influence their cost-effectiveness.

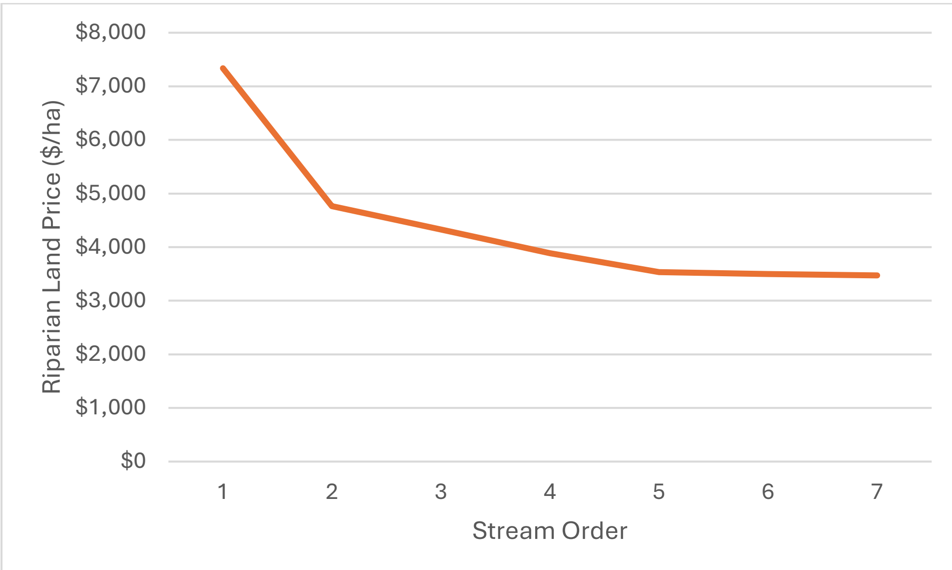
12 Siting Considerations

Siting considerations for riparian corridors and preserved floodplains involve a complex interplay of hydrologic, ecological, economic, and social factors. Effective siting requires analyzing the position within the watershed, the spatial configuration of the land, and the specific objectives of the preservation (e.g., water quality vs. wildlife habitat).

A study of land transaction data and stream size in the Upper Wabash River Basin in Indiana found that larger streams (i.e., those with more tributaries) tend to sell for lower prices, all else being equal (Frimpong, et al., 2007). Figure 1 shows the trend in land price as stream size increases. While the price data is not transferable to North Central Texas, the relationship shows that as stream size and concomitant flood risk increases, land prices decrease. Buyers are willing to pay less for land that is at more risk of flooding because it has the potential to cause damage to any agricultural activities taking place or structures built there. Reciprocally, buffers along

[38] Adjusted to 2025 dollars from $192 and $1,400 in 2017 USD using the GDP Deflator Index.

larger, downstream rivers tend to be wider and longer, making them more suitable for wildlife habitat and movement corridors (Fischer & Fischenich, 2000). Planners can take advantage of this relationship to acquire land for multipurpose floodplain preservation. On the other hand, riparian buffers in headwater (i.e., lower-order) streams have greater potential for improving water quality in a watershed than buffers in downstream reaches (Fischer & Fischenich, 2000). If pollution reduction is a priority, siting a riparian buffer along a headwater stream may be worth the greater cost.



Source: Adapted from Frimpong et al. (2007)

Figure 1. Land Price and Stream Order

It is also important to account for the physical dynamics of the river system, avoiding areas subject to rapid channel migration (unless the objective is to allow the river to occupy its natural floodplain), and prioritizing the removal of structures from deep and fast-flowing floodways where water velocity poses the highest risk to safety (Fischer & Fischenich, 2000; Vilay & Pollman, 2020). To balance stabilization and habitat needs, Fischer and Fischenich (2000) recommend a three-zone buffer system (Fischer & Fischenich, 2000). The first zone would include undisturbed forest at the stream edge (15 to 25 feet), then transition to managed forest (10 to several hundred feet) and finally to grass filter strips at the outer edge (15 feet if used with closer zones, or 35 feet by itself).

Continuity of preserved lands can help to preserve ecological function and improve management efficiency. Continuous corridors are superior to fragmented ones for moderating stream temperatures, water retention and facilitating wildlife movement (Fischer & Fischenich, 2000; Siglo Group, 2019). Isolated lots can limit ecological restoration and increase municipal maintenance burdens (Siders & Gerber-Chavez, 2021). Buyout programs are also typically most effective at a large scale, involving tens to hundreds of acres, in part for this reason (Naturally Resilient Communities, 2022). However, the voluntary nature of buyouts often leads to a scattered “checkerboard” pattern of vacant lots (Salvesen, et al., 2018). This pattern limits options for beneficial reuse. In comparison, a buyout model that prioritizes clustering properties together and selecting parcels in close proximity to existing open spaces like parks and protected areas generates larger, more contiguous green spaces that can provide greater value for flood mitigation, habitat, and community recreation (The Nature Conservancy; TAMU, 2019). Keeping these factors in mind can help target acquisitions to maximize return on investment.

13 Return on Investment

In spite of the costs, floodplain buyout programs consistently generate high ROIs. A FEMA report concluded that voluntary buyouts generated at least $2 in benefits for each dollar invested, based solely on the reduction of future flood insurance payments (Conrad, et al., 1998). A later study from the National Institute of Building Sciences included a comprehensive cost-benefit analysis of FEMA-funded hazard mitigation grants executed between mid-1993 and mid-2003, including flood projects (Rose, et al., 2007). Instead of only measuring asset damages, Rose et al. (2007) quantified benefits by estimating a wide range of avoided losses, including property damage, direct and indirect business interruption, non-market environmental damage, and societal losses such as deaths and injuries. The study's primary conclusion is that FEMA's hazard mitigation activities were highly cost-beneficial across all hazard types, with flood projects yielding a BCR of 5.1, the highest return on investment of the projects studied. Avoided business interruption losses contributed approximately 10 percent to the overall average BCR. Another FEMA study on coastal floodplain buyouts found that buyout programs produced returns between 212 and 265 percent in avoided damages in the ensuing five to ten years in states like Georgia, Iowa, Missouri, and Kentucky (White E. , 2011; GEMA, 2018; Polefka, 2013). Another study in Houston reported that Houstonians receive $7 for every $1 invested in buyouts, including savings in reduced future deaths, injuries, post-traumatic stress disorder (PTSD), repair costs, sheltering expenses, economic losses, and insurance payouts (Vilay & Pollman, 2020).

A study of proactive flood buyouts in central Tennessee also measured comprehensive avoided costs of flooding, including those of relocation, volunteer flood cleanup labor, and replacement costs for stormwater mitigation measures, in addition to the direct property damages caused by the flood (Nelson & Camp, 2020). The researchers compared the observed scenario (all buyouts included through 2010) to one in which all actual buyouts through 2016 occurred by 2010, and one in which all properties identified as repetitive loss properties were bought out (the "wishlist" scenario). Table 5 shows the resulting BCR for each scenario. Overall, even the most conservative scenario (the one that actually took place) had a BCR greater than 3.1. The BCR increased when additional properties were bought out, reflecting an increase in program size by a factor of 6.5, but the BCR decreased again when the program size was further increased. Additionally, in this case, including secondary benefits did not make a substantial difference in the BCR.

Table 5. BCRs by Buyout Scenario, Central Tennessee

Scenario	BCR (Avoided Flood Damages)	BCR (Avoided Flood Damages and Secondary Benefits)
Observed	3.0	3.1
Proactive Buyouts (through 2016)	4.4	4.4
All Repetitive Loss Properties Bought Out	3.9	3.9

Source: (Nelson & Camp, 2020)

Later analyses focus on additional decision-making criteria. A nationwide multiple-criteria analysis of five different land acquisition strategies for flood adaptation in the U.S. evaluated each strategy against several metrics: the traditional BCR, social equity (measured by the Gini index to assess benefit distribution across income levels), and the reduction in the at-risk population (Zhang, et al., 2023). Acquisition strategies included:

1. Damage strategy: Prioritizing lands with the highest BCRs, maximizing economic efficiency
2. Income strategy: Prioritizing acquisitions where benefits are weighted by income, assigning higher weights to low-income census tracts to address equity
3. Vulnerability strategy: Weighting benefits using a social vulnerability index that considers both income and expected damage
4. Depth strategy: Prioritizing lands with higher 100-year flood depths to maximize physical risk reduction per dollar
5. Population strategy: Prioritizing lands with higher population densities relative to cost to maximize the reduction of people exposed to floods

With a hypothetical budget of $1 billion, all five land acquisition strategies produced benefits that are at least six times the cost (BCR ≥ 6.0). The damage strategy had the highest BCR (10.6). The authors concluded that while no single strategy optimizes all objectives simultaneously, shifting acquisitions toward poorer and more populous areas (via the Income or Population strategies) can improve social equity and reduce population exposure. These social gains resulted in only low to moderate reductions (13 to 43 percent) in economic efficiency.

An alternative metric specific to flood studies is the Damage-Market Value Ratio (DMVR), which is used to measure the cost-effectiveness of acquiring properties for flood risk reduction. It is calculated with the numerator as the total flood loss between 1978 and 2017 for the parcels being considered, and the denominator as the assessed market value of the property (The Nature Conservancy; TAMU, 2019). The DMVR signifies the amount of financial loss that would be avoided if the properties were acquired and removed from the tax roll, relative to the loss of the property's economic value. A ratio higher than 1.0 indicates that the buyout scenario would result in a net financial benefit to the community.

Using post-Harvey damage assessments from Harris County, Texas, one study developed a proactive buyout model that prioritizes clustering properties together and near greenspace (The Nature Conservancy; TAMU, 2019). Although the actual ratio was not reported, the study found that this strategy indeed had a DMVR ratio greater than one, meaning that prioritizing buyouts of clusters of properties near greenspace would result in public savings.

