Water and Stormwater Management

Financing New York City's Oyster Reef Rehabilitation: A Blue Infrastructure Opportunity

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New York City's History in Oysters

New York City's history is innately linked with oysters. "When Henry Hudson first entered New York Harbor in 1609", it was "one of the most biologically productive and diverse environments on the planet."[i] Hudson had to carefully navigate through 220,000 acres of oyster reefs that had effectively sustained the area's first inhabitants, the Lenape, for generations.[ii] When Hudson first entered New York Harbor it contained nearly half of the world's oyster population.[iii]

As Hudson carefully plotted his course through the estuary that would one day come to bear his name, he encountered one of the world's most productive marine environments regulated by a dynamic bivalve and one of the area's most significant inhabitants, *Crassostrea Virginica*: The Eastern or American Oyster.[iv]

New York Harbor's oysters served as a keystone species, improving their marine environments and supporting life both above and below the water. From the early 17th to 20th centuries, oysters provided sustenance and inherently valuable ecosystem services to the region by filtering water, providing habitat for other marine species and protecting the shoreline through attenuating wave energy[v]. By 1880, New York was harvesting 700 million oysters a year, consumed in kitchens throughout the City[vi]; however, by 1927, over consumption and a toxic harbor defined by ever-increasing amounts of waste and raw sewage, all but eliminated oysters from the harbor.[vii] Today, New York Harbor's water quality is the best it has been in over a century[viii] and, led by the Billion Oyster Project, the American oyster is returning to what was once its greatest habitat.

Blue Infrastructure

Employing oysters as ecosystem engineers that can generate savings through water filtration and other ecosystem services has a strong historical precedent. The Billion Oyster Project (BOP) is an initiative of the New York Harbor Foundation focused on "restoring one billion oysters to New York Harbor through in-water restoration based on Science, Technology, Engineering and Math (STEM) educational programs." In addition, "the BOP collects oyster shells from 45 restaurants, trains teachers at 50 schools and works directly with students at New York Harbor School to design build and monitor reefs all in the murky, polluted, fast-moving waters of one of the busiest ports in the nation."[ix] As of August 8th, 2016, the BOP had restored

17 million oysters to the harbor, filtered 19.7 trillion gallons of water, removed 72,500 pounds of nitrogen and recycled 250,350 pound of oyster shell over the last six years.[x]

Murray Fisher is the co-founder of The Billion Oyster Project and Founder of The New York Harbor School. As a part of this report Fisher was interviewed in order to develop a deeper understanding of the BOP's operations. Currently the BOP is funded by a variety of grants including a recent award from the National Science Foundation of $5 million. The project's success has begun to attract broader interest, moving it from the philanthropic grant stage towards one where returns could be generated through ecosystem services and associated savings.[xi]

Mr. Fisher is particularly focused on the concept of "blue infrastructure", water-based natural infrastructure that offers the opportunity to undercut traditional gray infrastructure, such as water treatment plants and concrete storm surge barriers, on a cost-basis while generating additional ecosystem services. Blue infrastructure builds on New York City's increasingly popular green infrastructure developments, and leverages the inherent engineering efficiency of natural infrastructure to achieve desired outcomes.

As ecosystem engineers' endemic to New York Harbor, the American Oyster performs a plethora of innately valuable ecosystem services. Mr. Fisher described the full range of cost-effective savings opportunities provided by New York's oyster reefs, including: water filtration, coastal resilience through wave attenuation, carbon sequestration, local fishery development, aquatic ecosystem reconstruction, workforce development, educational opportunities, eco-tourism, and waterfront real estate value creation.

Financial Findings and Summary

Discussions with the BOP helped to shape this report's ecosystem service valuation methodology, discounted cash flow model, and financial analysis. Determining which of these services might be able to generate immediate savings and cash flows was a key consideration. This project's valuation methodology focused on the American Oyster's ability to filter wastewater discharged into New York Harbor. As filter-feeding bivalves, oysters can be thought of as small organic water filtration pumps, capable of filtering up to 50 gallons of wastewater per day.[xii]

Currently New York City commits nearly $376 million annually to wastewater treatment infrastructure and operation.[xiii] This report's valuation methodology and financing approach reviewed the potential benefits of employing oysters as a water filtration strategy on a broad-scale. The resulting analysis builds upon the BOP's target of the restoration of one billion oysters to New York Harbor.

This report reveals a distinct opportunity of oyster reefs as a blue infrastructure solution to under-cut New York City's current gray infrastructure approach while generating additional savings and value creation as highlighted below:

- The effective re-integration of oyster reefs at this scale would generate approximately $22 million in savings annually in water filtration costs when compared to current wastewater facility costs.
- The reintroduction of one billion oysters would result in $85 million annually in associated non-water filtration ecosystem services.
- Ultimately, at an installation cost of $155 million, one billion oysters could generate $337 million in wastewater treatment savings throughout New York City on an NPV basis over a 20-year period (Exhibit 2).

Gray Infrastructure Limitations

New York City's wastewater treatment plants currently address roughly 85% of the pollutants within wastewater before releasing it into the Hudson River Estuary as mandated by the Clean Water Act of 1972.[xiv] Despite significant gray infrastructure investment on storm water management, the City struggles to address pollutants that have been released directly into its waterways. Contemporary strategies such as dredging and iodine treatment are environmentally damaging and cannot be considered cost effective. New York's treatment efforts are focused on point source pollution controls, limiting the harmful nature of the discharge of pollutants through wastewater treatment and sewage plants, but do not effectively address water pollution after wastewater has been released.

