Innovative Waste Water Strategies in the Landscape: The Application of Green Infrastructure Principles in Cape Cod, Massachusetts

Innovative Waste Water Strategies in the Landscape: The application of green infrastructure principles in Cape Cod, Massachusetts

Kellie Fenton
Masters in Landscape Architecture
Department of Landscape Architecture and Regional Planning
University of Massachusetts, Amherst

Innovative Waste Water Strategies in the Landscape: The application of green infrastructure principles in Cape Cod, Massachusetts

Kellie Fenton
Masters in Landscape Architecture and Regional Planning
Department of Landscape Architecture and Regional Planning
University of Massachusetts, Amherst
October, 2017

Carolina Aragon, Committee Chair
Landscape Architecture and Regional Planning, UMass Amherst

Carey Clouse, Committee Member
Landscape Architecture and Regional Planning, UMass Amherst

Jane Thurber, Committee Member
Landscape Architecture and Regional Planning, UMass Amherst

Robert Ryan, Department Chair
Landscape Architecture and Regional Planning, UMass Amherst

Acknowledgments

This master's project is a culmination of my learning and experience at UMass. Many individuals, both within the UMass community as and beyond, have been a part of my success. In particular, I would like to thank:

Carolina Aragon, for providing inspiration and guidance throughout the program. Who always encouraged me to try new things and let my own interests and intuition guide me.

Carey Clouse, for her enthusiasm for pushing the boundaries of landscape architecture. And for sercving tea in class.

Jane Thurber, for stepping up to provide thoughful feedback to help me connect research and analysis to design.

Frank Sleegers, whose insistence to "zoom in and zoom out" helps me think in different scales to create cohesive designs.

My friends and family. They understood what going back to school has meant for me and have been supportive throughout the process.

Table of Contents

1 Introduction

Context

Wastewater management is an issue that every community faces. Whether a small-scale septic tank or a large-scale centralized wastewater treatment plant, these systems are often insufficient in accomplishing their singular purpose: cleaning water. This results in the contamination of hydrological systems. In its focus on the intersection of the natural and built environment, the practice of landscape architecture may include the design of wastewater management systems. This project demonstrates how landscape architecture principles applied to waste water management systems provides both ecological and human benefits.

Goals

The goal of this project is to find ways that waste water systems can be a part of green infrastructure initiatives. The project proposal demonstrates that landscapes can be multi-functional; in this case, a greenway can be a recreational amenity and provide waste water management.

Research Questions

How can waste water be managed in a more ecological manner?

How can the design of waste water treatment facilities provide benefits to the community beyond water cleansing?

Scope of Work

- Develop a typology to inventory waste water systems
- Case studies research of innovative waste water treatment systems
- Apply knowledge to address a waste water issues in region of Cape Cod, where increased development has resulted in contamination of the hydrological system.

The town of Barnstable faces the following challenges:

- Increased development
- Decrease in effectiveness of septic systems
- Ineffective centralized sewer system
- Excess nutrients in groundwater detrimental to hydrological health

This approach seeks to accomplish the following:

- Create a public greenway
- Reconnect fragmented hydrological network to improve ecosystem functionality
- Improve resilience of public water infrastructure

Waste Water Issues

Septic systems and centralized treatment systems are the standard approaches for dealing with wastewater. Yet there are issues with both of these treatment options, and communities are now looking at alternative methods for managing wastewater.

Septic systems may not clean the water sufficiently, either due to the conditions of the soil or because of an increase in water usage of individual households. These system insufficiencies have negative impacts on the surrounding environment.

Septic systems are insufficient because of the amount of waste water exceeds the land's capacity. Within the site, pipes distribute the wastewater to a leach field, where it moves through the soil, relatively quickly since the soils are sandy and there is a limited amount of root area for plants that would take up and process nutrients.

When development is spread out, the land's capacity can match the output of wastewater. Within this context, septic systems are effectively green infrastructure. They clean the water which then recharges the ground water. With increased development, the amount of waste water exceeds the land's ability to process it into clean water. As a result, centralized sewerage treatment plants collect and treat water through mechanical processes. This grey infrastructure approach, where pipes convey water and chemicals clean it in tanks within the treatment facility, is separated from the natural environment and results in a fragmented hydrological system.

Centralized systems are built in order to handle a larger volume of waste water, but still contributing to the degradation of water quality. They have high maintenance costs and public health issues related to outdated systems' insufficient capacity, and are not always able to treat the water to sufficient standards of cleanliness.

In Cape Cod, an increase in development coupled with sandy soils results in limited effectiveness in cleaning the water. An excess amount of nitrogen "has resulted in degradation of estuarine and marine water quality and habitat conditions, and wastewater is a major source of nitrogen." (Stearns and Wheeler, 2009)

This proposal seeks to provide an alternative wastewater treatment strategy that contribute to the overall system of water treatment. In doing so, it addresses both ecological issues through landscape design and public health issues through infrastructure.

Source: United States Geological Survey

Excess Nutrients in the Groundwater from Septic Systems

Named for Section 208 of the federal Clean Water Act, Cape Cod's Water Quality Management Plan or the 208 Plan, is designed to address the problems of excess nitrogen, the main cause of water quality degradation (Cape Cod Commission, 2016). The 208 Plan is a comprehensive, watershed-based approach that deploys regulatory reforms, innovative strategies, and community-wide processes to mitigate nitrogen pollution.

Looking at the town of Barnstable, the Mill Pond has been accumulating nitrogen and phosphorous over many years. The Barnstable Clean Water Coalition monitors the nitrogen and phosphorus levels and water flow throughout the Mill Pond system (inlet and outlets) to determine precise levels of nitrogen/phosphorus that are potentially flowing into the bays. This load is attributed to surface water inflow from upstream via the Marstons Mills River. Research and monitoring suggests there is some attenuation in the upper watershed (Massachusetts Estuaries Project, 2006). This attenuation is believed to be a function of a series of ponds, stream beds, and associated vegetated wetlands that are upstream of Mill Pond.

The Cape Cod Commission and the Barnstable Clean Water Coalition have prioritized Mill Pond for restoration. It is located within the within the 3 Bays watershed.

The Three Bays system exceeds its critical threshold for nitrogen, resulting in impaired water quality. The Massachusetts Estuary Project developed a range of alternatives that are based in green infrastructure technologies. This plan was prepared utilizing information from the Technologies Matrix along with a GIS-based site screening analysis that was developed to identify potential site for these technologies based on location within the watershed, depth to groundwater, availability of pubic rights-of-way (such as roads), parcel size and ownership.

Methodology

Typology > Descriptive Case Study > Application of Concepts

Step 1: Develop a typology of waste water treatment based on current practices.

A typology is "a taxonomic classification scheme applied comprehensively to entire categories of built form, relative to cultural values and practices." (Deming 133)

Why:
The typology provide a baseline understanding of current practices for treatment options. The typology includes an analysis that can be used to assess the fit between waste water treatment options and project goals.

How:
Researched guidelines from advisory organizations that provide guidelines and standards for implementation.
Sources: EPA, local, and non-government organizations - Cape Cod Commission, 3 Bays Preservation, Inc.
Inventory existing projects. Sources: Firms that construct and maintain them, Municipalities that operate the facilities.

Step 2: Descriptive Case Studies

Why:
Descriptive case study strategy builds "understanding about landscape characteristics and community values and activities to provide evidence in support of proposed design principles or local policy initiatives." (Deming 85)

Case studies illustrate the implementation of innovative waste water treatment methods. This collection of projects serves to build knowledge in the greening of waste water infrastructure.

Step 3: Application of Concepts

What:
Landscape urbanism, green infrastructure, ecosystem services, resilience

Why: To demonstrate how theories of landscape architecure can be applied in practice.

The proposal for a Waste Water Greenway applies the lessons learned from the research to one specific site in Barnstable, MA. In so doing so, the design suggests how green infrastructure systems can be implemented. The design proposes a multi-functional strategy as a model for land stewardship. The practice of landscape architecture can take many forms. The connection between humans and the environments is two-way; each influences the other. Through understanding issues of the envirnoment, landscape architects can shape the environment in an ecologically sensitive manner, in order to support the health and wellness of our communities.

Project Goal

A landscape-based approach to the design of waste water treatment considers current practices, responds to the regional conditions, and addresses hydrological issues. In this project, these components are formalized through a waste water typology, descriptive case studies, and site analysis. A typology of waste water treatment provides a baseline of current practices. Case study analysis demonstrates innovative waste water treatment projects and derives recipes for the implementation of landscape-based designs. An analysis of the Mill Pond site and its role within the watershed and of Cape Cod region provides an understanding of context. The resulting design proposal for a waste-water greenway in Barnstable, MA demonstrates the application of principles to address a specific waste water issue. The design for a neighborhood-scale Waste Water Greenway leverages biological treatment through a Living Machine and plant materials to clean water, restore wetlands, and support wildlife. This strategy can serve as a toolkit for how to design multi-functional landscapes that contribute to a healthier ecological systems in the built environment. In addition to the treatment of waste water, a neighborhood Waste Water Greenway would restore ecological processes and be a recreational amenity for the community. This project will explore alternatives to waste water treatment that could be implemented at the neighborhood scale.

A multi-functional neighborhood-scale water treatment facility could provide the following:

- Localized/decentralized water treatment
- Recharge the ground aquifer
- Recreational amenity for residents
- Educational opportunities
- Habitat that supports biodiversity
- Improved resiliency of overall water system
- Energy generation from heat extraction (from warm water), or the burning of biosolids

2 Literature Review

Ecosystem Services

The concept of ecosystem services is the environment, through its basic function, provides valuable goods and service to humans (see chart at right). For example, trees take in carbon dioxide, cleaning the air. They also provide shade, providing a comfort through shade and reduction of heat in urban areas. Scientists have begun to inventory, classify and evaluate these goods and services. Though scientific method, a specific ecosystem service can be assigned a value based on how much it would cost for humans to provide the benefit to ourselves. Urban ecologists, plant ecoloists and geologist such as Pickett, Wu have contributed to the body of research to define and evaluate the benefits of ecosystems services.

Humans depend on ecosystems for survival, and through considerate and appropriate management practices, can continue to benefit from these services. In order to facilitate healthy relationships between the built and natural environment, the planning and design disciplines can apply these ideas to practice. In terms of waste water, soils and plants provide the valuable ecosystem service of cleaning the water.

Ecosystem Services Include:

- Carbon sequestration
- Filter air and water pollutants
- Stabilizing soil to prevent or reduce erosion
- Providing wildlife habitat
- Reduce heat island effect
- Decrease public cost of water infrastructure
- Reducing energy usage through passive heating and cooling

Application of ecosystem services in green wastewater treatment:

- Reduction of costs for water management infrastructure through alternative waste water treatment concept
- Provide recreational and educational benefits through multi-functional design
- Provide wildlife habitat through considerate planting plan

Source: United States Geological Survey

Green Infrastructure

Green infrastructure is an approach to water management that protects, restores, or mimics the natural water cycle. Green infrastructure is effective, economical, and enhances community safety and quality of life. (American Rivers)

Through the consideration of natural systems and ecological processes, green infrastructure provides clean water, wildlife habitat and improves air quality. Green infrastructure contributes to a social, economic, and environmental health.

Rouse outlines six principles for the planning and design of green infrastructure. They are: multi-functionality, connectivity, habitability, resiliency, identity, and return on investment (Rouse, 37). Table 1 wincludes definitions of these principles and how a Waste Water Greenway would follow these principles.

There are many guides and toolkits that develop strategies and outline tactics for communities to implement green infrastructure in terms of storm water management. The University of New Hampshire's Stormwater Center and the United States Environmental Protection Agency provide research and manuals. These same green infrastructure concepts can also be adapted to wastewater management.

Just like storm water management planning and design, understanding and responsiveness to context is essential in order to develop tactics that will be effective. Considerations of climate, scale, and character of environment play an important role successful design.

Principle of Green Infrastructure	Definition	Application in Waste Water Greenway
Multi-functionality	Provide a range of ecosystem services	Recreation (walking, bird-watching)Water (cleansing, groundwater recharge), biodiversity
Connectivity	Maximize most effective in providing services and benefits when it is part of a physically connected system across the landscape	Greenway path provides access to nearby neighborhoods, and an alternative to roadways
Habitability	Provides outdoor habitat for people, flora, and fauna	Plantings to support wildlife activity (food for birds, healthier water ways for fish)
Resiliency	Increase a community's ability to adapt to or recover from disturbance (either in the short or long term)	Water treatment greenway is part of a decentralized approach to the waste water system. Segments can be build throughout a town to create a network and in terms of greenways, provides active mobility
Identity	Contributes to the definition of place, community character	Native plants reinforce character, community landscape in public park. The living treatment greenhouse is also an educational facility.
Return on Investment	Ensuring the benefits resulting from green infrastructure outweighing those costs	Living Machine costs less than traditional grey infrastructure at certain scales. It also provides a variety of ecosystems services

Table 1: Green Infrastructure Principles

3 Wastewater Typology

Historically in North American, septic systems have been the standard way to treat wastewater. With an increase in the density of development, such as in cities, came the need to manage wastewater on a larger scale. Centralized waste water treatment plants accomplish this. In less dense areas, septic systems are typical, while in higher density areas, centralized sewers are the standard method for handling waste water. Due to issues with the effectiveness of treatment, communities have begun to implement other systems to clean water. Septic systems and centralized waste water treatment plants represent two ends of a spectrum of options. While these alternatives also have limitations, they have been developed for specific contexts and to address specific issues that have arisen from the standard methods of treatment. Waste water management is slowly migrating away from a one-size fits most approach to a context-based approach as the connection between the management of wastewater and the health of the surrounding environment has become clear.

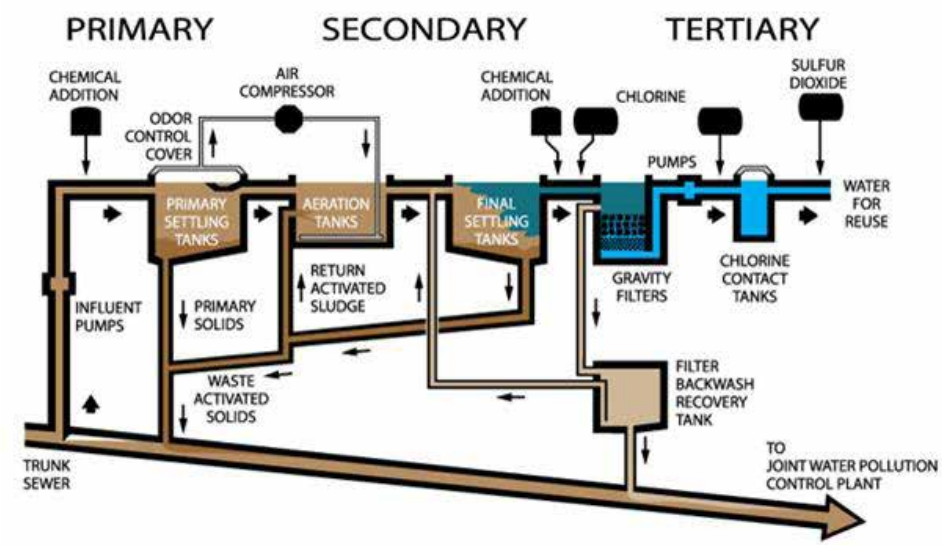
The typology of waste water management includes a range of interventions in terms of financial investment, scale, and technology. The types explored in this study are based on the evolution of systems with human development of the built environment in the landscape and are as follows:

- Septic systems
- Centralized sewage treatment system
- Package Treatment Plant
- Living Machines
- Constructed Wetlands

Each type of waste water treatment system includes the following details:

- Description of process
- Inputs
- Outputs
- Scale at which it operates / Size
- Benefits
- Drawbacks
- Diagram and photos

Centralized Sewer System



Portland waste water treatment plant

Centralized sewage treatment systems were developed in response to urbanization. With an increase in the number of people living in an area, there was a corresponding decrease in the land available to treat waste water with a septic system. This new approach introduces extensive pipes and is able to treat a much higher volume of water through an efficient series of processes employed at a large scale. The processes include physical, biological and chemical, and they employ various levels of technology. Physically, gravity does much of the work. Bacteria processes organic compounds through biological processes, assisted by aeration. Chemicals are added to flocculate and chlorine is used to disinfect. The chemical additions are used to decrease the time required when compared to natural processing.

Stage 1: Settle. Solids settle and the water is moved to the next stage, floating solids skimmed off of top.
Sage 2: Filter
Stage 3:Purification
Stage 4: Disposal (drying, burning, release into body of water)

Size: 1-2.5 million gallons per day, # of people/households served

Inputs: Human waste and waste
Additions in process: chlorine, sulfur dioxide
Output: [mostly] clean water, waste bricks that are burned/ disposed of elsewhere
Benefits: Treatment of a large volume of water
Drawback: capital and energy intensive, especially in the treatment of sludge

(Source: National Service Center of Environmental Publications, 1990)

Septic System

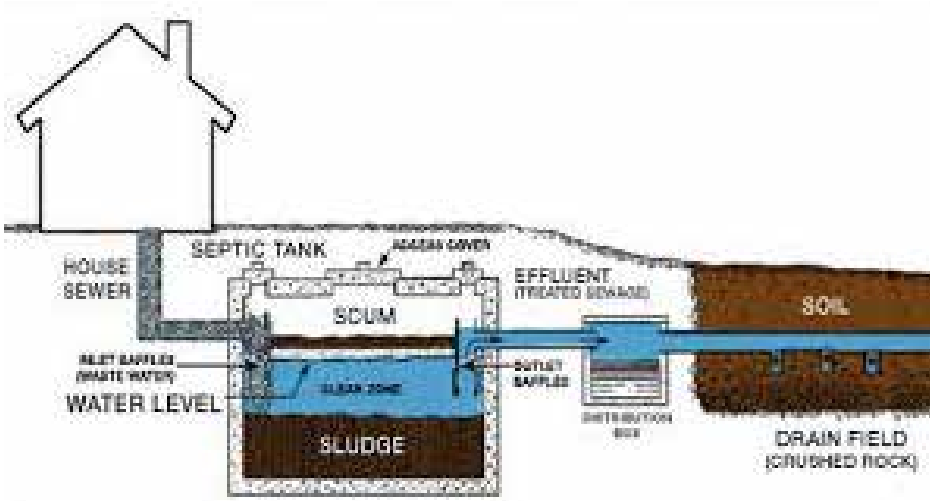


Diagram: Septic System

Photograph: Septic System

The septic system may be considered the prototypical tactic of green infrastructure. In the 1860s, John Mouras made a concrete tank and clay pipes to convey wastewater from his home. When the sewage overflowed from the tank, it would then be released into a cesspool. After nearly ten years, Mouras decided to open the tank to see how his prototype was holding up. At this time, it was virtually completely free of solids. Because of this success in France, this system was introduced into the United States in 1883 (Kasson, 1991).

Septic systems operate at a household level and are on-site. Pipes convey waste water from the individual home to a tank where solids settle, and the water then goes to pipes and is released into a drainfield, where soils and associated organisms filter and clean the wastewater. The clean water then moves through the soil profile and recharges the ground water aquifer. The process of filtering and cleaning and recharge happens underground, and employs natural forces (gravity) and systems (soil communities).

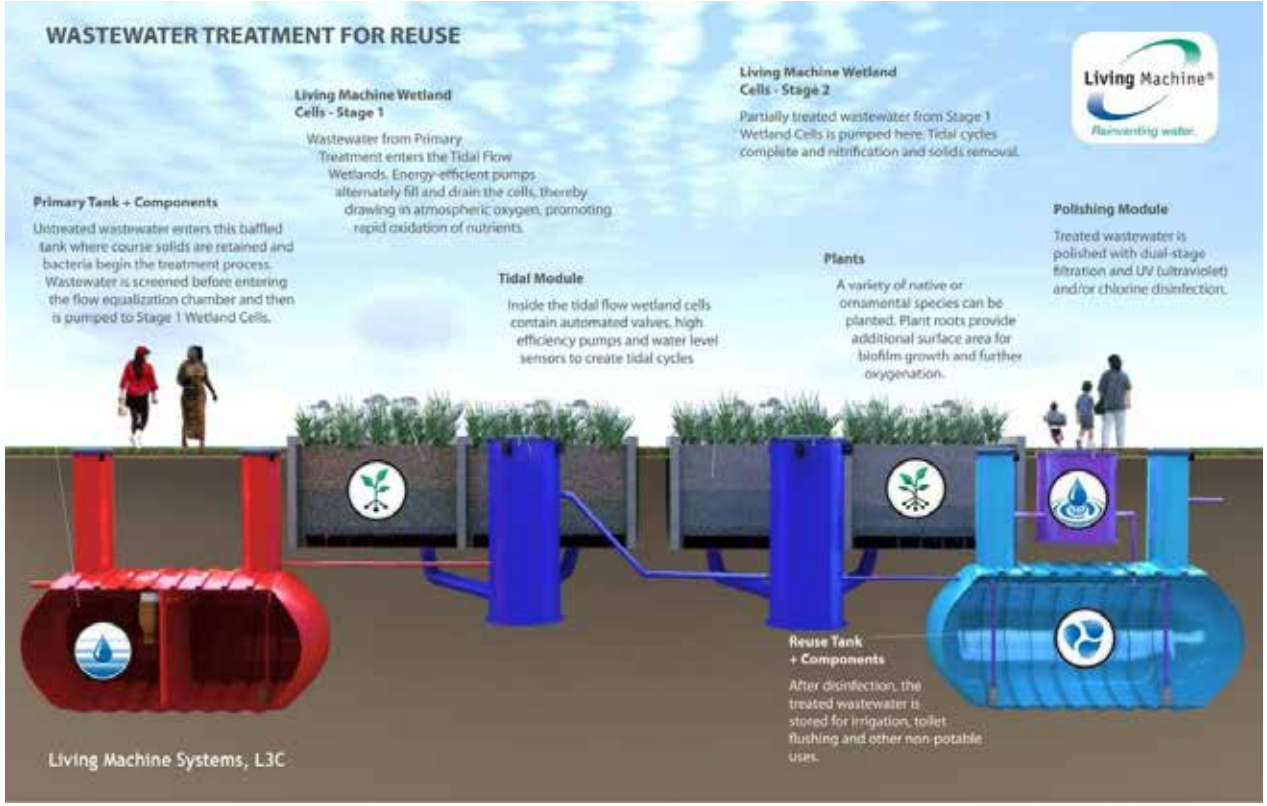
Input: human waste and water
Output: Clean water percolates into the ground, recharging the ground aquifer
Serves: 1 household
Cost of System: $8-15k for 3-4 bedroom house, up to $30k for a mounded system (Cape Cod Commission, 2013)
Cost of Operation: Septic systems are a model of sustainability - water is treated on-site, low-technology, and no additives to clean the water. Solids need to be removed from septic tank periodically.