One study provides evidence specific to the North Central Texas region. Johnson et al. (2019) examined the economic viability of acquiring and conserving natural lands in U.S. floodplains to prevent future development and associated flood damages. The researchers utilized a continental-scale hydrodynamic model to identify flood risk zones for 5-year (20 percent annual exceedance probability [AEP]), 20-year (5 percent), 50-year (2 percent), 100-year (1 percent), and 500-year (0.2 percent) flood events. They then used the EPA's Integrated Climate and Land Use Scenarios

(ICLUS) to predict future development without intervention. They assigned economic values to projected developments by intersecting the FEMA National Structure Inventory with the National Land Use Dataset to generate an average asset value per pixel. Finally, they projected the expected yearly damages for each year from 2018 to 2070 to account for the gradual nature of future development using USACE depth-damage functions. These losses were summed to estimate the Present Value (PV) of all future avoided damages using a discount rate of 2.75 percent. This avoided loss value was the benefit of the land acquisition in each county.

To calculate an upper limit for costs, they measured the cost to acquire *all* currently unprotected natural lands within the floodplains for each county, not only those projected for development. This approach accounted for uncertainty in development projections and the risk of displacement (leakage) where development might simply shift to other floodplain areas. They then compared this cost with the aforementioned benefit. Overall, the study found that preventing floodplain development provides the highest return on investment when targeted at the zone between the 5-year and 20-year floodplains.

While BCRs for each county are not reported, Johnson et al. (2019) depict a map of the U.S. with counties coded by BCR range, based on the scenario of acquiring natural lands within the 1 percent AEP, or 100-year floodplain. The authors report that if this strategy were applied across the whole country, it would yield a BCR of 1.94. Although this ratio is above one (i.e., the benefits are greater than the costs), the study notes that the *marginal* benefit of adding the specific land within the 100-year floodplain but not in the 50-year floodplain is actually inefficient. The BCR for acquiring just that additional area is only 0.5, lower than the BCR for acquiring land in the 5-year to 20-year flood zones (which has a marginal BCR of 4.3). However, according to the figure, the counties in the Study Area, including Denton, Wise, Parker, Tarrant, Johnson, Dallas, and Ellis, are in the category of counties that are expected to benefit most from acquiring natural lands up to the 100-year floodplain, with a BCR greater than 3.25 (Johnson, et al., 2019).[39] Acquiring floodplain lands in Hood County, a sliver of which is also part of the Study Area, would result in a BCR between 1.25 and 2.50.

In some cases, increases in property value and recreation value can provide economic justification for restoration on their own. A study of a wetland restoration and shoreline stabilization project in Muskegon, Michigan calculated that the project resulted in a six-to-one return on investment, based on property value increases and recreation value (Isely, et al., 2018). Another study examined the costs and benefits of different green stormwater practices in Grand Rapids, MI, and found that conserved natural areas generated the largest BCR (Nordman, et al., 2018). The study calculated the costs of preserved natural areas primarily as an opportunity cost, representing the forgone income from not developing the land with income-producing structures. Conserved natural areas were assumed to be forested, and the bulk of their expected benefit (56 percent) came from an expected 19 percent increase in property value of homes adjacent to forest preserves. With these assumptions, preserved natural areas produced a BCR of about 2.50.

Despite the prevailing evidence showing high returns for buyouts, another study found that removing buildings from the floodplain would result in a net cost to the community. As

[39] This estimate is with an annual discount rate of 2.75%; a higher discount rate would result in a lower BCR.

discussed in Section 11, tax revenue can fall unless development is strategically relocated within the town to preserve the tax base (Schiff, et al., 2015). Schiff et al. (2015) evaluated the costs and benefits of structures in the floodplain, including considerations related to flood damages, tax revenues, and ecosystem service valuation. The authors suggest elevating flood-prone buildings as an alternative to buyouts. This study emphasizes the need to consider multiple flood management alternatives and a comprehensive approach that considers the long-term community effects on social, economic, fiscal, and environmental conditions.

14 Summary: Nature-Based Solutions in North Central Texas

This review has provided an economic lens through which NCTCOG and regional planners can evaluate the implementation of NBS. The combination of climate change and rapid future development in the NCTCOG region has the potential to change floodplains and increase the extent and severity of future flood damages. Preservation of floodplains and riparian corridors can reduce these effects and reduce future uncertainty and risk. However, projecting the economic benefits of floodplain and riparian corridor preservation is inherently challenging. First, most cost and benefit data presented are transferred from studies conducted in other regions of the country. While these values provide a starting point for analysis, they require local validation to account for regional differences in construction costs, labor markets, and property values. Second, many social benefits, such as enhanced community cohesion or improved mental health, are difficult to monetize fully and may be undervalued in a purely economic assessment. Finally, the performance and cost-effectiveness of any NBS are highly site-specific and depend on local soil conditions, hydrology, and design details. The findings in this review should therefore be considered as guidance for strategic planning rather than a substitute for site-level engineering and economic analysis.

Deciding whether and how to invest in riparian or floodplain preservation requires an evaluation of economic efficiency, spatial configuration, ecological function, and social equity. From an economic point of view, there is strong evidence that nature-based flood mitigation, particularly land acquisition, provides a high return on public investment. Multiple independent analyses show BCRs ranging from 2:1 to 11:1, including in the NCTCOG region. These high returns on investment are not uniform across the landscape; rather, they are driven by spatial factors. Specifically, proximity to development often drives ROI. For example, wetlands located in developed areas tend to generate greater values compared to those in rural areas, because there are more built infrastructure and assets that are protected by wetland flood risk mitigation, and more people to appreciate aesthetic, recreational, or other values provided by the natural area. In particular, preserved natural areas that are designed to provide public amenities can increase property values, drive recreational activity, and improve the overall quality of life.

Planners can use several strategies to support an NBS approach to stormwater management. First, decision-support interfaces, such as the TFPT, can help in site choice. Second, proactive preservation is consistently more cost-effective than reactive buyouts, which often involve expensive relocation costs and result in fragmented parcels. Finally, long-term maintenance strategies established early can maintain ROI and project effectiveness. In summary, investing in riparian and floodplain preservation can provide robust benefits in the NCTCOG region. By prioritizing NBS in high flood risk areas, aiming for contiguous land acquisition, and accounting for the full suite of benefits and costs, the region can implement infrastructure solutions that provide fiscal, economic, social, and environmental benefits.

15 Economics of Green Stormwater Infrastructure in North Central Texas

GSI methods, a suite of practices that mimic natural hydrology by capturing and filtering runoff close to its source, can be cost-effective and beneficial solutions to manage stormwater. Unlike traditional gray stormwater infrastructure (e.g., pipes and concrete channels), GSI can also be designed to deliver a wide range of environmental, social, and economic co-benefits that increase ROI and enable local governments to achieve multiple community objectives. The purpose of this literature review is to summarize key economic considerations of GSI, drawing on prior analysis and case studies of the costs and benefits and overall ROI of different GSI strategies. The review also provides information on how factors such as local geography, land use, population density, and development trends may influence the financial viability and ROI of various GSI practices.

Since the costs and benefits of GSI vary based on GSI practice, design, scale, and local context, a successful regional strategy depends on selecting the right practices for the right locations. GSI practices reviewed in this overview are: engineered systems (detention/retention ponds, constructed wetlands), bio-infiltration (bioswales, rain gardens, bioretention), urban trees, green roofs, and permeable pavement. All these types of GSI have been implemented in the NCTCOG region and can be suitable for the region.

For each GSI practice, this section summarizes cost, benefits, ROI, and siting considerations to aid practitioners in assessing their applicability for addressing stormwater challenges in North Central Texas. All dollar values are adjusted to 2025 dollars using the GDP Deflator. Table 6 below summarizes findings from the literature review on the ecosystem service benefits of each type of GSI, including benefits related flood mitigation, public health, recreation/aesthetics/greenspace, property values, water quality, habitat, air quality/climate regulation, and groundwater recharge. Table 7 below summarizes costs, ROI, and siting considerations for each GSI practice.

Table 6. Benefits Matrix

Benefit Type	Detention / Retention	Constructed Wetlands	Bioretention / Rain Gardens	Urban Trees	Green Roofs	Permeable Pavement
Flood Mitigation	**High.** Reduces peak flows and flood risk.	**High.** Distributed wetlands more effective.	**High.** Reduces volume; bioretention can manage ~71% of stormwater volume in specific scenarios.	**Moderate.** Intercepts rainfall and promotes infiltration.	**Moderate.** Retains 40% to 80% of annual precipitation, but storage limited.	**High.** Reduces runoff volume and peak flows.
Public Health	**Mixed.** Can remove pollutants, but basins can be safety hazards or mosquito breeding grounds.	**Mixed.** Good pollution control, but pest concerns.	**Moderate.** Can reduce heat island effect and pollutants in the air.	**High.** Reduces urban heat island and improves air quality.	**Moderate.** Improves air quality and reduces heat island effect.	**High.** Reduces hydroplaning, ice formation, and heat island effect.
Recreation / Aesthetics /Greenspace	**Mixed.** High value if designed as amenities (trails/fishing); eyesores if not maintained.	**Moderate.** Depends on design.	**High.** Provides aesthetic value; "green street" areas command price premiums.	**High.** Enhances aesthetics and attracts shoppers in retail areas.	**Mixed.** Visual amenity but also maintenance concerns.	**Low.** Primarily functional, but offers noise reduction.
Property Values[1]	**Mixed.** +8-10% if park-like; can decrease value if unattractive or unmaintained.	**Mixed.** Dependent on local population preferences.	**Moderate.** 3.5-5% premium in Seattle.	**Mixed.** Dependent on context, usually high.	**Mixed.** +16% rental premium in NYC; but negative impacts also found in other studies.	**Low.**
Water Quality	**Mixed.** Detention ponds less effective than retention ponds, depends on design.	**High.** Among most effective.	**High.** Removes pollutants through filtration and soil media.	**Moderate.** Promotes infiltration.	**Mixed.** Generally improves quality, but fertilizers can reduce quality.	**High.** Can achieve 77% reduction in sediment.
Habitat	**Mixed.** Dependent on quality, retention superior to detention.	**High.** Excellent wildlife potential.	**Moderate.** Provides small habitat areas, particularly for insects.	**Moderate.**	**Moderate.** Can create habitat (e.g., birds/insects).	**Not Applicable.**
Air Quality / Climate	**Moderate.** Wetlands regulate air quality.	**Moderate.** Dependent on plant mix.	**Moderate.** General GSI benefit.	**High.** Sequesters carbon and shade reduces energy use.	**High.** Insulation reduces building energy use; captures carbon.	**Not Applicable.**
Groundwater Recharge*	**Low.** Depends on soils and design.	**Low.** Depends on soils.	**Low.** Designed to infiltrate water close to the source.	**Low.** Promotes infiltration at the base of the tree.	**Not Applicable.** Captures water on the roof structure.	**Low.**

[1]This value is highly related to and is often a measure of recreation/aesthetic/greenspace benefits; care must be taken to not double count these two types of benefits.
*Clayey soils in North Central Texas may limit the potential for groundwater recharge in the area; groundwater recharge may be higher in areas with more penetrable soils (Zhang Y. , Personal communication).

