Exploring the Success Factors of Constructed Stormwater Wetlands through the Alewife Stormwater Wetland Case Study

A thesis submitted by
Lydia R. Heely

in partial fulfillment of the requirements for the degree of
Joint Master of Science
in
Environmental Engineering Policy and Planning

Tufts University

August 2025

Advisor: Dr. Hassaan Furqan Khan
Reader: Dr. James Limbrunner

Abstract

Managing stormwater is essential to safeguarding water quality in urban settings. Constructed wetlands are a stormwater management technique that is attracting interest for its co-benefits as a recreational and ecological asset. However, few long-term holistic evaluations of stormwater wetlands exist in literature. This thesis presents a case study of the Alewife Stormwater Wetland (ASW) nearly a decade after construction, asking not only whether the system met its technical water quality goals but also whether it has delivered ecological and social value. Drawing on water quality data, project documentation, and interviews with operations personnel, I assess long-term functionality, challenges, and public perception of the ASW. I argue that ASW's success stems not only from design features but from its adaptive operations and maintenance practices— an overlooked but essential component of green infrastructure. This case study will help decision-makers better understand the benefits and challenges of stormwater wetlands and their maintenance requirements.

Acknowledgements

I would like to thank my advisor, Dr. Hassaan Furqan Khan, for his support throughout my research and writing process. Thank you for helping me refine my ideas and push through to the end! I am also very grateful to my reader, Dr. James Limbrunner for his help framing my project and for helping me develop my technical hydrology skills. Thank you to my academic advisor, Mary Davis (I couldn't have gotten through the program without you!), and all of the wonderful professors and peers I have gotten to know during my time at Tufts.

Special thanks to Scott Horsley for mentoring me over the years, and for helping to inspire my love for green infrastructure (and of course, for introducing me to the Alewife Stormwater Wetland!). Thank you, Duke Bitsko, for sharing your unending enthusiasm and knowledge of the ASW. Thank you to each of my other interviewees: Catherine Woodbury, Caitlyn Rodriguez, Jennifer Delgado, and Cambria Ung for your expertise on the project.

And finally, thank you to my family for your love and encouragement along the way.

Table of Contents

List of Tables

List of Figures

List of Appendices

List of Abbreviations

ASW - Alewife Stormwater Wetland

CSO - Combined Sewer Overflow

CW - Constructed Wetland

DCR - Department of Conservation and Recreation

DPW - Department of Public Works

EPA - Environmental Protection Agency

GI - Green Infrastructure

HLR - Hydraulic Loading Rate

MassDEP - Massachusetts Department of Environmental Protection

MS4 - Municipal Separate Storm Sewer System

MWRA - Massachusetts Water Resources Authority

NOI - Notice of Intent

NPDES - National Pollutant Discharge Elimination System

OM&M - Operation, Maintenance, and Monitoring

PAHs - Polycyclic Aromatic Hydrocarbons

PCBs - Polychlorinated Biphenyls

PFAS - Per- and Polyfluoroalkyl Substances

SCM - Stormwater Control Measure

SWMP - Storm Water Management Program

TMDL - Total Maximum Daily Load

TN - Total Nitrogen

TP - Total Phosphorus

TSS - Total Suspended Solids

USEPA - United States Environmental Protection Agency

VMP - Vegetation Management Plan

Chapter 1 Introduction

1.1. Background

This thesis examines the performance of the Alewife Stormwater Wetland (ASW) nearly a decade after construction, asking not only whether the system met its technical water quality goals but also whether it has delivered ecological and social value. Drawing on water quality data, project documentation, and interviews with key project team members, I assess long-term functionality, challenges, and public perception. I argue that ASW's success stems not only from design features but from its adaptive operations and maintenance practices - an overlooked but essential component of urban green infrastructure.

1.2. Stormwater and Urbanization

Stormwater wetlands like the ASW are an important strategy for managing stormwater in urban environments. Stormwater management is crucial in today's world for many reasons, including (but not limited to) flood control, water quality, and protection of developed property.

As the world urbanizes, impervious surfaces such as roads, parking lots, and roofs replace natural land cover such as meadows and forests. When it rains or snows, water that is usually attenuated by soils and microtopography collects on impervious surfaces, forming stormwater runoff (US EPA, 2015). Since impervious surfaces do not allow water to infiltrate the ground as it does under natural conditions, even minor storms can quickly generate high amounts of runoff (sometimes referred to as "flash flooding"). For example, if one inch of rain fell on one acre of forested land with well-draining soils, it is unlikely that there would be any noticeable runoff. Water would pool in surface depressions or infiltrate into the soil, filling voids formed by the geometry of soil particles and plant roots (U.S. Geological Survey, 2019). The same storm

occurring on one acre of pavement can generate an estimated 21,480 gallons of runoff[1], which is about the typical volume of a residential swimming pool. Excess runoff can erode landscapes, damage structures and present extreme hazards for people and wildlife. Poor drainage that leads to standing water may also attract pests, odors, and diseases.

1.3. Stormwater Pollutants

Stormwater also mobilizes excess nutrients, organic compounds, and heavy metals from lawns, rooftops, and roadways. Stormwater may flow over land directly into a waterbody or discharge from a storm drain network, polluting lakes, rivers, or coastal waterbodies (Zgheib et al. 2012).

Nitrogen and phosphorus, while essential nutrients necessary to sustain life, can degrade aquatic ecosystems when present in excess, leading to harmful algal blooms, low light levels, hypoxic conditions, increased turbidity, and lowered pH (Rodgers, 2017). This is known as eutrophication, and it can lead to a host of negative effects over time, like fish kills and decreased plant diversity (Rodgers, 2017). Warming waters due to climate change are thought to catalyze eutrophication by speeding up the growth rate of algae and cyanobacteria (Nazari-Sharabian et al., 2018). Higher temperatures can also increase the release of nutrients from sediment, further fueling eutrophication (Nazari-Sharabian et al., 2018). Decaying algae settles on the benthic zone, which can suffocate shellfish and other organisms, and over time, can accumulate to effectively make a water body shallower. The shallower water warms more easily and is therefore more prone to eutrophication, creating a compounding effect (Flavelle, 2023). More intense precipitation patterns can also indirectly increase eutrophication by increasing

[1] Approximately 21,480 gallons, assuming a curve number of 98. This figure was calculated using the SCS Curve Number method, which is described in Technical Release 55: Urban Hydrology for Small Watersheds (United States Department of Agriculture, Soil Conservation Service Engineering Division (1986).

runoff severity (and thus nutrient transport). Therefore, due to intensifying precipitation patterns brought on by climate change, total nitrogen loadings in riverine habitats are expected to increase by approximately 19% in China, India, and the U.S. over the next century (Sinha et al., 2017). Thus, eutrophication is expected to worsen for several reasons stemming from climate change.

Organic hydrocarbons such as oil and gasoline, and other petroleum-derived substances including polychlorobiphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), polychlorinated dibenzodioxins and some pesticides are also common in stormwater and can have deleterious effects on aquatic environments (Tursi et al., 2018). These compounds are highly toxic, mutagenic and carcinogenic, and can enter the food chain once released in a waterbody (van der Oost et al., 2003). PCBs and Dichloro-Diphenyl-Trichloroethane (DDT) are two examples of synthetic compounds shown to bioaccumulate in fish tissues (van der Oost et al., 2003) posing risks not only to the fish population but also their predators and humans that consume them.

Heavy metals, such as cadmium, chromium, mercury, nickel, lead, and zinc are also commonly found in stormwater (Zgheib et al., 2012). Damage to liver and kidney function from heavy metal poisoning has been observed in aquatic animals and in humans that consume fish or shellfish from impaired waters (Singh et al., 2024).

1.4. Stormwater Management

Engineered solutions to deal with excess stormwater in urban areas have existed for millennia, and versions of these systems are still in use today (McFarland et al., 2019). Early engineers in Chang'an, the capital of the Han Dynasty (ca. 202 BCE–220 CE), used a system of open ditches, underground sewers and riverine discharge points to manage stormwater (De Feo et al., 2014). Practices such as these were also stipulated by the government in some ancient

cities: the Code of Hammurabi, written in 1760 B.C.E., includes stormwater management regulations (Echols & Pennypacker, 2015). The focus of these early regulations was mainly to control peak runoff and reduce downstream flooding (Field et al. 2005). In today's world, however, urban stormwater presents new challenges regarding increased runoff volume and pollutant transmission.

Urban runoff is expected to increase dramatically in many areas of the world as cities densify and climate change triggers more intense precipitation events (Khan et al., 2019). Many predictive climate models suggest that extreme precipitation events will become more common worldwide, leading to a higher risk of flash flooding (Tabari, 2020). Combined with the decrease in the net retentive capacity of the environment and impervious sources replacing natural surfaces, urban flooding will become more frequent and intense.

The increasing quantity of runoff isn't the only modern management challenge: pollutants of concern are also changing. The quantity and variety of pollutants of concern have increased since pre-industrial times (Mishra et al., 2023), with a major source of pollution originating from automobiles and automobile infrastructure (Nixon & Saphores, 2007). Worn tires, exhaust systems, brake pads, rust, lubricants and antifreeze from vehicles contribute heavy metals; parking lots and gas stations are conduits for leaked oil and grease; and roadway construction and maintenance contribute sediments, road salts, fertilizers, pesticides, and herbicides— all of which can be transmitted in stormwater (Nixon & Saphores, 2007). Other modern contaminants, such as per- and poly-fluoroalkyl substances (PFAS), which have been manufactured widely since the 1950s (Buck et al., 2011) are now surfacing in stormwater. (Bodus et al., 2024).

Another source of pollution associated with stormwater is combined sewer overflows (CSO). In many older cities in the northeastern US and Great Lakes regions, such as Boston, New York, Chicago, and Detroit, sewerage and stormwater often share the same pipe network (USEPA, 2023) (Figure 1.1).

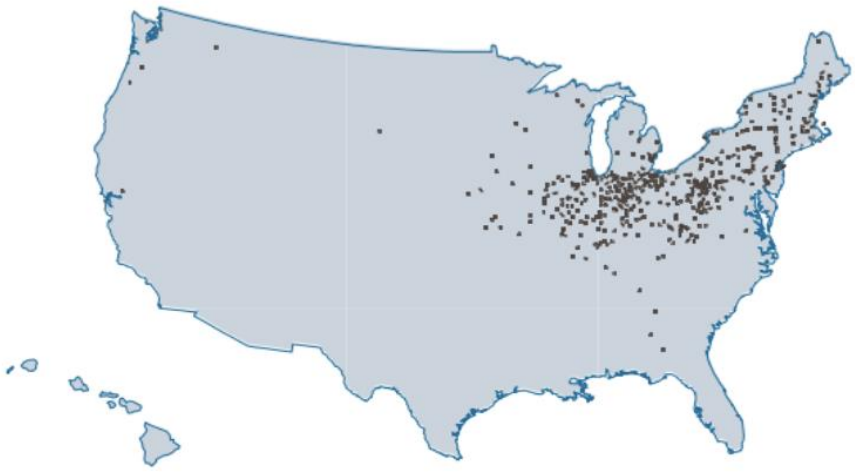


Figure 1.1 Cities in the United States with Combined Sewer Systems. Source: EPA

This is called a combined sewer. American cities began implementing combined sewers around 1855, and they were a substantial improvement over open roadside ditches previously used to carry sewerage and rainwater away from dwellings (Tibbetts, 2005). Combined sewers carried sewerage, rain and snow melt, and industrial waste together in an underground network before being discharged to a water body. Since the late 19th and early 20th centuries, the flow was directed to wastewater treatment plants for treatment before discharge. Combined sewers are cost effective, requiring only one network of pipes for stormwater and wastewater. Before modern flush toilets input water into the system, combined sewers were necessary because rainwater was needed to move flow (Wasser, 2021). Combined sewers function adequately in dry and mild wet weather, however, when it rains heavily, the large volume of stormwater entering the combined sewer can overwhelm its capacity. Older pipe networks were designed to accommodate a certain

volume of flow, based on the number of homes connected to the system, and— once centralized wastewater treatment became possible— the capacity of the treatment plant. However, as the population (and thus the wastewater load) increases, and the stormwater load increases from more impervious development and stronger storms, flows frequently exceed the network capacity. This can cause the combined sewage-stormwater to back up into houses. To prevent sewage from backing up into buildings, overflow pipes were built into the system. Thus, when it rains heavily and the system is overwhelmed, the excess flow escapes through the overflow pipes, discharging a mixture of stormwater and raw sewage into water bodies. (Tibbetts, 2005) This is known as a combined sewer overflow (CSO) Figure 2 shows how a combined sewer system works during dry weather and wet weather.

Thousands of communities around the world still rely on combined systems and experience CSOs regularly. Over 700 communities in the U.S. still rely on combined or partially combined sewer networks (USEPA, 2023). CSOs are a major public health risk: waterborne illnesses in areas prone to CSOs spike with heavy rainfall (Tibbetts, 2005). Thousands of cases of gastrointestinal illness are reported every summer that are linked to CSO pollution of recreational areas (US EPA, 2004), though illnesses are likely underreported (Tibbetts, 2005).

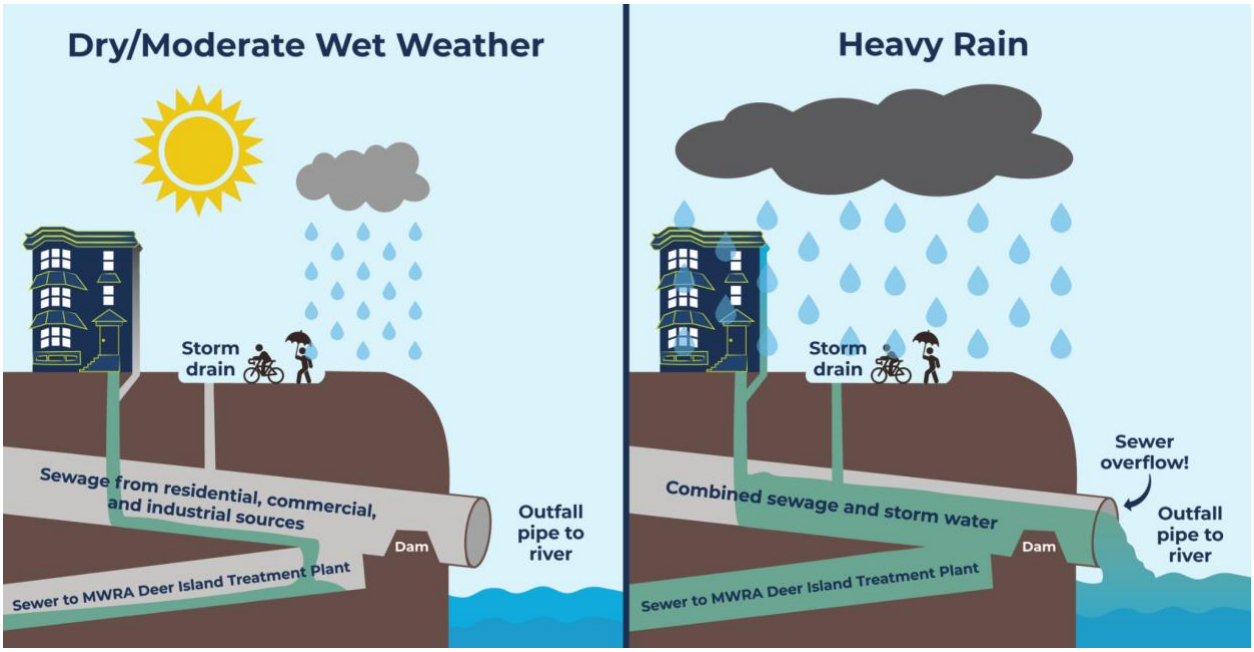


Figure 1.2 Combined Sewer in Dry and Wet Weather. Source: Mystic River Watershed Association

1.5. Regulations

The Federal Water Pollution Control Act of 1948 was the first major law passed in the United States to protect water quality, though it was minimally enforced and lacked comprehensive water quality standards (US EPA, 2013). Although water pollution (especially of drinking water supplies) was a common concern post-World II, there was disagreement regarding the roles of the states versus the role of the federal government, resulting in weak legislation (Federal Water Pollution Control Act (1948) | Major Acts of Congress, n.d.). In the late 1960s, public concern about water pollution began to increase following events such as the 1969 Santa Barbara Oil Spill, and the 1969 Cuyahoga River Fire in Cleveland, Ohio (U.S. National Park Service, n.d.). The year 1970 saw several landmark accomplishments for the environmental movement, such as the first Earth Day on April 2nd and the establishment of the Environmental Protection Agency on December 2nd (U.S. National Park Service, n.d.). In 1972,

the Federal Clean Water Act (CWA) was passed, making it illegal to discharge pollutants into waters of the United States without a permit (US EPA, 2013). This permitting system is known as the National Pollutant Discharge Elimination System (NPDES) (Roesner and Matthews, 1990). NPDES focuses on eliminating point sources (direct discharges), such as industrial effluent (DelGrosso et al., 2019). Section 502(14) defines point sources as "any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit… from which pollutants are or may be discharged." The CWA also set water quality standards and a funding pathway for municipal infrastructure such as water treatment plants (US EPA, 2013).

The CWA has had a massive positive impact, funding over 35,000 wastewater projects totaling $650 billion as of 2024, protecting wetlands and preventing hundreds of billions of pounds per year of industrial and sewage pollution from entering waterways (National Wildlife Federation, 2024). However, the power of the CWA to regulate nonpoint sources has been much more limited (Bennett, 2023). Stormwater discharges, groundwater pollution (which discharges slowly into surface water), and atmospheric deposition are the most common non-point sources of water pollution (US EPA, 2015).

Section 303(d) of the CWA, which was largely unenforced until additional regulations were passed in 1992 (Copeland 2014), requires each state to submit an "Integrated List of Waters" every two years that denotes the impairment level of their water bodies (Massachusetts Department of Environmental Protection, n.d.). Surface waters that do not meet water quality standards are required to undertake a Total Maximum Daily Load (TMDL) study. The TMDL establishes the maximum amount of a given pollutant that a waterbody can receive and still meet water quality standards, setting goals for remediation efforts (Massachusetts Department of

Environmental Protection, n.d.). A waterbody may have TMDLs for multiple pollutants. Though the TMDL program is a 'core element' of protecting water quality in the United States (Copeland 2014), scientific evaluations can take years to complete depending on the complexity of the project (California Water Boards, 2024), thereby delaying remediation efforts. Although several thousand TMDL studies are completed each year, as of 2014 it is estimated that over 41,000 impaired water bodies have not received a TMDL (Copeland, 2014).

When applicable, TMDL studies differentiate between point and nonpoint sources of pollution (Copeland, 2014). Since stormwater is often a major source of contaminants, especially in urban watersheds, it is important to address inadequate stormwater management systems to meet TMDLs. However, it wasn't until the 1987 reauthorization of the Clean Water Act (also known as the Water Quality Act) that Congress required the U.S. Environmental Protection Agency (US EPA) to issue permits for stormwater systems (Rosener & Mathews, 1990). These discharge permits provide a framework for tracking and regulating stormwater discharges. Stormwater permits for urbanized areas are issued under the Municipal Separate Storm Sewer System (MS4) Program. The MS4 program requires cities and towns that meet certain population density thresholds to implement a Storm Water Management Program (SWMP) that includes measures to prevent, control, monitor, and treat polluted stormwater (US EPA, 2024). Figure 3 shows regulated MS4 areas in southern New England.

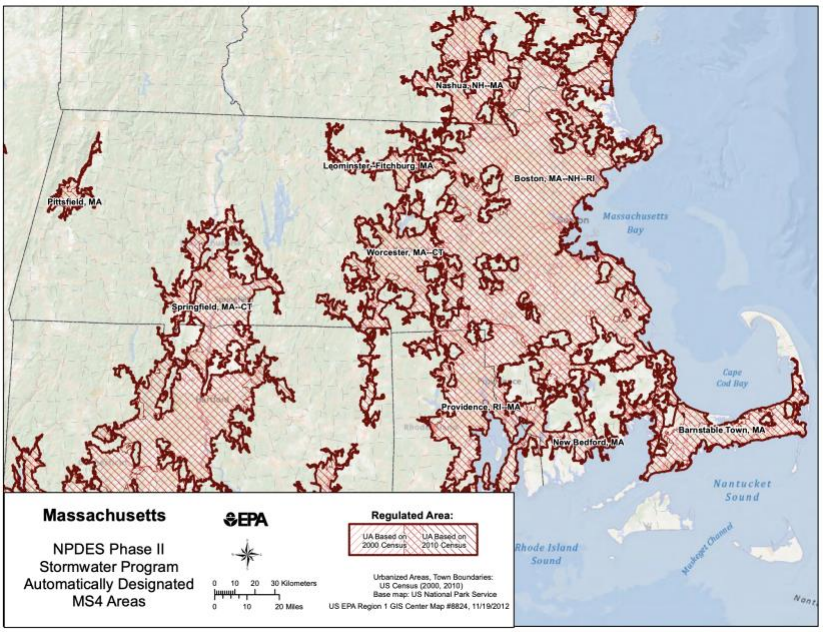


Figure 1.3 MS4 Regulated Areas in Southern New England. Source: MassDEP

This regulatory incentive has driven innovation in stormwater management over the past few decades. Municipalities are searching for economically favorable solutions (for design, construction and long-term maintenance) that fit within larger planning objectives and that can adapt to the pressures of increasing urbanization and climate change.

1.6. Stormwater Management Technologies

A variety of stormwater control measures (SCMs) can be suitable for managing stormwater depending on the context. It is common in the field to group approaches into two categories (gray or green infrastructure), though many projects benefit from a hybrid solution (Anderson et al., 2022). Conventional engineering approaches to stormwater management (often called “gray infrastructure”) consist mainly of piped networks that transport water to retention basins, infiltration chambers, and/or direct outfalls to lakes, rivers, and streams (Daigneault et al., 2016). These systems are generally perceived as more conventional and accepted but have limited adaptive capacity and few co-benefits (Anderson et al., 2022). Green infrastructure (GI)

on the other hand, leverages the flood-attenuating and pollutant-removing capabilities of vegetation, soils, and/or natural topography to detain and treat stormwater (US EPA, 2024). GI includes technologies such as rain gardens, green roofs, permeable ground cover, and constructed wetlands. GI can provide a host of co-benefits, such as providing recreational opportunities, and increasing biodiversity, and combatting the urban heat island effect, which is the phenomenon that the built environment retains heat more that the natural environment (US EPA, 2024). Figure 4 shows examples of SCMs and where they fall on the gray-green infrastructure continuum.

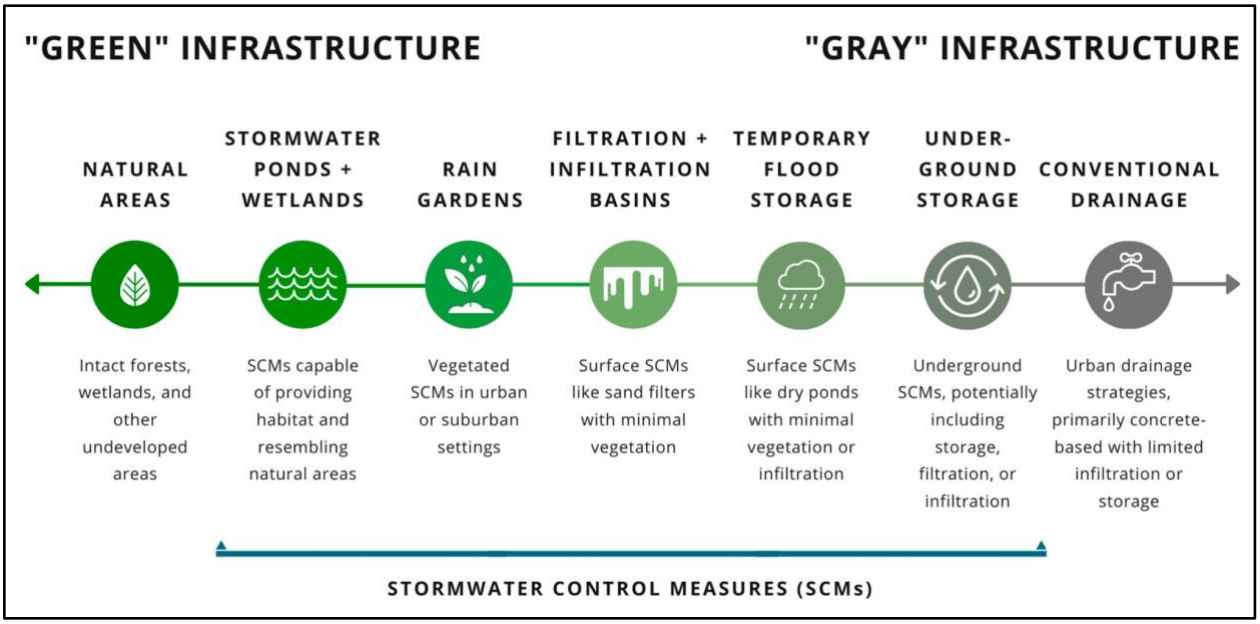


Figure 1.4 Gray and Green Stormwater Control Measures. Source: Taguchi et al., 2020

Constructed wetlands (CWs) are a type of GI that has gained in popularity in recent decades as a formal SCM (Malaviya & Singh, 2012). However, it's important to note that natural wetlands have been used for wastewater discharge in America since the earliest days for wastewater collection, a primary example being the Great Medows site in Lexington Massachusetts, which began receiving wastewater in 1912. (Kadlac & Knight, 1996). Some of

these “swamp discharges” went unmonitored until the 1960s or 1970s. Once monitoring was initiated by the EPA, researchers began to understand the water purification potential of wetland systems, (Kadlac & Knight, 1996). In Germany, formal foundational research started a decade earlier with K. Seidel and R. Kickuth’s studies at the Max Planck Institute. Seidel’s earliest work leveraged bulrush plants to reduce nutrients in the effluent of rural septic tanks (Vymazal, 2022), a technique now commonly known as phytoremediation— the use of plants to clean contaminated soil or water. In 1973, the first purpose-built wetlands for wastewater treatment were created in America at Brookhaven National Laboratory (Kadlac & Knight, 1996). E. C. Meiorin’s CW design in Freemont, California in the early 1980s is recognized as the earliest formal application of CW to urban stormwater (Vymazal, 2010). The design specifications and benefits of CWs are context-dependent but often multifold: CWs offer increased habitat and biodiversity, recreational space, heat resilience, carbon sequestration, and more (US EPA, 2015).

1.7. The Alewife Stormwater Wetland

This case study focuses on the Alewife Stormwater Wetland (ASW), a 3.4-acre facility in Cambridge, Massachusetts that is within the Mystic River Watershed (see Figures 5 and 6). It was the largest stormwater wetland in the northeastern U.S. when it was built in 2013 (Woodbury et al., 2013). It discharges to Alewife Brook, which is one of the most degraded tributaries of the Mystic River due to high concentrations of phosphorus and fecal coliform bacteria (Eastern Research Group, 2020). The ASW is part of a larger project to reduce combined sewer overflows (CSOs) discharging to Alewife Brook. Since the 1930s, the City of Cambridge has been working to reduce CSOs by separating sanitary and storm sewers. Approximately 55% of the collection system has been separated as of 2024 (City of Cambridge, 2024). Between 2013 and 2015, The City of Cambridge disconnected stormwater flow from the

combined sewer system in a 420-acre neighborhood located east of Fresh Pond (CAM 004– shown in light blue in Figure 1.5, inset) and routed this flow to the ASW (shown in green, Figure 6, inset), thus eliminating the CAM 004 combined sewer outfall. Although there are still existing combined sewer outfalls that periodically overflow (shown in yellow, Figure 1.6, inset), the CAM 004 disconnection was a major step towards improving water quality in Alewife Brook.

