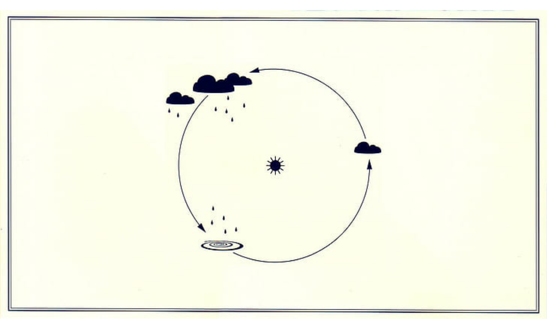
the belt

PROJECT BACKGROUND

Water is life: it is the most critical natural element and is necessary to sustain the life of all living things. Water is also a powerful and unpredictable force of nature having the ability to impact our environment without any warning. As such, we must pay close attention to Water Resource Management in our communities, neighborhoods and cities alike.

Being based in New York City, ACE Team 30 decided to address the Water Resource Management and Preservation issues impacting us locally. First, we analyzed global water resource management issues to understand the full breadth of the problem. Next, we applied this information to NYC and the surrounding areas to see what specific issues we could improve upon here.



GLOBAL WATER MANAGEMENT ISSUES

There are a number of water resource management and preservation issues facing us throughout the world. A summary of the most significant issues is below:

1. WATER SCARCITY - with increasing populations and urbanization, clean and potable water sources are diminishing and, in some parts of the world, obsolete. Access to safe, clean drinking water is not available to all. This poses an issue of global health crisis, economic distress, and population displacement.

2. CLIMATE CHANGE & SEA LEVEL RISE - sea level rise is caused by factors associated with global warming: (1) rising global temperatures cause rapid ice sheet melting and (2) seawater expands at higher temperatures. As Earth's climate continues to warm, the effects of climate change are increasingly apparent.

3. INCREASING VULNERABILITY TO SEVERE WEATHER EVENTS - due to climate change, we now experience more severe storm events than in the past, resulting in greater storm surge and intense flooding. Most communities are not equipped to recover quickly from such events, thus increasing vulnerability and potential for damage to existing infrastructure and property.

4. WATER POLLUTION - local and state regulations require municipalities to treat water to meet acceptable water quality standard prior to discharging into local water bodies. In many places, wastewater treatment plant capacities are not sufficient and combined sewer systems must discharge directly into recieving waterbodies prior to treatment.

5. AGING INFRASTRUCTURE - much of the worlds' water infrastructure was built over 100 years ago - in some places, centuries ago - and has come to the end of its useful life. Pipes and tunnels are leaking, mechanical and electrical equipment is failing and our water infrastructure is suffering because of it. Aging infrastructure results in unreliable systems, loss of water and water quality concerns.

LOCAL WATER MANAGEMENT ISSUES

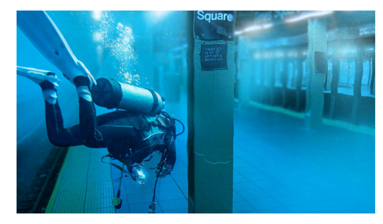
After analyzing the global water management and preservation issues, the team assessed the water management issues facing NYC. The team decided to address three main water management issues for this project.

CLIMATE CHANGE & SEA LEVEL RISE

Sea level surrounding NYC is projected to rise rapidly in the next 50-100 years. This issue could displace hundreds of thousands of New Yorkers and could also have a major economical impact. In order to protect the City, this issue must be addressed.

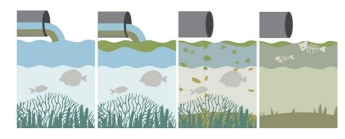
INCREASING VULNERABILITY TO SEVERE WEATHER EVENTS

Since NYC is surrounded by water, it is at a high risk of damage and flooding from severe weather events. NYC has experienced many devastating storm events in the past 20 years which have caused major disruptions to City operations and have put the City at risk for public safety and health concerns.



WATER POLLUTION

About 60% of New York City is on a combined sewer system which means both stormwater runoff and sewage are carried through a single pipe. During heavy rain events, sewers are inundated with higher flows than normal. Since treatment plants do not have the capacity to handle these high flows, the combined water is discharged into nearby waterways - these events are called Combined Sewer Overflows (CSOs). CSOs have a negative effect on water quality in NYC's waterways, which are recreational bodies and habitats to thousands of species.



EXISTING CONDITIONS

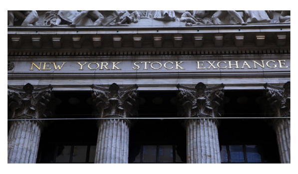
After identifying three major water management and preservation issues to address, Team 30 analyzed how these issues are impacting NYC. This analysis lead the team to conclude that Lower Manhattan is highly vulnerable to these three Water Management Issues.