Table 7. **Economic and Operational Summary**

BMP	Detention / Retention Basins	Constructed Wetlands	Bioretention / Rain Gardens	Urban Trees	Green Roofs	Permeable Pavement
Key Advantages	Cost-effective for flood control; potential recreational amenity.	High pollutant removal; high habitat value.	High flexibility for siting (yards, parking lots); large volume reduction.	Heat island mitigation; aesthetic/retail enhancement; energy savings.	Doubles roof life; building energy savings; requires no additional land.	Minimal space required; safety benefits.
Key Benefits	Flood mitigation; sediment/pollutant settling.	Flood risk reduction; water quality; wildlife habitat.	Stormwater retention; pollutant removal; aesthetic value; habitat.	Shade/cooling; carbon sequestration; air quality; stormwater retention.	Stormwater retention; insulation; air quality.	Safety (less ice/hydroplaning); groundwater recharge; stormwater retention.
Site Suitability	Requires large land area (2-3% of drainage); good for clay soils (Group C/D).	Requires large area.	Highly adaptable: parking lots, ROWs, yards. Works in clay with underdrains.	Streets, right-of-ways (ROW)s, parks, retail districts.	Commercial/Institutional flat roofs; best for new construction.	Low-traffic areas (parking, alleys, driveways); high-density areas.
ROI / Cost Savings	**Moderate.** Cost-effective for flood control; less so for water quality than other practices.	**High.** High benefit-cost (BC) ratios due to low maintenance and high ecosystem value.	**High.** Can save up to 80% vs. gray infrastructure; BCRs ~2.0 to 12.7.	**High.** Review of studies of urban trees, mostly in North America, shows avg BCR 5.4.	**Moderate.** BC ratio between 1.1 and 2.2, primary benefit is avoided roof replacement.	**Moderate.** Cost-competitive when used in place of storm drains; lower lifecycle costs than asphalt.
Cost	**Capital:** \$201k–\$864k/acre. **Maint:** 3% of capital cost/year (\$22k–\$166k/acre).	**Capital:** <\$1–\$55/sq ft (approx 25% more than ponds). **Maint:** <\$1–\$5/sq ft/year.	**Capital:** \$2–\$80/sq ft. **Maint:** <\$1–\$10/sq ft (lower than wet ponds).	**Capital:** \$100–\$1,000/tree. **Maint:** \$8–\$62/tree/year.	**Capital:** \$12–\$84/sq ft (High). **Maint:** \$0.11–\$2/sq ft/year.	**Capital:** \$3.52–\$491/sq ft (20-50% higher than traditional). **Maint:** Lower lifecycle O&M.
Drawbacks	Good design and maintenance necessary to ensure beneficial aesthetics; mosquitoes in retention basins; requires larger land area.	Requires larger land area; sensitive to human disturbance.	Requires maintenance (weeding/mulch) to function.	Conflicts with infrastructure (sidewalks/power lines); pruning costs.	High upfront cost; irrigation or drought-tolerant native species needed in hot climates.	Ongoing maintenance (risk of clogging, esp. in high-traffic areas; requires vacuum sweeping); high initial installation cost.

16 Detention/Retention Ponds

Detention and retention ponds are a hybrid form of stormwater infrastructure with the potential for gray and green qualities, depending on how they are designed. Wet ponds (retention ponds) maintain a permanent pool of water. Treatment occurs through pollutants settling (sedimentation) and biological uptake by algae and plants within the permanent pool (EPA, 2021a). Constructed wetlands are a specialized form of wet pond that incorporates a greater diversity of native vegetation and shallow marsh areas to maximize ecological function and pollutant removal (EPA, 2021a; Morrison & Mikulencak, 2012). In contrast, dry ponds (detention basins) are designed to hold water temporarily after a storm and then slowly release it and are normally dry between rains. Their primary function is limiting peak flow rates (JRH Engineering, 2023).

16.1 Benefits

Well-designed and maintained ponds offer a combination of benefits. As touched on in Section 7.2.1, their primary function is to detain stormwater, which reduces peak flows downstream and mitigates flooding. While dry detention basins can provide pollutant load reduction, they are not recommended as a standalone water treatment method since they are typically inefficient for pollution control (Wissler, et al., 2020; Morrison & Mikulencak, 2012). In contrast, retention ponds (wet ponds) improve water quality by allowing sediment, nutrients, and heavy metals to settle out of the water column or through biological uptake (Guerrero, et al., 2020; EPA, 2021b); for example they have been shown to be moderately effective at removing nitrogen (36 percent) and phosphorus (52 percent) (Morrison & Mikulencak, 2012).

Value may increase when these features are designed as central community amenities, offering recreational opportunities like walking paths and fishing, while also providing valuable habitat for birds and other wildlife (Kang, et al., 2024; Minnesota Pollution Control Agency, 2022). Large, multi-use detention basins, such as those containing trails, sports fields and courts, and other park amenities, can increase nearby property values more consistently; in one study of detention basins in College Station, TX, property values decreased by about $250 for every 10 meters further from the basin (Lee & Li, 2009).[40] It is well established in the literature that property values next to parks are about 8 to 10 percent higher than similar properties that are not (Crompton & Nicholls, 2020). These higher property values demonstrate the value to homebuyers of the aesthetic, recreational and flood control services provided by these areas. Meanwhile, greenspace can provide the financial means to maintain itself via increased property tax revenue.

However, without design and maintenance focused on aesthetics, detention basins may be perceived as an eyesore and a source of health and safety issues by the community, which can diminish property values (Emmerling-DiNovo, 1995; Debo & Ruby, 1982; Lee & Li, 2009). For example, a study in South Carolina showed homes adjacent to a stormwater pond site pre-construction had a 12.47-percent price premium, but after the pond's construction, the premium declined to 1.46 percent, possibly due to neglected maintenance or nuisance wildlife (Ureta, et al., 2025).

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[40] Adjusted to 2025 dollars from $164 in 2006 USD using the GDP Deflator Index.

16.2 Siting and Design Considerations

Properly designed ponds and constructed wetlands, particularly in new developments, can serve as cost-effective, dual-purpose solutions for both flood control and water quality improvement. They function well on hydrologic group "C" or "D" soils (clay soils), which are common in many parts of the North Central Texas region (NCTCOG, 2014). Their cost-effectiveness is greatest when they are integrated into development plans as recreational and aesthetic amenities for the community (EPA, 1995). Agencies sometimes retrofit existing gray detention ponds with green features (wetland shelves, native plantings, water quality forebays) so they contribute both flood control and ecological benefits within a green infrastructure network (Hawley, et al., 2017).

In many cases, as discussed in Section 9.1, maintaining natural areas in their current state may be more cost-effective than converting them into detention basins, since converting a natural site into a detention pond can also result in reductions in ecosystem services by replacing an existing natural area. For example, construction of large detention ponds in Harris County, Texas, actually resulted in decreased benefits of between $48,000 and $143,000 annually per acre (Berg, 2024).[41] This loss was the result of soil compaction from construction at the sites along with removal of functional woody wetlands and mixed forests at the site, which have high ecosystem service productivity. While this case study did not analyze benefits related to disaster risk reduction and stormwater regulation, it makes the point that woody wetlands and riparian forests also provide these services. Planners should consider preservation approaches when sites already provide valuable stormwater regulation services.

Planners should also note that these practices require a relatively large amount of land (two to three percent of the drainage area) compared to other BMPs, which may preclude their use in high-density areas, and increase land acquisition costs (NCTCOG, 2014). Land and construction costs can be minimized by using steep sideslopes (e.g., 3:1) (Travis & Mays, 2008). This design maximizes the storage volume for a given basin footprint, minimizing both the land cost and construction cost components of the total cost function.

Maintenance and replacement costs can also be minimized with proper siting. Although steep slopes maximize storage volume, sites with steep slopes (>15 percent) should be carefully considered for erosion risk, since steep slopes may increase the risk of instability or erosion during heavy rain (NCTCOG, 2014). Hence, in high-relief areas (like those west of Fort Worth), embankment heights may be restricted. Additionally, the bottom of the basin should remain at least 2 feet above the seasonal high water table to prevent standing water and mosquito breeding (NCTCOG, 2014).

16.3 Return on Investment

Capital costs for detention and retention basins are comparable with costs for conventional underground detention basins. Cost estimates for conventional underground detention basins range from about $8.60 to $15.08 for a system with a capacity of 75,000 cubic foot (CF) (StormTank, 2025). An analysis from the Barr Engineering Company (BEC) estimated that the

[41] Adjusted to 2025 dollars from $44,000 and $132,000 in 2022 USD using the GDP Deflator Index.

average capital cost per CF capacity for a wet detention basin[42] would fall between about $3 (for basins larger than 100,000 cubic feet) and $243 (for basins smaller than 10,000 cubic feet) (Barr Engineering Company, 2011).[43] Unit costs are greater for the smaller basin because of economies of scale. The fixed costs for both small and large basins would be similar, but they are spread over a smaller volume for the small basin. For the larger basin, maintenance costs would be about $0.12 per cubic foot, but BEC did not report a unit maintenance cost for smaller basins.[44]

The Hickory Creek study found that retention (wet) ponds ranked seventh out of nine options for cost-effectiveness across phosphorus and nitrogen removal, and eighth for sediment removal (Olivera, et al., 2013). Detention ponds ranked slightly better, ranking fifth across all three pollutant categories analyzed on urban land.