Figure 1.5. Massachusetts and City of Cambridge Locus Map

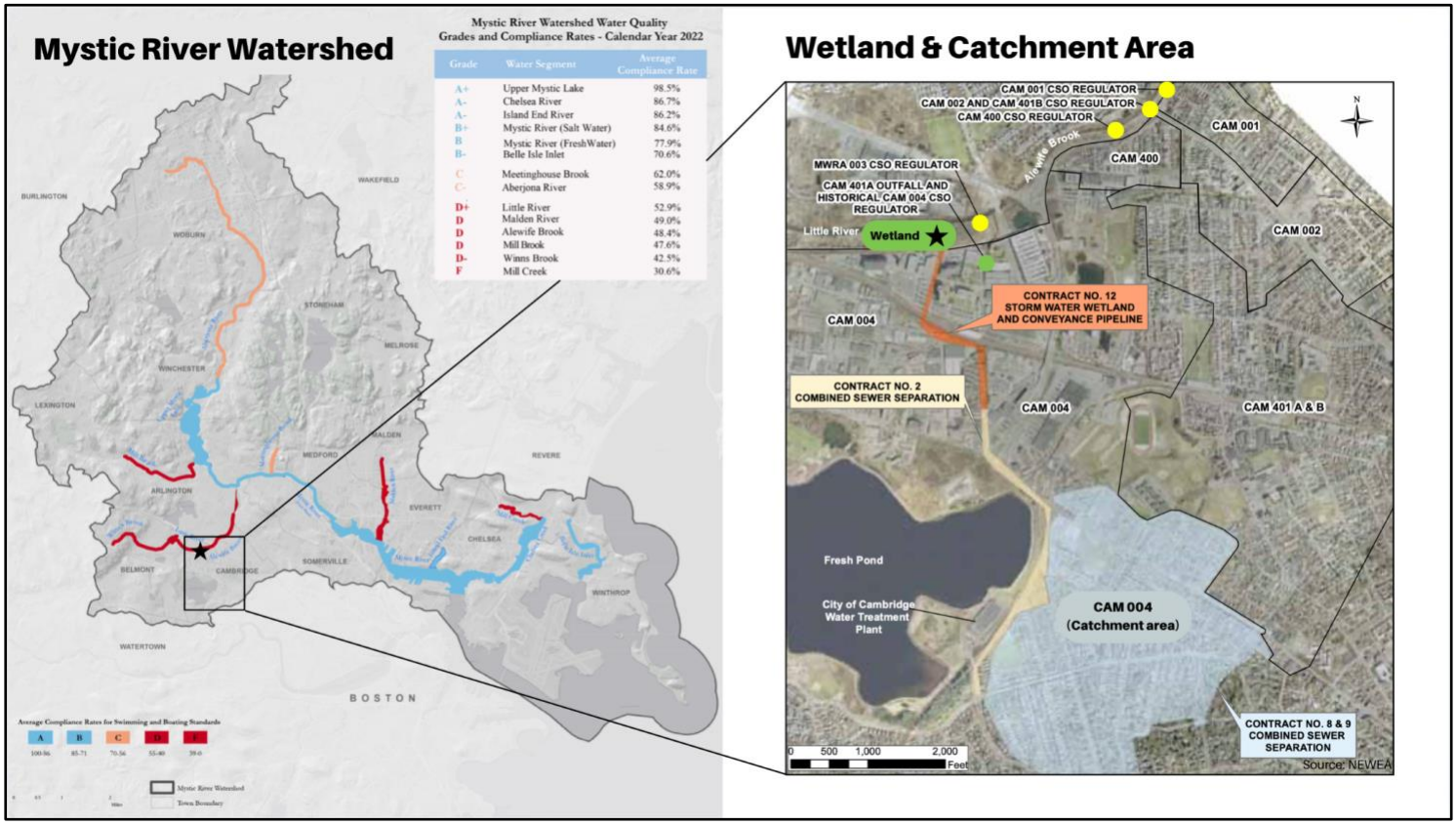


Figure 1.6 Alewife Stormwater Wetland Locus Map & Catchment Area. Image credits (left- Mystic River Watershed Association, right- Woodbury et al., 2015)

Although the primary design goal of the ASW was to detain excess stormwater and facilitate the CSO elimination project, it is hypothesized that the ASW provides some level of

stormwater treatment, removing pollutants such as excess nutrients and heavy metals. However, due to limited water quality monitoring data, the treatment efficacy of the ASW is not well understood.

Figure 1.7 depicts the flow of water from the neighborhood as it enters the wetland through an underground culvert, flows through the basins, and discharges into the Little River[2]. The flow path is designed to meander through the area to increase retention time, or the average amount of time it takes water to move from the inlet to the outlet. Longer retention times all for better attenuation of pollutants and moderate the flow of water into Alewife Brook, which reduces flood risk.

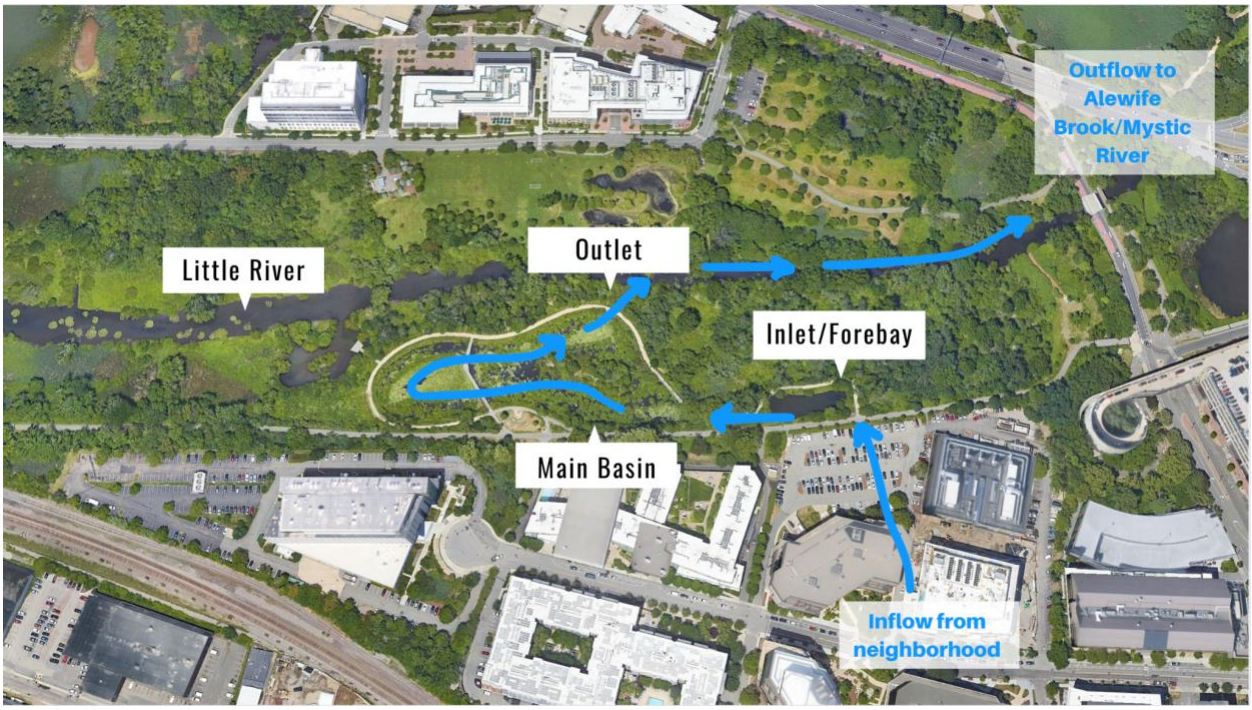


Figure 1.7 Alewife Stormwater Wetland Process. Image credit: Google Earth Imagery, 2023

1.8. Goals of This Thesis

[2] The Little River is a tributary of Alewife Brook that originates in Cambridge's Little Pond and joins the Alewife Brook near the Route 2 Bridge.

Although popular support for CWs is increasing (Malavia & Singh, 2012), decision-makers face complex challenges when employing CWs in a municipal stormwater management plan that must comply with regulations and meet community needs. Successful case studies of CW in urban environments are limited— several projects are known to be abandoned due to poor performance and/or public health concerns, such as mosquito breeding (Hunt et al., 2011). While decades of empirical performance data are available from conventional stormwater infrastructure systems, performance data and maintenance needs for stormwater wetlands are less developed (Hunt et al., 2011). Much of the existing literature on CWs focuses on short-term water quality studies to evaluate design principles, yet other factors—such as biodiversity and cultural value—also influence and demonstrate success. This project aims to evaluate the ASW using multiple criteria and identify the design, siting, and operational factors that support effective performance, providing insights that may inform future urban CW projects. Specifically, the research questions addressed in this project are:

1. **Performance Outcomes:** To what extent has the Alewife Stormwater Wetland (ASW) achieved its intended outcomes of CSO reduction, water quality improvement and biodiversity enhancements? How does its water quality performance compare to other constructed wetlands?

2. **Design and Siting:** How have the ASW's design features and urban siting influenced its pollutant removal performance, ecological functions, and accessibility as a public space?

3. **Operations and Maintenance:** How have operations, monitoring, and maintenance (OM&M) practices shaped ASW performance over time, and what recurring OM&M challenges most affect outcomes?

4. **Public Interaction and Collaboration**: What roles have interagency collaboration and public engagement played in the development, perception, and long-term management of the ASW?

I present this research in seven chapters: In Chapter 2, I discuss the research design and methodology I use to evaluate the ASW. In Chapter 3, I review existing literature on stormwater wetlands, discussing how constructed wetland technology has evolved over time, and the mechanics of pollutant removal. In Chapter 4, I describe the history of the Alewife area, and the regulatory landscape that catalyzes the creation of the ASW. I also explain the CAM-004 sewer separation project, and the basic design of the ASW. In Chapter 5, I assess the performance of the ASW by analyzing water quality data and interview data from key project team members, explaining the ecological and cultural impact of the project. In Chapter 6, I describe the operations and maintenance of the ASW, including the delegation of work, and the role of regulations and public feedback. In Chapter 7, I summarize the main findings of the project.

Chapter 2 Methods

2.1. Introduction

I structured the Alewife Stormwater Wetland Case Study using the single-case embedded design, as defined by Yin (2003) in his widely cited book, *Case Study Research: Design and Methods.* Yin writes that case study research "allows investigators to retain the holistic and meaningful characteristics of real-life events"— an objective that was important to me in assessing the success of this project through technical, ecological, and social lenses. Because stormwater wetlands are inherently multidisciplinary and shaped by institutional and stakeholder dynamics, I found Yin's framework, developed to explore "complex social phenomena" (Yin 2003), instrumental in understanding this project. Through the ASW case study, I examined the wetland's role in improving water quality and its impact on the local community and ecology. I also examined key aspects of maintenance that underpin the ASW's effectiveness.

2.2. Rationale and Research Design

I decided to use a case study format in response to limitations in existing research on stormwater wetlands. Existing research tends to focus on the technical and water quality performance of the projects without much discussion of their ecological benefits, community impact, or long-term operation and maintenance. The ASW project presents a unique opportunity to study these underexplored phenomena. It meets Yin's criteria for a *revelatory case*, offering rare access to longitudinal data and management insight through its extensive written documentation.

This is an *embedded* case study design (Yin, 2003), meaning that multiple units of analysis– project documentation, water quality data, and stakeholder interviews– are used to assess the wetland's performance and significance. The embedded approach allows for an in-depth yet holistic assessment of the project using quantitative and qualitative data. Using multiple data sources also allows for methodological triangulation, increasing the study's validity.

2.3. Document Analysis

I reviewed key planning and operations documents to get further insight into the regulatory and technical engineering aspects of the project. Sources included design drawings and reports written by the engineering firm, operations and maintenance manuals written by the engineering firm and the City of Cambridge, permit applications written by the City of Cambridge, and agency rulings from MassDEP and the Cambridge Conservation Commission. The key documents in my analysis were the site plans and the Operations and Maintenance Manual, both of which I received from Duke Bitsko, who was my main contact and a lead designer over the project's 20+ year history. I also analyzed public presentations and publicly posted written feedback from community members to understand the social impact of the project. I identified themes related to performance benchmarks, stakeholder involvement, and adaptive management. Adaptive management was a significant theme articulated in the project documentation that was corroborated with interview data. I used an ad hoc method to assess alignment between documented procedures and actual procedures discussed in the interviews.

2.4. Interviews

I conducted semi-structured interviews with key members of the ASW project team, including civil engineers, landscape architects, horticulturists, and public works professionals. I selected interviewees using purpose sampling based on their role in project design, permitting, operations, and/or maintenance. I conducted seven interviews with five project team members, each lasting 30-60 minutes. I conducted the interviews between September 2024 and April 2025. The interviews focused on regulatory and maintenance challenges, interagency collaboration, adaptive management, performance, and public perception. Several interviews occurred on-site, allowing me to gain an experiential understanding of the wetland system. A formal site walk was held in October 2024 to discuss improvements to the walking path and upcoming winterization of the facility. I attended the walk along with Duke Bitsko, Caitlyn Rodriguez, Cambria Ung, and representatives from DCR. I also attended two informal site walks (conducted by Duke Bitsko and Scott Horsley of Tufts University/Harvard University) with the purpose of educating students in October 2024. Finally, I led a group of Tufts Graduate students on an informal site walk in April 2024. Approval was obtained from the Tufts IRB (Appendix A) to conduct the interviews. Interview questions are included in Appendix B. Interviewees are described in Table 2.1.

Table 2.1 List of Interviewees

Interviewee	Organization	Expertise
Duke Bitsko	Hatch (formerly Bioengineering Group)	A leading member of the design team, active throughout the project's 20+ year history (main project contact)
Catherine Woodbury	City of Cambridge Department of Public Works	Engineering Project Coordinator for the City of Cambridge, active throughout the project's 20+ year history
Caitlin Rodriquez	Essex Horticulture	Lead horticulturalist maintaining and documenting changes at the wetland over the last several years
Jennifer Delgado	Mystic River Watershed Association	Watershed field scientist collecting data on the health of the watershed over time
Cambria Ung	City of Cambridge Stormwater Program	Stormwater program manager overseeing regulatory compliance with the state

2.5. Water Quality Data Statistical Analysis

I obtained the ASW water quality data from the City of Cambridge for 2017-2020. The wetland inlet and outlet were sampled in dry weather for total nitrogen, total phosphorus, E. coli, total suspended solids (TSS), and conductivity, among other parameters (a complete list is included in Chapter 5). After cleaning the data, I calculated descriptive statistics and compared the removal efficiency of the ASW with approximately 200 other wetlands compiled by Land et al. in a 2016 meta-analysis. I conducted a k-means clustering analysis to illustrate how factors such as climate and hydraulic loading rate correlate with nutrient removal efficacy in the

wetlands studied. I used pandas and scikit-learn libraries in Python to perform this analysis. A full description of the methodology can be found in Chapter 5.

Chapter 3 Literature Review of Stormwater Wetlands

3.1. Constructed Wetland Mechanics

Constructed wetlands (CWs) are engineered environments designed to capitalize on the processes present in natural wetlands to improve water quality. Formal research on constructed wetlands for wastewater treatment began in the 1950s in Germany (Seidel, 1955, as referenced in Liu et al., 2024). CWs may be designed to process a variety of influent types, including urban stormwater runoff, agricultural runoff, and domestic wastewater. Though design specifics vary greatly, CWs include four main components: water, media (soils), microbes and vegetation.

There are several main types of constructed wetlands, each suitable for different applications (see Figure 8). Free Water Surface wetlands (FWS) have a variable water depth (anywhere from a few inches to 4-6 ft deep) and a diverse community of floating, submersed, and emergent plants (Land et al., 2016). Subsurface Flow Wetlands, by contrast, are planted primarily with emergent wetland plants, which treat flowing subsurface water in the rhizosphere (root zone). Effluent can be fed into a subsurface wetland system either horizontally or vertically, as depicted in Figure 6. Both FWS and subsurface wetlands are typically constructed with a subsurface barrier to limit seepage (US EPA, 1993). Other hybrid designs include aerated CWs, which use air flow to boost nitrification (Pascual et al., 2024) and microbial fuel cell, wherein the naturally occurring redox gradient in the CW is used to generate electricity (Doherty et al., 2015).

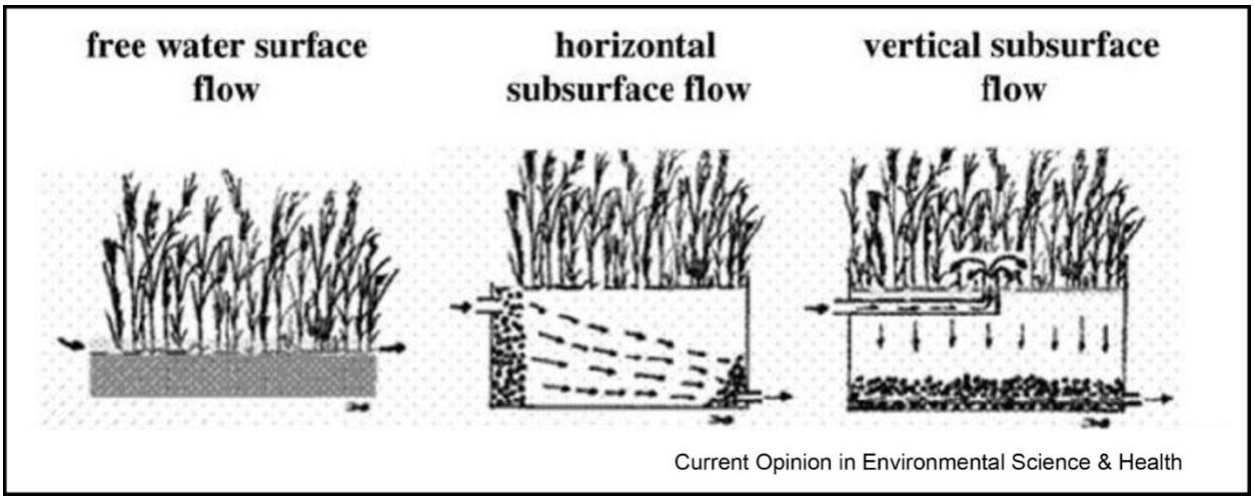


Figure 3.1Types of Constructed Wetlands Categorized by Hydrologic Regime. Source: Ghermandi et al., 2007

The physical and biogeochemical processes through which pollutant removal occurs are relatively well known. Pollutants such as heavy metals, hydrocarbons and nutrients are removed through sedimentation, filtration, phytoremediation (uptake by plants), and microbial degradation (Shelef et al., 2013). Microbes ideally suited to the anoxic soil conditions in the wetland convert nitrate nitrogen to nitrogen gas, a process known as denitrification (Martínez-Espinosa et al., 2021). However, the complex interplay of these processes in the wetland environment makes it difficult to predict pollutant removal efficiencies. Nutrient removal efficiencies across different wetlands vary considerably, due to variation in inflow nutrient concentration, hydraulic retention time, temperature, hydraulic efficiency, precipitation patterns and type of wetland (Land et al., 2016). Removal of metals is also highly variable, depending mainly on soil chemistry (Wang et al., 2017). Further, it is more difficult to model pollutant removal in stormwater wetlands than in wastewater treatment wetlands because stormwater wetlands have inherently stochastic inputs (variable frequency/intensity rainfall determines inflow and pollutant load concentrations), whereas wastewater treatment wetlands receive moderated volumes of influent with generally stable pollutant concentrations (Carleton et al., 2001).

Given the variability of individual systems and limitations in modeling, it is difficult to discern a target pollutant removal rate for a constructed wetland. Thus, it is useful to evaluate CWs using a holistic technique that incorporates measures of ecosystem services as well as measures of water quality.

3.2. Key Pollutants and Removal Processes

Natural wetlands are complex biogeochemical systems that can attenuate pollutants by various processes. Nutrients such as nitrogen and phosphorus are necessary for biological productivity but are considered pollutants when found in excess. The molar proportions of carbon, nitrogen and phosphorus found in marine biomass is 106:16:1 (or 41:7:1 on a mass basis). This is known as the Redfield Ratio, a concept that illustrates the delicate balance of nutrients required to sustain the marine food web. The ratio is generally more variable in freshwater biomass (Wetzel, 2001), but ideal concentration ranges for each nutrient also exist in freshwater environments. It is generally held that excess nitrogen drives eutrophication in saltwater environments and excess phosphorus drive eutrophication in freshwater environments, though there are many exceptions to this theory (National Research Council, 2000). Still, the high phosphorus load in wastewater and stormwater has been shown to disrupt homeostasis in the freshwater wetland ecosystem in many cases (Kadlac and Knight, 1997).

3.2.1 Nitrogen

Nitrogen is the most abundant element in earth's atmosphere and an essential component of all living matter. Nitrogen exists in the environment in various forms, including nitrogen gas (N_2), nitric oxide (NO), nitrous oxide (N_2O), nitrate (NO_3^-), nitrite (NO_2^-), ammonium (NH_4^+), and organic nitrogen which may be in the form of living or decomposing organic matter. The

nitrogen cycle (depicted in Figure 9) describes the processes that transform nitrogen from one form to another. Nitrogen fixation is the transformation of nitrogen gas from the atmosphere into organic nitrogen. Most nitrogen fixation is carried out by bacteria that live in the rhizosphere of legumes; a small amount of nitrogen fixation also occurs via lightning strikes. This organic nitrogen is assimilated into plants, some of which are consumed by animals. When plants or animals die or produce waste, the resulting organic nitrogen is broken down into ammonium by decomposers such as fungi and bacteria. Nitrifying bacteria in the soil oxidize ammonium to nitrites, and other bacteria oxidizes nitrites to nitrates. Nitrification is important because ammonium is toxic to plants. However, nitrates are highly soluble and can easily impact groundwater. This is commonly observed in communities that rely on septic systems for wastewater treatment. Groundwater enriched by nitrates can have negative human health effects when used as drinking water (such as Blue Baby Syndrome) and can impact surface waters leading to eutrophication. Dentification is the final step of the cycle that reduces nitrates back to nitrogen gas. This transformation is carried out by bacteria that live in anaerobic conditions.

Humans have more than doubled the global amount of available (non-atmospheric) nitrogen by burning fossil fuels and industrially fixing nitrogen to produce fertilizers (Vitousek et al., 1997). Urban areas are particularly vulnerable to nitrogen pollution due to concentrated fossil fuel burning (from traffic, heating and energy generation), use of fertilizers, and urban characteristics that impede the natural nitrogen cycle (sparse vegetation, compromised natural wetlands, and stream channelization) (Balderas-Guzmán, 2013). Additionally, urban areas are more impervious, providing more direct conduits for nitrogen transmission via stormwater. Thus, when stormwater wetlands receive nitrogen-heavy inflows, it is critical that they facilitate the proper nitrification and denitrification processes necessary to convert the various forms of

nitrogen back to nitrogen gas. Figure 3.2 shows a simplified diagram of the nitrogen cycle in a free-water surface CW.

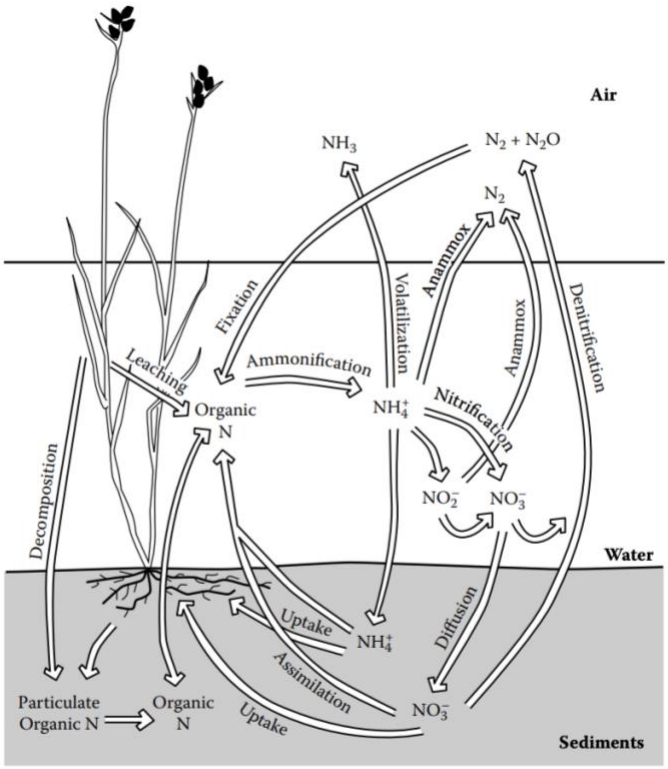


Figure 3.2 Simplified Nitrogen Cycle in a Free-Water Surface Treatment Wetland. Source: Kadlec & Knight (1996)

3.2.2 Phosphorus

Phosphorus is a nutrient essential to plant growth. In freshwater environments, phosphorous is often a limiting factor for plant growth, meaning its concentration in the aquatic environments can have a profound effect on the overall health of the ecosystem (Kadlac & Knight, 1996). Besides surface inflows, phosphorus also comes from atmospheric deposition (both during dry and wet weather). Removing phosphorus from wastewater or stormwater is a difficult process. In a wastewater treatment plant, aluminum sulfate, ferric chloride or lime

(calcium hydroxide) is used to principate the phosphorus. This by-product is then removed by sedimentation or filtration.

Phosphorus is transformed through several processes in a wetland, including sedimentation, uptake by plants, decomposition, volatilization, and combustion. However, the only long-term storage of phosphorus occurs by soil accretion. This is why phosphorus removal efficiency is thought to decrease in older constructed wetlands, as soil binding sites become saturated over time (Deslippe & Bentley, 2025). Although phosphorus is stored in plant matter (until the plants decompose), phosphorus removal via harvesting biomass is not known to be efficient. Studies have shown the amount that can be removed by this method is relatively low, on the order of 2.5 to 5% (Harskowitz, 1986; Kim & Geary, 2001). Phosphorus removal efficiency in a wetland is highly dependent on the influent phosphorus concentration, existing phosphorus load in soils, and design and climate factors such as retention time, plant cover, and temperature (Land et al., 2016; Kill et al., 2022) In a systematic review of 203 CWs, Land et al (2016) found a median total phosphorus removal efficiency of 46% with a 95% confidence interval of 37-55%. Other studies have shown significantly lower rates (Kill et al., 2022). Overall, phosphorus removal in wetlands it is not efficient on a land-unit basis. Significant phosphorus reduction requires a large wetland area—larger than the area required for significant nitrogen or heavy metal removal (Kadlac & Knight, 1996).

3.2.3 Pathogens

Many varieties of pathogenic bacteria, virus and protozoa exist in stormwater and wastewater. Measuring or quantifying all these organisms is difficult, so engineers instead track indicator organisms that are easy to document and correlate with populations of other pathogenic organisms. A popular indicator species is the coliform bacteria group, although total coliform

measurement is not specific enough to indicate human fecal contamination. For that, a ratio of fecal coliforms to fecal streptococci is used.

Fecal indicator bacteria are removed in wetlands via natural die-off, sedimentation and filtration, exposure to UV radiation from the sun, exposure to biocides excreted by plants, and predation by nematodes and protists (Wu et. Al, 2016). As with nutrient removal, characteristics of the wetland that influence removal include retention time, temperature, and vegetative cover.

3.3. Measuring Performance Holistically: Ecosystem Services

Evaluating CWs solely as water treatment infrastructure discounts the known benefits that they provide as ecosystems. Agaton et al., (2023) argue that assessing the ecosystem services of constructed wetlands is essential to understanding the extent of their value. Ecosystem services are the benefits that humans can obtain from interacting with a natural system. The term "ecosystem services" was first coined by the Millennium Ecosystem Assessment (MEA). The MEA is an international scientific study initiated by the United Nations in the early 2000s to assess and encourage the "sustainable use of ecosystems and their contributions to human well-being". The four categories of ecosystem services described by the MEA are: provisioning, regulating, supporting, and cultural. Agaton et al (2023) describe how CWs embody these four types of ecosystem services.

Provisioning services are material resources, such as water and biomass, that humans can use. Constructed wetlands can foster growth of plants that can be used for food, medicine, building, and fuel (Avellan et al., 2017). Sometimes, as in a Costa Rican case study presented by Synder (2019), the benefit of a constructed wetland's water treatment services can offset the cost of farming biomaterials, essentially provisioning those resources for free. Bolstering the water supply with reclaimed water is another benefit of constructed wetlands (Agaton et al., 2023).

Reclaimed water from stormwater wetlands can be used in industry, construction, and irrigation without much need for advanced treatment.

Regulating services maintain the environment in which humans live and work. As mentioned, the primary regulating ability of constructed stormwater wetlands is to purify water, thus maintaining the health of receiving waters (Agaton et al., 2023). In a meta-analysis of 203 constructed wetland studies, Land et al., (2016) found an average removal efficiency for total nitrogen was 37 %, with a 95 % confidence interval of 29–44 %, and the average removal efficiency for total phosphorus was 46 % with a 95 % confidence interval of 37–55 %, indicating that CWs can effectively remove excess nutrients that may cause eutrophication. CWs are also capable of sequestering metals. A 20-year study in South Carolina found an average removal rate of 80% for copper, 74% for lead, and 65% for zinc in an urban stormwater wetland (Knox et al., 2021). Constructed wetlands can attenuate floods, which is especially critical in urban areas where the density of impervious surfaces causes high volumes of runoff. Constructed wetlands can also reduce erosion and capture sediments, thus reducing turbidity in receiving waters (Cooper et al., 2019).