LOWER MANHATTAN

For most of New York's 400 year history, the City only existed below Chambers Street. New York's rich history began in Lower Manhattan and many of its historical monuments still exist today: Ellis Island, Bowling Green Park, City Hall (the oldest city hall in the country), the Woolworth Building, New York Stock Exchange and Trinity Church, just to name a few. This area of NYC, known as Lower Manhattan or Downtown Manhattan, has evolved into the epicenter of finance, government and world commerce.

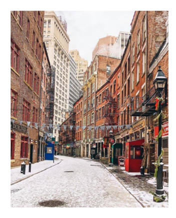
Today, this one square mile area of Lower Manhattan continues to flourish - see below for some statistics on the area:

BUSINESS
- 300,000 public & private sector employees, making up some 70% of the areas workforce
- Private sector employment at highest level since 2001
- 90 million square feet of office space, including buildings such as 1 World Trade Center



VISITORS AND TOURISM
- 14.6 million annual tourists
- 7700 hotel rooms and 35 hotels
- 12 new hotels under construction planned to open in the 2020's

ENTERTAINMENT & RESIDENTIAL
- Nearly 600 bars and restaurants
- Approximately 700 stores & storefront services
- 337 existing residential buildings with 17 under development
- 65,000 increase in residents in 2019



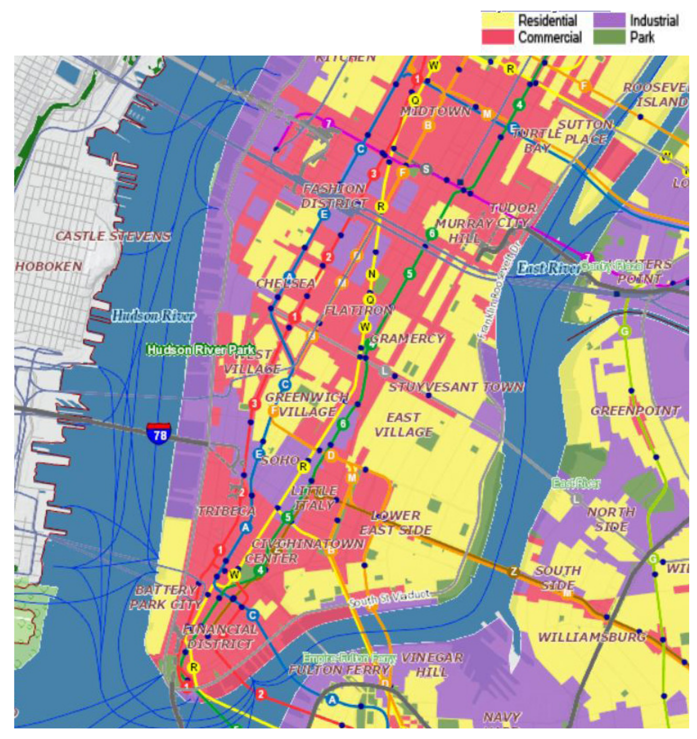
EDUCATION
- 27 K-12 public & private schools
- Total K-12 enrollment: 14,000
- 18 institutions of higher learning with total enrollment of 54,000

EXISTING CONDITIONS MAPPING

Lower Manhattan is zoned primarily as residential and commercial districts, with smaller areas of industrial and park land along the waterfront. Industrial areas are highly concentrated along the west side near existing piers. Residential areas and parkland are concentrated along the east side in the Lower East Side and East Village neighborhoods. Many NYC housing complexes are located in these two neighborhoods, as seen indicated in yellow on the map. As discussed previously, Lower Manhattan is also a heavy business district - as such, the large majority of the area is zoned as commercial.

There is a vast public transportation network in Lower Manhattan. The area has 13 of the 27 total MTA subway lines, 30 MTA bus routes and 17 commuter ferry lines leading to outer boroughs and New Jersey. In addition, there are three major bridges to Brooklyn - the Brooklyn Bridge, Williamsburg Bridge and Mahnattan Bridge - and two tunnels to Brooklyn and New Jersey, respectively - the Brooklyn Battery Tunnel and the Holland Tunnel.

Knowing that Lower Manhattan is a major business area and also a public transit hub with many connections both inside and outside the city, it was important for the Team to take this into consideration when developing their design elements.



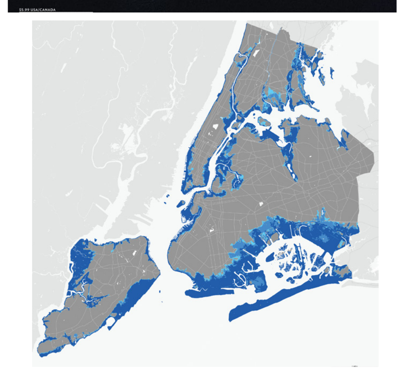
ZONING DISTRICTS, SUBWAY LINES & FERRY ROUTES

HISTORIC FLOODING

New York City has experienced many extreme storm events in the past century. Of the most extreme, most have occured within the past 30 years - amongst them, Hurricane Irma and Hurricane Sandy. These events have caused severe flooding, property damage and loss of life.

