CRWA

Transformation: Water Infrastructure for a Sustainable Future

By Charles River Watershed Association

Acknowledgments

Transformation: Water Infrastructure for a Sustainable Future is the result of intensive work done over three years by the listed project teams. Principal authors of this book were Julie Dyer Wood, Bob Zimmerman, Pallavi Mande, Bruce Douglas, and Bob Black. Nishaila Porter did its layout.

Charles River Watershed Association
Robert Zimmerman Jr.
Julie Dyer Wood
Pallavi Mande
Nigel Pickering, PhD, PE
Nishaila Porter
Margaret Van Deusen
Kate Bowditch

Project Partners
Natural Systems Utilities (NSU)
Ed Clerico, PE
Sheng Chu, PhD
Bruce Douglas PE
Axel Hester
Adam Stern PE
Barbara Wingler

Industrial Economics Corporation (IEc)
Robert Black

Technical Advisory Committee (TAC)
Massachusetts Water Resources Authority (MWRA)
Massachusetts Department of Environmental Protection (MassDEP)
Built Environment Coalition
Boston Water and Sewer Commission (BWSC)
City of Boston Energy, Environment and Open Space Department
City of Cambridge
Massachusetts Department of Energy Resources (DOER)
Boston Planning and Development Agency
NRG Energy
U.S. Environmental Protection Agency (US EPA) Region 1 (Ex Officio)

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EXECUTIVE SUMMARY

Most cities across the globe face a plague of water infrastructure problems, from combined sewer overflows to stormwater pollution to deteriorating pipes and treatment plants. As our climate changes, that infrastructure is proving inadequate to the tasks of building resilience to drought or managing severe flooding. Many wastewater treatment plants situated on the coast are directly threatened by impending sea level rise. Moreover, 19th Century water systems cause significant damage to our natural world, something that has been accepted as a necessary cost of modern life. Toxic algal blooms, low flow, stormwater pollution, oxygen depletion, are all consequences of existing water management systems. In the 21st century, new technologies and methodologies make these impacts no longer inevitable. Furthermore, many cities are leading the way in climate adaptation and mitigation. Major metropolitan cities are setting aggressive carbon reduction goals but are struggling to establish clear paths toward meeting them.

Due to the inherent damage large centralized water systems visit on the environment, Charles River Watershed Association (CRWA) has for 20 years been pursuing a financially responsible approach to re-engineering them to restore nature, build resilience to drought and flooding, and build flexibility into water infrastructure in anticipation of climate changes. With our partners Natural Systems Utilities (NSU) and Industrial Economics (IEc), we conceptually tested a unique concept for distributed wastewater treatment systems, called Community Water and Energy Resource Centers (CWERCs). Throughout the project, our team met and reviewed our work regularly with a dedicated and knowledgeable Technical Advisory Committee (TAC). Our TAC was comprised of: the Massachusetts Water Resources Authority (MWRA), the Massachusetts Department of Environmental Protection (MassDEP), the Built Environment Coalition, the Boston Water and Sewer Commission (BWSC), the City of Boston Energy, Environment and Open Space Department, City of Cambridge, the Massachusetts Department of Energy Resources (DOER), the Boston Planning and Development Agency (BPDA), NRG Energy, and the U.S. Environmental Protection Agency (US EPA) Region 1 (Ex Officio).

CWERCs are distributed energy generating and waste recycling plants. CWERCs mine sewage infrastructure, treating 1 to 5 million gallons daily and recycle organic waste in urban and suburban areas where it is produced. In our conceptual design, the CWERCs combine a membrane bioreactor, thermal energy heat pump, anaerobic digester, combined heat and power (CHP) system, nutrient recapture and composting. Utilities and products produced by each CWERC include electricity, thermal energy for heating and cooling, reclaimed water meeting drinking water standards for non-potable uses, and fertilizer and nutrients. Generating energy from sewage and reducing the distance food waste needs to be trucked significantly reduces green house gas emissions.

In this study, CWERC operations are extensively modeled using real-world conditions. A site selection analysis was conducted to identify two local urban neighborhoods to model CWERC operations using actual site conditions. In a three-phase site selection process two neighborhoods were selected for modeling in the City of Boston. The Innovation (or Seaport) District and the Stony Brook neighborhood encompassing parts of numerous Boston neighborhoods including Mission Hill, Fenway and Roxbury, an environmental justice neighborhood, serve as the two study area neighborhoods.

We ran multiple technical and financial scenarios to assess outputs of the prototype CWERCs and analyze their operational feasibility. CWERC 1, designed to treat

2 million gallons daily (mgd) of sewage, has a capital cost of $46.7 million, and generates over $7 million in income from utility sales, renewable energy credits, and tipping fees. Operations and maintenance costs are estimated at $4.9 million. Income is generated from sales of electric and thermal energy, reclaimed water, renewable energy credits, soil amendment products, and tipping fees for the disposal of organic waste. The model does not include a fee for wastewater treatment. CWERC 2, treating 3 mgd daily, has a capital cost of $53.8 million. Income for CWERC 2, without collecting a fee for wastewater treatment, is estimated at $9.6 million against $7 million in operations and maintenance costs. CWERC 1 is modeled to collect 80 wet tons of food waste daily as the neighborhood contains multiple food and beverage production and processing facilities, while CWERC 2 collects 54 wet tons of food waste per day.

Through modeling, our team determined scenarios in which plants are financially viable without charging a fee for wastewater treatment. Under existing site and regulatory conditions, if CWERCs receive favorable public financing of 0% to 2% interest and require no capital investment for the property they are built on, CWERCs will “break even.” Break even conditions are defined as a scenario in which the net present value of the infrastructure is equal to zero over a twenty year life span (including capital replacement reserves) with no additional revenue or capital investment required (i.e., the CWERC is self sustaining). Collecting a small wastewater treatment fee, a third or less of Boston’s current rate, would make the CWERCs viable in every public and private financing scenario investigated. The modeling further revealed that site specific conditions such as organic waste availability, sewage availability, and markets for reclaimed water and thermal energy influence financial conditions. Therefore consideration of these conditions, neighborhood input, and local water management impacts should drive site selection (See Chapter 4 for full neighborhood scale results).

In the study area neighborhoods, CRWA also examines historic natural hydrology. CWERCs are introduced to restore natural hydrology using a portion of the water reclaimed. With such restoration, neighborhoods gain improvements in flood control and drought resilience, heat island mitigation, reductions in polluted stormwater runoff, enhanced groundwater recharge, and an increase in open space amenities. In Neighborhood 1, we propose 44 new acres of green infrastructure across the district, enough to filter runoff from a 1 inch rain storm. Multiple opportunities to create new or restore historic water features using CWERC effluent are also presented including reestablishing buried canals by daylighting two large stormwater culverts. An ambitious design for a 300 acre floodable wetland is also presented. This large wetland area recreates flood storage for what was once an historic open water bay. Allowing this area to flood would protect the neighborhood against fresh water flooding, and modest storm surge and sea level rise, while also providing new, unique recreational opportunities in an urban setting.

Neighborhood 2, the Mission Hill/Stony Brook neighborhood, is a densely developed area that overlays the historic confluence of the Stony Brook, Muddy River, and Charles River tidal estuary. Currently the Stony Brook is completely buried in culverts, the dammed Charles River is no longer tidal, and nearly all the rivers natural flood plain wetlands have been filled and developed. Our greening plan for the neighborhood identifies 14 new acres of green infrastructure, enough to filter or infiltrate runoff from a half-inch rainfall event. A site identified within the neighborhood hosts CWERC 2, and the design includes a constructed urban stream for treated water to flow to the Muddy River, mimicking the historic confluence of the Muddy River and Stony Brook. Base flow to the restored tributary would come from CWERC reclaimed water. (See Chapter 5 for greening designs)

In addition to our analysis of the financial viability of CWERCs, we also looked at the social welfare benefits of CWERCs and associated greening plans. Social welfare benefits include the value of both resource recovery (renewable energy generation, emissions reduction, reclaimed water) and environmental restoration (wetland services, ecosystem services, carbon sequestration, recreation potential, property value enhancement).

For Neighborhood 1, the assessment of potential benefits including annualized energy production and savings, reduced carbon emissions, air quality improvements, greening enhancements, and property value enhancements produce a range of economic benefits from $7 million to $14 million annually. If the 300 acre proposed wetland is included in the analysis, the social welfare economic benefits increase the range to $9 million to $20.5 million annually. For Neighborhood 2, the estimated potential benefits range from $11.75 million to $24 million annually. If groundwater recharge to preserve wooden building supports are included in the analysis, the range jumps to between $20 million to $47 million due to the avoided cost of replacing rotted wooden pilings.

Site specific social welfare benefits are an important aspect of managing water, energy, and waste more holistically. Benefits are significant, and will alter the quality of life in the affected districts. Further, property value enhancement and associated increases in property taxes as a direct consequence of the greening can help provide the revenue necessary to fully implement and maintain new green spaces. (See Chapter 6 covering the social welfare benefits)

There are a number of creative ways progressive cities across the nation have used to pay for the broadcast introduction of "green infrastructure." In "Opportunity: Stormwater Trading" (page 52), we introduce Blue Cities Exchange, CRWA's stormwater trading website based on trading pounds of phosphorus. Cost differentials between introducing green infrastructure to dense, impervious urban sites compared to less dense and more permeable sites support a market for trading stormwater treatment credits.

Finally, extrapolating from the financial and economic analyses of the two CWERC and neighborhood greening plans, we investigate expanding CWERCs to all 43 communities in the Massachusetts Water Resources Authority wastewater system. Recognizing the limitations in such an extrapolation, particularly given the site-specific nature of expenses and income, and that the two sites modeled for this study are located in two of the most dense and therefore most expensive areas in Massachusetts, the analysis remains useful. In the analysis, we introduce additional storage to each CWERC at 3 and 5 times the daily volume treated, and introduce collection of residential food waste to increase power generation. We estimate that a system of CWERCs could be operated at costs very similar to the cost of operating and maintaining the existing system. For a fee covering the operations and debt for its existing centralized system, regional authorities operating those systems could over time shift treatment responsibilities to a mix of their own CWERCS and others operated by city departments, neighborhood organizations, and private entities. Given the social welfare benefits, the enormous environmental benefits, and the climate change preparedness gained, CWERCs and the greening and restoration of natural hydrology presented here make for a compelling argument to transform our wastewater and stormwater systems over time. (See Chapter 7)

CRWA started this investigation 20 years ago as we systematically studied the Charles River and its myriad issues. The analysis in Transformation represents our take on what is necessary to fully restore the Charles River, prepare eastern Massachusetts for many of the vagaries of climate change, and achieve those ends in a financially responsible and economically desirable way.

Foreword

CRWA has been working for a long time to study, understand, and resolve the problems urbanization has visited on the Charles River and its watershed. Among the most confounding are the water and wastewater systems we have built because they are antithetical to natural systems in the way they move, store, and manage limited and valuable fresh water resources. For example, the Charles River experiences debilitating flow losses from the combined demand for drinking water supply, loss of recharge to groundwater due to runoff from development, and loss of groundwater to infiltration into our wastewater pipes. Additionally, now and into the future, changing rain and temperature patterns caused by global climate change will have significant impacts on the Charles and watershed residents. Stormwater management poses a considerable challenge both to water quality and water quantity, and we know our existing stormwater systems are not adequate to serve us under future climate conditions.

In eastern Massachusetts, 300 million gallons of water is collected, treated, and discarded daily at the Deer Island Wastewater Treatment Plant. Thought of as “waste” in some historic sense, what is collected is really warm fresh water and organics that can be harvested to generate significant renewable thermal and electric energy, provide reclaimed fresh water, and produce rich fertilizers and compost materials. Currently, however, after expending energy to treat the wastewater collected from 43 communities, the water is discharged as a waste end product to Massachusetts Bay. Further, nearly half of the water treated is not actually “wastewater,” but groundwater and rainwater leaking into the sewer system through infiltration and inflow (I/I). Rather than discard that water, we can and should reclaim it to drinking water standards for any among our myriad uses not involving drinking or bathing. This would dramatically reduce our water demand and therefore our exposure to drought, while consequently enhancing groundwater storage and river instream flow. The organics and thermal energy in our “wastewater” can and should be captured to produce renewable energy and to restore natural carbon and nutrient cycles.

A driving force at CRWA for some time has been finding alternatives to our existing urban/suburban water systems. It has been a daunting task because our existing systems are seen as essential, though time has shown that they are also expensive, inflexible, and environmentally damaging. Instead, CRWA has worked to develop water systems that keep use more local, reduce our overall demand, and restore natural hydrology. The difficult issue, of course, has been to find a financially responsible way to move, over time, from our expensive centralized systems to systems more environmentally sound.

This short book contains some rather revolutionary concepts, defined and tested. Questions remain, of course, but taken together, our approaches to wastewater, stormwater, stream and river management, and climate change mitigation and preparedness offer a transformative vision of a more flexible and sustainable future for water in any city.

Bob Zimmerman, Executive Director
Charles River Watershed Association
February, 2017

Table of Contents

CHAPTER 1: INTRODUCTION

Charles River Watershed Association's (CRWA) comprehensive and ambitious urban water infrastructure vision addresses most of the water environment problems facing urban and suburban communities. Our approach creates infrastructure that works with or replicates natural water, nutrient, and carbon cycling processes while it integrates management of potable water, wastewater, stormwater, and surface and groundwater. Small scale Community Water and Energy Resource Centers (CWERCs) will capture discarded renewable energy in wastewater and organic food waste. Wastewater treatment costs will be subsidized by the sale of energy, treated water, recovered nutrients and compost. This new model of infrastructure respects and supports the natural and historical flow of surface and ground water, rendering human water demand merely a bend in the river, working with the natural water cycle, restoring rivers and streams, flora and fauna, and enhancing our cities and towns.

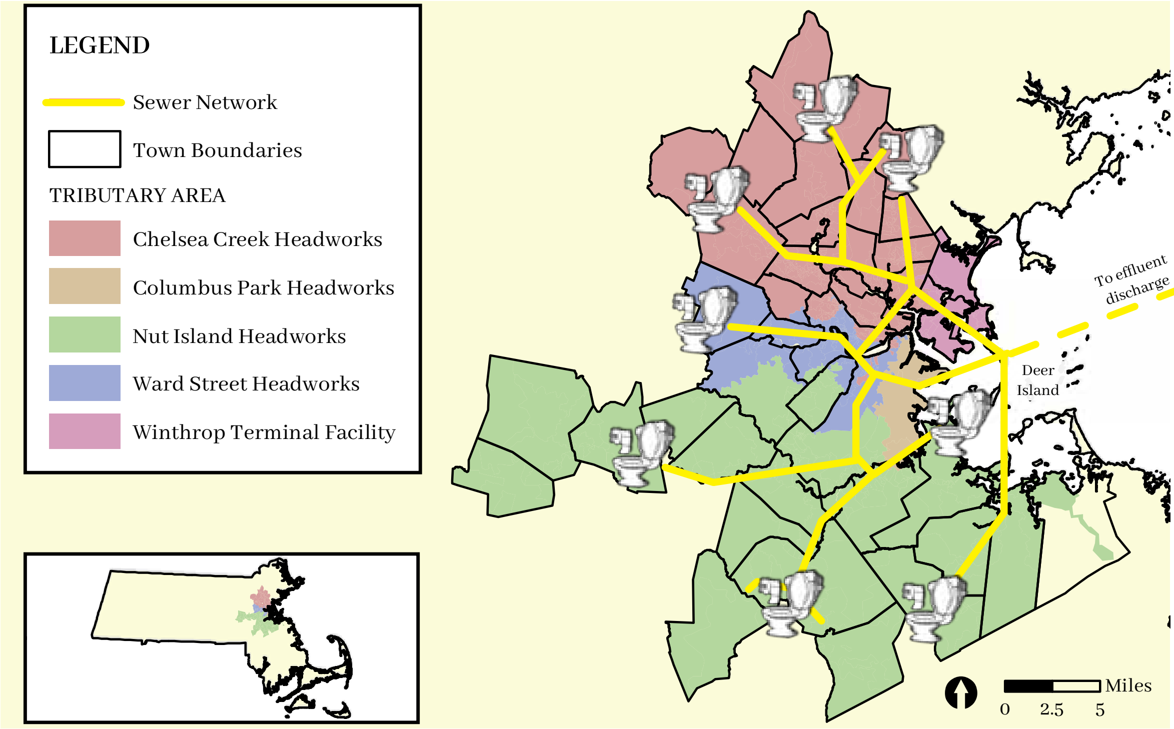

Figure 1. Existing Deer Island System

In most urban areas, wastewater treatment has evolved to favor large centralized systems designed to move water from one location for use in our homes and businesses and then treat and discharge it miles away in the ocean or into an adjacent or downstream watershed where it fails to recharge the system from which it was extracted. While these systems met the public health needs of an earlier generation they are abhorrent to natural systems and are entirely unsustainable. Large centralized systems collect and throw away significant volumes of organics and freshwater, resources we could use to generate renewable energy and reduce water demand on our natural systems. The traditional "take-make-waste" model underlying these systems is destroying our planet and is economically unsustainable. Furthermore as our climate changes, flexibility, redundancy, and resiliency will be essential characteristics of all infrastructure.

Using the *Water Infrastructure for a Sustainable Future* approach, we can manage water locally in even the most dense urban settings. CWERCs treat wastewater in small scale, enclosed structures. The water itself is reclaimed to potable standards for reuse. Wastewater organics generate electricity or fuel. Thermal energy in the wastewater is captured for use in heating and cooling the plant and surrounding buildings and homes. Organic food waste is diverted from landfills to energy-producing CWERCs. Solid waste is transformed into beneficial products such as compost for local food production.

Treated water is used to restore the natural environment and beautify our neighborhoods through the restoration of streams and wetlands previously lost to development. CWERCs are small, quiet, and odor-free. They are even suitable for siting within larger buildings.

CRWA has been developing and investigating this transformative infrastructure approach for many years. This report summarizes a detailed investigation conducted over three years. Our goal was to determine whether a system of small-scale alternative wastewater treatment plants spread across a city or region could provide a high level of service at an affordable cost, reducing environmental harm and increasing long-term sustainability. We sought an economically responsible, even profitable approach to water infrastructure that is more resilient, flexible, and sustainable; a system that supports economic development in depressed areas, and improves neighborhoods with disproportionate environmental burdens.

CRWA led the project, though it would not have been possible without our strong team of consultants and advisors. Technical assistance in wastewater treatment, wastewater-to-energy, and treatment plant design and modeling was provided by Natural Systems Utilities (NSU) based in Hillsborough Township, NJ. Economic analysis was performed by Industrial Economics (IEc) of Cambridge, MA. Throughout the project we met regularly with a dedicated and knowledgeable group that made up our Technical Advisory Committee (TAC) (See box).

Technical Advisory Committee (TAC)
Massachusetts Water Resources Authority (MWRA)
Massachusetts Department of Environmental Protection (MassDEP)
Built Environment Coalition
Boston Water and Sewer Commission (BWSC)
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Boston Planning and Development Agency (BPDA)
NRG Energy
U.S. Environmental Protection Agency (US EPA) Region 1 (Ex Officio)

Background and Problem Statement

Urban water problems across the United States have common roots. Nearly every city is struggling with polluted water bodies, groundwater depletion, flooding, sewer overflows, loss of streamflow, and vanishing habitat. As our climate changes, these issues are exacerbated and new challenges arise.

Our existing infrastructure is ill-prepared to weather these changes. We see the impacts of our deteriorating infrastructure repeatedly on the news or in our own lives in the form of chronic or extreme urban flooding, urban waterways closed to swimming or even boating, water shortages, and sink holes. While the public health benefits of modern sewage treatment are obvious, recent experience highlights countervailing considerations. In addition to human waste, sewers collect clean groundwater and rainwater. Over 50% of the water collected and delivered for treatment by urban sewers can be either groundwater leaking in or rainwater collected in sewers by design. The excess water in the sewer system, referred to as infiltration and inflow (I/I), means that freshwater resources we need for a sustainable local ecosystem and economy are drained away to distant treatment plants.

Energy is required to clean this once pure water after it has been co-mingled with sanitary waste. Treated water of extremely high quality is thrown away in oceans or downstream. Thus, aquifers and surface water bodies that provide drinking water, recreational opportunities, and valuable ecological habitat are starved of clean replenishment and the natural water cycle is critically altered.

Traditional sewer systems have a fixed capacity and at times they are overloaded; combined sewer overflows (CSOs) and sanitary sewer overflows (SSOs) flood urban waterways with pollution. The paved urban landscape, managed with curb and gutter infrastructure to capture and convey runoff as quickly as possible to sewers or storm drains, cuts off the natural connection between rainwater and groundwater and parches urban vegetation. Ground and surface water drawdown from potable water demand, infiltration into sewers, and lack of recharge from extensive impervious cover combine to cause low flows in rivers, streams, and lakes. Low flow reduces water oxygen levels, concentrates pollutants, elevates water temperatures, and diminishes and degrades habitat. Large centralized systems dewater the regions they serve, exacerbate even brief droughts, and threaten the viability of both drinking water supply and river health.

Renewable energy sources will remain untapped as long as we continue to view wastewater as waste. Nationally, the wastewater sector has the potential to produce nearly five times the energy required for treatment. Instead of generating energy however, treatment at the approximately 1,000 largest plants in the country represents nearly 1% of the nation's electricity use.[1] Finally, large centralized systems lack flexibility in the face of climate change. As storms become more powerful, lack of capacity leads to flooding and sewer overflows. Centralized treatment plants constitute a single point of failure with the potential for major disruption and environmental harm.

For the 43 cities and towns in metro Boston served by the Deer Island Wastewater Treatment Plant (DITP), drinking water is either imported from a watershed in central Massachusetts, 65 miles west, or sourced from local groundwater. In either case, none of the water extracted for potable use is replenished to source aquifers or watersheds. Along with the water used in our homes, twice as much again enters our system as I/I and is sent to DITP along with the sanitary waste. DITP does generate energy through anaerobic digestion to biogas creation; however no heat extraction occurs, wasting trillions of British Thermal Units (BTUs) of potential renewable energy every year.

This book presents CRWA's transformative *Water Infrastructure for a Sustainable Future* approach to water systems. This is infrastructure that serves human needs and protects public

Image 1: Flooding in Colfax, Iowa in August 2010

Image 2: Flooded Treatment Facility

health, while restoring environmental health and building resilience and flexibility. Over time, we need to repurpose current systems, creating integrated and sustainable water infrastructure. Nineteenth century wastewater treatment practices simply cannot meet 21st Century challenges.

Goals and Approach

The goal of this project was to create conceptual designs for urban districts where water is managed holistically, in a way that mimics the natural water cycle. These districts could be used to replace larger centralized treatment across the region. The team performed a thorough technical and economic investigation of the design. Our designs focus on reimagining the existing landscape and infrastructure in urban Boston, a far greater challenge than visioning for a newly designed community. Two major focal pieces of this work are natural stormwater management using green infrastructure (GI) systems and small-scale wastewater-to-resource centers called CWERCs.

Guiding CRWA's approach were the following five principles to replicating natural systems in human infrastructure:

•**Waste-to-resource.** Waste from one element of the system becomes a resource to another.
•**Keep water local.** Fresh water is valued in natural systems; landscapes have evolved unique and varied methods of holding on to this scarce natural commodity. We need to engineer our infrastructure to do the same.
•**Flexibility, adaptability, interconnectedness.** Nature is inherently adaptable, and all elements are connected. By rethinking development on watershed scales and designing each site to respect and restore historic natural hydrology, we can, over time, restore that hydrology and gain flexibility in the process. We also acknowledge the connections and impacts of traditional development.
•**Promote and support rich diversity.** Nature celebrates diversity as a strength. Diversity offers a way for communities to be more adaptable and resilient, gaining strength through evolution. In our approach, promoting diversity means two things: restoring habitat to support greater numbers and varieties of species, and creating new financial and economic opportunities in environmental justice communities.
•**Restore nature.** Modern development significantly alters the natural connection between rainwater, groundwater and surface water. Design or redesign infrastructure to replicate and restore a region's historical natural hydrology.

Design and analysis were conducted at two levels. The first phase of the project focused on developing designs for two real urban neighborhoods as defined and selected by the project team. This involved highly detailed and site specific design and modeling work. Results of this work are presented in Chapters 2-6. The second phase of the project was the development of a conceptual model for replacing the centralized Deer Island Wastewater Treatment Plant which serves 43 communities in greater Boston with a network of distributed small-scale wastewater-to-energy facilities (Figure 1). Results of this analysis are presented in Chapter 7.

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[1] Tarallo, S. Utilities of the Future Energy Findings. 2014. https://www.americanbiogascouncil.org/pdf/waterUtilitiesOfTheFuture.pdf.

CHAPTER 2: CWERC DESIGN

Image 3: CWERC Rendering

A Community Water and Energy Resource Center, or CWERC, is a small scale water and energy recovery plant designed to fit in to an urban or suburban setting and serve as part of a distributed network of water and energy management facilities. CRWA developed a prototype CWERC design for this study. Technologies can be interchanged, removed or added depending on site conditions and availability of resources (wastewater and food waste).

The prototype CWERC design mines 1 to 5 million gallons of wastewater per day (mgd)[2] from existing collection systems and treats it to reuse water quality standards using a membrane bioreactor. After treatment, the water's thermal energy is captured by a heat pump. Commonly, in wastewater thermal energy recovery, heat is extracted directly from raw sewage, which can cause the heat pump components to become fouled by the wastewater. By capturing heat from treated reuse water, this approach minimizes the extent to which heat pump components experience fouling and maximizes resource recapture. This may also have advantages under new proposed state regulations which would make thermal energy from "non-biomass sources" (i.e. not wastewater) eligible as alternate energy under the state's alternative portfolio standards (APS). Capturing heat in district scale systems is far more efficient than large systems where valuable heat is lost in transmission.

Thermal energy can be used for heating and cooling applications at the CWERC or can be sold locally within the CWERC district. In keeping with Massachusetts' regulations, the reclaimed water can be sold for such applications as irrigation, water for recreational use, industrial or commercial cooling or air conditioning, toilet flushing, agricultural use, laundry, carwashes, snowmaking, fire protection, and street cleaning.[3] The reclaimed water will also be used to restore degraded natural water systems, create wetlands, recharge aquifers, and help reestablish the natural water cycle.