(Source: National Service Center of Environmental Publications, 1990, United States Environmental Protection Agency, 2016)

Living Machines

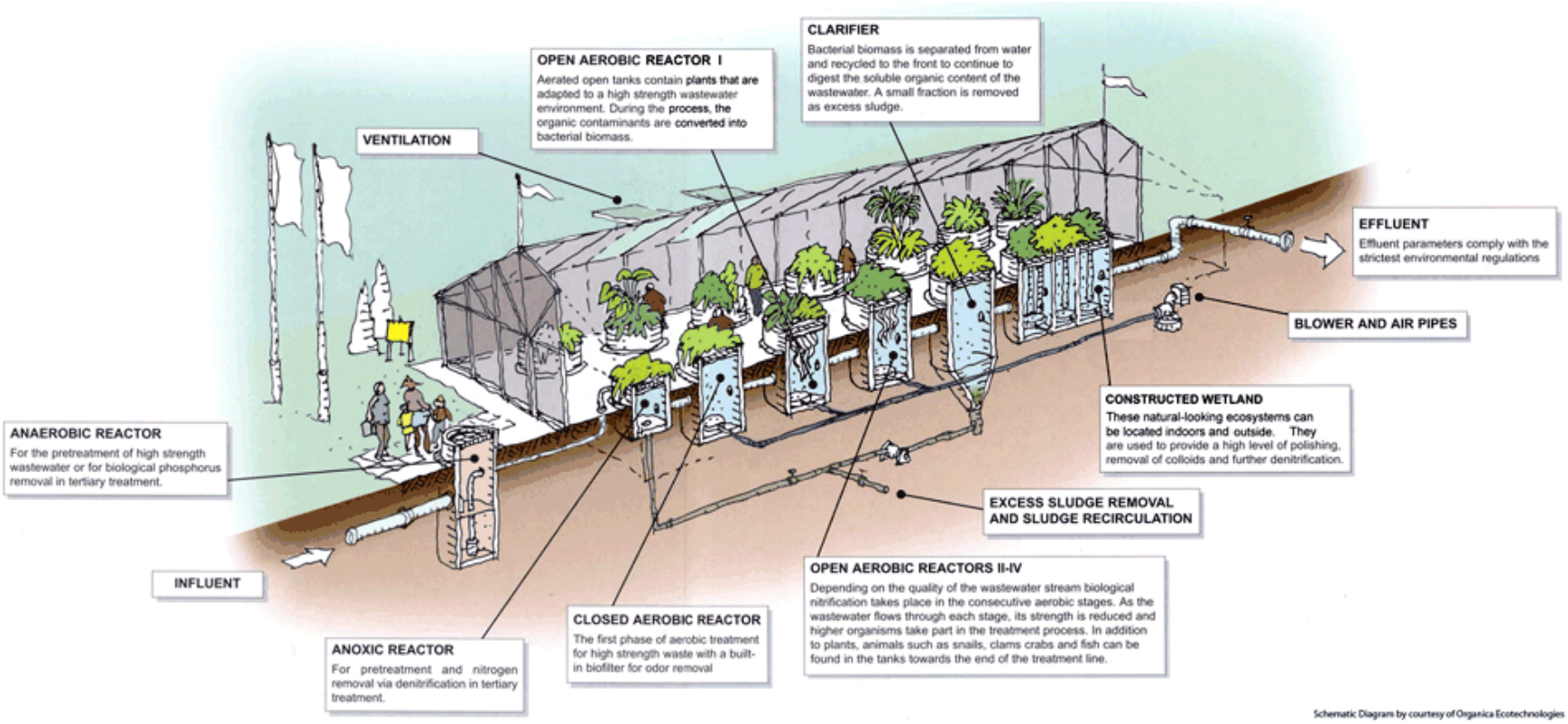
The Living Machine is a concept of treating wastewater utilizing biological processes and following principles of ecological systems design. Dr. John Todd, President of the non-profit organization Ocean Arks International, first developed a design concept for a Living Machine. (Lyle, 1994) Like conventional systems, the treatment is done through a series of processes (sedimentation, filtration, clarification, adsorption, nitrification and de-nitrification, volatilization, and anaerobic and aerobic decomposition). Unlike a conventional system, a Living Machine's processes leverage the activity of living organisms - plants, animals and other organisms, to clean the water. The living system takes human waste water, and without the addition of harmful chemicals such as chlorine and sulfur dioxide, produces clean water. The reason no chemicals are added is because it is designed as an ecological system - the plants and organisms take up the nutrients and chemicals, and thus clean the water. The plant residuals can be composted.

The design of a Living Machine considers both process and components. A series of cells forms the basic design. The contents of each cell varies based on the stage in the process and the corresponding biological function needed for the filtering and cleaning of water.



Photograph: Septic System

Living Machines



Schematic Diagram by courtesy of Organica Ecotechnologies

Characteristics:
Various cells with designated purpose
Living components (plants, microorganisms, algae)

Cost: Living Machines can cost about 20% less than conventional systems

Drawbacks: Natural systems require monitoring and balancing of elements through seasonal variations. Complex biological processes need to be maintained for the system to operate.

Benefits: low-cost, on-site treatment, aesthetically pleasing, educational and recreational ecosystem services, integration with ecosystem, utility, habitat. The greenhouse provides year-round recreational and educational benefits. Reduction in the amount of sludge produced

Living Machine as a Systems-based Solution

Living Machines focus on conserving and processing water at a local level. While some may consider them to be a flawed attempt of designing a closed-loop system, these machines are exemplary in the integration of natural systems in the treatment of waste water. The Living Machine offers flexibility to employ the system at various scales. At the smaller end of the range, a Living Machine can clean and provide water for a neighborhood, such as a community ranging in size from 25 – 50 homes. On a larger scale, existing infrastructure systems can use Living Machines as a retrofit. In this manner, the natural processes can be a way to reduce costs of cleaning the water, or as a way to increase capacity.

The design of Living Machines, based on the John Todd Ecological Design, has three main characteristics: utility, amenity and habitat. As utility, the system functions to clean waste water. Since the water treatment process utilizes plants and other aspects of the natural environment, it serves as an amenity for humans; people can view the process, and enjoy the plants. These plants are part of a larger ecological system, and thus provide habitat for fish, insects and birds. The multi-functional design of the Living systems utilizes concepts from ecological systems, and provide an alternative to conventional wastewater treatment.

Living Machines can function independently, and are also a way to integrate grey and green infrastructure. Through retrofits that expand the capacity of more traditional, centralized water treatment plants, or through creating modules of green infrastructure water management that can accommodate an increase in growth of the built environment and the accompanying increase in waste water produced. Additionally, these smaller-scale modules reduce the load on the grey infrastructure systems by creating nodes or modules in the overall water management system, having a positive impact in terms of increasing resiliency of systems and the communities of which they are a part.

Ideas of sustainability (recycling water), managing water efficiently, and employing natural systems underpin the idea of a Living Machine. There are several projects that showcase the effectiveness of this integrated system approach, including an elementary school in Washington, D.C., a municipal treatment experiment in Vermont, and a wellness retreat in New York (John Todd Ecological Design, 2017). These systems vary in scale and design, as well as the extent to which they employ ecological systems in their functioning.

Package Treatment Plants

Package treatment plants represent a decentralized yet community-based approach to managing wastewater. Though it utilized natural processes, these processes are often separate from the surrounding area.

A Package Treatment plant is a form of decentralized wastewater treatment system. It utilizes the biological extended aeration principle in its operation, which is a variation of the activated sludge treatment process. This system functions by creating an environment with sufficient oxygen levels and agitation to allow for bio-oxidation of the wastes to suitable levels for discharge.

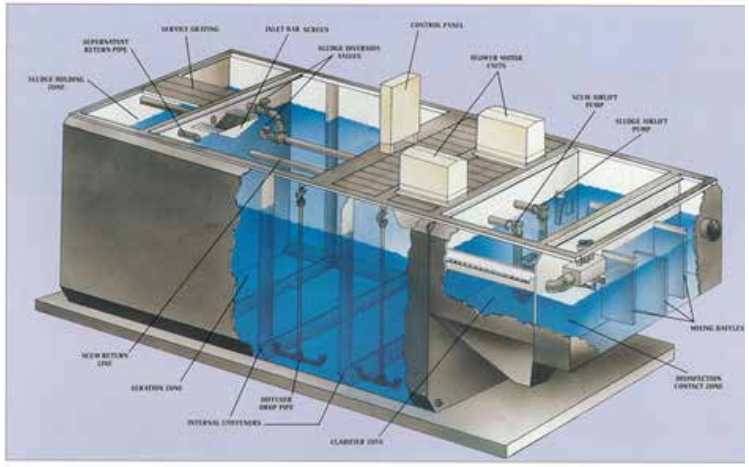
Waste material in domestic wastewater is generally organic (biodegradable) which means that microorganisms can use this matter as their food source. A biological wastewater treatment system makes use of bacteria and other microorganisms to remove up to 90% of the organic matter in the wastewater.

Source: US EPA Fact Sheet, 2001

Emulating Nature
Biological waste water treatment systems mimic natural biological processes. As waste enters the stream, the dissolved oxygen content in the water decreases and bacteria populations increases. As the waste moves downstream, the bacteria eventually consume all of the organic material. Bacterial populations then decrease, the result of which is replenishment of dissolved oxygen. The process of cyclical fluctuations continues as the water moves through various stages. Though the process is biological, it lacks integration with the surrounding environment until the point of discharge. (Pollution Control Systesm, 2017)

Scale: Typical applications include housing subdivisions, military bases, mobile home parks, government compounds, small communities, remote areas

Advantages: Package Treatment plants represent a migration away from centralized approaches. In this vein, they offer a modular way to deal with waste water which can be duplicated easily in different areas.



Constructed Wetlands

Constructed wetlands are used as a standard tactic for the on-site treatment of storm water. In the treatment of wastewater, they can be a component of a centralized sewer system or a component of a Living Machine. Constructed wetlands utilize natural materials and leverage biological processes to treat water in an open environment; it is a landscape feature, versus taking place in an enclosed interior of a building.

Size: varies based on application, but range from are typically 4-5 square meters per person (~50 sq. ft.)

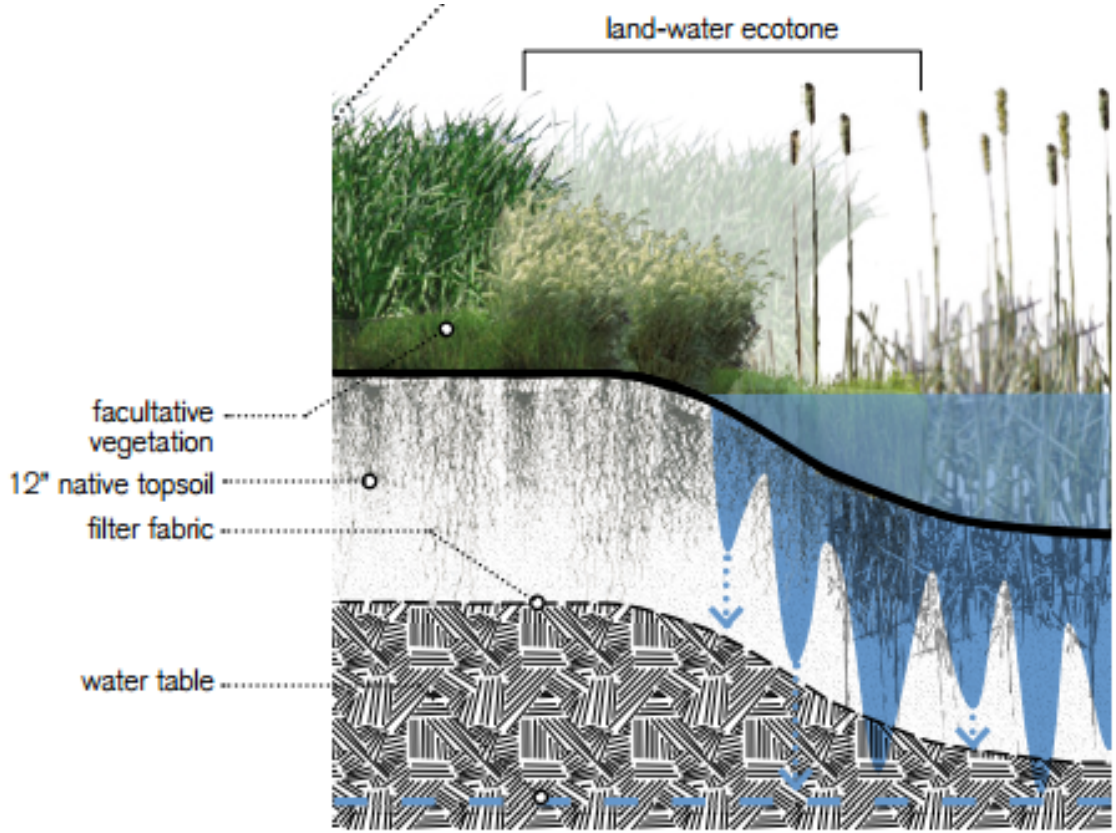
Input: Pre-treated water. This is not a stand-alone system for waste water treatment

Benefits: Valuable wetland habitat for waterfowl and other wildlife, education and recreation

Drawbacks: Establishment time for plants, maintenance, This is not a stand-alone system for waste water treatment

Opportunities: Wetland restoration - implement where wetlands may be compromised already to re-establish them

Source: US Environmental Protection Agency, 1993



References:
Low Impact Development Manual for Michigan
United States Department of Housing and Urban Development
Minnesota Urban Small Sites BMP Manual

Constructed Wetlands Considerations

The primary objective in vegetation management is to maintain the desired plant communities where they are intended to be within the wetland. This is achieved through consistent pretreatment process operation, changes in the water levels, and harvesting plants when and where necessary. Where plant cover is deficient, management activities to improve cover may include water level adjustment, reduce the amount of effluent, pesticide application, and replanting.

(Source: Constructed Wetlands Treatment of Municipal Wastewaters p. 129)

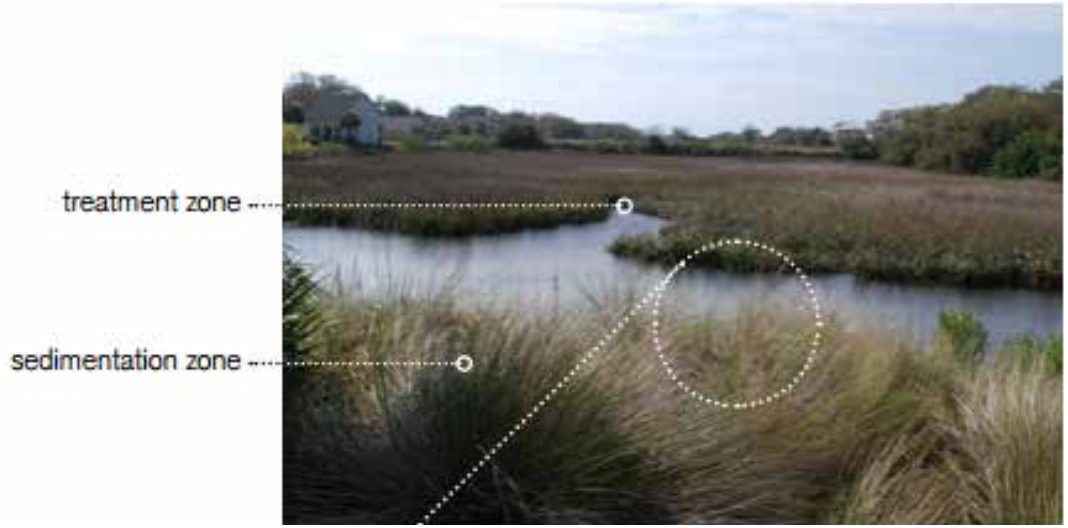
While horizontal-flow constructed wetlands provide good conditions for denitrification, the ability to process ammonia is very limited. Therefore, various types of constructed wetlands may be combined with each other in order to exploit the advantages of specific designs. In the case of the excess nutrient issue in Barnstable, horizontal-flow wetlands would address the priority to remove nitrogen from the hydrological system.

(Source: Vymazal, 2007)

Site selection criteria for constructed wetlands:

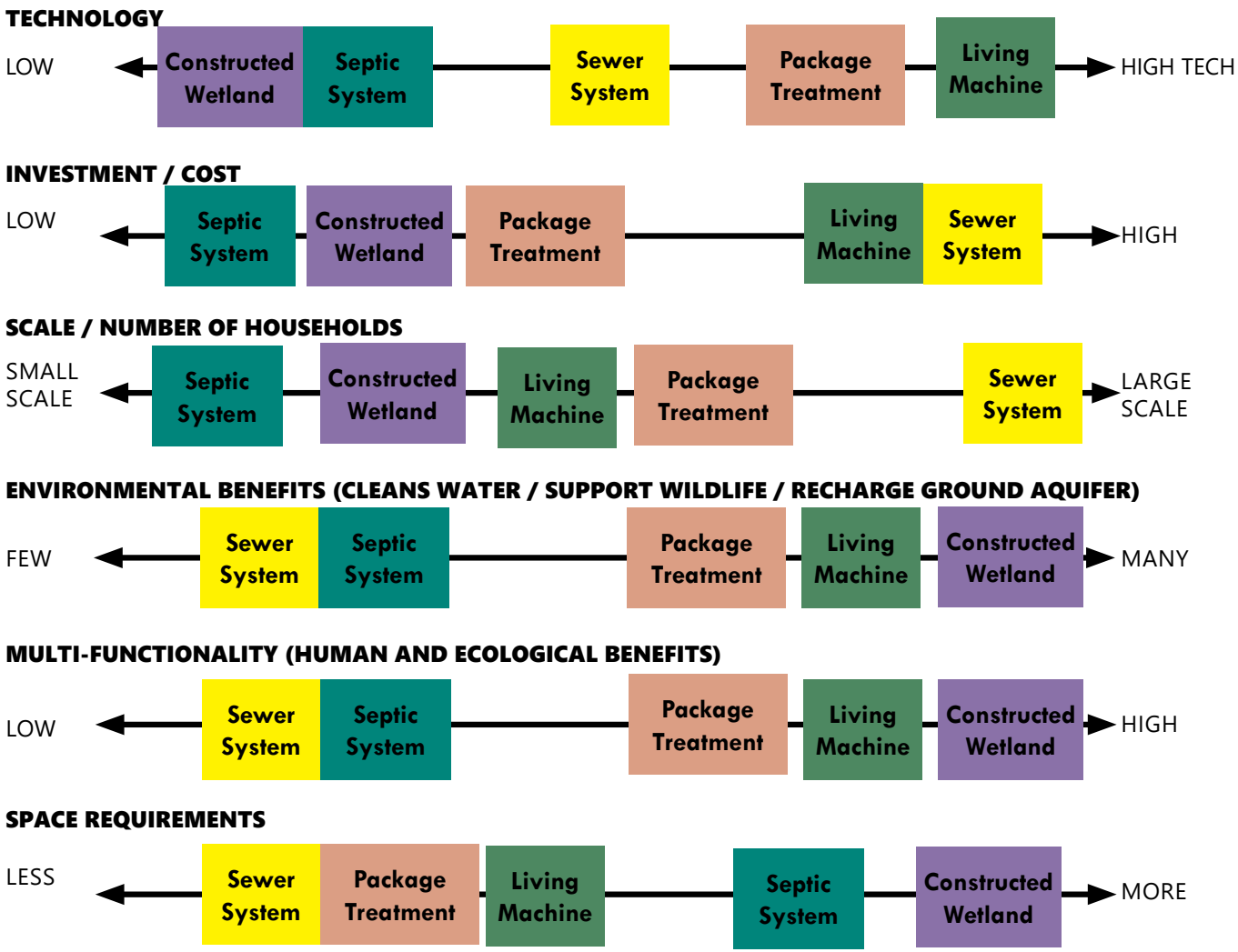
- Located near the source of wastewater
- Provides adequate space
- Proper slope to allow the water to flow through the system naturally (gravity)
- Soils that can be compacted to limit the seepage into the groundwater
- Is above the water table
- Is not in a floodplain
- Does not contain endangered species
- Does not contain historic resources

Source: Davis, 2000



Source: LID, 2007

Assessment of Characteristics



The features of waste water treatment systems can be used to categorize them. The pertinent characteristics are:

- Technological Sophistication
- Cost
- Scale / Number of Households Served
- Environmental Benefits
- Multi-functionality
- Space Requirements

Evaluation of each system based on these characteristics can provide guidance in determining which system may be appropriate for a specific context. In Barnstable, where there is relatively low-density and a high value on preservation of the natural environment, a Living Machine or constructed wetland would be appropriate.

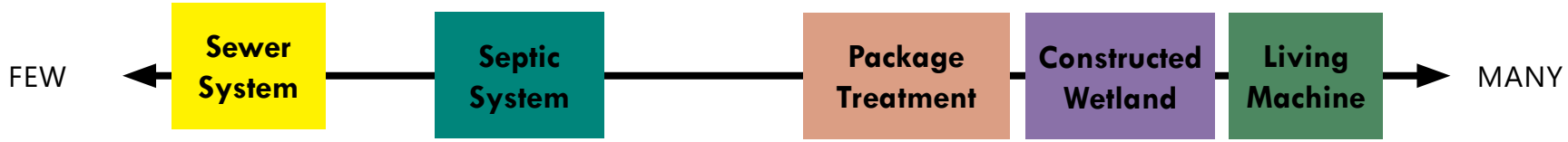
Ecosystem Services

The proposed application of an alternative wastewater system proposes a combination of approaches, borrowing from each:

- Septic: treatment in landscape, local
- Centralized sewer: none
- Package treatment: natural processes
- Living Machine: ecological processes, landscape
- Constructed wetland: landscape approach

Living Machines have thus far been designed for single buildings. This project seeks to apply available treatment techniques to a wider scale that is integrated with the ecosystem and built environment in a multi-functional manner, to treat a larger volume of sewage.