CWs have also been shown to regulate the local microclimate (Kuşçu Şimşek & Ödül, 2018). Vegetation can cool the air via transpiration and produce shade, while open water captures heat and reduces temperature variation (Zhang et al., 2013). Maintaining water temperature is of paramount importance to protecting cold water fisheries that may receive treated water from a CW (Jones & Hunt, 2010). Research is mixed on whether the climatic effects of constructed wetlands include net carbon sequestration. A recent 29-year longitudinal study of two CWs in Columbus, Ohio found that the carbon stores of the CWs increased until year 15, after which no net gai or loss in sequestration was observed (Ruane et al., 2025). Other

research indicates that constructed wetlands may act as sources of carbon, rather than sinks, a phenomenon that is seen in some natural wetlands (Mander et. Al, 2014). Mander et al., (2014) estimate that the global warming potential of CWs is small but found a large range of methane and nitrous oxide emissions in the 20 CWs they studied. They found that wetlands with more emergent vegetation and a pulsing water regime had lower emissions comparatively (Mander et al., 2014). A pulsing water regime is characteristic of stormwater wetlands (because rain falls intermittently), so stormwater wetlands theoretically emit less carbon than other types of constructed wetlands. Additionally, Ingrao et al. (2020) assert that CWs for wastewater treatment emit less greenhouse gas emissions than wastewater treatment plants. Therefore, even if a city could capture all its wastewater and stormwater flow without the risk of a CSO, it would be advantageous from an emissions-reduction perspective to divert the stormwater to a wetland for treatment, rather than designing a larger wastewater treatment plant to accommodate the combined flow.

Cultural services are intangible benefits that constructed wetlands can offer the local community. These services include recreational and aesthetic benefits (which make be linked to the local economy), biodiversity, and education and research. Agaton et al. (2023) argue that education is an often-missed valuation component. Nature-based education and cognitive tourism are important to increase public engagement with conservation initiatives and, in the words of Mocior & Kruse (2016), "shorten the distance between the scientific and popular knowledge."

A particularly interesting aspect of cultural services is a shared sense of place or identity linked with the management of an environment (Quijas & Balvanera, 2013). This idea is fertile ground for discussing the benefits of an OM&M regime beyond just making sure the system

functions (for water quality) and even beyond ensuring the quality of ecosystem services. A participatory OM&M regime can be a galvanizing force in a community working toward a shared sustainability goal.

Supporting services facilitate the above three categories of services. Agaton et al. (2023) identified habitat formation and nutrient cycling as key supporting services in CWs. Natural wetlands are some of the most biodiverse and productive environments on earth per unit area (Snyder, 2019). CWs, though generally less biodiverse, can still provide habitat for an impressive array of species, depending on design and purpose (Zhang et al., 2020). A study of two CWs in subtropical Tawin by Hsu et al. (2011) indicate that wetland area, macrophyte (aquatic plant) coverage, and water quality were the three main factors affecting the quality of habitat in the CWs (as indicated by the number of species present). Lager wetlands with higher macrophyte coverage and lower total phosphorus concentrations supported higher richness and abundance of bird, fish, and invertebrate species (Hsu et al., 2011).

Nutrient cycling is another key benefit of CWs. As in natural wetlands, CWs facilitate the movement and biological availability of chemical substances that support and/or limit growth of various types of organisms (Everard, 2018).

3.4. The OM&M Research Gap

Stormwater wetlands require specific operation, monitoring, and maintenance (OM&M) protocols because they are living, dynamic systems that require adaptive, multi-disciplinary management. Typically, one department of a city government (usually the Department of Public Works or “DPW”) oversees all stormwater infrastructure. This management structure is effective for conventional infrastructure because it follows a relatively static maintenance plan and has a predictable life cycle (Knapik et al., 2024). For example, The Massachusetts Stormwater

Handbook stipulates that deep sump catch basins (shown in Figure 10) must be cleaned four times per year, and at the end of foliage and snow removal seasons (Massachusetts Stormwater Handbook, Vol II Ch II: *Structural Best Management Practices*). This is a consistent maintenance requirement, year after year. CWs, on the other hand, change dynamically over the years as vegetation grows, new species present, and the bio-physiochemistry of the system shifts. Effectively managing CWs thus requires an adaptive protocol and insight from multiple fields, such as botany, wildlife biology, chemistry, engineering, landscape architecture, and urban planning.

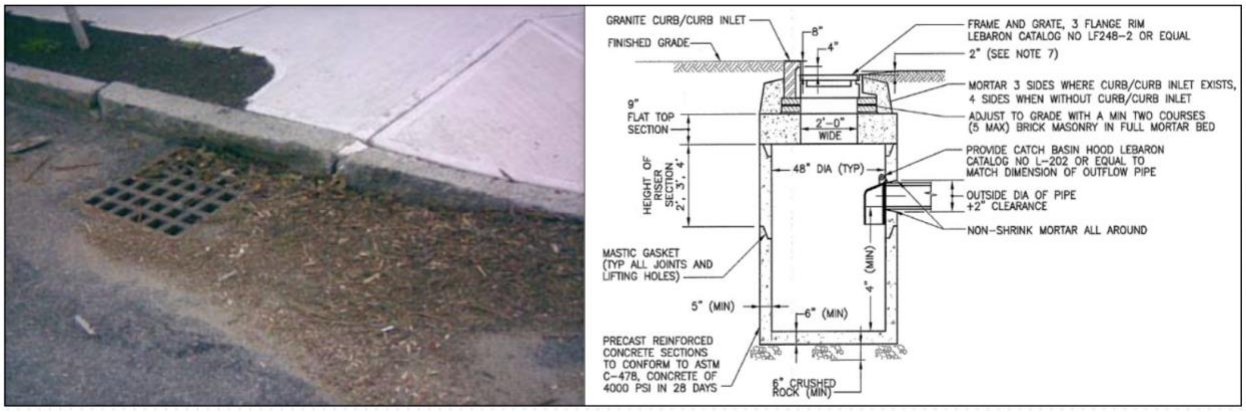


Figure 3.3 Deep Sump Catch Basin. Image Credits Massachusetts Stormwater Handbook, Volume II Chapter II (left), University of New Hampshire Stormwater Center (right)

Many studies have cited uncertainty around maintenance requirements as a barrier to CW implementation (Abourached et al., 2024; Makopondo et al., 2020; Wilson et al., 2019). While stormwater management manuals make general recommendations for maintenance of various green infrastructure (GI) systems, few studies provide empirical data on frequency and intensity of maintenance to achieve optimal performance (Erikson et al., 2010). Many studies have shown that maintenance of GI systems is often inadequate, leading to reduced facility performance, reduced longevity, aesthetic concerns, and worsening water quality downstream (Reyes et al., 2023). The literature suggests there are two main reasons that constructed wetlands do not

perform well over the long run. One reason is sub-optimal water depth from sediment deposition or improper outlet position (which affects retention time), and the other is growth of invasive species or monoculture (Hunt et al., 2011). These performance issues can have cascading negative effects on the ecosystem, such as worsening eutrophication and decline of beneficial species. The resulting aesthetic concerns may in turn diminish the socio-ecological value of the system.

Chapter 4 Site History and ASW Design

4.1. Watershed History

The ASW sits on land with a rich geologic and anthropologic history. Present-day Cambridge and Arlington sit atop a deeply buried pre-glacial valley known as the Fresh Pond buried valley (Chute, 1959). Glacial activity during the last ice age filled the valley—which reaches depths of 170 feet below present-day sea level— with sediments, forming features of the landscape that can be seen today, such as Spy Pond and Alewife Brook. Glacial activity also formed the Boston Basin, a large topographic depression encompassing Boston Harbor and much of the Boston metro area (Kaye, 1976) and Mystic River Watershed. The Basin is defined on its western edge by an escarpment running through Malden, Medford, Arlington, and Waltham. Kaye (1976) notes that a traveler's descent into the Boston Basin is especially notable when traveling into Alewife area on Route 2, as "he descends the escarpment at Arlington [and sees] the extensive lowland stretched below and the towers of the city in the distance." The Alewife area thus marks a transition between geologic worlds, from upland to riverine lowland.

Early inhabitants of the Alewife area include the Pawtucket and Neponset bands of the Massachusetts Native American tribe. Seasonal fishing camps, established to fish the annual runs of alewife and blueback herring, dotted the shores of Little and Spy ponds (Massachusetts Metropolitan District Commission, 2003). The Pawtuckeog used weirs along the Alewife Brook to catch these diadromous fish as they migrated from the ocean up the Mystic River to spawn (Hilton, 2024). At this time, the Alewife Brook was brackish, and the surrounding marshland ecosystems were adapted to the salty water.

The Alewife area was known from the earliest days of the European Bay Colony as “The Great Swamp”. The colonists formed inroads for grazing, which later became cart paths that bridged Newtowne (now Cambridge) and Concord. As Newtowne expanded, more of the swamp was ditched and drained for cattle grazing and farming. The Great Swamp was also used to discharge residential sewage. As agriculture gave way to industry in the early 19th century, the swamp seemed like an ideal place for glue factories, slaughterhouses, and other industries that were undesirable in the residential centers (Massachusetts Metropolitan District Commission, 2003). But it was the rich alluvial clay deposit beneath the Great Swamp birthed a new major industry in the early 1800s: brickmaking. Several clay deposits in the area were excavated, one of these excavations forming present day Jerry’s Pond. The booming brick industry spurred the establishment of the Central Mass Railroad in the early 1880s.

By the late 1800s, pollution in the Great Swamp was becoming a grave public health concern. Cambridge and Belmont “traded accusations” as to who’s sewage was polluting the area (Pei, 2008). An uptick in malaria cases at turn of the 20th century added to the negative public perception of the Great Swamp and its associated streams (the Little River, Alewife Brook, and Wellington Brook). On August 4, 1900, The Cambridge Chronicle declared "Wellington Brook Must Be Purified: Petitioners Declare That Its Condition Is Offensive and a Menace to Public Health – Thursday's Hearing at City Hall" (Pei, 2008).

It is interesting that around the same time the Great Swamp was under siege for being a dirty, disease-attracting place, the newly established field of landscape architecture and the cleansing properties of wetlands were being highlighted not too far away, in Frederick Law Olmstead’s the Fenway. By 1908, the state had taken ownership of most of the Great Swamp and launched a drainage improvements project. The Little River was channelized with a concrete

bottom and rerouted, as shown in Figure 4.1. This allowed the water in the brook to move faster, shrinking the floodplain and making more land available for development. While this intervention effectively shrank the swamp —thereby reducing the malaria risks associated with its earlier neglect—it consequently increased flooding severity downstream and reducing riverine habitat. The c. 1890 map below shows the original path of the Little River and the new path.

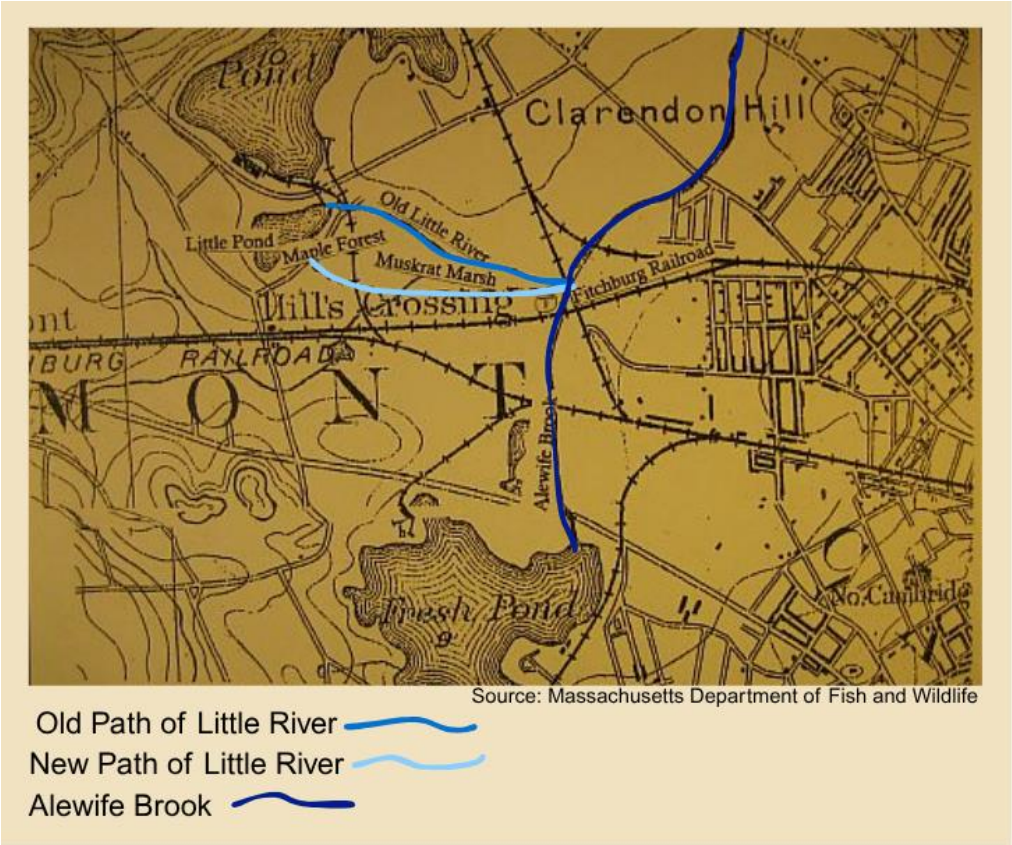


Figure 4.1 Channelization of the Little River

4.2. Differing Visions for the Future

130-acres of land from the Great Swamp acquisition were set aside for the Alewife Reservation, sparking interest in a potential public park system, though many parts of this plan were never realized (Friends of Alewife Brook Reservation, n.d.). Famous landscape architect

Charles Elliot envisioned connecting the Mystic River and Fresh Pond through the Alewife Reservation and Parkway (Massachusetts Metropolitan District Commission, 2003). The Alewife Brook Parkway, completed in 1916, was first designed for leisurely scenic drives in carriages, and later, in automobiles. As urbanization intensified in the latter half of the 20th century, the Parkway became increasingly burdened with traffic it was not designed to accommodate (Massachusetts Metropolitan District Commission, 2003). Development encroached upon the borders of the reservation, parts of which became a dumping ground for excess highway materials from Route 2 construction in the 1930s (D.B., Personal Communication).

Still, with the most offensive polluters of the nineteenth century out of the area, the Alewife Reservation had potential to become an urban oasis for people and wildlife. However, a dearth of funding at the DCR and lax zoning around the reservation spelled a different future. A 1979 City of Cambridge planning report called Alewife an "unplanned industrial area" with parking lots and warehousing being the predominant land uses (City of Cambridge Community Development Department, 1979). The planning report called for infrastructure improvements, such as new water and sewer connections, and intentional zoning to "mold future development into a planned and orderly district." (City of Cambridge Community Development Department, 1979). Ambitious ideas, including a canal and bridge across the Little River, were proposed to draw residents to the area.

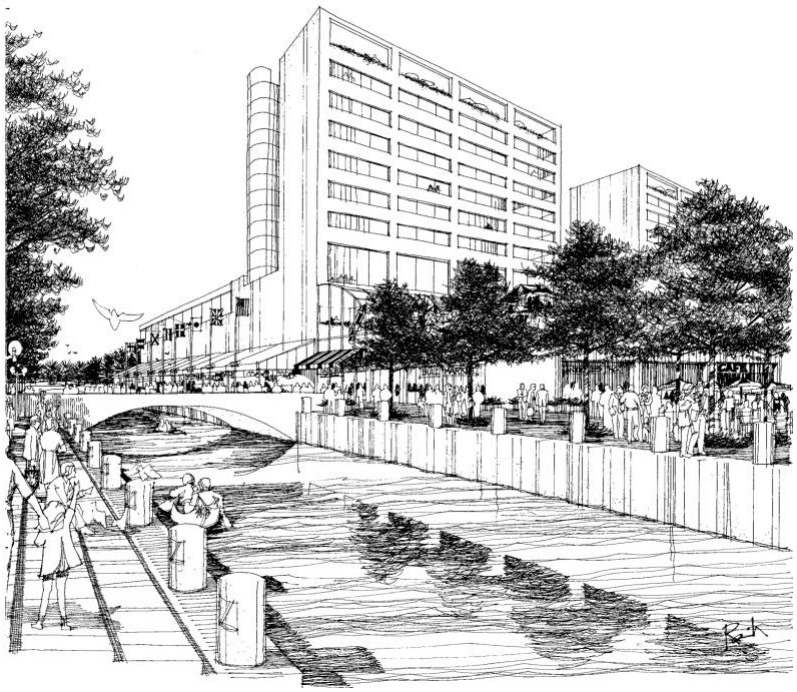


Figure 4.2 Artist's Rendering of Proposed Little River Canal and Bridge, 1979 Masterplan

While infrastructure improvements, such as the 1980s extension of the MBTA red line from Harvard Square, helped bring other business to the Alewife area, few of the calls for public recreational amities were answered over the next several decades. A 1995 revised plan reported that "virtually no one lives in the entire area; there is little of the vitality that flows from the mix of uses elsewhere in the city; and the scale and pattern of development is almost completely automobile-oriented, with few incentives to stroll through the area or to linger anywhere within it." The Reservation itself was overgrown with invasive plants, bereft of wildlife, and largely forgotten by the public.

The Little River and Alewife Brook were not faring any better. The natural hydrology of the area had been so badly disturbed by urbanization that habitat was scarce, and flooding was frequent. The Amelia Earhart Dam, constructed in 1966 to alleviate flooding on the Mystic

River, prevented saltwater backflow and diadromous fish runs that defined the Alewife Brook for millennia. This converted the Alewife Brook and its wetlands from brackish to freshwater environments, permanently altering the local ecology. To make matters worse, by the 1980s, there was an average of 63 CSOs per year contributing around 53 million gallons of combined sewage into the brook. (Trust for Public Land, 2016). Pollution from stormwater alone was also significant. Roadways flooded often, even during mild rain events of the then-2yr storm intensity (Trust for Public Land, 2016). Basement sewer backups in the adjacent neighborhoods were also frequent, decreasing residents' quality of life. It was clear that something had to be done. By the early 2000s, more than a dozen citizen interest groups were active on the subject, intent on improving sanitary, habitat, and recreation conditions of the Alewife area (Alewife Master Plan, 2003). Still, a lack of funding and regulatory incentive kept proposals from moving forward. That was until The Long-Term CSO Control Plan began in earnest in Cambridge.

4.3. The Boston Harbor Cleanup and Long Term CSO Control Plans

Boston Harbor and its related network of watersheds is an important natural and commercial resource, home to historic shipping industries, valuable fishing and shell fishing resources, recreation and tourism. However, centuries of sewage overflows and industrial pollution had significantly degraded the harbor by the mid-twentieth century. In the 1980s, Boston Harbor infamously become known as "America's Dirtiest Harbor" (Hecht, 1992 as cited in Savage, 1995) with regular beach closings among other maladies. After the City of Boston failed to comply with secondary sewage treatment requirements of the Clean Water Act (and thus lost out on federal aid for infrastructure improvements), the need for action was critical. In 1982, the neighboring city of Quincy sued Boston for violation of the CWA and common law nuisance. The following year, the Conservation Law Foundation, a New England-based

environmental advocacy organization, also sued the City of Boston and Commonwealth of Massachusetts for violations of the CWA. The EPA joined as a plaintiff in this suit, heightening the profile of the case. The legal pressure led the Massachusetts Legislature to establish the Massachusetts Water Resources Authority (MWRA) in 1985. The MWRA was tasked with improving the water quality of Boston Harbor, a multi-decade project known as The Boston Harbor Cleanup (Savage, 1995).

A major facilitating step of the Boston Harbor cleanup was the upgrade of the Deer Island wastewater treatment plant. First opened in 1968, the Deer Island plant was rebuilt with expanded capacity and secondary treatment capabilities from 1985 to 2000. These upgrades improved wastewater treatment processes and allowed more communities to connect to the system. However, combined sewer outfalls to the Harbor and its tributaries (Charles River, Mystic River and Neponset Rivers) were a major problem not addressed by the Deer Island upgrades (see Figure 13). Thus, the MWRA developed the first Long-Term CSO Control Plan (LTCP) in 1994. At the start of the LTCP there were 84 active outfalls in the Boston area. From 1987 to 2015, all 34 of the original CSO Control Plan Projects mandated by the court order were completed, eliminating over 2.8 billion gallons per year of combined sewer overflow. This includes the work done in the Alewife Brook CSO control Plan, described below.

Figure 4.3 CSOs in the Boston Area. Source: MWRA, updated May 2020

The Alewife Brook CSO Control Plan was mandated to be complete by 2015. Its goal was to minimize CSO inputs to Alewife Brook (and thus the Mystic River and Boston Harbor) by separating combined sewers and upgrading hydraulic capacities at MWRA interceptor connections (Laskey et al., 2013). The project was projected to reduce CSO volume in Alewife Brook by 85%, from 50 million gallons in 1997 to 7.3 million gallons by 2015 and reduce CSO events from an average of 63 per year to an average of 7 per year. The MWRA hydraulic model

predicted that these interventions would allow Alewife Brook to comply with Class B water quality standards (fishing and boating— secondary contact) 98.5% of the time (MWH Global, 2016).

The main target of the Alewife Brook CSO Control Plan was closing the CAM-004 outfall, which was the most severe outfall in the Little River/Alewife Brook at the time. CAM-004 was also significant because it is near the Fresh Pond Reservoir, which is a major source of drinking water for Cambridge, contributing 12 to 16 million gallons of water per day to the raw water supply (Cambridge Water Department, n.d.). CAM-004 discharged an average annual volume of 24 million gallons of combined sewage, which was about 50% of the total going to Alewife Brook at the time (MWH Global, 2016). Eliminating the CAM-004 outfall required separating the combined sewer and stormwater drainage systems in its 335-acre catchment area. The sewer separation eliminated CSO volume going to the Little River and reduced the stormwater volume going to Deer Island by an estimated 137.3 million gallons per year.

The sewer separation project cost $90 million and was split between the MWRA and the City of Cambridge. The project involved eliminating shared manholes, installing separate pipes for sewer and stormwater, removing illicit connections on private property, moving water and gas mains, upgrading sidewalks to allow better infiltration, planting trees, and creating bioretention basins (MWH Global, 2016).

However, the sewer separation was only part of the battle. The MWRA and City of Cambridge needed to find a method for dealing with roughly 137 million gallons of stormwater that would now be diverted from Deer Island. The simplest solution would be to discharge it into the Little River, effectively transforming CAM-004 into a stormwater only outfall. However, it was determined that the amount of stormwater entering the brook would overwhelm it and

worsen flooding in the area. Under the then-current CSO conditions, water (combined stormwater-sewerage) was only discharged from CAM-004 to the brook during more intense storms. The new proposal would allow discharge to Alewife Brook every time it rains, which would overtop the shallow, flood-prone river. The Cambridge Conservation Commission further challenged the proposal on the grounds that it would provide no treatment for the bacteria, TSS, and nutrients found in stormwater, and would worsen water quality in the already impaired brook.

To evaluate potential alternatives, the City of Cambridge contracted MWH Global (now part of Stantec) to develop the City's first hydraulic model using InfoWorks ICM software. This tool helps evaluate local subwatersheds under different storm scenarios, modeling how the network of manmade infrastructure, land cover, and the natural hydrology convey floodwaters during different storm events (Water Online, n.d.). It was clear that the stormwater would need to be detained before discharging into the river to avoid flooding adjacent neighborhoods. The gray infrastructure alternative was to build a detention pond or structure near CAM-004, which would likely be situated on the Alewife Reservation for hydraulic and economic reasons. But DCR did not want infrastructure sited on the parkland that would detract from its recreational value. "The MWRA came to us asking to put a giant underground concrete cistern in the Alewife Reservation," said Dan Driscoll, director of recreational facilities planning and design for DCR. "We didn't like that idea at all. We said, 'Is there some way we can make this stormwater work with the environment rather than against it?' (as quoted in Trust for Public Land, 2016). That's when the city teamed up with BioEngineering (now Hatch), an engineering consultant with expertise in environmentally sensitive design. To satisfy the DCR, the project had to also be a public amenity that enhanced the parkland. Thus, a stormwater wetland was proposed. This

happened to coincide "perfectly" with the rewriting of the Alewife Master Plan in 2003 (Catherine Woodbury, Personal Communication). MWRA agreed to pay for some of the upgrades that DCR had been demanding, such as accessibility improvements. The goal of the new proposal was to make the area a functional public park that could also detain and treat stormwater.

4.4. ASW Design Goals

The primary design goal of the ASW was to facilitate the combined sewer separation project that would allow the CAM-004 outfall to permanently close. Another critical goal was to eliminate flooding for the 10-year storm event, which was affecting the residents' commute along the adjacent greenway path. Other goals for the project identified by the City of Cambridge in their 2003 Notice of Intent (NOI)[3] included:

- Attenuating stormwater flows to the Little River through the constructed wetland basin.
- Improving the quality of discharged stormwater.
- Enhancing habitat for diverse vegetative and wildlife communities.
- Affording passive and active recreational activities and educational opportunities.
- Maintaining the volume of the 100-year floodplain consistent with FEMA and State Regulations; and
- Sustainably preserving the net positive effects of this project on surrounding resources areas.

The initial feasibility study from MWH Global indicated that the proposed stormwater wetland could handle large inflows of stormwater from the catchment area within a reasonable footprint. However, the because the project would be sited on state parkland, it was subject to Article 97 of the Amendments to the Massachusetts Constitution, meaning that it could not be used for purposes other than conservation and public use without a two-thirds approval of the

[3] A Notice of Intent (NOI), also known as Wetlands Protection Act Form 3, is part of the permitting process for construction work that will impact a wetland or wetland buffer zone. An NOI is submitted both to the local conservation commission in a municipality and to MassDEP to describe how the project intends to comply with the Massachusetts Wetlands Protection Act regulations (310 CMR 10.00) and any applicable local regulations, which may have additional requirements. An NOI was submitted for this project because it was proposed within an existing wetland.

legislature. Catherine Woodbury, the Engineering Project Coordinator for the City of Cambridge Department of Public Works, noted that this hurdle greatly extended the permitting process.

There were also complications of existing resources. Alterations to the riverfront area, existing wetlands, and bordering land subject to flooding are all regulated by the Massachusetts Wetlands Protection Act (310 CMR 10.00). The project team planned the wetland footprint to avoid pockets of existing wetlands, limiting alterations of existing wetlands to less than 5,000 sf to remain in compliance with the Act. This constraint is part of the reason the main basin of the wetland is kidney-shaped (the other reason is that this shape induces a favorable flow path for a long detention time).

Once the Cambridge Conservation Commission was satisfied with the design of the wetland, a new obstacle emerged. A group of about 10 residents appealed the Commission's decision to move forward with the wetland, citing concerns about the project being on public parkland. Even though the parkland was "underdeveloped and run down" and relatively inaccessible to the public, the group "thought the project should be elsewhere." (Catherine Woodbury, Interview). In addition, some residents were concerned about mosquito breeding, maintenance, and the general aesthetics of the project. "We got 1001 comments [about mosquitos] during public the hearings… We tried to educate the public that if a healthy ecosystem is maintained, we won't have that issue" (Catherine Woodbury, Interview). The resident group tried to appeal the project under the Wetlands Protection Act, claiming that the disruption to existing wetlands on the site was too extreme. This delayed the project for more than four years. "Defending against the opponents in court cost the city of Cambridge $4.5 million," said William Pisano, a principal with the engineering firm MWH Global. "Beyond that,

I calculated that during those years of delay there was enough sewer overflow to cover the entire city of Cambridge to a depth of seven inches." (as quoted in Trust for Public Land, 2016).

4.5. Site Preparation and Construction

Because of the lengthy permitting process, site work did not begin in earnest until 2011. During the pre-construction phase, the project team undertook a pre-construction wildlife and rare plant survey. The work area was searched for burrows, dens and nests. Specially placed gaps were left in construction fencing to allow animal egress. Site monitoring was established to identify any at-risk animals (Bitsko, 2015). In September 2010, Gentiana Andrewsii (commonly known as Closed Bottle Gentian) was discovered. This plant is listed as endangered on the Massachusetts Endangered Species Act.

Because the goal was to avoid disturbing existing wetlands as much as possible, significant upland areas were excavated to create the stormwater wetland. Fortunately, the underlying soils were hydric soils suitable for the wetland, and fill was not imported. Aside from a limited volume of contaminated soil removed under the Massachusetts Contingency Plan (310 CMR 40.00), all soils were reused on site.

Figure 4.4 Initial Excavation of ASW. Source: Duke Bitsko

4.6. Sewer Separation Components/Gray Infrastructure

Several infrastructure alterations and upgrades were needed outside of the ASW construction area to pre-treat and regulate the inflow of stormwater to the wetland. As shown on Figure 12, several grey infrastructure devices, such as grit pits, remove some of the sediment load before the water reaches the wetland. The bending weir (near railroad, Figure 12) allows flows up to a level of 2.39 (NGVD) to enter the ASW forebay and diverts extreme flows to a new stormwater outfall on the Little River (where the former combined CAM004 outfall had been). This control prevents flooding of the wetland and low-lying parts of the upstream catchment area during severe storms. For a detailed description of the wetland components, see Appendix C.