Wastewater solids captured in the membrane bioreactor undergo digestion on-site in an anaerobic digester; the solids are converted into compost. Biogas produced during decomposition is captured to produce energy in a combined heat and power (CHP) system. In a CHP system, heat is recovered from the electricity generation process. In a CWERC, thermal energy from the CHP unit augments the thermal energy captured from wastewater. Compost is produced in accordance with the requirements for "Class A" biosolids, as specified by the U.S. Environmental Protection Agency in its Standards for the Use or Disposal of Sewage Sludge.[4]

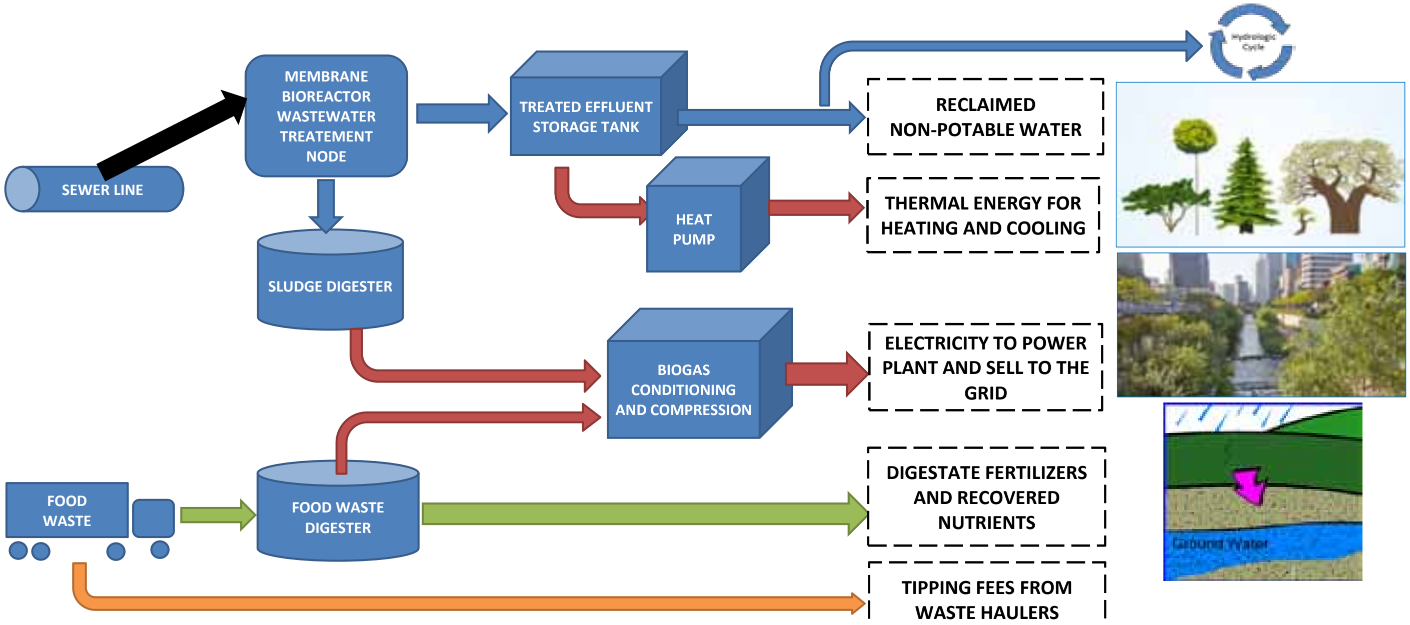

Figure 2. CWERC Flowchart

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[2] Larger scale centralized systems treat wastewater in the range of 100 to 1000 mgd.
[3] 314 CMR 20.06 (2)
[4] Title 40, Part 503, Code of Federal Regulations

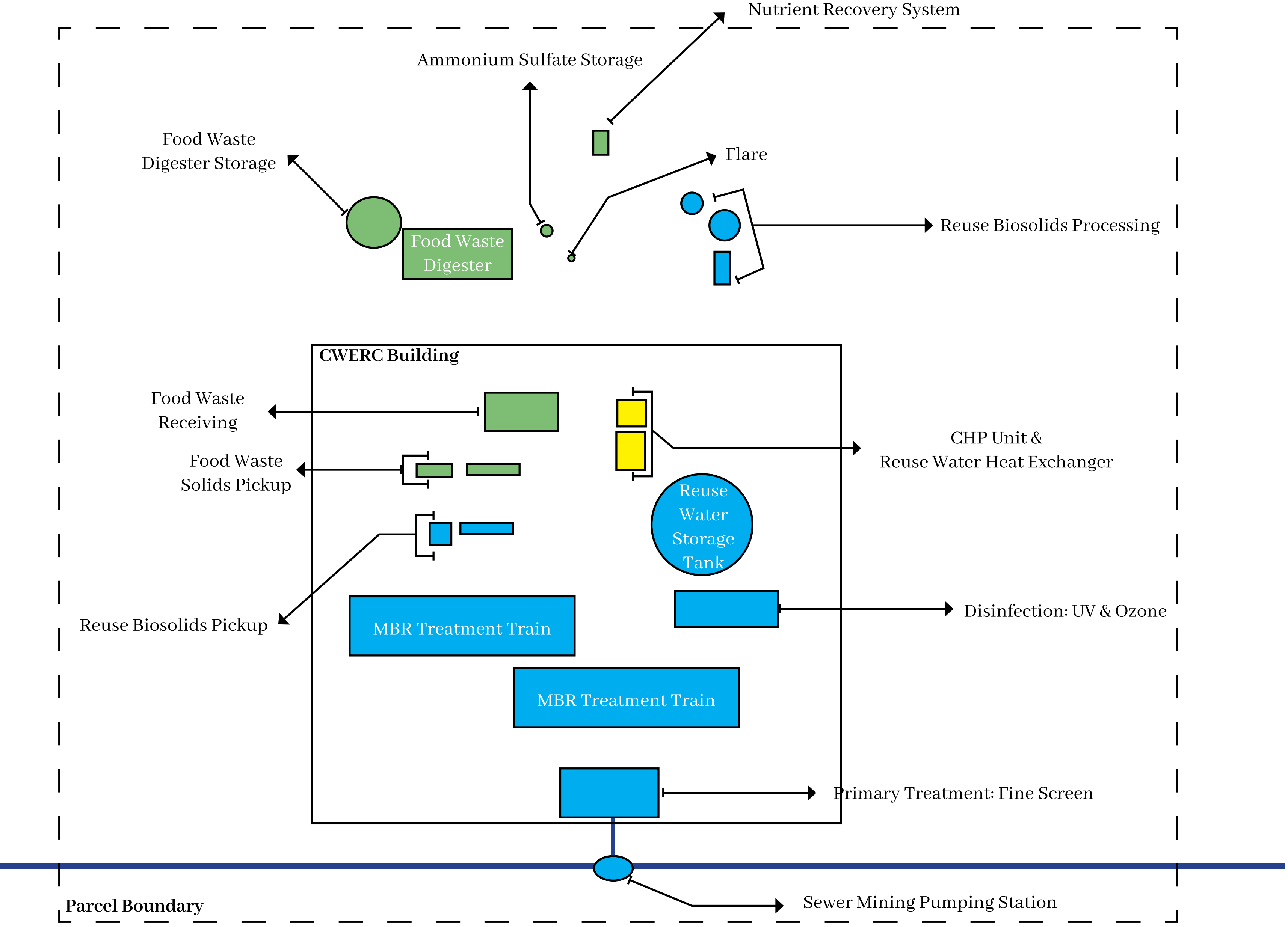

Figure 3. CWERC Layout

In Massachusetts, restaurants, grocery stores, hospitals, and similar establishments that generate more than one ton of organic waste per week are prohibited from disposing their organic materials in landfills.[5] Capitalizing on this situation, the prototype CWERC accepts organic waste from commercial producers, collecting an accompanying "tipping" fee. CWERCs can also collect residential organic waste from local collection programs, although typically a tipping fee would not be charged in this case. CWERCs helps divert solid waste from landfills, reduce greenhouse gas emissions, and produce valuable renewable energy. Food waste makes up nearly 30% of all U.S. solid waste.[6]

In the CWERC prototype, organic waste goes into a dedicated food waste anaerobic digester. Biogas from the food waste digester combines with the biosolids biogas to feed into the combined heat and power system. Electricity produced is used to power the facility or is sold back to the electric grid. Alternatively, the biogas can be turned into compressed natural gas (CNG) to power vehicles, depending on local demand.

The liquid portion of the digested material from the food waste digester can be treated by ammonia-stripping technology to produce a high-quality liquid fertilizer. A soil amendment product can be produced from the food waste solids that remain after undergoing digestion followed by dewatering, or compost can be produced if space is available.

The footprint of the prototype facility to treat approximately 1-5 mgd waterwater, including the anaerobic digesters and composting, is estimated to be about 2 acres. At this scale, the entire prototype facility, except for the two digesters and associated safety equipment, could be incorporated into a building or parking structure where adequate noise and odor control measures are taken to accommodate an urban or suburban setting. Such a facility would cost approximately $50 million to construct and have annual operating costs of $3.2 million.[7]

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[5] 310 CMR 19.000

[6] Washuk, Cost of Buying Food We Throw Out. Sun Journal

[7] This estimates includes the savings from energy produced on-site being used at the facility. Modeling results are discussed in detail in Chapter 4.

CHAPTER 3: SITE SELECTION

The first critical step was to determine whether there were appropriate sites in urban Boston to host a CWERC. The goals of this process were to: 1. Identify viable sites to host CWERCs in greater urban Boston, and 2. Select two sites for conceptual design and modeling.

The project team developed a three phased site selection methodology based primarily on technical and regulatory factors and our project goals. Community input was not solicited at this stage since the ultimate goal was to select sites for conceptual design and modeling, and not necessarily to select an ideal site for near-term implementation. The use of real-world sites in the design and modeling effort allowed us to ground-truth modeling and design inputs.

A three stage process was developed for neighborhood selection. Focused on the neighborhood or district-scale and developing sustainable, closed-loop, neighborhood-level systems, sites were identified based on local availability of CWERC resources, the market for CWERC outputs, and critically, the CWERC's role in restoring local hydrology. The site selection methodology was tailored to our project goals. The team defined criteria for urban density. We also developed specific methods for selecting an economic development study area and an environmental justice neighborhood study area. These methods should be adapted to achieve the goals of individual projects.

METHODS

Level 0 establishes the basic screening criteria with metrics for each. Level 0 eliminates non-viable neighborhoods. Level 1 and 2 rank possible districts against a user-defined set of values. Geographic information systems (GIS) analysis was used to apply level 0 criteria which are primarily spatial (Table 1). Based on the criteria for "urban" neighborhoods, the screening was ultimately performed across a six city region of metro Boston. These six cities are the most densely populated in the state of Massachusetts.

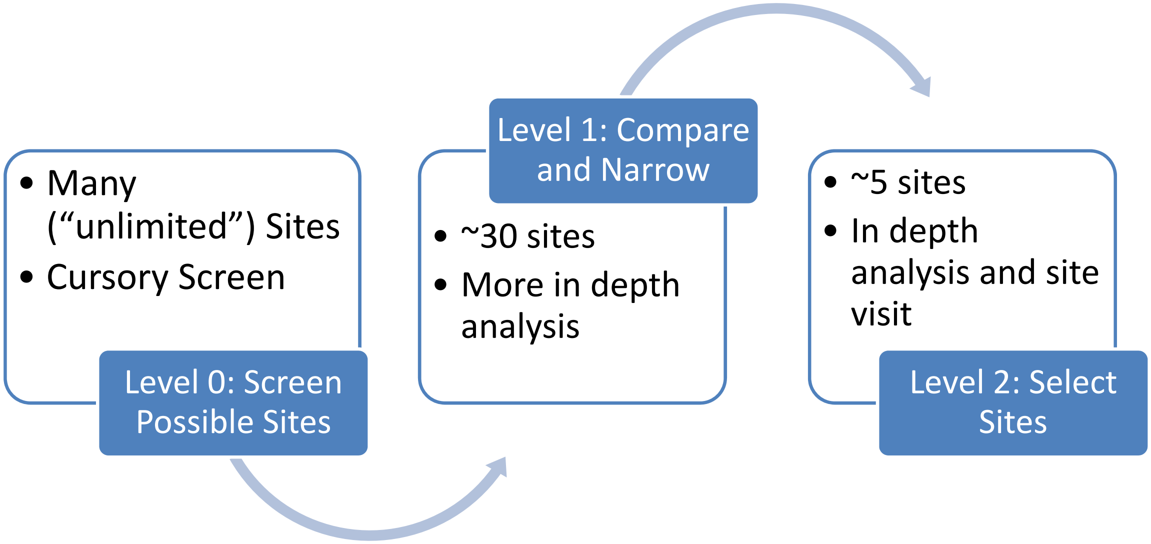

Figure 4. Three-tier Neighborhood Identification Methodology

The results of the Level 0 screen were then refined into distinct neighborhoods, either based on census blocks (environmental justice neighborhoods) or zoning designations (economic development areas). Neighborhoods ranged from a few hundred to over 1000 acres. Once defined, neighborhoods were scored against the Level 1 criteria. The Level 1 criteria as developed by the team and TAC are summarized in Table 2.

Level 0 identified possible sites. The Level 1 analysis allowed the team to prioritize those potentially viable sites based on a set of value propositions developed by the team. Some of these value propositions are related to technical elements of the prototype CWERC design, such as proximity to food waste, while some are related to specific project goals, such as environmental restoration.

Level 2, the final step, is a detailed site analysis which was performed on the top 5 scoring neighborhoods from the Level 1 analysis.[8] Level 2 is also a scoring analysis. Many of the criteria are related to the project goals of environmental restoration and community resilience. Some Level 2 criteria require a more detailed assessment method, including site visits, that would not have been possible at either the Level 0 or Level 1 stages.

The final step of the process is to identify one or more viable sites for the CWERC to be located within the selected district(s). Multiple sites were identified in each neighborhood based primarily on:

- Available vacant space or proposed large scale redevelopment that could encompass a project
- Access to adequate sewage (as could be determined from limited sewer metering data)

Table 1. Level 0 Screening Criteria and Metrics

Criteria	Metric(s)	Assessment Methods
Urban	-Existing MWRA DITP sewer customer -Defined as "City" -Population density > 10,000 people/square mile -Neighborhoods land use is not entirely residential	GIS
Accessible source of adequate sewage that is presently flowing to DITP	Within ½ mile of a sewer pipe with 1-5 million gallons per day (mgd) of flow (pipe size used as surrogate for flow)	GIS
Environmental justice neighborhood	As defined by EPA criteria based on 2010 census blocks	GIS
Economic development/growth area	As defined by the City itself	Review of zoning maps and city web-sites Discussion with TAC and city contacts

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[8] In some cases adjacent neighborhoods were combined to form one larger neighborhood during this step.

Table 2. Level 1 Scoring Criteria

Criteria	Score Basis	Assessment Methods
Property/Land Use		
Proximity to sewer infrastructure scheduled for upgrade	Facility within ½ mile buffer area, higher points awarded for facilities scheduled for work in recent capital improvement plan (CIP)	GIS and CIP review
Potential institutional/business/residential partners	Review of five largest buildings within neighborhood, scored by team	GIS and team meetings
Space availability	# of vacant lots >1 acre within neighborhood	GIS
Zoning allows for mixed uses by-right	Yes or no	Zoning code review
Environmental		
CSO or sanitary sewer surcharge area	Partial or full CSO area; within half mile of recent sanitary sewer overflow	GIS, review of sanitary sewer overflow reports
Groundwater recharge needed	Within the groundwater conservation overlay district or area of low groundwater as identified by state sustainable water management initiative	GIS
In an area subject to a Total Maximum Daily Load (TMDL)	Point for each TMDL the area is subject to	GIS
Energy		
Large energy user(s) present	# of buildings with >75,000 sf	GIS
Economic		
Proximity to large scale food waste producer(s)	# producers subject to MassDEP food waste ban within ½ mile buffer area, also considered total # of facilities which produce organic waste	GIS and MassDEP report on organic food waste
Transportation and Infrastructure		
Proximity to major ground transportation for food waste	Proximity to highway or freight line	GIS
Proximity to water transportation for food waste	Waterfront access	GIS

Table 3. Level 2 Scoring Criteria

Criteria	Score Basis	Assessment Methods
Property/Land Use		
Public (non-conservation) or utility vacant land or above-ground sewer infrastructure	# parcels	GIS
Environmental		
Brownfields	# brownfields in neighborhood	GIS
Energy		
Energy demand increase expected (growth potential)	See Economic below	
Need for consistent, reliable, resilient or redundant energy source	# hospitals, emergency services and shelters, research facilities or "data farms"	GIS, TAC input, site survey
Major energy infrastructure	Present in neighborhood	GIS, site survey
District energy present	Higher points for areas with existing district energy loops	TAC input, internet research
Economic		
Market for resale energy	# buildings reliant on oil boilers within neighborhood	
Market for resale water	# large users within neighborhood	TAC input, site survey, approximation based on facility size and type
Private investment potential (also used as surrogate for energy demand increase potential)	Economic analysis, comparison and ranking	Performed by project team economist
Transportation and Infrastructure		
Proximity to public transportation for people	Accessibility to train, subway, and bus	GIS
Political Climate		
Fit with a community's planning and zoning goals	Community prioritization of sustainability, renewable energy, and/or resilience	Review of community documents and website
Community has a renewable energy plan program or staff person	Present	Review of city websites

RESULTS

The initial screening results of the Level 0 analysis overlaid with economic development and environmental justice areas are shown in Figures 5 and 6 respectively. Distinct “neighborhoods” were then identified and defined, resulting in 23 neighborhoods which were run through the Level 1 analysis. The top five scoring neighborhoods were then considered in Level 2 which included both scoring methodology and site visits by the project team. Two of the Level 2 neighborhoods were defined as economic development areas, one was defined as strictly environmental justice and the remaining two were categorized as both.

The team selected a neighborhood for our economic development study area early on and recommended it to the TAC for approval (See Neighborhood 1 on following page). Some initial modeling was done on Neighborhood 1 prior to selecting an environmental justice study area allowing the team to determine if any refinements were needed in the Level 2 analysis. In selecting the second neighborhood study area, the team put a higher premium on river restoration potential. Additionally, since Neighborhood 2 was selected after about 8 months of working on Neighborhood 1, the team had already established good relationships and contacts with the City of Boston. Consequently, a preference for continuing the work in Boston was also prioritized. In Neighborhood 1, one site was identified and prioritized for CWERC siting. In Neighborhood 2, three possible sites were identified.

DISCUSSION

The site selection methodology is designed such that Level 0 identifies areas that meet the minimum technical requirements, and Levels 1 and 2 allow users to rank and prioritize based on project goals. Other projects or future projects may refine or change these elements based on different goals. After the project modeling was performed, it became clear that a critical element of the CWERC design and the facility’s financial integrity is the ability to sell reclaimed water. Identification of potential resale water customers was a challenge of the site selection process in this study. Information on water use by building is not publicly accessible, and even when we were able to obtain some of this information for select sites, it was not always possible to estimate what percent of the water could be offset by a non-potable supply. This is a critical technical element to the project, and in future projects, attempts would be made to identify a surrogate for these criteria in Level 0 or Level 1. Finally, as described in Chapter 5, CRWA developed conceptual designs for plant effluent discharge being returned to the natural environment in a restorative way, however, discussion with regulatory officials regarding discharge permitting did not occur at this stage. Therefore technical and regulatory requirements of an effluent discharge are not considered in neighborhood selection, only in design.

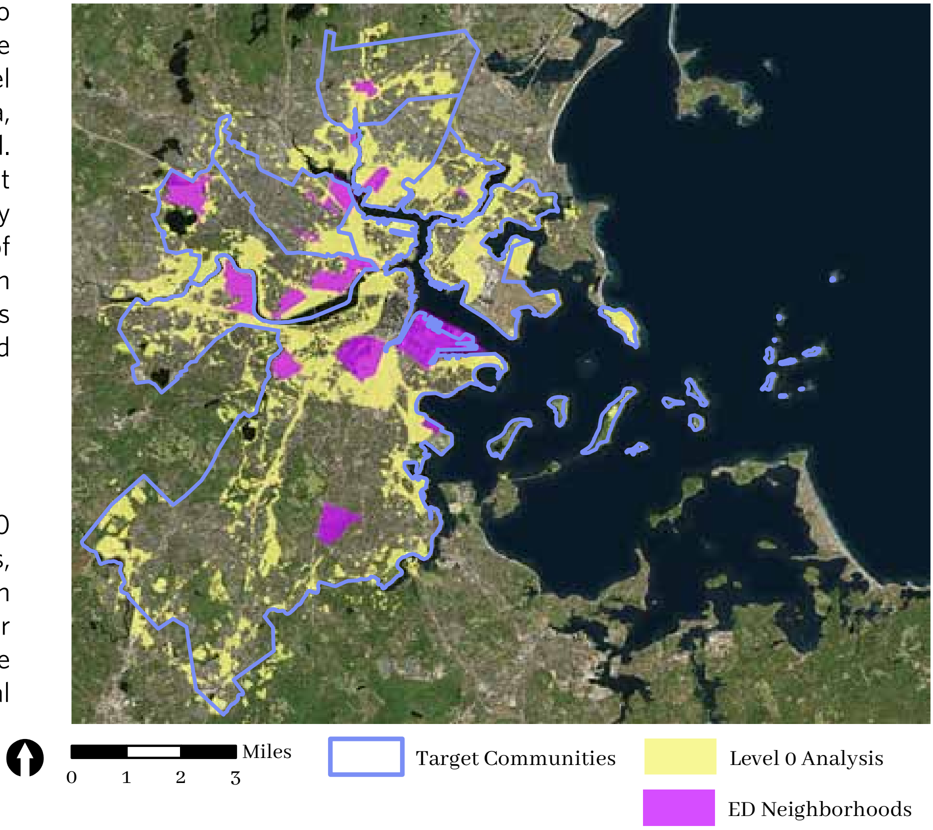

Figure 5. Level 0 Results Overlaid with Economic Development Area.

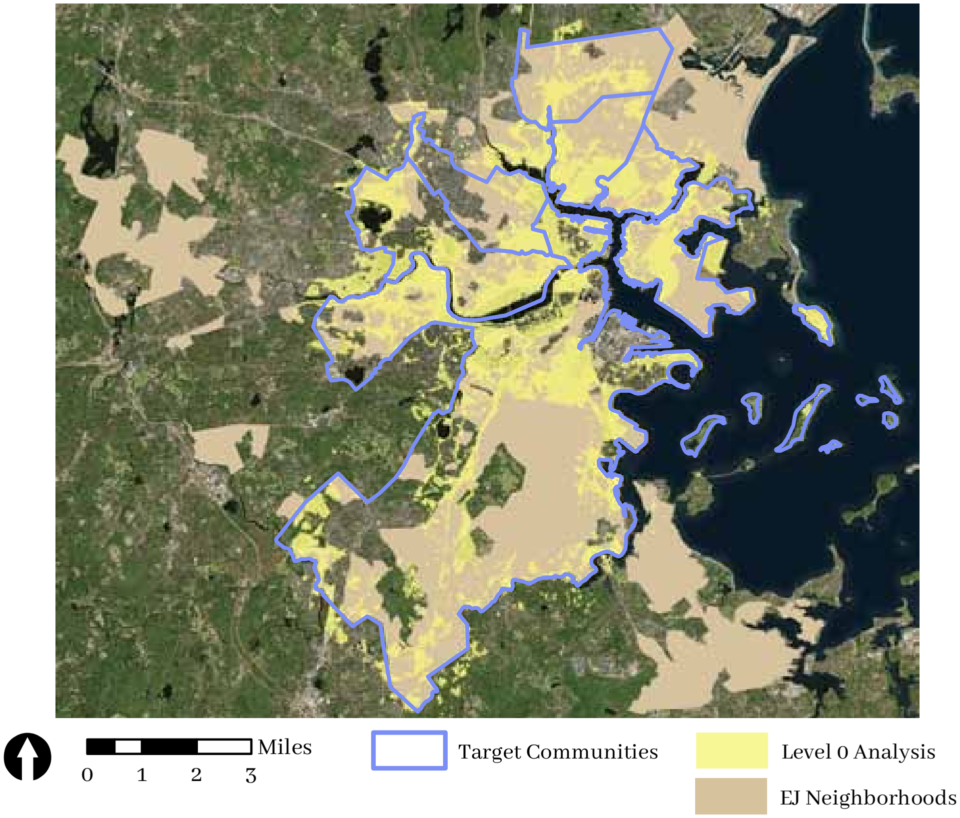

Figure 6. Level 0 Results Overlaid with Environmental Justice Areas

Neighborhood 1: Boston's Innovation District

The Innovation District, located on Boston Harbor adjacent to Downtown Boston has undergone a dramatic transformation in recent years. The future home of General Electric's headquarters, the neighborhood has transformed from a primarily industrial area into "a 24-hour neighborhood that fosters innovation, collaboration, and entrepreneurship."[9] The City of Boston estimates that collected development of this area will result in over 6,500 new jobs. The City has also prioritized environmental sustainability in this neighborhood, making commitments to improve public and non-motorized transportation opportunities. The City is also actively working to promote and implement district energy there. Numerous climate vulnerability assessments, including those by City and state agencies have warned of significant impacts to the area from sea level rise and flooding in the coming century (Figure 7) without adequate adaptation measures.

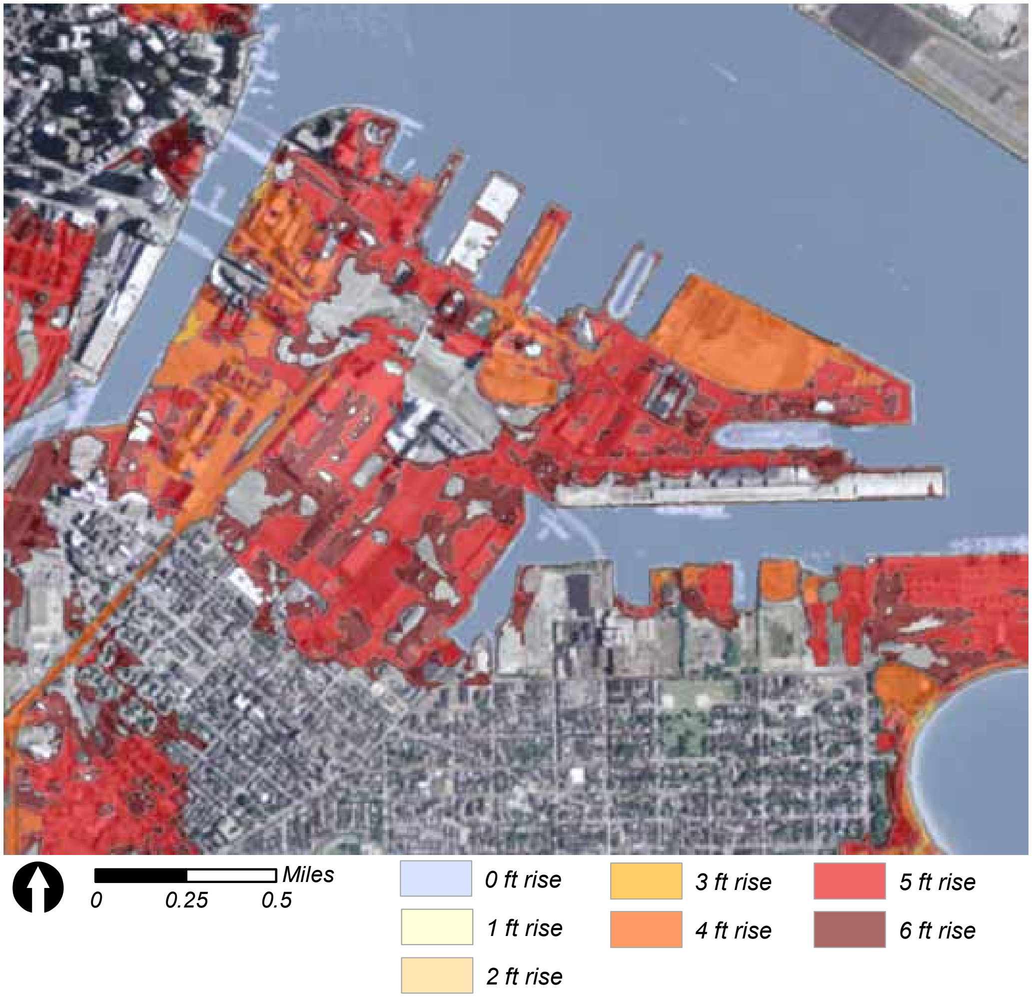

Figure 7. Sea Level Rise Map for Innovation District (Seaport District)

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[9] Boston Planning and Development Agency (BPDA) formerly Boston Redevelopment Authority (BRA) website.