During a high rain event, due to the City's limitations as a combined sewer system, only 70% of wastewater treatment plants effectively filter water.[xv] During these events, pollutants and raw sewage are dumped directly into New York's water bodies. As a result, the current approach

to storm water management and water filtration will likely not support the City's goal of opening 90% of its waterways to recreational use by 2030.[xvi]

Oysters Reef Restoration - Natural Infrastructure's Role

According to the World Resources Institute (WRI), "By 2030, the world is projected to spend an estimated $10 trillion on repairing and expanding water infrastructure."[xvii] Oyster reef restoration is one of the many natural infrastructure alternatives that offers multiple ecosystem services, specifically water quality improvement, seashore stabilization, carbon burial, habitat provisioning for mobile fish and invertebrates, habitat for epibenthic fauna, diversification of the landscape, and actual oyster production.[xviii] For the purposes of this report, the targeted ecosystem service of oyster reef restoration in NYC is the water quality improvement through water filtration.

According to Mr. Fisher, the president and co-founder of New York Harbor Foundation, "The actual standing volume of New York harbor is 74 billion gallons, and if an adult oyster filters 1 gallon of water an hour, one billion oysters would be (filtering) 24 billion gallons of water a day. Which means that, theoretically the standing volume of the harbor would be filtered once every three days."[xix] In partnership with the New York Harbor Foundation, the BOP aims to provide an ongoing natural water filtering service to New York's harbor. "Restoring oysters and reefs will, over time, restore the local marine ecosystem's natural mechanisms for maintaining itself, resulting in cleaner water and greater biodiversity."[xx]

In developing a water filtration valuation methodology this analysis relied heavily on Grabowski et al.'s "Economic Valuation of Ecosystem Services Provided by Oyster Reefs", published in *BioScience*. This study provides a framework for the valuation of the ecosystem services of oyster reefs. In particular, our analysis focused on the "water quality services" and filtration services delivered by oysters. Using Grabowski et al.'s analysis, which details the annual value of ecosystem services provided by oyster reefs on a per hectare basis (Exhibit 1), this report determines that oysters are cost competitive with the City's contemporary wastewater treatment expenditure.

In addition, Grabowski et al.'s ecosystem services table provides an estimate of the full range of benefits provide by broad-scale oyster reintroduction. Although the effective valuation of oyster ecosystem services is in its infancy, and thus carries with it certain risks and liabilities

as a valuation methodology, the emerging body of research overwhelming supports the positive impacts associated with oysters' natural ecosystem regulating activities.

Oysters are particularly well suited to improve water quality, as they are filter feeders that subsist through removing particulates from the water column. Oyster reefs are specifically capable of removing a variety of substances from their aquatic surroundings including chlorophyll, bacterial biomass and nitrogen while simultaneously reducing water turbidity.[xxi] Unfortunately the economic value of chlorophyll and bacterial removal has yet to be quantified on a broad scale; however, nitrogen removal is a key consideration for current wastewater infrastructure as excess nitrogen can promote overstimulation of aquatic plants and algae harmfully limiting dissolved oxygen amounts within water bodies.[xxii]

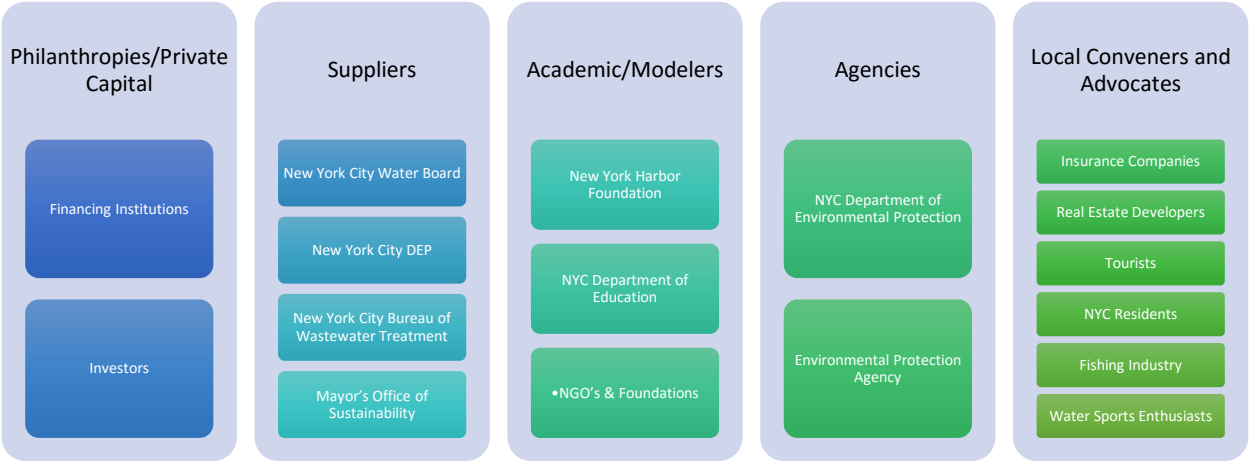
This report compared the current amount of nitrogen removed by oysters within the Hudson River Estuary based on data provided by the BOP with the nitrogen removal retrofit expenses currently associated with wastewater treatment plants according to New York's Nitrogen Control Action Plan[xxiii]. The resulting analysis determined that an oyster is able to filter nitrogen at roughly 7% efficiency of a wastewater treatment plant on a per-pound of nitrogen. In contrast, each gallon of conventionally treated wastewater is equivalent to roughly 14.3 gallons of wastewater filtered by oysters. Ultimately, despite being less efficient on a gallon-to-gallon basis, an oyster is capable of filtering between 10 and 50 gallons of water a day and collectively can remove nitrogen at a fraction of the cost of New York's current wastewater treatment plants.