The National Cooperative Highway Research Program (NCHRP) replicated the results of the Denton study, providing cost-effectiveness estimates for several BMPs, including wet ponds and dry detention, which are shown in Table 8 (NCHRP, 2014). The first two columns in the table are volume reduction and volume capture. Volume capture measures the total runoff that is intercepted and managed by a BMP, meaning it does not bypass or overflow the system. It includes both the water that is treated and subsequently released (effluent) and the water that is permanently removed from surface flow (lost volume). Volume reduction refers to this latter portion that is removed from the surface water system through infiltration into native soil, evapotranspiration (ET), or consumptive use. In this table, treatment strategies are assumed to be sized with "routing," which means they are optimized for a specific goal, in this case 80 percent volume capture. All costs are updated from 2013 U.S. dollars (USD) to 2025 USD using the GDP Deflator Index.

Table 8. Annualized Cost per Unit of Performance for Detention Ponds and Wet Ponds

BMP Type	Volume Reduction ($/ft³ removed)	Volume Capture ($/ft³ captured)	E. coli ($/10¹² colonies)	Total Nitrogen (TN) ($/lb)	Total Phosphorus (TP) ($/lb)	TSS ($/lb)
Wet pond	NA†	$0.19	$12	$1,855	$13,229	$26
Dry detention	$0.23	$0.05	$3	$660	$3,624	$7

Source: (NCHRP, 2014)
†NCHRP assumed wet ponds reduce no volume, since they have a permanent pool of water and are already saturated.
Note: Original costs, first row: NA, $0.12, $8, $1,201, $8,563, $16.97. Second row: $0.15, $0.03, $2.08, $2.13, $427, $9,373, $2,346, $4.72. Costs adapted from 2013 dollars to 2025 dollars using the GDP Deflator Index.

16.4 Costs

Construction costs for ponds are variable, and annual maintenance is typically estimated at about 3 percent of the initial construction cost (EPA, 2021b). Capital costs include land acquisition and

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42 Synonymous with a wet pond or retention basin.
43 Adjusted to 2025 dollars from $2 and $145 in 2010 USD using RSMeans Cost Index.
44 Adjusted to 2025 dollars from $0.07 in 2010 USD using RSMeans Cost Index.

construction, while regular maintenance involves removing accumulated sediment from forebays to maintain storage capacity and performance, tasks which can be demanding and costly compared with maintenance tasks for other stormwater infrastructure (EPA, 2021a; Houle, et al., 2013). Based on an analysis of the available literature, capital costs for ponds may amount to between $200,000 to $864,000 per acre, while maintenance costs could be between $22,700 and $166,000 per acre annually (Headwaters Economics, 2022; Houle, et al., 2013).[45]

A large portion of the capital costs for any method of GSI is the cost of land acquisition. Based on data from the National Agricultural Statistics Service, the normalized average cost of pasture land in Texas between 2019 and 2025 was $2,106 per acre; however, land in northeast Texas is likely worth more (National Agricultural Statistics Service, 2025). As shown in Table 4 in Section 11, working land costs in the Study Area range from about $7,500 to $75,000 per acre.

17 Constructed Wetlands

A constructed wetland (also known as a stormwater wetland) is an engineered shallow marsh system designed to treat urban stormwater runoff and control runoff volumes (Morrison & Mikulencak, 2012). While constructed wetlands mimic the functions of natural wetlands, they are engineered specifically for treating stormwater and typically possess less biodiversity than natural wetland systems. They utilize a combination of physical, chemical, and biological processes to remove pollutants from the water.

17.1 Benefits

Stormwater wetlands can provide substantial flood risk reduction. While there is limited literature measuring the economic benefits of constructed wetlands, there is extensive evidence of the benefits of existing wetlands. A nationwide study compared the loss in upstream wetland area to downstream changes in FEMA claims over time and estimated that the loss of an average acre of wetland cost society on average $1,076 annually in flood damages, with this cost rising to over $4,854 per acre in developed zones (Taylor & Druckenmiller, 2021).[46] The authors note that these figures likely represent a lower bound of the true value because the dependent variable (NFIP claims) captures only a portion of total flood damages; it excludes uninsured properties, commercial/government properties not covered by NFIP, crop damages, and non-flood ecosystem services like recreation or water filtration.

Importantly, as mentioned in Section 9.1, the researchers found no effect of wetland gains (such as through compensatory mitigation requirements) on flood insurance claims (Taylor & Druckenmiller, 2021). The authors suggest this indicates that created or restored wetlands may not provide the same flood mitigation services as mature, naturally occurring ecosystems, or that

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[45] Maintenance costs: Low cost adjusted from $4 per square foot in 2020 USD from (Headwaters Economics, 2022), and high cost adjusted from $7,830 over 299 square meters in 2012 USD from (Houle, et al., 2013). Capital costs: Low cost adjusted from $2.43 in 2020 USD from (Headwaters Economics, 2022), which was converted into a cost per acre, and high cost adjusted from $40,700 over 299 square meters in 2012 USD from (Headwaters Economics, 2022). These were converted into costs per acre and adjusted to 2025 USD using RSMeans Cost Index.
[46] Original values are nominal values based on claims maid between 2001 and 2016. Adjusted to 2025 dollars from $1,840 per hectare per year and $8,294 in 2009 dollars (the midpoint) using the GDP Deflator Index, then divided by 2.47 acres per hectare.

they are being placed in areas where they do not effectively protect assets. This evidence contradicts other studies that demonstrate strong flood mitigation benefits from wetlands. For example, a Virginia field study of stormwater constructed wetlands and basins recorded average peak inflow reductions of about 46 to 48 percent at monitored sites, with some storm events seeing total system peak reductions of up to 90 to 93 percent (Yu, et al., 1998). Similarly, a recent study of a constructed stormwater wetland in Pennsylvania found that it provided stormwater volume reduction year-round and reduced areal flood risk by limiting the amount of runoff reaching downstream areas (McGauley, et al., 2025). Finally, a Tulane University modeling study in the Brazos River basin, Texas, tested over 140 wetland scenarios and found that decentralized constructed wetlands provided cumulative flood peak reduction and additional storage, outperforming existing dams in flood control (Shah, et al., 2023).

Constructed wetlands are also among the most effective practices for removing pollutants. They have been estimated to remove 74 to 80 percent of TSS and are effective at removing bacteria and nutrients (NCTCOG, 2014; Morrison & Mikulencak, 2012). Data suggests removal rates of approximately 35 percent for nitrogen and 47 percent for phosphorus (Morrison & Mikulencak, 2012). The pollution removal, water savings, habitat, and recreational benefits provided by wetlands are discussed in detail in Section 9.

These benefits are sometimes reflected in increased property values. A recent study in Philadelphia found that a 100 percent increase in the square footage of wetlands, basins, or trenches within 250 feet of a home was associated with a 0.23 percent higher residential sale price (SB Friedman & CNT, 2020). However, this result was not replicated in Seattle, possibly due to the small sample size there. This property value increase was also not as high as for other GSI types in this study, which may be related to the safety and pest (e.g., mosquito) concerns related to these practices.

17.2 Siting and Design Considerations

Constructed wetlands require a relatively large amount of space, typically consuming 3 to 8 percent of the tributary drainage area; however, they require a minimum drainage area of 25 acres (or 10 acres for smaller “pocket” wetlands) to maintain the necessary permanent pool and hydrologic balance (Barr Engineering Company, 2011; NCTCOG, 2014; Houle, et al., 2013). Hence, although they require a sizeable amount of land for siting, they can also treat a large area. They are most cost-effective in less dense areas where land costs and pollutant loads are moderate.

While large-scale, connected wetlands may provide greater habitat benefit, having multiple wetlands throughout the watershed can greatly reduce flood peaks. A study in Texas utilized coupled hydrologic and hydrodynamic models in the Brazos River Basin to evaluate the flood mitigation potential of constructed wetlands (Shah, et al., 2023). Their experiments revealed that a distributed portfolio of smaller wetlands is far more effective for flood mitigation than centralized large ones, with two smaller sites (12 square kilometers each) reducing flood peaks nearly six times more than a single large site of equal total area. By simulating portfolios of wetlands ranked by storage capacity, the authors found that constructing approximately 18 wetlands could create flood storage equivalent to roughly 10 percent of Lake Whitney’s capacity. While distributed GSI sometimes creates additional maintenance costs for municipalities, wetlands usually require little maintenance, so smaller, distributed wetlands are less likely to substantially increase costs in the same way.

Additionally, when they are located more closely to development, constructed wetlands located in peri-urban parks can serve as a source of positive externalities, particularly when used for environmental restoration and treated wastewater reuse (Agaton & Guila, 2023). More and smaller wetlands would mean a greater ratio of wetland border to area, which may allow for greater property value increase for development on the edges of smaller wetlands versus larger wetlands.

17.3 Return on Investment

While there is strong evidence of cost savings when wetlands are built for wastewater treatment, evidence of wetlands' benefit for flood management is more sparse (Masoud, et al., 2024; de Simone Souza, et al., 2017; Teng, et al., 2012). Research indicates that existing wetlands often yield high net benefits due to lower operational costs and high ecosystem service valuation. A benefit transfer study comparing urban stormwater ponds to created wetlands in central Oklahoma found that created wetlands had a much higher BCR than stormwater ponds (White L. M., 1998). For example, the BCR for created wetlands ranged from approximately 18.4 to 45.3, using a 5-percent discount rate and a 20-year period.[47] The study attributed this finding to assuming a maintenance cost of $0 for wetlands (which did not require fountains or chemical treatments for algae). Additionally, White (1998) cautioned that due to their use of the benefit transfer method, these estimates were derived from studies in different regions with varying socioeconomic characteristics; however, the author chose lowest-bound estimates from these studies to estimate the benefits. These BCRs are extraordinarily high and only possible because of the low capital costs associated with the wetlands, the absence of maintenance costs, and the inclusion of all benefits.