Neighborhood 2: Stony Brook

The second study area, identified by the project team as Stony Brook, overlays the intersection of numerous Boston neighborhoods including Fenway, Back Bay, Mission Hill and Roxbury. A defining characteristic of the neighborhood is the Muddy River, a highly urbanized tributary to the Lower Charles River. The Muddy River is notable in that it is the only tributary to the Lower Charles which is not buried in a culvert. It sits instead within Boston's Emerald Necklace. The largest tributary to the Lower Charles, the Stony Brook, is nearly entirely contained in underground culverts. Prior to the urbanization of Boston, the Stony Brook neighborhood was the site of the confluence of the Muddy, the Stony Brook, and the Charles River/Boston Harbor tidal estuary (Figure 8). 65% of the defined area is made up of environmental justice neighborhoods (Figure 9).

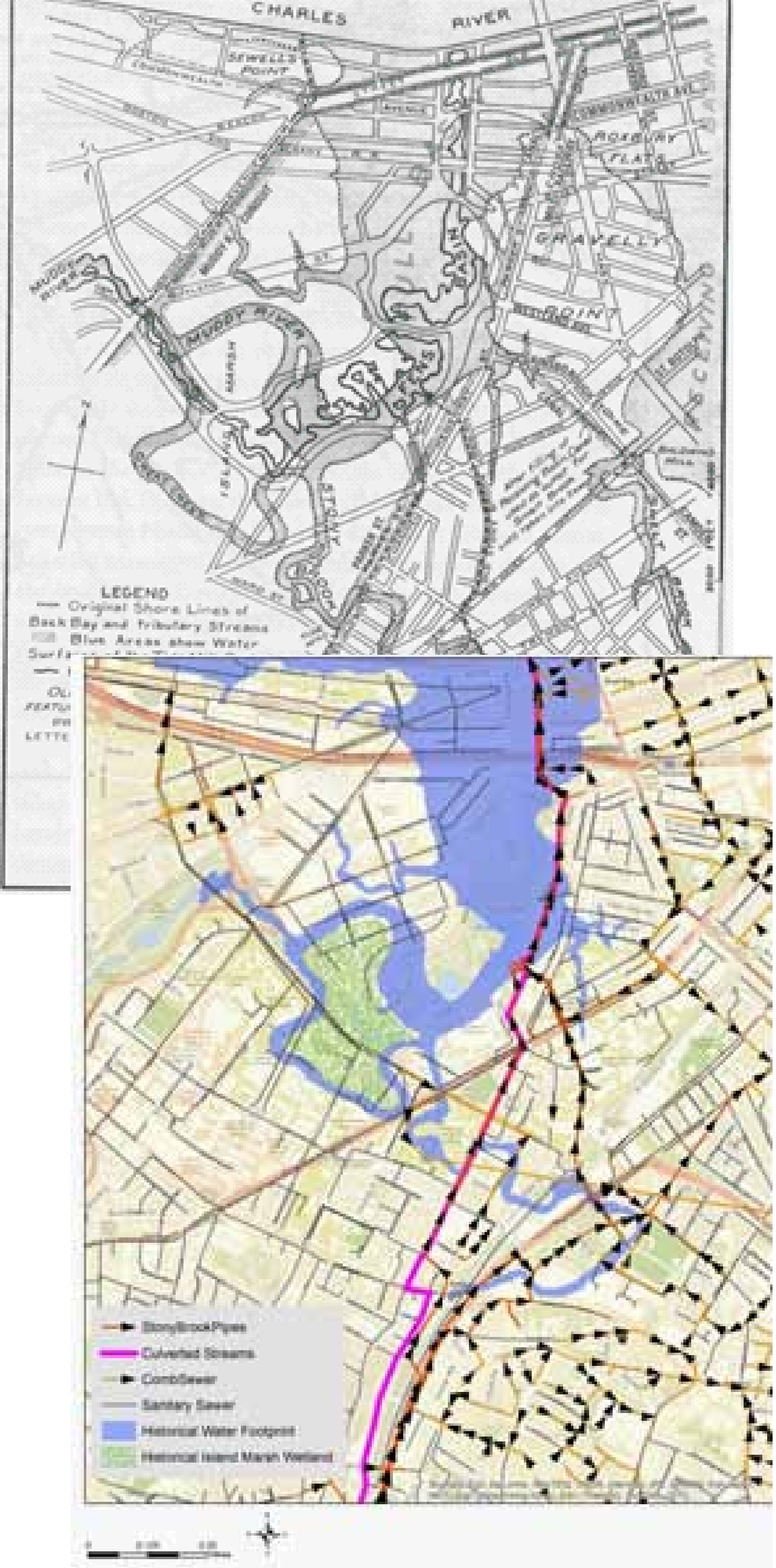

Figure 8. Historical Hydrology in Back Bay Fens Overlaid with Current Infrastructure (top image)

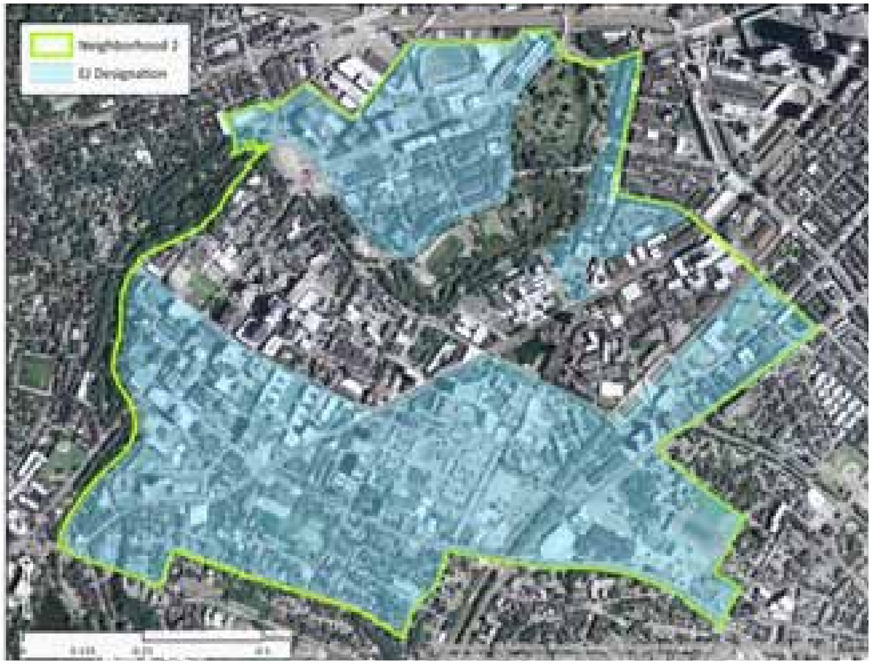

Figure 9. Neighborhood 2 Environmental Justice Designation

CHAPTER 4: PILOT SITE MODELING

The team developed technical and financial models to assess outputs of the prototype CWERCs as operable in each district in both commodity and monetary values. Multiple modeling scenarios were run on each pilot CWERC. Models were developed and run by Natural Systems Utilities (NSU) in conjunction with CRWA. Modeling results reveal that CWERCs are not only environmentally desirable but financially desirable as well.

METHODOLOGY

The team developed a technical model to calculate CWERC outputs of energy (electrical and thermal), compost, soil amendment, nutrients, and treated water from the inputs of wastewater and food waste. Outputs are determined based on technical inputs, CWERC processes, unit biogas and solids production for both biosolids and food wastes, sizing of process tanks and equipment (based on design parameters), and parasitic energy consumption of the CWERC. Table 4 summarizes model input parameters and assumptions. Model assumptions were determined through research and stakeholder meetings and are tailored to Boston specific values when possible and relevant. Model values for CWERC inputs are based on an analysis of the relevant study area neighborhood. Influent sewage flow characteristics are based on the influent flow at Deer Island. Certain model runs do not include income from wastewater treatment fees at the request of project partner MWRA. Output from the technical model consists of the resulting utility production after processing, as well as energy consumed in processing (See Figure 10). Output quantities are reported on an annual basis.

Capital costs, operating costs, and product generated income serve as inputs to the financial model. The financial model assesses a range of potential business model operating scenarios by evaluating the effect of various financing options on the financial viability of a CWERC. Capital construction and operations and maintenance costs, except where documented as model inputs in Table 4, are based on elements in the prototype designs and industry standards. The model includes a yearly cash flow analysis based on operating costs and revenues, along with financing costs associated with capital investment requirements. All cost and revenue components are inflated by 3% annually. Capital replacement is included in the model through an annual reserve fund (0.75% of total capital costs) to provide funds for the replacement of the entire plant at the end of the project life (at least 20 years). Annual administration expenses are included as 0.5% of the total capital costs.

The model analyzes the effect of different business model arrangements by comparing the net present value (NPV)[10] assuming 20 years of operation. The cash flow analysis allows the team to adjust certain input variables to determine conditions for which a pilot plant is financially feasible, meaning that the net present value (NPV) is equal to at least zero assuming a 20 year life span, or in other words, the plant is able to cover all operating expenses, debt payments and build a replacement reserve within a 20 year timeframe. The business model scenarios differ in the debt-to-equity ratio and the interest rate of debt. The use of public versus private land for the site of the pilot plant is also considered in the business model scenarios by adding or removing an annual land lease fee. The team found it difficult to determine a representative land lease fee since land leases in the local area are highly variable. The equity discount rate is 20% for all modeling scenarios and, in combination with the debt-to-equity ratio and interest rate, sets the project NPV discount rate.

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[10] Net Present Value (NPV) is the difference between the present value of cash inflows and the present value of cash outflows and is used in capital budgeting to analyze the profitability of a projected investment or project.

Table 4. Input Variables and Assumptions

Parameter	Value Range	Source
Wastewater Flow (mgd)	2 to 3	Set by team based on sewage availability
Renewable Energy Credit ($/MWh)	$65.30	Personal communication from DOER; rate in 4th quarter 2013 trading
Natural Gas Price ($/MMBtu)	$9.77	U.S. EIA
Electricity Cost ($/MWh)	$121-147	Olivier, Jacobson, Ruberti, Haswell, Northeast Utilities. Personal communication. (2014)
Electricity Sales Price for Net metering ($/MWh)	$89	Olivier, Jacobson, Ruberti, Haswell, Northeast Utilities. Personal communication. (2014)
Food Waste (wet tons / day)	54-80	Set by team based on estimated availability
Food Waste Tipping Fee ($/wet ton)	$60-$80	Boston PWD (2013), TAC
Reuse Water Sold (% of treated water)	66-75%	Set by team based on national reuse rate research
Reuse Water Sale Fee ($/1000 gallons)	$2.20-$6.50 (33-100% 2014 water rates)	BWSC (2014)
Biogas to Combined Heat and Power	Yes or No	
Biogas to Compressed Natural Gas	No or Yes	
Value of Compost from Class A Biosolids	$25/cu yd	Estimated based on regional values
Value of Soil Amendment (Digested Food waste solids)	$12/cu yd	Estimated based on regional values
Value of Extracted Nutrients (Ammonium Sulfate)	$0.70/lb N	Estimated based on regional values

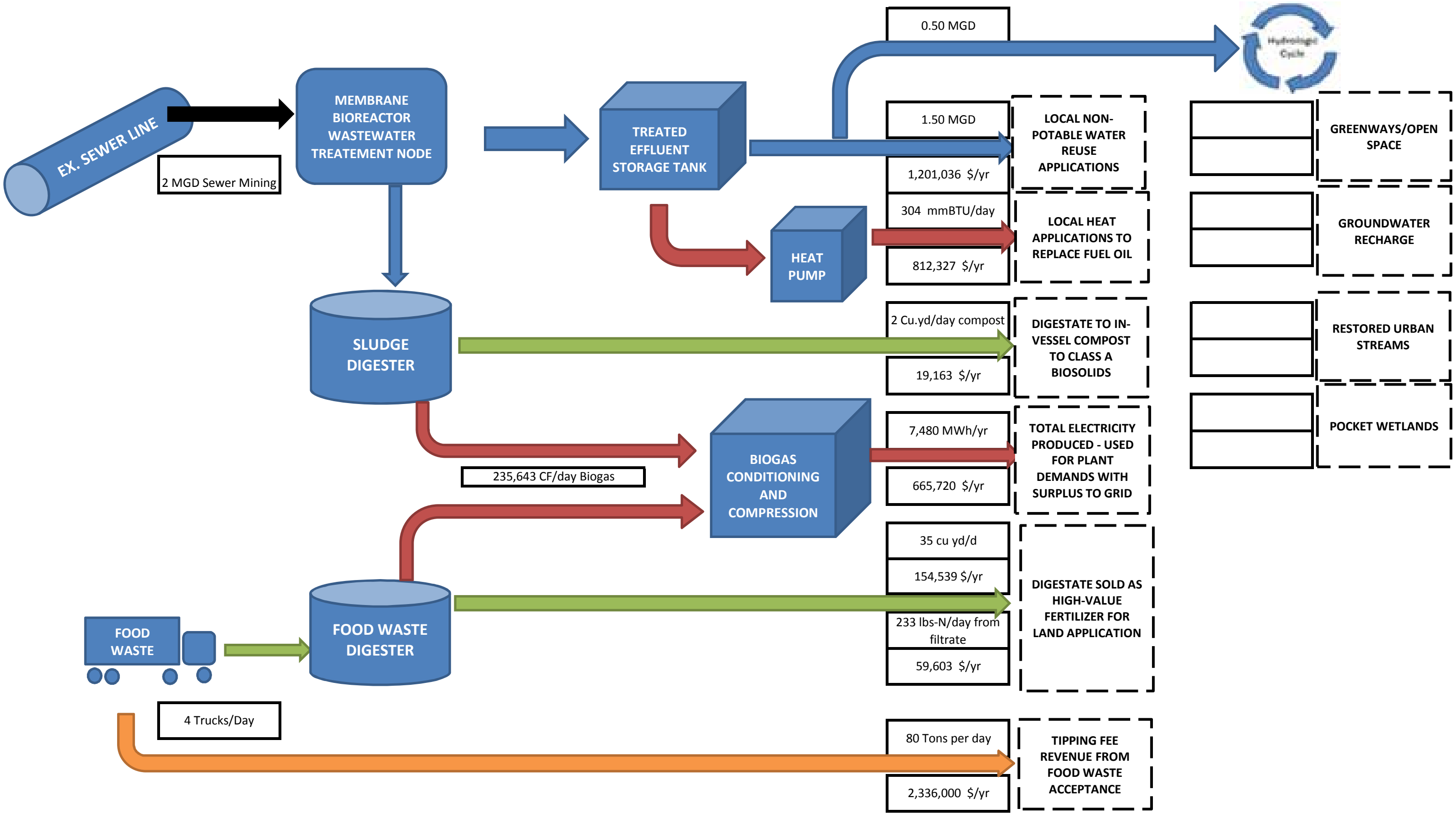

Figure 10. CWERC Influent and Effluent Product Flows (Image Credit: Natural Systems Utilities)

At this level of analysis local construction or labor rates were not used in the capital costs and labor portion of the operational costs of the pilot plant components; these are based on national averages.

RESULTS

CWERC 1, sited in study area Neighborhood 1, has assumed inputs of 2 mgd wastewater and 80 wet tons per day (wtpd) of food waste. Short term flow metering data from BWSC indicates that the desired volume of sewage is available in a pipe adjacent to the Neighborhood 1 preferred CWERC site.

Like many of the pipes in this study area, the pipe is a combined sewer pipe and therefore influent flow would be more dilute during rain events. It is also assumed that 1.5 mgd will be sold as reclaimed water and 0.5 mgd will be reintroduced back into the environment.

Food waste information was based on 2011 U.S. EPA estimates of food waste producers in Massachusetts.[11] Within a roughly 1.5 mile radius area surrounding Neighborhood 1, 655 food waste producers were identified. Of those it is estimated that at least 10% are subject to the Massachusetts food waste landfill ban, although data is missing for over 20%. Based on the data available for those 655 producers, it is estimated they produce at least 80 wtpd of organic waste. Statewide it is estimated that 2,600 wet

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[11] Mass.gov Commercial Food Waste Disposal Ban webpage. http://www.mass.gov/eea/agencies/massdep/recycle/reduce/food-waste-ban.html. It is important to note that food waste estimates available do not include manufacturing facilities which make up roughly 56% of all food waste statewide. While this may result in an underestimate of the food waste available locally, many of the producers may already be taking advantage of the resources in their own food waste through composing, recycling, or digestions.

tons are discarded daily, and that 960 wtpd would be subject to the landfill ban. The target of 80 wtpd represents roughly 8% of the statewide total for waste subject to the ban.

The results of one modeling scenario are shown in Table 5. Results assume a tipping fee for commercial food waste of $80/wet ton, no residential food waste, and a reuse water rate of $2.20/1000 gallons (a third of 2014 rates) (see Table 4 for remaining input values). CWERC utility sales income varies per utility and product dependent on the site.

Annual values for energy metrics are gross values, prior to subtraction of energy used in the operation of the facility. After subtracting the thermal energy required to heat the building and an anaerobic digester, 292,981 mmBTUs/year is available for use in the surrounding district or a co-located structure. This total includes the energy input to operate the heat pump. The conceptual design includes a heat pump with a COP of 1.5, this means two units of energy input are required to extract one unit of energy output, all three units are available for use. For this model, 183,121 MMBtu/yr of energy are input using natural gas to extract 91,060 MMBtu/yr from the wastewater. The CHP system supplies another 19,800 MMBtu/yr. Net electricity available for resale to the grid, after operational demand, is 3610 MWh/year. An advantage of combining a food waste digester with a wastewater treatment system is the ability to cover the electricity demand peaking factor with on-site energy generation. For the neighborhood level studies, the ratio of wastewater to food waste is set so that at a minimum the plant will cover its own parasitic load. In CWERC 1 there is considerable supplemental electricity for sale.

The capital cost for CWERC 1 is estimated at $46.7 million based on cost estimates for individual components and their sizes for the concept design. Operations and maintenance costs, also estimated by component, are roughly $4.9 million annually, including electrical demand costs which can be covered by electricity produced on site. For the CWERC scenario presented in Table 4, public financing at 0% interest, 100% debt, and no land lease would make the project financially feasible as defined above. If the interest rate is set at 2% in the above scenario, the project needs $2.8 million dollars in additional upfront capital investment or an additional $120,000 a year in operating income to be feasible. This gap could be closed by increasing water resale rates or introducing a very modest wastewater treatment fee. For a private ownership scenario with an assumed land lease of $600,000/year, 6% cost of debt, and an 80% debt-to-equity ratio, $3.3 million of additional annual revenue would be needed, or $35 million in additional capital investment or grant funding, making this scenario likely out of reach without charging for wastewater treatment. The assumption of all the scenarios for CWERC 1 is that there is no wastewater treatment fee.[12]

Table 5. Modeling Results for Select CWERC 1 Scenario

Parameter	Volume	Value ($/year)
Income		
Mined wastewater	2 mgd	$0
Renewable Energy Credit (accounting for 90% utilization)	6,732 MWhr/yr	$439,400
Thermal Energy (includes energy input to heat pump)	273,181 MMBtu/yr	$2,326,000
Thermal Energy from CHP	26,145 MMBtu/yr	$223,000
Total Electricity Generation (for demand with excess to grid)	7,480 MWh/yr	$665,720
Sludge compost (Class A biosolids)	770 cu yd/yr	$19,200
Food Waste Tipping Fees	29,200 tons/yr	$2,336,000
Reuse Water Sales	1.5 mgd	$1,201,000
Food Waste Digestate Soil Amendment	12,650 cu yds/yr	$151,800
Food Waste Digestate Nitrogen Recapture (Ammonium Sulfate)	85,100 lbs-N/yr	$59,600
Income Total		**$7,421,720**
Operating and Maintenance (O&M) Expenses		
Electricity Demand	3,870 Mwh/yr	$432,600
Natural Gas Demand (Heat pump and CHP)	188,466 MMBtu/yr	$1,840,100
Labor, Chemicals, Maintenance		$2,602,800
O&M Total		**$4,875,500**

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[12] Per agreement with project partner MWRA and TAC member BWSC.

In Neighborhood 2, the prototype CWERC is designed to treat 3 mgd of wastewater and incorporate 54 wtpd of food waste. No preferred site was designated in Neighborhood 2, as in that neighborhood there are three possibilities for CWERC siting. Each is currently vacant but scheduled for development and could potentially accommodate a CWERC within the development. The largest of these sites has a tentative layout which includes a parking garage that is large enough to house the entire CWERC on the first or second floor. Access to sewage could be achieved through connections to one or possibly two sanitary sewer pipes. There are three metered pipes in the vicinity of the largest possible CWERC site with sewage flows on average between 1.5 and 2.3 mgd, indicating that adequate sewage volume does flow through the area, although more work would be required to identify an access point. There is also a sewer pipe in the area which may need to be relocated due to future development. Though no flow data is currently available, it represents a good access opportunity. In this area, sanitary flow would offer a more concentrated sewage source, although for the model, sewage influent is assumed to have the same characteristics as sewage influent to Deer Island at both pilot sites. For this site it was assumed that 2 mgd of treated water would be sold for reuse.

The 54 wtpd of food waste would be sourced from an area within approximately 3 miles of the neighborhood. Within this 3 mile radius, 348 food waste producers were identified, exclusive of those assumed to be contributing to CWERC 1. Based on the producers with available food waste estimates (~80%), 54 wtpd are produced in this area. This is roughly 5% of the food waste estimated to be subject to the ban statewide.

The results of one modeling scenario are shown in Table 6. Results assume a food waste tipping fee of $60/wet ton and reuse water rate of $5.23/1000 gallons (see Table 4 for remaining input values). Annual income values for energy metrics are gross values, prior to subtraction of resources used in the operation of the facility. After subtracting the thermal energy required for operations, 421,926 MMBTUs/year is available as thermal energy from a heat pump for use in the surrounding district or co-located structure.[13] This includes heat pump energy input provided by natural gas in this scenario with digester and building heating substracted out. Net electricity available for resale to the grid after operational demands are satisfied is 370 MWh/year. Significantly more thermal energy is available in this scenario due to the higher wastewater flow; less electricity is produced due to the lower volume of food waste, and considerably less net electricity is available due to a higher on site electrical demand.

Table 6. Modeling Results for Select CWERC 2 Scenario

Parameter	Volume	Value ($/year)[3]
Income		
Mined wastewater	3 MGD	$0.00
Renewable Energy Credit (accounting for 90% utilization)	4,770 MWhr/yr	$311,100.00
Thermal Energy from Wastewater (includes energy input to heat pump)	409,772 MMBtu/yr	$3,488,000.00
Thermal Energy from CHP	18,509 MMBtu/yr	$158,000.00
Total Electricity Generation (for demand with excess to grid)	5295 MWh/yr	$471,300.00
Sludge compost (Class A biosolids)	1150 cu yd/yr	$28,700.00
Food Waste Tipping Fees	19,710 tons/yr	$1,182,600.00
Reuse Water Sales	2 mgd	$3,798,810.00
Food Waste Digestate Soil Amendment	8,540 cu yds/yr	$102,500.00
Food Waste Digestate Nitrogen Recapture (Ammonium Sulfate)	57,500 lbs-N/yr	$40,200.00
Income Total		**$9,581,210.00**
Operating and Maintenance (O&M) Expenses		
Electricity Demand	4,930 MWhr/yr	$709,845.00
Natural Gas Demand (Heat pump and CHP)	279,536 MMBtu/yr	$2,712,036.00
Labor, Chemicals, Maintenance		$3,578,119.00
O&M Total		**$7,000,000.00**

CWERC 2 is estimated to cost approximately $53.8 million in initial capital investment with operations and maintenance expenses of $7 million annually.[14] For the CWERC 2 design and the scenario presented in Table 6, looking at the best case scenario of public

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[13] Includes energy input of 181,121 MMBtu/year for absorption heat pump (COP = 1.5) CWERC building heat and anaerobic digester heating demand subtracted out.

[14] Operations and maintenance estimate does not account for the savings from energy produced on site.

ownership at 0% financing and with no land costs, the CWERC would be financially feasible. Under a private ownership scenario, with 6% interest, 80% debt and 20% equity financing, and a $600,000/year land lease, reuse water rates would need to be raised to $6.50/1000 gallons and a wastewater treatment fee of $2.87/1000 gallons would need to be assessed to achieve financial viability.

CHAPTER 5: ENVIRONMENTAL RESTORATION

In each district, wastewater and potable water management are only a piece of the full environmental restoration that CRWA's approach encompasses. Stormwater runoff is the leading cause of pollution to most urban waterbodies. Traditional urban development impedes natural rainwater and groundwater interactions. CRWA developed designs focused on restoring natural hydrologic function for both study areas.

METHODS

The critical first step in CRWA's design process for restoring nature is developing an understanding of an area's historical natural hydrology. Paving or building on a landscape alters the water cycle in a fairly predictable way, reducing groundwater recharge and evapotranspiration, and increasing polluted stormwater runoff. For many urban neighborhoods, however, the alterations extend far beyond simply a change in land cover. Over the course of hundreds of years of human development, local wetlands and waterways may have been completely filled and built on. Streams and rivers were buried or put into pipes after being so severely degraded by pollution that they constituted a public health threat. Rivers and estuaries were dammed, significantly and permanently altering their habitats.