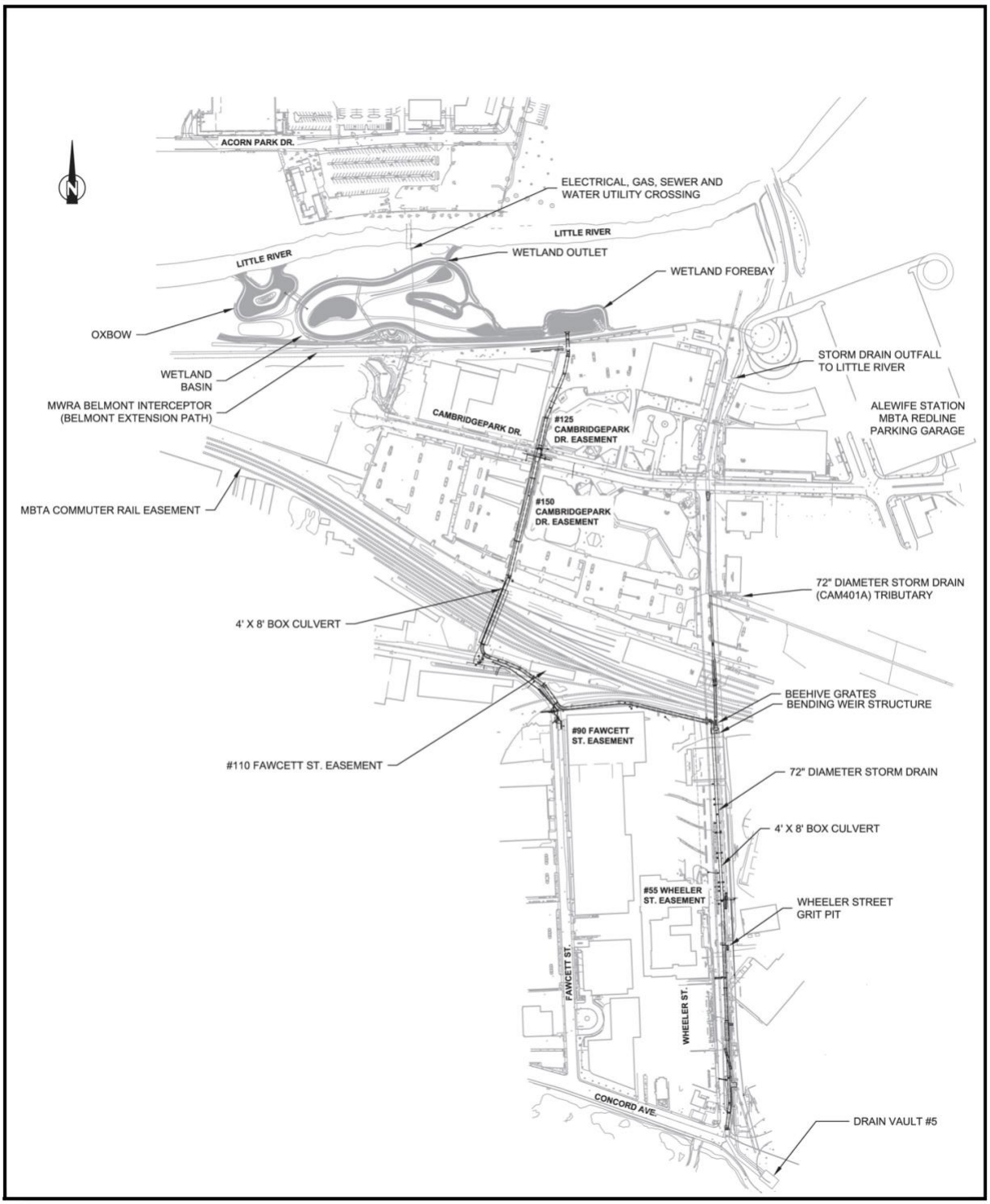


Figure 4.5 Influent Piping and ASW Schematic. Source: Operations and Maintenance Manual

4.7. Design Features that Facilitate Mosquito Management

Predators that are normally present in a healthy wetland, such as dragonflies, fish, fungi, worms, and protozoa, feed on mosquito eggs and larva. Eggs must be laid in stagnant water that remains stagnant through the larval and pupal stages of the mosquito (lasting 10-14 days) (CDC, 2024). Moving water disrupts the breathing tube that larva and pupa use to breathe beneath the water. Thus, diverse vegetation that provides habitat for predators and constantly moving water make the wetland inhospitable to mosquitos.

The grading of the ASW was designed so that the wetland pools would have a surplus of water during normal conditions due to groundwater infiltration. This creates a small flow of water from across the main basin from west to the discharge point in the east (Bioengineering Group, 2004). During droughts, when the water level in the main basin drops below the water level in the Little River, a flow management valve opens, allowing water from the Little River to enter the basin and promote freshwater flow (Bioengineering Group, 2004). Additionally, the large surface areas in the main wetland basin and forebay means that wind can agitate the surface to further discourage stagnant water conditions.

Additionally, the flow equalization manhole (described in-depth in Appendix C) helps regulate the water level in the main basin by exchanging water with the Little River during extreme low or high flow periods. This was a feature added later in the design to improve the performance of the system. It is critical to maintain a proper water level in the main basin to support the plant ecosystem (and thus the mosquito predator habitat).

Points of shallower or slower moving water on the periphery of the wetland are more prone to mosquito egg laying. Dead vegetation may also disrupt surface flow, creating pockets of

stagnant water that can facilitate mosquito growth. Removing this material as part of regular maintenance is stipulated in the O&M manual.

4.8. Regulatory Compliance

The Cambridge Conservation Commission issued an Order of Conditions (June 16, 2004) requiring the project team to submit a complete Operations and Maintenance Plan as well as regular inspection reports including vegetation monitoring. The Operations and Maintenance Plan was submitted to the Cambridge Conservation Commission and MassDEP in June 2015, and annual reports are submitted each January.

The project also adheres to MassDEP Stormwater Standards despite not meeting the regulatory definition of 'new development', which makes meeting the stormwater standards obligatory. Important standards achieved by the project include 80% (or greater) reduction of total suspended solids (TSS) in post-development conditions, erosion and sediment controls implemented during construction, and creation of an operations and maintenance plan for all BMPs. Hydraulic and hydrologic modeling confirms that the project meets flood storage and stormwater standards. Table 4.1 describes the performance of the wetland in different design storms. In general, the water level in the main basin is about 6 inches higher than the Little River.

Table 4.1 Design Storm Effects on ASW. Adapted from Operations and Maintenance Manual

Storm Event	Inches/24 Hours	Approximate Drain Time (Days)	Description
6-month MWRA	2.25	1 day 9 hours	
1-year NCRS	2.7	1 day 22.5 hours	Flow over the cross berm from forebay
2-year NCRS	3.3	2 days 10.8 hours	Flow over the weir to 36” outlet
5-year NCRS	4	2 days 21 hours	Main basin nearly full
10-year NCRS	4.7	3 days 15 hours	Flow over spillway
25-year NCRS	5.7	3 days 22 hours	Flow over entire basin perimeter

Chapter 5 Measuring Performance of the ASW

This chapter describes how I assessed the performance of the ASW using several holistic measures: water quality, ecological value, and cultural value. I aim to answer research questions 1, 2, and 4 in this section, using a mixed-methods approach.

5.1. Water Quality

5.1.1 ASW Data Exploration

To assess the water quality performance of the ASW, I studied trends in water quality parameters, and then I compared ASW averages to other constructed wetlands complied in a systematic review by Land et al. (2016).

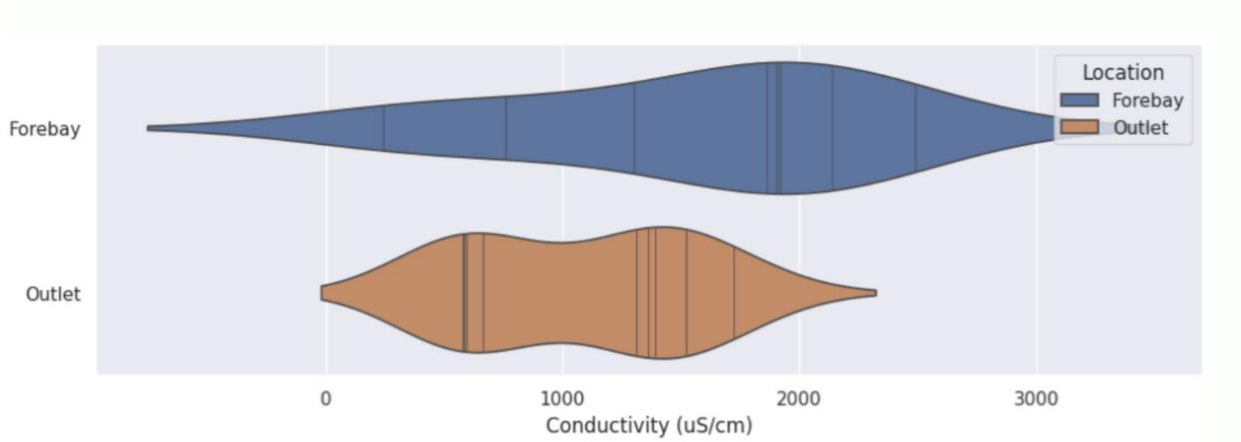
The ASW water quality data was collected beginning in 2017, four years after construction was completed. The City of Cambridge conducted a series of ten dry-weather water quality sample events, which included grab samples collected before treatment in the stormwater box culvert at Cambridgepark Drive, and after treatment at the outlet of the ASW system. The purpose of this sampling regime was to look for differences in inlet and outlet concentrations of 12 water quality variables:

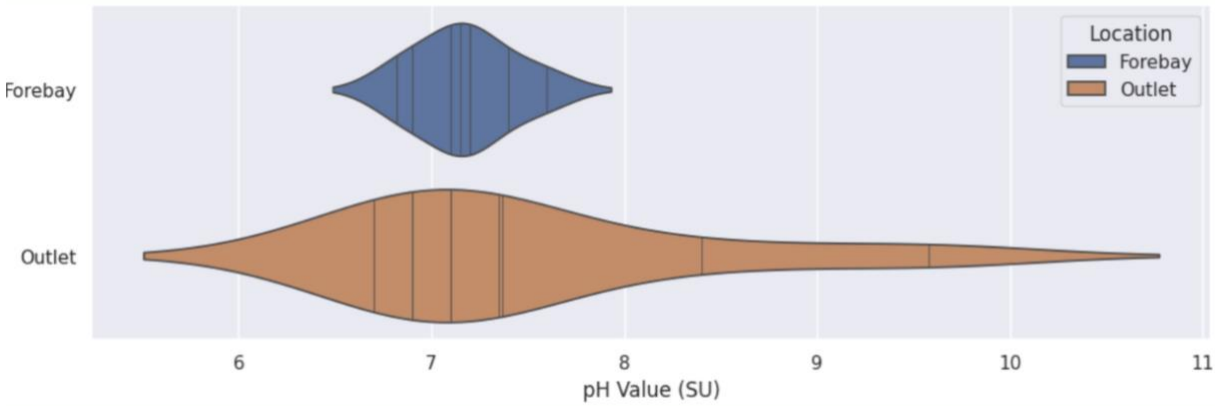
- pH Value (SU)
- Conductivity (uS/cm)
- E. coli (MPN/100ml)
- Enterococci (MPN/100ml)
- Fecal Coliform (Colonies/100ml)
- Ammonia Nitrogen (mg/L)

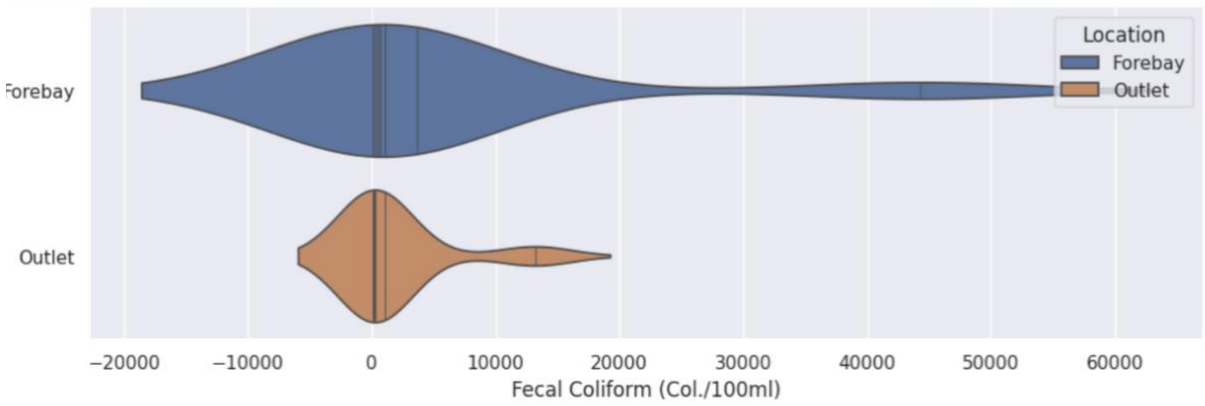
- Nitrate Nitrogen (mg/L)
- TKN (mg/L)
- Nitrite Nitrogen (mg/L)
- Total Phosphorus (mg/L)
- TSS (mg/L)
- BOD (mg/L)
- MBAS (Surfactant) (mg/L)

The sampling dates ranged from 4-10-17 to 8-27-20, with most of the samples taken between April and August in 2017 and 2018. The wetland was sampled once in November 2018, once in January 2019, and once in August 2020.

Figure 5.1 shows preliminary data exploration of ASW inlet and outlet pollutant concentrations for Total Nitrogen, Total Phosphorus, E. coli bacteria, Conductivity, pH value, and Fecal Coliform. For all variables except pH, the spread of the data decreased from inlet to outlet. It is expected that the pH of the stormwater entering the wetland would be more acidic (pH less than 7) due to the presence of urban pollutants such as NO_2 in rainwater (Papagiorgio, 2019). It is somewhat surprising that the mean pH is not significantly lower at the inlet, but this may be because the water goes through some smaller GI interventions in the CAM-004 neighborhood before it discharges to the outlet, which offers some pre-treatment and potential pH buffering. The degree to which the wetland can raise the pH of stormwater to a more biologically conducive level of 7 or 8 depends on many factors, such as temperature, plant species present, and animal activity (Papagiorgio, 2019). These factors were likely highly variable during the study period, leading to highly varied readings of outlet pH.


Location
Forebay
Outlet
Forebay
Outlet
0
1000
2000
3000
Conductivity (uS/cm)


Location
Forebay
Outlet
Forebay
Outlet
6
7
8
9
10
11
pH Value (SU)


Location
Forebay
Outlet
Forebay
Outlet
−20000
−10000
0
10000
20000
30000
40000
50000
60000
Fecal Coliform (Col./100ml)

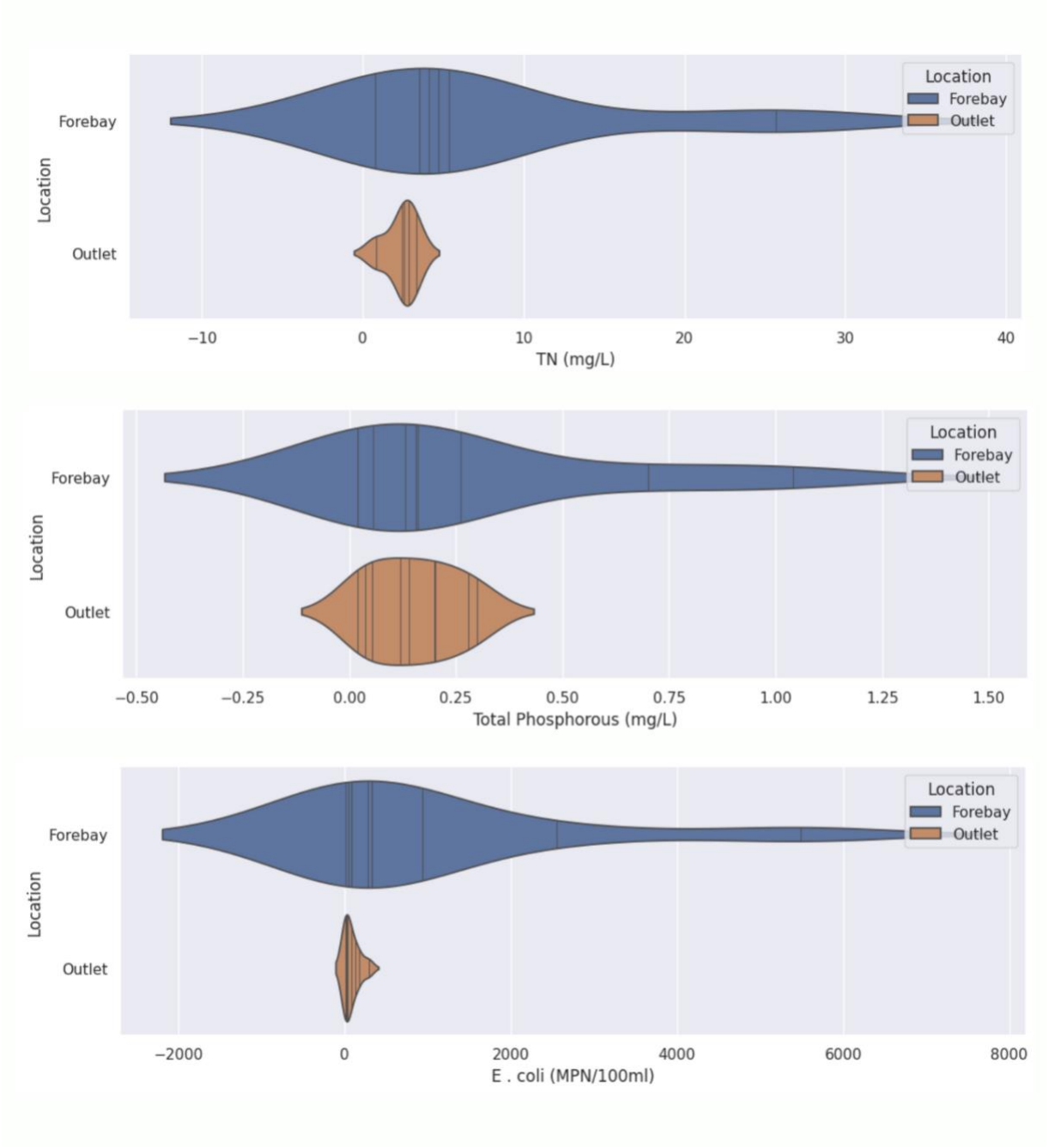


Figure 5.1 Violin Distribution Plots of Selected Pollutants at ASW

Mean conductivity is lower in the outlet samples than in the inlet samples, indicating improvement in water quality since lower conductivity is typically associated with fewer

dissolved solids (US EPA, 2013). When read in context, this trend may indicate that the wetland is reducing concentrations of dissolved soils from the stormwater.

The outlet concentrations of Nitrogen, Phosphorus, E. coli, and Fecal Coliform show lower spread than the inlet concentrations, and lower mean values. The high range of values in the inlet concentrations may be due to precipitation patterns. Because sediment (which can be a carrier for several pollutants) on impervious surfaces can mobilize during rain events in an exponential fashion (modeled by Equation 5.1), the "first flush" of a rainstorm carries a higher load of pollutants. Depending on how intensely and frequently it rained in the days leading up to sampling, pollutant load might be highly variable. Nevertheless, the lower standard deviation in the outlet concentration data suggests a stabilizing effect.

$$W = C_1 \cdot q^{C_2} \cdot B$$

where:

W	=	rate of pollutant load washed off at time t in lbs/hr
C_1	=	washoff coefficient in units of $(\text{in/hr})^{-C_2}(\text{hr})^{-1}$
C_2	=	washoff exponent
q	=	runoff rate per unit area at time t, in/hr
B	=	pollutant buildup remaining on the surface at time t, lbs.

Equation 5.1 Exponential Wash-Off Equation used in the U.S. Environmental Protection Agency's Stormwater Management Model (SWMM)

5.1.2. Comparative Analysis

The comparative data that I analyzed comes from a 2016 paper entitled "How effective are created or restored freshwater wetlands for nitrogen and phosphorus removal? A systematic review" (Land et al., 2016). The objective of the paper was to estimate the magnitude of nutrient removal efficiencies in different constructed wetlands using a black box approach. Because very few studies included full nutrient budgets or adequate replication, it was not possible in the scope of the review to form conclusions on the actual nutrient removal mechanisms. The authors extracted nitrogen and phosphorus removal data from 203 constructed wetlands across the globe, only including studies that met rigorous screening criteria. To avoid selection bias (i.e., sampling at a given wetland was only done at certain conditions, for example only periods of low inflows), the authors only included studies that: 1) covered a full annual cycle with adequate sampling frequency; 2) included complete hydrologic budget calculations[4]; 3) employed the same sampling and analytical methods for all observations; and 4) had the same number of samples for inlet and outlet. The authors selected studies in Köppen-Geiger climate classification Group D (snowy climates), Group C (warm temperate climates) and parts of group A (Equatorial climates with one dry season). Other climate zones were not included.

In addition to nitrogen and phosphorus loading and removal rates, Land et al. collected data on variables that may affect nitrogen and phosphorus removal. These variables are listed in Table 5.1.

[4] A hydrologic budget is a mass balance of the flow of water in and out of a system. Unaccounted for volume of water may indicate that an external process (rather than the wetland process) is driving results.

Table 5.1 Selection of Variables Collected by Land et al., 2016

Geographic/Temporal Variables	**Climate Variables**	**Wetland Design Variables**
State/Country	Air temp (°C)	HLR (m/yr)[5]
Lat/Long	Precipitation (mm/yr)	Water regime[6]
Time of Study	Climate Zone	Wetland type[7]
		Inflow type[8]
		Area (m^2)
		Vegetation type

The authors then calculated loading rates ($g/m^2/yr$) for total nitrogen (TN) and total Phosphorus (TP), with removal efficiencies calculated using the following formula:

$$Removal_{efficiency} = 100 \times \frac{Substance_{flow_{in}} - Substance_{flow_{out}}}{Substance_{flow_{in}}}$$

Equation 5.3 Removal Efficiency (Land et al., 2016)

Preparing the ASW dataset to align with all the variables used by Land et al. (2016) required several steps. First, to get the values of TN inlet and outlet concentration, I added all the species of nitrogen using the following formulas:

TKN (Total Kjeldahl Nitrogen) = NH_3 + Organic Nitrogen

Total Nitrogen (TN) = TKN + NO_2 + NO_3

(Total phosphorus was already tabulated in the lab results).

[5] Hydraulic Loading Rate (HLR) is the volume of inflow divided by the surface area of the wetland. It is a measurement of flow per area.

[6] Water regime is how the water enters the wetland. Water regime can be precipitation-driven (such as for a stormwater wetland) or generally constant flow (such as for a wastewater treatment wetland).

[7] Examples of wetland types include free water surface (most common), riparian, or various types of subsurface flow, as described in Chapter 3.

[8] Examples include stormwater, wastewater, agricultural runoff, etc.

Next, I needed to determine TN and TP removal rates, or the mass of nutrient removed per unit area per year. Because the ASW dataset lacks flow data needed to determine an accurate hydrologic budget, an approximate flow was used to calculate TN and TP loading rates.[9] I used an approximate wetland surface area of 2.75 acres, a catchment area of 335 acres, and average annual rainfall rate of 48 inches per year, and a runoff coefficient of 0.6 to calculate an approximate flow of 264 million gallons (999,861 m^3) per year. I calculated average influent concentrations of 8.68 mg/L TN and 0.28 mg/L TP; and average effluent concentrations of 2.24 mg/L TN and 0.15 mg/L TP. Using the flow rate calculated above, the ASW removes approximately 6,263 kg-TN and 132 kg-TP per year. When accounting for the surface area of the wetland, this converts to removal rates of 562.8 $g/m^2/yr$ and 11.9 $g/m^2/yr$ for TN and TP respectively. The overall removal efficiency, which is the percent reduction in concentration or load, is 72% for TN and 47% for TP. The same flow approximations yielded a Hydraulic Loading Rate (HLR) of 89.8 m/yr. Full calculations can be found in Appendix D.

I used both the removal efficiency and the removal rate to compare the performance of the ASW to other wetlands in the Land et al. (2016) study. Removal efficiency measures the load percent of load removed per unit volume of water. It is a useful metric for public communication, as different treatment technologies are commonly compared using these percentages. However, removal efficiency does not consider the relative size of the wetland, a factor that Land et al. (2016) note highly influences performance and overall productivity. For example, if Wetland A and Wetland B both have an influent concentration of 10 mg/L, and Wetland A has an effluent of

[9] Note that this calculation does not include specific recharge and runoff rates determined by land cover and soil type (the catchment area is assumed 100% impervious). It does not account the proportion of annual rainfall that arrives in a major storm event and would thus trigger the flow bypass mechanism (see Chapter 5). It also does not include runoff from the wetland's local sub-watershed, or any effect of the flow equalization manhole. A more detailed hydrologic budget is recommended as a next step for this project.

3 mg/L and Wetland B an effluent of 5 mg/L, one could determine that Wetland A is more efficient because it boasts a 70% removal efficiency to Wetland B's 50% removal efficiency. However, if Wetland A processes 10,000 m^3 water per year and Wetland B 1,000,000 m^3, Wetland B removes more mass per unit area (500 $g/m^2/yr$ vs. Wetland A's 70 $g/m^2/yr$). Therefore, in addition to removal efficiency, I include removal rates ($g/m^2/yr$) to provide a more complete and technical comparison of ASW performance to wetlands in the Land et al. dataset.

As indicated by Table 5.3, ASW removal efficiency and removal rate for both TN and TP exceed the median values reported in Land et al. (2016). This suggests that the ASW is highly effective at nutrient removal, both on a per unit volume basis (as reflected by removal efficiency) and a per unit area basis (as reflected by removal rate), compared to other constructed wetlands in the study.