17.4 Costs

While often less expensive than some structural controls like sand filters, wetlands are estimated to be approximately 25 percent more expensive to construct than stormwater ponds of equivalent volume (Morrison & Mikulencak, 2012). Capital costs for constructed wetlands range widely from about $250 per acre for a minimal design to $2.4 million per acre for a gravel wetland (Hathaway & Hunt, 2007; Noack, 2018; San Antonio River Authority, 2019; Hansen, 2015; Ellis, et al., 2014; Houle, et al., 2013).[48] Some studies indicate constructed wetlands can be the least expensive option when land costs are excluded (Weiss, et al., 2005).

The capital costs per cubic foot for constructed wetlands are variable based on size and design. One estimate put the cost at $1.68 per cubic foot, making them the most cost-effective GSI type

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[47] Based on reported benefits of $3,277 and $2,802 (Wetland 2) over years 1-20 and costs of $900 (Wetland 1) and $1,900 (Wetland 2) in year zero.

[48] Capital costs: Low cost adjusted from $171 per acre for a restored wetland in 2015 USD from (Bogar & Beyer, 2016), high cost adjusted from $67,800 over 179 square meters in 2012 USD to 2025 USD using RSMeans Cost Index.

in the study; however, there were no data for maintenance costs (Barr Engineering Company, 2011).[49] Another study looked at gravel wetlands, which contain a gravel stone bed below the surface and are more resource-intensive, and estimated the capital cost at about $33.73 per cubic foot (Woodward & Curran, 2013).[50]

Maintenance costs for constructed wetlands will change over time. Initial maintenance is often high during vegetation establishment. Long-term maintenance includes inspection, mowing of side slopes, debris removal, and sediment removal (NCTCOG, 2021). Maintenance costs reportedly range greatly between $8 to $200,000 per acre per year, again depending on the design (Hathaway & Hunt, 2007; Noack, 2018; San Antonio River Authority, 2019; Hansen, 2015; Ellis, et al., 2014; Houle, et al., 2013). [51]

18 Infiltration Practices: Bioretention, Rain Gardens, and Bioswales

Infiltration practices consist of vegetated, shallow depressions with engineered soil media designed to capture, treat, and infiltrate stormwater runoff close to its source, as touched on in Section 7.2.3 (Hathaway & Hunt, 2007). Rain gardens are shallow depressions planted with species meant to absorb water from a property before it becomes runoff, while bioretention systems are engineered rain gardens. A bioswale is a type of bioretention system that is linear and gently sloped to convey water along a path.

18.1 Benefits

Infiltration practices provide multiple benefits, including pollutant removal, aesthetic value, and habitat (CNT, 2020; Weiss, et al., 2005). These benefits are reflected in increased property values; a study in Seattle found a 3.5 to 5 percent price premium for homes located in "green street" areas with bioswales (Hoover & Hopton, 2020). Another study from Seattle and Philadelphia found that doubling the square footage of rain gardens, swales, or planters within 250 feet of a home is associated with increases in residential sale price of 0.38 to 0.69 percent (SB Friedman; CNT, 2020). However, this finding was not replicated in Omaha, Nebraska, where proximity to BMPs had no effect on home values (Hoover & Hopton, 2020).

18.2 Siting and Design Considerations

Retention practices are adaptable and can work well in many contexts. They are commonly used in parking lots, along roadways (as bioswales), and in residential yards (as rain gardens) (Morrison & Mikulencak, 2012). Vegetated swales are highly suitable for integration into transportation corridors and public rights-of-way. A study modeling the City of Dallas's existing stormwater system identified parking lots as the largest spatial opportunity for GSI implementation (Jack, et al., 2021). The study identified areas of under-capacity, aiming to quantify how different GSI interventions could reduce stormwater overflow under various storm

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[49] The assumed water quality volume (storage) of the wetland was estimated as its surface area multiplied by 18 inches. Adjusted to 2025 dollars from $1 per cubic foot in 2010 USD using the RSMeans Cost Index.
[50] Adjusted from $21.83 per cubic foot capacity in 2013 USD to 2025 USD using RSMeans Cost Index
[51] Maintenance costs: Low cost based on 3% of capital low cost per (EPA, 2007), and high cost adjusted from $2.88 over 179 square meters in 2012 USD (McPherson E. , et al., 2006) to 2025 USD using RSMeans Cost Index.

intensities and climate scenarios. Parking lots offered between 41 and 48 percent of the total potential GSI capacity in the study area. Furthermore, the study determined that bioretention areas would have the most potential impact compared with rain gardens and water cisterns. Of the three practices analyzed, bioretention accounted for approximately 71 percent of the total stormwater volume managed by GSI across all storm scenarios.

One important cost consideration for retention practices is soil type. While planners have the option of replacing native soils with imported media to improve drainage for infiltration systems, the NRCS describes many of the soils in the Study Area as well-draining and slowly permeable (NRCS, 2020; NRCS, 2020; NRCS, 1997). This means that pooling at the surface is unlikely, yet the subsoil will transmit water slowly. This type of soil would work well with vegetated practices, since roots will not be waterlogged but will be able to suck up water. Generally, filter media layers with a smaller ratio of soil to sand (e.g., 1:4) will result in faster infiltration (Rinchumphu, et al., 2024). In cases where such soil is not available, guidance from the San Antonio River Authority notes that bioretention can still achieve 20 to 70 percent volume reduction on slow-draining soils when designed with an underdrain system (San Antonio River Authority, 2019). An underdrain allows filtered stormwater to be discharged into the drainage system even when deep infiltration is slow, thereby preserving the practice's primary benefits of volume reduction and water quality treatment.

18.3 Return on Investment

Infiltration practices can result in cost savings. An EPA report included case studies comparing the costs of traditional grey infrastructure to LID practices, including infiltration practices (EPA, 2006). Rain gardens and swales demonstrated cost savings of up to 80 percent compared to estimates for conventional solutions, such as underground vaults (EPA, 2006). For example, projects in Maryland and Washington State eliminated the costs of a retention pond and paving costs, which resulted in savings of 32 and 25 percent, respectively (Franklin Regional Council of Governments, 2015). In Houston, Texas, a roadway project incorporating a bioswale median eliminated the need for off-site detention, resulting in a 7 percent total cost reduction compared to traditional design (NCTCOG, 2017). The Hickory Creek study in Denton, Texas, found that grassed waterways/filter strips ranked second in cost-effectiveness for sediment and phosphorus removal, and third for nitrogen removal (Olivera, et al., 2013).

The NCHRP provides cost-effectiveness estimates for several types of infiltration BMPs (NCHRP, 2014). As in Table 9, treatment strategies are again assumed to be sized with routing for 80 percent volume capture. All costs are updated from 2013 USD to 2025 USD using the RSMeans Cost Index.

Table 9. Annualized Cost per Unit of Performance for Infiltration Practices

BMP Type	Volume Reduction ($/ft^3 removed)	Volume Capture ($/ft^3 captured)	E. coli ($/10^{12} colonies)	TN ($/lb)	TP ($/lb)	TSS ($/lb)
Swales*	$0.36	$0.06	$21	$1,645	$5,888	$10
Bioretention (no underdrain)	$0.17	$0.17	$10	$791	$6,050	$19

Bioretention (with underdrain)	$0.32	$0.11	$6	$1,234	$11,468	$13
Filter strip	$0.06	$0.05	$4	$303	$1,995	$6

Source: Adapted from (NCHRP, 2014)
*Swales have steep slopes and are used primarily for flow channeling, while filter strips are more effective for capturing pollutants.

One study examined the costs and benefits of different GSI practices in Grand Rapids, Michigan (Nordman, et al., 2018). The researchers standardized the size of each practice to treat a water quality volume (WQv) of 3,000 CF for a 1-inch rain event and compared costs and benefits. The rain garden produced benefits from avoided runoff, pollution, flood risk, and property value increase. Nordman et al. (2018) assumed a property value increase of 6 percent for properties within 164 feet. Costs included capital, maintenance, and opportunity costs (the forgone use of the land used for the rain garden). The researchers found that rain gardens produced a BCR of about 2.0, the second highest after natural areas. On the higher end, a cost-benefit analysis for small urban green infrastructure projects in Hinesville, Georgia, used a benefit transfer method based on a meta-analysis by Bockarjova et al. (2020), adjusting for the smaller size of GSI compared with the parks on which the meta-analysis was based (Landry, et al., 2022; Bockarjova, et al., 2020). The proposed project included rain gardens and bioswales, and yielded BCRs between 7.1 and 12.7.

18.4 Costs

Costs of filtration practices include excavation, specialized soil media, plants, and ongoing maintenance such as weeding, sediment removal, and mulch replacement to ensure proper function (Gulliver, et al., 2010). Costs can vary widely depending on the design and location, at between a couple of dollars to $82 per square foot (NCTCOG, 2017; San Antonio River Authority, 2019; Houle, et al., 2013; Morrison & Mikulencak, 2012; EPA, 2007; USDA NRCS, 2024).[52] Annualized maintenance costs for bioretention systems are typically lower than for conventional wet ponds, usually at about 5 to 7 percent of construction costs (Houle, et al., 2013; Barr Engineering Company, 2011). Vegetated swales, in particular, are consistently noted as one of the least expensive BMPs to construct (Minton, 2003).

One study compared several GSI options with a conventional underground detention facility in Mississippi, using a 30-year lifecycle and a 5.5 percent discount rate. They estimated an average capital cost per cubic foot of rain garden capacity of $8.38 and an average maintenance cost per cubic foot capacity of $1.17 (Abera, et al., 2025).[53] This cost is similar to that of a conventional detention basin designed to store the same amount of water, with a capital cost of $8.38 and a maintenance cost of $0.17 per cubic foot.[54] In spite of the higher maintenance costs, the rain garden resulted in cost savings of 9 percent over the life of the project, because it reduced landscaping costs and simultaneously replaced the necessary storage of the accompanying detention basin.