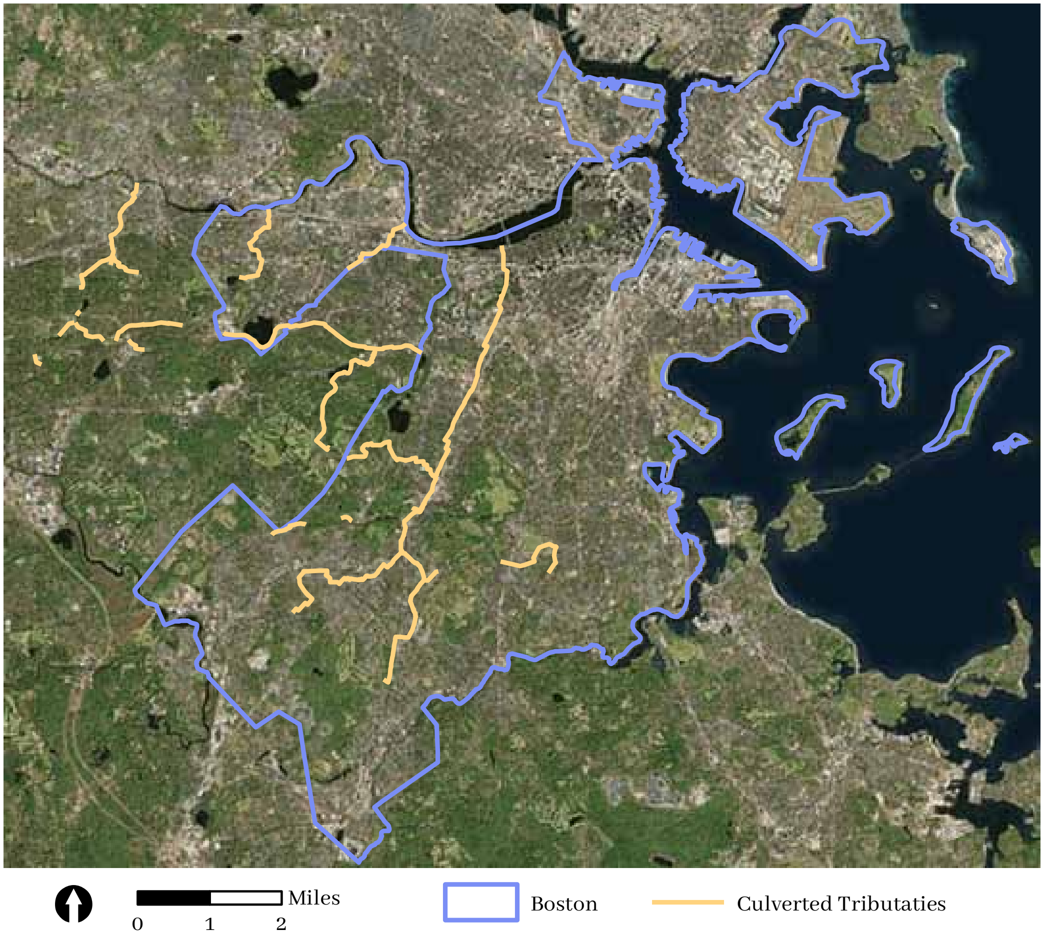


Figure 11. Culverted Charles River Tributaries

A thorough existing conditions assessment is completed prior to beginning the restoration design process. To understand natural hydrology, CRWA reviews historical maps and documents, and investigates natural topography (Figure 8). Superimposed on these natural conditions, we review current infrastructure, impervious cover, open spaces, canopy cover, regional connectivity, and present day water resources. Finally, to help us identify opportunities for green infrastructure we investigate soil conditions, property ownership, regional and local plans, and near and long-term site development plans.

In each of the study neighborhoods the goal was to develop plans that manage runoff from a 1 inch rainfall consistent with the volume BWSC expects to be retained on site for new and redevelopment projects. Total runoff volume to be managed across the neighborhood from the target storm is calculated based on land cover conditions. From this volume we estimate the approximate volume and surface area of green infrastructure (GI) systems necessary to store, treat or infiltrate the target runoff volume.

Greening plans are presented at two scales, district-wide and site scale. At the district wide scale, GI systems are sited and identified by type (biofiltration systems, gravel wetlands, infiltration trenches and infiltration basins), based on the following criteria:

•Identify areas with minimal slope, high depth to groundwater, pervious cover and good soils

•Identify available space in the neighborhood where GI systems could be incorporated into existing sites and street rights of way

•Maximize GI on publicly owned sites

•Maximize GI in the public rights of way

•Maximize infiltration in the groundwater conservation overlay district (GCOD)

•Maximize GI in areas proposed as greenspace or open space in community planning documents

•Maximize storage in combined sewer drainage areas

•Modest GI proposed on currently vacant sites, scheduled to be developed

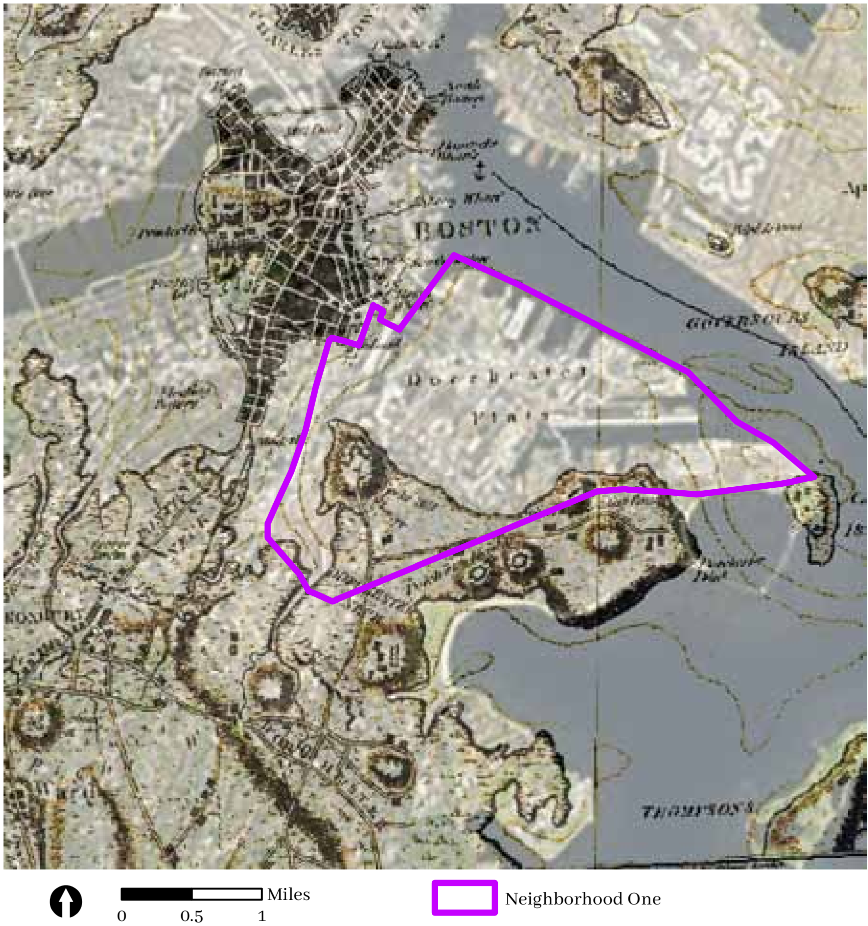
What is the GCOD?
The City of Boston has adopted a Groundwater Conservation Overlay District (GCOD) in sections of the City to protect wood pile foundations of buildings from being damaged by low groundwater levels. Low groundwater levels expose wood pilings to air which causes them to rot and can result in structural damage to the buildings above. In this area, construction or renovation projects are required to infiltrate runoff on site to help maintain local groundwater levels. Throughout the GCOD there is an extensive network of groundwater monitoring wells to track groundwater levels on a regular basis.

Site-scale detailed conceptual designs are also presented for sites identified as good opportunities for stormwater management improvements. For select sites, near-term and long-term design scenarios are presented. Long-term designs do not adhere to existing land use and importantly these designs more explicitly incorporate climate adaptation strategies to account for major threats facing Boston's future: increased rainfall, heat, and sea level rise. Site level designs offer far more detail; system sites and types are selected based on more detailed analyses of stormwater flows, drainage area, groundwater levels and opportunities to infiltrate, as well as site character. System locations and sizes are based on the topography of the actual site, specifically, how much water can be directed to a particular location.

Certain systems are designed to intercept and treat runoff after it has already entered a stormwater pipe. Site scale designs include plans for returning treated CWERC effluent to the environment.

In Neighborhood 2, a series of site scale designs focus on using stormwater wetlands for extended detention and storage of large rain events. Areas "upstream" in the connected stormwater drainage system overlaying Neighborhood 2 are the focus area for this approach and the goal is to implement upstream controls to improve downstream conditions where dense development makes implementation of large GI systems difficult. Peak flows from four large "drainsheds" are approximated using BWSC sampling data and HydroCAD modeling software.[15] Approximate treatment system sizes are calculated based on runoff from the 10 and 100 year rainfall events, intensified by 10% to account for future climate conditions. The stormwater best management practices (BMPs) are designed as dry detention basins with approximate storage volume for a 12-hour detention time in a basin, to give a minimum approximate system footprint based on an assumed 4 foot depth.

Finally, iTree, an urban forestry model, is used to assess three tree cover scenarios in each study area: existing tree canopy cover, modest increase scenario, and 35% (the city's stated goal). Existing canopy cover was determined using NASA Landsat Data Collection (NLDC) satellite imagery in ArcMap. An on the ground survey of about 5% of the trees in each study area neighborhood was conducted to determine species and diameter at breast height (DBH) for input into the model.



Figures 12. South Bay Overlaid with Historic Map.

RESULTS

Neighborhood 1

Neighborhood 1 was historically open water, a section of Boston Harbor known as "Dorchester/South Boston Flats". This area was filled in to create land in the late 19th and early 20th centuries and used historically for shipping and industry. Today this area of Boston is flat, low-lying and highly impervious.

The western section of the neighborhood was an open water inlet known as South Bay (Figure 12). South Bay has been completely filled in today but as recently as the 1950s a small canal and section of open stream remained. Mapping this historic landscape against present day infrastructure reveals that the canal and open stream are now two large culverts that discharge to the Fort Point Channel (Figure 13).

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[15] Boston water and Sewer Commission (BWSC). 2012 Stormwater Modeling Report.

Treating runoff from a 1 inch storm across Neighborhood 1 translates to infiltrating or filtering roughly 34.5 million gallons of water. Using the methodology described, approximately 44 acres of green infrastructure were sited across the neighborhood (Figure 14). This represents enough area to treat runoff from a 1 inch storm or the first inch of a larger storm. As noted, however, the conceptual design at the neighborhood scale does not account for how runoff would be routed to individual treatment systems.

Existing tree canopy cover in Neighborhood 1 was determined to be only 2.7%. The iTree model was run for existing, 15%, and 35% cover; results are presented in Chapter 6.

Multiple site specific designs were developed for the study area and two are presented here.

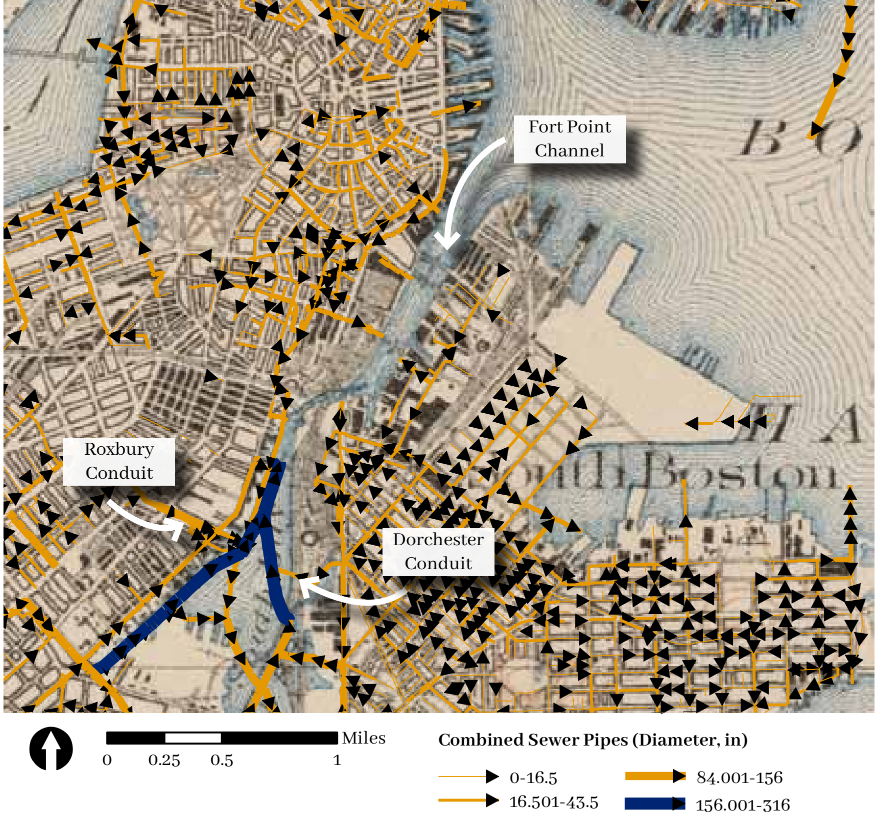

Figure 13. Large Culverts on Site of Historical Canals

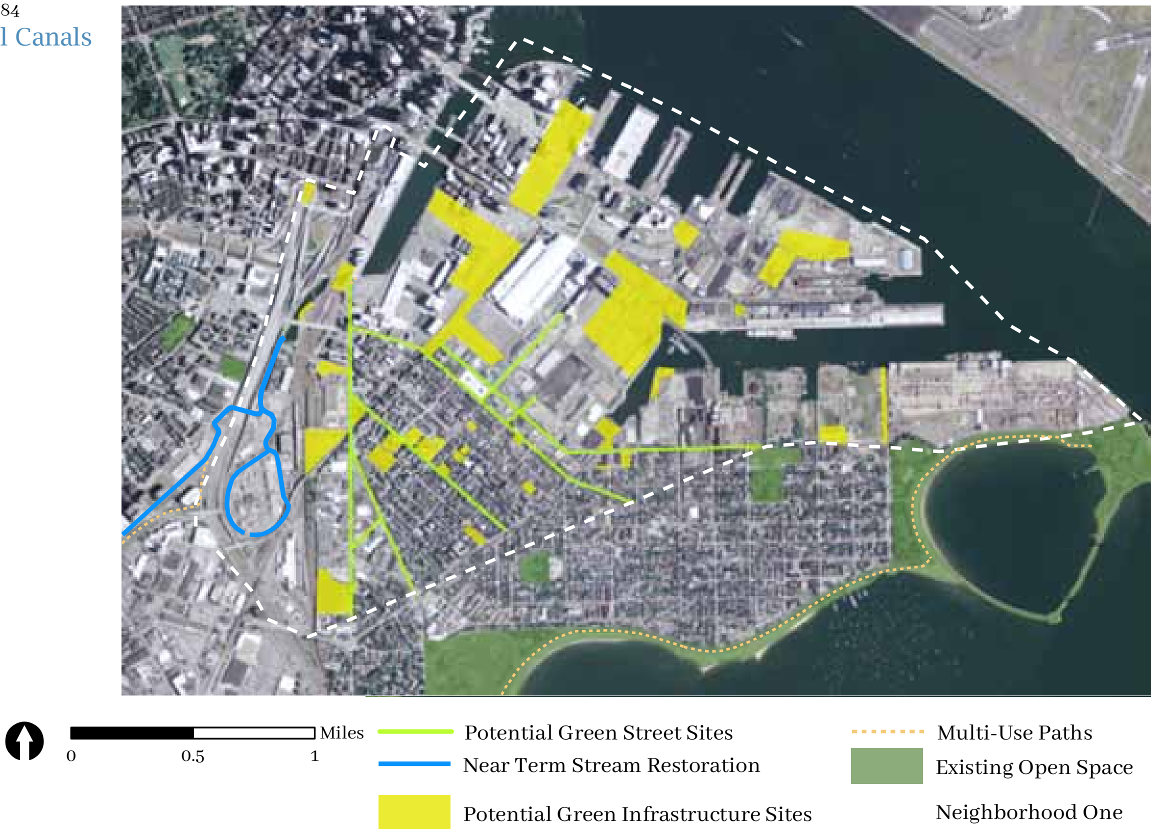

Figure 14. Neighborhood 1 Greening Plan Overview

Figure 15. Site Design: Gillette Parking Lot

100 Acres Area

The area, along the southern and eastern edge of Fort Point Channel has been the subject of numerous planning efforts and was recently the focus of a climate change adaptation competition in the City of Boston (Figure 16). Near and long-term green infrastructure plans were developed with reference to previously produced plans.

The near-term plan focuses on adapting the landscape, based on current uses but incorporating as much green infrastructure as possible. Biofiltration systems and infiltration trenches to treat runoff from a 1 inch storm are incorporated into an existing parking lot (Figure 15). The long-term plan identifies opportunities to alter the area to include more open space and green infrastructure in accordance with previous plans. CRWA sited stormwater wetlands in two areas that are planned as open space in the proposed 100 Acres Master Plan. Wetlands treat 1 inch of runoff which is intercepted from the underground stormwater systems (Figure 17).

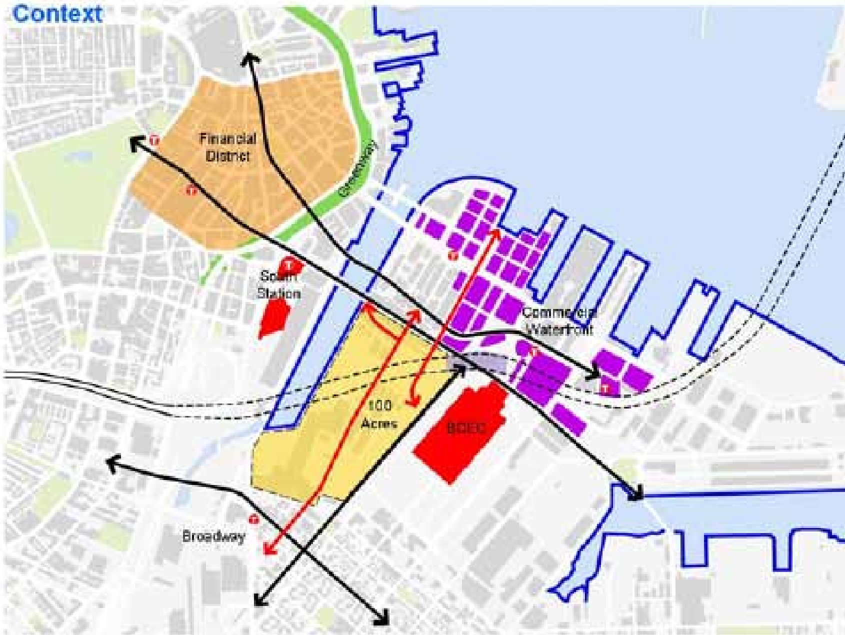

Figure 16. 100 Acres Master Plan Area

Figure 17a. Existing View of Future Open Space Identifed in 100 Acre Plan

Figure 17b. Rendering of 100 Acre Wetland

Figure 18. Neighborhood 1, Near-Term Stream Paths

CWERC District

The preferred CWERC site for Neighborhood 1 is a parking area presently used to store vehicles which have been towed from city streets. The near term proposal is for combined stormwater treatment of overland runoff with effluent discharge in a small constructed stream. Two possible stream paths are shown, streambed locations correspond to the paths of underlying stormwater infrastructure, historic stream and canal footprints, and alongside planned green routes, wherever possible (Figure 18).

Unlike previous designs which were based on a 1 inch storm, this design targets the maximum precipitation for a typical year, which is a 2.5 inch storm (one-year, 24-hour event), to size the stream channel. Streams are designed to treat runoff from the impervious areas within the surrounding watershed and are assumed to be non-tidal under normal conditions, the outlet into Fort Point Channel (which is tidal) is situated above the current mean-high-high-water level. Larger storms will overflow back into the pipe system when near-bankfull conditions occur. No sustained natural baseflow is expected from this watershed, but a baseflow of 0.8 cubic feet-per-second (cfs) (0.5 mgd) will be provided by CWERC 1 effluent (Figure 19).

Figure 19. Rendering of Neighborhood 1 Stream

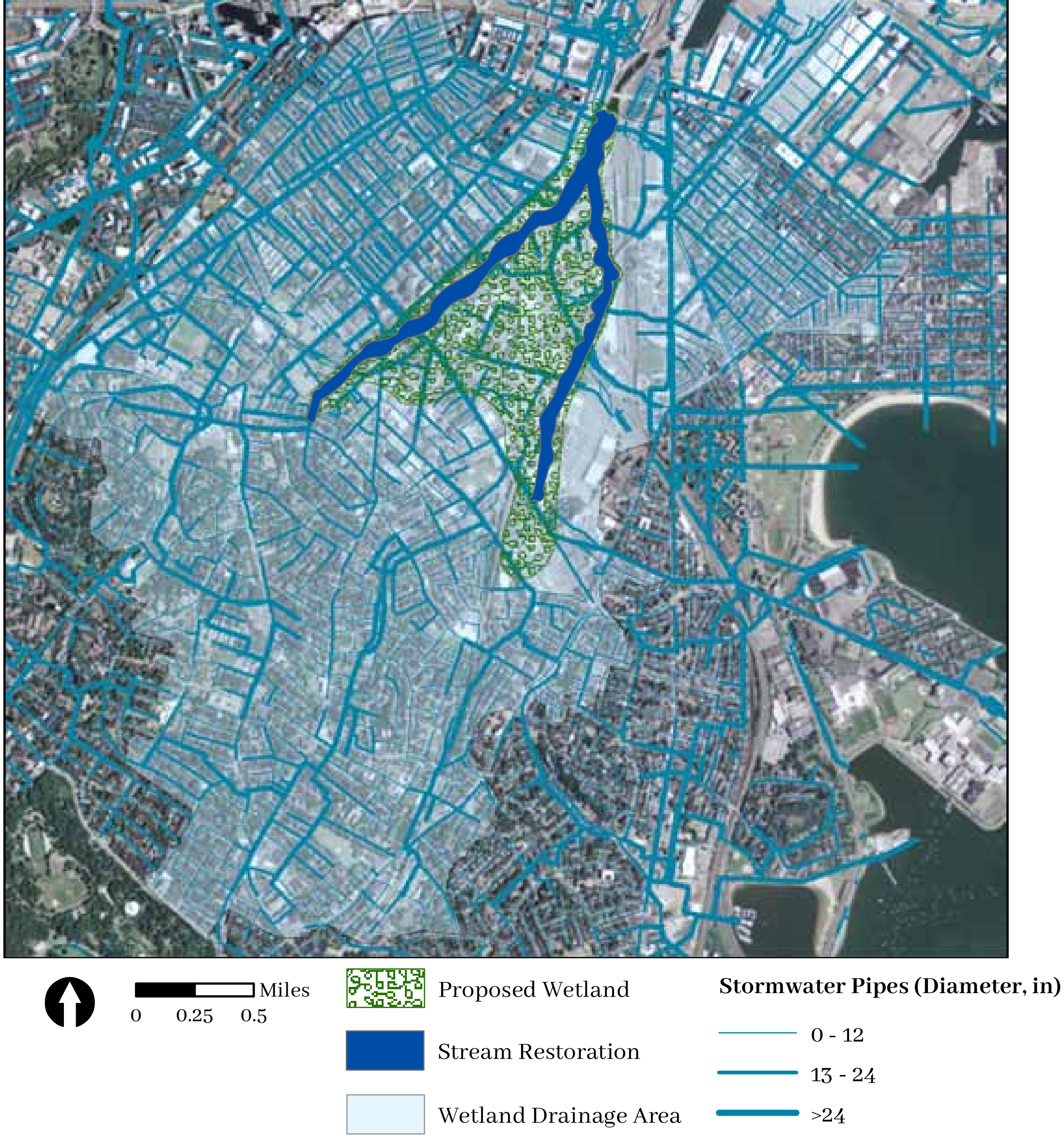

Figure 20. Fort Point Channel Wetland

The long term plan is ambitious and involves significant changes to existing land uses, including retreat of hard structures such as roadways and buildings from an area very susceptible to future flooding. The proposal is for a large wetland surrounding two naturalized stream channels. The proposed Fort Point Channel wetland will provide storage for flooding from stormwater or sea water overlaying much of the historic footprint of the now-filled South Bay (Figure 20). Unsurprisingly, multiple vulnerability assessments have identified this as an area prone to fresh water flooding, storm surge, and sea level rise given its natural history (Figure 21). The plan includes daylighting of existing stormwater culverts which will receive continuous input from one or more CWERC(s) and the creation of a surrounding wetland park or recreational flood plain that can be used extensively for recreational activities during dry weather and be safely submerged during wet weather. This plan assumes sewer separation in all areas contributing to the proposed daylighted streams.

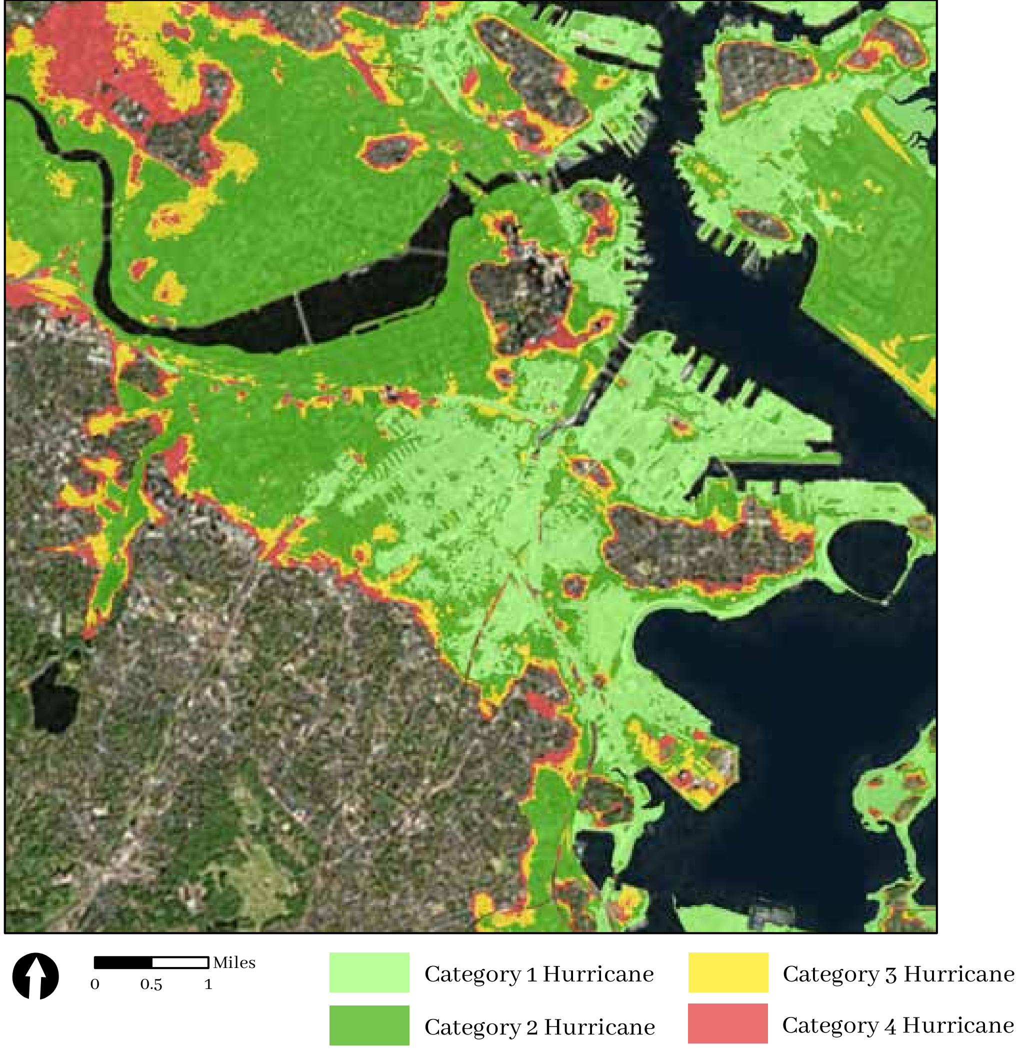

Figure 21. Map of Possible Freshwater Flooding in this Area

Runoff from a 2.5 inch rainstorm was used to determine the depth and width for stream channels. A very large rain event, likely to occur under future climate conditions was used to determine the size of the surrounding overflow wetland area. A 10 inch storm represents a 10% increase above today's 100 year storm, or a storm with a 1% chance of occurring in a given year. This stream is assumed to be tidal with the outlet at the mean-low low-water level. As with many urban streams, natural baseflow is expected to be minimal; to improve stream aesthetics and prevent stagnant water, natural baseflow will be augmented by 1.2 cfs from one or more CWERC(s). The wetland area is designed to detain and release extreme runoff from the watershed even under high tide or coastal surge (high tide plus 1 foot) conditions. This approach is conservative because it allows for a slight increase in sea level from climate change or a small storm surge and does not account for tidal variation during the storm. Under these conditions, a detention storage volume of 900 acre-feet is required, or 300 acres of area with a depth of 3 feet (Figure 20). This system would protect over 1000 acres of the surrounding area from flooding by providing a safe place to store water.