Table 5.2 Alewife Stormwater Wetland TN and TP Removal Rates

Nutrient	**ASW Removal Efficiency**	**Land et al. (2016) Median Removal Efficiency**	**ASW Removal Rate ($g/m^2/yr$)**	**Land et al. (2016) Median Removal Rate ($g/m^2/yr$)**
Total Nitrogen	72%	37%	562.8	93.0
Total Phosphorus	47%	46%	11.9	1.2

The performance of the ASW was further evaluated by comparing removal efficiencies to the ~203 wetlands in the Land et al. (2016) dataset using histograms (shown in Figures 5.2 and 5.3)

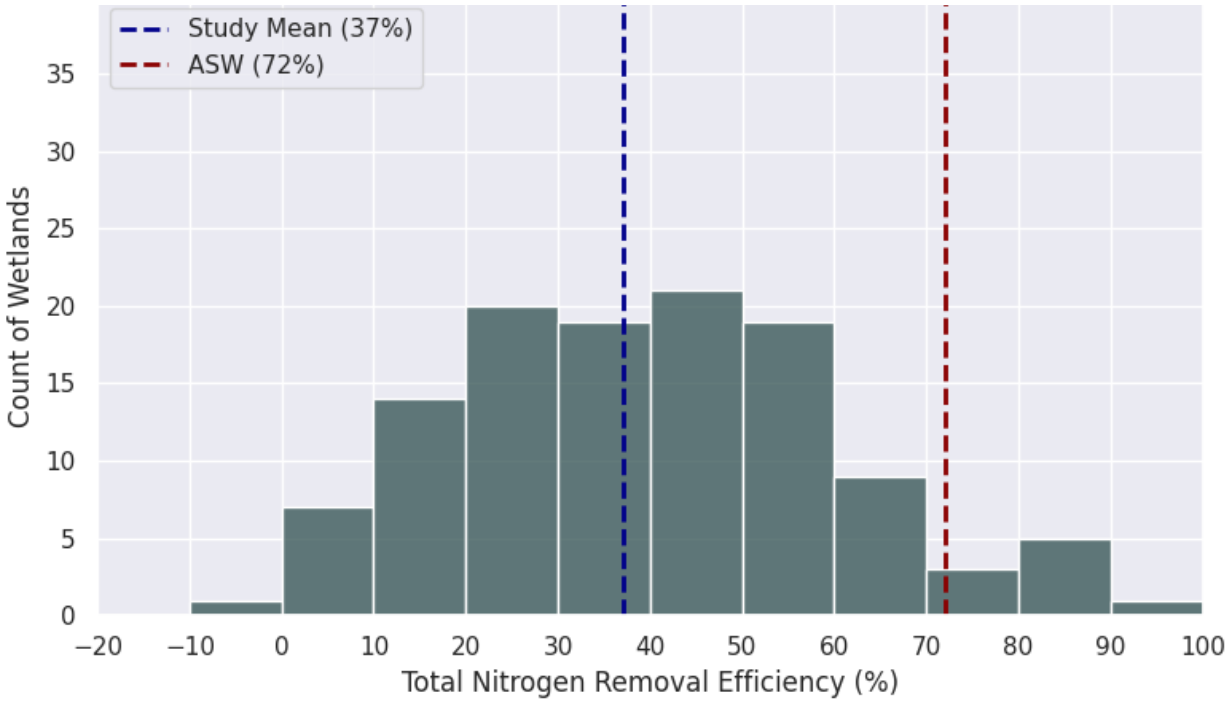


Figure 5.2 Land et al. (2016) Total Nitrogen Removal Efficiency Counts

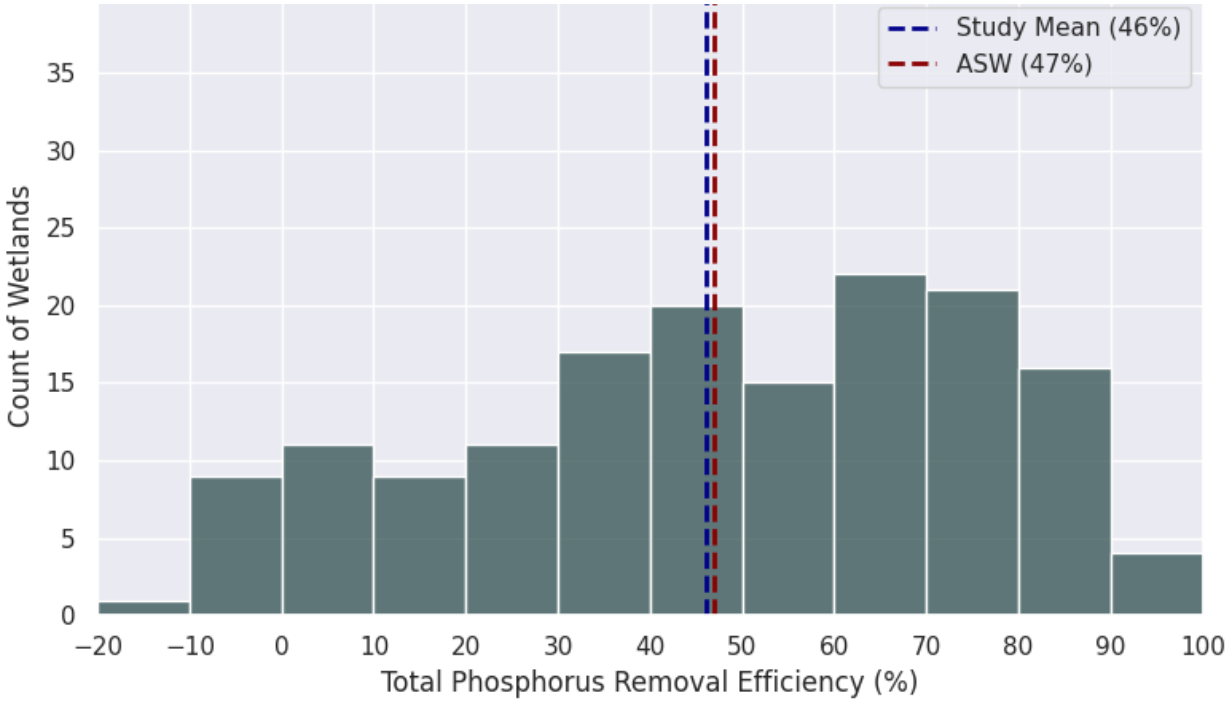


Figure 5.3 Land et al. (2016) Total Phosphorus Removal Efficiency Counts

The range of removal for Nitrogen was considerably smaller than the range of removal for Phosphorus. Land et al. suggest that because many of the wetlands studied were situated near agricultural land with soils enriched from fertilizer (a major source of phosphorus), they may present as sources of phosphorus rather than sinks (i.e. they have negative phosphorus removal rates). The ASW outperformed the study mean for both pollutants.

Bar plots of removal efficiency by inflow subgroup add depth to this observation. Figure 5.4 shows Nitrogen removal efficacy across the different inflow types represented in the study.

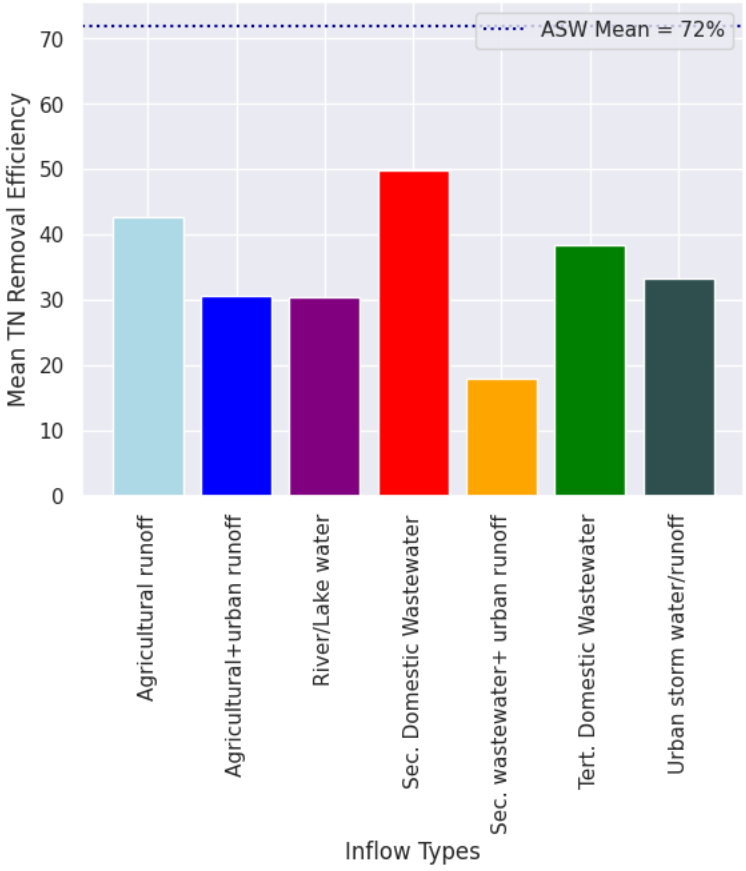


Figure 5.4 Total Nitrogen Removal Efficiency Means by Inflow Type

As shown, the ASW mean is much higher than any of the group averages. Stormwater wetlands show the third highest removal efficiency of any of the inflow types. Figure 5.5 shows the equivalent plot for phosphorus removal:

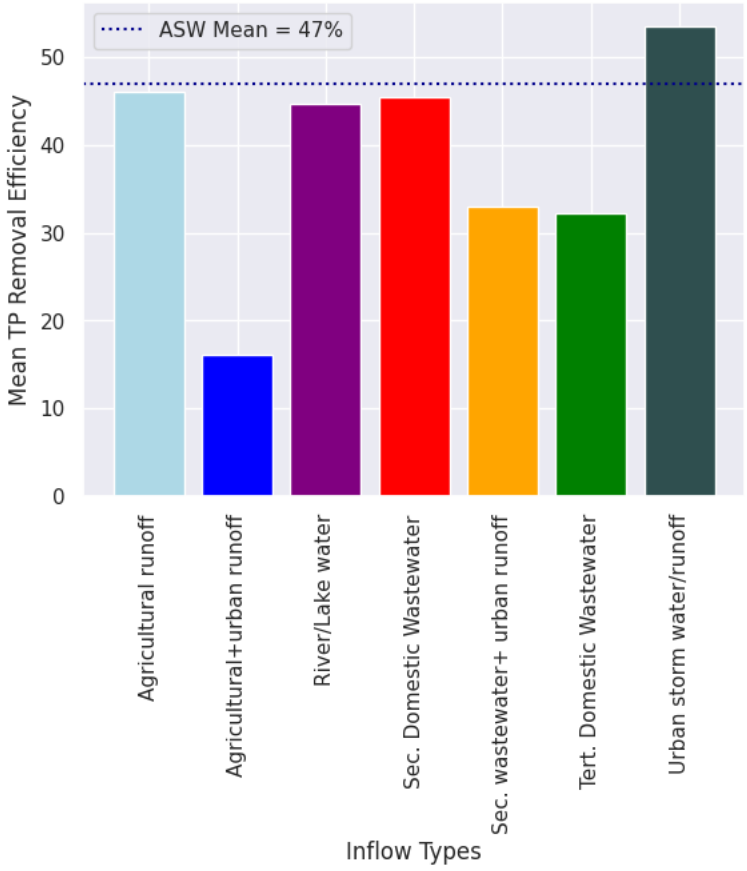


Figure 5.5 Total Phosphorus Efficiency Means by Inflow Type

As shown, the ASW does not achieve as high an average TP removal efficiency as the stormwater wetland group mean. This is an important complication of Figure 5.3 Because other types of wetlands (especially agricultural runoff types) are overrepresented in the study, the study mean skews lower than the stormwater group average. Thus, the ASW is not an outlier when evaluated within its group.

5.1.3 Correlation Studies

The correlation matrix in Figure 5.6 shows the relationship between Air Temperature, Precipitation, Hydraulic Loading Rate, TP Removal Efficiency, and TN Removal Efficiency. There is a moderately strong positive correlation between Air Temperature and Precipitation. This finding was somewhat expected, as these two variables are often positively correlated, especially in subtropical climates[10] where many of the included studies were conducted.

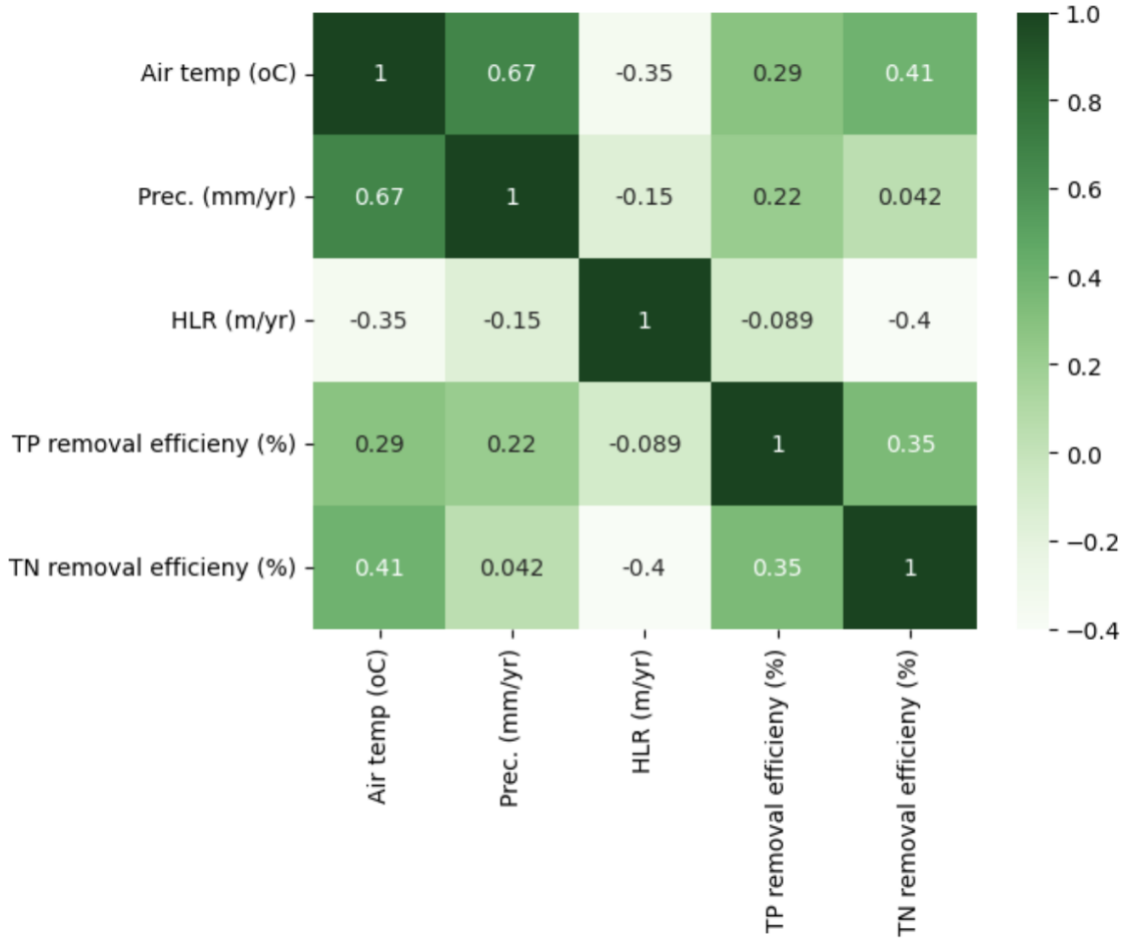


Figure 5.6 Correlation Matrix

[10] Trenberth, Kevin E., and Dennis J. Shea. "Relationships between Precipitation and Surface Temperature." *Geophysical Research Letters* 32, no. 14 (2005). https://doi.org/10.1029/2005GL022760.

There was a low-moderate positive correlation of 0.35 between TN removal efficiency and TP removal efficiency. Both Nitrogen and Phosphorus can be removed by sedimentation and plant uptake.[11] Therefore, wetlands that promote sedimentation (e.g. through increased detention time) and promote growth of vegetation would support high removal rates of both nutrients. The flow path of the ASW meanders the wetland, lengthening detention time and helping to remove nutrients through sedimentation. Additionally, the wetland was carefully designed to support a diverse array of plant species, which might support high uptake capacity for both nutrients.

There is a moderately negative correlation between HLR and TN removal, suggesting that high flows into the wetlands hinders TN removal (possibly through reduced detention time). Phosphorus removal efficiency doesn't appear to correlate to HLR.

Temperature and TN removal efficiency are positively correlated (r = 0.41) while temperature is less positively correlated with TP removal (r = 0.29). The opposite set of relationships is observed with precipitation: TP and precipitation are slightly positively correlated (r = 0.22), while TN and precipitation show very little relationship (r = 0.042). Figure 5.7 shows the difference in correlation patterns related to temperature between Nitrogen and Phosphorus.

[11] Land, Magnus, Wilhelm Granéli, Anders Grimvall, Carl Christian Hoffmann, William J. Mitsch, Karin S. Tonderski, and Jos T. A. Verhoeven. "How Effective Are Created or Restored Freshwater Wetlands for Nitrogen and Phosphorus Removal? A Systematic Review." Environmental Evidence 5, no. 1 (May 9, 2016): 9. https://doi.org/10.1186/s13750-016-0060-0.

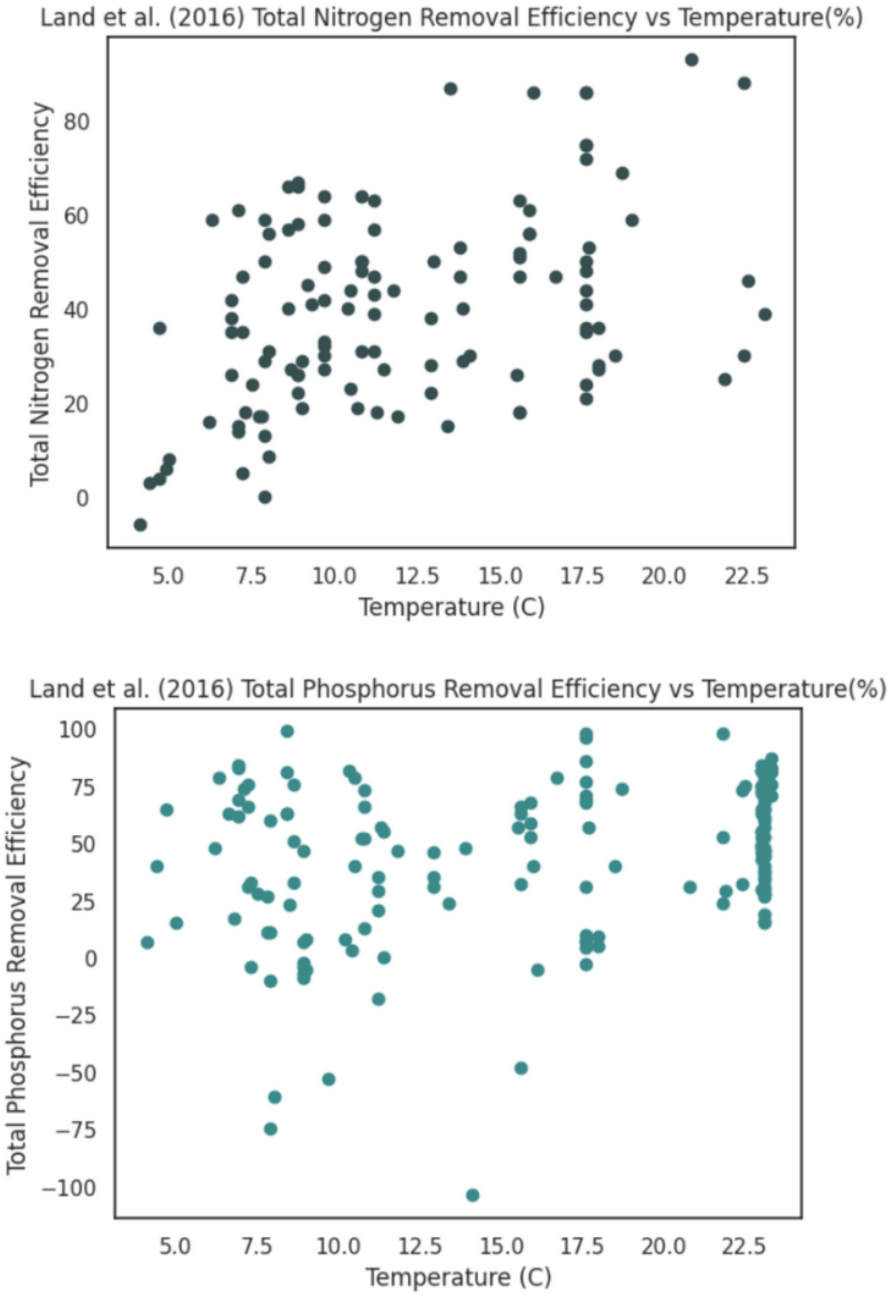


Figure 5.7 Temperature vs Removal Efficiency for Nitrogen (top) and Phosphorus (bottom)

5.1.4. K-Means Clustering Analysis

A K-Means clustering analysis was run on the data to identify the wetlands that were most similar to the ASW based on the five variables. ASW is in Cluster 6, which is characterized by lower-than-average HLR, around average TN and TP removal efficiency, slightly lower than average precipitation and slightly higher than average air temperature. The black dashed lines in Figure 5.8 represent the mean values for each variable across the entire sample, and the colored sectors represent the within-cluster mean.

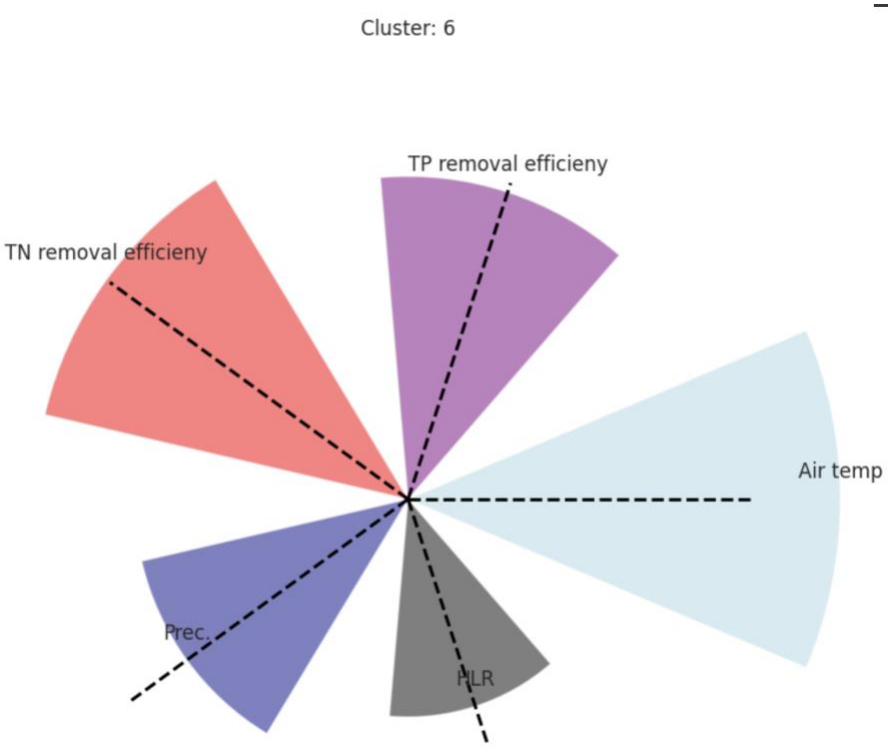


Figure 5.8 Cluster 6, K-means Cluster Analysis

5.1.5. Discussion

This analysis found that the ASW demonstrates relatively high removal efficiency rates for nitrogen and phosphorus compared to other constructed wetlands worldwide. When compared just to other stormwater wetlands, the ASW demonstrates better removal efficiency for

TN, and slightly below average removal rates for TP. Land et al.'s data also explored the variables that are most highly correlated with TN and TP removal efficiency, revealing that while temperature may be more related to TN removal efficacy, precipitation is more correlated with TP removal efficiency. HLR is negatively correlated with removal of both pollutants.

For projects that have already been constructed, like the ASW, ongoing scientific studies can help guide recommendations for maintaining or increasing the removal efficiency of the system. For example, it may prove fruitful to try to increase the TP removal efficiency of the ASW to meet water quality goals in Alewife Brook, given that the Mystic River system has known phosphorus impairments. Since high HLR is found to be negatively correlated with Phosphorus removal efficiency, interventions may be taken to lower the HLR of the ASW, perhaps by increasing its surface area.

5.2. Ecological Value

Ecosystem services are an important benefit of the ASW, but unlike the empirical data, ecological value is evaluated qualitatively. For this analysis, ecological value of the wetland was derived from interviews with maintenance staff. Below is a summary of how the ASW provides ecosystem services described by the MEA:

Provisioning Services: Although the wetland was not designed to cultivate plants for harvest, there are several circumstances where biomaterials are removed from the wetland. The first is when the horticulturalists hand-cut vegetation to manage growth, remove dead plants or remove invasive/aggressive species. When the native meadow is mowed to improve growth habit some of the material is left in place, which allows viable seeds to resow.

The horticulturists reported that park visitors occasionally harvest plants, such as Oriental Bittersweet (*Celastrus orbiculatus*), which is an aggressive and fast-growing vine with bright red

berries. Interviews with staff suggest that this is a somewhat regular occurrence during the fall when the berries are visible. This is an unexpected symbiotic relationship between the wetland system and park visitors.

Regulating services: Perhaps the primary regulating service of the ASW is its effect on local hydrology and water quality. Before the ASW was implemented, flooding was a regular occurrence around the reservation and surrounding neighborhoods. Hydraulic modeling of the sewer separation area suggests that flooding has been greatly reduced up to the 10-year storm event.

Other benefits to the local microclimate include heat sequestration effects of the open water and trees. The high heat capacity of water allows waterbodies such as the ASW to absorb ambient heat without a large temperature increase. Because the surrounding land warms faster than the water, the thermal contrast creates a breeze system which cools the land (Miller et. al, 2003). Vegetation also helps to reduce heat exposure by shading land, deflecting solar radiation, and transpiration cooling (EPA, 2025). The project included the planting of 375 trees and over 120,000 wetland plant plugs during the construction of the wetland, with more young plants brought in over time as part of adaptive management.

5.3. Cultural Value

The ASW's *Cultural services,* or intangible benefits to the local community, are multifold and began before the project was completed. A team of volunteers including community members and students helped plant thousands of wetland plants during construction. The ASW contributes to student stewardship and learning. According to the Mystic River Watershed Association, several area schools take annual field trips to the ASW, and children as young as elementary age are building a vocabulary of water quality, ecology, and engineering

terms. Students from local universities have participated in site walks, stream flow measurements and water quality sampling.

The integration of the ASW with the Minuteman Commuter Bikeway, existing walking paths, and Alewife Red Line Station means that it is accessible to many, including Environmental Justice populations. CWs of this size are rare in urban areas due to land constraints. Thus, the ASW is a unique asset for recreation and citizen science.

Maintenance crew have also reported forming relationships with residents of the nearby apartment buildings, who they encounter while performing twice weekly maintenance during the growing season. The residents report wildlife and rare plant sitings, and/or maintenance concerns that get incorporated in their routine reporting. According to the interviewees, some park-goers are inquisitive about invasive plant removal and ask for species identification. Many give thanks to the maintenance crew or inquire further about their job. A staff member received a letter of thanks from a resident 2021, which described how the ASW provided a much-needed nature outlet during the COVID-19 lockdowns of 2020 and improved the individual's mental health.

5.4. Public Understanding and Policy Context

While the ASW itself has received a lot of positive feedback from community members, its role in shaping public perception of stormwater management in Cambridge is not well-known. Outside of a few activist groups, public awareness of stormwater infrastructure is generally limited, says Cambria Ung, the City of Cambridge Stormwater Program Manager. As described in Chapter 3, regulations like the MS4 permit play a critical role in how stormwater infrastructure is selected, maintained, credited, and evaluated, but the public tends to know little about the regulatory process. I interviewed Ung to better understand how regulations and public perception shape stormwater policy in Cambridge, and how the ASW fits into that landscape.

A main challenge that Ung identified was that the public generally does not interact with stormwater infrastructure until something goes wrong. “Trying to get them to think [about stormwater] is a challenge. It’s out of sight, out of mind,” she said, especially in times of drought. She added that some GI measures, such as the curbside bioretention employed in the CAM-004 catchment area, are more visible than underground infrastructure, which can be a good way to spark conversations. However, GI (particularly curbside bioretention) has provoked mixed reactions from residents in Cambridge who perceive them as a threat to mobility or parking. She noted that some residents felt positive towards the installations in general but cited concerns about having them outside their homes. Ung recounted several cases of vandalism of the bioretention basins, one instance where someone had installed a basketball hoop within it.

Ung noted that the ASW on the other hand has generally received positive feedback from nearby residents after construction. However, public awareness of the ASW’s role in stormwater management seems mostly limited to people who live in the CAM-004 neighborhood and witnessed sewer separation construction, or people who live near the Little River and witness CSOs. For people who do not live near the area or interact with the site often, stormwater management remains somewhat of an abstract concept, and many still hold the misconception stormwater flowing into regular catch basins is treated before discharging into waterbodies.

Ung also offered insight into how the ASW fits into the MS4 permitting process. Historically, Cambridge did not claim credit for nutrient removal at the ASW under MS4. Although it was originally constructed for flood attenuation, the ASW could potentially be claimed as a water quality Best Management Practice (BMP), meaning that the phosphorus reductions it provides could be counted toward pollution reduction goals that the city needs to meet regarding the Mystic River TMDL. The ASW will likely be evaluated as a phosphorus reduction BMP when the new MS4 permit requirements go into effect[12], reports Ung. Under the new MS4 permit, phosphorus reduction BMPs are assigned removal credits based on design type and storage capacity, rather than being calculated with empirical data. Ung viewed this a positive, explaining that calculating actual removals could be complicated for regulators to verify and potentially reduce the amount of credit received.

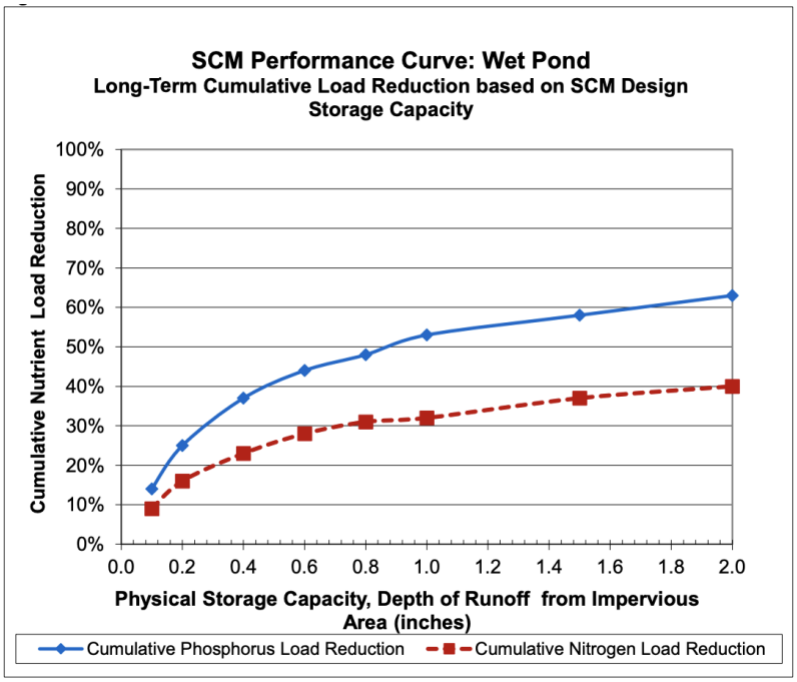


Figure 5.9 MS4 Nutrient Load Reduction Calculation Curve for Wet Ponds

[12] As of May 2025, the new Draft MA MS4 General Permit is in a public comment period. It is likely to be finalized later in 2025.