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[52] Adjusted to 2025 dollars from $1 (EPA, 2007) in 2006 USD and $53 in 2013 USD (NCTCOG, 2017) using RSMeans Cost Index.
[53] Adjusted to 2025 dollars from $8 and $1.12 in 2023 USD using the GDP Deflator Index.
[54] Adjusted to 2025 dollars from $8 and $0.043 in 2023 USD using the GDP Deflator Index.

In the City of Dallas, a study looked at the cost of updating the existing gray stormwater network to manage a 100-year (1 percent) design storm, and compared it with implementation of GSI (Jack, et al., 2021). In this latter scenario, researchers assumed that bioretention areas would occupy 10 percent of parking lots, 35 percent of vegetated road medians, 35 percent of planting strips, 35 percent of wide commercial sidewalks, and 10 percent of parks, while one 200 square feet rain garden would be implemented for every residential and commercial structure.[55] The study assumed that for every square foot of area, bioretention areas would have 1.5 CF of capacity, and rain gardens would have 0.5 CF of capacity. The costs per CF of capacity for bioretention areas and rain gardens were compared with the costs per CF capacity to implement a gray infrastructure pipe upgrade for handling the 100-year design storm with no overflow. The study did not adjust GSI costs from the literature for inflation, so we expect that these unit costs may be conservative. Results are shown in Table 10 below.

Table 10. Comparison of Costs per Cubic Foot of Capacity in Dallas, TX

Cost Type	Gray Infrastructure	Bioretention Area	Rain Garden
Capital Cost	$79.29	$11.82	$25.73
Maintenance Cost		$1.35	$10.02

Source: (Jack, et al., 2021)
Note: Original costs, top row: NA, $1.58, $3.44. Bottom row: $10.60, $0.22, $1.63. Costs adapted from 2020 dollars per gallon to 2025 dollars using GDP Deflator, then multiplied by 7.48 gallons per cubic foot.

On the higher end, BEC released cost estimates based on their own work in Minnesota and data from the International Stormwater BMP Database (Barr Engineering Company, 2011). Their findings for infiltration practices are reported in Table 11 below. The "water quality volume" in this case means the total holding capacity below any outlet or overflow.

Table 11. Cost per Cubic Foot of Infiltration Practices

BMP Type	Average Capital Cost ($/ft³ of Water Quality Volume)	Average Annual O&M Cost ($/ft³ of Water Quality Volume)
Bioretention Basins	$25	$2.09
Biofiltration Basins*	$97	No data
Infiltration Trenches	$18	$0.65

Source: (Barr Engineering Company, 2011)
*Biofiltration basins are nearly identical to bioretention basins, but include a drain tile below the filtration area, and may be used in areas with low infiltration rates into the underlying soil.
Note: Original costs, first column: $15, $58, $11. Second column: $1.25, NA, $0.39. Costs adapted from 2010 dollars to 2025 dollars using RSMeans Cost Index.

[55] Also assumed one 1,000-gallon rain cistern (with 750 gallons of available capacity) for every residential and commercial structure. Because rain cisterns are typically implemented on private property, we do not cover them here.

19 Urban Forestry: Street and Park Trees

Urban trees, particularly those with large canopies, act as a form of GSI by intercepting rainfall on leaves and bark, promoting infiltration at their base, and reducing the volume and velocity of stormwater runoff (Selbig, et al., 2022).

19.1 Benefits

A mature tree canopy intercepts rainfall, reducing the volume of runoff that enters the storm drain system. A local study on the Southern Methodist University campus in Dallas valued the annual stormwater benefits from a single mature live oak at $98 per year, based on avoided stormwater management costs (Monear, et al., Downtown Dallas Tree Inventory & Ecosystem Services Benefits Report, 2013).[56] On the low end, the *State of the Dallas Urban Forest Report* reports runoff values per tree per year at between $0.29 and $0.54, based on guidance from the U.S. Forest Service's Community Tree Guide Series, which itself also bases costs on avoided stormwater fees (Texas Tree Foundation, 2015; Vargas, et al., 2007).[57] Overall, stormwater benefits per tree may range between less than a dollar to $100 per tree per year, depending on the size of the tree and its location (urban vs. rural).

Urban trees deliver several quantifiable co-benefits. Shade from trees cools asphalt, reducing pavement fatigue and deferring costly repaving schedules. One study projected savings of $12.09 per square meter of tree canopy over a 30-year period for a Sacramento, California street shaded by large trees (McPherson & Muchnick, 2005).[58] The average tree canopy per tree in downtown Dallas is about 49.3 square meters,[59] so assuming half of the tree's canopy hangs over the street, an average tree in North Central Texas might be expected to reduce pavement costs by about $300 over a 30-year period, or $10 per year, based on this estimate (Monear, et al., Downtown Dallas Tree Inventory & Ecosystem Services Benefits Report, 2013). In addition, shade from trees reduces building energy consumption for air conditioning (Clements, et al., 2021). In a region characterized by hot summers, the urban tree canopy has the potential to mitigate the urban heat island effect and reduce energy costs for cooling. Finally, trees improve air quality by removing pollutants and sequestering atmospheric carbon (Nowak, et al., 2013). A study in Denton, Texas, documented the ability of oak trees to act as a sink for elemental carbon (soot) (Rindy, et al., 2019). Across Texas, urban trees are estimated to sequester 2.165 million metric tons of carbon per year (Nowak, et al., 2013).

Aesthetic and other related benefits are often the single largest benefit category for urban trees (McPherson E. G., et al., 2005). Studies have shown that street tree plantings are associated with property value increases of 7 to 11 percent (Wachter & Wong, 2008). Evidence from within the

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[56] Adjusted to 2025 dollars from $75 in 2012 USD using the GDP Deflator Index.

[57] Divided total runoff value by number of trees for each section of Dallas. Adjusted to 2025 dollars from $0.22 and $0.41 in 2015 USD using the GDP Deflator Index.

[58] Adjusted to 2025 dollars from $7.13 in 2012 USD using the GDP Deflator Index.

[59] According to a 2015 inventory of trees in Downtown Dallas (an area of 1.6 square miles), 7.4 percent of the downtown area is covered in the canopy provided by 6,218 trees (Monear, et al., 2015). This equates to an average tree canopy of 49.3 square meters.

Study Area, in Tarrant County, showed that increased urban tree cover reduced the adverse effect on house prices of proximity to chemical facilities (Lee, et al., 2008). Furthermore, trees in retail districts help create satisfying, memorable places that attract shoppers and enhance economic activity (Wolf K. , 2008). However, the value of an additional tree may depend on the neighborhood. A study of home sales in San Antonio, Texas, found a contrast in the valuation of tree canopy across different market segments: in the lowest-value area, the presence of either more or less tree canopy than the local median was found to decrease property values by about 3 percent (Lee & Thomson, 2025). In comparison, in the highest-value area, tree canopy provided a price premium. Low levels of canopy were associated with a sales price loss of up to 8 percent, while a high degree of neighborhood canopy could add a premium of 4 to 6 percent. In the two middle-value areas, the analysis revealed a generally positive trend where more tree canopy, particularly at the neighborhood level, contributed positively to home sale prices by about 3.5 to 6.3 percent. The authors suggest this contrast in results may be due to perceptions of maintenance costs, risks from unmaintained trees, or the prevalence of less desirable tree species. Lower-income households may be less able to afford the maintenance costs of trees.

The *State of the Dallas Urban Forest Report* quantifies the benefits provided by the city's tree canopy, including over $13.4 million annually in energy savings (including carbon costs), $5.2 million in avoided stormwater infrastructure costs, $10.8 million in carbon dioxide absorption, and $20 million in reduced air pollution. With a total of 14.7 million trees, each tree provides an annual value of $3.36 (Texas Tree Foundation, 2015).[60]

19.2 Siting and Design Considerations

To maximize these benefits and ensure long-term resilience, strategic species selection is important. The Dallas tree inventory recommends diversifying new plantings, as the current canopy is dominated by just three species, making it vulnerable to pests and disease (Texas Tree Foundation, 2015). Some tree species with high water retention rates include open-grown species, such as *Eucalyptus nichollii* (44 percent rainfall retention), *Thuja plicata* (Western red cedar, 61 percent), and *Ficus benjamina* (weeping fig, almost 60 percent during leaf-on periods) (Kuehler, et al., 2017). Generally, conifers demonstrate greater depths of water retention throughout the year compared to broadleaf species (Kuehler, et al., 2017). Planners may also wish to prioritize targeting resilient, low-maintenance, native species that can withstand the expected risks of climate change, such as increased frequency and intensity of drought.

Another cost-mitigation strategy is proper tree siting to avoid future conflicts with infrastructure like sidewalks, sewer lines, and overhead power lines, which can lead to expensive repairs (McPherson E. G., et al., 2006). Additionally, maintenance can have equity impacts. Planners should ensure regular maintenance of trees in lower-income areas that might be more vulnerable both to flood impacts and risks of unmaintained trees (Lee & Thomson, 2025).

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[60] Adjusted to 2025 dollars from $10.2 million, $8.2 million, $4.0 million, $15.2 million, and $2.25 in 2015 USD using the GDP Deflator Index

19.3 Return on Investment

There is extensive evidence of the positive ROI of urban trees. Song et al. (2018) conducted a systematic review of 34 studies regarding the economic benefits and costs of urban trees. They found that benefits outweighed costs in 22 of the 26 studies that analyzed a BCR or NPV (Song, et al., 2018). The mean BCR across all studies was 5.4, with a median of 2.7. This aligns well with the range of values found in a study of five cities across the West, which estimated that street trees returned benefits of $2.22 to $5 for every dollar spent (McPherson E. G., et al., 2005).[61] Likewise, a study in Portland, Oregon found a total of $5.53 in quantified benefits for every dollar spent on public trees, and the Forest Service estimated that for the Interior West (the covered region closest to North Central Texas), $4.42 is returned for every dollar invested (Davey Resource Group, 2009; Vargas, et al., 2007).[62] The review noted that aesthetic and amenity benefits typically provided the highest economic value, followed by shading and water regulation. Nordman et al. (2018) conducted a CBA of GSI practices and found that street trees had the third-highest BCR among the practices studied, at about 1.4, including the benefits of avoided flood volume and risk, avoided TSS and TP pollution (45 percent of the benefit value), amenity value, energy savings, and carbon dioxide storage.