Neighborhood 2

Neighborhood 2 overlays the natural, historical confluence of the Stony Brook, Muddy River, and Charles River tidal estuary (Figure 8). Today, the Charles River has been dammed and is no longer an estuary, and the Stony Brook has been placed in underground culverts. The area is densely developed and home to multiple large university and hospital campuses. The Muddy River and Emerald Necklace Greenway pass through the area, and the Muddy River's historical path has been altered and the system changed from tidal to riverine. In 2016, two small culverted sections of the Muddy River within our study area were daylighted as part of an Army Corps of Engineers flood control project. Treating a 1 inch rainstorm across the study area would require managing roughly 16 million gallons of runoff. In this area, that is not achievable given normal measures. The district -wide greening plan consists of systems that collectively treat an approximately 0.45 inch rainfall event or capture the first 0.45 inches of runoff from a larger rainfall event. Total surface area of these discrete, often small, systems is 14 acres, far less than in Neighborhood 1 due to the lack of available space.

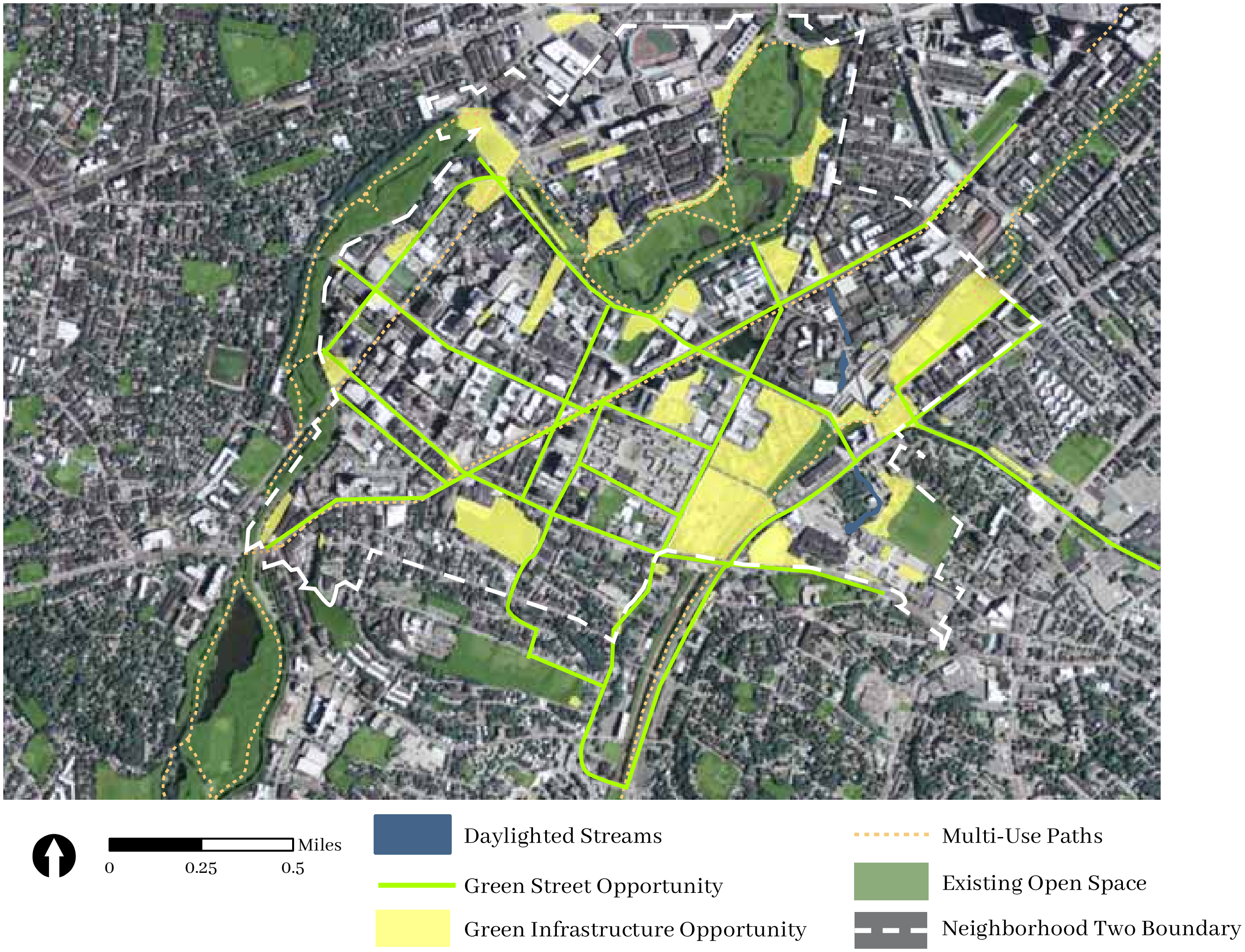

Figure 22. Neighborhood 2 Greening Plan Overview

Table 7. Neighborhood 2 Greening Plan Summary

GI Type	Area (acres)	Max Event Treatment (gallons)	%	Annual Treatment (gallons)
Biofiltration	1.58	1,130,132.22	15.8%	48,219,916
Green Street	5.01	3,594,724.79	50.4%	153,377,916
Infiltration Basin	3.83	1,086,528.90	15.2%	46,359,471
Infiltration Trench	2.90	1,059,539.02	14.8%	45,207,880
Porous Concrete	0.03	18,431.57	0.3%	786,429
Rain Garden	0.67	189,373.57	2.7%	8,080,097
Small Stormwater Wetland	0.03	24,438.86	0.3%	1,042,745
Gravel Wetland	0.03	34,024.32	0.5%	1,451,733
Total	**14.10**	**7,137,193.30**		**304,526,186**

Existing tree canopy cover in Neighborhood 2 was determined to be 15%, significantly higher than Neighborhood 1. The iTree model was run for existing cover, 25%, and 35% cover. Results are presented in Chapter 6.

Five detailed conceptual designs were developed for study area 2 and two are presented here.

Tremont Crossing CWERC District

In Neighborhood 2, more than one suitable site was identified for CWERC siting based primarily on available space and access to sewage. The largest of the possible sites, a property known as Tremont Crossing, offers a unique opportunity to recreate a connection between the Stony Brook and Muddy River. The proposed design is for a constructed stream to carry plant effluent in a naturalized channel from the CWERC to the Muddy River (Figure 23). While the path of the constructed stream does not follow the historical path of the Stony Brook exactly, it mimics the confluence of these two streams meeting before discharging to the Charles (Figure 24). This design is a minimalist approach that could be implemented under current land use conditions. The stream channel is sized based on a 2.5 inch rainstorm. The maximum stream width is 20 feet (about half of a large roadway); the stream would be able to manage runoff from a watershed area of about 124 acres (Figure 23), protecting it from recurring stormwater flooding. Natural groundwater levels are deep and no sustained baseflow is expected from the watershed, so a baseflow of 1.5 cfs is supplied by the CWERC. The location of the stream coincides with the underlying drainage network and, where possible, also follows alongside planned green routes or connects existing open spaces. This design does not include any detention area for larger storms but will be designed to overflow back into the pipe system when bankfull conditions occur.

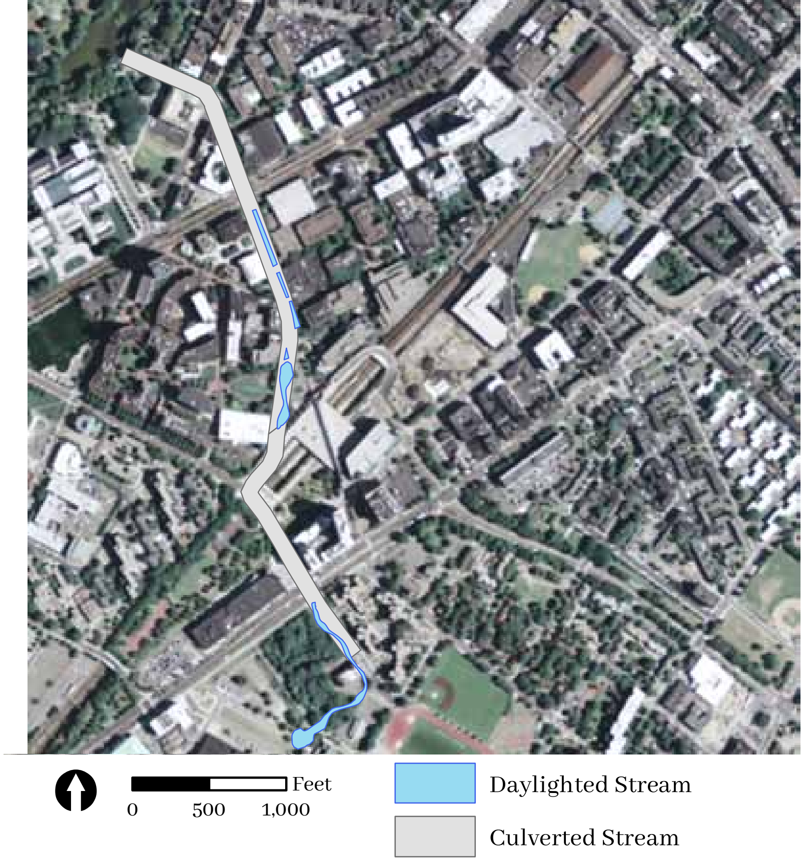

Figure 23. CWERC 2 Stream Channel

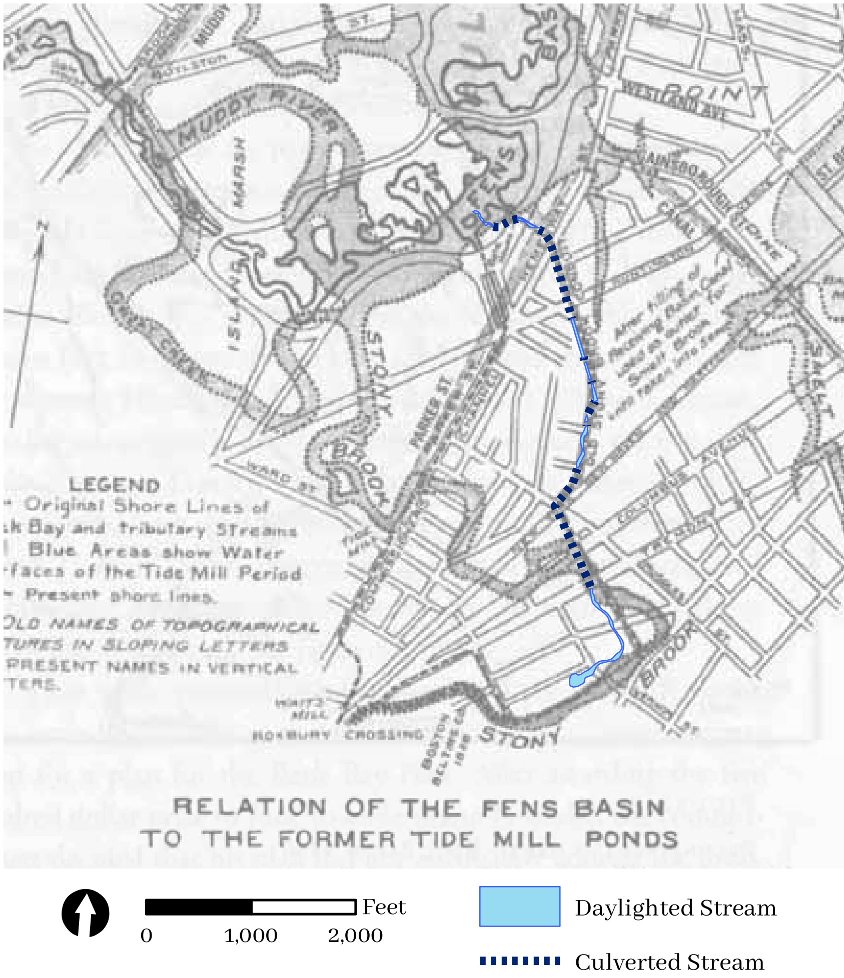

Figure 24. CWERC 2 Stream Design with Historic Stony Overlay

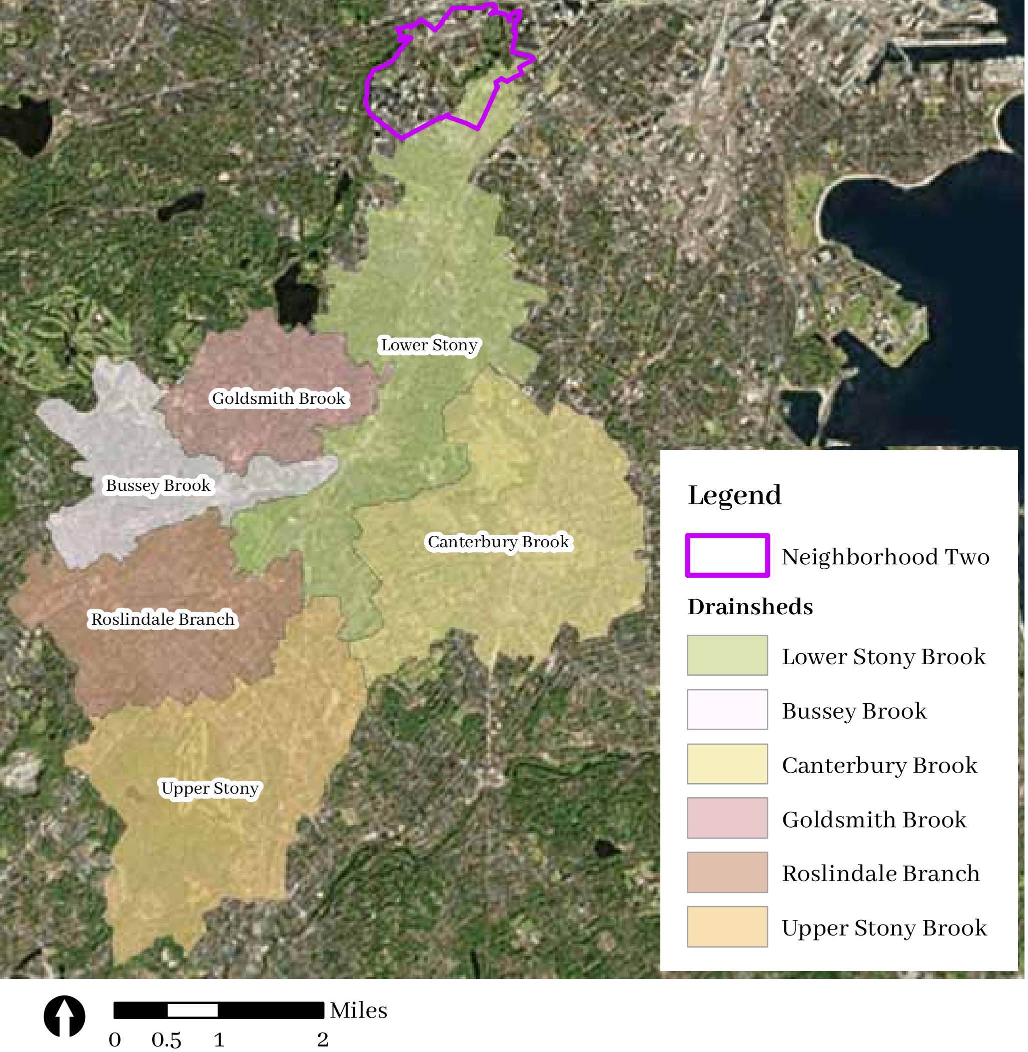

Figure 25. Map of Drainsheds and Neighborhood 2

Due to the constrained nature of the neighborhood, having maximized possible treatment within the boundaries of our study area and only achieved control of a 0.45 inch rain event, we expanded our focus to the watershed level to identify upstream control opportunities which would improve downstream conditions. Additionally, moving outside this dense urban neighborhood allowed us to explore opportunities to employ existing green spaces for stormwater control, while maintaining or improving their current functions and values. This also allows us to focus on controlling large or extreme rain events, well beyond 1-2 inches in size.

Looking at the larger stormwater pipe network reveals numerous, connected "tributary" drainage areas (Figure 25). Of these, we focused on the Upper Stony, Canterbury, Bussey and Goldsmith Brooks. In each of these drainsheds, one or more stormwater wetlands is proposed to treat runoff from large rain events. Many of the proposed designs involve mining/intercepting stormwater runoff from the underground drainage system and are sited accordingly.

Table 8. Neighborhood 2 Large Wetland Systems

Stormwater Wetland	Drainage Area(s) Treated	Design Storm[+]	Wetland Area (acres)
Goldsmith	Goldsmith Brook	10 inches (100 year +10%)	32
Bussey West	Bussey Brook	10 inches (100 year +10%)	51
Bussey East	Bussey Brook/Upper Stony	5.5 inches (10 year +10%)	22
Canterbury North	Canterbury Brook	>10 inches (100 year +10%)	49
Canterbury South	Canterbury Brook	10 inches (100 year +10%)	101
Upper Stony Large	Upper Stony	5.5 inches (10 year +10%)	34
Upper Stony Small	Upper Stony	5.5 inches (10 year +10%)	8

[+] Northeast Regional Climate Center (NRCC). Extreme precipitation in New York and New England.

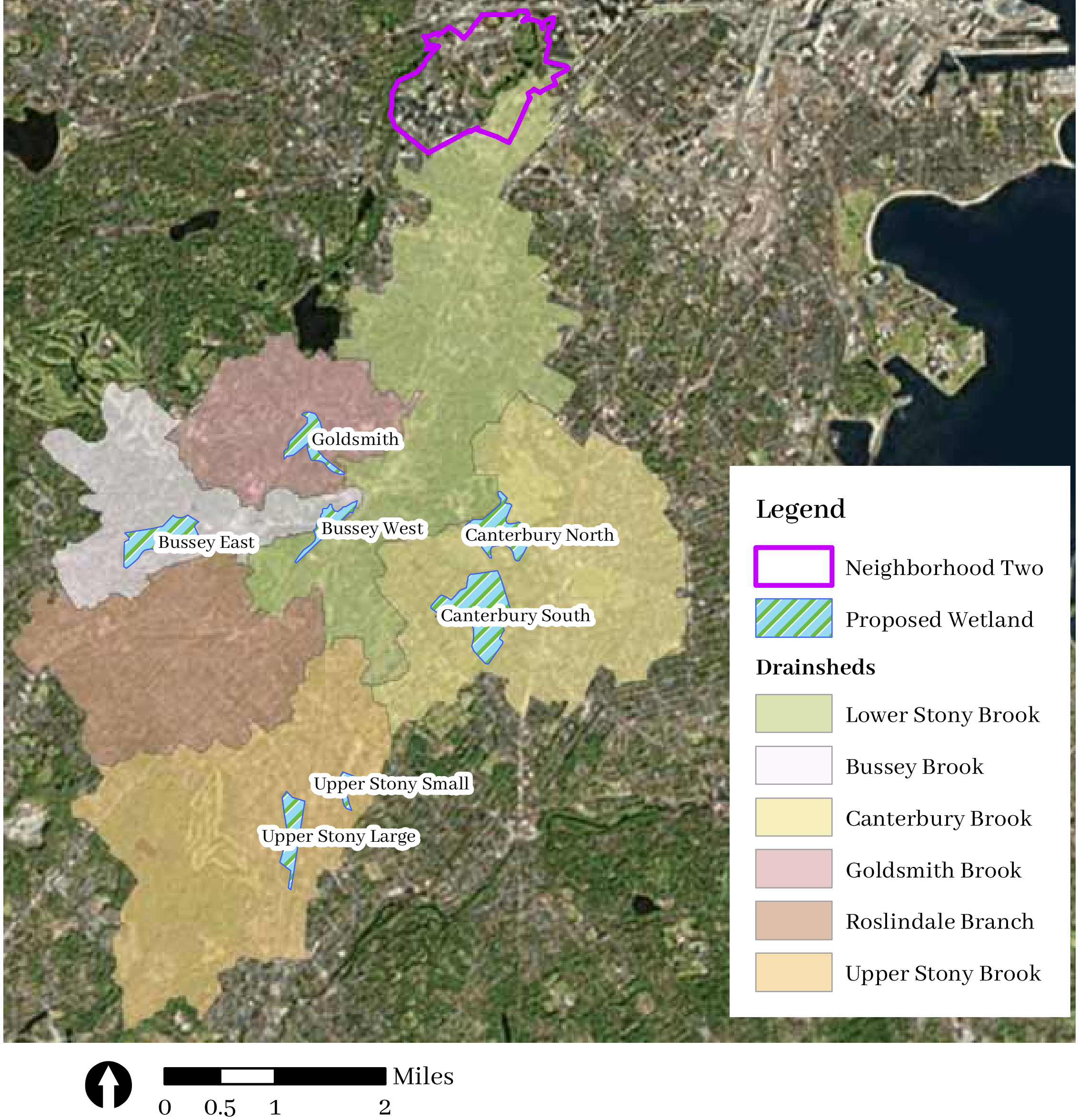

Figure 26. Map of Wetland Sites

One stormwater wetland is proposed for Goldsmith Brook, which would treat runoff from up to a 10 inch rain event from roughly three-quarters of the drainshed, preventing flooding and storm system backups over the entire area. The remaining drainsheds have two wetlands proposed per drainage area. The Bussey East wetland accommodates runoff from both the Bussey and Upper Stony drainsheds due to its proposed site adjacent to the Stony Brook drain and the availability of open space beyond that required to treat runoff from the immediate area. A second wetland is designed in the Bussey to treat up to a 10 inch storm from the remaining area of that drainshed. The remaining runoff from the Upper Stony drainshed is treated in two systems totaling about 42 acres which will manage the 5.5 inch rain events. Two wetlands are proposed in the Canterbury drainshed which treat runoff from up to a 10 inch storm from over 80% of the drainage area (Figure 26).

These large systems in the upstream region of the drainage network protect surrounding area while also helping to alleviate downstream flooding and combined sewer overflow issues. They also improve water quality and provide educational opportunities and urban wildlife habitat. Large systems alone, however, will not solve our water quality challenges. Runoff from dense urban areas, where large systems are not feasible, must also be treated, even at relatively small volumes (0.4 to 1 inch design storms) prior to discharge into local waterways. Using these two techniques together can address both water quality and water quantity goals.

CHAPTER 6: PILOT SITE ECONOMIC ANALYSIS

The economic benefits of centralized wastewater treatment are well established. Collecting sewage and treating it at a large, regional plant exploits economies of scale, making it possible to treat wastewater at a relatively low unit cost. A critical component of this study was to examine how distributed treatment could achieve wastewater treatment objectives while also producing valuable by-products (e.g., energy and non-potable water) and restoring the natural water cycle in urban environments. By fully recognizing the economic value of resource recovery and environmental restoration, this economic analysis provides a more informed comparison of the *Water Infrastructure for a Sustainable Future* approach with traditional approaches.

METHODS

The team performed a welfare economic analysis which examines changes in the aggregate well-being of individuals to measure the collective social utility associated with a policy change or other action. These are primarily social welfare gains and losses occurring outside of traditional markets. Social welfare economic benefits are analyzed at both the Neighborhood scale, for CWERCs 1 and 2 and the respective greening plans, as well as at the regional scale of distributed treatment implemented across a broader geographic area in greater Boston. The study area for the broad scale implementation is the 43 communities across greater Boston that currently discharge to DITP. Broad scale implementation is discussed in **Chapter 7**.

The economic benefits of distributed treatment, resource recovery, and green infrastructure are complex and highly diverse. The team did not perform an in-depth analysis of any one topic; instead the comparative economic significance of many different environmental and energy-related outcomes were explored applying a broad screening approach. This simplified approach incorporates readily available data to provide a survey of the multifaceted implications of distributed treatment.

Economists have developed a variety of analytic techniques for measuring non-market impacts. These include methods that gauge individuals' willingness-to-pay (WTP) for various outcomes through indirect market signals (e.g., travel cost models to value recreational resources) as well as survey-based methods that rely principally on eliciting subjective assessments from people. Using established analytical techniques, three categories of benefits are examined here:

- Energy Benefits: economic value estimates for net energy creation and energy efficiency

- Emissions Reduction Benefits: focusing primarily on greenhouse gas emissions but also addressing criteria pollutant emissions, available estimates of air pollution social costs are used to characterize the economic value of reduced emissions

- Green Infrastructure Benefits: recreation potential, property value enhancement, wetland services, and other ecosystem services provided by green installations (e.g., carbon sequestration)

Energy Benefits

To assess the net energy benefits of the *Water Infrastructure for a Sustainable Future* approach, the team completed a full accounting of the major changes directly influenced by CWERC operations and the associated green infrastructure. Figure 27 summarizes the primary changes in energy use and production:

- Food waste used in co-digestion will be transported more efficiently due to the siting of CWERCs in urban areas where waste is primarily produced, reducing fuel use relative to baseline patterns. Transportation mileage to urban CWERCs was compared to transportation to existing or potential food waste management sites around the state. Diesel fuel use for various scenarios are compared and valued at $3.53/gallon pre-tax.[16]

- Through co-digestion and thermal heat recovery, CWERCs produce both heat and electrical power, replacing conventional energy sources. Wastewater flows are slightly reduced at DITP, resulting in further reductions in bulk electrical power use. However, these benefits are partially offset by reduced power recovery at the plant. The avoided cost of supplying thermal energy through conventional means is valued at the wholesale price of natural gas of $7.64/MCF;[17] avoided cost for electricity generation is valued at the wholesale electric price for the region, $0.076/kWh.[18] A wholesale price (in comparison to retail prices) is reflective of the social cost of extracting and delivering the natural gas. Additionally, there will be less transmission loss from energy produced in an urban setting close to energy users, therefore thermal energy values are increased by 15% and electric values by 5.5% based on the amount of natural gas/electricity needed to generate an equivalent amount produced locally at the CWERC. We did not take into account the relative efficiency of CHP systems which produce energy far more efficiently than traditional systems, and therefore results are likely an underestimate of the value of energy recovery at the CWERCs.

- CWERCs expand energy capacity; the New England ISO sells capacity credits in annual Forward Capacity Market (FCM) auctions where providers submit bids to supply capacity three years in advance. Capacity increase as valued at the auction clearing price was $3.21/kW-month in ISO New England's auction covering the 2014/2015 commitment period. This is a market based value, not a social welfare value.

- Trees and other GI elements provide shading in the summer, reducing electricity used for air conditioning, and a windbreak in the winter, reducing use of natural gas or other heating fuels. The iTree model, developed by the U.S. Forest Service, was used to assess energy benefits. iTree was applied to existing canopy cover in each neighborhood and two increased canopy cover scenarios including the City of Boston's target canopy cover of 35%. Results for a modest increase in scenarios are presented. The results reflect the benefits from the increase in canopy cover, relative to the existing baseline. This equates to an increase from roughly 3% to 15% canopy cover in Neighborhood 1, and 15% to 25% canopy cover in Neighborhood 2.