New York City's Department of Environmental Protection (DEP) states that the current wastewater treatment system treats 1.3 billion gallons of wastewater a day. This existing infrastructure requires over 6,000 miles of sewer pipes; 135,000 sewer catch basins, over 495 permitted outfalls for the discharge of combined sewer overflows (CSOs), and 95 wastewater pumping stations that transport it to 14 wastewater treatment plants located throughout the five boroughs.[xxiv] The process applied at the wastewater treatment plant consists of five major processes: preliminary treatment, primary treatment, secondary treatment, disinfection and finally, sludge treatment.

Primary and secondary treatments remove roughly 85% of pollutants from wastewater before it is disinfected and discharged into local waterways.[xxv] The water filtration system provided by oysters seem less complex and less labor intensive: "oysters are filter feeders,

consuming phytoplankton (free-swimming algae) and improving water quality while they filter their food from the water." [xxvi]

Stakeholders



The stakeholder outreach for the ecosystem services provided by oyster reintroduction in New York City is vast. Core stakeholders include the Mayor's Office of Sustainability, the NYC DEP, and the NYC Water Board. Direct stakeholders include the EPA, NYC Department of Education that is designated to the BOP, and The Harbor Foundation. Various NGO's (non government organizations), foundations, and investors who have something to gain from benefits of the oyster reefs in the harbor are also a part of this projects direct stakeholders. Indirectly, oyster reefs will also have an immense reach to City residents, tourists, water sport enthusiasts, and the aquatic ecosystems and fishing industries that call the harbor home.

Regulatory Framework

The Clean Water Act (CWA) of 1972 is currently the dominant regulatory framework in determining New York Harbor's water quality.[xxvii] This act requires the removal of 85% of all pollutants before wastewater is released from the City's treatments plants. As a result of the CWA, water quality has improved to the point in which oysters have been able to be reintroduced to the harbor successfully. While the 85% pollutant removal minimum set by the CWA is the contemporary threshold for wastewater before it is released into New York Harbor, there are distinct benefits to restoring the harbor itself and continuing to improve water quality within the City's waterways.

Over the past 10 years, the City has invested over $10 billion in improving water quality, which is the highest in over a century.[xxviii] Bacteria levels are down and oxygen levels are up throughout New York City's waterways, which signifies dramatic improvement and a strong start towards reaching PlaNYC's goal of opening 90% of the City's waterways to recreation by 2030[xxix]. Ultimately, the CWA set a strong precedent for water quality improvement within New York. Given the City's current policy ambitions and the dormant economic opportunities inherent within its waterways, continued efforts to improve water quality beyond the CWA's minimum to meet PlaNYC's goal is expected.

It is expected that the broad-scale reintroduction of oysters as a blue infrastructure strategy will be a crucial part of this process. Oysters can continually filter water, even after it has been released by wastewater treatment plants, and could help meet regulatory requirements such as the CWA. Oysters offer a unique blue infrastructure opportunity that can be blended with the wastewater treatment plant gray infrastructure to improve water quality throughout the Hudson River Estuary.

Valuing Blue and Gray Infrastructure

This report's research uncovered a variety of oyster rehabilitation projects including a notable program in The Chesapeake Bay focused on nutrient trading. Current oyster reintroduction work in Mobile Bay, Alabama, however, provides the strongest basis for this analysis.

The Nature Conservancy has documented Mobile's efforts and has shown that the oyster reef restoration makes both good economic and social sense. Alabama made a one-time investment of $150 million, which provided the funding to build 100 miles of oysters reefs over the next decade. The reef was placed in the northern Gulf of Mexico and has provided a hefty return on investment for the state. Mobile realized an annual increase of sales by $7.3 million in the commercial seafood supply chain, and revenue and of crab, fish, and oyster harvests increased by $7.87 million annually. Mobile is expecting to support an additional 380 jobs per year during the 10-year construction phase of the reef. In the case of Alabama, this represents a major boost in employment opportunities for the coastal communities.

The oysters protect shorelines by absorbing wave energy by 76%-93%, and Mobile has shown that the reefs are more cost-effective in the long term when compared to grey

infrastructure costs that property owners would be spending on construction and replacement of rip-rap or bulkheads. Protection from coastal erosion and flooding caused by waves has resulted in $150 million in savings for property owners, as construction of bulkheads is no longer required. Studying Mobile reveals that a large-scale oyster restoration project can result in a resilient coastal ecosystem while being economically sustainable and provide a wide opportunity to raise funds for natural infrastructure.

Given the information gathered from Mobile, this report identified potential funding sources for the oyster reefs in New York City including property insurance companies, real estate developers, the NYC Water Board, and the aforementioned stakeholders.