ENVIRONMENTAL BENEFITS - SUPPORTS WILDLIFE, RECHARGES GROUND AQUIFER



MULTI-FUNCTIONALITY - HUMAN AND ENVIRONMENTAL BENEFITS

Cost

INVESTMENT / COST (PER HOUSEHOLD SERVED)

Cost Comparison: Living Machines and Conventional Systems			
Process	40,000 GPD*	80,000GPD	1 Million GPD
Living Machine with Greenhouse	$1,077,777	$1,710,280	$10,457,542
Living Machine without Greenhouse	$985,391	$1,570,246	$9,232,257
Conventional System	$1,207,036	$1,903,751	$8,579,978

*Gallons Per Day

Source: EPA, 2001

Table 2: Cost Comparison, Waste Water Systems

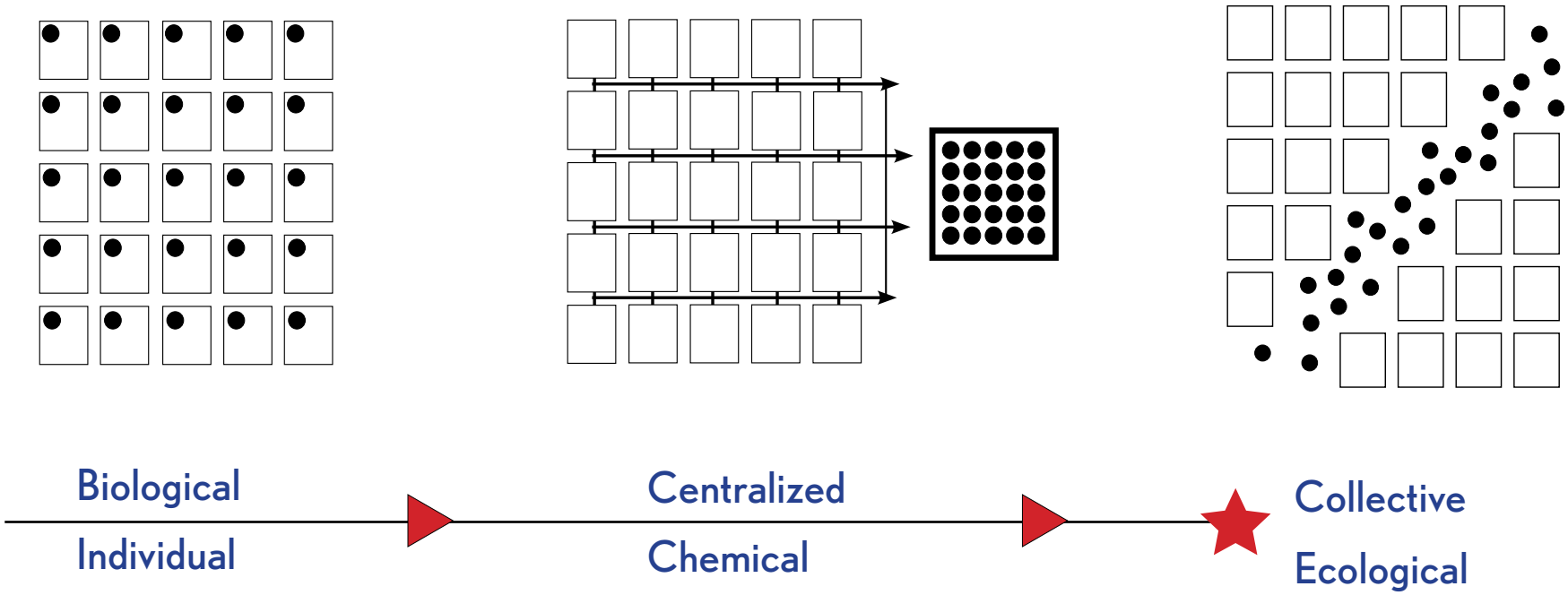
Sizing of Systems

The typology of waste water management tactics varies based on many factors. The need to treat a greater volume of water has driven the increasing size of systems, with centralized treatment used as the optimal system to serve the largest number of people. The recent shift in thinking in favor of decentralized systems is the result of increased knowledge and experience. Failures of centralized systems and an increase in monitoring of water quality has influencd thinking of innovative solutions to improve the interaction between humans and natural systems. Decentralization often occurs at household levels "through local-level operations and would be able to monitor and adjust their behaviors accordingly." (Hill, 2007, p. 264) Decentralization is a strategy through which waste water management can be integrated into grey infrastructure for a more sustainable system.

Type of System	Capacity largest range	Typical Size
Septic System	450 - 1,200 GPD	450 - 600 GPD (for a 2- bathroom house with 4 occupants)
Package Treatment	2,000 - 500,000 GPD	10,000 - 250,000 GPD
Centralized Sewer System	1-2.5 million GPD	1.5 million GPD
Living Machine	120,000 GPD	40,000-80,000

SCALE / NUMBER OF HOUSEHOLDS SERVED

Evolution of Water Treatment



4 Case Study Research

Introduction

Case Studies were selected based on the functions that they demonstrate and the alternative technologies they employ. Each case study has been documented along with the following details:

- System description - referencing the typology
- Background - context, the issue that the new system addresses, ownership and designer
- System operation - inputs and outputs
- Size - volume of water processed, amount of land utilized, or the number of households served by the system
- Time - how long it takes to clean the water
- Landscape features - images to demonstrate scale and degree of integration with the surrounding environment and community, and ecosystem services

Featured Case Studies:

1. Sidwell Friends School, Washington, D.C.
2. Wakodahatchee Wetlands, Florida
3. Living Machine, South Burlington, VT

Other Case Studies:

- Highway Rest Stop, Sharon, VT
- New Haven Waste Water Treatment Plant, CT
- San Luis Central Waste Water Facility, CA
- Columbia Boulevard Waste Water Treatment Plant (Portland, OR)
- Omega Institute (Rhinebeck, NY)
- Dockside Green Waste Water Treatment (Victoria, British Columbia, Canada)

- Design with topography
- Pump stations in situations where there are topographic constraints
- Natural systems require time to clean the water
- Treatment areas often are lined to retain water Utilize topography to slow the flow and move water
- Modular design is more easily implemented than an entire network
- Network of treatment systems
- De-centralization

Factors in the Treatment of Waste Water

- Capacity
- Slope of Land
- Character of Soils
- Seasonality
- Space
- Time

Sidwell Friends School Washington, D.C.

Project: Sidwell Friends School
Location: Washington, D.C.
Designers: Landscape Architecture firm Andropogon, Kieran Timberlak, Natural Systems International

Background: The private Middle School building and grounds feature a Living Machine, water-efficient landscaping, green roofs, and rooftop agriculture. The courtyard features a constructed wetland designed to utilize storm and wastewater for both ecological and educational purposes.

Type of System: Living Machine + constructed wetlands

Landscape Features

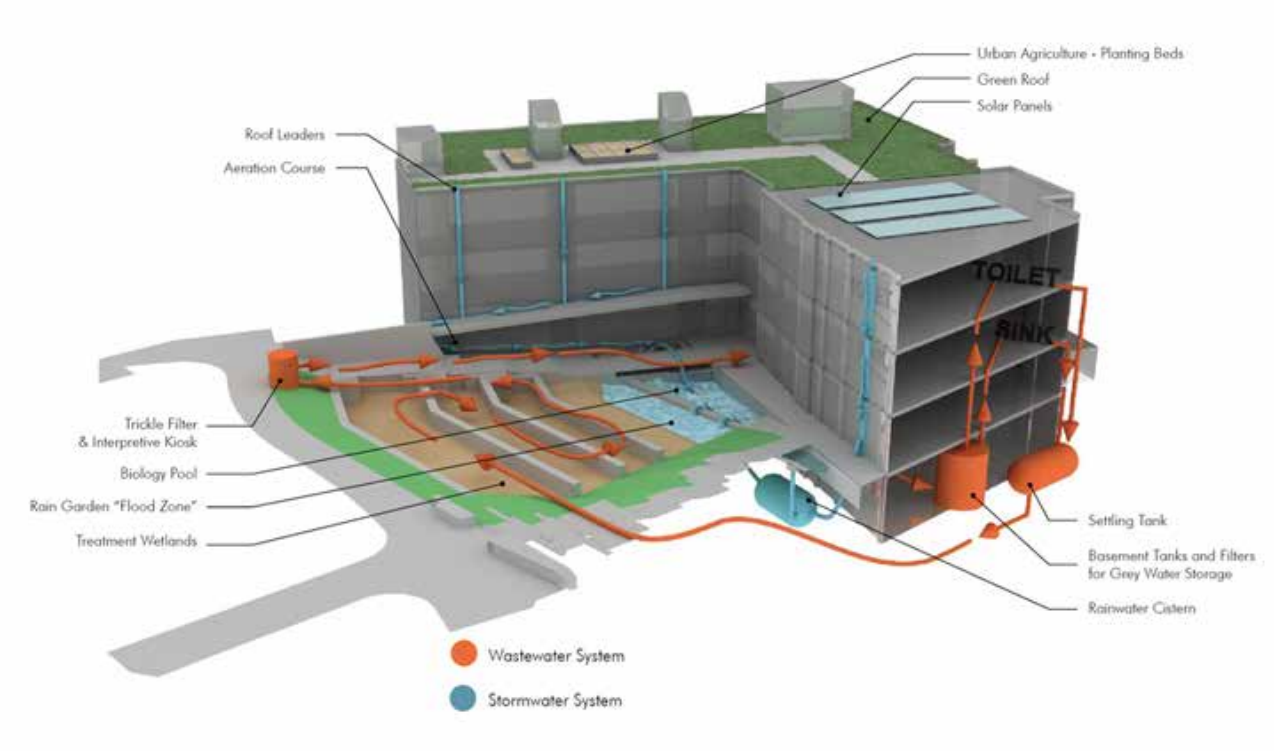
Ecosystem Services

- Prevents over 317,900 gallons of wastewater from entering the District of Columbia's overburdened sewer system each year, saving $1,687 in sewer charges.
- Reduces potable water consumption by an average of 8,500 gallons per month by reusing treated wastewater to flush toilets.
- Educational Opportunities for students and visitors - promotes environmental awareness with over 10,000 visitors touring the site in its first five years. Students at the school give the tours.

Source: Landscape Architecture Foundation, 2017

Source: Andropogon Associates

Sidwell Friends School Washington, D.C.



Source: Andropogon Associates

Amount of waste: 3,000 gallons/day
Wetland Area: ~5500 sq. ft. (0.13 acres)
Time to Process: 2.9 days
Savings: reduced water consumption by 93%

Waste Treatment Process: Waste water from the toilets and sinks goes to a settling tank where solids settle out. The waste water is pumped through a terraced treatment wetland then back inside through filters for final cleaning. The greywater is stored in a tank into the basement and used for toilets and sinks in the building.

Plant Materials: The water is treated in a sub-surface manner, in order to limit human interaction with the waste water.

Takeaways:
Closed-loop, living systems have benefits and drawbacks. Cleaning waste-water and using it on-site is efficient but costly. Pumps are needed to circulate the water through the system in order to clean it into the allotted treatment area. The systems is not truly closed, as energy is needed to operate the system, drinking water is sourced and the solids need to be removed from the settling tank.

Wakodahatchee Wetlands

Owner: Palm Beach County Water Utilities Department
Location: Palm Beach, FL
Year: 1995/1996
Cost: $2.85 million

Type of System:
Centralized System utilizing dispersed to Constructed Wetlands (for Tertiary Treatment) instead of previous tactic of outfall to the ocean

Background:
The east coast of Florida is under development pressure. Partially treated water from the sewage treatment plant is circulated through the system where the excess nutrients are utilized by the wetland ecosystem, and the wetland naturally filters and finishes the wastewater. Wakodahatchee allows Palm Beach County to perform the required task of waste water filtration while simultaneously reclaiming wetland environment and providing the public with a park-like setting. The name is Seminole Indian language meaning "created waters." (Bays, 2000, p. 60)

Sizing:

- Land Utilization : 50 acres of land owned by utilities. Demonstrates how underutilized land can be transformed into a wetland ecosystem
- Total wetland area: 39 acres. 8 different marsh areas, each between 3-10 acres
- Volume of water: 2 million gallons/ day of treated water is pumped into the wetlands from the reclamation facility, and the total amount of water is ~20 million gallons

Source: Palm Beach County Water Utilities, 2017

The Wakadahatchee Wetlands demonstrates how a waste water treatment can be integrated with a wetland ecosystem with many benefits for the community

The Wakadatchee Wetland is part of the waste water treatment plant and located within a suburban setting of Delray Beach, Florida.
Source: Google maps

Wakodahatchee Wetlands

Landscape Features
Different wetland communities are designed to manage water and foster biodiversity, and include:

- Open pond water areas to attract waterfowl and diving birds
- Emergent marsh areas for rails, moorhens, and sparrows
- Shallow shelves for herons and egrets
- Islands with shrubs and snags to serve as roosting, nesting, and basking sites
- Forested wetland areas for long-term habitat development

Ecosystem Services

- Provides food and habitat for many important wildlife species, including many of Florida's threatened and endangered species
- Recreation - bird watching - 140 bird species sighted
- Detain storm-waters, protecting downstream areas from flooding.
- Naturally purify waters containing nutrients like nitrogen and phosphorous without using fossil-fuel-based energies or producing sludge

Source: Wakodahatchee Wetlands Park, 2000

39 acres of wetlands
8 different marsh environments
treats 2 million gallons of water per day

Living Machine in Municipal Wastewater

Project: South Burlington Municipal Eco-Machine
Location: South Burlington, VT
Designers: Living Technologies and Dr. John Todd with Ocean Arks International
Area: 7,800 sq. ft.
Volume: 80,000 gpd
Number of people: 1,200 people (~6 sq. ft per person)

Background:
This Living Machine project operated from 1995 until 2001, and was the basis for testing the effectiveness of this approach to waste water treatment. Built adjacent to the city's centralized waste water plant, it diverted sewage to treat via biological methods.

System Operation:
Sewage flowed to a greenhouse with two treatment paths, each with five aerobic reactors, a clarifier and three Ecological Fluidized Beds. The open aerobic reactors used diffusers and floating plant racks to maintain a diversity of vascular plant species (over 350 species were tested including many flowering plants). The air and plants hosted a variety of organisms that digested the nutrients and pollutants in the wastewater.

Source: Todd, 2003

Source: Ocean Arks Institute

Living Machine in Municipal Wastewater

Plants were evaluated for:
(1) their ability to tolerate sewage,
(2) the extent of the root zones,
(3) disease and pest resistance,
(4) ease of management, and
(5) secondary economic value.

Results
Biochemical Oxygen Demand (BOD), Total Suspended Solids (TSS) ammonia and total Nitrogen were reduced in this stage of treatment.

The design of the system at Omega Institute are three foot deep beds, lined with rubber, and filled with gravel. About two inches beneath the gravel is wastewater, which flows from the anoxic tanks, to the splitter box, to the upper two constructed wetlands. The wetlands use microorganisms and native plants, including cattails and bulrushes, to reduce biochemical oxygen demand, remove odorous gases, continue the denitrification process, and harvest nutrients, including phosphorus. As the wastewater flows through the wetlands, the microorganisms and plants are fed.

Source: https://www.treehugger.com/green-architecture/omega-center-sustainable-living-eco-machine-living-building-water-treatment.html

Source: Todd, 2003

Plants in the Living Machine extract nutrients from the wastewater, such as phorphorous and nitrogen. These elements are the issue in Cape Cod.

Source: Ocean Arks Institute

Case Study Take-aways

Research of case studies is useful to understand how design can overcome challenges. The following are design guidelines derived from case study research:

- Design with topography. Take advantage of water flow - centralized treatment and septic systems utilize gravity
- Pump stations can be used like centralized treatment systems (just specify where they would be) in situations where there are topographic constraints
- Natural systems require time to clean the water
- Treatment areas often are lined to retain water.
- Utilize topography to slow the flow and move water
- Modular design is more easily implemented than an entire network. Proposed phasing can be modular
- Living Machine - indoor facility for year round treatment and public amenity
- Network of treatment system create non-traditional figure grounds (from case studies to demonstrate concept diagrammatically) - zoom out to show the broader network

Factors in the Wetland Treatment of Waste Water

- Capacity - number of households served (Quantity of Waste - 80-100 GPD per person per day)
- Slope of Land - gradual is optimum (2% slope to move water slowly)
- Character of Soils - sandy drains quickly
- Seasonality
- Functionality of Plant Materials and other Living Organisms
- Destination of waste - grey-water, re-use, end application
- Space - availability may dictate the type of system used

Source: Ocean Arks Institute

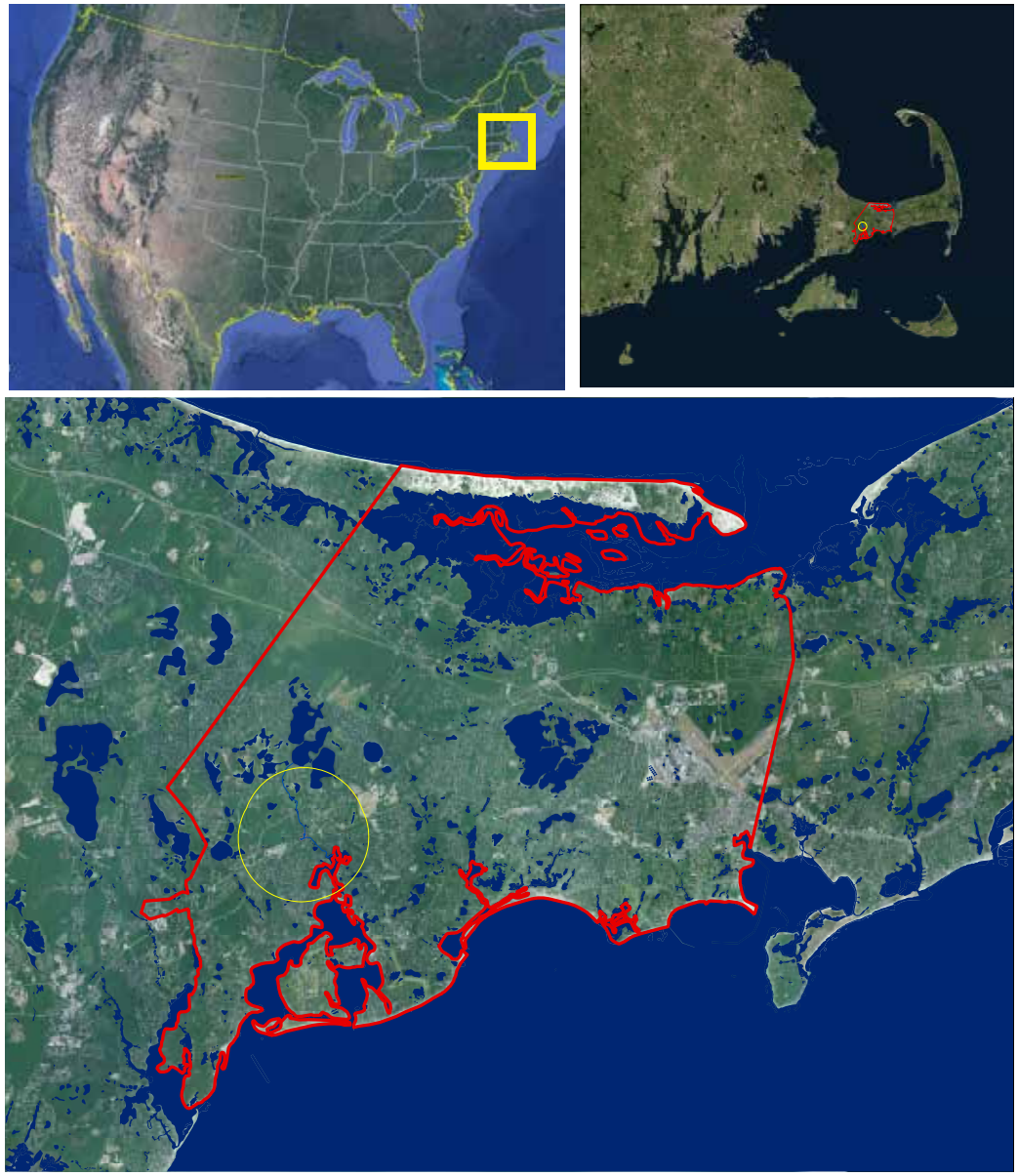
5 Application of Concepts

Location in Region

The focus of this project is Mill Pond, located in the town of Barnstable on the peninsula of Cape Cod in Massachusetts. The Atlantic Ocean is on the south side and the Cape Cod Bay is on the north side.

Mill Pond is 7 miles from Cape Cod Bay and 4 miles from the Atlantic Ocean. It is in close proximity to the Three Bays Estuary, and important area in terms of environmental concern, and one affected by the activity in Mill Pond and upstream. Development in the area upstream from the three bays is the cause of water quality issues. Specifically, there are excess nutrients from waste water. This excess nitrogen and phosphorous is nutrient pollution that the EPA has stated is most widespread, costly and challenging environmental problems (EPA Nutrient Pollution, 2017).

At the same time, there is development pressure in the town. Barnstable is in close proximity to beaches, making it a desirable area to live and visit. In order for the town to sustain itself economically, it needs to manage these valuable natural resources.



Source: Google Earth

Site Definition

A collection of parcels in the area immediately adjacent to Mill Pond comprises the site, for a total of 47 acres. Eighteen acres is owned by the River Ridge Neighborhood Association. One parcel in the southwestern portion of the site is privately owned (13 acres) while the rest is owned by the Town of Barnstable. These sixteen acres have been set aside as conservation land. The Mill Pond itself is six acres.

Source: MassGIS, GoogleEarth, Town of Barnstable, MA

Figure: Site Definition, Source: MassGIS

Photo Tour of Mill Pond - Main Entrance

Mill Pond is one of 182 freshwater ponds in Barnstable, and was created to power an adjacent mill in the 19th century. Today, the pond is realtevely undeveloped and is popular for bird-watching. A parking area is a small pull-off area on Route 27 near the intersection with Route 149. From here, there is a short trail that leads from the parking area to the pond.

Photo Tour of Site

A short trail leads from the parking area around Mill Pond. Within an eighth of a mile, song birds and swans can be viewed through the foliage. A granite tablet reminds visitors that though it is a this prime bird-watching area, Mill Pond was created as part of a mill development in the late 17th century.

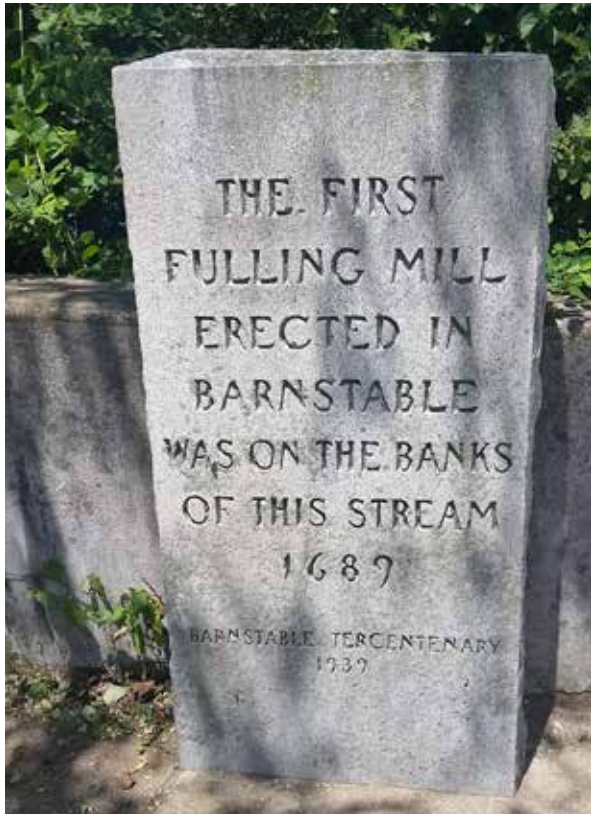


Photo Tour of Site - Fish Ladder

The Mill River connects the Mill Pond to other hydrological resources, such as the Three Bays Estuary downstream. The Mill River has been comprised by human development, and a derelict fish ladder was constructed in order to facilitate wildlife.

Photo Tour of Site - Backside Entrance

There is another vehicular access point to the site from the west side, along Old Post Road. The wide path provides utility vehicles with travel and service the nearby utility lines. Another path leads down the hill to the Mill Pond. A greenway could link to this segment and provide more extensive trails for residents and visitors.