In October 2012, Hurricane Sandy hit NYC and caused a major amount of devastation - $19 billion in damages, 250,000 people without power, 17% of total landmass flooded and 43 deaths. Power loss and flooding was most severe in low-lying areas of Manhattan, specifically Lower Manhattan below 14th Street, as seen in the New York Magazine Cover Photo on the right. It took almost two weeks to fully restore power and return utilities to full operation. Storm surge also reached a record high in the Lower Manhattan area, reaching levels of about 14 feet high in New York Harbor.

The damage from Hurricane Sandy was so severe that many NYC agencies released reports outlining how they planned to recover quickly from future storm and flooding events in order to protect the public and the City's vital infrastructure. Amongst those plans were the NYC Department of Environmental Protection's Resiliency Plan for Wastewater Facilities, NYC Mayors Office East Side Coastal Resiliency Plan, NYC Residential Flood Insurance Affordability Study and MTA's Fix &



PROJECTED 100 YR & 500 YR FLOOD LEVELS

SEA LEVEL RISE PROJECTIONS

Four of NYC's five boroughs are completely surrounded by water, making the City very vulnerable to the effects of climate change and sea level rise.

Sea levels surrounding NYC have been slowly rising for years. Studies from the past decade have shown that levels are rising more rapidly than in the past, as much as 1 inch every 8 years, and are projected to rise exponentially in the next 100 years. Due to their low elevations, areas in Lower Manhattan, Staten Island and Southeast Brooklyn have seen higher sea level rise than other areas of the City. For perspective on this issue, the sea level surrounding Battery Park in Lower Manhattan has risen 6 inches in the past 40 years. This is a sharp increase as compared to other areas of the city.

Studies project that sea levels around NYC will rise 6 feet by 2100. The maps below show Lower Manhattan's current Mean Higher High Water (MHHW) level (or sea level) and future MHHW level with the 6 feet increase expected in 2100.

CURRENT SEA LEVEL

YEAR 2100 SEA LEVEL

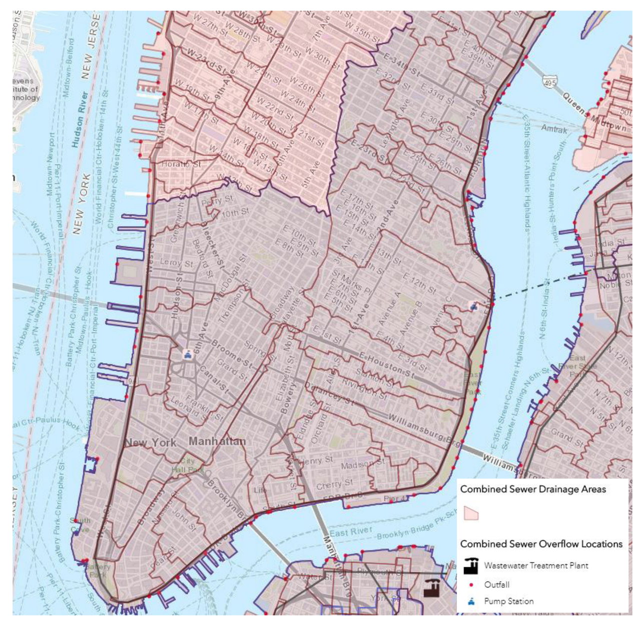
COMBINED SEWER OVERFLOWS (CSOs)

NYC has approximately 700 CSOs along its waterfront which discharge to open waters during wet weather events. Due to limited capacity at the City's 14 wastewater treatment plants and more frequent and severe wet weather events in recent years, CSOs have been discharging an average of 20 billion gallons of combined sewer overflows into New York City waterways annually. CSOs have a negative effect on water quality by introducing bacteria and decreasing oxygen concentration in waterways. They pose a hazard to ecosystems, an increase in algae growth, and lead to increases in carbon dioxide and methane production in tidal wetlands.

The City has implemented a Long Term Control Plan (LTCP) to help reduce the number of CSOs and thus improve water quality throughout the City. The plan has recommended increasing storage capacity via tunnels and/or tanks in order to capture overflows in lieu of immediately discharging to waterways.

Although Lower Manhattan was not considered in the LTCP for CSO management, there are still a significant number of outfalls in this area.

The map on the right shows the CSO outfalls and drainage areas in Lower Manhattan. There are approximately 38 outfalls on the east and west sides of Manhattan below 14th Street. This area also covers approximately 2.2 square miles of drainage area with two pumping stations which convey flows to Newtown Creek Wastewater Treatment Plant in North Brooklyn.