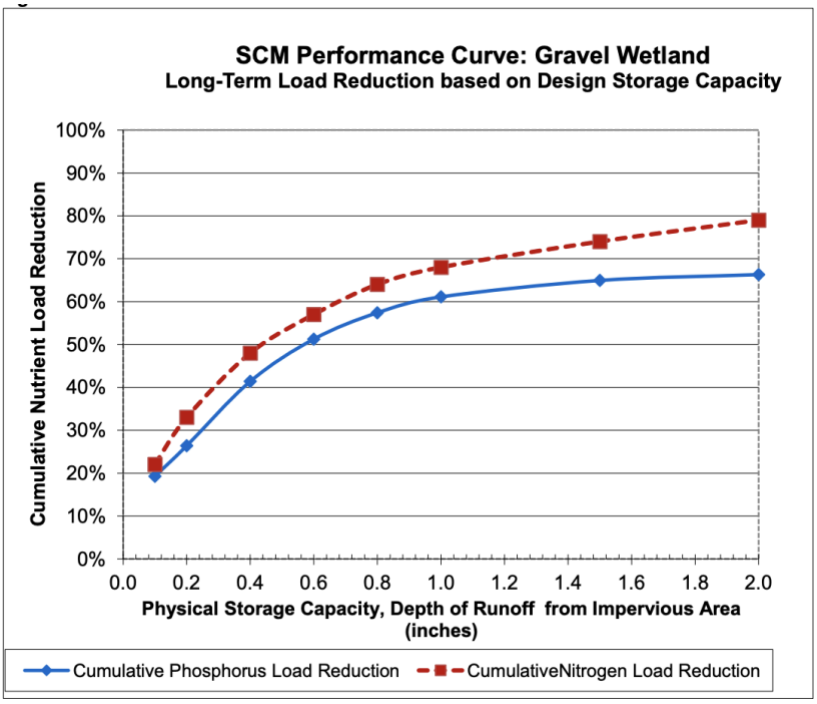


Figure 5.10 MS4 Nutrient Load Reduction Calculation Curve for Gravel Wetlands

Figures 5.9 and 5.10 show the performance curve of a wet pond and a gravel wetland (Massachusetts Draft MS4 General Permit, Appendix F, Attachment 3).[13] As discussed in the previous chapter, the ASW can store between 4 and 4.7 inches of runoff in a 24-hour storm before water overflows its banks. According to the water quality data previously analyzed, the ASW reduces phosphorus by an average of 47% and reduces nitrogen by an average of 72%. This exceeds the nitrogen reduction predicted by the wet pond curve but falls below the phosphorus removal estimate. The ASW performs below the estimate for both nutrients on the gravel wetland curve. This analysis underscores Ung's point that calculating empirical nutrient reductions may not be beneficial from a regulatory standpoint.

[13] The draft regulations define performance curves for wet ponds, dry ponds, and gravel wetlands, but there is no performance curve specifically for vegetated wetlands like the ASW, so I use the wet pond and gravel wetland curves as examples.

Overall, it can be seen as a positive that the new MS4 regulations provide tools for enhance nutrient management planning without a need for water quality monitoring of SCMs. Especially because it would not be feasible to conduct water quality monitoring for many small SCMs, like curbside bioretention basins. This is especially import in urban watersheds like the Mystic River Watershed, which has known nutrient impairments and a huge array of SCMs. However, the credit-based system might not be an accurate fit for large installations such as the ASW. The credit system provides for streamlined accounting, though potentially at the expense of encouraging empirical data collection and enhancing scientific knowledge of at-scale CWs. As discussed in Chapter 5, the water quality monitoring program at the ASW was limited in several ways, possibly because there was no regulatory incentive to conduct a robust program.

Chapter 6 Operations, Maintenance, and Monitoring

A key factor in the ASW's success is its well-documented and appropriately delegated maintenance regime. As discussed in earlier chapters, aesthetics and maintenance are common public concerns about GI projects. Because the ASW is located on public parkland, this concern was especially strong. In keeping with the Cambridge Conservation Commission Order of Conditions, the engineering and landscape architect consultants authored a comprehensive Operations and Maintenance Manual (O&M Manual) in 2016. Information in this chapter is drawn from the O&M Manual, my notes taken during site walks, and interviews with project team members. Interviews referenced in this chapter were not audio recorded. Instead, detailed handwritten notes were taken during and after the interviews. Quotes are paraphrased based on these notes with the intention of reflecting the essence of the interviewees' perspectives as accurately as possible.

6.1. Delegation

A 2014 Memorandum of Understanding between the DCR and the City of Cambridge describes that the DCR is responsible for maintaining the park features, such as the walking paths, amphitheater, bicycle racks, boardwalks, and signage. Cambridge DPW is responsible for maintain the stormwater wetland and upstream SCMs. Vegetation management within the stormwater wetland, sediment forebay, water quality swale, and oxbow areas outlined in the vegetation management plan (VMP). Cambridge subcontracts a special horticultural firm to conduct specialized vegetation management. Essex Horticulture holds the current contract, which

is rebid every three years. Figure 6.1 depicts the delegation of work.

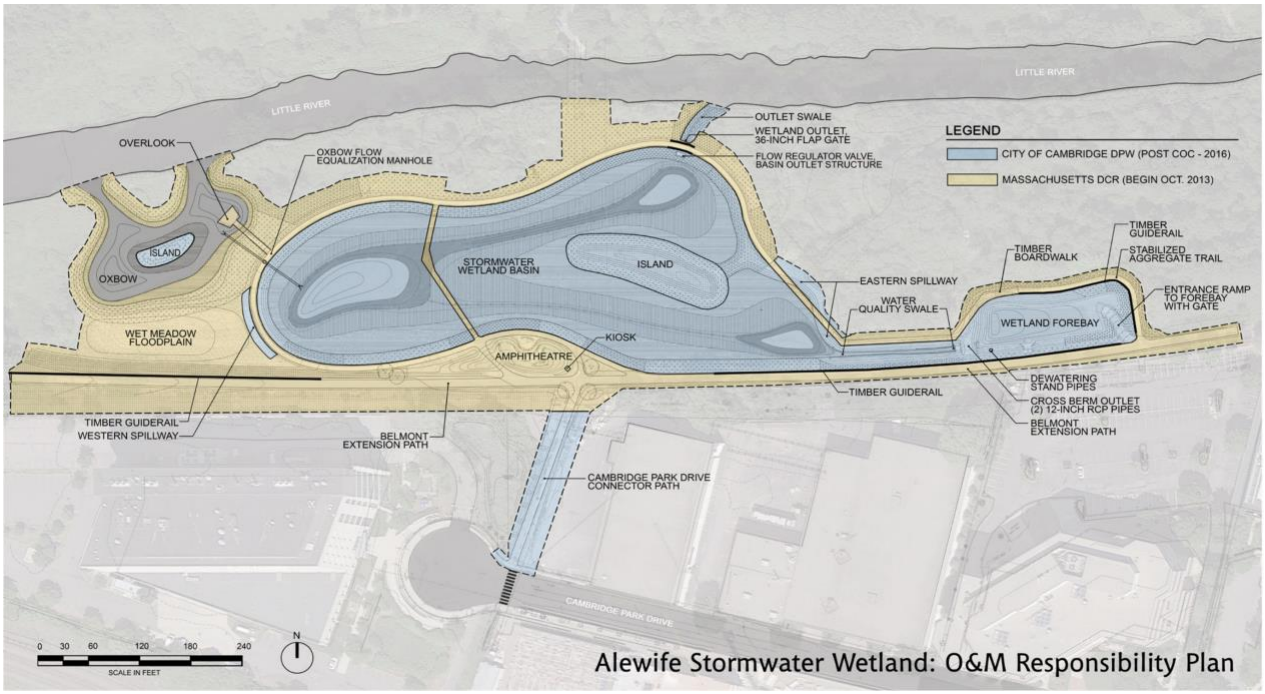


Figure 6.1 ASW O&M Responsibility Plan. Source: O&M Manual

Even though tasks are delgated, lines of communication between the three main entities (DCR, City of Cambridge, and Essex Horticulture) are well established. Representiatives from each organization attend bi-annual site walks to discuss the ever-changing maintence needs and challneges at the wetland.

6.2. Management of Gray Infrastructure

As discussed in previous chapters, maintenance for typical SCMs, such as grit pits and catch basins, has been informed by decades of empirical studies. Detailed checklists per manufacturer's specifications of each SCM are included in the O&M Manual. Many of these technologies are implemented elsewhere in Cambridge, so the skills involved for maintenance are transferable. Figure 6.2 is a checklist describing function and maintenance cadence of major gray and green infrastructure components of the project. This underscores that maintenance is highly tailored to each component of the system, and that timing of maintenance is both adaptive

to weather conditions and regularly scheduled.

Checklist Key Chart
Alewife Stormwater Wetland Field Inspection Checklist

		Timing (after Storms, Monthly, Annually)				
Checklist Item	**Function**	**A**	**3M**	**6M**	**12M**	**24M**
Grey Infrastructure						
4'x8' Box Culvert	Conveyance					X
Box Culvert Headwall	Allow flow to the forebay				X	
Grit Pit Manhole	Capture sediment		X	X	X	X
Wetland Forebay and Cross Berm Inlet/Outlet	Provide a pretreatment area for the wetland		X	X	X	
Bending Weir Structure	Regulate flow between the Little River and the wetland basin	X		X	X	
Bending Weir	regulate flow between the Little River and the wetland basin	X			X	
Vortex Valve	Provide constant flow to the Little River	X		X	X	
Flap Gate	Control flow; gate closes whenwater on front side of flap is of greater depth than back side	X		X	X	
Beehive Grate	Allow overflow to the surrounding geographic low point	X			X	
Oxbow Flow Equalization Manhole	Limit the amount of flow released into the Little River oxbow			X	X	
Flow Regulator Valve	Manage flow between the Little River oxbow and the wetland basin		X	X	X	
Basin Outlet Structure	Regulate the discharge of water to the 36-inch flap gate manhole	X	X	X	X	
Flexible Fish Flap	Prevents large animals from entering a structure and becoming stranded within structure or rip-rap	X	X	X	X	
Flap Gate Manhole	Control the elevation that water discharges from the wetland to the Little River				X	
Green Infrastructure						
Water Quality Swale	Pollutant Removal & Conveyance	X	X	X	X	
Wetland Basin - Emergency Spillways	Emergency Conveyance	X	X	X	X	
Wetland Basin - Sediment Removal	TSS Removal & Habitat				X	X
Outlet Channel to Little River	Conveyance	X	X	X		
Oxbow	Flood Storage & Habitat			X		

Figure 6.2 Maintenance of Major ASW Components. Source (O&M Manual)

6.3. Wetland Components

The bulk of my O&M research was spent investigating maintenance of the wetland components. In addition to learning about many aspects of the regime from Duke Bitsko during site walks, I interviewed Caitlyn Rodriguez, a horticulturalist at Essex Horticulture who oversees specialized vegetation management at the wetland. I also interviewed Cambria Ung, the Stormwater Program Manager for the City of Cambridge, to get more insight on public and regulatory perception of the O&M program.

One of the most critical features of the wetland to maintain is the forebay. The forebay captures much of the sediment that remains in the stormwater after the pretreatment SCMs, making it necessary to periodically dredge the forebay to maintain its capacity to store sediment. The sediment depth is measured and tracked on an annual basis. The O&M Manual recommends dredging the forebay when the sediment reaches 2' in depth. The forebay was dredged in 2021, approximately 8 years post construction. Wildlife biologists relocated fish, reptiles, and amphibians prior to dredging. As Duke Bitsko explained during a site walk in October 2024 (see Section 2.4 for details), staff discovered an unexpected array of animals forebay, which was thought to be a poor habitat due to relatively poor water quality. American Eels, which are endangered, were discovered, along with several types of turtles, fish, and amphibians. He noted that this degree of species diversity was expected in the main basin, but everyone on the team was surprised by the findings in the forebay!

Caitlyn Rodriguez described ongoing erosion issues at the forebay possibly caused by geese or pedestrians trying to access the water by traversing the banks. Several rounds of woody plants intended to stabilize the banks failed to thrive, possibly because they were shaded by larger trees that had grown in since the original planting plan was designed. The team observed

several species of plants spontaneously growing in barren patches— known as volunteer seedlings— and decided to adapt the planting plan to feature these species. This is a great example of adaptive management to solve an unanticipated problem.

The outlet of the forebay to the water quality swale must also be inspected for sediment and/or trash accumulation. It is vital that the outlet pipes from the forebay remain clear of debris. Like the forebay, the swale is inspected after every major storm (exceeding 2" in 24 hours) and four times per year. At the October 2024 site walk the team noted that the plantings in the water quality swale were progressing well and effectively reducing erosion along its banks.

6.4. Wetland Basin & Outlet Structure

The maintenance crew measures sediment levels in each of the three permanent pools in the main basin once per year. A boat is necessary to take measurements in the deepest pool (5.5') on the west side of the basin. As of 2025, over 10 years of data has been accumulated, showing little sediment accumulation. The 2004 Operations and Maintenance Plan, written before the project was delayed in the permitting phase, estimates that the pools would need to be dredged every 20 years. Based on the actual data collected, the team does not expect to dredge any part of the basin in the near future.

The team also regularly inspects for emerging tree growth, erosion of the path and wetland banks after storms, animal damage, and dead animals (dead birds are tested for avian botulism). As with the swale inflow pipes, it is critical that the outflow structure and the flow equalization pipe remain free of blockages and buildup to keep the water flowing as designed.

6.5. General Vegetation Management

As discussed previously, ensuring healthy growth of the correct plant species in the ASW is not only important for nutrient removal—it is vital to fostering a balanced ecosystem that

prevents public nuisances like mosquitos from over populating. Regular maintenance of vegetation is also crucial to the aesthetic and recreational value of the site. Perhaps the most vital step to encouraging a balanced ecosystem is removing invasive plants. Invasive plants are typically non-native species that have spread to the wild by humans. They thrive in disturbed conditions, such as construction sites. Invasive species often have no local disease or pests to control them; thus, they quickly spread and outcompete native plant species. This displaces animals that depend on native species for food and shelter.

Some notable invasive plants found on the project site include *Polygonum cuspidatum* Sieb. & Zucc. (Japanese Knotweed), *Alliaria petiolata* (Bieb.) Cavara & Grande (Garlic Mustard), and *Phragmites australis* (Common Reed). Prior to construction, *Phragmites* comprised approximately 11% of the plant population onsite. The dense stands of these reeds outcompeted native plants and created stagnant areas in the wetlands—perfect for mosquito breeding. The inhibited flow can also trap sediments, trash, and odors in the wetland. Although these species have been eradicated from the site area, dense stands still exist immediately around the site, owing to the historical land disturbance in the area. Figure 6.4 shows dense stands of Phragmites in the unmaintained wetlands along the Alewife Brook Greenway approximately 0.25 miles away from the ASW. This illustrates the potential outcome at the ASW were it not properly maintained—inviting all of the negative effects of wetland monoculture described above.

Figure 6.3. Alewife Brook Greenway. Photo credit: Wikipedia Commons User Pi.1415926535

Rodriguez explained that the horticulturalists remove all state-listed invasive species, mostly by hand. Herbicide is rarely used and never sprayed. When it necessary to combat invasives that do not respond to manual methods, such as Japanese Knotweed, a cut-and drip application is used sparingly.

They also keep close account of the native species, using detailed photographic logs to document growth and dispersal over time. Adaptive management is a guiding principle of the work, according to Rodriguez. She emphasized throughout our conversation that the balance of species in the wetland is incredibly important to maintain, and that even native species are periodically removed if they appear to be outcompeting others. For example, Arrow Arum and Pickerelweed are native to Massachusetts, but tend to form monocultures. As mentioned previously, the team also pays close attention to volunteer plants to guide future planting. Replanting, either using live stakes (dormant cuttings of woody shrubs) or seedlings, is a recurring activity in some areas that see heavy erosion or animal disturbance. At the October 2024 site walk, Rodriguez highlighted a small area in the wetland basin taped off with metallic

ribbon and netting. The installation is one of several trial plantings designed to increase species diversity (and the enclosure designed to protect the young plants from waterfowl damage). Testing and acclimating new species, Rodriguez explained, is a regular part of her job, as the environment is constantly in flux. At the end of the growing season, the team collects and conserves seeds to be sown the following spring.

Routine vegetation management is performed twice weekly during the growing season and on a reduced schedule during winter. There are several major seasonal clean ups per year where more extensive work takes place with the added input of the design team, DPW, and DCR personnel. The annual cost for vegetation management is around $50,000 USD (2023 dollars).

6.6. Public Interaction and Education

When I asked what she thought the most challenging aspect of maintaining the wetland was, Rodriguez replied emphatically, “maintaining the people!” The wetland receives many visitors due to its integration with the Minuteman Commuter Bikeway and the larger Alewife Reservation. While erosion from people straying from paths is a regular concern, the effects of people feeding wildlife is are probably the most damaging to the ecosystem. Feeding waterfowl has led to artificially large populations of birds, such as geese, which damage vegetation and degrade water quality when present in large numbers. People have also damaged signage; Rodriguez reports that theft of the “Do not feed waterfowl” signs is a weekly occurrence in the summer. Rodriguez and the horticulture team report these incidences to the city as they arise (this was a prominent topic of discussion at the October 2024 site walk).

However, the wetland’s popularity is an inherent benefit of the project, as it fosters many opportunities for reciprocal education: Rodriguez frequently fields questions about her work, while regular visitors volunteer valuable observations that enhance Rodriguez’s field notes.

Chapter 7 Conclusions

The ASW is part of an incredibly complex urban hydrologic network that bears the effects of hundreds of years of human intervention. The project represents a landmark step in the Long Term CSO Control Plan and a testament to the powerful co-benefits of green infrastructure. It received the 2014 Environmental Project of the Year award from the American Public Works Association, A New England's Best Projects Award from the Engineering News Record, and a National Recognition Award from the American Council of Engineering Companies.

Given that there are few holistic case studies of stormwater wetlands documented in scientific literature, I endeavored to contribute research to help address this gap. This thesis aimed to evaluate the ASW's performance using a holistic, mixed-methods framework that assesses water quality, ecological impact, and cultural value. I conducted statistical analysis of water quality data, a document analysis, and interviewed representatives from the project team to understand the evolution of the project, its impact, and the factors that contributed to its success. Several themes emerged from my research process, the most important of which are described below.

7.1. Main Findings

7.1.1. Interagency Collaboration

One of the most prominent themes that emerged from the interviews was that interagency collaboration turned this project from a proposal into a reality. Regulatory pressure to solve the CSO problem, DCR's rejection of grey infrastructure and lack of funds to otherwise improve the

parkland, and MWRA and the City of Cambridge's willingness to take on an alternative project coincided to create the ASW. The fact that the project was part of the LTCP was critical to securing funding from the state and is an important caveat to replicability in other areas.

The interagency collaboration that helped catalyze the project is also an important factor contributing to its ongoing success. As discussed in previous chapters, maintenance regimes for stormwater wetlands are underexplored in literature, and require site-specific knowledge and coordination across several entities to effectively develop and implement. The ASW's O&M Manual and contracts have been used as templates at several new municipal stormwater wetlands in Massachusetts, demonstrating their rigor and perceived effectiveness in the field.

Most importantly, the holistic value of the project greatly benefitted from interdisciplinary teams. Hundreds of people were involved and continue to support the project in large and small ways, including landscape architects, engineers, wildlife biologists, hydrologists, students, wetland scientists, public works professionals, volunteers, and community members. If the wetland had been just a stormwater control device and not a publicly accessible urban park and ecosystem, its valuable ecosystem services would be diminished. Almost all the interviewees indicated in some way that one of the most valuable aspects of green infrastructure is the way it brings environmental issues to the public consciousness.

7.1.2. The Importance of Siting and Design

Another critical success factor of this project was the site itself. Though the existing wetlands posed a regulatory challenge, the hydric soils in the area made the adaptation to a stormwater wetland relatively straightforward. And of course, the proximity of CAM-004 to the parkland was a key reason the wetland was proposed in the first place. Catherine Woodbury indicated that the team looked at alternate sites for a wetland, but none were large enough for the

storage capacity they needed. In fact, the Alewife Reservation was the only viable place in Cambridge for such a project.

In addition, the connectivity of the site to other public amenities undoubtedly enhanced the project from a cultural perspective. The ASW is accessible to many people, and that is part of what makes it a valuable fixture in the community, and an important tool for education. As Cambria Ung shared, the visibility of the ASW helps people see stormwater management in a more practical and less abstract way.

The discussion of location leads to another important point about replicability: siting stormwater wetlands in dense urban areas is a challenge. As discussed in previous chapters, a lower HLR typically means higher pollutant removal efficiency. A lower HLR with the same flow rate can be achieved by increasing the surface area of the wetland. In urban environments with a high percentage of impervious cover, flows will be heavy, and the appropriate wetland area may be larger than available land area. The ASW is a unique case wherein the appropriate land area and natural hydrologic connections were available to site a stormwater wetland.

Finally, the project illustrates how design affects performance outcomes. Key design choices, such as the grading of the main basin and the installation of the flow equalization manhole, were made partially to achieve an ecological benefit by maintaining appropriate water levels for a robust habitat. These decisions had implications for long-term performance of the wetland by limiting growth of invasive species and fostering diverse plant growth. This in turn enhanced the cultural and recreational value of the site by curbing mosquito populations and improving the aesthetics of the site. Thus, ecologically informed design was an important factor in garnering public acceptance of the wetland.

7.1.3. Adaptive Management

In many ways, the project team committed to an adaptive management approach. They made several design adjustments during the startup of the facility to improve its function. There was a period shortly after construction where water level in the basin remained too high for the appropriate plant species to flourish. Thus, adjustments to the flow regulator valve, swales, and flap gate were made to bring the water level back to ideal. In another instance, the water in the basin was too low, leading to invasive aquatic plant growth, so the team adjusted the flow regulator to the oxbow to bring in more water from the river during drought. Adaptive management is also heavily practiced in maintenance, as discussed in Chapter 5 through staff anecdotes. The O&M manual is described as "a living document which will need to be revised periodically to reflect dynamic conditions in the wetlands, and the evolving knowledge gained by those responsible for the facilities"— a statement that I saw truly come to life during site walks and interviews with project staff.

7.2. Limitations

This thesis has several clear limitations. Most significant is the lack of long-term, well-rounded water quality data. As discussed in Chapter 5, samples were only collected during dry weather conditions, preventing us from making a detailed assessment of the wetland's performance during storm events, when pollutant loads are expected to be highest. Additionally, no flow data was collected, preventing me from developing an accurate hydrologic budget. Data was collected starting several years into operation and was only collected over a roughly 5-year span, which limits our understanding of how pollutant removal rates may change over time— a factor that has been observed to vary over the lifespan of a constructed wetland. Due to these gaps, there is a high potential for selection bias in the dataset. Although this preliminary analysis

indicates that the ASW removes nutrients, the data do not fully a capture the empirical performance of the ASW. Unfortunately, time did not permit for me to conduct my own sampling.

During the interviews, team members cited various reasons for the sporadic sampling regime and why monitoring stopped altogether in 2020. Perhaps the most significant is the lack of a regulatory driver. The pollutant removal performance of the ASW is not tracked in MS4 reporting because the wetland was technically constructed for flood attenuation (not as a stormwater treatment BMP). While the new Massachusetts MS4 permits will assess the ASW as a phosphorus removal BMP, actual monitoring will not be required to determine the credits it receives. As Cambria Ung explained, the removal credits will be assigned based on storage volume. Thus, the new MS4 requirements will not directly incentivize robust monitoring. Perhaps a formal partnership with a local university could be forged to collect this data going forward.

Second, the method that I used to calculate removal efficiency may be ill-suited to the data given its high variability. I used mean inlet and outlet concentrations, but the median may have been more appropriate. Adjusting the calculation, in addition to collecting more data, could improve the robustness of this aspect of the study.

Third, my study design does not address other important dimensions such as climate change. Flooding is a major resident concern in the Alewife area and is expected to become more extreme due to shifting precipitation patterns brought on by climate change. The 10-year storm of today is larger than the 10-year storm of the previous decade, and this gap will only widen in the future, leaving the ASW vulnerable to more inundation than it was designed to withstand.

Finally, the study is limited by the relatively small number of interviews. Because the project was completed over 10 years ago, some of the original team members were no longer active, which limited my pool of potential interviewees. I was unable to speak with a representative from the Department of Conservation and Recreation (DCR) in a formal interview. The perspective of DCR would have helped me better understand how the team arrived at the idea to create a stormwater wetland instead of a traditional engineering solution. I also did not interview community members directly, instead relying on written comments.

7.3. Conclusion

This thesis examined the Alewife Stormwater Wetlands through four interrelated questions on performance outcomes, design and siting, operations and maintenance, and public interaction. The findings show that the ASW has largely achieved its intended outcomes of CSO reduction, water quality improvement, biodiversity enhancement, and sociocultural value, though available data was limited for some measures. The siting and design of the project shaped both its technical performance and ecological value. Key factors included the hydrologic characteristics of the site, ecologically informed design decisions, and the project's visibility within the Alewife reservation. As a guiding principle of the O&M regime, adaptive management supported the long-term function of the project despite operational challenges. Finally, interagency collaboration and public involvement greatly influenced the feasibility and acceptance of the project.