Photo Tour of Site - Trails and Forested Area

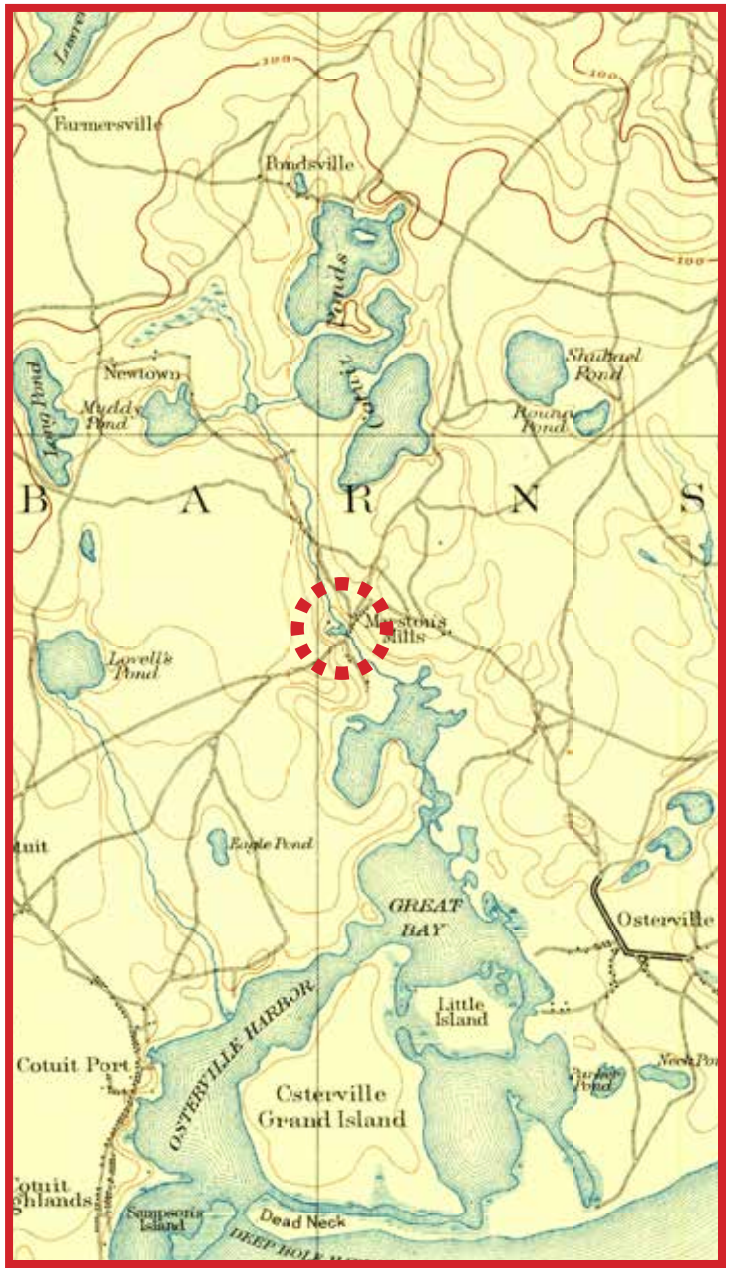
While one edge of the Mill Pond is directly adjacent to roads, a large portion of its perimeter is undeveloped. The paths are sandy, and the forest itself consists of a mixture of scrub oak and pine trees.

Hydrology and Human Development of the Mill Pond

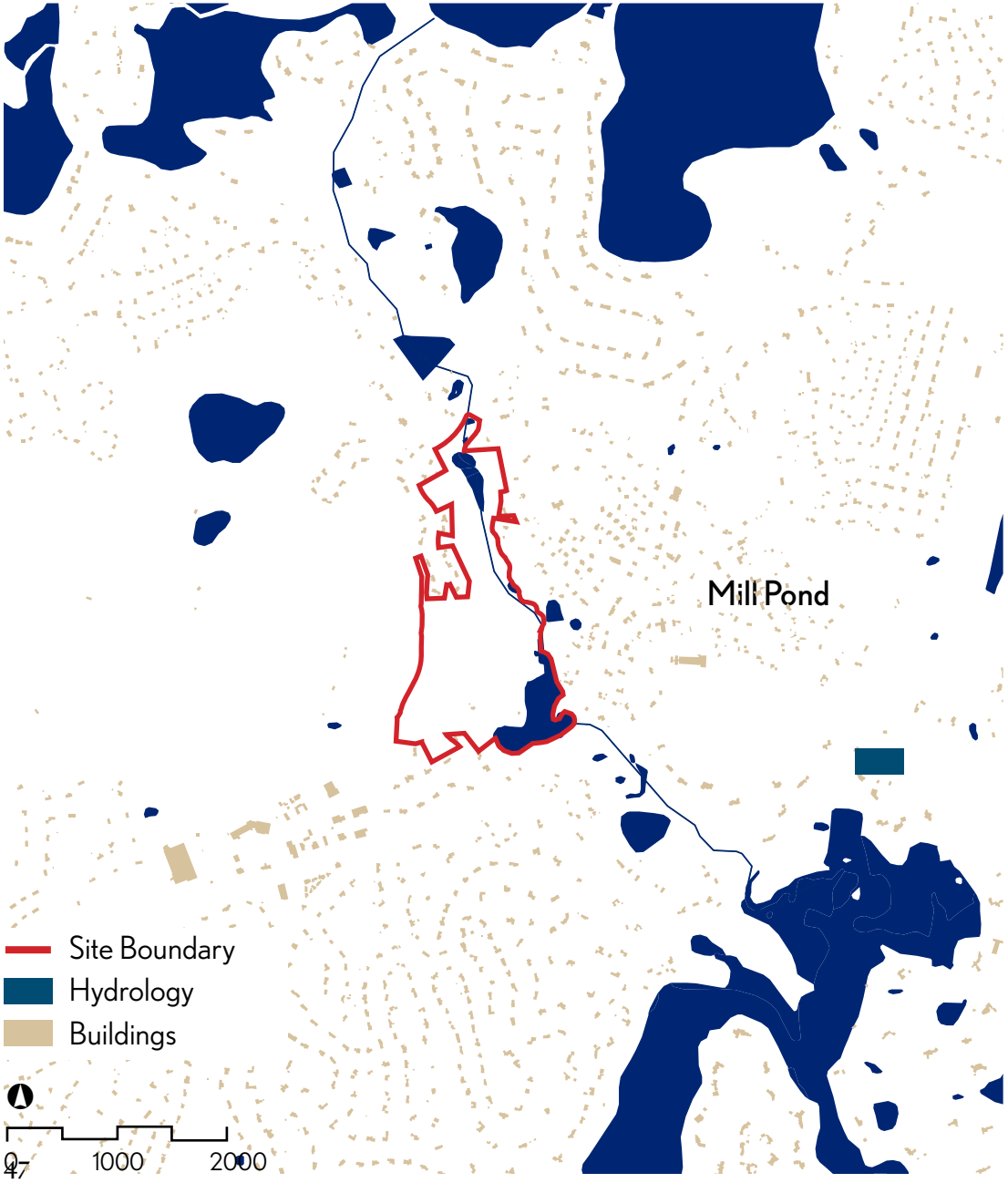
Mill Pond has historically been a node within the hydrological system influenced by human development. It was created originally for the mill that was located nearby and has served as a key landmark in the historic village center of Marstons Mills for the last 300 years.

The Mill Pond was created by a small dam, built to power the gristmill on its shore that dates back to a grant of the Barnstable Proprietors, who owned the land, to John Stacy in 1705 for the right to place a grist mill dam on the Cotuit River (Cape Cod Commission, 2016, p 7). Later, a hydroelectric plant was also temporarily operated immediately downstream of the pond by David Leland just before Word War II. To this day, Mill Pond remains a scenic refuge for wildlife and is one of the most photographed locations in the Town of Barnstable. It serves as an active herring run and provides an intermediate resting place for the fish on their passage upstream to their spawning ground in Middle Pond. Herring have been observed during their migration starting in late March through early April throughout the pond's history.

The Mill Pond has served both human and ecological purposes for the past 300 years.



Hydrology



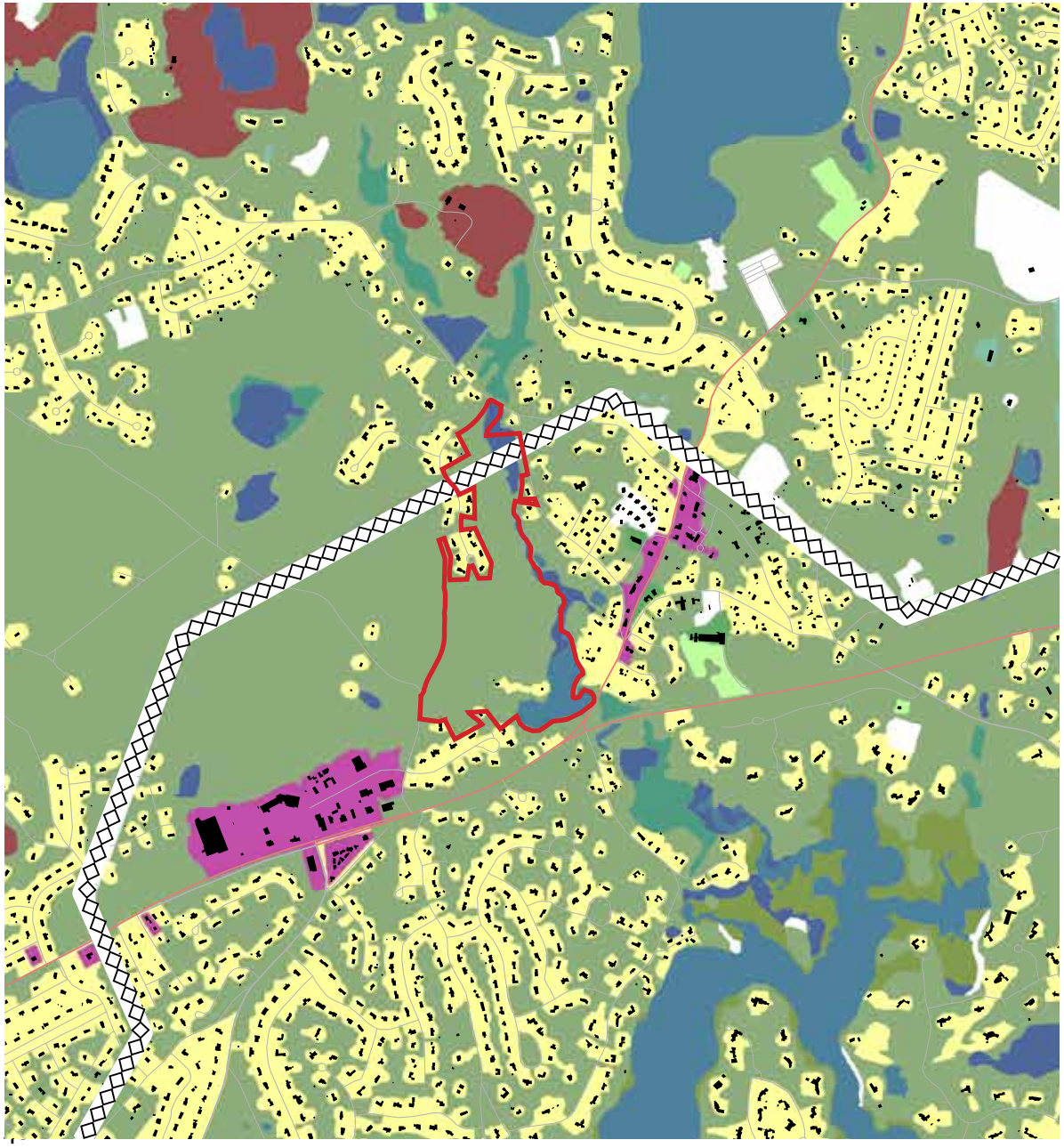
> There are more than 8,000 homes in the watershed, and every septic system is a point source contributing to the pollution of our ponds and bays.
>
> *-Michael J. Egan, President of the Board of Directors of Three Bays Preservation, Inc*

Inventory
The hydrological system consists of rivers, ponds, bays and ocean. The history of glacial activity shaped the land. As the glacier retracted, large masses of rock and ice were left behind (Oldale, 1981). Depressions formed from the melting of the ice, and then filled with water.

With the growth of development, humans have altered the land, both through buildings and water use. In the 18th century, entrepreneurs created the Mill Pond in order to power mills. Though man-made, the Mill Pond is an important part of the hydrological system, functioning as a sink for excess nutrients from anthropogenic activities. It has negative ecological effects downstream on the North Bay, Cotuit Bay and West Bay, which are known collectively as the Three Bays Estuary.

Assessment
Human activity has compromised the hydrological system, but it can also be the source of reconnecting

Land Use



Inventory

The area around Mill Pond is primarily residential, with some commercial activity. Road infrastructure includes main roads along the east (Cotuit Rd/Route 149) and south (Falmouth Rd/ Route 28)) sides of the Pond. The area to the northwest is mostly forested with several different owners including public utilities, land trust and the town of Barnstable under conservation restriction. The Barnstable United Elementary School school is 1.8 miles away.

Assessment

A greenway at this location would provide recreational benefits to the surrounding homes and could be a part of future greenway development to connect with the school.

- Site Boundary
- Water
- Residential
- Commercial
- Forests
- Wetlands
- Cranberry Bog
- Passive Recreation
- Public/Institutional
- Utilities

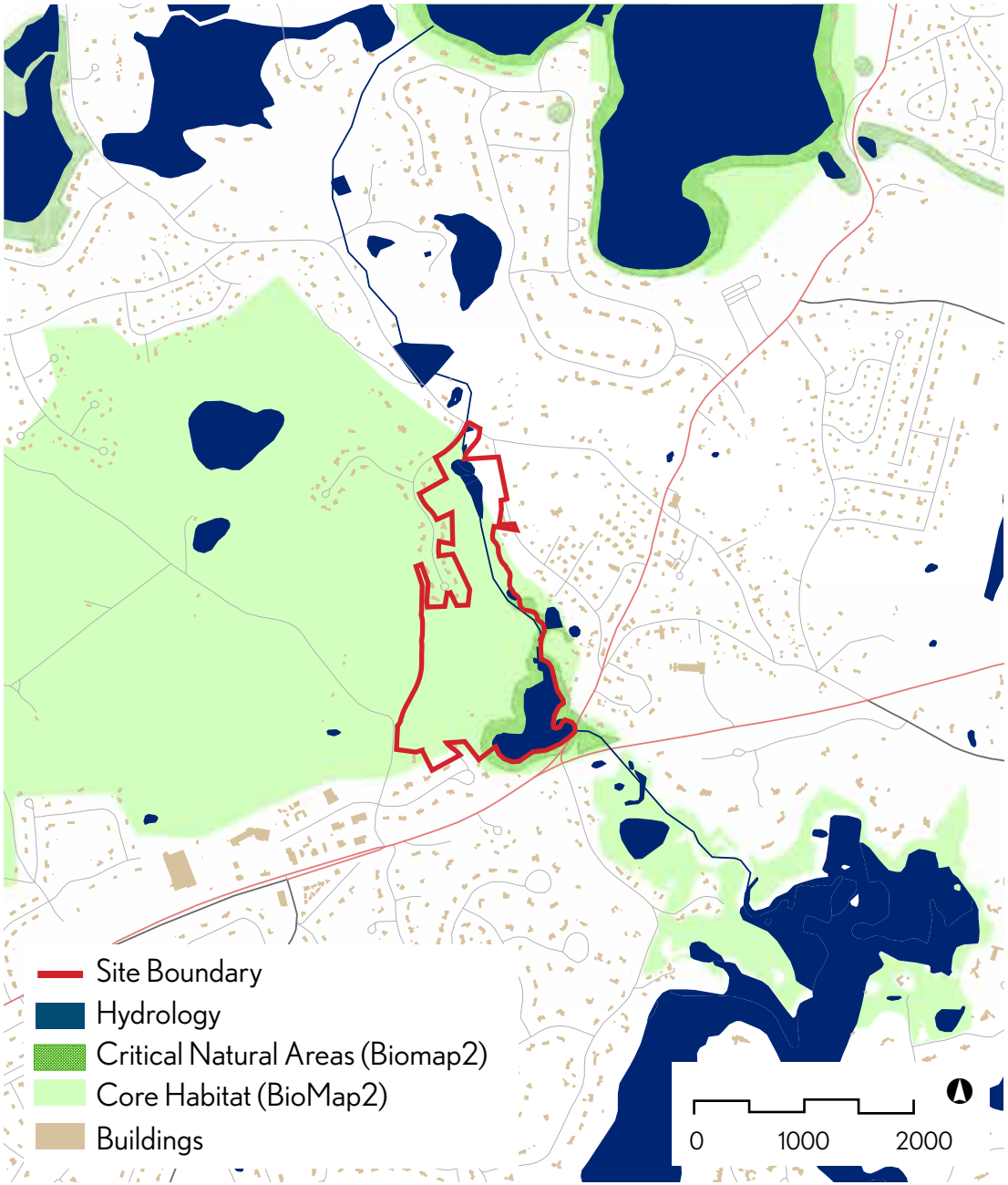
0 1000 2000

Natural Resources

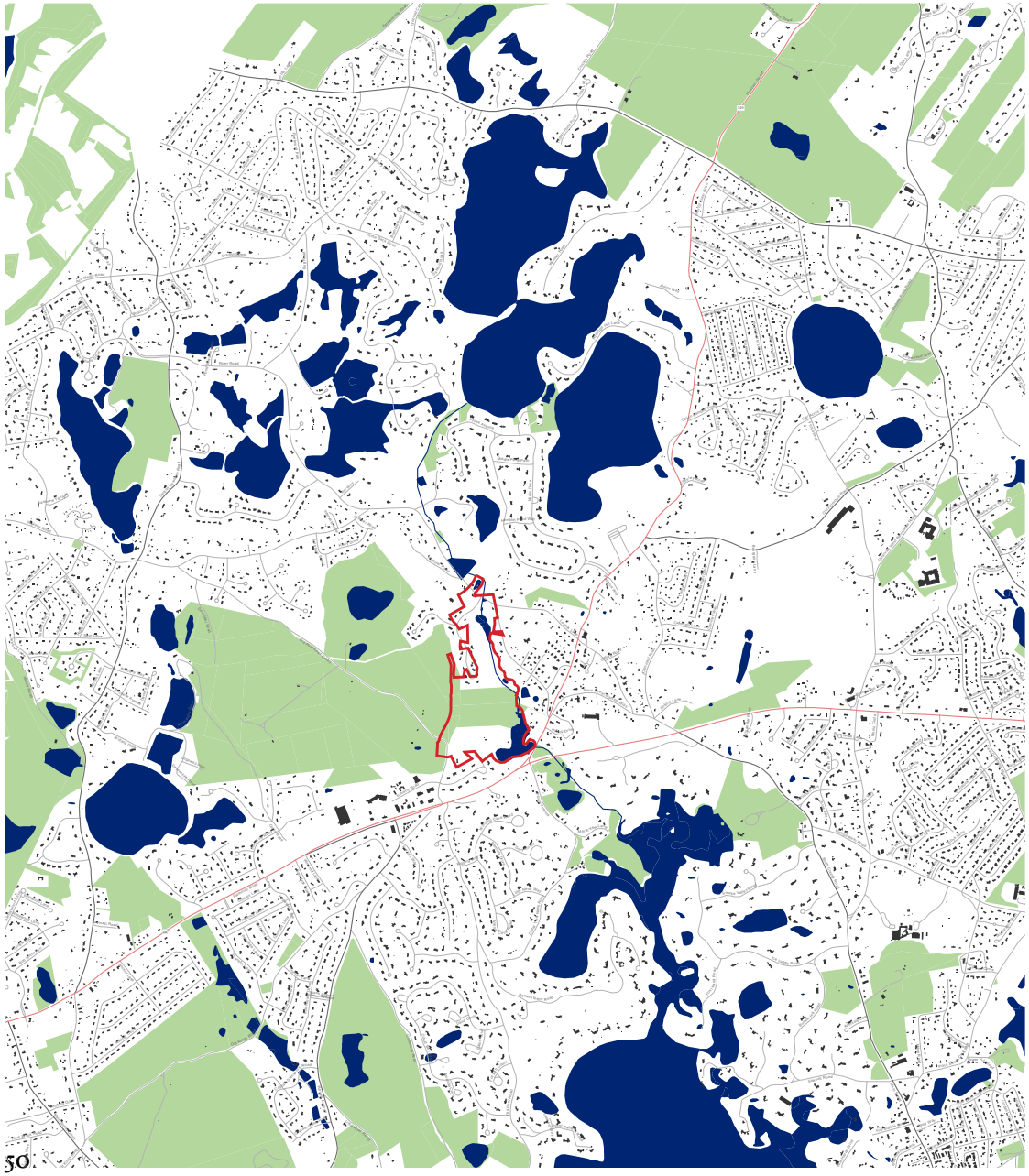
Aside from abundant hydrological resources, other natural resources include the Mashpee National Wildlife Refuge and the Cape Cod National Seashore. For the past 22 years, the state of Massachusetts has utilized the BioMap to identify core habitats and supporting natural landscapes (Conservation Fund, 2006). This resource can be used to help make land use and land protection decisions as well as to guide land planning.

The goal of the BioMap Project was to "promote strategic land protection by producing a map showing areas that, if protected, would provide suitable habitat over the long term for the maximum number of Massachusetts' terrestrial and wetland plant and animal species and natural communities" (Conservation Fund, 2006, p. 2)

The Mill Pond is located within a Priority Habitat of Special Concern for the Bridle Shiner. This small fish is protected under the Massachusetts Endangered Species Act (MESA) (Massachusetts. Natural Heritage & Endangered Species Program , 2015) The Natural Heritage & Endangered Species Program (NHESP) concluded any proposed project will require a management plan to protect the Bridle Shiner and as such must meet the performance standards for a Conservation and Management Permit. The NHESP provided recommendations to alter the project footprint to confine dredging to a more limited portion of the pond to protect the shoreline habitat as well as provide an area of refuge in the southeastern portion of the pond during dredging.



Open Space



The town of Barnstable has many conservation areas, though the area of Marstons Mills has relatively little open space. The open spaces also lack access. This is an opportunity to make the most of the open space that is available. There is an easement that provides access to the open space adjacent to Mill Pond along Cotuit Road.