Emissions Reduction Benefits

Several of the energy benefits identified also have implications for emissions of greenhouse gases (GHGs) and other air pollutants. The economic benefits associated with emissions reduction are characterized in the following ways:

- GHG emissions will be reduced due to food waste hauling efficiencies. CO_2 emissions reductions are calculated based on the amount of vehicle miles saved and valued using the Social Cost of Carbon (SCC), produced by the Interagency Working Group on the SCC. In the lower bound, this analysis applies a social cost factor of $12.27 per metric ton of CO_2; in the upper bound, we use a social cost factor of $63.58 per metric ton.[19]

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[16] EIA, New England Gasoline and Diesel Retail Prices, 2014 average, net of taxes

[17] EIA, Massachusetts Natural Gas Prices (data series); 2014 average MA Citygate price

[18] The average NEPOOL wholesale price for 2014; reported by EIA, "Wholesale Electricity and Natural Gas Market," http://www.eia.gov/electricity/wholesale/

[19] The figures are adjusted from 2007 dollars to 2014 dollars using the Gross Domestic Product Implicit Price Deflator, as reported in Table B-3 of the 2015 Economic Report of the President. It is noteworthy that the Working Group has established higher cost factors for future periods (when the marginal cost of carbon emissions is expected to be greater); hence, applying the 2015 figures may understate long-run CO_2 emissions reduction benefits.

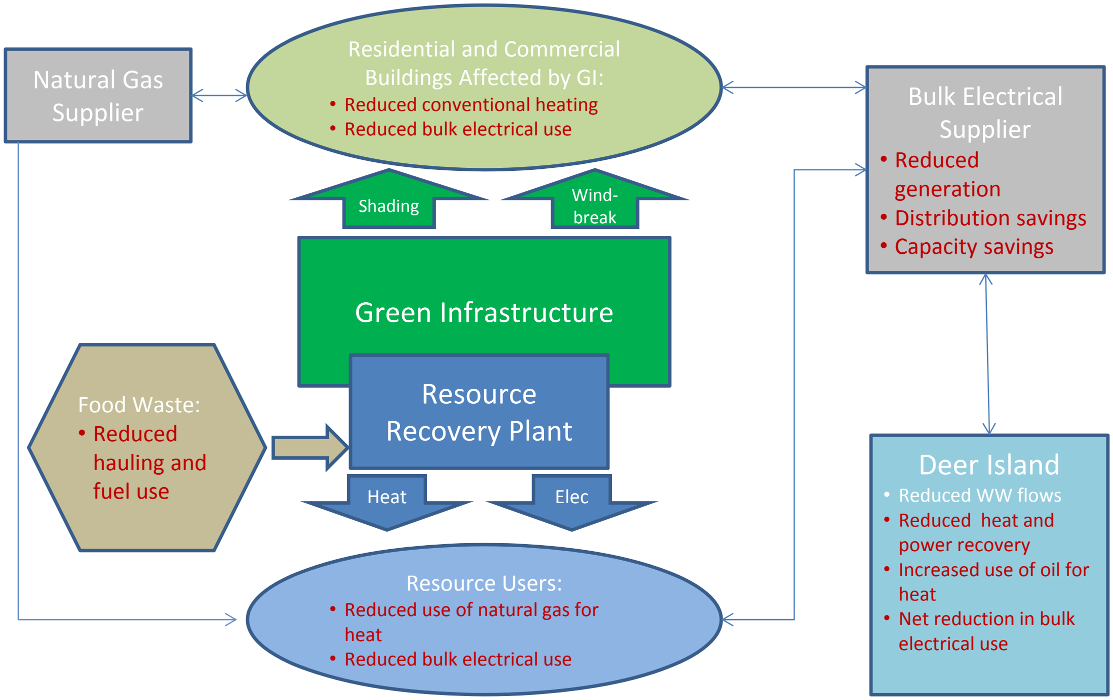

Figure 27. Energy Production and Efficiency Benefits

- Reduced emissions will also result from bulk electricity generator offsets. In addition to GHG emissions from bulk power sources, we also consider reductions in criteria pollutants (sulfur dioxide, nitrogen oxides, and particulate matter) commonly associated with fossil fuel combustion. For electricity generation the social cost for each unit of CO$_2$ released is valued by the prevailing allowance price in the Regional Greenhouse Gas Initiative (RGGI), rather than using the SCC. RGGI is a market-based regulatory program that permits power producers in nine northeast states to trade CO$_2$ emissions allowances. A marginal reduction in power production at one supplier would not result in an overall emissions reduction because the affected supplier could sell allowances to another producer under the trading program. The lower bound value is based on a March 2015 auction resulting in a clearing price of $5.41 per short ton of CO$_2$; for the upper bound, the figure is doubled to $10.82 per ton, reflecting the likely increase in allowance prices as the CO$_2$ cap is lowered. The economic benefits of reducing criteria pollutant emissions (SO$_2$, NO, and PM$_{2.5}$) are based on cost factors estimated for the Environmental Protection Agency's Clean Power Plan. The figures reflect the health benefits, per ton reduction of each pollutant, as determined in multiple epidemiology studies.

- Reduced heating fuel combustion will also reduce emissions. Valued by applying the SCC to the reduction in heating-related CO$_2$ emissions.

- CWERCs effect emissions at DITP because of the reduction in wastewater flows. Although DITP will likely need to purchase less electricity due to reduced flows, the plant may also experience a decrease in the energy generated by the current on site CHP system. This CO$_2$ increase is valued using the SCC as decreased on site energy production would be replaced with heating oil.

Green Infrastructure Benefits

As described in Chapter 5, CRWA developed greening plans to restore environmental function to our urban study area districts. Greening plans were developed to manage target stormwater runoff volumes, but there are additional, well-documented, secondary benefits of green infrastructure systems. This analysis characterizes economic benefits associated with various ecosystem services of GI, including both the stormwater and dry weather benefits accrued at multiple scales, from the neighborhood scale of increased property values to the global scale of greenhouse gas sequestration. Green infrastructure benefits are characterized in the following ways:

- Property Values. This analysis assesses the property value impacts of neighborhood-wide greening, through the development of the proposed green streets and small- to medium-size GI installations, and newly created green open spaces, through the development of larger GI systems. We follow the Center for Neighborhood Technology's recommendation that the property value impacts of large GI installations be assessed using literature on park value, whereas the property value impacts of smaller GI installations be assessed using literature on the value of new tree plantings or private gardens.[20] Because the literature on willingness-to-pay (WTP) is more robust for residential properties in comparison to commercial and other types of properties, this analysis is limited to residential properties. In areas of mixed residential and commercial development, only half the value is included. Integrating the findings from this research, we adopt 2% and 4% as the lower and upper bounds, respectively, for the residential property value impacts of neighborhood-wide greening.[21] To characterize the baseline residential property values for the study area, we sum the total assessed value of all residential buildings in the zip codes that overlap our study areas.

- Wetland Services. Extensive literature exists on wetlands valuation. Wetlands provide services to the surrounding areas, including flood control, groundwater recharge, water quality improvement, and property value enhancement. These benefits are valued using benefit transfer applications of the findings of two meta-analysis wetland valuation studies.[22] Values for flood control, groundwater recharge, water quality improvement, and property value enhancement (amenity value) are calculated based on site-specific design elements of proposed wetland opportunities, large and small, identified in the greening plans (see Chapter 5).

- Stream Daylighting. "Daylighting" a stream means bringing it out of an underground pipe or culvert into an above-ground stream channel. Daylighting improves ecological function and neighborhood livability. Similar to the wetland services these benefits are valued using a benefits transfer approach, based on two studies, one conducted in Baltimore on WTP for the aesthetic and recreational benefits of a daylighted stream and a second which uses a hedonic model showing how stream services, namely flood control, influence residential property values.[23] Benefits are determined based on the length of the stream daylight design for Neighborhood 2. This analysis is not performed on the small constructed streams proposed for Neighborhood 1.

- Stormwater Management. GI systems provide value by reducing or eliminating a need for conventional, gray stormwater infrastructure. Potential benefits are valued using a range of $0.005 to $0.01 per gallon of stormwater treated by the proposed green infrastructure based on past work by CRWA, the Trust for Public Land, and the U.S. Forest Service iTree model. Annual stormwater treatment volumes were calculated based on local rainfall conditions and conceptual treatment system design sizes.

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[20] Wise, S., et al., "Integrating Valuation Methods to Recognize Green Infrastructure's Multiple Benefits," Center for Neighborhood Technology, April 2010, accessed online at http://www.cnt.org/sites/default/files/publications/CNT_CNTLIDpaper.pdf, page 13.

[21] Ward, Bryce, Ed MacMullan, and Sarah Reich, "Effect of Low-Impact Development on Property Values," Sustainability 2008, pages 318-323; Netusil, Noelwah, et al., "Valuing Green Infrastructure in Portland, Oregon," Landscape and Urban Planning 124 (2011), pages 14-21; Been, Vicki, and Ioan Voicu, "The Effect of Community Gardens on Neighboring Property Values," New York University Law and Economics Working Papers (2006); and Wachter, Susan, and Grace Wong, "What is a Tree Worth? Green-City Strategies, Signaling, and Housing Prices," Real Estate Economics 36 (2008), pages 213-239.

[22] Brander, L.M., R.J.G.M. Florax, and J.E. Vermaat, "The Empirics of Wetland Valuation: A Comprehensive Summary and a Meta-Analysis of the Literature" Environmental & Resource Economics 33 (2006), pages 223-250; and Ghermandi, A., J.C.J.M. van den Bergh, L.M. Brander, H.L.F. de Groot, and P.A.L.D. Nunes, "Values of Natural and Human-Made Wetlands: A Meta-Analysis" Water Resources Research 46 (2010), W12516.

[23] Kenney, et al. (2012); Loomis and Steiner (1995)

- Carbon Sequestration and Other Air Quality Benefits. Air quality benefits from an increase in tree canopy cover are calculated using the iTree model which values SO_2 deposition and net CO_2 sequestration (accounting for both CO_2 sequestration and CO_2 decomposition release). Biofiltration and planted infiltration systems will also provide air quality benefits, these are valued using pollutant uptake data for green roofs based on studies conducted in similar climates. The analysis of biofiltration and planted infiltration systems does not account for CO_2 released during vegetation decomposition, so results may overestimate the net air quality improvements resulting from these systems. In both scenarios, values for pollution uptake are from the SCC and the criteria pollutant cost factors in EPA's Clean Power Plan.

- Recreation. This benefit is only calculated for the large scale Fort Point Channel wetland described in the long-term GI plan for Neighborhood 1, although other smaller proposed wetlands may also offer recreational opportunities. We utilize the unit day value method which applies average values per unit of recreational use to the level of recreational activity, producing an aggregate estimate of consumer surplus (the difference between the consumer's WTP for recreational opportunities and the amount actually paid in travel costs, entrance fees, and other costs). The average value per unit of use is derived from existing empirical studies.[24] Average annual visitation is estimated from visitation from a nearby urban wetland. We assume that half the visitors would be new to the park and half would be visitors drawn from other nearby parks. For the visitors simply drawn away from other nearby parks, the estimated unit day value is adjusted downward to only account for the difference between the aggregate consumer surplus gained from the new site and that already gained from existing sites. The analysis focuses on the value of general recreational activities.

RESULTS

Energy Benefits

Table 10 summarizes the potential savings associated with food waste management at CWERC 1 relative to three other baseline or possible scenarios. The savings are a direct function of the relative distances of the management facilities from the food waste generators. Annual savings are greatest when CWERC 1 is considered relative to the existing anaerobic digestion facility in Rutland, MA. Savings are least when considered relative to co-digestion at DITP (transported via a Charlestown processing facility), although this facility does not exist currently and future plans are uncertain. Very similar results were observed for the Neighborhood 2 CWERC food waste transport analysis. Tables 11 and 12 summarizes the complete results for energy benefit valuations for both CWERCs. Energy benefits range from roughly $1.15 to $1.6 million annually. The largest portion of the value is generated by recovered thermal energy, reducing the need to burn natural gas or heating fuel.

Emissions Reduction Benefits

Table 13 summarizes and aggregates the estimated emissions reductions and associated economic benefits calculated for CWERC 1 and the Neighborhood 1 greening plan. The net economic benefits of CO_2 emissions reduction are between $95,000 and $455,000 per year. The economic benefits of reducing criteria pollutants at bulk electrical facilities adds significantly to the estimated benefits, yielding an overall annual benefit estimate of $272,809 to $898,475. At CWERC 2 the benefit values are similar with estimates for CO_2 emissions and criteria pollutant reduction values ranging from $185,773 to $800,695 annually, and CO_2 emissions reductions totaling 24 million pounds a year.

Table 9. Pilot Neighborhood Results

	Neighborhood 1	Neighborhood 2
CWERC Capacity	2 mgd	3 mgd
Annual Electricity Production	7,480 MWh/yr	5,295 MWh/yr
Annual Thermal Energy Production (Wastewater Extraction and CHP)	117,205 MMBtu	155,100 MMBtu
GI Average	44 acres	14.1 acres

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[24] U.S. Army Corps of Engineers, "Unit Day Values for Recreation, Fiscal Year 2014," accessed online at http://planning.usace.army.mil/toolbox/library/EGMs/EGM14-03.pdf.

Table 10. Annual Benefits of Reduced Food Waste Hauling, CWERC 1 Relative to other Scenarios

		BASELINE SCENARIOS		
Parameter	Scenario 1: CWERC 1	Scenario 2: Nearest Anaerobic Digester	Scenario 3: Nearest Compost Facility	Scenario 4: DITP Co-Digestion (Trucking)
Facility name	CWERC 1	New England Organics, Jordan Farm	Rocky Hill Farm	DITP
Facility location	Boston, MA	Rutland, MA	Saugus, MA	Charlestown, MA
Reduction in total miles traveled per year		271,443	55,597	4,672
Annual fuel cost savings		$191,259	$39,174	$3,292

Table 11. Summary of Energy Benefits from CWERC 1

Energy Type	Contributing Source	Estimated Annual Benefit – Lower Bound	Estimated Annual Benefit – Upper Bound
Diesel Fuel	Waste Hauling Efficiency	$3,292	$191,259
Natural Gas	Net Heat Production at CWERC 1	$777,749	$777,749
	Heat Savings from GI	$120,264	$120,264
	Heat Production Loss at DITP	-$82,192	-$82,192
Electricity	Net Electrical Generation at CWERC 1	$290,212	$290,212
	Electricity Savings from GI	$35,573	$35,573
	Capacity Cost Savings	$16,173	$16,173
	Electrical Generation Loss at DITP	-$11,012	-$11,012
Net Value of Annual Energy Generation and Savings		**$1,150,058**	**$1,338,025**

Table 12. Summary of Energy Benefits from CWERC 2

Energy Type	Contributing Source	Estimated Annual Benefit – Lower Bound	Estimated Annual Benefit – Upper Bound
Diesel Fuel	Waste Hauling Efficiency	$3,777	$132,433
Natural Gas	Net Heat Production at CWERC2	$1,325,592	$1,325,592
	Heat Savings from GI	$98,502	$197,003
	Heat Production Loss at DITP	-$123,288	-$123,288
Electricity	Net Electrical Generation at CWERC2	$29,745	$29,745
	Electricity Savings from GI	$27,413	$54,827
	Capacity Cost Savings	$862	$862
	Electrical Generation Loss at DITP	-$16,519	-$16,519
Net Value of Annual Energy Generation and Savings		**$1,346,084**	**$1,600,655**

Although thorough, this analysis is likely an underestimate of economic benefits of emissions reductions for the following reasons:

- Reduced waste hauling and gas heating may yield additional reductions in criteria pollutant emissions not quantified here
- Green infrastructure may retain stormwater and reduce DITP treatment flows to a degree greater than assumed in the analysis
- Diverting food waste from composting to anaerobic digestion may yield a decrease in GHG emissions because of relative differences in the emissions rates associated with the two waste management methods

It is also noteworthy that the estimated GHG emissions reductions would contribute to meeting the Commonwealth's goals under the Massachusetts Global Warming Solutions Act, a statewide plan to reduce GHG emissions 5% by 2020 and 80% by 2050 below 1990 baseline levels.[25]

Green Infrastructure Benefits

Welfare valuations are based on site specific greening designs for the study area neighborhoods described in Chapter 5. Table 14 summarizes residential property value impacts based on full implementation of the Neighborhood 1 greening plan. In Neighborhood 2, residential property value increase estimates range from $21 to $42 million, as the baseline for this neighborhood was much lower at $1.1 billion.

Green infrastructure benefits vary by system type. Wetlands, specifically the large scale Fort Point Channel wetland in Neighborhood 1, provide some benefits not realized by smaller systems, namely the ability to provide recreational opportunities. Table 15 displays the recreational benefits quantified for the Fort Point Channel wetland. This valuation category was unique to this system.

The full potential benefits, including property values, recreation, air quality, avoided stormwater costs and wetland services are summarized in Table 16 for the proposed Neighborhood 1 Greening Plan; Neighborhood 2 Greening Plan benefits are presented in Table 18. These benefits cannot be readily aggregated because there is considerable overlap between different categories. For example, property values serve as a market signal for many different amenities in the surrounding neighborhood such as recreational opportunities, reduced need for building heating and cooling, and air quality improvements. Therefore annual benefits for which overlap is minimal are summed up, while the remaining benefit estimates are listed separately.

Values for the greening plans range from about $10 to $29 million. In the Neighborhood 1 greening plan the largest benefits (recreation and avoided stormwater infrastructure costs) are dominated by the Fort Point Channel wetland park. This feature is part of the long term plan which may prove more necessary and more viable as a climate adaptation strategy in the coming century as Boston faces a significant threat from sea level rise and stormwater flooding. As a result, the benefit streams associated with the wetland park are likely to be realized over a different time horizon than the rest of the plan. In Neighborhood 2, avoided stormwater management costs are the largest factor and the lion's share of those values are attributable to the large wetland system designed "upstream" of the Neighborhood 2 boundary.

The GI installations are also likely to provide additional benefits that are not quantified here, including public health benefits associated with the reduced urban heat island effect, improved or newly created wildlife habitats, improved community cohesion, and other cultural and educational benefits.

Total Benefits

Benefits of this concept are extensive and diverse in nature. This diversity means that when characterizing total benefits both quantitative estimates and qualitative findings must be carefully integrated to avoid double-counting and other analytic distortions. Table 17 summarizes benefits for Neighborhood 1 (CWERC and greening plan). Benefits are broken down by those with and without overlap. The benefits associated with the Fort Point Channel wetland, which is part of the long-term greening plan are separated out as these likely have a different timeline for realization. Additive benefits, excluding the large scale wetland, total $6,435,711 to $12,281,565; the wetland benefits add

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[25] Massachusetts Executive Office of Energy and Environmental Affairs; http://www.mass.gov/eea/air-water-climate-change/climate-change/massachusetts-global-warming-solutions-act/

$9,274,323 to $20,490,228. Adding the previous sum renders a total benefit for the large scale wetland ranging from $15,710,034 to $32,771,793.

Neighborhood 2 benefits are summarized in Table 18. The total for additive benefits ranges from $20,354,537 to $46,910,249. This includes benefits from the large-scale, long-term wetlands as well as the very large benefits of avoided cost of repairing wood pilings resulting from damage due to low groundwater levels.

Groundwater Recharge Benefits

As described in Chapter 5, Boston's unique history of landfilling and large stock of historical buildings combine to form a unique challenge for property owners in certain sections of the city. Low groundwater levels can leave historic wood support pilings exposed to the air and therefore subject to rot. There are robust requirements for rainwater infiltration in these areas, but this is not always enough to remediate the problem, especially during periods of dry weather or drought. Presently, certain properties augment groundwater using potable water, which is a waste of money, energy and potable quality water (especially in a drought). If, alternatively, reuse water from a CWERC were to be used for the purpose of replenishing groundwater to maintain a steady water table level the cost would be lower and the value of avoided building renovations would be enormous. Our team estimated this value by determining an approximate volume of water necessary to raise groundwater levels sufficiently in two 50-acre areas within the Groundwater Conservation Overlay District (GCOD). We determined a sufficient volume of water could easily be supplied from reuse water produced by a single CWERC. Based on estimated underpinning costs and building perimeters within the two 50 acre focus areas, we determined the annualized value of avoided piling repairs range from $2 to $15 million per 50 acre area, or $29 to $198 million for the entire GCOD.

Table 13. Summary of Emissions Reductions and Economic Benefits at CWERC1

Pollutant	Contributing Change	Annual Emissions Reduction (Pounds)	Annual Economic Benefit	
			Lower	Upper
CO_2	Food Waste Transport Efficiency (assumes CWERC1 relative to nearest anaerobic digester)	1,216,066	$6,768	$35,072
	Reduced Bulk Electrical Generation (CWERC1 production, GI, DITP demand)	4,298,317	$11,627	$23,254
	Reduced Conventional Heating (CWERC1 production and GI)	14,487,769	$80,635	$417,837
	Increased DITP Emissions Due to Flow Reduction (oil for heat)	(731,845)	-$4,073	-$21,107
	SUBTOTAL	19,270,307	$94,957	$455,056
NO_x	Reduced Bulk Electrical Generation	2,925	$9,222	$23,055
SO_2	Reduced Bulk Electrical Generation	7,250	$137,163	$342,906
$PM_{2.5}$	Reduced Bulk Electrical Generation	461	$31,467	$77,457
	SUBTOTAL		$177,852	$443,419
Total Annual Economic Benefits of Emissions Reduction			**$272,809**	**$898,475**

Table 14. Residential Property Value Impacts of Neighborhood 1 District Greening Plan (2014$)

Baseline Residential Property Values	Property Value Impacts	Lower Bound Increase in Property Values	Upper Bound Increase in Property Values
$4,826,092,539	2% to 4%	$96,521,851	$193,043,702

Table 15. Annual Recreational Benefits for Fort Point Channel Wetland (2014$)

Visitation Type	Annual Number of Visits	Unit Day Value (Increase Consumer Surplus)	Lower Bound Total Annual Value	Upper Bound Total Annual Value
Visitors Engaging in New Recreational Activity	225,000	$2.75 to $11.53	$618,750	$2,594,250
Visitors Substituting from Existing Park to Fort Point Channel Wetland	225,000	$2.75 to $5.75	$618,750	$1,293,750
TOTAL	450,000	-	$1,237,500	$3,888,000

Table 16. Benefits Associated with Neighborhoods 1 and 2 Greening Plans

	Neighborhood 1		Neighborhood 2	
	Lower Bound Value	Upper Bound Value	Lower Bound Value	Upper Bound Value
Energy (N2 results based on increase to 25% and 35% canopy cover scenarios)	$156,000	$156,000	$123,232	$246,464
Carbon Emissions	$11,935	$58,228	$9,480	$46,335
Criteria Emissions	Not Quantified separate from CWERC in N1	Not Quantified separate from CWERC in N1	$13,396	$33,399
Carbon Sequestration	$1,690	$3,390	$3,991	$20,679
Air Quality	$13,932	$47,232	$6,755	$16,889
Avoided Stormwater Infrastructure Costs	$12,911,234	$25,822,469	$10,075,174	$20,150,346
Stream Daylighting	Not Quantified	Not Quantified	$139,442	$1,426,351
Recreational Opportunities (Fort Point Channel wetland only)	$1,237,500	$3,888,000	Not Quantified	Not Quantified
Additive GI Benefits	**$14,332,291**	**$29,975,319**	**$10,371,470**	**$21,940,463**
Annualized Property Value (Street Greening)	$14,332,291	$29,975,319	$10,371,470	$21,940,463
Annual Wetland Services (Large Wetlands)	$129,668	$795,642	$96,422	$894,514

Table 17. Summary of Economic Benefits for Neighborhood 1

Category	Benefit	Estimated Annual Benefits		Comments
		Lower	Upper	
Annual Welfare Benefits, Excluding Fort Point Channel Wetland	Energy Production and Savings	$1,150,058	$1,338,025	
	Reduced Carbon Emissions	$94,957	$455,056	
	Reduced Criteria Pollutant Emissions	$177,852	$443,419	
	Green Infrastructure Carbon Sequestration	$1,690	$3,390	
	Air Quality Improvements from Green Infrastructure	$13,932	$47,232	
	Avoided Stormwater BMP Costs	$4,997,222	$9,994,444	Partial overlap with wetland services estimate
	TOTAL	$6,435,711	$12,281,565	
Quantified Welfare Benefits that Overlap with Other Categories	Annual Wetland Services	$6,858	$21,439	Reflects only the wetland services associated with the two medium-scale wetlands; overlaps with avoided BMP costs.
	Annual Property Value Enhancements from Greening	$6,992,375	$13,984,751	Reflects broad set of amenities and therefore overlaps with other benefits (e.g., energy savings, recreational benefits); Annualized assuming 7% discount rate and 50-year useful life.
	TOTAL	$6,999,233	$14,006,190	
Annual Welfare Benefits Associated with Fort Point Channel Wetland	Fort Point Channel Recreation	$1,237,500	$3,888,000	
	Fort Point Channel Wetland Services	$122,810	$774,203	
	Avoided Stormwater BMP Costs for Fort Point Channel Wetland	$7,914,013	$15,828,025	
	TOTAL	$9,274,323	$20,490,228	

Table 18. Summary of Annual Benefits for Neighborhood 2.

	Benefit Category	Value	
		Lower	Upper
Additive	Energy Recovery and Energy Savings	$1,343,402	$1,595,289
	Reduced Carbon Emissions	$129,864	$661,303
	Reduced Criteria Pollutant Emissions	$55,909	$139,392
	Carbon Sequestration from GI	$3,991	$20,679
	Air Quality Benefits from Greening	$6,755	$16,889
	Avoided Stormwater Infrastructure Costs*	$10,075,174	$20,150,346
	Avoided Underpinning Costs	$8,600,000	$22,900,000
	Stream Daylighting Benefits	$139,442	$1,426,351
	TOTAL	**$20,354,537**	**$46,910,249**
Areas of Significant Overlap	Property Value (Street Greening)	$1,522,778	$3,045,556
	Wetland Services (Large Wetlands)	$96,422	$894,514

Opportunity: Stormwater Trading with Blue Cities Exchange

CRWA has worked for over a decade to design and build green infrastructure (GI) to reduce stormwater runoff and increase groundwater recharge. GI provides myriad benefits for the environment, public health, and community enhancement, as well as creating opportunities for jobs around installation and maintenance of GI facilities. A key driver in the Charles River watershed is severe eutrophic conditions resulting from phosphorus concentrations that are roughly double those that should be found in a healthy Charles River ecosystem.

Soil and plant based green infrastructure systems, particularly systems that infiltrate stormwater runoff, are extremely effective at filtering out phosphorus. Site conditions, such as the soil permeability, can cause GI installation costs to vary widely across the watershed. Varying levels of density in land use and underground utilities further influence costs. Optimizing locations where existing open space and porous soils make installation of GI relatively inexpensive helps drive down overall restoration costs.

Charles River Nutrient Total Maximum Daily Load (TMDL)
Charles River Watershed Association, in cooperation with the Massachusetts Department of Environmental Protection, conducted a pollution sourcing study for the upper 70 miles of the Charles called a total maximum daily load (TMDL) analysis. The study revealed that approximately 50% of the phosphorus pollution in the river comes from stormwater runoff from commercial, industrial, high-density residential, and institutional properties, all land uses which all have high levels of impervious cover (buildings, roads, parking areas, sidewalks, etc.). These land uses combined contribute 50% of the pollution load, despite making up only 20% of the land area. To achieve the necessary pollution reductions and improve water quality in the river to reduce aquatic weed growth and toxic algae blooms, concentrations of phosphorus in runoff from these properties must be reduced significantly.