Financing Oyster Reintroduction

The reintroduction of oyster reefs to New York can be a cost effective method for wastewater filtration. After quantifying these benefits, this analysis reveals that a strong claim can be made on a portion of the public dollars devoted to this necessary function. Public dollars will likely be the primary source of revenue for the project as its economic value comes largely from the savings generated for the State and City. There is opportunity to solicit private investment as well. Most applicably, this would be through fixed income investment. There are also tangential benefits such as contributions to coastal resilience through wave attenuation, and potential commercial benefits to augmenting local fish populations that could attract private dollars as well. Discussed below are some of the means through which funding can be generated

Public: The current budget for green infrastructure construction is insufficient for introducing oyster reefs at a scale needed to impact wastewater filtration. The PlaNYC report from 2012 calls for only $2 million in new investment in green infrastructure. The total investment needed to install one billion oysters would be approximately $155 million (Exhibit1). Therefore, new and additional sources of revenue beyond the PlaNYC budget would need to be secured.

One potential means of revenue sourcing could be from a Tax Increment Financing (TIF) program. Typically, such programs are used as subsidies for community improvement projects whereby the assumed incremental tax revenue resulting from the improvements are dedicated to future repayment of the costs of improvements. In the case of the BOP, as opposed to future tax revenues, the source of repayment would be

through the savings generated as oysters supplement existing methods employed for water filtration. Details of the savings are shown in Exhibits 1 and 2.

Private: Private capital can be engaged through a green bond offering issued by the New York City municipality. Green bonds are borrowings issued by municipalities and in some cases private entities in which the proceeds are pledged to finance projects aimed at energy efficiency, pollution prevention, sustainable agriculture, the protection of aquatic and terrestrial ecosystems, clean transportation, sustainable water management, and the cultivation of environmentally friendly technologies.

Green bond issuance totaled $41.8 billion in 2015 so there exists a deepening marketplace by which the funds can be raised. This analysis demonstrates the value in oyster reefs in contributing to the health of New York waterways. As a result oyster reintroduction can qualify for green bond status with the offering, and attract the private capital dedicated to sustainable and socially responsible investing. Additionally, with the backing of the City as a known borrowing entity eligible for attractive rates, interest costs could be minimized. Currently the S&P New York Municipal Bond Index is quoting a yield of 2.75%. As a result, this is the interest rate used in all of this report's borrowing cost calculations. This is the interest rate used for calculating the borrowing costs associated with this project.

Conclusion

This analysis evaluated a project in which New York City could raise $155 million through a green bond offering at an interest rate of 2.75% to finance the installation of reefs supporting one billion oysters in the Hudson River Estuary. In doing so, these reefs can supplement water filtration services that the City is currently accomplishing through a combination of gray and green infrastructure methods. The net present value of the costs of this project including initial installation, annual maintenance, and financing charges, equals approximately $495.7 million (Exhibit 2). This value can be compared to the net present value of $832.4 million that the City is currently paying for comparable services. Ultimately the Billion Oyster Project has the potential to return a savings of $336.7 million over a 20-year span and is worthy of investment.

Some important notes for understanding this project's discounted cash flow model:

- All assumptions and sources are listed in Exhibit 1.
- The financial model employed in this analysis is included in the attached spreadsheet under Exhibit 2.
- The expenses associated with the current gray and green processes for water filtration are multiplied by a factor of 7% to account for the fact that on average an oyster can perform approximately 7% of the water filtration function of typical gray infrastructure processes on a nitrogen removal basis.
- Initial expenses are 7% of those listed in Exhibit 1 as a result of the above.
- An interest rate of 2.75% was used to raise capital through the City based on the current S&P New York Municipal Bond Index yield of 2.75%.
- The discount rate of 2% is based on the current 20 year U.S. Treasuries, and thus is an appropriate risk free rate at which to discount the cash flow.
- Expenses for all processes are assumed to grow at an annual rate of 2%, as an estimate of inflation.
- This report's base financial model assumed that the full investment required to fund the project would be borrowed.
- Exhibit 3 illustrates a version of the cashflow model in which some philanthropic revenue offset some costs. Overall, any philanthropy dollars would reduce installation and financing expenses and make the project even more appealing.
- This report's base financial model assumed that the only value of the project is cost savings realized from undercutting traditional water filtration approaches.
- In Exhibit 4, alternatively, a version of the model employed includes a broader range of additional ecosystem services oysters provide through marine life restoration value (per a study from Urban Habitats). Exhibit 4 details these potential revenue sources.
- The sourcing for the study is shown in Exhibit 1 as well as earlier in the paper.
    - Note that this analysis also identified other potential economic benefits through ecosystem service savings. If included, these services would meaningfully add to the benefits of the project. As they were additional large potential benefits in the

context of this water filtration-focused model, this report chose to exclude them pending further study for the sake of providing a more conservative estimate.

Exhibit 1:

Table 4. Total annual value of ecosystem services provided by oyster reefs in 2011 dollars per hectare per year.

Ecosystem service values	Minimum	Maximum	Average
Oyster habitat state			
Pristine	12,186	21,959	17,072
Degraded	880	880	880
Finfish and mobile crustacean value			
Recreational	n/a	n/a	n/a
Commercial	4123	4123	4123
Water quality services			
Chlorophyll *a* removal[a]	0	0	0
Nitrogen removal[b]	1385	6716	4050
Recreational use	n/a	n/a	n/a
SAV enhancement[c]	0	2584	1292
Bacterial removal	n/a	n/a	n/a
Carbon burial	n/a	n/a	n/a
Shoreline protection[c]	0	85,998	860
Habitat for epibenthic infauna	0	0	0
Landscape processes	0	0	0
Nonoyster harvest service total	5508	99,421	10,325

Note: n/a represents insufficient data to assess the economic value of the service.