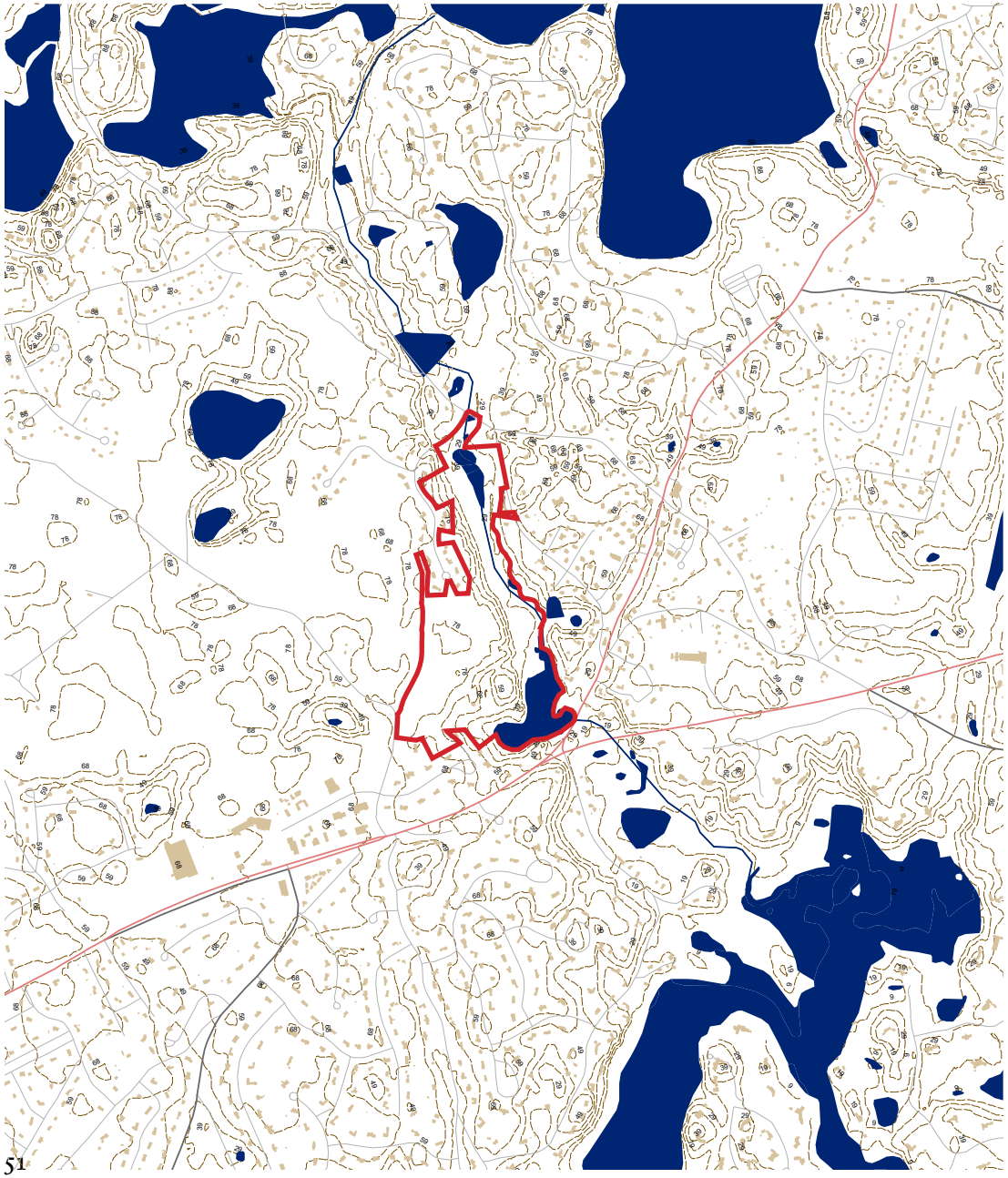
Marston Mills has 124 acres of conservation land.

Conservation Areas in Marston Mills area of Barnstable, MA

32.97	1990	Joel Davis, Holbrook Davis & Nathanael Davis
27.33	2011	Kenneth & Suzanne R. Sutherland
22.44	2012	Fuller Farm
10	2006	Mill Pond CR
7.1	2000	Plummer/Marstons Mills River
5.22	1991	D. Bruce McHenry - Mistic Drive CR
4.83	1992	Cape Cod Bank & Trust Co.
3.77	1991	Frances R. Pittendreigh
2.33	1991	Marion Hickman, Joan Vos & Seely Thomas
2.01	1991	D. Bruce McHenry
1.28	2012	Martha C. Thompson (Tr.)
1.2	2015	Habitat for Humanity of Cape Cod
1.17	2013	Boathouse Realty Trust
0.7	2007	Marstons Mills River CR
0.68	1989	Cape Cod Five Cents Savings Bank
0.6	1997	McKay Family Trust

Table 3: Conservation Areas in Marston Mills

Topography

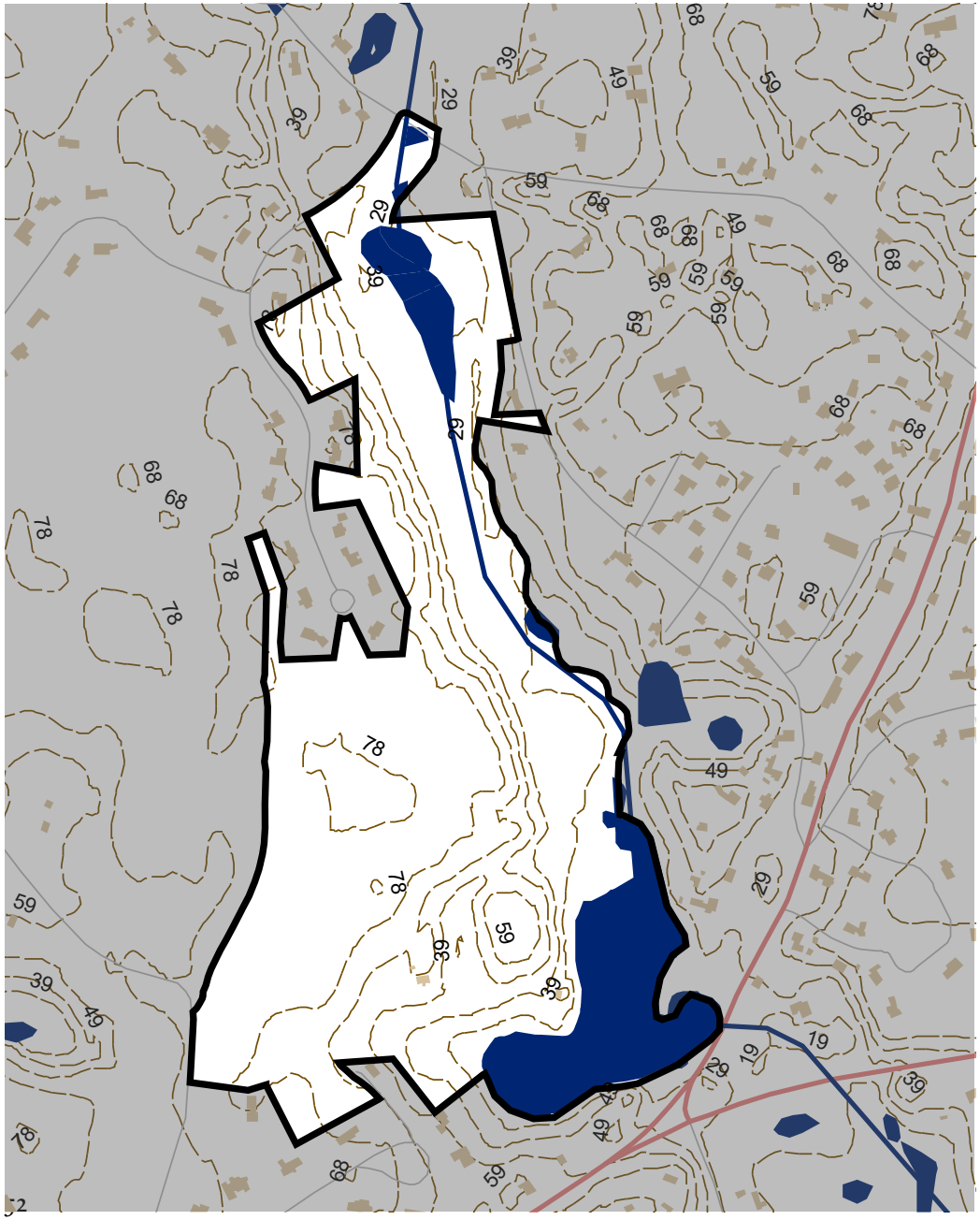


The topographical character of the area is rolling hills. Traditional waste water utilizes slope to convey water. The Waste Water Greenway proposal presented in this thesis would do the same. The application of this in a concept diagram demonstrates how the watershed can be divided into sub-sheds. Each sub-shed would have it's own treatment greenhouse and treatment greenway. These greenways would connect to create a recreational trail network throughout the town. Just as the rebuilding of roads is an opportunity to install sidewalks and bikeways, the rebuilding of grey infrastructure offers opportunities to integrate green wastewater treatment.

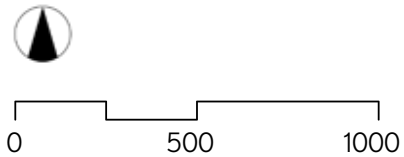
Site Boundary
Hydrology
Buildings

0 1000 2000

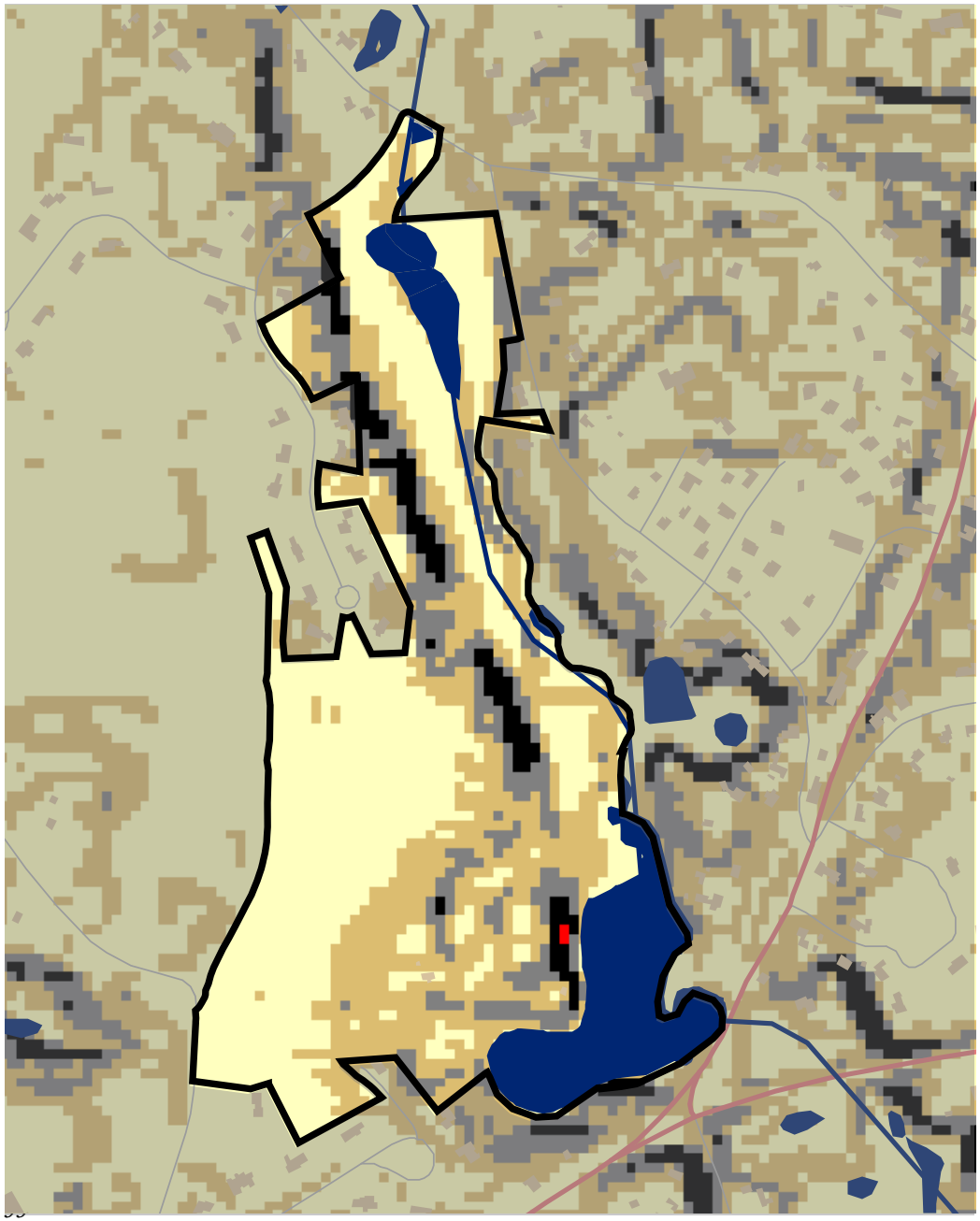
Topography



The topographical character of the area is rolling hills. Traditional waste water utilizes slope to convey water. The Waste Water Greenway would do the same. The application of this in a concept diagram demonstrates how the watershed can be divided into sub-sheds. Each sub-shed would have it's own treatment greenhouse and treatment greenway. These greenways would connect to create a recreational trail network throughout the town. Just as the rebuilding of roads is an opportunity to install sidewalks and bikeways, the rebuilding of grey infrastructure would be opportunities to integrate green wastewater treatment.



Slope



The Mill River and asociated ponds meader south through the site. Slopes range from very flat (less than 2%) to very steep (over 15%). wThere is a thin, narrow band of steeply sloping land in the range of 8% to 15% that runs roughly parallel to the line of the Mill River. There is a small area of significantly sloping land within 50' of the Mill Pond. This area acts as a natural viewing area for bird watching and the Pond.

Site Boundary
Hydrology
0 - 2%
2 - 5%
5 - 8%
8 - 15%
over 15%'

0 500 1000

Regional Water Treatment Infrastructure

The Cape Cod, Massachusetts region is continuing to develop. With its location on the coast, there is limited room to accommodate growth. With this growth has come issues related to waste water management.

Barnstable Town Statistics (US Census, 2010):

Population (2010 census)	45,193
Density	756 people/square mile
Land Area	59.8 square miles
Water Area	16.5 square miles

Barnstable County has promoted the use of Alternative/ Innovative (A/I) Systems and has a system in place to test their effectiveness in removing nitrogen from the community's hydrological system.

Number of I/A Septic Systems in Barnstable (town): 81 (Town of Barnstable, 2014)

This is much fewer than the number in other towns. For example, the neighboring town of Dennis, with a population of 14,207, has 243 AI systems in place.

Monitoring is a key component of assessing the effectiveness of green infrastructure. The Divison of Fish and Wildlife currently conducts regular water testing at Mill Pond. Environmental scientists monitor the nutrients in the water and fish population. This system can be leveraged to test the effectiveness of the water treatment greenway.

Source: Barnstable County Department of Health and Environment, 2014

Barnstable is behind other towns in Cape Cod in terms of developing alternative waste water treatment options.

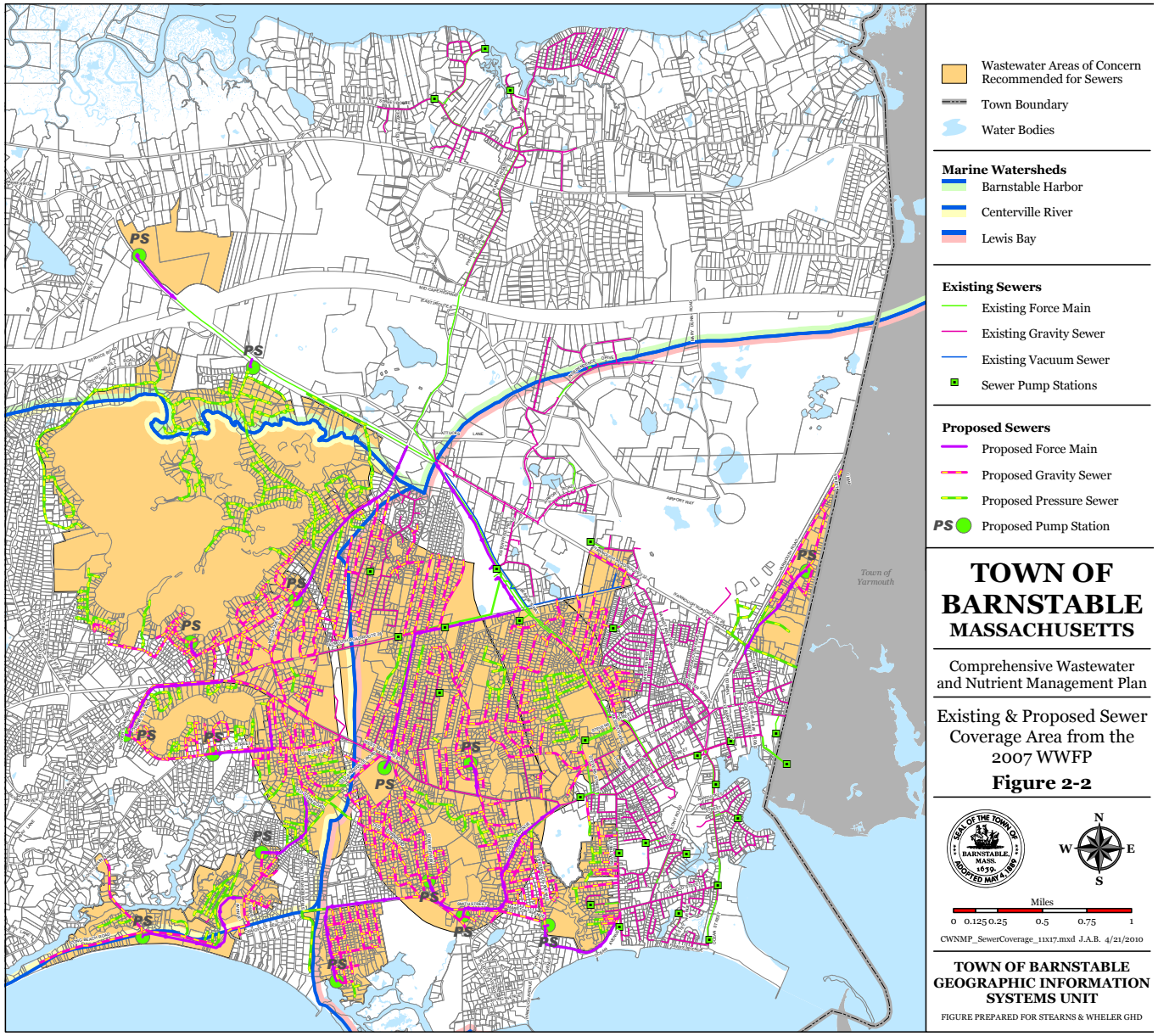

capecodtoday
cape cod community news
Barnstable Bourne Brewster Chatham Dennis Eastham
Mashpee Orleans Plymouth Provincetown Sandwich Truro
HOME NEWS POLICE & FIRE POLITICS OBITUARIES

State reviewing Cape Cod's water treatment strategy

Cape could turn to wood chips and oysters as water treatment alternatives

ARTICLE | NEWS | APRIL 24, 2015 06:00 AM | BY ANDY METZGER, STATE HOUSE NEWS SERVICE

Existing Infrastructure Centralized Sewers in Barnstable, MA



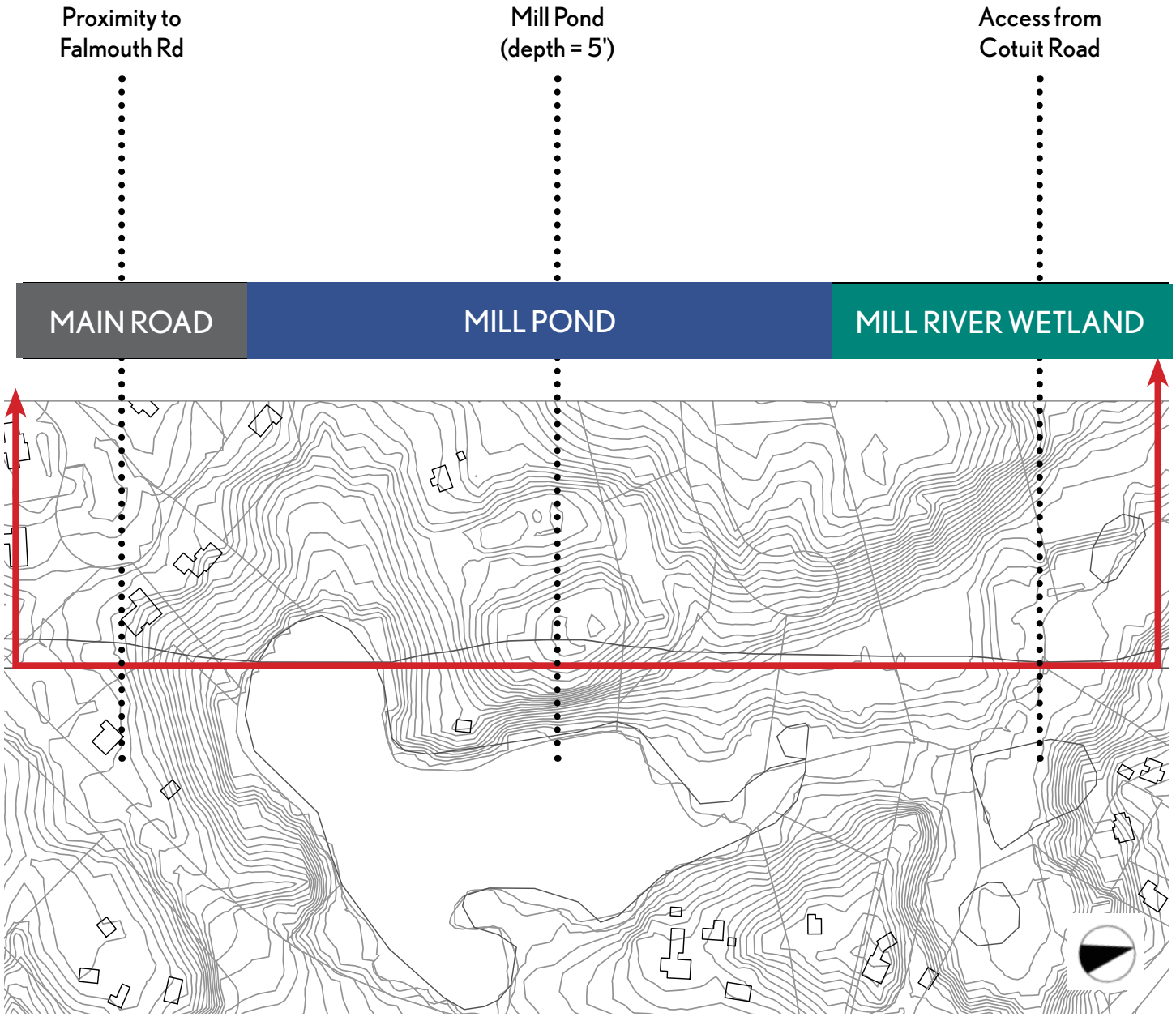
The town of Barnstable utilizes septic systems for the majority of its development, both residential and commercial. There is a municipal sewer service available in a small area of Barnstable Village, portions of Hyannis, and Independence Park. The facility can not be expanded due to design constraints, and there is groundwater mounding at the control facility. Due to these issues, there is a low viability of centralized sewer treatment system, which warrants the implementation of alternative treatment systems. (Town of Barnstable Open Space and Recreation Plan, 2010, p 31)

There are currently three town-operated waste water treatment plants that serve a small area within Barnstable. This is primarily the southeastern area of the town. Additionally, there are two privately owned WWTF's in Barnstable: the Cotuit Stop and Shop WWTF, and the Cape Regency Skilled Nursing and Rehabilitation Center WWTF. There are no plans to provide sewering system in the western part of the town.