Creating incentives to control stormwater runoff to reduce its nutrient load, increase infiltration to groundwater, enhance flood control, and restore natural hydrology are all high priorities for CRWA. CRWA has developed Blue Cities Exchange (BCE), a stormwater trading web tool, built to facilitate improved stormwater control that leads to flow and river water quality improvements, reduced flooding, and lower costs for achieving these outcomes. As communities invest in GI as a way to meet their stormwater and CSO permit obligations, CRWA believes BCE can make the transition more effective and affordable.

Stormwater trading is not a new concept, although it has yet to be widely adopted. A number of water quality trading programs have been established in recent years, although few focus on stormwater runoff. Washington, D.C., however, developed a stormwater retention trading system in 2013 that is similar to the approach we are exploring. The theory of stormwater trading is relatively simple. Properties where water can be infiltrated relatively cheaply can infiltrate significant volumes of stormwater runoff. Owners of such properties would then offer trade credits for sale to upstream property owners required to remediate their sites, but facing much more expensive options.

According to the economic literature, the success of environmental trading systems depends on several criteria:

- **Large cost differential:** Buyers and sellers have significantly different control costs.
- **Low transaction costs:** Standardized tools and transparent processes minimize transaction costs, which are the costs (or time and effort) associated with identifying and contracting with trading partners, verifying and maintaining credits, and enforcing compliance.
- **Sufficient demand:** The number of regulated entities (potential buyers) is large enough and the regulatory (or non-regulatory) driver stringent enough to create demand for credits.
- **Flexibility and risk minimization:** The system allows for flexibility in achieving off-site mitigation and protects against liability risk for regulated entities that choose to trade.[26]

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[26] Fisher-Vanden, K., & Olmstead, S. (2013). Moving pollution trading from air to water: Potential, problems, and prognosis. The Journal of Economic Perspectives, 147-171; and Selman, M., Greenhalgh, S., Branosky, E., Jones, C., & Guiling, J. (2009). Water quality trading programs: An international overview. WRI Issue Brief, 1, 1-15.

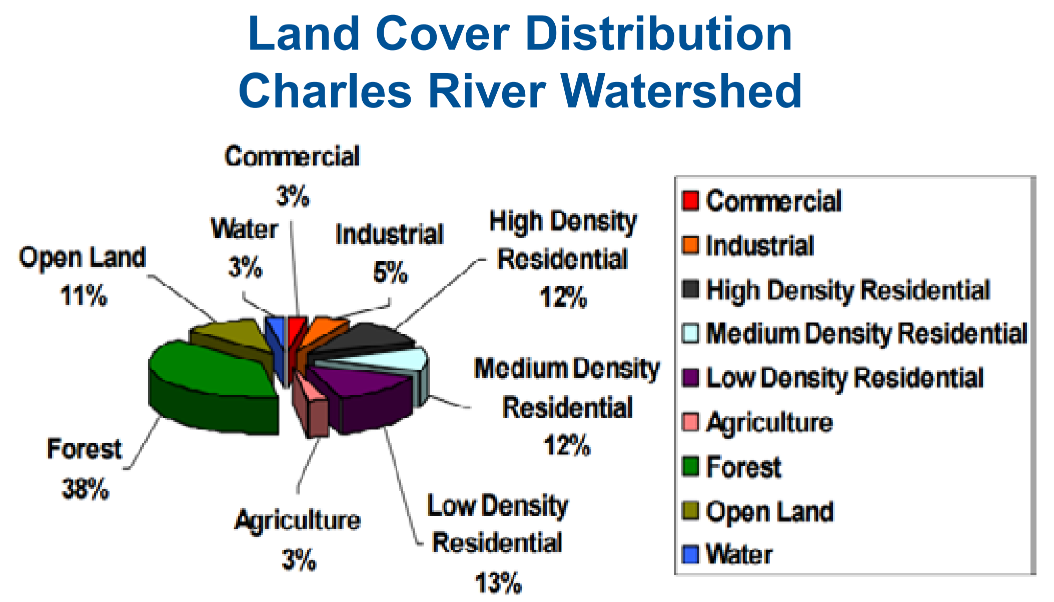

Image 4. Land Cover Distribution for the Charles River Watershed

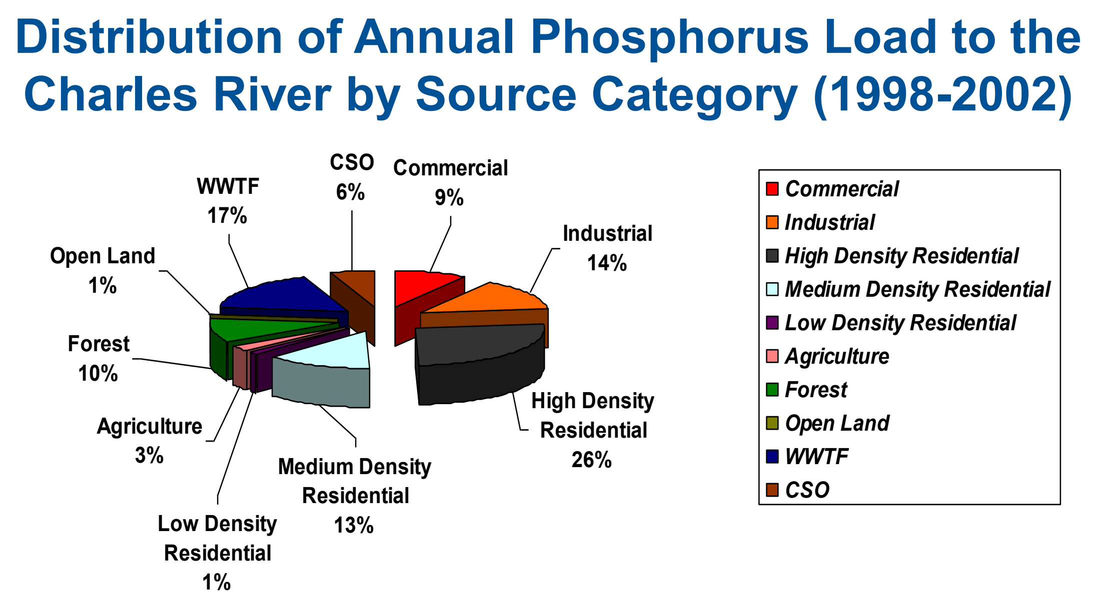

Image 5. Distribution of Annual Phosphorus Load to the Charles River by Source Category

Residual Designation Authority (RDA) and Blue Cities Exchange
With our partner, Conservation Law Foundation, CRWA filed a lawsuit based on the science of the completed TMDLs to require EPA Region 1 to use its "residual designation authority" (as provided by the Clean Water Act) to require permits from sources with large impervious areas discharging pollutants to the Charles. These sources of phosphorus-laden stormwater runoff are commercial, industrial, high density residential, and institutional properties with one acre or greater imperviousness. In March, 2017, the court, giving deference to EPA's regulatory interpretation, ruled that the agency did not have a nondiscretionary duty to require these stormwater dischargers to apply for pollution discharge permits. However, the court recognized that the Charles TMDLs "contain highly detailed information regarding stormwater discharges, their severe impact on the Charles, and the reductions required from major land use categories to achieve water quality standards."

CRWA envisions BCE as a "one stop" website, helping to connect buyers and sellers and driving down transaction costs for market participants. As currently configured, property owners can identify their properties on the website, investigate probable soil conditions, and determine the probable costs to control stormwater onsite. Algorithms developed for BCE then offer the owner cost differentials between types of stormwater controls, and make recommendations on whether the owner might want to consider trading as a lower cost alternative.

A previous analysis by CRWA and Industrial Economics, Inc. determined that across the Charles River watershed cost differentials are likely significant enough to encourage a stormwater trading market. In this study, transactional costs were estimated to be roughly 35% of the GI system installation cost, while the cost differential between implementing GI systems in urban setting like Boston was estimated to be roughly four times (400%) the cost of implementing systems in a more suburban community. Regardless of who is bearing the transactional cost (buyer, seller or system administrator) this cost differential is enough to overcome barriers to trading.

Cost for compliance in Franklin, MA = \$5,000/parcel
Cost for compliance in Boston, MA = \$20,000/parcel

Necessary cost differential for trades if the administrator bears none of the transactional costs:
= [System cost] * (1.35 * (1 - 0)) = [System cost] * (1.35)
=(\$5,000)x1.35 = \$6,750
Actual cost differential = \$15,000 (>minimum required differential \$6,750)

Whether sufficient demand is present is difficult to determine at this conceptual stage. If commercial, industrial, high density residential, and institutional properties with significant impervious cover were regulated under RDA (see text box) this would bring thousands of properties into the market. The BCE web trading tool, which was developed to allow these potentially-regulated property owners to trade, also has application for municipalities subject to the stormwater general permit to drive down the cost of compliance, put stormwater into the ground where it naturally infiltrates, and achieve environmental and flood control benefits. Furthermore, using BCE, municipal governments could also sell credits for stormwater management projects that exceed their regulatory requirements. This could offset the expenses of implementing the proposed greening plans described in Chapter 5. As communities throughout the watershed also begin to implement stormwater fees (a.k.a. stormwater utilities), more regulated and unregulated private properties may also be driven to the market as they sell credits for projects such as reduced impervious cover and increased on-site infiltration that stormwater fees are intended to incentivize. At this conceptual stage, BCE does not address issues around flexibility and risk mitigation, although these would be key issues to address in implementation.

Although few studies have attempted to quantify the economic factors necessary for a successful trading program, high transaction costs and perception-related effects can substantially impact participation rates and trade volumes. CRWA has taken significant steps toward minimizing these effects by developing the Blue Cities Exchange web tool to facilitate the identification of potential trading partners. Additionally, our analysis shows that due to variable land use and soil conditions across the watershed, costs of compliance are sufficiently divergent between sites to make trading a feasible and desirable solution. Further, the propability that unregulated property owners with good soils would trade with regulated property owners with poor soils is high. To evolve the tool, CRWA and regulators will need to develop standardized guidance, consider and facilitate the use of credit aggregators, and conduct extensive and targeted outreach.

CHAPTER 7: EXPANSION AND REPLICATION

Extensive site specific investigations and modeling were completed for the two neighborhood study areas. Based on this work the team developed a model to simulate the expansion of Community Water and Energy Resource Centers across the 43 community Deer Island Wastewater Treatment Plant sewer service area (Figure 29). The model is a tool to examine the potential costs, benefits, and environmental outcomes of regionally expanding the concept of CWERCs to all of greater Boston to transition from a large centralized system to a decentralized system.

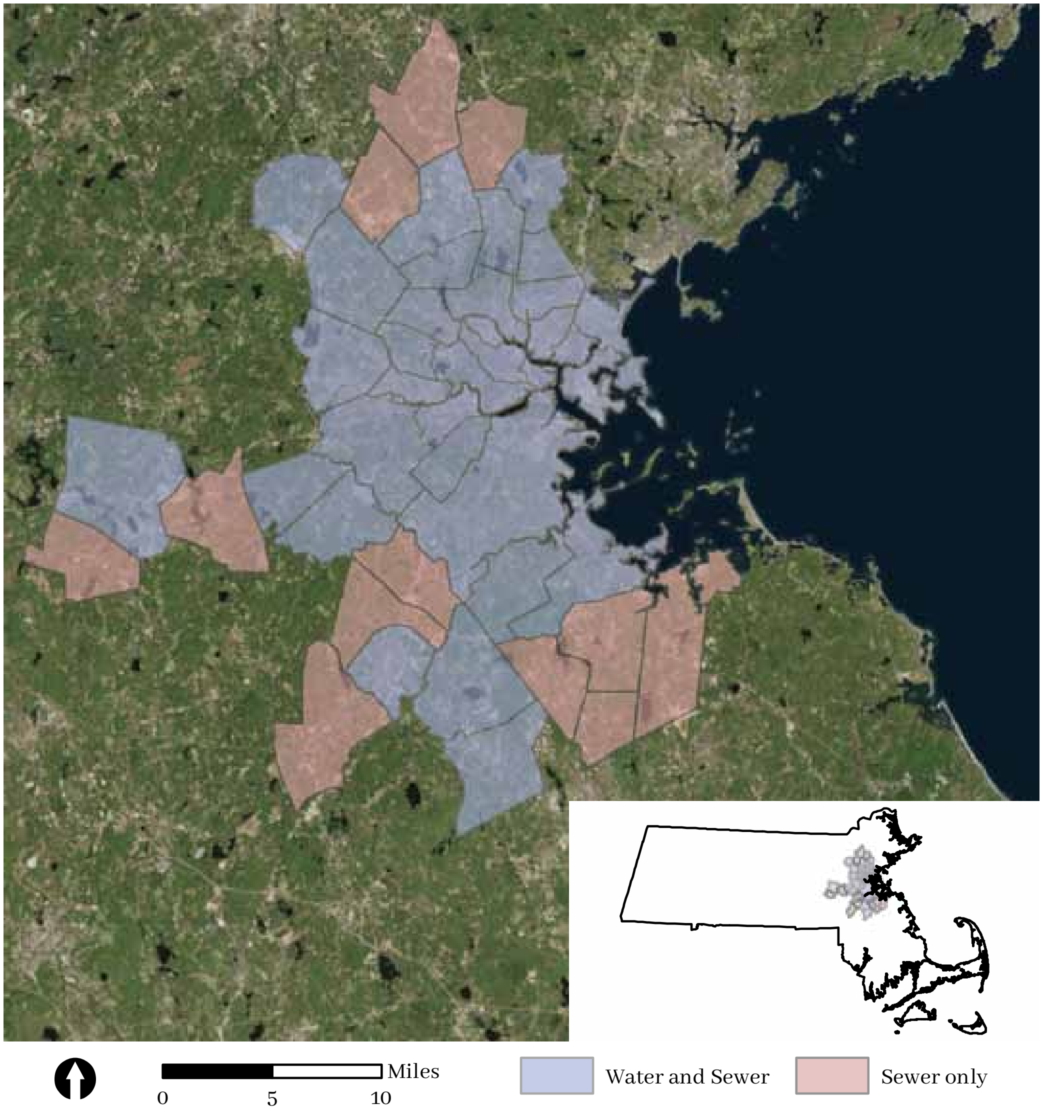

Figure 29. DITP Sewer Service Area Communities

METHODOLOGY

Distributed Wastewater Treatment

Our team developed a spreadsheet model to simulate CWERC expansion across the 43 communities presently on the DITP sewer system. Although a sewerage system is actually comprised of a series of connected watersheds, or sewersheds, this analysis was instead broken down by community since data is readily available at that scale. Inputs to the model are wastewater flow based on a community's average daily flow in 2014 as reported by MWRA and commercial and residential food waste available locally.[27] Commercial food waste is assumed to come from all food waste producers subject to the MassDEP "source separated organics ban" within the specific community, as well as the communities outside but directly adjacent to the DITP sewer service area. Unlike in the pilot studies, this analysis also assumes that a certain percentage of household food waste will be collected as part of the community's regular recycling day pickup and transported to a CWERC for use in food waste digesters. Household food waste also includes an assumed volume of waste from some smaller commercial producers, such as local restaurants, which are not subject to MassDEP's landfill ban.[28] A tipping fee is associated with commercial food waste but not with household food waste.

The team developed a series of multipliers to scale up the pilot plant results in a linear fashion. Some error is expected with this linear approach, especially in the scenarios where plant treatment capacity to food waste ratios vary significantly from those modeled for the pilot CWERCs. Additionally, a linear model does not capture possible benefits associated with economies of scale and economies of scope. All food waste derived numbers are presented as unit constants in terms of wet tons per day (wtpd) and the biosolids multipliers are expressed in terms of million gallons per day (mgd) of wastewater flow.

Most of the multipliers were derived from CWERC 1 and CWERC 2 designs except for the following which came from available literature:

- Residential food waste per person = 1.8 lbs of food waste/day/person[29]
- One-day storage for peaks = 3-5 mg/mgd – estimated from MWRA WWTF flow data[30]
- Wastewater storage = $1,000/mg
- Public water use in sewered area = 1/85% of sanitary flow (15% consumptive use based on common industry assumption).

Capital costs are also estimated by community based on system inputs (i.e. capital cost for wastewater volume treatment, capital cost for food waste processes, capital cost for water and wastewater stored). The expansion model does not include a breakdown of the number of CWERCs that would be best suited to treat the input volume of wastewater and food waste within each community, nor is there any attempt at this scale to investigate siting options. Some communities may have one CWERC while others may need more than a dozen to accommodate all the waste generated.

The expansion model includes a capital cost for wastewater storage, not present in the neighborhood studies. In the existing DITP system, flow rates can vary by as much as 6 times based on the time of year and weather. Full implementation of CWERCs and increased green infrastructure would reduce this fluctuation, nevertheless, storage was added to the capital costs in the expansion model which was not included for the neighborhood sites to account for the need to store wastewater during periods of high flow. No operating costs are assumed for the wastewater storage which may be an underestimate as some sites would require pumping into and/or out of storage facilities. The total storage volume varies by scenario.

Operations and maintenance costs are estimated on an annual basis. To annualize capital costs, the model uses a capital recovery factor based on an interest rate, which varied by model scenario, and an assumed 25 year life cycle.

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[27] MWRA annual infiltration and inflow (I/I) reduction report for fiscal year 2015, http://archives.lib.state.ma.us/handle/2452/279375

[28] Mass.gov Commercial Food Waste Disposal Ban webpage. http://www.mass.gov/eea/agencies/massdep/recycle/reduce/food-waste-ban.html.

[29] Mass.gov Commercial Food Waste Disposal Ban webpage. http://www.mass.gov/eea/agencies/massdep/recycle/reduce/food-waste-ban.html.

[30] MWRA annual infiltration and inflow (I/I) reduction report for fiscal year 2015, http://archives.lib.state.ma.us/handle/2452/279375

Model outputs include values, and where relevant, volumes, for the following products: electricity, thermal energy, reclaimed water, tipping fees, renewable energy credits, compost, nitrogen, and soil amendments. Electricity is produced in a combined heat and power (CHP) unit powered by biogas from a wastewater biosolids anaerobic digester and a food waste anaerobic digester. For all electric energy produced on site, 90% of the energy has a value corresponding to the renewable energy credit (RECs), even if the electricity is consumed on site. Only 90% of this electricity is eligible for RECs since it is assumed that 10% of the time, the CHP unit will need to be powered by natural gas due to regular digester maintenance.

Net electricity (on site production minus usage) was also calculated by community based on wastewater and food waste inputs. If net electricity was positive it was assumed to be sold back to the grid at a whole sale rate in a net metering scenario. If net electrical production was negative (more electricity consumed than produced), a retail electricity charge of $134/KWh is applied in the model to capture the expense of electricity that would need to be supplied from the grid.

As in the neighborhood scenarios, thermal energy produced by wastewater and the CHP unit is valued at the price of natural gas ($9.77/MMBTU). Compost, nitrogen and soil amendment volumes are all determined by community based on volume of inputs and values are identical to those used in the pilot site analysis (Table 4). Reclaimed water rates, percentage of household food waste delivered to the CWERCs, and wastewater user fees varied by model scenario.

Annual operating costs and annualized capital costs are subtracted from the sum of annual income streams to determine net cost or surplus by community. These are then totaled for all communities for a total annual system cost or surplus for a variety of scenarios. This expansion model does not address the method of transition from a centralized to a decentralized system.

Finally, CRWA also explored the broader economic considerations of full scale implementation. One element of this work is a determination of the avoided costs for capital investment and operations of the centralized system. This value, presented as an upper and lower estimate, reflects the upgrades, maintenance and repairs that would not be required at DITP with a shift to CWERCs. Estimates are based on a thorough review of MWRA Wastewater System Master Plan (2013) and MWRA Capital Improvement Plan (2015) which cover the period from FY2014 to FY2053. The Lower bound accounts for avoided costs beginning after FY24 and relate to wastewater treatment only, the upper bound begins accounting for avoided costs as of FY2019 and assumes reductions will be realized in treatment system costs as well as in collection system and pumping upgrades (i.e., distributed systems will allow for downscaling of the collection network and result in reduced pumping). A model scenario in which CWERCs annualized capital expenses and operations equate to avoided capital costs (annualized) and operations costs at Deer Island is presented below. The economic analysis also scaled the social welfare benefits determined in **Chapter 6**, up to the full-implementation plan.

Greening Plan Replication

Broad scale greening plans are also presented at a very high level for each community to assess the impacts of widespread green infrastructure implementation in conjunction with CWERC expansion. For each community a target phosphorus reduction is determined using either the Charles River Nutrient TMDL results (for communities in the Charles River watershed) or a derived equation relating required TMDL reductions to a community's level of imperviousness, tree cover and population density. For each community, the team determined the costs of complying with this target using either green infrastructure systems (biofiltration and infiltration) or more traditional stormwater treatment infrastructure (dry and wet ponds). Costs are based on the land area required to implement the systems and the cost of constructing the treatment systems. The broad scale greening plans do not include any treatment system siting; results are a total target area for green and traditional treatment systems for each community.

Social Welfare Valuation

In addition to extrapolating the benefits at the neighborhood level, the team identified a suite of entirely new and unique benefits that would only be realized once the *Water Infrastructure for a Sustainable Future* model reached a critical expansion point. As discussed, cost savings from avoided long-term investments in the centralized system is one such benefit that is only realized when the centralized system is replaced with a networked, distributed treatment system. The team also explored savings on traditional stormwater infrastructure through investments in large scale implementation of green infrastructure. In addition to these very direct benefits, however, many secondary benefits will result from the large scale transition. These benefits include:

- The value of instream flow enhancements on the Charles River (and other rivers)
- The value of instream flow enhancements on the Swift River
- Reduced water supply costs

Flow in local river systems will be considerably enhanced from increased groundwater recharge from CWERC effluent, green infrastructure system installation, reduction of impervious cover, and reduction of infiltration and inflow export out of the watershed. For this analysis, the team limited the scope solely to water returned to the Charles River watershed from CWERC effluent; therefore it is a very conservative valuation of the impact as our study area intersects nearly a dozen watersheds. Consistent with the CWERC expansion model, the analysis assumes 30% of all treated water is returned to the natural environment and the percentage determined to be returning to the Charles River watershed, as opposed to a neighboring watershed, is based on the percent of residents in each community who live within the boundary of the watershed.

The economics literature offers many studies of the public's willingness to pay for increased river flow. The team employed a transfer analysis based on a study of the Cache la Poudre River in Fort Collins, Colorado, which determined a willingness to pay for streamflow enhancement in that river to be about $0.005 per acre foot per household.[31] To transfer this to the Charles, our team estimated the number of households that would derive economic value from enhanced flows in the Charles. For the lower bound, this is defined as the population living within one mile of the upper and middle portions of the Charles River.[32] For the upper bound, we use the full population of the Upper/Middle Charles watershed. We translate these figures to a number of households assuming 2.44 individuals per household, the average for the three counties in the Charles watershed.

We then multiplied the annual willingness to pay per household per acre foot ($0.005) by the number of households and annual acre feet of water added to the Charles. To appropriately apply the model to the Charles we adjusted the estimated economic benefits to account for differences in the flow of Cache la Poudre relative to the Charles. Sources suggest that withdrawals from the Cache la Poudre divert 60% of the river's flow during the summer low-flow months.[33] The team analyzed how diversions, impervious surfaces, and infiltration/inflow combine to reduce the flow of the Charles overall; since flow reductions are not as dramatic in the Charles the value was adjusted downward to reflect this.

We also explored flow enhancements to the Swift River resulting from reduced potable demand from the increased use of reuse water proposed in this plan. The Swift River system provides water supply to the Quabbin Reservoir. It also supports an active cold-water trout fishery, allowing us to use a benefits transfer analysis from other economic valuation studies.

The first step in the analysis involves assessing the extent to which average monthly flows in the rivers fall short of flows expected under natural conditions where water is not diverted into the reservoirs. Annual average flow was calculated from continuous streamflow measurements. Measurements were compared to the flow estimates produced by the Sustainable Yield Estimator (SYE). The USGS SYE estimates the natural streamflow at the same location where the stream gauge flow readings are collected. The SYE includes an algorithm to estimate natural streamflow at the chosen site from the upstream watershed characteristics and a matched gauged watershed with near-natural streamflow. Natural streamflow from the SYE minus the average actual flow provides an estimate of the average flow shortfall.

To value potential flow increase, we reviewed literature on the relationship between streamflows and recreational fishing benefits and selected two relevant studies for benefit transfer. These two studies, based on rivers in Colorado and Montana, provide estimates of the marginal value of an acre foot of additional streamflow. Both studies used a "tiered" approach to estimate the marginal value of increased flows at different flow levels. We

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[31] Loomis, John, "Comparing households' total economic values and recreation value of instream flow in an urban river," Journal of Environmental Economics and Policy, Vol. 1, No. 1, March 2012

[32] Flow enhancements are likely to be most pronounced in the Middle Charles watershed. The upper reaches of the river would receive limited water supplements, while the Lower Basin (below the Watertown Dam) is impounded and unlikely to experience noticeable changes in flow.

[33] See http://www.savethepoudre.org/the-nisp-glade-project.html, accessed on May 13, 2016.

convert these tiered marginal value estimates to current dollars using the GDP Implicit Price Deflator and apply the values to anticipated increases in Swift River flows from increased water recycling.

Finally, the team valued the cost savings from transporting less potable quality water from the MWRA system. This value was determined by estimating a cost per gallon of potable water delivered based on MWRA's annual operations and maintenance budget for water supply and applying that figure to an assumed volume or reuse water supplied by CWERCs.

RESULTS

Distributed Wastewater Treatment

After constructing the expansion model, multiple scenarios were examined: two are presented here. Model inputs for each scenario are presented in Table 19.

In Scenario A, system-wide income is calculated as roughly $425 million annually. Annual system-wide expenses, including the initial capital investment to construct the CWERCs (on an annualized basis) are nearly $820 million, resulting in a net annual cost of $394 million which would need to be covered by wastewater user fees, increasing potable water fees or initial capital investments from grants or other resources. Under Scenario B assumptions, the system operates at a net cost of just over $1 million annually which could be made up through a small increase in the wastewater treatment fee or other product revenue charge.

Avoided capital investment at DITP from FY2019 (upper bound estimate) or FY2024 (lower bound estimate) total $727,750,000 to $1,863,442,000. Potential avoided operating costs are estimated to be $65,876,500 annually; therefore total annual avoided costs of centralized treatment for this area range from $118,608,511 to $200,900,511/year. It is certainly possible to construct and operate a distributed system within this range given certain criteria. One possible scenario for operating a full-scale system of CWERCs within this range, before accounting for any income from wastewater treatment fees, which is an existing income source at MWRA, would be to recycle 60% of household food waste at CWERCs, construct storage for 3x the daily flow, charge $5.00/1000 gallons for reuse water (less than current retail rates in many communities), and assume a 3% interest rate. Model inputs can also be adjusted to identify conditions under which the CWERC expansion system is profitable to the utility or CWERC operator, or would allow user fees to be eliminated. Thermal energy generated from wastewater and the CHP unit is not currently eligible for renewable energy credit, such incentives are likely to become eligible by 2018. If renewable thermal production was financially incentivized this would generate a significant new income stream for CWERCs.