Despite these limitations, this study demonstrates the value of a holistic approach to evaluating stormwater wetlands and provides an in-depth account of a revelatory case. Popular and scientific thinking about wetlands has changed drastically over the 19th and 20th centuries. The Great Swamp has also changed drastically over the centuries—from a thriving ecosystem to

an industrial wasteland to a vital water quality feature within Cambridge's urban hydrologic network. Though the ASW is a unique case, lessons on interagency collaboration, ecologically informed design and adaptive management make it an important case study of constructed wetland design and maintenance, showing that interdisciplinary design enables solutions to complex urban water management challenges

Bibliography

Abourached, C., Linden, Y., Stelmach, R., Kennedy, C., Radin, M., & Raman, K. (2024). *Enablers and Barriers of Constructed Wetlands as a Nature-Based Solution for Wastewater Treatment: Case Studies in Jordan, Kenya, Senegal, the Dominican Republic, and the Philippines* (SSRN Scholarly Paper 5005462). Social Science Research Network. https://doi.org/10.2139/ssrn.5005462

Agaton, C. B., & Guila, P. M. C. (2023). Ecosystem Services Valuation of Constructed Wetland as a Nature-Based Solution to Wastewater Treatment. *Earth*, *4*(1), Article 1. https://doi.org/10.3390/earth4010006

Akratos, C. S., & Tsihrintzis, V. A. (2007). Effect of temperature, HRT, vegetation and porous media on removal efficiency of pilot-scale horizontal subsurface flow constructed wetlands. *Ecological Engineering*, *29*(2), 173–191. https://doi.org/10.1016/j.ecoleng.2006.06.013

Al-Rubaei, A. M., Engström, M., Viklander, M., & Blecken, G.-T. (2016). Long-term hydraulic and treatment performance of a 19-year old constructed stormwater wetland—Finally maturated or in need of maintenance? *Ecological Engineering*, *95*, 73–82. https://doi.org/10.1016/j.ecoleng.2016.06.031

Anderson, C. C., Renaud, F. G., Hanscomb, S., & Gonzalez-Ollauri, A. (2022). Green, hybrid, or grey disaster risk reduction measures: What shapes public preferences for nature-based solutions? *Journal of Environmental Management*, *310*, 114727. https://doi.org/10.1016/j.jenvman.2022.114727

Avellan, C. T., Ardakanian, R., & Gremillion, P. (2017). The role of constructed wetlands for biomass production within the water-soil-waste nexus. *Water Science and Technology*, *75*(10), 2237–2245. https://doi.org/10.2166/wst.2017.106

Balderas-Guzmán, C. (2013). *Strategies for systemic urban constructed wetlands* [Thesis, Massachusetts Institute of Technology]. https://dspace.mit.edu/handle/1721.1/80907

Barón-Hernández, J. A., Baños-Francia, J. A., Gerritsen, P. R. W., & Quijas, S. (2024). Towards a Conceptual Approach on the Connections of Urban Metabolism and Entropy with the Human Habitat. *World*, *5*(4), 1101–1119. https://doi.org/10.3390/world5040055

Beharrell, M. (2004). Chapter 19—Operation and Maintenance for Constructed Wetlands. In M. H. Wong (Ed.), *Wetlands Ecosystems in Asia* (Vol. 1, pp. 347–359). Elsevier. https://doi.org/10.1016/B978-044451691-6/50022-3

Bennett, N. (2023). Shortcomings of the Clean Water Act. *Maine Policy Review*, *32*(1). https://doi.org/10.53558/PWAR7951

Biochemical Oxygen Demand (BOD) and Water | U.S. Geological Survey. (2019, October 22). https://www.usgs.gov/special-topics/water-science-school/science/biochemical-oxygen-demand-bod-and-water

Bioengineering Group. (2004). *Operations and Maintenance Plan for BMPs Associated with CSO LTCP for Alewife Brook*. https://hatchengineering.sharepoint.com/sites/ExternalAccess/Alewife%20Wetland%20Case%20Study/Shared%20Documents/Forms/AllItems.aspx?id=%2Fsites%2FExternalAccess%2FAlewife%20Wetland%20Case%20Study%2FShared%20Documents%2FDrawings%20and%20Specifications%2FI%5FMOA%20btw%20DCR%20%26%20COC%5F2010%2D03%2D17%2Epdf&par

ent=%2Fsites%2FExternalAccess%2FAlewife%20Wetland%20Case%20Study%2FShared%20Documents%2FDrawings%20and%20Specifications

Bodus, B., O'Malley, K., Dieter, G., Gunawardana, C., & McDonald, W. (2024). Review of emerging contaminants in green stormwater infrastructure: Antibiotic resistance genes, microplastics, tire wear particles, PFAS, and temperature. *Science of The Total Environment*, *906*, 167195. https://doi.org/10.1016/j.scitotenv.2023.167195

Buck, R. C., Franklin, J., Berger, U., Conder, J. M., Cousins, I. T., de Voogt, P., Jensen, A. A., Kannan, K., Mabury, S. A., & van Leeuwen, S. P. (2011). Perfluoroalkyl and polyfluoroalkyl substances in the environment: Terminology, classification, and origins. *Integrated Environmental Assessment and Management*, *7*(4), 513–541. https://doi.org/10.1002/ieam.258

California Water Boards. (2024, September 21). *What are TMDLs?* https://www.waterboards.ca.gov/rwqcb2/water_issues/programs/TMDLs/whataretmdls.html

Cambridge Public Works. (n.d.). *Combined Sewer Overflows*. Retrieved January 10, 2025, from https://www.cambridgema.gov/en/Services/combinedseweroverflows

Carbon capture from constructed wetlands declines as they age. (n.d.). ScienceDaily. Retrieved July 22, 2025, from https://www.sciencedaily.com/releases/2025/01/250131132449.htm

Carleton, J. N., Grizzard, T. J., Godrej, A. N., & Post, H. E. (2001). Factors affecting the performance of stormwater treatment wetlands. *Water Research*, *35*(6), 1552–1562. https://doi.org/10.1016/S0043-1354(00)00416-4

CDC. (2024, May 14). *Life Cycle of Anopheles Mosquitoes*. Mosquitoes. https://www.cdc.gov/mosquitoes/about/life-cycle-of-anopheles-mosquitoes.html

Chute, N. (1959). *Glacial geology of the Mystic Lakes-Fresh Pond area, Massachusetts*. US Geological Survey. https://doi.org/10.3133/b1061f

City of Cambridge. (1995). *Alewife: A Plan for Sustainable Development*. https://www.cambridgema.gov/~/media/Files/CDD/Planning/Studies/Alewife/alewife_sustainable_plan_1995.pdf

City of Cambridge. (2024, December 2). *Combined Sewer Overflows*. https://www.cambridgema.gov/en/Services/combinedseweroverflows

City of Cambridge Community Development Department. (1979). *Alewife Revitalization: Alewife Urban Design Study Phase II*.

Cooper, R. J., Battams, Z. M., Pearl, S. H., & Hiscock, K. M. (2019). Mitigating river sediment enrichment through the construction of roadside wetlands. *Journal of Environmental Management*, *231*, 146–154. https://doi.org/10.1016/j.jenvman.2018.10.035

Copeland, C. (2014). *Clean Water Act and Pollutant Total Maximum Daily Loads (TMDLs)*.

Daigneault, A., Brown, P., & Gawith, D. (2016). Dredging versus hedging: Comparing hard infrastructure to ecosystem-based adaptation to flooding. *Ecological Economics*, *122*, 25–35. https://doi.org/10.1016/j.ecolecon.2015.11.023

De Feo, G., Antoniou, G., Fardin, H. F., El-Gohary, F., Zheng, X. Y., Reklaityte, I., Butler, D., Yannopoulos, S., & Angelakis, A. N. (2014). The Historical Development of Sewers Worldwide. *Sustainability*, *6*(6), Article 6. https://doi.org/10.3390/su6063936

DelGrosso, Z. L., Hodges, C. C., & Dymond, R. L. (2019). Identifying Key Factors for Implementation and Maintenance of Green Stormwater Infrastructure. *Journal of Sustainable Water in the Built Environment*, *5*(3), 05019002. https://doi.org/10.1061/JSWBAY.0000878

Deslippe, J. R., & Bentley, S. B. (2025). The role of wetland restoration in mediating phosphorus ecosystem services in agricultural landscapes. *Current Opinion in Biotechnology*, *91*, 103227. https://doi.org/10.1016/j.copbio.2024.103227

Doherty, L., Zhao, Y., Zhao, X., Hu, Y., Hao, X., Xu, L., & Liu, R. (2015). A review of a recently emerged technology: Constructed wetland – Microbial fuel cells. *Water Research*, *85*, 38–45. https://doi.org/10.1016/j.watres.2015.08.016

E. Sinha, A. M. Michalak, & V. Balaji. (2017). Eutrophication will increase during the 21st century as a result of precipitation changes. *Science*. https://www.science.org/doi/full/10.1126/science.aan2409

Eastern Research Group, Inc. (2020). *Mystic River Watershed Alternative TMDL Development for Phosphorus Management—Final Report* (EPA Contract No. EP-C-16-003).

Echols, S., & Pennypacker, E. (2015). The History of Stormwater Management and Background for Artful Rainwater Design. In S. Echols & E. Pennypacker (Eds.), *Artful Rainwater Design: Creative Ways to Manage Stormwater* (pp. 7–22). Island Press/Center for Resource Economics. https://doi.org/10.5822/978-1-61091-318-8_2

Elemental Phytoplankton Profiles. (n.d.). Retrieved July 19, 2025, from https://www.tamug.edu /phytoplankton/projects/Phyto-Profiles.html

Erickson, A. J., Gulliver, J. S., Kang, J.-H., Weiss, P. T., & Wilson, C. B. (2010). Maintenance for Stormwater Treatment Practices. *Journal of Contemporary Water Research & Education*, *146*(1), 75–82. https://doi.org/10.1111/j.1936-704X.2010.00393.x

Everard, M. (2018). Nutrient Cycling in Wetlands. In C. M. Finlayson, M. Everard, K. Irvine, R. J. McInnes, B. A. Middleton, A. A. van Dam, & N. C. Davidson (Eds.), *The Wetland Book: I: Structure and Function, Management, and Methods* (pp. 1437–1440). Springer Netherlands. https://doi.org/10.1007/978-90-481-9659-3_256

FAQs—Water—City of Cambridge, Massachusetts. (n.d.). Retrieved May 22, 2025, from https://www.cambridgema.gov/water/freshpondreservation/reservationuserinformation/faqs

Federal Water Pollution Control Act (1948) | Major Acts of Congress. (n.d.). Encyclopedia.Com. Retrieved January 27, 2025, from https://www.encyclopedia.com/history/encyclopedias-almanacs-transcripts-and-maps/federal-water-pollution-control-act-1948

Field, R., & Tafuri, A. N. (2006). *The Use of Best Management Practices (BMPs) in Urban Watersheds*. DEStech Publications, Inc.

Flavelle, C. (2023, January 1). A Toxic Stew on Cape Cod: Human Waste and Warming Water. *New York Times*. https://www.clf.org/news-clip/a-toxic-stew-on-cape-cod-human-waste-and-warming-water/

Gato-Trinidad, S., Carroll, J., Aladin, E., Gilbert, T., Gato-Trinidad, S., Carroll, J., Aladin, E., & Gilbert, T. (2022). Understanding the Role of Constructed Wetlands in Stormwater Management. In *Flood Risk in a Climate Change Context—Exploring Current and Emerging Drivers*. IntechOpen. https://doi.org/10.5772/intechopen.102912

Ghermandi, A., Bixio, D., & Thoeye, C. (2007). The role of free water surface constructed wetlands as polishing step in municipal wastewater reclamation and reuse. *Science of The Total Environment*, *380*(1), 247–258. https://doi.org/10.1016/j.scitotenv.2006.12.038

Gorgoglione, A., & Torretta, V. (2018). Sustainable Management and Successful Application of Constructed Wetlands: A Critical Review. *Sustainability*, *10*(11), Article 11. https://doi.org/10.3390/su10113910

Han, S., & Kuhlicke, C. (2021). Barriers and Drivers for Mainstreaming Nature-Based Solutions for Flood Risks: The Case of South Korea. *International Journal of Disaster Risk Science*, *12*(5), 661–672. https://doi.org/10.1007/s13753-021-00372-4

Herskowitz, J. (with Ontario Ministry of the Environment). (1986). *Town of Listowel Artificial Marsh Project - Project No. 128rr: Final Report*. Ontario Ministry of the Environment. http://archive.org/details/townoflistowelar00ontauoft

Hiestand, E. (2021, September 1). Watershed: An Excursion in Four Parts. *The Georgia Review*. https://historycambridge.org/articles/watershed/

Hsu, C.-B., Hsieh, H.-L., Yang, L., Wu, S.-H., Chang, J.-S., Hsiao, S.-C., Su, H.-C., Yeh, C.-H., Ho, Y.-S., & Lin, H.-J. (2011). Biodiversity of constructed wetlands for wastewater treatment. *Ecological Engineering*, *37*(10), 1533–1545. https://doi.org/10.1016/j.ecoleng.2011.06.002

Hunt, W. F., Greenway, M., Moore, T. C., Brown, R. A., Kennedy, S. G., Line, D. E., & Lord, W. G. (2011). Constructed Storm-Water Wetland Installation and Maintenance: Are We Getting It Right? *Journal of Irrigation and Drainage Engineering*, *137*(8), 469–474. https://doi.org/10.1061/(ASCE)IR.1943-4774.0000326

Imfeld, G., Braeckevelt, M., Kuschk, P., & Richnow, H. H. (2009). Monitoring and assessing processes of organic chemicals removal in constructed wetlands. *Chemosphere*, *74*(3), 349–362. https://doi.org/10.1016/j.chemosphere.2008.09.062

Ingrao, C., Failla, S., & Arcidiacono, C. (2020). A comprehensive review of environmental and operational issues of constructed wetland systems. *Current Opinion in Environmental Science & Health*, *13*, 35–45. https://doi.org/10.1016/j.coesh.2019.10.007

Ji, M., Hu, Z., Hou, C., Liu, H., Ngo, H. H., Guo, W., Lu, S., & Zhang, J. (2020). New insights for enhancing the performance of constructed wetlands at low temperatures. *Bioresource Technology*, *301*, 122722. https://doi.org/10.1016/j.biortech.2019.122722

John F. Davis. (1965, December). *The Life Story of Cambridge Water*. Cambridge Water Board. http://www.rwinters.com/undercambridge/Davis1965.htm

Jones, M. P., & Hunt, W. F. (2010). Effect of Storm-Water Wetlands and Wet Ponds on Runoff Temperature in Trout Sensitive Waters. *Journal of Irrigation and Drainage Engineering*, *136*(9), 656–661. https://doi.org/10.1061/(ASCE)IR.1943-4774.0000227

Kadlac, R., & Knight, R. (1996). *Treatment Wetlands*. CRC Press.

Kaye, C. A. (1976). *The geology and early history of the Boston area of Massachusetts, a bicentennial approach* (US Geological Survey Bulletin 1476). https://doi.org/10.3133/b1476

Kepler.gl. (n.d.). Retrieved April 17, 2025, from https://kepler.gl/demo

Kill, K., Grinberga, L., Koskiaho, J., Mander, Ü., Wahlroos, O., Lauva, D., Pärn, J., & Kasak, K. (2022). Phosphorus removal efficiency by in-stream constructed wetlands treating agricultural runoff: Influence of vegetation and design. *Ecological Engineering*, *180*, 106664. https://doi.org/10.1016/j.ecoleng.2022.106664

Kim, S. Y., & Geary, P. M. (2001). The impact of biomass harvesting on phosphorus uptake by wetland plants. *Water Science and Technology: A Journal of the International Association on Water Pollution Research*, *44*(11–12), 61–67.

Knapik, E., Brandimarte, L., & Usher, M. (2024). Maintenance in sustainable stormwater management: Issues, barriers and challenges. *Journal of Environmental Planning and Management*, *0*(0), 1–27. https://doi.org/10.1080/09640568.2024.2325041

Knox, A. S., Paller, M. H., Seaman, J. C., Mayer, J., & Nicholson, C. (2021). Removal, distribution and retention of metals in a constructed wetland over 20 years. *Science of The Total Environment*, *796*, 149062. https://doi.org/10.1016/j.scitotenv.2021.149062

Kubiak, D. A., Smoske, N. S., Coughlin, K., Rando, L., Wu, D., & Whittaker, E. (2016). *Massachusetts Water Resources Authority Combined Sewer Overflow Control Plan 2015 Annual Progress Report*.

Kuminoff, N. V., Parmeter, C. F., & Pope, J. C. (2010). Which hedonic models can we trust to recover the marginal willingness to pay for environmental amenities? *Journal of Environmental Economics and Management*, *60*(3), 145–160. https://doi.org/10.1016/j.jeem.2010.06.001

Kuşçu Şimşek, Ç., & Ödül, H. (2018). Investigation of the effects of wetlands on micro-climate. *Applied Geography*, *97*, 48–60. https://doi.org/10.1016/j.apgeog.2018.05.018

Land, M., Granéli, W., Grimvall, A., Hoffmann, C. C., Mitsch, W. J., Tonderski, K. S., & Verhoeven, J. T. A. (2016). How effective are created or restored freshwater wetlands for nitrogen and phosphorus removal? A systematic review. *Environmental Evidence*, *5*(1), 9. https://doi.org/10.1186/s13750-016-0060-0

Laskey, F. A., & Hornbrook, M. J. (n.d.). *Matthew A. Beaton, Chairman John J. Carroll, Vice-Chairman Joseph C. Foti, Secretary Austin F. Blackmon Kevin L. Cotter Paul E. Flanagan Andrew M. Pappastergion Brian Peña Henry F. Vitale John J. Walsh Jennifer L. Wolowicz*.

Laskey, F. A., Hornbrook, M. J., Kubiak, D. A., Smoske, N. S., & Lam, C. (2013). *MWRA Combined Sewer Overflow Control Plan Annual Progress Report 2013*.

Leggett, C. G., & Bockstael, N. E. (2000). Evidence of the Effects of Water Quality on Residential Land Prices. *Journal of Environmental Economics and Management*, *39*(2), 121–144. https://doi.org/10.1006/jeem.1999.1096

Li, Y., Zhang, H., Zhu, L., Chen, H., Du, G., Gao, X., & Pu, Y. (2020). Evaluation of the long-term performance in a large-scale integrated surface flow constructed wetland–pond system: A case study. *Bioresource Technology*, *309*, 123310. https://doi.org/10.1016/j.biortech.2020.123310

Liu, S., Zhang, Y., Feng, X., & Pyo, S.-H. (2024). Current problems and countermeasures of constructed wetland for wastewater treatment: A review. *Journal of Water Process Engineering*, *57*, 104569. https://doi.org/10.1016/j.jwpe.2023.104569

Makopondo, R. O. B., Rotich, L. K., & Kamau, C. G. (2020). Potential Use and Challenges of Constructed Wetlands for Wastewater Treatment and Conservation in Game Lodges and Resorts in Kenya. *The Scientific World Journal*, *2020*, 9184192. https://doi.org/10.1155/2020/9184192

Malaviya, P., & Singh, A. (2012). Constructed Wetlands for Management of Urban Stormwater Runoff. *Critical Reviews in Environmental Science and Technology*, *42*(20), 2153–2214. https://doi.org/10.1080/10643389.2011.574107

Mander, Ü., Tournebize, J., Kasak, K., & Mitsch, W. J. (2014). Climate regulation by free water surface constructed wetlands for wastewater treatment and created riverine wetlands. *Ecological Engineering*, *72*, 103–115. https://doi.org/10.1016/j.ecoleng.2013.05.004

Marjorie, H. (n.d.). Native Americans thrived in the 'Great Swamp,' marshy headwaters that we know of as Alewife. *History Cambridge*. Retrieved January 30, 2025, from https://historycambridge.org/articles/native-americans-thrived-in-the-great-swamp-marshy-headwaters-that-we-know-of-as-alewife/

Martel-Rodríguez, G. M., Millán-Gabet, V., Mendieta-Pino, C. A., García-Romero, E., & Sánchez-Ramírez, J. R. (2022). Long-Term Performance of a Hybrid-Flow Constructed Wetlands System for Urban Wastewater Treatment in Caldera de Tirajana (Santa Lucía, Gran Canaria, Spain). *International Journal of Environmental Research and Public Health*, *19*(22), 14871. https://doi.org/10.3390/ijerph192214871

Martínez-Espinosa, C., Sauvage, S., Al Bitar, A., Green, P. A., Vörösmarty, C. J., & Sánchez-Pérez, J. M. (2021). Denitrification in wetlands: A review towards a quantification at global scale. *Science of The Total Environment*, *754*, 142398. https://doi.org/10.1016/j.scitotenv.2020.142398

Massachusetts Department of ENvironmental Protection. (n.d.). *Integrated Lists of Waters & Related Reports | Mass.gov*. https://www.mass.gov/lists/integrated-lists-of-waters-related-reports

Massachusetts Metropolitan District Commission. (2003, June). *Alewife Reservation & Alewife Brook Master Plan*. https://www.mass.gov/doc/introduction/download

McFarland, A. R., Larsen, L., Yeshitela, K., Engida, A. N., & Love, N. G. (2019). Guide for using green infrastructure in urban environments for stormwater management. *Environmental Science: Water Research & Technology*, *5*(4), 643–659. https://doi.org/10.1039/C8EW00498F

Millennium Ecosystem Assessment (Ed.). (2005). *Ecosystems and human well-being: Synthesis*. Island Press.

Mishra, R. K., Mentha, S. S., Misra, Y., & Dwivedi, N. (2023). Emerging pollutants of severe environmental concern in water and wastewater: A comprehensive review on current developments and future research. *Water-Energy Nexus*, *6*, 74–95. https://doi.org/10.1016/j.wen.2023.08.002

Mocior, E., & Kruse, M. (2016). Educational values and services of ecosystems and landscapes – An overview. *Ecological Indicators*, *60*, 137–151. https://doi.org/10.1016/j.ecolind.2015.06.031

MWRA SSO Notifications. (n.d.). Retrieved April 10, 2025, from http://ftp.mwra.com/harbor/html/sso_reporting.htm

Mystic River Watershed Association. (n.d.). *Mystic River History*. Mystic River Watershed Association. Retrieved January 30, 2025, from https://mysticriver.org/history

National Research Council. (2000). *Clean Coastal Waters: Understanding and Reducing the Effects of Nutrient Pollution*. National Academies Press. https://doi.org/10.17226/9812

National Weather Service. (n.d.). *Simplified hydrologic cycle*. Retrieved January 31, 2025, from https://www.weather.gov/mrx/hydro_cycle

National Wildlife Federation. (2024). *Clean Water Act*. National Wildlife Federation. https://www.nwf.org/Home/Our-Work/Waters/Clean-Water-Act

Nazari-Sharabian, M., Ahmad, S., & Karakouzian, M. (2018). Climate Change and Eutrophication: A Short Review. *Engineering, Technology and Applied Science Research*, *8*(6), 3668–3672.

Nixon, H., & Saphores, J.-D. (2007). Impacts of motor vehicle operation on water quality in the US – Cleanup costs and policies. *Transportation Research Part D: Transport and Environment*, *12*(8), 564–576. https://doi.org/10.1016/j.trd.2007.08.002

North Cambridge History Hub. (n.d.). *History Cambridge*. Retrieved January 30, 2025, from https://historycambridge.org/history-hubs/north-cambridge-history-hub/

Papagiorgio, N. (2019, November 22). *Factors That Affect The pH Of Water In Wetlands*. Sciencing. https://www.sciencing.com/factors-affect-ph-water-wetlands-6723700/

Pascual, A., Álvarez, J. A., de la Varga, D., Arias, C. A., Van Oirschot, D., Kilian, R., & Soto, M. (2024). Horizontal flow aerated constructed wetlands for municipal wastewater treatment: The influence of bed depth. *Science of The Total Environment*, *908*, 168257. https://doi.org/10.1016/j.scitotenv.2023.168257

Pei, L. (2011, January 25). *Past, Present, and Future on Little River*. Friends of Alewife Reservation. http://www.friendsofalewifereservation.org/Past-Present-Future-on-Little-River.htm

Pitt, R., Field, R., Lalor, M., & Brown, M. (1995). Urban stormwater toxic pollutants: Assessment, sources, and treatability. *Water Environment Research*, *67*(3), 260–275. https://doi.org/10.2175/106143095X131466

Pramanik, B. K., Roychand, R., Monira, S., Bhuiyan, M., & Jegatheesan, V. (2020). Fate of road-dust associated microplastics and per- and polyfluorinated substances in stormwater. *Process Safety and Environmental Protection*, *144*, 236–241. https://doi.org/10.1016/j.psep.2020.07.020

Read "Clean Coastal Waters: Understanding and Reducing the Effects of Nutrient Pollution" at NAP.edu. (n.d.). https://doi.org/10.17226/9812

Reyes, N. J. D. G., Geronimo, F. K. F., Guerra, H. B., & Kim, L.-H. (2023). Bibliometric Analysis and Comprehensive Review of Stormwater Treatment Wetlands: Global Research Trends and Existing Knowledge Gaps. *Sustainability*, *15*(3), Article 3. https://doi.org/10.3390/su15032332

Rodgers, E. M. (2017). Adding climate change to the mix: Responses of aquatic ectotherms to the combined effects of eutrophication and warming. *Biology Letters*, *17*(10), 20210442. https://doi.org/10.1098/rsbl.2021.0442

Roesner, L., & Matthews, R. (1990). Stormwater Management for the 1990s. *The American City & County*, *105*(2), 44.

Ruane, D., Martin, J., Brooker, M., Bernal, B., Anderson, C., Nairn, R., & Mitsch, W. J. (2025). 29 years of carbon sequestration in two constructed riverine wetlands. *Ecological Engineering*, *210*, 107435. https://doi.org/10.1016/j.ecoleng.2024.107435

Sandra Quijas & Patricia Balvanera. (2013). Biodiversity and Ecosystem Services. In *Encyclopedia of Biodiveristy* (Second, Vol. 1, pp. 341–356). Academic Press.

Savage, A. T. (n.d.). Boston Harbor: The Anatomy of a Court-Run Cleanup. *ENVIRONMENTAL AFFAIRS*, *22*.

Scott, R. (n.d.). *Understanding the Basic Principles of Nitrogen*. Atlantic States Rural Water & Wastewater Association.

Sea breeze: Structure, forecasting, and impacts—Miller—2003—Reviews of Geophysics—Wiley Online Library. (n.d.). Retrieved May 29, 2025, from https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2003RG000124

Seidel, K. (1955). *Flechtbinse: Oekologie, Morphologie und Entwicklung, ihre Stellung bei den Voelkern und ihre wirtschaftliche Bedeutung | Wageningen University and Research Library catalog*. https://library.wur.nl/WebQuery/titel/481135

Shelef, O., Gross, A., & Rachmilevitch, S. (2013). Role of Plants in a Constructed Wetland: Current and New Perspectives. *Water*, *5*(2), Article 2. https://doi.org/10.3390/w5020405

Singh, V., Ahmed, G., Vedika, S., Kumar, P., Chaturvedi, S. K., Rai, S. N., Vamanu, E., & Kumar, A. (2024). Toxic heavy metal ions contamination in water and their sustainable reduction by eco-friendly methods: Isotherms, thermodynamics and kinetics study. *Scientific Reports*, *14*(1), 7595. https://doi.org/10.1038/s41598-024-58061-3

Snyder, B. F. (2019). The Inclusion of Ecosystem Service Valuations in Bioenergy Cost Analysis: A Case Study of Constructed Wetlands in the Neotropics. *Ecological Economics*, *156*, 196–201. https://doi.org/10.1016/j.ecolecon.2018.10.005

Stormwater Wetland Reduces Sewer Overflow By 84 Percent. (n.d.). Retrieved May 22, 2025, from https://www.wateronline.com/doc/stormwater-wetland-reduces-sewer-overflow-by-percent-0001

Tabari, H. (2020). Climate change impact on flood and extreme precipitation increases with water availability. *Scientific Reports*, *10*(1), 13768. https://doi.org/10.1038/s41598-020-70816-2

Taguchi, V. J., Weiss, P. T., Gulliver, J. S., Klein, M. R., Hozalski, R. M., Baker, L. A., Finlay, J. C., Keeler, B. L., & Nieber, J. L. (2020). It Is Not Easy Being Green: Recognizing Unintended Consequences of Green Stormwater Infrastructure. *Water*, *12*(2), Article 2. https://doi.org/10.3390/w12020522

The Trust for Public Land. (2016). *City Parks, Clean Water: Making Great Places Using Green Infrastructure*. https://urbanwaterslearningnetwork.org/wp-content/uploads/2016/04/City-Parks-Clean-Water-report_TPL-2016.pdf

Tibbetts, J. (2005). Combined Sewer Systems: Down, Dirty, and Out of Date. *Environmental Health Perspectives*, *113*(7), A464–A467.

Tursi, A., Beneduci, A., Chidichimo, F., De Vietro, N., & Chidichimo, G. (2018). Remediation of hydrocarbons polluted water by hydrophobic functionalized cellulose. *Chemosphere*, *201*, 530–539. https://doi.org/10.1016/j.chemosphere.2018.03.044

US EPA. (1993). *Constructed Wetlands for Wastewater Treatment and Wildlife Habitat | 17 Case Studies*.

US EPA. (2004). *Report to Congress on Impacts and Control of Combined Sewer Overflows and Sanitary Sewer Overflows* (p. 640).

US EPA. (2015, September 15). *Basic Information about Nonpoint Source (NPS) Pollution* [Overviews and Factsheets]. https://www.epa.gov/nps/basic-information-about-nonpoint-source-nps-pollution

US EPA, O. (2013a, February 22). *History of the Clean Water Act* (Great Lakes) [Overviews and Factsheets]. https://www.epa.gov/laws-regulations/history-clean-water-act

US EPA, O. (2013b, November 21). *Indicators: Conductivity* [Overviews and Factsheets]. https://www.epa.gov/national-aquatic-resource-surveys/indicators-conductivity

US EPA, O. (2015, October 1). *Reduce Heat Islands* [Overviews and Factsheets]. https://www.epa.gov/green-infrastructure/reduce-heat-islands

US EPA, O. (2024, July 11). *Environmental Benefits of Green Infrastructure* [Overviews and Factsheets]. https://www.epa.gov/green-infrastructure/environmental-benefits-green-infrastructure

US EPA, R. 01. (2015, August 20). *Soak Up the Rain: What's the Problem?* [Collections and Lists]. https://www.epa.gov/soakuptherain/soak-rain-whats-problem

US EPA, R. 06. (2016, July 8). *Municipal Separate Storm Sewer System (MS4) Storm Water Management Program (SWMP)* (Texas) [Other Policies and Guidance].

https://www.epa.gov/tx/municipal-separate-storm-sewer-system-ms4-storm-water-management-program-swmp

U.S. Geological Survey. (2019, June 8). *Infiltration and the Water Cycle*. https://www.usgs.gov/special-topics/water-science-school/science/infiltration-and-water-cycle

U.S. National Park Service. (n.d.-a). *Metropolitan Park System of Greater Boston*. Retrieved January 10, 2025, from https://www.nps.gov/places/metropolitan-park-system-of-greater-boston.htm

U.S. National Park Service. (n.d.b). *The 1969 Cuyahoga River Fire (U.S. National Park Service)*. https://www.nps.gov/articles/story-of-the-fire.htm

van der Oost, R., Beyer, J., & Vermeulen, N. P. E. (2003). Fish bioaccumulation and biomarkers in environmental risk assessment: A review. *Environmental Toxicology and Pharmacology*, *13*(2), 57–149. https://doi.org/10.1016/S1382-6689(02)00126-6

Van Deren, M. (2017). *Evaluating Changes in Water Quality: A Hedonic Model Linking Combined Sewer Overflows and Seattle's Housing Market*.