[a]The value of chlorophyll *a* removal was not included in the summary table because this service is considered potentially redundant if nitrogen removal through denitrification is also considered.

[b]The value of nitrogen removal was estimated by quantifying the value of enhanced denitrification rates on oyster reefs.

[c]The average submerged aquatic vegetation (SAV) enhancement and shoreline stabilization was valued assuming that 1% of the linear length of reefs perform this function.

Exhibit 1

Key Metric Examined	Amount / %
Total Gallons treated daily	1,300,000,000
Current % of pollutants removed	85%
BWT annual operation budget	$262,000,000
BWT annual capital budget	$114,000,000
BWT Gallons Treated Daily	1,400,000,000

Current "Gray" Infrastructure Annual Costs	$376,000,000
Current "Gray" Infrastructure Costs per day	$1,030,137
Current "Gray" Infrastructure Costs per gallon	$0.0008
Current "Gray" Infrastructure Costs per hundred cubic feet	**$0.592765**

Current "Green" Infrastructure Annual Capital Funding	$ 187,474,641
Current "Green" Infrastructure Annual Expenses	$ 14,159,022
Current "Green" Infrastructure Costs per day	$ 552,421
Current "Green" Infrastructure Costs per gallon	$0.0004
Current "Green" Infrastructure Costs per HCF	**$ 0.317876**

Projected NYC Oyster Development Costs

Exhibit 1

Oyster Annual Seed Costs (per acre)	$10,000
Oyster Racks and Infrastructure Annual Cost (per acre)	$2,000
Maintenance Hours (12 hours per day)	$ 65,700
Total annual costs to install an acre of oysters	$ 77,700
Oysters per acre	500,000
Oyster growth time 0 - 5 years see columns M through S	
Labor Reduction Rate	after year 5 down 2 hours each year untill
Growth Rate	See Row 35

Annual cost to Install an Oyster (including maintanance)	$0.16
Daily oyster costs	$0.000426
Total gallons filtered per oyster per day	10
Gallon to Gallon Ratio	7%
WWTP Gallon Equivalent of 10 gallons of oyster filtration	0.7
Oyster Water Filtration cost per gallon	$0.000607
Oyster Water Filtration costs per HCF	**$0.454217**
Oyster daily costs to filter 1.3 bilion gallons watewater	$ 789,361

Exhibit 1

NYC Oyster Installation Costs	
Costs to install one billion oysters	$155,400,000
Total Gallons Filtered by one billion oysters	701,174,028
Percentage of current water filtration hypothetically replaced by 1 billion by oysters	54%
Acres of oysters required to reach one billion oysters	2,000

Additional Benefits (based on 1billion Oysters Installed)	
Annual flood reduction savings per hectacre	$99,695
Acres per hectacre	2.47
Annual shoreline protection savings per acre	$40,362.45
Total annual shoreline protection savings per one billion oysters	$ 80,724,900
Annual marine life restoration value per hectacre	$4,780
Annual marine life restoration value per acre	$ 1,935
Total annual marine life restoration value per one billion oysters	$ 3,870,192
Annual SAV removal savings per hectacre	$ 1,498
Annual SAV removal savings per acre	$ 606.39
Total annual SAV savings removal per one billion oysters	$ 1,212,779
Total annual ecosystem service savings	$ 85,807,871

Exhibit 2

Comparison Of Costs Between Current Water Filtration Methods And Oyster Reefs

		0	1	2	3	4	5	6	7	8	9	10
		2016	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**
Operating Expenses												
Current Gray Fixed Costs												
BWT annual operation budget		$ 18,340,000	$ 18,706,800	$ 19,080,936	$ 19,462,555	$ 19,851,806	$ 20,248,842	$ 20,653,819	$ 21,066,895	$ 21,488,233	$ 21,917,998	$ 22,356,358
BWT annual capital budget		$ 7,980,000	$ 8,139,600	$ 8,302,392	$ 8,468,440	$ 8,637,809	$ 8,810,565	$ 8,986,776	$ 9,166,512	$ 9,349,842	$ 9,536,839	$ 9,727,575
Current Green Fixed Costs												
Annual Capital Funding		$ 13,123,225	$ 13,385,689	$ 13,653,403	$ 13,926,471	$ 14,205,001	$ 14,489,101	$ 14,778,883	$ 15,074,460	$ 15,375,950	$ 15,683,469	$ 15,997,138
Annual Operating Expenses		$ 991,132	$ 1,010,954	$ 1,031,173	$ 1,051,797	$ 1,072,833	$ 1,094,289	$ 1,116,175	$ 1,138,499	$ 1,161,269	$ 1,184,494	$ 1,208,184
Total Expenses (Current)		$ 40,434,356	$ 41,243,044	$ 42,067,904	$ 42,909,262	$ 43,767,448	$ 44,642,797	$ 45,535,653	$ 46,446,366	$ 47,375,293	$ 48,322,799	$ 49,289,255
NPV (2% discount rate)	$832,472,044											
Billion Oyster Project Costs												
Installation Costs		$155,400,000										
Maintenance Costs			$9,353,400	$9,540,468	$9,731,277	$9,925,903	$10,124,421	$10,326,909	$10,533,448	$10,744,117	$10,958,999	$11,178,179
Interest Expense			$10,205,387	$10,205,387	$10,205,387	$10,205,387	$10,205,387	$10,205,387	$10,205,387	$10,205,387	$10,205,387	$10,205,387
Total Expenses (Current)		$155,400,000	$19,558,787	$19,745,855	$19,936,664	$20,131,290	$20,329,808	$20,532,296	$20,738,835	$20,949,503	$21,164,386	$21,383,566
NPV (2% discount rate)	$495,757,553											