The social welfare benefits of making this transition are extremely compelling. The value of annual recovered energy, both thermal and electric, is roughly $134 million. The total annual value of emissions reductions ranges from $17 to $81 million and means a reduction in CO_2 emissions of roughly 1.8 billion pounds per year.[34]

Greening Plan Replication

The critical finding of the greening plan replication analysis is that due to the efficacy of green infrastructure systems in removing nutrients from stormwater, in each community far less space is required to implement the green infrastructure plan in comparison to the traditional plan[35] (Figure 30). This results in a lower overall cost, despite the fact that constructing green systems can be more costly on a straight unit ($/gallon of water treated) basis (Figure 31). This difference amounts to an annualized savings of over $200 million from implementing the green infrastructure plan in comparison to the traditional infrastructure plan.[36] These plans help municipalities comply with new federal and state stormwater regulations.

It is estimated that the full scale green infrastructure plan would increase property values across the 43 community study area by $23 to $95 million. In this analysis, communities with a greater than 50% existing tree canopy cover are excluded, due to the fact that increased greening will have a negligible effect on property values in these already "green" communities.

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[34] See Chapter 6 for methodology details

[35] Using two traditional stormwater treatment management systems: dry ponds and wet ponds (old school SW management tecniques)

[36] Savings annualized using a discount rate of 7% and a useful life of 50 years

Social Welfare Valuation

The estimated annual willingness to pay for Charles River flow enhancement ranges from $2,893,156 to $20,599,474. The lower bound is based on an assumed 65,969 households affected, while the upper bound assumes 469,706 households affected, or the entire population of the Upper/Middle Charles River watershed. Based on expected recharge to the watershed from the distributed networks of CWERCs, an assumed 13,442 acre-feet of water is added to the Charles on an annual basis. Finally, recognizing that the extent of flow depletion is greater for the Cache la Poudre than for the Charles, we reduce the estimated economic benefits by a third (40% reduction in Charles/60% reduction in Cache la Poudre = 66.7%).

CWERC regional expansion could provide as much as 170 mgd for communities currently on MWRA's water supply system. The average flow shortfall (actual flows vs. natural flows) for the Swift River is estimated to be roughly 273 cfs (146 mgd), or over 70% of the natural flow in the Swift downstream of the Quabbin. If, over time, this gap could be eliminated due to reduced potable water demand, economic benefits associated with enhanced flows and improved trout fishing on the Swift River could be realized. The team determined the annual willingness to pay for increased flow on the Swift River to range from $2,725,915 to $3,307,115.

Finally, savings from avoided water supply costs are estimated to be roughly $8.3 million annually. MWRA reports total deliveries of about 62 billion gallons per year. As a conservative estimate, we assume that 30% of all MWRA-supplied water, about 21.4 billion gallons per year could be replaced with reuse water from the CWERCs. MWRA's annual budget for operation and maintenance of its water supply system is approximately $27.6 million, implying an average cost of about $385 per million gallons delivered.

DISCUSSION

In total, benefits of the Water Infrastructure for a Sustainable Future plan are considerable. Table 16 summarizes the estimated annual economic benefits under regional expansion Scenario B. The grand total of estimated benefits ranges from $555 million to $960 million per year. In the lower bound, the benefits are dominated by the value of recovered heat, avoided capital and operating costs for the centralized wastewater treatment system, and net savings on stormwater BMPs. In the upper bound, these same benefit categories are prominent, as well as avoided underpinning costs and property value enhancements from street greening. The benefits associated with operation of the CWERCs (as opposed to GI) account for roughly 55% to 65% of the total estimated benefits.

Our analysis considers numerous benefits, including the avoided cost of investments in centralized wastewater treatment. However, distributed treatment can offer other benefits not examined in detail, including the following:

- Capacity Sizing: Reliance on distributed CWERCs may allow more accurate tailoring of capacity to local growth and stormwater patterns. While centralized treatment is typically equipped with idle capacity to accommodate peak flows, a decentralized system could potentially be planned more efficiently, eliminating excess capacity and reducing capital investment.

- Collection Efficiency: Other capital and operating savings are possible through avoidance of extensive collection system costs. Centralized systems offer economies of scale in direct wastewater treatment processes; however, collection systems are frequently a large share of overall costs, potentially outstripping the savings realized through treatment-related economies of scale. Distributed treatment systems, designed correctly, can serve regional populations with a less extensive collection network.

- Reliability and Resilience: Natural hazards (e.g., storms) and intentional disruption (e.g., through a terrorist act) have the potential to interrupt service for large regions served by centralized wastewater treatment. Distributed treatment offers the potential for avoiding these risks and the associated economic costs. This same resilience advantage extends to other services offered by the CWERCs, such as electrical service.

- Development Incentives: The electricity, heating, and water services that CWERCs offer can serve as a development incentive for surrounding areas. As examined in the pilot analyses, the CWERCs offer the potential for reduced-rate services if properly planned in coordination with residential or commercial developments.

- Reduce Wastewater Flow: Green infrastructure installed in conjunction with CWERCs will reduce infiltration and inflow into the wastwater system, reducing unnecessary treatment of clean water.

Table 19. Expansion Model Scenario Parameters

Input Parameter	Scenario A	Scenario B
Residential Food Waste Collection Rate	50%	50%
Commercial Tipping Fee	$70/wet ton food waste	$70/wet ton food waste
Peak Storage Volume	5x daily flow volume	3x daily flow volume
Water Recycling Rate (% resold)	70%	70%
Reclaimed Water Sales Rate	$3.80/1000 gallons	$4.00/1000 gallons
Capital Recovery Factor Interest Rate	5%	3%
Wastewater Treatment Fee	$0	$2.21/1000 gallons
Wastewater Volume Treated (normal flow conditions, no storage)	309 mgd	309 mgd
Food Waste Input Assumed	1,384 wtpd (20% commercial/80% other)	1,384 wtpd (20% commercial/80% other)

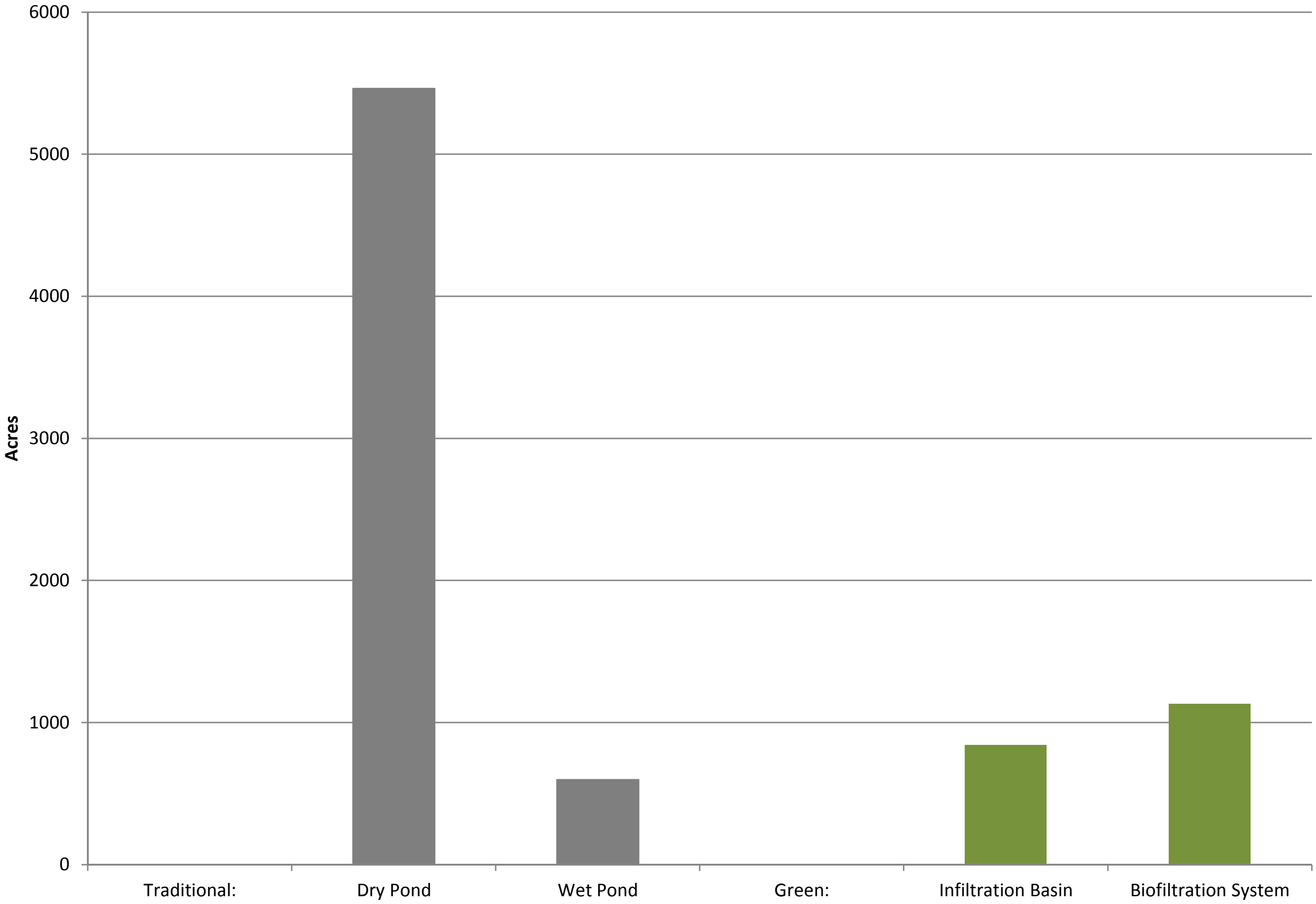

Figure 30. Total Required Stormwater Treatment System Area

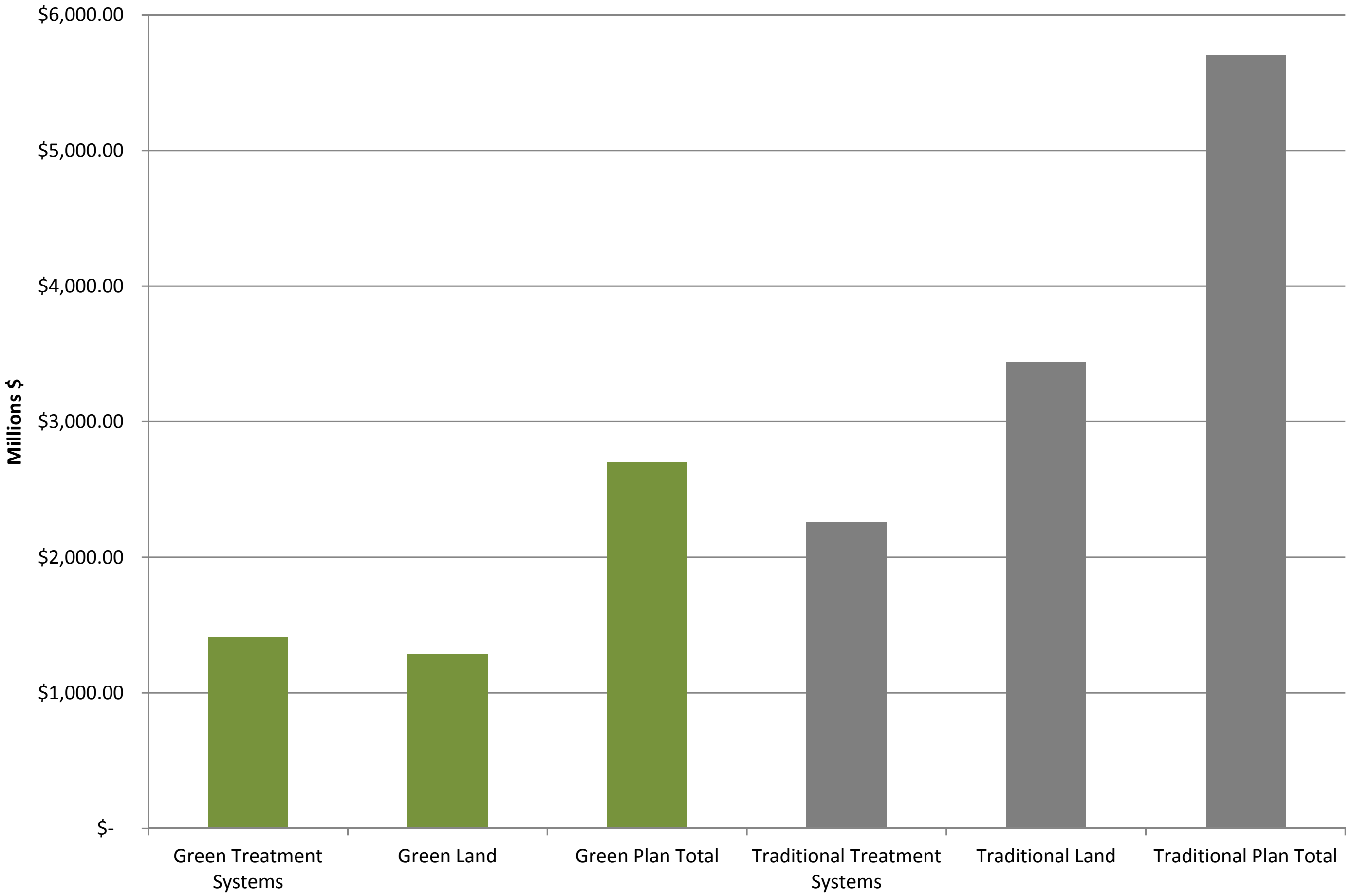

Figure 31. Estimated Costs of Green Plan vs. Traditional Stormwater Treatment Plan

Table 20. Estimated Annual Economic Benefits under Regional Expansion Scenario B

	Benefit Category	Lower Estimate	Upper Estimate
Scaled	Energy Recovery - Electricity	$12,700,000	$13,000,000
	Energy Recovery - Heat	$121,600,000	$121,600,000
	Emissions Reduction - Electricity	$6,400,000	$15,800,000
	Emissions Reduction - Heat	$10,900,000	$65,300,000
	Property Value Enhancement from Street Greening	$23,800,000	$95,200,000
	Avoided Underpinning Costs	$29,500,000	$198,300,000
	SUBTOTAL SCALED	$205,000,000	$509,400,000
Threshold	Charles River Flow Enhancement	$2,900,000	$20,600,000
	Swift River Flow Enhancement	$2,700,000	$3,300,000
	Avoided Cost of Water Deliveries	$8,300,000	$8,300,000
	Annualized Capital Investment Avoided	$52,700,000	$135,000,000
	Annual Operating Costs Avoided (DITP)	$65,900,000	$65,900,000
	Avoided Stormwater BMP Costs	$217,800,000	$217,800,000
	SUBTOTAL THRESHOLD	$350,300,000	$450,800,000
	GRAND TOTAL	$555,300,000	$960,200,000
	CWERC-ONLY TOTAL	$308,100,000	$623,300,000

Note: All estimates rounded to nearest hundred thousand dollars.

CHAPTER 8: OUTREACH

Implementing *Water Infrastructure for a Sustainable Future* requires involvement, feedback, and cooperation from individuals and groups across a wide array of sectors. Planning and implementation will involve varying levels of government, individuals, groups and organizations with a wide variety of expertise, representatives from multiple utilities, and strong partnerships between all parties. Partners to supply food waste and to purchase water and energy would need to be identified, engaged and contracted with in the early stages of implementation. There are significant logistical and regulatory issues. Critical to success is engaging communities, local residents, and business owners. As a community based recource management system, this approach would need to be thoroughly vetted by or, ideally, planned in conjunction with the local community. Significant outreach and education is required to raise awareness with the public around urban water management issues and the solutions we have identified here. It was this awareness raising that was the focus of the extensive outreach campaign undertaken during this project.

Technical Advisory Committee

A technical advisory committee (TAC) (See page 7) met regularly for a total of 15 meetings over the course of the project to provide the team with input and feedback primarily on design and modeling. The TAC also advised on implementation strategies and next steps, helped to make connections for our team, and assisted in promulgating and promoting the concept within their organizations and sectors.

Outreach Meetings

CRWA discussed our vision of water smart neighborhoods in a myriad of forums and participated in advocacy efforts to promote certain steps, regulations, structural changes, and policy adaptations that will lay the groundwork for successful implementation of the concept.

CRWA executive director Bob Zimmerman authored a popular blog series entitled Water Transformation. Installments were published biweekly on CRWA's website in the winter and spring of 2015. The Water Transformation Blog generated over 3,000 direct hits and is still available on CRWA's website. Project results were presented at conferences both locally and across the country in cities like Austin, TX, San Francisco, CA, Washington, D.C., and Albuquerque, NM. Our team co-authored a feature article on the concept for Civil Engineering Magazine's July/August 2015 issue. In late December 2015, The Boston Globe ran a story on the project which generated a lot of conversation on social media and in person. The story was followed by a brief interview on public radio with Bob Zimmerman.

> I think the important thing to underscore, which is consistent with all posts, is that there is no one size fits all model to wastewater treatment. It is unlikely there ever will be. I very much appreciate Al's comments about Holliston and in Holliston's case, requiring local effluent disposal effectively stopped the advancement of a centralized treatment option which was needed given the lack of local disposal sites - an unfortunate outcome. Bottom line, engineers need a range of options to maximize opportunities to "keep water local" without putting up obstacles when a more centralized solution is needed.
> -Carolyn Dykema
> Massachusetts State Senator

> Important Globe story on a terrific idea from Bob Zimmerman and the Charles River Watershed Association, building upon the work of the Water Infrastructure Finance Commission (WIFC), and decentralizing water infrastructure, which both keeps water local, saves money, and better protects the environment. Rep. Carolyn Dykema and I recently met with Bob Zimmerman, to begin outreach to the Baker administration on this idea.
> -Jamie Eldridge
> Massachusetts State Senator

CRWA met one-on-one with nearly 50 individuals, organizations, and agencies. CRWA also met with numerous elected officials in Boston, Cambridge and surrounding areas. These conversations served as an introduction to the project and focused on the potential community advantages the plants and associated greening offer. The objective of the outreach campaign was to engage community members and leaders, solicit their comments and concerns, and adapt our work appropriately.

In March 2016, CRWA partnered with Foundation for a Green Future, the Office of Massachusetts Representative Chris Walsh, the Boston Society of Architects (BSA), the City of Boston, the Massachusetts Water Resources Authority (MWRA), and the Metropolitan Area Planning Council (MAPC) to put on the 4th Annual Massachusetts Water Forum, a half day event focused on the *Water Infrastructure for a Sustainable Future* concept and implications for implementation in Massachusetts. Over 100 people attended the half day forum which was a wonderful opportunity to engage with environmental professionals, water advocates and the general public alike.

CHAPTER 9: CONCLUSION

The key to constructive restorative change lies in managing water, carbon, and nutrients in a way that replicates their natural cycles. Our team applied the principles of nature to develop a plan for a new generation of water infrastructure that effectively provides for human demand and restores nature while building resilience to drought, flooding, and warming. CRWA rejects the concept of “waste” and proposes generating significant energy from organics currently being thrown away. We restore the natural water cycle by breaking up centralized systems into distributed networks of interconnected water and energy facilities which mine sewer pipes to reuse the water, reducing potable demand, and producing local, renewable energy. We recreate natural hydrology through stream and wetland restoration and the introduction of green infrastructure. By reconnecting stormwater and reclaimed water to restored urban water resources, our landscapes flourish and we build natural and social resilience. We accomplish all this while capturing new revenue streams and in the process both adapt to and mitigate global climate change.

CWERCs are replicable and adaptable. Through integration of water, energy and waste management, CWERCs integrate the function of multiple facilities that individually are resource and capital intensive. This dramatically reduces system wide costs and environmental externalities inherent to the current single-function, linear, take-make-waste infrastructure model.

CRWA’s case studies reveal that CWERCs are self-sustaining while charging users only a fraction of current water rates for non-potable reuse water and wastewater treatment. In our Boston case studies, based on local input factors for commodity costs and sales, CWERCs are sustainable at roughly 30% of the current potable water charge and $0 wastewater treatment fees. A single CWERC, treating 2 to 3 million gallons per day (mgd) of wastewater reduces annual CO_2 emissions by as much as 30 million pounds. Finally, our economic models show that we can construct a distributed network of CWERCs to replace existing centralized systems while remaining cost neutral in the near term and likely profitable in the medium and long terms.

Based on the results of this study, CRWA is actively seeking partners to work with on a CWERC implementation project. Through our robust advocacy program we are also seeking regulatory and policy changes necessary to encourage and incentivize our holistic approach. In many ways, cities are leading the way on climate change adaptation planning, and the City of Boston is one of the leaders in this movement. Cities are recognizing the benefits of district scale energy generation both for resiliency and to improve efficiency and help achieve greenhouse gas reduction targets. Green infrastructure is also being identified as a method of achieving multiple goals such as flood mitigation, CO_2 sequestration, cooling, energy reduction, CSO compliance, improving air and water quality, and more.

It is essential that the infrastructure we invest in today is ready to face the challenges climate change will bring. It is imperative that we transition away from a fossil fuel based economy as soon as we possibly can. This will require significant investment in renewable sources and employing all renewable energy generation opportunities at hand. Nature’s remarkable endurance and self-healing abilities must be guiding forces as we chart our course forward. We can no longer just live *on* the Earth, we must instead, using Nature’s own principles, learn to live *with* the Earth.

CREDITS

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Figures 6, 7, 8, 12, 13, 14, 15, 16, 18, 20, 21, 22, 23, 24, 25, 26, 28: Source: Esri, DigitalGlobe, Geo Eye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, Swisstopo, the GIS User Community, MassGIS, BWSC, City of Boston and MWRA.

Image 1: Leo 'Jace' Anderson. "Flooded area of Colfax Iowa." Federal Emergency Management Agency. 15 Aug. 2010, https://www.fema.gov/media-library/assets/images/57767#details. Accessed Dec. 2016.

Image 2: New England Interstate Water Pollution Control Commission. "Interstate Water Report." vol. 8, no. 1, April 2013.

Images 4 and 5: Mass DEP and US EPA, New England. "Final-Nutrient TMDL Development for the Lower Charles River Basin, Massachusetts CN 301.0." June 2007, p. 105.

Figure 3: Image created by Charles River Watershed Assocaition and Natural Systems Utilities

Figure 8 and 24: "Relation of the Fens Basin to the former Tide Mill ponds." http://archives.lib.state.ma.us/handle/2452/50193. Accessed 2016.

Figure 10: Created by Natural Systems Utilities

Figure 16: Boston Redevelopment Authority. "Economic Development Strategies: WP1 Case Study Reports 2012." April 2012, p 9.

Figure 27: Created by Industrial Economics Corporation

Afterword

The antiquated water systems on which we depend are incompatible with nature and represent significant risks to society as they age and as our climate changes. They throw away water and organic resources, are inflexible, expensive, and most are in need of repair and replacement. Nevertheless, as better approaches are identified, these systems are extraordinarily difficult to replace. Existing water infrastructure is generational because water authorities have multi-year budgets, five year capital plans, 10 to 20 year planning horizons, and 30-plus year funding and structural debt. Combined with historic precedent, risk aversion leading to a strong preference for "standard practices," political pressure and political realities, regulations, permits, expectations, and perhaps most importantly, the lack of a sense of urgency around the future realities of our changing climate, any transformational change to these systems becomes nearly impossible. Consequently, as we continue to do what we have always done simply because it is what we have always done, this deeply rooted Inertia kills all but the most incremental of changes.

Right now we are confronting water infrastructure repair and replacement we cannot afford. The American Society of Civil Engineers has estimated that existing infrastructure needs $3.6 trillion in repairs and replacement by 2020, while infrastructure spending levels are unclear under the new administration, this gap is likely too large to close. Add the drought and flooding of climate change, and the stark inadequacies of our 19th Century water systems are clear. From sea level rise to flooding and drought, from loss of groundwater to harmful algae blooms, rising temperatures, and carbon dioxide and methane emissions, we cannot continue to accept the status quo for water infrastructure. If all we do is rebuild and extend our existing inflexible centralized systems, promoting them by adding modest bells and whistles to generate some energy at end-of-system treatment plants, we will witness their spectacular failure in the face of climate change.

CRWA has identified an approach that is both restorative of natural systems and financially and economically responsible, even desirable. Additionally, the Community Water and Energy Resource Centers (CWERCs) we analyzed provide us the opportunity to leverage value in existing centralized infrastructure as we move away from it over time. Our existing infrastructure is not a "sunk cost;" it provides us a means of starting the transition to a more resilient system. Additionally, as elements of our existing systems are phased out, they can be repurposed for things like flood storage and conveyance. CWERCs allow us to think about pipes and capacities in very different and far more flexible ways.

There is also a very important social side to the creation of CWERC districts. There are opportunities for new ownership and utility models as energy generation becomes more distributed. Not every CWERC needs to be owned and operated by a central water authority. Neighborhood-owned CWERCs, providing treatment and energy and water utilities to neighborhood desired development could give neighborhoods greater control of their destiny. Further, our work has shown that due to the resource generating potential of wastewater, there is significant opportunity to stabilize water and wastewater rates, which have risen inexorably over recent decades, a trend that will certainly continue if we elect to rebuild existing infrastructure. Price increases unduly burden those at the lowest income levels. Contrast that reality with rates subsidized by wastewater-generated utility sales. Together with the introduction of restored streams and green infrastructure as both neighborhood amenities and resilience to climate change, CWERCs will contribute to a sense of place while enhancing affordability.

The transformation of centralized water systems to CWERC districts will take years. During that transformation, we must use the opportunity to restore natural hydrology, flexibility and adaptability, and urban surface waters. We must integrate management of all "types" of water: drinking, reclaimed, surface, ground, waste, a concept becoming known as "One Water." Green infrastructure is a necessary companion to CWERC implementation that completes the fully integrated water management and restoration objectives. The move to CWERCs gives us a one-time opportunity to address most all the failings of the water infrastructure we have inherited, an opportunity we must not squander. CRWA's approach to restored streams and green infrastructure using our "Blue Cities Exchange" trading system for stormwater will drive down costs as it provides the necessary financing.

With the construction of CWERCs in several locations across the country we can continue to add to the knowledge base we have established with this publication. There are myriad regulatory and ownership questions we look forward to addressing, as well as many questions related to siting, construction, and operations. There are additional social impact questions such as costs and equity, community utility ownership models, climate adaptation, Blue Cities trading, even simple concepts like the separate collection of household food waste for use in CWERC energy generation.

As CWERCs are constructed, their cost and nature will begin to change. We acknowledge it is important to get implementation costs down over time to enhance financial viability. Innovation around this new investment opportunity will lead to CWERCs becoming cheaper to build while increasing their ability to handle more waste on less land, generating more energy more efficiently, and engaging new partners to provide new opportunities we have not yet identified or investigated.

CRWA is actively pursuing CWERC pilot projects in Massachusetts and cities across the country. The environmental benefits are compelling: restoration of flow and water quality to urban rivers, restoration of flow to water supply watersheds, renewable energy, reduced greenhouse gas emissions, increased flood control, resilience to drought, reduced heat island effect, improved air quality, and improved public health. The need is real, the opportunities are real, and the time to start is now.

CWERC economics are so compelling, I believe, that the construction and operation of just a few will result in their replication everywhere.

Bob Zimmerman, Executive Director
Charles River Watershed Association
February, 2017