19.4 Costs

Costs of urban trees include planting, irrigation, pruning, pest management, removal of dead or hazardous trees, and repairing infrastructure conflicts such as sidewalk, curb, and sewer line damage (McPherson & Peper, Costs of Street Tree Damage to Infrastructure, 1996). A study of five Southwest cities found that annual management costs ranged from $30 to $149 per tree (McPherson E. G., et al., 2005).[63] This study found that pruning was the largest expense, at between 27 to 43 percent of annual costs, followed by mitigating conflicts between roots and pavement (45 percent in Berkeley, CA), tree litter removal (30 percent in Cheyenne, WY), tree removal (13 to 16 percent), administration and inspection, and tree planting (2 to 14 percent). Another study from Portland determined that city budgeting per tree ranged from $5.38 to $99.46 for 10 coastal cities (Davey Resource Group, 2009).[64] Other cost estimates range from $100 to $1,000 per tree for establishment / installation costs, and from $8 to $62 per tree annually for maintenance costs (Nordman, et al., 2018; NCTCOG, 2017; NOAA, 2015; McPherson E. , et al., 2006; McPherson & Peper, Costs of Street Tree Damage to Infrastructure, 1996).[65]

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[61] Adjusted to 2025 dollars from $15, $60, $1.37, and $3.09 in 2004 USD using the GDP Deflator Index

[62] Adjusted to 2025 dollars from $3.80 in 2008 USD using the GDP Deflator Index

[63] Adjusted to 2025 dollars from $13 and $65 in 2004 USD using RSMeans Cost Index.

[64] Adjusted to 2025 dollars from $3.70 and $68.36 in 2008 USD using the GDP Deflator Index.

[65] Maintenance costs: Low cost adjusted from $2.50 per tree in 1993 USD (McPherson & Peper, Costs of Street Tree Damage to Infrastructure, 1996), and high cost adjusted from $26.89 in 2004 USD (McPherson E. , et al., 2006) using RSMeans Cost Index. Capital costs: Low cost adjusted from $44 in 2004 USD from McPherson et al. (2006) using RSMeans Cost Index, and high cost based on $20,000 for 30 trees from NCTCOG (2017), for $667 per tree, which is adjusted from 2014 USD to $999 using RSMeans Cost Index.

20 Permeable Pavements

Permeable pavements are specially designed paving surfaces that let water pass through them into the layers and soil below instead of running off like on regular concrete or asphalt. They can reduce flooding, improve water quality, and recharge groundwater.

20.1 Benefits

Permeable pavements, including porous asphalt, pervious concrete, and interlocking pavers, reduce runoff volume and peak flows by allowing rainwater to infiltrate into an underlying stone reservoir and the soil below. This process also helps to replenish local groundwater supplies (Alsobrooks, 2022). Studies demonstrate their effectiveness in improving water quality; one analysis found permeable interlocking concrete pavers in southern Texas achieved a 77 percent average concentration reduction in TSS (Mahmoud, et al., 2020). As with other GSI, permeable pavement can lessen or eliminate the need for other stormwater management infrastructure, specifically underdrain pipes and other BMPs that are required for conventional impermeable surfaces (Chen, et al., 2017). A new housing development on previously undeveloped land in New Hampshire reported capital cost savings of 6 percent when using porous asphalt instead of conventional asphalt for all paved surfaces (sidewalks, parking lots, driveways, roads) (Franklin Regional Council of Governments, 2015). Although there were increased costs for paving the driveways and roads, the development achieved great savings in drainage and erosion control. Similarly, another site in New Hampshire achieved 26 percent savings using porous asphalt, due to avoiding the installation of large-diameter piping (Franklin Regional Council of Governments, 2015).

Permeable pavements also offer safety and comfort benefits. Permeable pavements offer safety benefits by reducing water spray and splash behind vehicles and minimizing the risk of hydroplaning (Agouridis, et al., 2011). In winter conditions, the rapid drainage of melting snow and ice reduces the formation of black ice and freezing puddles (Alsobrooks, 2022). From a temperature perspective, these pavements help mitigate the urban heat island effect because they transfer less heat than conventional dark asphalt and facilitate evaporative cooling (Antunes, et al., 2018). Finally, the open pore structure of the pavement can reduce tire noise, contributing to a quieter urban environment (Rehan, et al., 2018).

As with other structures, these benefits are reflected in increased property values. As mentioned in Section 7.1, the Seattle/Philadelphia study found that doubling the square footage of permeable pavement within 250 feet of a home was associated with increases in residential sale price of between 0.28 to 0.78 percent (SB Friedman; CNT, 2020).

20.2 Siting and Design Considerations

Permeable pavements are best suited for low-traffic areas such as parking stalls, alleyways, and residential driveways (Alsobrooks, 2022). For rapidly densifying corridors in urban areas, where land acquisition or excavation for traditional detention is prohibitively expensive, the higher initial cost of permeable pavements may be justified as it integrates stormwater management directly into the transportation footprint (Zhang & Ariaratnam, 2021). Because they serve a dual purpose as both pavement and a stormwater management practice, permeable pavements do not require additional land, making them an ideal choice where space is limited and land values are high (Alsobrooks, 2022). However, in areas dominated by the Blackland Prairie's high-clay soils, direct infiltration may be limited (Texas State Historical Association, 2021). Permeable pavements on these soil types may require the use of underdrains to convey filtered water to the storm sewer system, a design modification that affects cost but still provides water quality and peak flow reduction benefits (STEP, 2025).

20.3 Return on Investment

While the initial installation cost of permeable pavement can be higher than traditional materials, it often eliminates or reduces the need for expensive traditional stormwater infrastructure, such as curbs, gutters, and detention ponds (EPA, 2013). Eliminating the need for large retention ponds frees up valuable land for development or other uses (Alsobrooks, 2022; Applied Research Associates Inc., 2018). Life-cycle cost analyses have shown that when factors such as reduced winter maintenance and avoided infrastructure costs are included, permeable pavements can be more cost-effective than conventional pavements over the long term (Applied Research Associates Inc., 2018; EPA, 2015a).

. The Mississippi study discussed earlier in Section 18.4 found that permeable pavements increased capital costs by 6 percent, and O&M costs by 3 percent, compared with underground detention (Abera, et al., 2025). Together with storage savings, energy savings, and property value increases, permeable pavements ended up with additional benefits of $57,215.[66] It was overall less cost-effective than either the rain garden and grassy ditch examined in the same study. On the other hand, Rehan et al. (2018) found that when stormwater treatment costs are accounted for, permeable pavements are more economical than conventional impermeable pavements over 20-year and 30-year analysis periods. Nordman et al. (2018) calculated a BCR of 2.27 for porous asphalt designed to infiltrate 3,000 CF of stormwater. In addition to avoided flood volume and risk, benefits included avoided TSS and TP pollution. This benefit could only be achieved by using porous asphalt instead of conventional asphalt at the outset, and thereby avoiding the cost of the traditional asphalt.

20.4 Costs

The initial construction costs for permeable pavements are generally higher than for their conventional counterparts, often ranging from 20 to 50 percent more (Alsobrooks, 2022). Specific cost estimates place the installation cost in the range of $2.77 (for interlocking pavers) to $35 per square foot (for porous asphalt), with most estimates weighted toward the lower end (NCTCOG, 2017; San Antonio River Authority, 2019; Hathaway & Hunt, 2007; Houle, et al., 2013; Morrison & Mikulencak, 2012; New York Department of Environmental Conservation, 2007).[67]

In addition, permeable pavements may require specialized maintenance, such as periodic vacuum sweeping, to prevent surface clogging (Houle, et al., 2013). Maintenance costs are typically between less than a dollar per square foot to $15 per square foot per year (NCTCOG, 2017; San

[66] Original value reported as $54,630, and converted to 2025 USD using GDP Deflator Index.
[67] Low cost adjusted from $1.50 in 2007 USD using (New York Department of Environmental Conservation, 2007), and high cost adjusted from $23 in 2013 dollars from NCTCOG (2017) using the RSMeans Cost Index.

Antonio River Authority, 2019; Hathaway & Hunt, 2007; Houle, et al., 2013; Morrison & Mikulencak, 2012; New York Department of Environmental Conservation, 2007).[68] The BEC report estimated that the unit cost of pervious pavement would be about $27 per cubic foot of storage, but unit maintenance costs were not estimated due to a lack of data.[69] This cost is slightly more expensive than the one estimated for bioretention basins, and in the same range as other types of GSI.

In spite of the higher capital costs, the overall life-cycle costs of permeable pavement can be substantially lower than conventional pavement. One study showed that despite having initial costs that were over 50 percent higher than those of asphalt concrete pavement, permeable interlocking pavement produced life-cycle savings of $2 million over 40 years due to O&M costs that were a quarter of those for the conventional pavement (Applied Research Associates Inc., 2018).[70] Another study found that permeable pavements were more economical over the 20- and 30-year periods, but were surpassed by Portland cement concrete in the 40-year period (Rehan, et al., 2018). Higher costs may be rationalized since cost savings can be made by avoiding the need for other stormwater infrastructure like detention basins, curb-and-gutter systems, and underground pipes.

21 Green Roofs

Green roofs consist of a layer of vegetation and growing medium installed over a waterproofing membrane on a flat or slightly sloped roof. They are designed to absorb and retain rainfall, reducing runoff while providing several building-level co-benefits (GSA, 2023; Blackhurst, et al., 2010).