		11	12	13	14	15	16	17	18	19	20
		2027	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**
Operating Expenses											
Current Gray Fixed Costs											
BWT annual operation budget		$ 22,803,485	$ 23,259,555	$ 23,724,746	$ 24,199,241	$ 24,683,225	$ 25,176,890	$ 25,680,428	$ 26,194,036	$ 26,717,917	$ 27,252,275
BWT annual capital budget		$ 9,922,127	$ 10,120,570	$ 10,322,981	$ 10,529,441	$ 10,740,029	$ 10,954,830	$ 11,173,927	$ 11,397,405	$ 11,625,353	$ 11,857,860
Current Green Fixed Costs											
Annual Capital Funding		$ 16,317,081	$ 16,643,422	$ 16,976,291	$ 17,315,817	$ 17,662,133	$ 18,015,376	$ 18,375,683	$ 18,743,197	$ 19,118,061	$ 19,500,422
Annual Operating Expenses		$ 1,232,347	$ 1,256,994	$ 1,282,134	$ 1,307,777	$ 1,333,933	$ 1,360,611	$ 1,387,823	$ 1,415,580	$ 1,443,892	$ 1,472,769
Total Expenses (Current)		$ 50,275,040	$ 51,280,541	$ 52,306,152	$ 53,352,275	$ 54,419,320	$ 55,507,706	$ 56,617,861	$ 57,750,218	$ 58,905,222	$ 60,083,327
NPV (2% discount rate)	$832,472,044										
Billion Oyster Project Costs											
Installation Costs											
Maintenance Costs		$11,401,742	$11,629,777	$11,862,373	$12,099,620	$12,341,613	$12,588,445	$12,840,214	$13,097,018	$13,358,958	$13,626,138
Interest Expense		$10,205,387	$10,205,387	$10,205,387	$10,205,387	$10,205,387	$10,205,387	$10,205,387	$10,205,387	$10,205,387	$10,205,387
Total Expenses (Current)		$21,607,129	$21,835,164	$22,067,760	$22,305,007	$22,547,000	$22,793,832	$23,045,601	$23,302,405	$23,564,345	$23,831,525
NPV (2% discount rate)	$495,757,553										

Assumed Growth Rate Current	2.00%
Filtering Adjustment Factor	7.00%

Projected NYC Oyster Development Costs	
Oyster Annual Seed Costs (per acre)	$10,000
Oyster Racks and Infrastructure Annual Cost (per acre)	$2,000
Maintenance Hours (12 hours per day)	$ 65,700
Total annual costs to install an acre of oysters	$ 77,700
Oysters per acre	500,000

Annual cost to Install an Oyster (including maintanance)	$0.16
Daily oyster costs	$0.0004
Total gallons filtered per oyster per day	25
Oyster Water Filtration cost per gallon	$0.000017
Oyster Water Filtration costs per HCF	**$0.012739**
Oyster daily costs to filter 1.3 billion gallons watewater	$ 553,479

NYC Oyster Installation Costs	
Costs to install one billion oysters	$155,400,000
Total Gallons Filtered by one billion oysters	25,000,000,000
Percentage of current water filtration hypothetically replaced by 1 billion by oysters	1923%
Acres of oysters required to reach one billion oysters	2,000