Source: Town of Barnstable, 2016

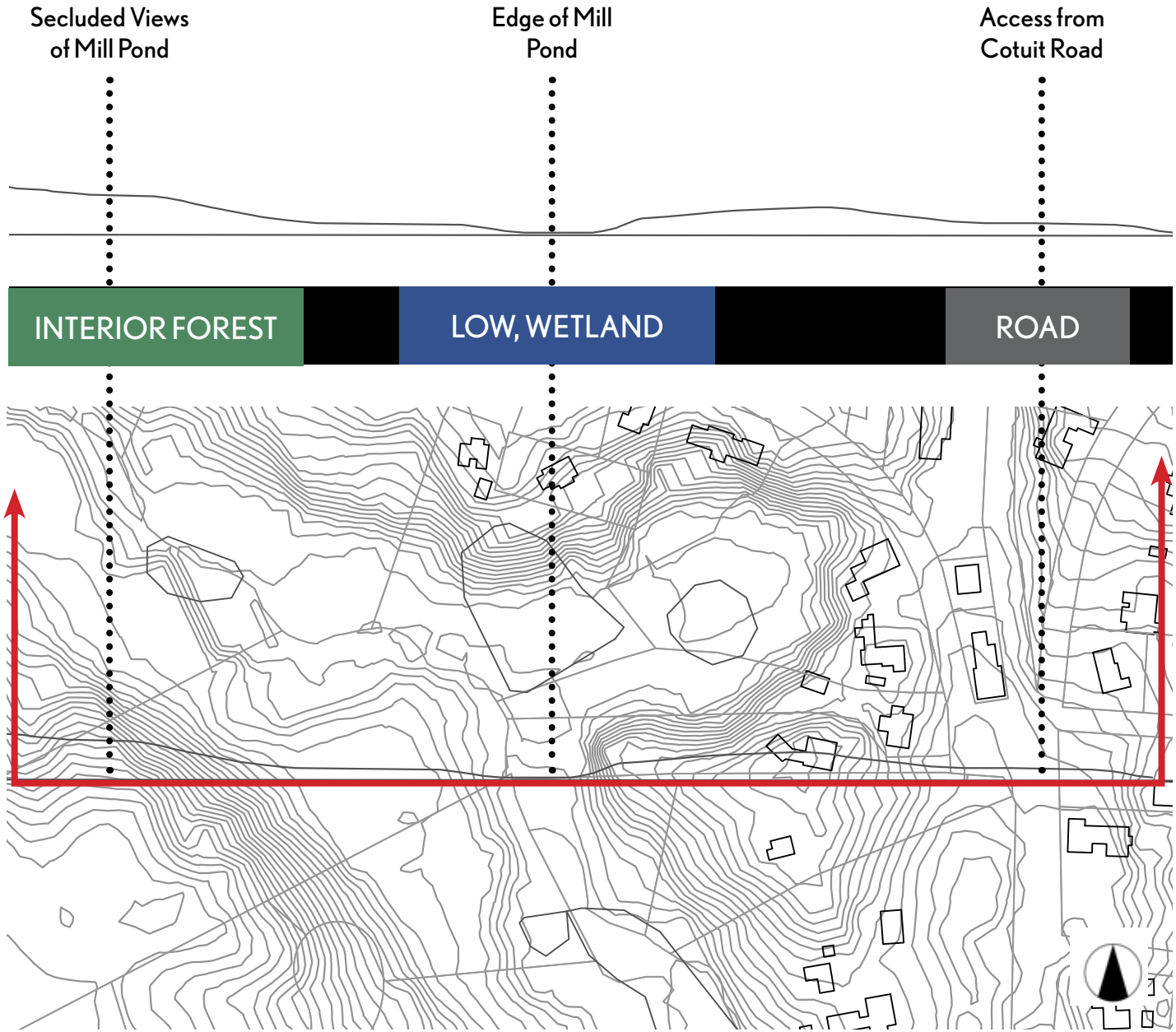
Existing Conditions - Section Through SW side of Mill Pond

Exploration through section can reveal information about the site. Sections through the site were taken in order to consider access to the site and placemnet of the Living Machine. Mill Pond is located in a low point and the land slopes upward from it in all directions. Exploring access to the site from main roads, Falmouth Rd/Route 28 is a busy road lined with private property which impedes access to Mill Pond from this road. The change in elevation is 36 feet.

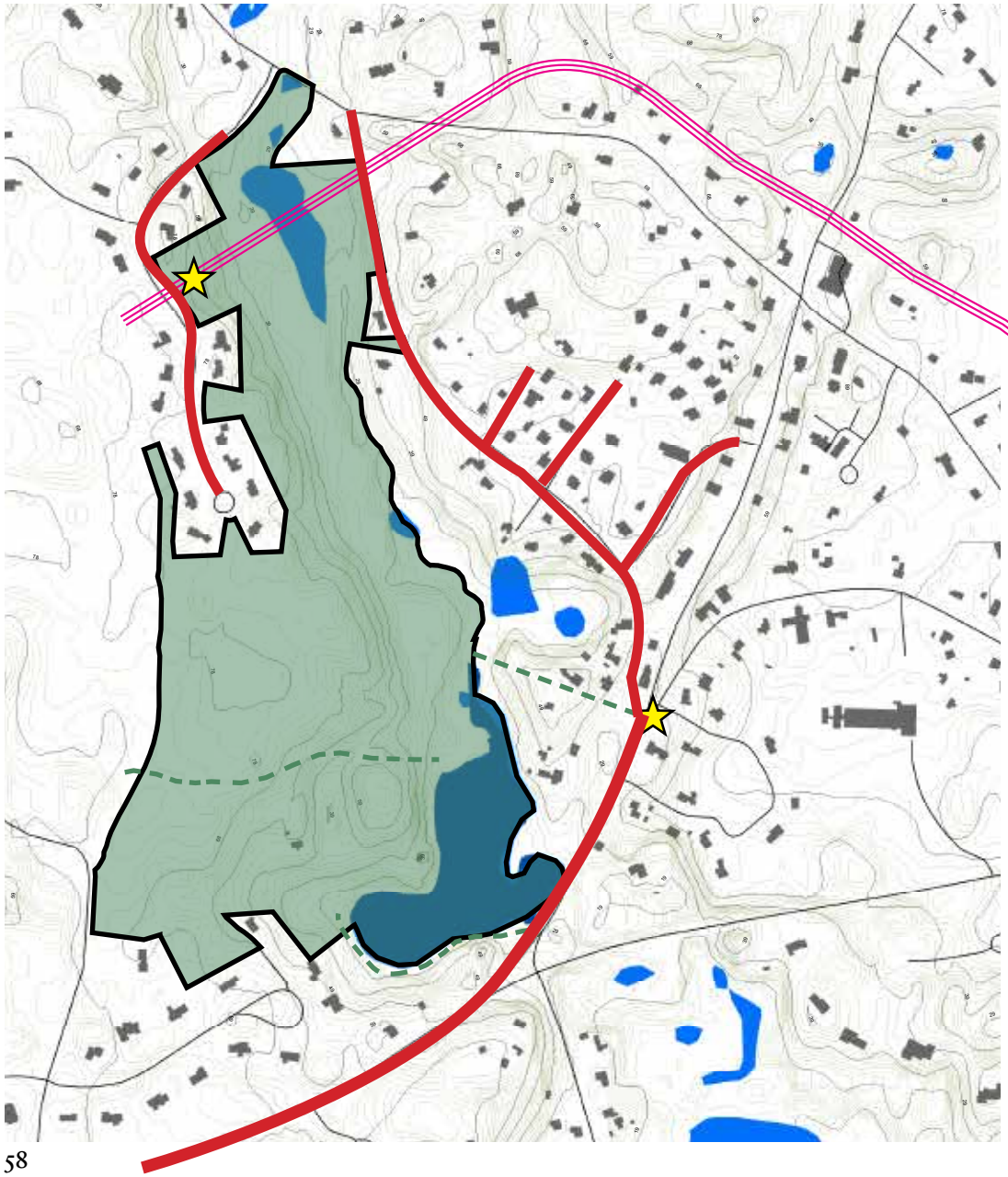


Existing Conditions - Section B - through existing easement

There is an existing easement which can be leveraged for access to the site from Cotuit Rd/Route 149. Due to proximity to private property, it may be better to retain the easement as a walking path and connect it with greenway.



Challenges and Opportunities



Challenges:

- Failing septic systems due to increased development and sandy soils.
- Compromised hydrological systems due to excess nutrients from septic systems

Opportunities

- Address water management through the landscape
- Provide recreational amenity for people through expansion of trail network and bird-watching opportunities
- Enhance habitat (wetlands, forest)
- Education
- Adjacency to residential areas - both for water treatment and for recreation

Site
(Proximity to) Road Infrastructure
(Proximity to) Utilities
Sandy Soils
Problematic Septic Systems
(Proximity to) Residential Areas
(Fragmented) Trail Network
(Fragmented) Hydrological Network
(Availability of) Open Space
Potential Access Points

0 500 1000

Siting Wastewater Treatment Strategies

Three Bays Estuary ecosystem exceeds its critical threshold for nitrogen, resulting in impaired water quality. (Howes, 2005). The Cape Cod Commission is currently working in conjunction with Three Bays Preservation to address the excess nitrogen and phosporous in order to improve hydrological health.

Elements of site asseessment include various geological character, ecological systems and anthropomorphic activities, as follows (Arenovski, 1996):

Natural Conditions and Environmentally Sensitive Areas

- Physical Geology
- Groundwater Hydrology
- Freshwater Bodies and Associated Watershed Areas
- Coastal Resource Areas
- Wetland Buffer Areas
- Open Space, and Critical Wildlife and Plant Habitat
- Floodplains
- Archeological and Historical Resources

Existing Water Supply

Water Use

Current Land Use

Current Demographic Conditions

Existing Wastewater Flows and Loadings

- Sewered Areas
- Un-sewered Areas

Existing Wastewater Collection and Conveyance Systems, and Centralized Treatment Facilities

- Collection and Conveyance Systems
- Centralized Treatment Facilities

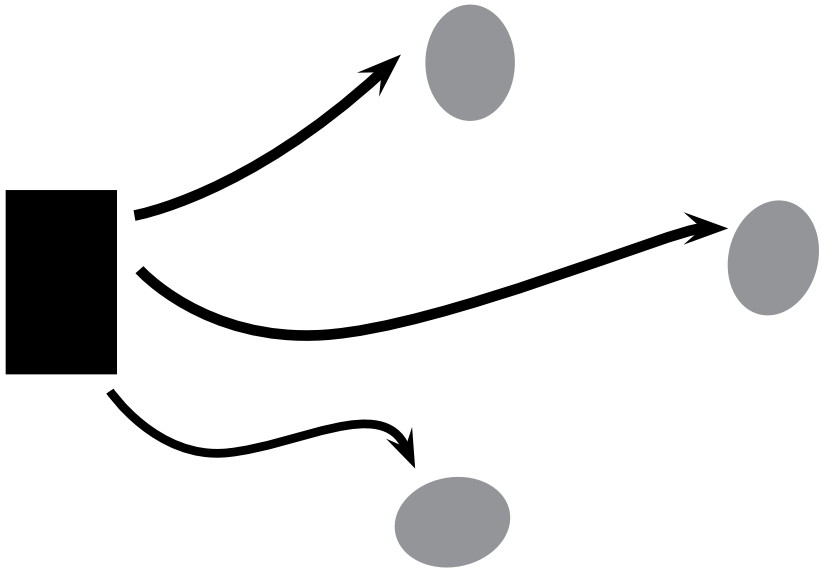
Existing On-Site Wastewater Treatment and Disposal Systems

Future Growth and Economic Development

- Population Projections and Future Land Use
- Future Water Supplies
- Projected Wastewater Flows and Loadings

Concept Layout - Path Alternatives

Dispersion

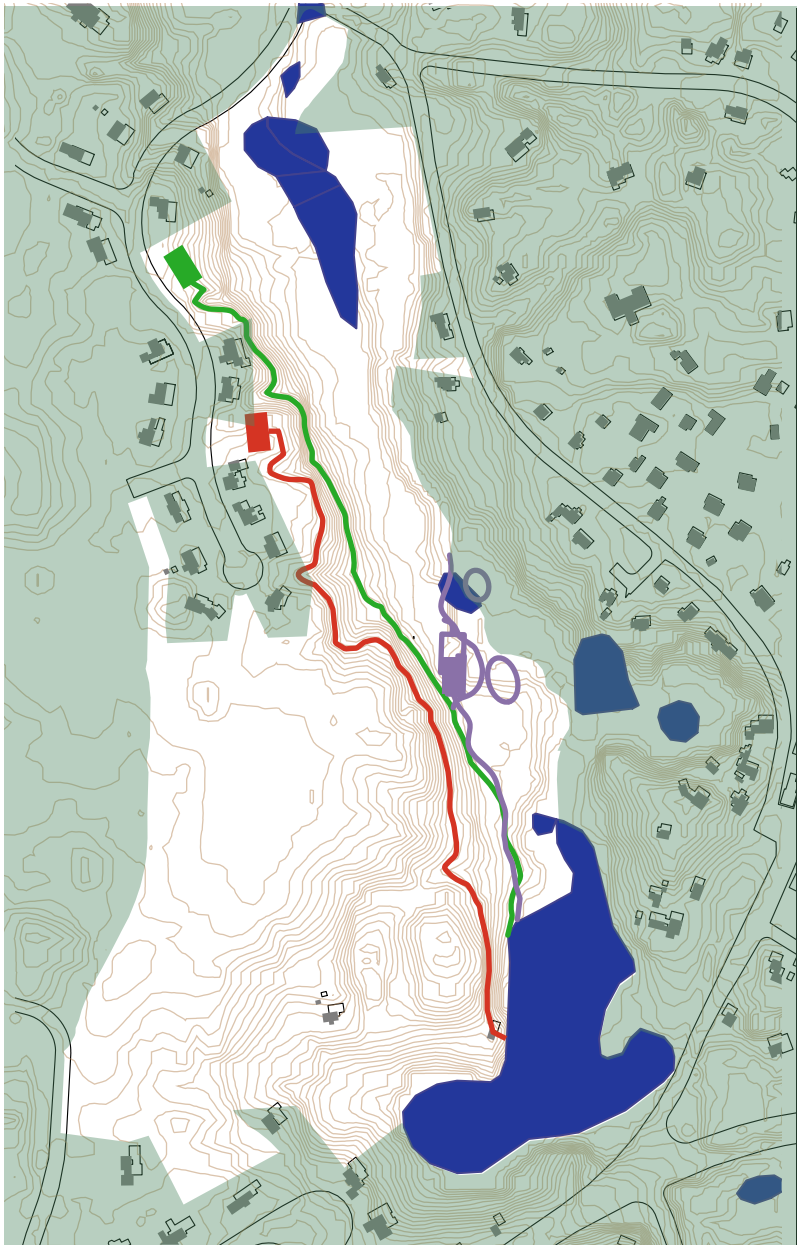


Minimizes site disturbance
Mimics natural dispersion of water through various treatment measures

Meander

Focus on the linear form of the greenway, maximizing length by setting the treatment greenhouse/Living Machine at highest point and uses a meandering channel to treat water.

System Configuration Alternatives



Each path alternative is based on a different set of parameters, or prioritization of them. For instance, the Living Machine was placed at different locations, and the path methodically follows the topography. These paths provide guidelines for the development of the greenway with the least amount of disturbance to the environment.

Path Alternative	Priority	Length	Advantages
A	Utilizing existing roadways	2,100'	Places Living Machine closest to utility lines to energy generation opportunity
B	Utilizing existing roadways	1,900'	Extensive greenway to maximize natural plantings and can treat the most amount of waste water for the greatest amount of time
C	Natural dispersion of water	1,100'	Alternative techniques are separated into segments so can be monitored for effectiveness

Table 4: Greenway Path Alternatives

Configuation Alternatives

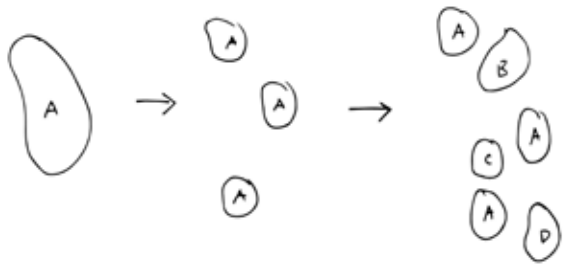
Living Machine A
Living Machine B
Living Machine C

Greenway A
Greenway B
Greenway C

0 500 1000

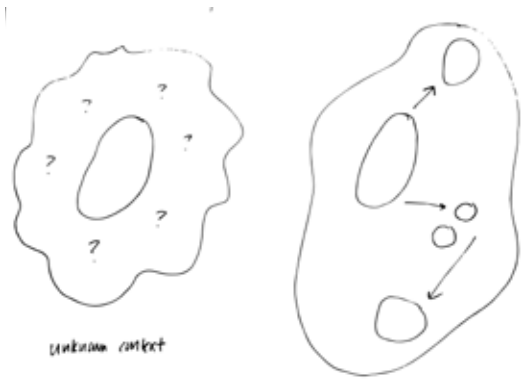
Conceptual Framework for Wetlands

The exploration of concepts for the layout of the greenway takes cues from natural water flows and consideration of urban ecology. The concepts below are derived from France's guidelines for planning and design. (France, 2003, pp. 24-27)



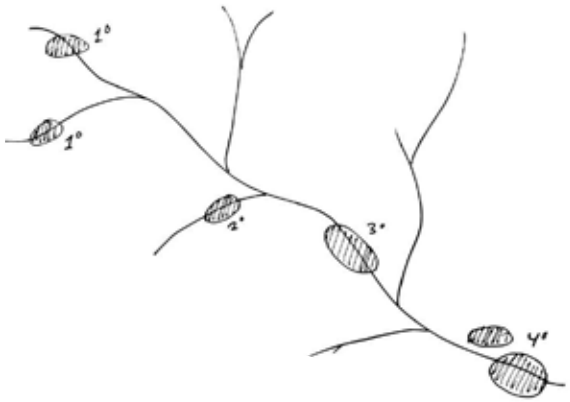
Land Mosaic

There is a debate about whether wetlands should be rebuilt as they were before (in-kind replacement), or whether different types of wetlands can enable wildlife to expend less energy searching for food and appropriate habitats. The variability of habitats is demonstrated with different types of nodes.



Integrative Landscape

Understanding the relationship of individual wetlands to the overall hydrological system and landscape is important in developing successful tactics to enhance the system.



Hierarchical Utility

The location of a wetland within the watershed determines the role it plays and value to the system. First order wetlands directly treat contaminants on site. Third and forth order wetlands are important for flood control and wildlife habitat, as well as contaminant removal.

PROPOSAL

Plan for Water Flow - Meandering Path Scenario (Alternative A)

Length: 2,100 feet

Change in Elevation: 36'

Average slope: 1.7%

Treatment area: 0.3 acres

Water treated: 40 households (initially) with flexibility to expand

1. Entrance from Road
2. Living Machine
3. Constructed Wetland
4. Trail
5. Mill Pond

Layout Alternative B maximizes the linear form of the greenway, which guides the water along the path and into constructed wetland areas. This arrangement maximizes the time in which water is in the system, and thus the time for cleaning and filtering the water before it reaches the sensitive estuary area. In order to accomplish this, the treatment greenhouse is sited at the highest point, utilizing gravity as the greenway meanders down the hillside. This alternative demonstrates the maximum length at 2% slope that will facilitate natural flow of water.

Advantages:
This alternative also utilizes the existing road and utilities, leveraging them for access and to reduce the amount of construction required. The proximity to the public utilities offers the opportunity for future energy generation by retrofitting with biodegasser.

Layout Plan for Human Experience - Multi-functionality

Students Learn about Ecological Systems at the Outdoor Classroom

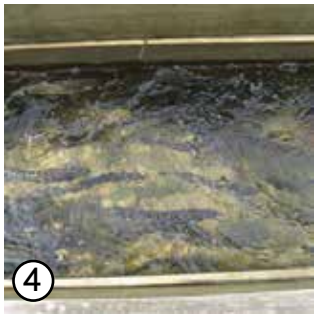
A destination for casual visitors and field trips, the Living Machine offers indoor and outdoor areas for learning and integration.

Residents utilize Greenway for Active Outdoor Recreation

The Waste Water Greenway provides 0.4 miles of trails and connect with other trails in the area. The interdigitated edge and plant selection facilitates wildlife movement.

Visitors come from Near and Far for Bird Watching and Tranquil Views

Mill Pond attracts water foul, including swans. The greenway would facilitate the health of the ecosystem and visits to enjoy it.