Vitousek, P. M., Mooney, H. A., Lubchenco, J., & Melillo, J. M. (1997). Human Domination of Earth's Ecosystems. *Science*, *277*(5325), 494–499. https://doi.org/10.1126/science.277.5325.494

Vymazal, J. (2011). Constructed Wetlands for Wastewater Treatment: Five Decades of Experience. *Environmental Science & Technology*, *45*(1), 61–69. https://doi.org/10.1021/es101403q

Vymazal, J. (2018). Do Laboratory Scale Experiments Improve Constructed Wetland Treatment Technology? *Environmental Science & Technology*, *52*(22), 12956–12957. https://doi.org/10.1021/acs.est.8b05709

Vymazal, J. (2022). The Historical Development of Constructed Wetlands for Wastewater Treatment. *Land*, *11*(2), Article 2. https://doi.org/10.3390/land11020174

Wang, J., Zhao, Y., Yang, L., Tu, N., Xi, G., & Fang, X. (2017). Removal of Heavy Metals from Urban Stormwater Runoff Using Bioretention Media Mix. *Water*, *9*(11), Article 11. https://doi.org/10.3390/w9110854

Wasser, M. (2021, June 17). *Boston's Stormwater Problems Are Older Than The City Itself*. https://www.wbur.org/news/2021/06/17/boston-stormwater-sewer-history

Wetzel, R. G. (2001). *Lake and River Ecosystems*.

Wilson, R. S., Doidge, M., & Soldo, C. (2019). *Using Constructed Wetlands to Address Water Quality Challenges: An Analysis of Farmer Willingness to Adopt Edge-of-Field Conservation Measures in the Western Lake Erie Basin*.

Wu, S., Carvalho, P. N., Müller, J. A., Manoj, V. R., & Dong, R. (2016). Sanitation in constructed wetlands: A review on the removal of human pathogens and fecal indicators. *Science of The Total Environment*, *541*, 8–22. https://doi.org/10.1016/j.scitotenv.2015.09.047

Xu, B., Wang, X., Liu, J., Wu, J., Zhao, Y., & Cao, W. (2017). Improving Urban Stormwater Runoff Quality by Nutrient Removal through Floating Treatment Wetlands and Vegetation Harvest. *Scientific Reports*, *7*(1), 7000. https://doi.org/10.1038/s41598-017-07439-7

Yin, R. (2003). *Case Study Research Design and Methods* (Third). Sage Publications. https://iwansuharyanto.wordpress.com/wp-content/uploads/2013/04/robert_k-_yin_case_study_research_design_and_mebookfi-org.pdf

Zgheib, S., Moilleron, R., & Chebbo, G. (2012). Priority pollutants in urban stormwater: Part 1 – Case of separate storm sewers. *Water Research*, *46*(20), 6683–6692. https://doi.org/10.1016/j.watres.2011.12.012

Zhang, C., Wen, L., Wang, Y., Liu, C., Zhou, Y., & Lei, G. (2020). Can Constructed Wetlands be Wildlife Refuges? A Review of Their Potential Biodiversity Conservation Value. *Sustainability*, *12*(4), Article 4. https://doi.org/10.3390/su12041442

Zhang, H., Qi, Z., Ye, X., Cai, Y., Ma, W., & Chen, M. (2013). Analysis of land use/land cover change, population shift, and their effects on spatiotemporal patterns of urban heat islands in metropolitan Shanghai, China. *Applied Geography*, *44*, 121–133. https://doi.org/10.1016/j.apgeog.2013.07.021

Appendix A: Tufts IRB Not Human Subjects Research Determination

NOT HUMAN SUBJECTS RESEARCH

June 11, 2025

Lydia Heely
Tufts University
Lydia.Heely@tufts.edu

Dear Lydia Heely:

On 6/11/2025, the IRB reviewed the following submission:

Type of Review:	Initial Study
Title of Study:	Exploring the Success Factors of Constructed Stormwater Wetlands Through the Alewife Stormwater Wetland Case Study
Investigator:	Lydia Heely
IRB ID:	STUDY00005786
Funding:	Tufts University
Documents Reviewed:	• Interview Questions , Category: Other;• LHeely_HRP-217_ FORM - SBER IRB NR-NHSR Request_04_04_25.doc, Category: IRB Protocol;

The IRB determined that the proposed activity is not research involving human subjects as defined by DHHS and FDA regulations.

IRB review and approval by this organization is not required. This determination applies only to the activities described in the IRB submission and does not apply should any changes be made. If changes are made and there are questions about whether these activities are research involving human in which the organization is engaged, please submit a modification request to the IRB for a determination. You can create a modification by completing the "Create Modification/CR" activity in eIRB.

Sincerely,
A O'Brien

Amanda O'Brien
IRB Analyst

Appendix B: List of Interview Questions

Interview Questions

Duke Bitsko, Director of Interdisciplinary Design, Hatch Engineering

Design & Construction

1. When did you become involved in the project? (planning stage, design stage, etc.) Can you describe the project prior to your involvement?
2. What sparked Hatch Engineering's interest in the project?
3. What entity/regulation was the primary catalyst of the project?
4. Can you describe the interorganizational partnerships that made this project possible? Which entity spearheaded the design and/or public process?
5. What was the permitting process like? How did the team navigate state, city, privately owned land? You mentioned that construction was delayed due to permitting issues– how did the project team cope with that?
6. Were there unforeseen issues in the design that were uncovered during construction? How were they managed?

Public Concerns

7. Was there popular appetite for this type of project in Cambridge? What type of community outreach was done?
8. What were the biggest concerns from the public about this wetland?
9. Can you elaborate more on mosquito and wildlife concerns?
10. Was there any pushback from real estate developers who had/were planning to invest in the area?
11. How has the project changed the community?

Caitlyn Rodriguez, Horticulturist

Project Role

1. How long have you worked at the Alewife Stormwater Wetland?
2. How do horticulturists observations in the field influence management decisions? (i.e. adaptive management)

Ecological Valuation

3. What changes have been observed at the site from season to season and year to year (in plants, animals, public use, water quality)?
4. Are there rare or endangered species at the wetland?

5. Are there elements of the maintenance regime specifically geared towards improving habitat?
6. What role does the wetland play in the larger landscape (as a wildlife corridor, etc)

Maintenance Challenges

7. What is the most challenging aspect of maintaining the wetland?
8. Are there other green infrastructure installations in the area? What are their maintenance regimes like? Are they meeting design objectives?
9. What is the philosophy for managing invasive species?
10. What would happen if the wetland was no longer maintained?

Interactions with the Public

11. Do people recreating in the wetlands ask about the work of horticulturists? What is the general perception of your role?

Catherine Woodbury, Senior Project Manager, Cambridge DPW (retired)

Project Role

1. Can you walk me through the combined sewer separation project?
2. When was the stormwater wetland initially proposed? What was the general opinion of the DPW professionals (and the public) when it was proposed?

Project Stages

3. What were the challenges with design and permitting? What types of professionals contributed to this stage of the project?
4. Were there unforeseen challenges after the project was built? Were there guiding documents for maintenance?
5. What role does the ASW play today in managing stormwater/CSOs in the area today? Does the performance of the system differ from what was anticipated?
6. What is the biggest challenge associated with the project?

Public Perception

7. Has the project received attention from community members? Has the project received any negative attention?

8. What is the biggest misconception about the project?

Jennifer Delgado, Watershed Scientist, Mystic River Watershed Association

Mystic River Watershed TMDL

1. Can you walk me through the Mystic River TMDL study timeline?
2. How does the alternative TMDL process differ from the traditional TMDL process?
3. How are CSOs modeled in the alternative TMDL?

Data/Monitoring

4. What types of water quality data are available for the Little River/ Alewife Brook?
5. What are the challenges with monitoring/ managing water quality data?
6. What data from the ASW would be most meaningful to further scientific knowledge of the Mystic River System?
7. If there were no financial constraints, what interventions would have the most positive impact on meeting the phosphorus TMDL?

Appendix C: Design of the Alewife Stormwater Wetland

Design of the Alewife Stormwater Wetland

The following section is a technical description of the main components of the Alewife Stormwater Wetland.

Bending Weir

The first important piece of infrastructure is the bending weir that lies within the 4 x 8 box culvert that conveys stormwater flow from the catchment area.

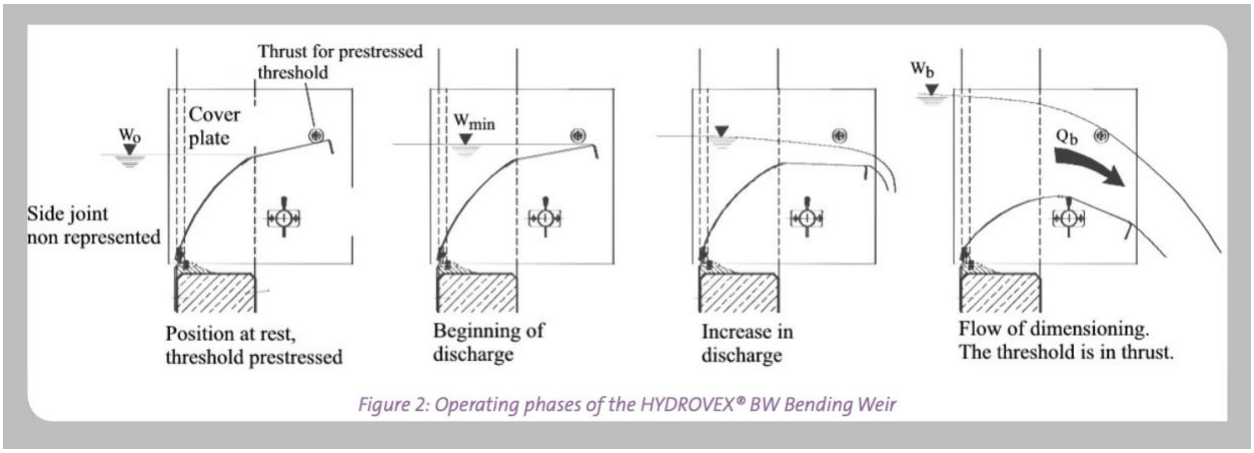


Figure 1. Operating Phases of the HYDROVEX BW Bending Weir (Veolia, 2011)

A bending weir can create overflow characteristics equivalent to a weir 2 to 5 times longer for the same overflow rate and water level (Veolia, 2011). This allows for more control of the water level within a small footprint. When the upstream water level reaches the activation point, the water pressure progressively bends the weir. Its flexion creates a powerful weir coefficient, C_w, that changes in response to upstream water level allowing for flow proportional to the upstream water level. The following equation describes weir flow:

$$Q = C_w L H^{3/2}$$

Where:

Q = discharge over weir, cfs (cms)

L = length of the weir crest, ft (m)

H = distance between water surface and the crest, ft (m)

C_w = weir coefficient

The bending weir is helpful in this application because space is limited inside the subsurface structure. Also housed in the bending weir structure is a vortex valve, which allows an average flow of .96 cfs to pass directly to the Little River to maintain historical water level. A 12-inch flapper valve prevents river backflow from entering the vortex valve and stormwater wetland.

Oxbow Flow Equalization Manhole

The flow equalization manhole limits the amount of flow released from the wetland to the Little River oxbow (Figure 2). There is a flow regulator valve inside that activates depending on the water elevation in the oxbow. During drought conditions, if the water level in the Little River is higher than the water level in the wetland, river water will backflow to the wetland. This keeps the wetland water level high enough to support fish populations even when stormwater inputs are limited.

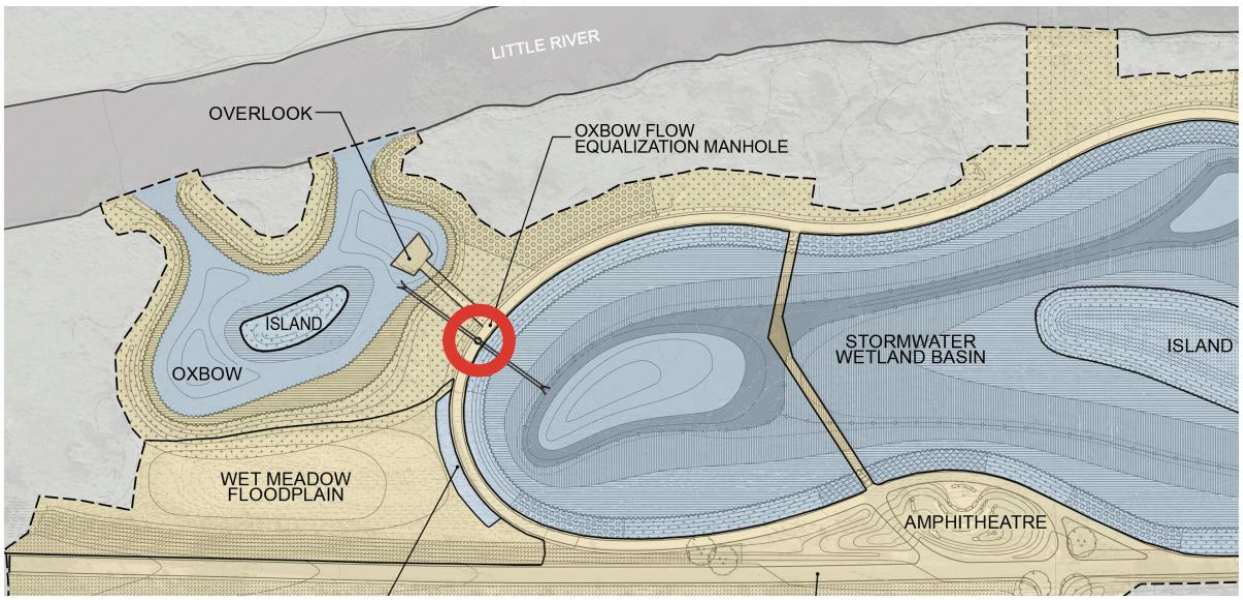


Figure 2. Oxbow Flow Equalization Manhole. Source: O&M Manual

Wetland Components

This section was developed through review of the O&M manual and several interviews with Duke Bitsko, a lead project designer with Bioengineering group (now Hatch) who has been active in the project since its inception. Photos shown in the following sections correspond to the Photograph Location Key Plan (Figure 3), which is found in the O&M Manual.

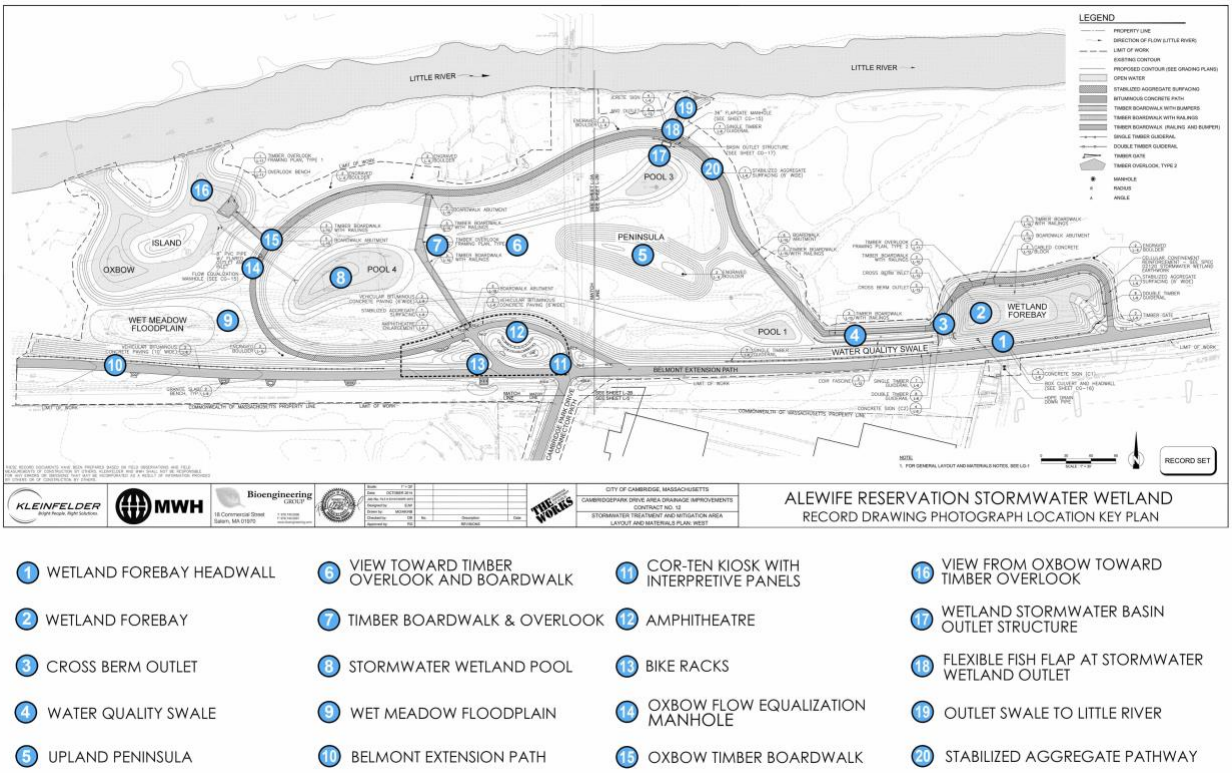


Figure 3 Photograph Location Key Plan. Source: O&M Manual

Wetland Forebay

Stormwater collected from the 335-acre catchment area flows into the wetland through a 4'x 8' box culvert (headwall shown in Image 1). Constructing the box culvert required several permanent easements and special utility crossings. The stormwater entering the forebay has undergone some pre-treatment (bioretention, BMP catch basins, 6' sump manholes, and grit removal in the catchment area) before entering the forebay. The purpose of the 0.7-acre forebay is to trap any remaining large debris and allow the sediments to settle before water flows to the

main basin. The forebay has a maximum depth of four feet and is lined with cabled concrete block to facilitate sediment removal as part of regular maintenance. The forebay has an access ramp (rear Image 2), and a PVC wellhead that can be used to dewater the local groundwater table to facilitate dredging the forebay.

Inlet headwall from box culvert into wetland forebay

Wetland forebay (access ramp at rear, dewatering stand pipe on right)

Water Quality Swale

The forebay discharges to the water quality swale, shown in Images 3 and 4. The swale is a 140 ft long channel that moderates flow to the main basin during storms and promote infiltration during low-flow periods. The slope of the swale is stabilized with a permanent erosion control blanket and 12” coconut coir logs, which biodegrade as plants mature. Live stakes of several varieties of native woody shrubs were planted on the banks for additional erosion control. High marsh plugs were planted on the bottom, because they tolerate inundation and do not drastically impede flow as woody plants might.

Cross berm outlet, (2) 12-inch RCP pipes leading to water quality swale (looking East)

Elevated boardwalk overlooking water quality swale (looking East)

Main Basin

The main basin is approximately 2 acres in area and detains approximately 10.35 acre-feet (AF) of stormwater under normal conditions. The basin was constructed with an undulating bottom surface to create different pool depths, lending themselves to different habitat types. There are five main habitat types in the system, as depicted in Figure 16 below, based on unique hydrologic zones.

• Riparian woodland (elevation > 1.0’ NGVD)

• High marsh (elevation 1.0’ to 0.5’ NGVD)

• Emergent marsh (elevation 0.5’ to -0.5’ NGVD)

• Deep marsh (elevation -0.5’ to -2.0’ NGVD)

• Open water – unplanted (elevation -2.0’ to -4.5’ NGVD)

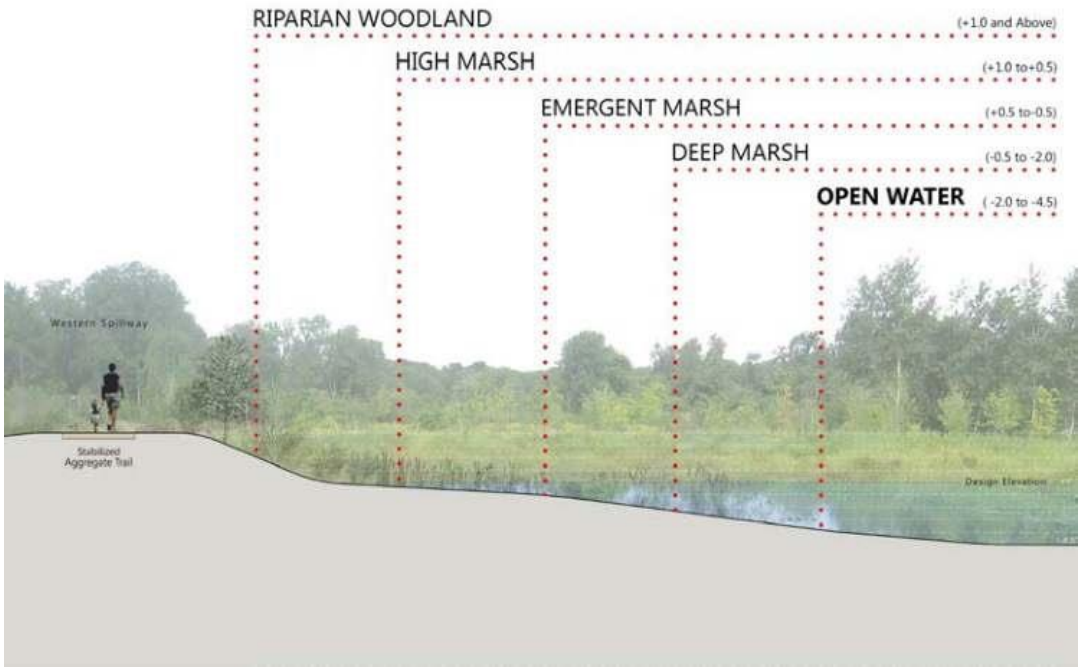


Figure 4 Habitats of The Main Basin at the ASW. Source: O&M Manual

There are several permanent deep pools in the main basin, the largest is shown in Image 8. The deep pools provide important habitat and allow for long-term sediment accumulation. Because of all the other sediment removal technologies present in the system before the water reaches this point, it is unlikely that sediment will accumulate to a detrimental degree over the expected life of the basin.

Permanent stormwater wetland pool (from timber overlook, looking West)

Peninsula

An upland peninsula juts into the eastern side of the main basin. The main purpose of the peninsula is to encourage a longer flow path for the stormwater, thus increasing retention time before discharge. Higher retention time is correlated with increased pollutant removal, especially for nutrients. The peninsula also increases the upland habitat area.

Upland peninsula at center of stormwater wetland basin (looking Northeast)

Wet Meadow Floodplain and Western Spillway

The wet meadow covers approximately 1 acre of area. Its primary function is to provide additional flood storage for a 10-year storm event. This area also provides additional habitat for wetland plants and related fauna.

Wet meadow floodplain and western spillway (looking West)

Oxbow

The oxbow is an artificial meander of the Little River created to create an additional 0.3 acres of flood storage (Figure 5). It also provides a unique island habitat, and a deep pool for herring spawning. It has been reported that a school of herring was observed in this area in 2021, which is further testament of the success of this project and the improved health of the ecosystem. The oxbow also replaces floodplain volume taken when the stormwater wetland was

created. It helps to slow down the Little River and further attenuate flooding during intense storm events.

Figure 5 Oxbow. Source: O&M Manual

Outlet Structure

The culvert releasing flow back to the Little River is a 36” outlet controlled with a 12” underflow and high-level weir - another design feature that maximizes retention time. The outlet is significantly smaller than the 4 x 8’ box culvert that would be needed for a traditional stormwater outfall. The outlet structure includes a flexible rubber fish flap that allows fish to pass out of the wetland but prevents large animals from entering the structure and becoming stranded.

36” flexible fish flap gate at stormwater wetland outlet

Appendix D: Water Quality Calculations

Alewife Stormwater Wetland Water Quality Data Analysis

Objective: Find mass removal efficiencies for TN and TP

Assumptions: Note that this calculation does not include specific recharge and runoff rates determined by land cover and soil type (the catchment area is assumed 100% impervious). It does not account the proportion of annual rainfall that arrives in a major storm event and would thus trigger the flow bypass mechanism (see Chapter 5). It also does not include runoff from the wetland's local sub-watershed, or any effect of the flow equalization manhole. A more detailed calculation for HLR is recommended as a next step for this project.

WATER QUALITY DATA				
Date Collected	**TN_in (mg/L)**	**TN_out (mg/L)**	**TP_in (mg/L)**	**TP_out (mg/L)**
4/10/17			0.155	0.037
5/10/17			0.056	0.054
6/16/17			0.16	0.2
3/6/18	4.73	2.838	1.04	0.28
4/24/18	25.687	2.582	0.02	0.14
5/30/18	5.354	3.369	0.26	0.12
8/1/18			0.7	0.3
11/30/18	4.09	0.836		
1/15/19	3.544	2.461	0.02	0.02
8/27/20			0.13	0.202
AVERAGE	8.68	2.42	0.28	0.15

REMOVALS				
	TN		TP	
Convert to g/m^3/yr:	8.68	2.42	0.28	0.15
Mass (conc x flow) (g/yr)	8679791	2416863	282294	150312
Mass removed (g/yr)	6262928		131982	
Removal rate (g/m^2/yr)	562.8		11.9	
Removal Efficiency	72%		47%	

kg removed per year:	6262.927587	131.9816152

FLOW CALCULATION	
AREA	
Wetand Surface Area (ac):	Wetland Surface Area (m^2):
2.75	11129
Catchment Surface Area (ac):	Catchment Surface Area (m^2):
335	1355698
	Total Surface Area (m2):
	1366827
RAINFALL	
Cambridge Average Rainfall (in/yr)	Cambridge Average Rainfall (m/yr)
48	1.219199342
FLOW (m^3/ year)	
annual rainfall x surface area x runoff coefficient:	999861

HLR (m/yr)	
flow rate / wetland area	89.8

Conversions	
4046.86	m^2 per acre
39.3701	inches per meter
1000	mg per g
1000	L per m^3
0.6	runoff coefficient

Date Collected	Location	pH Value (SU)	Conductivity (uS/cm	E . coli (MPN/100ml
4/10/17	Forebay	6.82	2140	333
4/10/17	Outlet	7.37	1520	20
5/10/17	Forebay	7.15	242	86
5/10/17	Outlet	9.58	582	10
6/16/17	Forebay	7.1	757	5490
6/16/17	Outlet	6.7	581	171
3/6/18	Forebay	6.9	2490	933
3/6/18	Outlet	6.9	1360	288
4/24/18	Forebay	7.6	1920	10
4/24/18	Outlet	8.4	1390	10
5/30/18	Forebay	7.4	1860	52
5/30/18	Outlet	7.1	1310	10
8/1/18	Forebay	[redacted]		86
8/1/18	Outlet			85
11/30/18	Forebay	7.2	1300	331
11/30/18	Outlet	7.1	663	31
1/15/19	Forebay	7.2	1900	275
1/15/19	Outlet	6.9	1720	10
8/27/20	Forebay	[redacted]		2550
8/27/20	Outlet	7.35	592	130

Enteroccoci (MPN/1	Fecal Coliform (Col.	Ammonia Nitrogen (	Nitrate Nitrogen (mg/L)
30	1100	1.98	1.52
10		0.47	0.786
10	1100	0.182	0.183
10	100		0.035
85	44300	0.7	[redacted]
41	13200	0.5	
780	3700	3.2	0.897
31	300	1.4	0.911
10	100	3.9	1.06
10	100	0.5	0.35
301	100	10.8	2.68
122	100	2.6	0.037
10	500	0.7	0.071
332	1100		0.052
142	700	3.1	0.968
52	200	0.4	0.323
52	300	3.3	1.1
10	100	1.8	0.236
[redacted]			

TKN (mg/L)	Nitrite Nitrogen (mg/L)	TN (mg/L)	Total Phosphorous (
4.37	[redacted]	[redacted]	0.155
0.964	[redacted]	[redacted]	0.037
0.235	[redacted]	[redacted]	0.056
0.224	[redacted]	[redacted]	0.054
1.1	[redacted]	[redacted]	0.16
1.8	[redacted]	[redacted]	0.2
3.8	0.033	4.73	1.04
1.9	0.027	2.838	0.28
24.6	0.027	25.687	0.02
2.2	0.032	2.582	0.14
2.6	0.074	5.354	0.26
3.3	0.032	3.369	0.12
0.7	0.008	0.779	0.7
0.3	[redacted]	[redacted]	0.3
3.1	0.022	4.09	[redacted]
0.5	0.013	0.836	[redacted]
2.4	0.044	3.544	0.02
2.2	0.025	2.461	0.02
[redacted]	[redacted]	[redacted]	0.13
[redacted]	[redacted]	[redacted]	0.202

TSS(mg/L)	BOD (mg/L)	MBAS (Surfactant) (mg/L)
25.3	[redacted]	
4.5		
4.4	5	0.592
7.2	4	[redacted]
14	15	0.12
	6	0.1
9	4	[redacted]
4	4	
4	4	0.09
14	9	0.03
11	4	0.26
2	4	0.31
21	4	0.36
5	4	0.12
6	4	0.06
4	4	[redacted]
2	4	0.19
9	4	0.33
2	11	[redacted]
2	4	