Green Bond Borrowing	$155,400,000
Rate	2.75%

Exhibit 3

Comparison Of Costs Between Current Water Filtration Methods And Oyster Reefs

		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
		2016	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**
Operating Expenses																						
Current Gray Fixed Costs																						
BWT annual operation budget		$ 18,340,000	$ 18,706,800	$ 19,080,936	$ 19,462,555	$ 19,851,806	$ 20,248,842	$ 20,653,819	$ 21,066,895	$ 21,488,233	$ 21,917,998	$ 22,356,358	$ 22,803,485	$ 23,259,555	$ 23,724,746	$ 24,199,241	$ 24,683,225	$ 25,176,890	$ 25,680,428	$ 26,194,036	$ 26,717,917	$ 27,252,275
BWT annual capital budget		$ 7,980,000	$ 8,139,600	$ 8,302,392	$ 8,468,440	$ 8,637,809	$ 8,810,565	$ 8,986,776	$ 9,166,512	$ 9,349,842	$ 9,536,839	$ 9,727,575	$ 9,922,127	$ 10,120,570	$ 10,322,981	$ 10,529,441	$ 10,740,029	$ 10,954,830	$ 11,173,927	$ 11,397,405	$ 11,625,353	$ 11,857,860
Current Green Fixed Costs																						
Annual Capital Funding		$ 13,123,225	$ 13,385,689	$ 13,653,403	$ 13,926,471	$ 14,205,001	$ 14,489,101	$ 14,778,883	$ 15,074,460	$ 15,375,950	$ 15,683,469	$ 15,997,138	$ 16,317,081	$ 16,643,422	$ 16,976,291	$ 17,315,817	$ 17,662,133	$ 18,015,376	$ 18,375,683	$ 18,743,197	$ 19,118,061	$ 19,500,422
Annual Operating Expenses		$ 991,132	$ 1,010,954	$ 1,031,173	$ 1,051,797	$ 1,072,833	$ 1,094,289	$ 1,116,175	$ 1,138,499	$ 1,161,269	$ 1,184,494	$ 1,208,184	$ 1,232,347	$ 1,256,994	$ 1,282,134	$ 1,307,777	$ 1,333,933	$ 1,360,611	$ 1,387,823	$ 1,415,580	$ 1,443,892	$ 1,472,769
Total Expenses (Current)		$ 40,434,356	$ 41,243,044	$ 42,067,904	$ 42,909,262	$ 43,767,448	$ 44,642,797	$ 45,535,653	$ 46,446,366	$ 47,375,293	$ 48,322,799	$ 49,289,255	$ 50,275,040	$ 51,280,541	$ 52,306,152	$ 53,352,275	$ 54,419,320	$ 55,507,706	$ 56,617,861	$ 57,750,218	$ 58,905,222	$ 60,083,327
NPV (2% discount rate)	$832,472,044																					
Billion Oyster Project Revenues																						
Philanthropy			$ 10,000,000	$ 10,200,000	$ 10,404,000	$ 10,612,080	$ 10,824,322	$ 11,040,808	$ 11,261,624	$ 11,486,857	$ 11,716,594	$ 11,950,926	$ 12,189,944	$ 12,433,743	$ 12,682,418	$ 12,936,066	$ 13,194,788	$ 13,458,683	$ 13,727,857	$ 14,002,414	$ 14,282,462	$ 14,568,112
Billion Oyster Project Costs																						
Installation Costs		$155,400,000																				
Maintenance Costs			$9,353,400	$9,540,468	$9,731,277	$9,925,903	$10,124,421	$10,326,909	$10,533,448	$10,744,117	$10,958,999	$11,178,179	$11,401,742	$11,629,777	$11,862,373	$12,099,620	$12,341,613	$12,588,445	$12,840,214	$13,097,018	$13,358,958	$13,626,138
Interest Expense			$10,205,387	$10,205,387	$10,205,387	$10,205,387	$10,205,387	$10,205,387	$10,205,387	$10,205,387	$10,205,387	$10,205,387	$10,205,387	$10,205,387	$10,205,387	$10,205,387	$10,205,387	$10,205,387	$10,205,387	$10,205,387	$10,205,387	$10,205,387
Total Expenses (Current)		$155,400,000	$9,558,787	$9,545,855	$9,532,664	$9,519,210	$9,505,486	$9,491,488	$9,477,210	$9,462,647	$9,447,792	$9,432,640	$9,417,185	$9,401,421	$9,385,342	$9,368,941	$9,352,212	$9,335,148	$9,317,744	$9,299,991	$9,281,883	$9,263,413
NPV (2% discount rate)	$303,523,797																					

Assumed Growth Rate Current	2.00%
Filtering Adjustment Factor	7.00%

Projected NYC Oyster Development Costs	
Oyster Annual Seed Costs (per acre)	$10,000
Oyster Racks and Infrastructure Annual Cost (per acre)	$2,000
Maintenance Hours (12 hours per day)	$ 65,700
Total annual costs to install an acre of oysters	$ 77,700
Oysters per acre	500,000

Annual cost to Install an Oyster (including maintanance)	$0.16
Daily oyster costs	$0.0004
Total gallons filtered per oyster per day	25
Oyster Water Filtration cost per gallon	$0.000017
Oyster Water Filtration costs per HCF	**$0.012739**
Oyster daily costs to filter 1.3 bilion gallons watewater	$ 553,479

NYC Oyster Installation Costs	
Costs to install one billion oysters	$155,400,000
Total Gallons Filtered by one billion oysters	25,000,000,000
Percentage of current water filtration hypothetically replaced by 1 billion by oysters	1923%
Acres of oysters required to reach one billion oysters	2,000