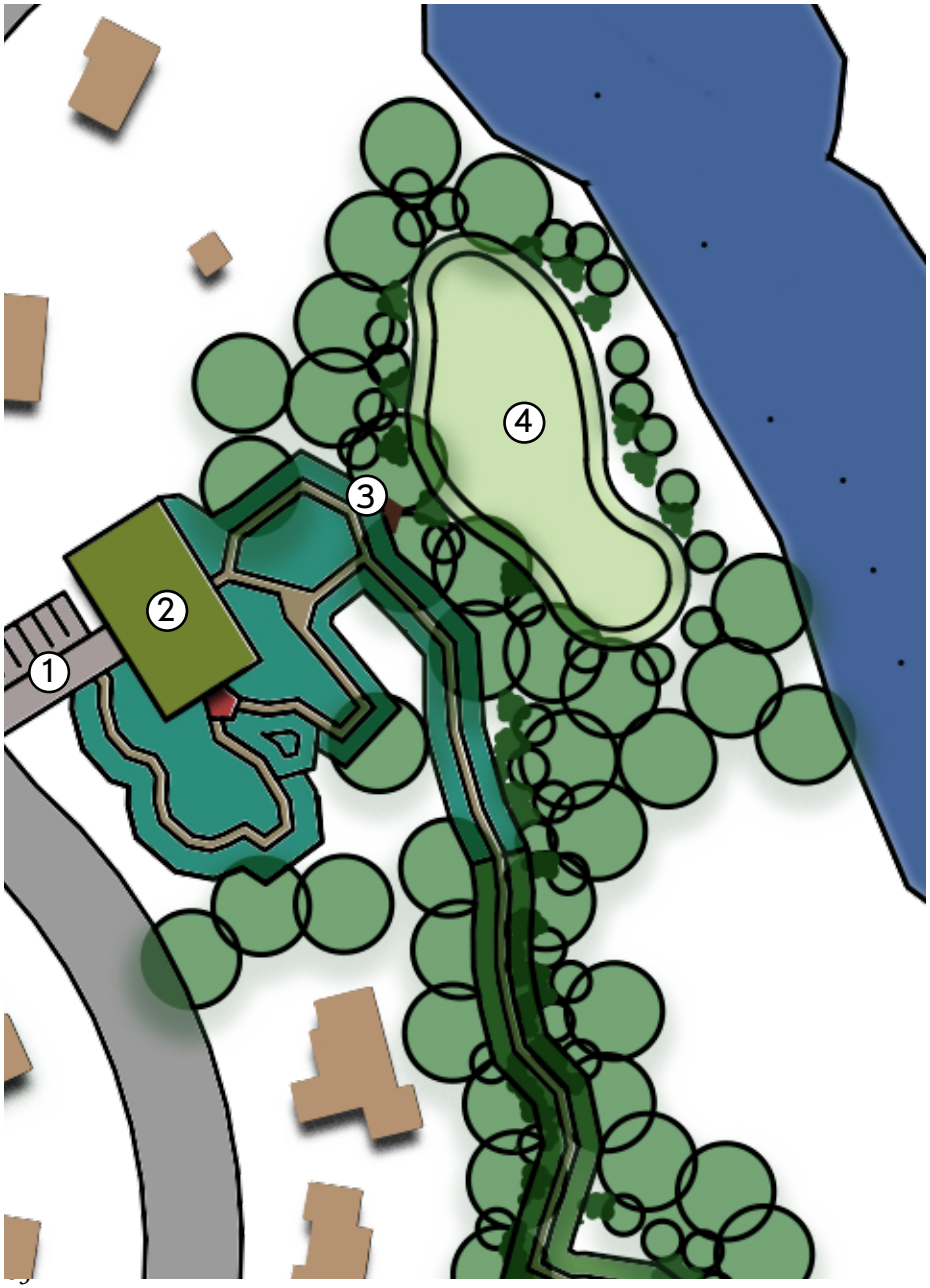


Pond Restoration assists Endangered Bridle Shiner and Herring Run

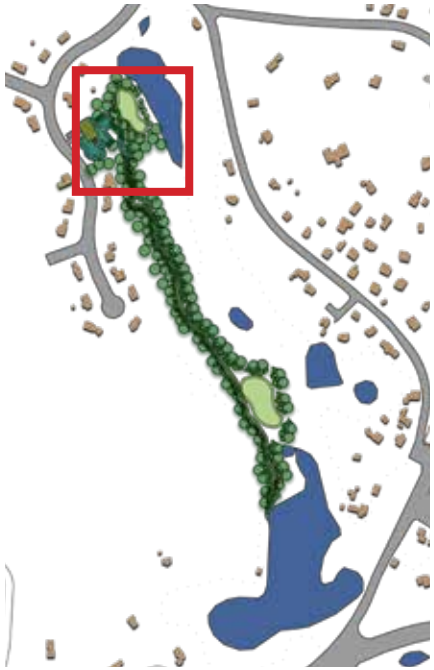
The Mill Pond is spawning ground is restored by the greenway's water cleansing function.

PROPOSAL

Stage 1: Living Machine Plan



1. Entrance
2. Living Machine with outdoor classroom
3. Viewing Platform
4. Constructed Wetland

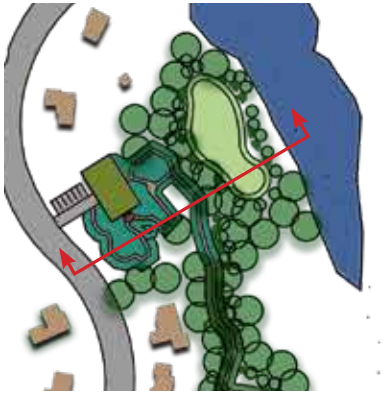


0 50 100

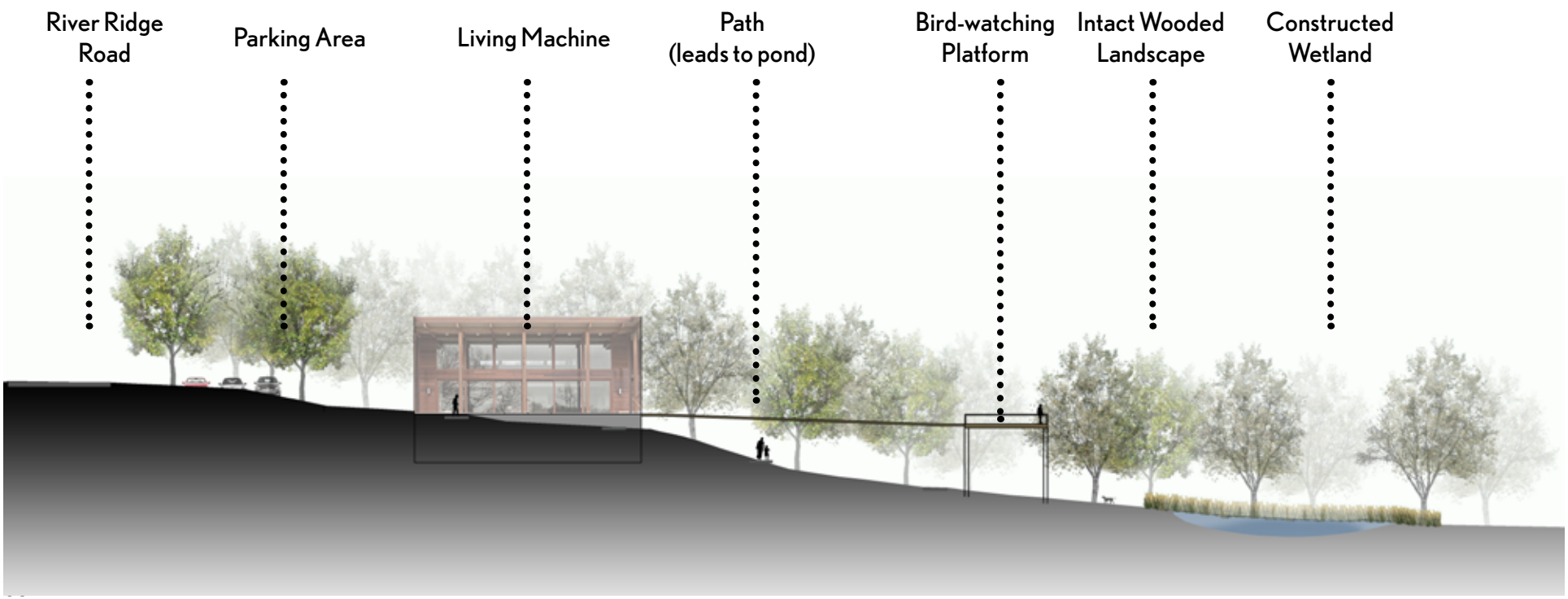
The Living Machine is a facility both for the processing of waste water and for the enjoyment of people. It is a combination of waste water facility, plant conservatory, and educational facility. The building is set into the hill where the waste water is piped for processing. The beginning, "dirty" stage of the settling process takes place in the settling tanks in the hill. The water is then channeled through planting cells, both inside and outside. The paths surrounding the Living Machine are wheelchair accessible. There is a lookout platform with seating and a view of the constructed wetland. This wetland serves as a reservoir for partly cleaned wastewater, thus providing restorative benefits to the wetland downhill.

PROPOSAL

Stage 1: Living Machine Section



The Living Machine and surrounding water gardens comprise a node on the greenway which accommodates seasonal shifts. In the winter, when the outdoor plants are dormant, the Living Machine can process the wastewater inside to completion. It also provides a respite from New England winters with place to sit and enjoy the warmth and greenery.

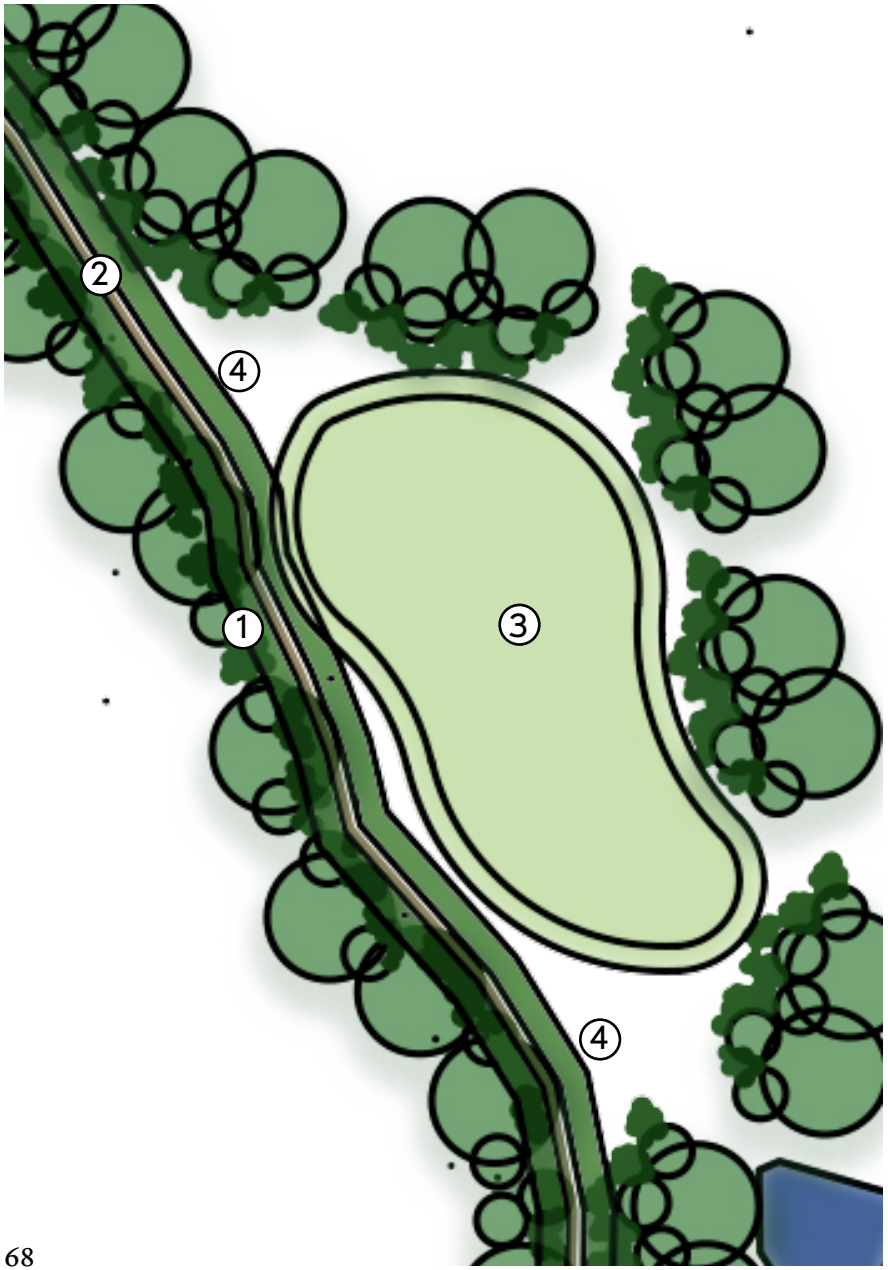


PROPOSAL

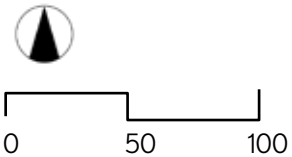
Waste Water Greenway Vision

The Waste Water Greenway is a multi-functional 0.5 mile trail within a forested area in Cape Cod, MA. It provides tertiary water cleansing, public recreation and environmental education. Utilizing native plants to increase the uptake of nitrogen and phosphorous, the greenway will contribute to rebuilding the health of the hydrological network.

Stage 2: Constructed Wetland Node Plan

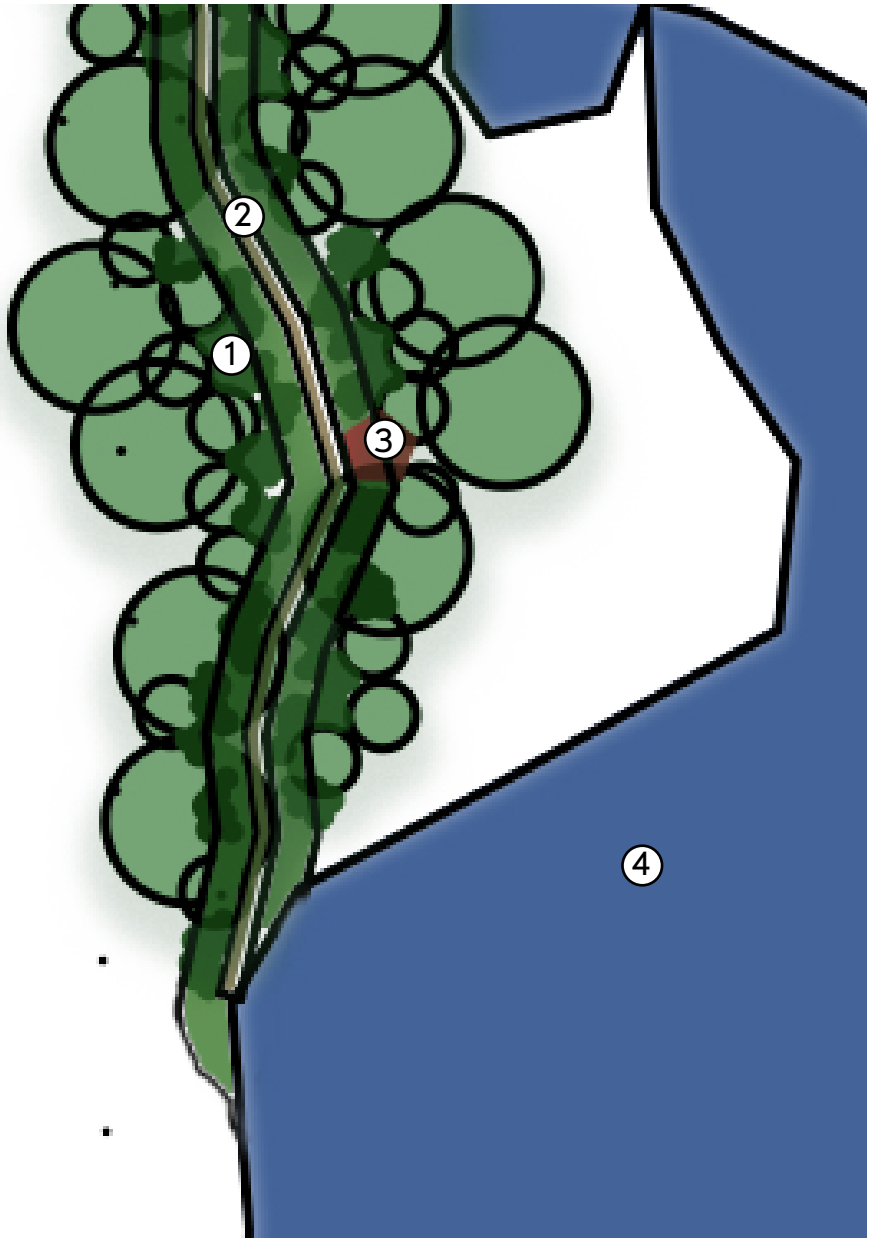


1. Interdigitated Forest Edge
2. Path
3. Constructed Wetland
4. Observation Area

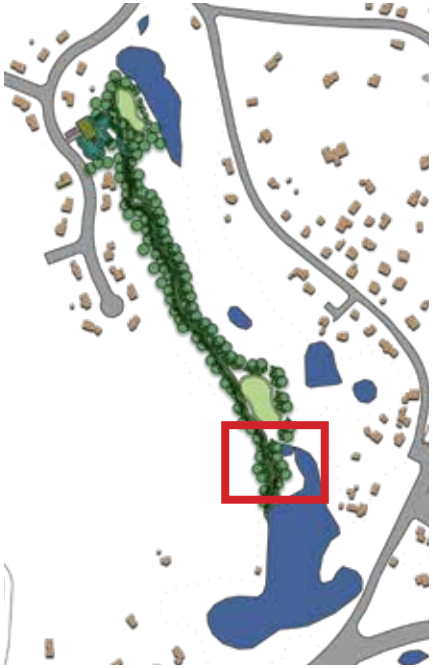


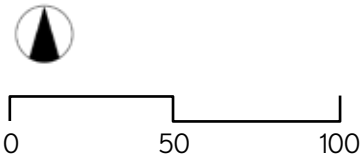
Nodes of constructed wetlands along the greenway will provide known benefits for human and animal visitors. The placement of them takes advantage of the topography and groundwater conditions, creating pools of wetlands that have been compromised by human development. The pools are areas of water retention where water is held in order for waste to be processed by native grasses. The placement and composition, utilizing wetland species, would enhance the fragmented hydrological system. These small wetland areas have decreased in size due to to drawing ground water for human use (Schaider et al., 2013). This constructed wetland node is created from the channeling of waste water and takes advantage of the surface and subsurface functions to clean the water. The area of the wetland is 100 square feet, which, on its own would only clean water for 2 people. This is why having a Living Machine coupled with the greenway is so important.

Stage 3: Pondside Treatment Plan



1. Interdigitated Forest Edge
2. Path
3. Observation Area
4. Mill Pond

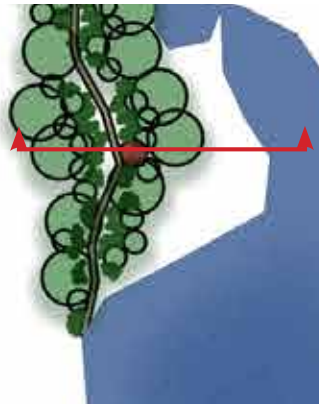




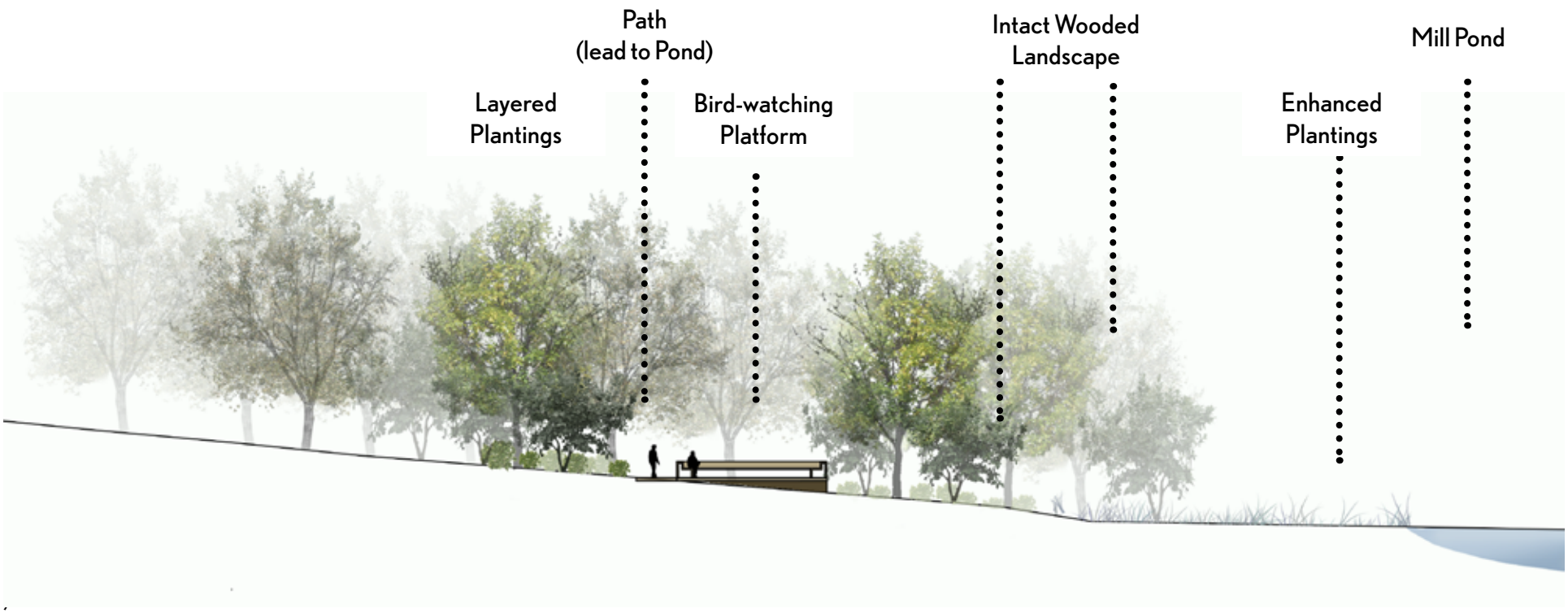
The treatment greenway offers recreational enjoyment of Mill Pond and enhances the ecological value in terms of wildlife. Mill Pond is a popular area for bird-watching. This node on the greenway provides a quiet place to observe birds with benches, shade trees and a view of the pond. The vegetation includes low plants to provide a view of the water and larger trees where people can sit comfortably in the shade and observe birds.

PROPOSAL

Stage 3: Pondside Treatment Section



The wastewater treatment greenway would be an enhancement from the standard greenway design. As with typical greenways, the path utilizes the existing topography. As an improvement over typical greenways, the proposed greenway design utilizes ecological planting design to enhance biodiversity, reduce invasive plants, and provide water cleansing.