21.1 Benefits

Benefits of green roofs include stormwater retention (retaining 40 to 80 percent of annual precipitation), reduced building energy consumption due to added insulation, and improved local air quality (RAND E&A, 2014; Sustainable Business Network, 2016; Adams, et al., 2016). To compare the energy savings performance of different kinds of roofs, William et al. (2016) used a model that resolves water and energy balances through coupled vegetation and soil layers. With data from the green roof at the University of Illinois at Urbana-Champaign, the authors calculated annualized costs over a 39-year period, factoring in installation, maintenance, and energy costs. Green roofs dampened diurnal temperature variations, resulting in lower daily average costs for both heating and cooling compared to traditional roofs, resulting in energy savings of about $0.45 to $0.47 per square foot per year (William, et al., 2016).[71] Another study

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[68] Low cost adjusted from $0.15 in 2020 USD from (Headwaters Economics, 2022), and high cost adjusted from $7 in 2005 USD from (Hathaway & Hunt, 2007) RSMeans Cost Index.

[69] BEC assumed that the water quality volume (storage) would be equal to the void space of the engineered base aggregate below the paving surface. Original cost was adjusted to 2025 dollars from $16 in 2010 USD using the RSMeans Cost Index.

[70] Originally reported as savings of $1,597,584 in 2018 dollars. Adjusted to 2025 dollars using the GDP Deflator Index.

[71] Original savings were $112.2 and $117.8 in 2014 USD in average monthly energy cost savings. These were divided by the roof area of 372 square meters, then divided by 10.7639 square feet per meter and multiplied by 12 months, and adjusted to 2025 USD using the GDP Deflator.

estimated benefits and costs for a green roof on an academic building in Utah (Wu & Smith, 2011). Based on conditions in conditions in Ogden, Wu and Smith (2011) estimated annual energy savings of about $0.39 per square foot.[72] Additionally, the same qualities that help to conserve energy inside the building can protect the underlying roofing membrane from UV radiation and extreme temperature fluctuations, which can effectively double its service life (Nordman, et al., 2018; EPA, 2013). This value would be equal to the avoided cost of replacing a conventional roof at the end of its life.

Green roofs are effective tools for controlling stormwater runoff. While green roofs are generally noted for improving water quality, they may export higher concentrations of nutrients like nitrogen and phosphorus due to the organic matter in the soil, though the overall pollutant load is often reduced due to the reduction in runoff volume (Kuok, et al., 2023; Minnesota Pollution Control Agency, 2025). The Utah study estimated that annual stormwater retention value was about $0.09 per square foot (Wu & Smith, 2011).[73] Similarly, the Florida study calculated additional benefits of stormwater capture ($0.06 per square foot) (Yao, et al., 2020).[74]

Green roofs also provide carbon absorption and localized air quality improvement. The study in Utah estimated air quality improvements worth $0.01 per square foot and carbon emissions savings of $0.04 per square foot, while the study in Florida calculated similar carbon capture benefits ($0.02 per square foot), but did not report air quality benefits (Wu & Smith, 2011; Yao, et al., 2020).[75]

Finally, it is not clear to what extent green roofs may offer economic benefits as a visual amenity. Ichihara and Cohen (2010) applied a hedonic pricing model to examine how green roofs influence apartment rents in New York City. Their results indicated that the presence of a green roof increased rental prices by about 16 percent (Ichihara & Cohen, 2011). However, the small sample size (44 observations) suggests that these results should be interpreted with caution. Because the study focused on a densely developed area with limited green space, residents in such high-income contexts may be willing to pay a premium for access to greenery. In a less dense area, researchers in Finland used small urban parks in Helsinki as proxies for green roofs and estimated that views of such greenery could increase property values by up to 1.2 percent (Nurmi, et al., 2016). In contrast, a hedonic study from Taiwan reported negative effects of green roofs on residential property prices (Chen, et al., 2014). The authors attributed this outcome to concerns about higher maintenance costs. Hence, as with detention and retention ponds, the aesthetic impact of green roofs may differ depending on how it is maintained and the relative development density of the surrounding area.

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72 Original savings was $4,128.55 over 15,000 ft^2. This ratio was adjusted from 2010 USD to 2025 USD using the GDP Deflator.

73 Original savings was $942.30 over 15,000 ft^2. This ratio was adjusted from 2010 USD to to 2025 USD using the GDP Deflator.

74 Original savings were $660 over 1,372 square meters. This ratio was divided by 10.7639 square feet per meter, and adjusted from 2017 USD to 2025 USD using the GDP Deflator.

75 Utah: Original air quality benefit was $60 over 15,000 ft^2. Original emissions reduction was $384.84 over 15,000 ft^2. These values were adjusted from 2010 USD to 2025 USD using the GDP Deflator. Florida: Original savings were $202 over 1,372 square meters. This ratio was divided by 10.7639 square feet per meter, and adjusted from 2017 USD to 2025 USD using the GDP Deflator.

21.2 Siting and Design Considerations

As a specialized, higher-cost BMP, green roofs are most likely to be cost-effective for larger commercial, institutional, or multi-family residential buildings. In these applications, the multiple co-benefits, especially direct energy savings for the building owner, can be fully realized and help offset the initial investment (EPA, 2021a). The potential for energy savings makes green roofs a particularly attractive option for North Central Texas's hot climate. Deeper, more intensive green roofs will have a much higher upfront cost for moderate improvements in insulation and energy savings (William, et al., 2016). Additionally, higher green roof area to volume in the building envelope will lead to greater energy savings (Wu & Smith, 2011).

The need for irrigation is a consideration, given the region's pattern of intense but often infrequent rainfall followed by prolonged dry, hot periods. This demand, however, could be met sustainably through on-site rainwater harvesting systems (Sustainable Business Network, 2016). Overall, green roofs are best suited for buildings with low-angle and ideally flat roofs where structural loads can be incorporated into the initial design.

21.3 Return on Investment

Green roofs are more expensive in terms of pure capital costs, but they often pay off over time due to other benefits, especially since they need to be replaced less frequently than conventional roofs. A CBA conducted by the U.S. General Services Administration (GSA) determined that green roofs can have over a 50-year lifespan (GSA, 2023). In a case study analyzed by the GSA, a green roof provided an ROI of 2.24 in approximately six years through a combination of extended roof life, stormwater benefits, and energy savings (GSA, 2023). As with other types of green infrastructure, larger green roofs will have greater ROIs due to economies of scale (GSA, 2013).

However, payback periods can vary based on the scope of benefits included. For instance, in Michigan, Clark et al. (2008) compared a conventional roof with a green roof. While adding a green roof increased capital costs by 39 percent, the green roof's total adjusted cost was 25 to 40 percent lower than that of a conventional roof due to avoided stormwater fees, energy savings and pollution reduction. The overall lifetime benefits of the green roof offset the green roof's higher upfront costs. The key factor was the replacement of the conventional roof, which was expected to occur after 20 years. This length of time was the breakeven point where the adjusted costs of the conventional roof exceeded those of the green roof. Similarly, an analysis by the Portland Bureau of Environmental Services found that the private benefits of ecoroofs did not exceed the costs until year 20, again the typical replacement age for a conventional roof (EPA, 2013). However, when including the public benefits, such as carbon reduction, improved air quality, and habitat creation, there is a positive BCR by year five.

On the lower end of expected returns, a Utah green roof was also projected to pay off with a BCR of 1.13, using a 2.8 percent discount rate and a 40-year period, and including many of the aforementioned benefits (Wu & Smith, 2011). In contrast, a Florida study resulted in a negative net savings, in spite of the avoided cost of roof replacement (Yao, et al., 2020). This latter study measured stormwater management, energy savings, and social cost of carbon savings, but did not include air quality improvements, urban heat island mitigation, and recreation benefits. However, the energy savings in this case were measured relative to a white roof, not a conventional roof, so they were not a meaningful benefit compared with the other cases.

21.4 Costs

Green roofs can range between $12 to $84 per square foot, depending on the depth of the installation and whether it is a new building or a retrofit, which tends to have a higher cost (Hathaway & Hunt, 2007; EPA, 2025b; EPA, 2007; Deeproot, 2010; RAND E&A, 2014; EPA, 2021a; Feng & Hewage, 2018).[76] Maintenance costs are higher during the first five years while vegetation becomes established, and then typically level off to a range of $0.11 to $2 per square foot per year (Feng & Hewage, 2018; EPA, 2021a).[77]

22 A Framework for Cost-Effective GSI Planning in North Central Texas

GSI and NBS are economically viable components of resilient urban infrastructure. The costs of green stormwater infrastructure are often comparable to conventional stormwater infrastructure or result in savings over time, while providing additional benefits. This final section synthesizes the key takeaways from the review into a strategic framework of guiding questions and recommendations to aid planners in the North Central Texas region.

First, the benefits and costs of GSI and NBS can be highly variable depending on design and placement. Investment should be guided by data-driven site prioritization and engineering. Hydrologic and hydraulic modeling can identify hotspots where GSI can have the greatest impact on flood reduction (Jack, et al., 2021). Areas where flood reduction is maximized will tend to provide greater benefit per dollar.

Second, the highest returns are achieved when GSI and NBS projects are designed to "stack" multiple functions and meet diverse community goals. Planners should seek opportunities to integrate GSI and NBS with other capital improvement plans, such as creating recreational amenities in parks, achieving urban tree canopy targets, or enhancing the resilience and aesthetics of transportation corridors.

Finally, based on the economic and applicability analysis in this review, a hybrid approach that combines large-scale preventative measures with distributed, site-level controls offers the most promising path forward for the region. For dense urban areas, the priority should be on retrofitting existing developed areas. Integrating practices like bioretention, permeable pavements, and street trees will be most cost-effective in these contexts. For rapidly developing suburban and exurban areas, the emphasis should be on preventative strategies. Proactive floodplain and riparian corridor preservation, along with the construction of multifunctional wet ponds and wetlands, can be encouraged by promoting conservation-oriented development design. By pursuing a strategic, data-driven investment in a diverse portfolio of GSI practices, North

[76] Low cost adjusted from $6 in 2006 USD from (EPA, 2007), and high cost adjusted from $50 in 2010 dollars from (Feng & Hewage, 2018) using RSMeans Cost Index.
[77] Costs adjusted from $0.07 and $1.25 in 2010 USD from (Feng & Hewage, 2018) using RSMeans Cost Index.

Central Texas can forge the most cost-effective path toward mitigating flood risk, enhancing environmental quality, and building more resilient and vibrant communities for the future.

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