Green Bond Borrowing	$155,400,000
Rate	2.75%

Exhibit 4

Comparison Of Costs Between Current Water Filtration Methods And Oyster Reefs

		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
		2016	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**
Operating Expenses																						
Current Gray Fixed Costs																						
BWT annual operation budget		$ 18,340,000	$ 18,706,800	$ 19,080,936	$ 19,462,555	$ 19,851,806	$ 20,248,842	$ 20,653,819	$ 21,066,895	$ 21,488,233	$ 21,917,998	$ 22,356,358	$ 22,803,485	$ 23,259,555	$ 23,724,746	$ 24,199,241	$ 24,683,225	$ 25,176,890	$ 25,680,428	$ 26,194,036	$ 26,717,917	$ 27,252,275
BWT annual capital budget		$ 7,980,000	$ 8,139,600	$ 8,302,392	$ 8,468,440	$ 8,637,809	$ 8,810,565	$ 8,986,776	$ 9,166,512	$ 9,349,842	$ 9,536,839	$ 9,727,575	$ 9,922,127	$ 10,120,570	$ 10,322,981	$ 10,529,441	$ 10,740,029	$ 10,954,830	$ 11,173,927	$ 11,397,405	$ 11,625,353	$ 11,857,860
Current Green Fixed Costs																						
Annual Capital Funding		$ 13,123,225	$ 13,385,689	$ 13,653,403	$ 13,926,471	$ 14,205,001	$ 14,489,101	$ 14,778,883	$ 15,074,460	$ 15,375,950	$ 15,683,469	$ 15,997,138	$ 16,317,081	$ 16,643,422	$ 16,976,291	$ 17,315,817	$ 17,662,133	$ 18,015,376	$ 18,375,683	$ 18,743,197	$ 19,118,061	$ 19,500,422
Annual Operating Expenses		$ 991,132	$ 1,010,954	$ 1,031,173	$ 1,051,797	$ 1,072,833	$ 1,094,289	$ 1,116,175	$ 1,138,499	$ 1,161,269	$ 1,184,494	$ 1,208,184	$ 1,232,347	$ 1,256,994	$ 1,282,134	$ 1,307,777	$ 1,333,933	$ 1,360,611	$ 1,387,823	$ 1,415,580	$ 1,443,892	$ 1,472,769
Total Expenses (Current)		$ 40,434,356	$ 41,243,044	$ 42,067,904	$ 42,909,262	$ 43,767,448	$ 44,642,797	$ 45,535,653	$ 46,446,366	$ 47,375,293	$ 48,322,799	$ 49,289,255	$ 50,275,040	$ 51,280,541	$ 52,306,152	$ 53,352,275	$ 54,419,320	$ 55,507,706	$ 56,617,861	$ 57,750,218	$ 58,905,222	$ 60,083,327
NPV (2% discount rate)	$832,472,044																					
Billion Oyster Project Revenues																						
Total annual marine life restoration			$ 3,870,192	$ 3,947,596	$ 4,026,548	$ 4,107,079	$ 4,189,220	$ 4,273,005	$ 4,358,465	$ 4,445,634	$ 4,534,547	$ 4,625,238	$ 4,717,742	$ 4,812,097	$ 4,908,339	$ 5,006,506	$ 5,106,636	$ 5,208,769	$ 5,312,944	$ 5,419,203	$ 5,527,587	$ 5,638,139
Billion Oyster Project Costs																						
Installation Costs		$155,400,000																				
Maintenance Costs			$9,353,400	$9,540,468	$9,731,277	$9,925,903	$10,124,421	$10,326,909	$10,533,448	$10,744,117	$10,958,999	$11,178,179	$11,401,742	$11,629,777	$11,862,373	$12,099,620	$12,341,613	$12,588,445	$12,840,214	$13,097,018	$13,358,958	$13,626,138
Interest Expense			$10,205,387	$10,205,387	$10,205,387	$10,205,387	$10,205,387	$10,205,387	$10,205,387	$10,205,387	$10,205,387	$10,205,387	$10,205,387	$10,205,387	$10,205,387	$10,205,387	$10,205,387	$10,205,387	$10,205,387	$10,205,387	$10,205,387	$10,205,387
Total Expenses (Current)		$155,400,000	$15,688,595	$15,798,259	$15,910,117	$16,024,211	$16,140,588	$16,259,292	$16,380,370	$16,503,869	$16,629,839	$16,758,328	$16,889,387	$17,023,067	$17,159,421	$17,298,501	$17,440,364	$17,585,063	$17,732,657	$17,883,202	$18,036,758	$18,193,386
NPV (2% discount rate)	$421,359,400																					

Assumed Growth Rate Current	2.00%
Filtering Adjustment Factor	7.00%

Projected NYC Oyster Development Costs	
Oyster Annual Seed Costs (per acre)	$10,000
Oyster Racks and Infrastructure Annual Cost (per acre)	$2,000
Maintenance Hours (12 hours per day)	$ 65,700
Total annual costs to install an acre of oysters	$ 77,700
Oysters per acre	500,000

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Oyster Water Filtration costs per HCF	**$0.012739**
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NYC Oyster Installation Costs	
Costs to install one billion oysters	$155,400,000
Total Gallons Filtered by one billion oysters	25,000,000,000
Percentage of current water filtration hypothetically replaced by 1 billion by oysters	1923%
Acres of oysters required to reach one billion oysters	2,000

Green Bond Borrowing	$155,400,000
Rate	2.75%

Additional Benefits (based on 1billion Oysters Installed)	
Annual flood reduction savings per hectacre	$99,695
Acres per hectacre	2.47
Annual shoreline protection savings per acre	$40,362.45
Total annual shoreline protection savings per one billion oysters	$ 80,724,900
Annual marine life restoration value per hectacre	$4,780
Annual marine life restoration value per acre	$ 1,935
Total annual marine life restoration value per one billion oysters	**$ 3,870,192**
Annual SAV removal savings per hectacre	$ 1,498
Annual SAV removal savings per acre	$ 606.39
Total annual SAV savings removal per one billion oysters	$ 1,212,779
Total annual ecosystem service savings	$ 85,807,871

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http://www.nyc.gov/html/dep/pdf/green_infrastructure/gi_annual_report_2016.pdf pgs 12 and13

NYC Water Board 2015 Report - current gray infrastructure costs and rate info:

http://www.nyc.gov/html/nycwaterboard/pdf/blue_book/bluebook_2015.pdf pg. 1 and 6

Current Wastewater Treatment expenses: http://www.nyc.gov/html/dep/pdf/wwsystem.pdf pgs. 4 and 13

Ecosystem services and benefits:http://bioscience.oxfordjournals.org/content/62/10/900.full.pdf+html pg. 901

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