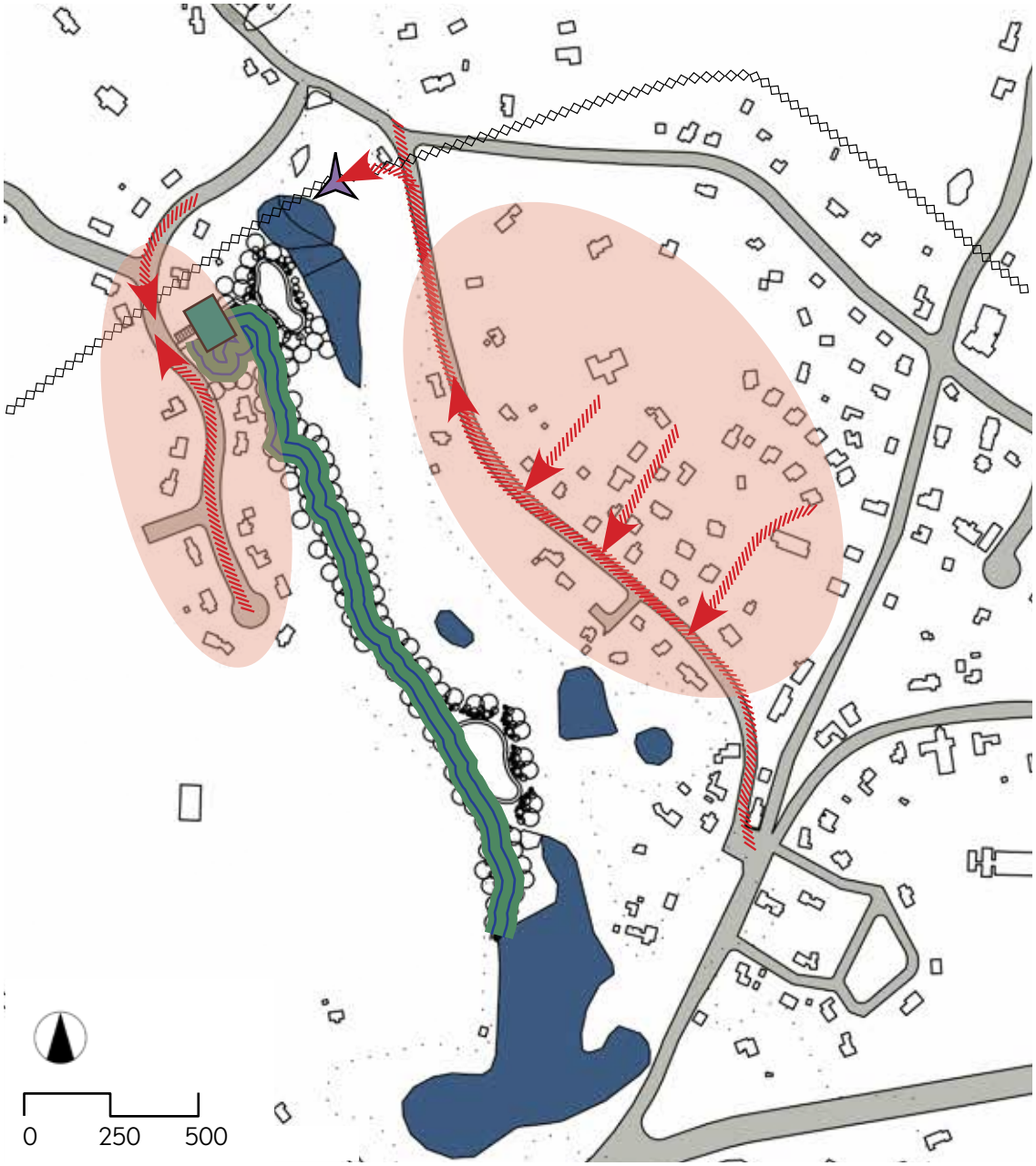


PROPOSAL

Mill Pond Vision

PROPOSAL

Water Cleansing Process



Stage 1: Residential Water Disposal
Untreated wastewater is piped downhill along existing roads

Service Areas

Stage 2: Pump Station
raw sewage is collected and pumped up to Living Machine

Utility Lines are integrated into design

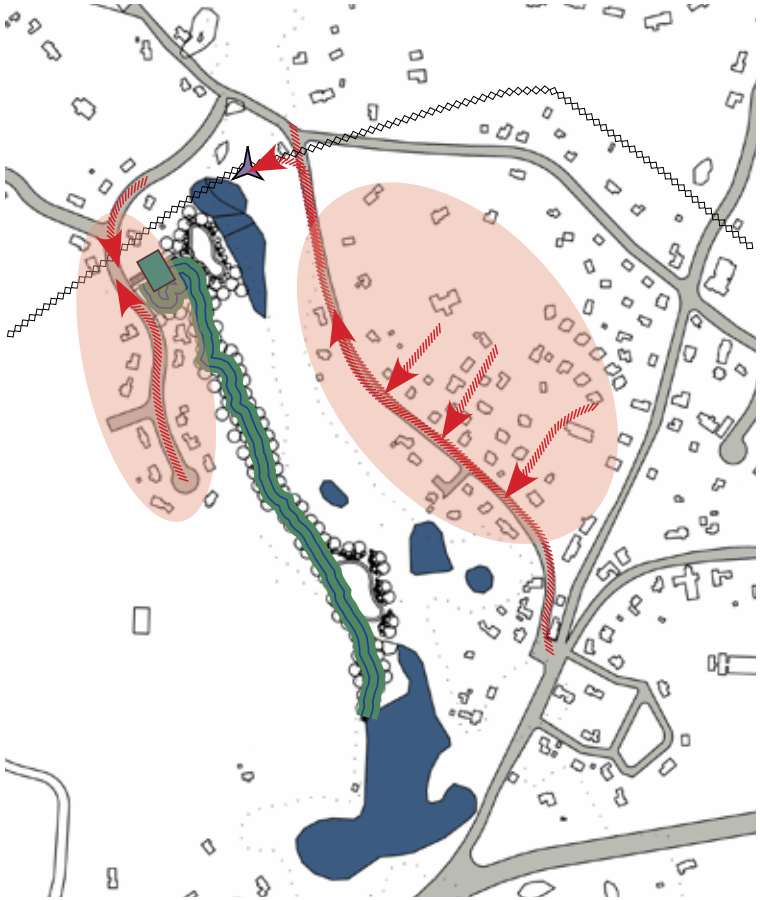
Stage 3: Living Machine
Primary and Secondary Processing
Living Machine processes include: removal of solids and processing of nutrients

Stage 4: Tertiary Treatment Greenway
Water is moved to tertiary treatment areas

Result: Plants clean the water thus restoring the health of the Three Bays Estuary downstream

Water Cleansing Process

The focus is the high-density residential areas uphill from the Mill Pond. These developments are closest to the Mill Pond, and where an intervention would have the greatest benefits and lowest cost. Utilizing slope of the land to determine location, stations located at lower elevations collect waste-water. At this point, the sewage would be pumped to the Living Machine for processing. The greenway treatment area also utilizes slope to treat water once it is released from the greenhouse machine.



0 500 1000

Stage 1: Residential Water Disposal
Untreated wastewater is piped downhill along existing roads

Service Areas

Stage 2: Pump Station
raw sewage is collected and pumped up to Living Machine

Utility Lines are integrated into design

Stage 3: Living Machine
Primary and Secondary Processing
Living Machine processes include: removal of solids and processing of nutrients

Stage 4: Tertiary Treatment Greenway
Water is moved to tertiary treatment areas

Result: Plants clean the water thus restoring the health of the 3 Bays Estuary downstream

Plant Palettes and Strategies

Materials and Strategy

Native plant species are often selected over exotic ones due to their ability to survive and thrive in local conditions - they are suited to the place. At the same time, human development has drastically changed the landscape. Therefore, finding plants that will survive in the conditions that humans have created becomes a bit more challenging. The criteria for plant selection is for native species that will thrive, and also plants that will perform the desired functions to realize the ecosystem services. Claudia West and Kate Kennen have developed strategies for planting that consider both form and function (Kirkwood and Kennen, 2015). Due to the ability to process nitrogen and other excess nutrients that are in waste water, native plants with this specific ability are used to clean the water so that it can recharge the ground aquifer and reduce pollution in the area. Additionally, the plant palette includes species that will provide food and nesting areas for birds, as well as for bees and other pollinators. This is often the other advantage of native plant species - plant and animal specifies have evolved together and are part of a ecosystem (Ranier and West, 2015, p. 22).

The ecosystems services provided by the vegetation is the following:

- Remove nitrogen and phosphorous from waste water
- Enhance biodiversity (food for birds, insects, pollinators)
- Stabilize soil

Lastly, these plants are low maintenance due to their suitability in the environment. While some phytoremediation techniques require the removal and disposal of plants, this design functions naturally and continuously. The plants will uptake the nitrogen and phosphorous as part of their survival, thus providing a low-maintenance way to manage wastewater that is integrated with the surrounding ecosystem.

Nitrogen-fixing Trees

Styphnolobium japonicum
Japanese Pagodatree

Family: Fabaceae
Native to China, Japan
Height: 50 to 75 feet
Spread: 50 to 75 feet
Attractive, creamy white blossoms. In the fall, 3-8" pods turn brown and stay on tree.

Alnus incana
Grey Alder

Thrives in anthropogenic habitats, as well as edges of meadows and wetlands. They contribute to the growth of poplar whten grown nearby, as the speckled alder and can share in the nitrogen fixed by the alders bacterial partner.

Cercis canadensis
Eastern Redbud

Family: Fabaceae
In the pea family, this is a strong nitrogen fixer. With a height of 20-30 feet, and a spread of 25-35', this makes a great understory tree. Adds interest in Springtime with brightly colored flowers in April, it also attracts butterflies

Laburnum anagyroides
Golden Chaintree

Understory tree in the pea family, it is noted for chains of showy, yellow flowers it produces in May to June.

Nitrogen-fixing Shrubs

Comptonia peregrina
Sweetfern

Lespdeza acutifolia
Bush Clover

Myrica pennsylvanica
Northern Bayberry

Hippophae rhamnoides
Sea Buckthorn

PLANT PALETTE

Cape Cod Heritage

These plants are part ofthe identity of Cape Cod. Cape Cod has many different landscapes, from healthlands to scrub oak, to sand dunes. The palette includes plants that thrive in sandy soils, and provide food for wildlife and nesting areas for birds.

Gaultheria procumbens
Tea Berry
Groundcover
Height: 0.25 to 0.50 feet
Spread: 0.50 to 1.00 feet

Mitchella respens
Partidgeberry
Groundcover

Gaylussacia baccata
Black Huckleberry
Densely-branching, 3 foot (1m) tall shrub of dry woods
Dark purple berries are edible for people and wildlife

Clethra alnifolia
Sweet pepperbush

Quercus alba
White Oak

Juniperus virginiana
Eastern Red Cedar

Constructed Wetlands

Juncus effusus
Soft Rush

Very effective in sub-surface filtering.
Roots quickly and deeply.
They spread across the media and are very pest resistant and winter hardy.
Maximum water depth - 3"
Tolerates wet and dry conditions. Food for birds

Typha (latifolia, angustifolia, domingensis, orientalis and glauca)
Narrow-leaved Cattail

Aggressive.
Tubers eaten by muskrat and beaver
high pollutant treatment
pH: 3.0 - 8.5

Scirpus (e.g. lacustris, validus, californicus and acutus)
Common Bullrush
Conditions: Max depth - 12"
Growth Habit: Aggressive.
Functionality: High pollutant removal
Ecosystem: High waterfowl and songbird value

Phytoremediation

Populus deltoides
Cottonwood

Salix spp.
White Willow

Brassica juncea L.
Indian Mustard

PLANTING STRATEGY

Evolving Plant Communities

6 Next Steps

Current Work in Watershed

The following are descriptions of the current proposals in the watershed to remedy the issue of excess nutrient pollution.

Permeable Reactive Barrier
A permeable reactive barrier (PRB) is a subsurface emplacement of reactive materials through which a dissolved contaminant plume must move as it flows, typically under natural gradient. Treated water exits the other side of the PRB. This in situ method for remediating dissolved-phase contaminants in groundwater combines a passive chemical or biological treatment zone with subsurface fluid flow management. (A Citizen's Guide to Permeable Reactive Barriers, EPA, September 2012)

Fertigation
Wastewater contains nutrients (such as carbon, nitrogen, phosphorus and potassium) that are used in fertilizer. Treatment of wastewater to a certain degree can render it usable for agricultural purposes.

Aquaculture
Can be added to the process to make use of byproducts of the waste water treatment process, in two ways: 1) burning biosolids or 2) extracting the heat from the waste water.

Floating Constructed Wetlands
Floating constructed wetlands are human-made islands that support plant life. The root zones of these plants extend below the growing medium to uptake nitrogen and phosphorous from the water in ponds and estuaries. These roots also provide habitat for fish and beneficial microorganisms. Floating constructed wetlands can be outfitted to support shellfish and seaweed populations for commercial harvest. When built along the shore, they protect exposed coasts from storm damage. (https://capecodgreenguide.wordpress.com/floating-wetlands/)

Dredging+
Nutrient Harvesting - for Fertilizer
This tactic makes use of particular by-products abundant in wastewater - nitrogen and phosphorus. The material is de-watered in beds in order to have a light-weight, transportable product that can be distributed for agricultural purposes.

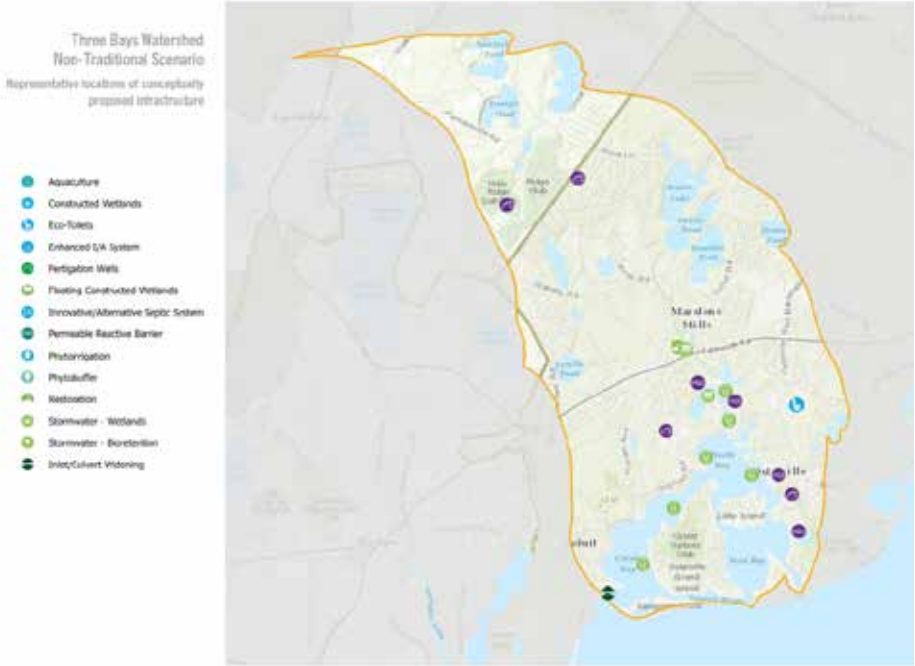
A Collection of Interventions in the Watershed

There are many projects in the watershed that are working to address the issue of excess nutrients in the hydrological system. The Waste Water Greenway is a proposal that would be one of a constellation of projects that together enhance the environment and community resiliency.

A network of waste water treatment projects would advance ideas of increasing resiliency. Jack Ahern presents five resilience planning strategies in his Trandisciplinary Method for Spatial Planning of Resilient-Sustainable Cities (2010). The principles are multifunctionality, redundancy and modularization, (bio)diversity, multi-scale networks, and adaptive capacity (p. 145). The Waste Water Greenway accomlishes many of these strategies. Through providing water cleansing and recreational amenities, it is mult-functional. It is a design that, with modifications based on context and need can be scaled up to handle a larger volumes of waste. It can be connected to other trails in the area for further connectivity. Redundancy is through the different treatment zones. Plant materials and planting strategy provides food and shelter for wildlife, thus enhancing biodiversity. Rottle's resiliency ideas include: system, scale, dynamics and diversity.

The Town of Barnstable submitted a draft Comprehensive Wastewater Management Plan (CWMP) in 2012, which characterized the wastewater needs of the Three Bays watershed in terms of required nitrogen reduction according to the MEP technical report and TMDL (Watershed Report draft, April 2016). Potential solutions for enhanced watewater treatment include :

- Permeable Reactive Barrier
- Fertigation - Turf
- Dredging
- Aquaculture
- Floating Constructed Wetlands



Green Refotrofits to Grey Infrastructure

Water treatment systems come in many forms. These systems vary in approach. Individual components of systems can be added-on either to increase capacity or to enhance the functionality of the system. While they can be retrofitted to an existing system, they can also be designed as part of a new system. Add-ons include:

Composting Toilets
This is an example of small-scale intervention at the source of waste water. Composting toilets do not use water or pipes, and waste is treated on-site. They operate at the scale of one household or one building.

Aquaculture for food production
There are several areas where partially treated waste water is used to support fish farming, or to grow plants that will treat the water and feed fish.

Biodigester for energy generation
These large tanks, typically used on farms to process agricultural waste, can be added to the process to make use of byproducts of the waste water treatment process, in two ways:
1) burning biosolids or
2) extracting the heat from the waste water

Conclusion

Research Questions

Can waste water be managed in a more ecological manner?

How can the design of waste water treatment facilities provide benefits to community beyond water cleansing?

The Waste Water Greenway demonstrates how waste water can be managed in an ecological manner. Through research, analysis and exploratory design, this proposal applies the concepts of green urbanism to consider the integration of green infrastructure in the built environment.

Study of existing waste water treatment options led to the development of a waste water typololgy. Insight and guidance from representatives from the Cape Cod Commission and Three Bays Preservation, Inc. complemented document review and research into the iussues of wastewater in Cape Cod. Case study research of innovative waste waste water treatment facilities revealed the potential to move toward green infrastructure solutions to local issues.

The proposal for a Waste Water Greenway demonstrates how landscape can be shaped in an ecologically sensitive manner to address issues facing our communities. The methodology can be used to address waste water issues in other places, from rural to urban communities, in other climates and in other countries. These small scale, multi-functional landscapes enhance the environment and contribute to system resilience.

7 Appendix

References

Ahern, J. (2011). From fail-safe to safe-to-fail: sustainability and resilience in the new urban world. Landscape Urban Planning 100(4):341–343

Arenovski, Andrea L., and Frank C. Shephard. A Massachusetts guide to needs assessment and evaluation of decentralized wastewater treatment alternatives. Marine Studies Consortium, 1996.

Barnstable Open Space and Recreation Plan, Town of Barnstable, MA, 2010

Bays, James, et al. "Treatment wetlands for multiple functions: Wakodahatchee wetlands, Palm Beach county, Florida." Proceedings of the Water Environment Federation 2000.9 (2000): 15-37.

Cape Cod Commission. Three Bays Watershed Report Draft. April 2016. Provided by: 3 Bays Preservation, Inc. in May 2016

Cape Cod Commission. Regional Wastewater Management Plan: Understanding the Cost Factors of Wastewater Treatment and Disposal. March 2013

Davis, Luise. (2000) *Handbook of Constructed Wetlands* USDA-Natural Resources Conservation Service and the US Environmental Protection Agency-Region III, in cooperation with the Pennsylvania Department of Environmental Resources. Washington, D.C. Accessed at: https://www.epa.gov/sites/production/files/2015-10/documents/constructed-wetlands-handbook.pdf

Deming, M. Elen and Simon Swaffield. (2011). *Landscape Architecture Research: Inquiry, Strategy, Design*, John Wiley & Sons, Inc.

DiGregorio, Mario J. and Wallner, Jeff (2003). Cape Cod Wildflowers: A Vanishing Heritage, Lebanon, NH: University Press of New England.

EcoLogic LLC and Stearns & Wheler GHD. *Action Plan for the Barnstable Ponds. April 2009. Accessed through Town of Barnstable website: http://www.town.barnstable.ma.us/CitizensAdvisory/A%205-1%20Action%20Plan%20for%20the%20Barnstable%20Ponds.pdf*

Egan, Michael J. "Three Bays Preservation: We are one Cape." July 1, 2016, Accessed at: http://www.barnstablepatriot.com/news/20160701/three-bays-preservation-we-are-one-cape

Fay Jones School of Architecture. *Low Impact Development A Design Manual for Urban Areas.* Fayetteville, AR: University of Arkansas Press. 2010.

Foreman, R.T.T. (2104) .*Urban Ecology: Science of Cities*. Cambridge and New York: Cambridge University Press.

France, R.L. (2003). *Wetland Design: Principles and Practices for Landscape Architects and Land-Use Planners.* New York, NY: W. W. Norton & Company, Inc.

Howes, B. L., et al. "Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for the Three Bays System, Barnstable, MA." SMAST/DEP Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA (2005).

Kennen, K., & Kirkwood, N. (2015). P*hyto: Principles and resources for site remediation and landscape design.*

Nitrogen-fixing Plant List: http://homesteadandgardens.com/soil-blog/wp-content/uploads/nitrogen-fixing-plants-chart.pdf
Haase, D., Haase, A., & Rink, D. (2014). Conceptualizing the nexus between urban shrinkage and ecosystem services. Landscape and Urban Planning, 132, 159-169.

Landscape Architecture Foundation, Sidwell Friends Case Study Brief. Landscape Performance Series. Accessed January 2017 at: https://landscapeperformance.org/sites/default/files/Sidwell%20Friends%20Methodology_0.pdf

Lin, B. B., Philpott, S. M., & Jha, S. (2015). *The future of urban agriculture and biodiversity-ecosystem services: Challenges and next steps. Basic and Applied Ecology, 16(3), 189-201.*

References

Metzger, Andy, *"State reviewing Cape Cod's water treatment strategy."* Cape Cod Today, April 24, 2015. Accessed March 28, 2016 at: CapeCodToday.com

McGrew, S. and Rivera, D . *The Sustainability "Hat Trick": Reclaimed Water, Pelletization of Biosolids, and Biogas To Energy,* Florida Water Resources Journal, March 2013, 28-32.

Pickett, S. T. A., Cadenassso, M.L., and J. M. Grove (2004). "*Resilient cities: meaning, models, and metaphor for integrating the ecological, socioeconomic, and planning realms*," Landscape and Urban Planning 69(4):369–38.

Pickett, Steward TA, and Mary L. Cadenasso. "The ecosystem as a multidimensional concept: meaning, model, and metaphor." Ecosystems 5.1 (2002): 1-10.

Urban Hydrology for Small Watersheds, United States Department of Agriculture, Natural Resource Conservation Service, Conservation Engineering Division, Technical Release 55 (June 1986) http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044171.pdf

Ranier, T. and West, C. (2015). *Planting in a Post-Wild World: Designing Plant Communities for Resilient Landscapes*. Portland, OR: Timber Press.

Rouse, D.C. and Bunster-Osso, I.F. "*Green Infrastructure: A Landscape Approach*," American Planning Association, Planning Advisory Services, Report Number 571, January 2013

Schaider, L. Rodgers, K., Rudel, R. *Contaminants of Emerging Concern and Septic Systems: A Synthesis of Scientific Literature and Application to Groundwater Quality on Cape Cod*. Newton, MA: Silent Spring Institute.

Sisolak, J. and Spataro, K. *Toward Net Zero Water: Best Management Practices for Decentralized Sourcing and Treatment*. Cascadia Green Building Council, *2011. Accessed at: https://living-future.org/wp-content/uploads/2016/11/Toward_Net-Zero_Water.pdf*

Todd, J, Brown, E.J.G., Well, E. *Ecological Design Applied*." Ecological Engineering 20 (2003) 421–440

United States Environmental Protection Agency, Waste Water Technology Fact Sheets. Office of Water, Washington, D.C., 2000. Accesssed at: https://www3.epa.gov/npdes/pubs/living_machine.pdf

Wakodahatchee Park, 2000. Accessed in March, 2017 at: http://www.pbcgov.com/waterutilities/wakodahatchee

Waldheim, Charles, et al. (2011). Landscape Infrastructure: Case Studies by SWA. Basel: Birkhauser GMBH.

World Bank, Water and Environmental Health at and Loughborough (WELL), Brief 37: Re-use of Waste Water, Loughborough University. Accessed at: http://www.worldbank.org/en/topic/water

World Bank, Water and Environmetnal Health at London and Loughborough (WELL), Brief 64: Wastewater Treatment Options Technical Brief, Loughborough University. Accessed at: http://www.worldbank.org/en/topic/water

Wu, Jianguo. "Landscape sustainability science: ecosystem services and human well-being in changing landscapes." Landscape ecology 28.6 (2013): 999-1023. APA

Vymazal, Jan. Removal of nutrients in various types of constructed wetlands, Science of The Total Environment, Volume 380, Issues 1–3, 15 July 2007, Pages 48-65.

Zipperer, Wayne C., et al. "The application of ecological principles to urban and urbanizing landscapes." Ecological applications (2000): 685-688.