DESIGN ELEMENTS

FLOODING AND SEA LEVEL RISE SOLUTION

After identifying the three main water management issues, the team set out to design a flood and sea level rise resistant structure. Considerations for both a seawall and a berm were analyzed. These two very different structures would both protect Manhattan, but would have much different visual impacts to the well-established coast of Manhattan.

SEAWALL

Seawalls have been used in many coastal cities and towns around the US to protect land from storm surge. The seawall would be a vertical structure, built into the sediment and rock of the Hudson and East Rivers.

+
- provides excellent protection against sea level rise and flooding
- requires less space for construction and lower overall footprint

−
- integration into existing marine infrastructure, such as tunnels, would be challeneging and create gaps in the seawall
- visual impact of a wall around Manhattan would be non-favorable to New Yorkers who value coastal views

VS.

BERM

Berms are raised barriers separating two areas. The berm would be a concrete-box like structure filled with soil and other earthen material. The structure would be supported by piles, drilled into bedrock of the Hudson and East Rivers.

+
- pile placement could be coordinated with existing infrastructure as to not interfere
- create more space for park, residential, commercial space on the coastline of Manhattan
- more opportunity for funding options (commercial spaces could draw revenue)

−
- larger footprint
- larger capital cost
- more coordination with enviromental and permitting agencies

The design flood elevation for the 500-year storm (DFE500) was calculated based on the project site's Coastal Transect Data. This transect data dictates the stillwater elevation (E500), which is 12.9 [feet NAVD88] for the project site and accounts for wave run-up (maximum vertical extent of the wave when it hits the berm). The stillwater depth (d500) was calculated using the project site's average grade elevation of 10 [feet NAVD88], as

$$d_{500} = E_{500} - Average\ Grade\ Elevation$$

$$d_{500} = 12.9 - 10.0$$

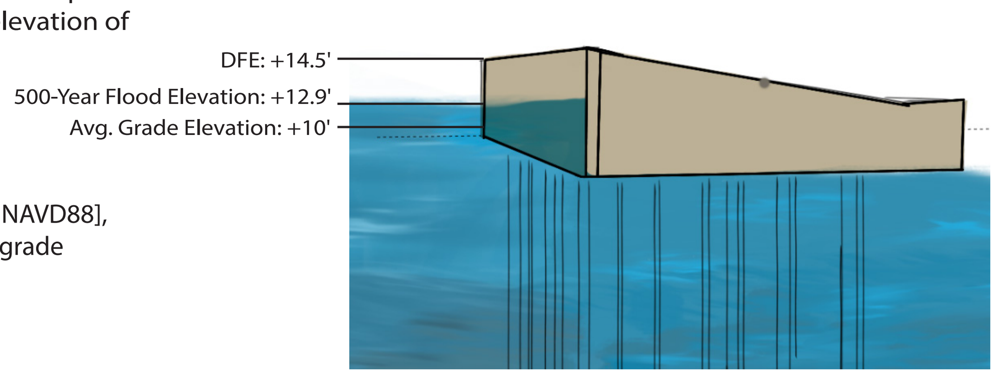
$$\mathbf{d_{500} = +2.9\ [feet\ NAVD88]}$$

Using the formula below, DFE500 was calculated to be +14.5 [feet NAVD88], which was used to determine the berm height by subtracting the grade elevations along the Manhattan coastline from DFE500.

$$DFE_{500}\ [\text{feet NAVD88}] = E_{500} + 0.55 \times d_{500}$$

$$DFE_{500}[\text{feet NAVD88}] = 12.9 + 0.55 \times 2.9$$

$$\mathbf{DFE_{500} = +14.5\ [feet\ NAVD88]}$$



The team utimetaly chose the berm, as it would be easier to integrate into the existing coastline, and marine infrastucture such as tunnels. It would also provide acres worth of new space along the coast of Manhattan, which could serve as community, residential, and commercial

COMBINED SEWER OVERFLOWS

After choosing a berm as the sea level rise and flooding resisting strucure, the team sought to identify the CSO mitigation plan. Two types of infrastructure were analyzed, a CSO tunnel and a CSO tank. Both provide the same benefit to an overloaded combined sewer system, but are constructed very differently.

TUNNEL

CSO tunnels are underground tunnels which hold stormwater overfall during rain events. The tunnel would be constructed utilizing a tunnel boring machine, and would connect to the exsiting CSO outfalls by gravity.

+
- less disruptive construction, as tunnel boring machines would construct tunnel in bedrock
- requires less space for construction and smaller overall footprint

−
- higher capital cost due to underground tunneling
- coordination with existing infrastructure (road tunnels, subway infrastructure, building foundations) would be necessary and critical to sucecss of tunnel
- would be independent of the berm structure

VS.

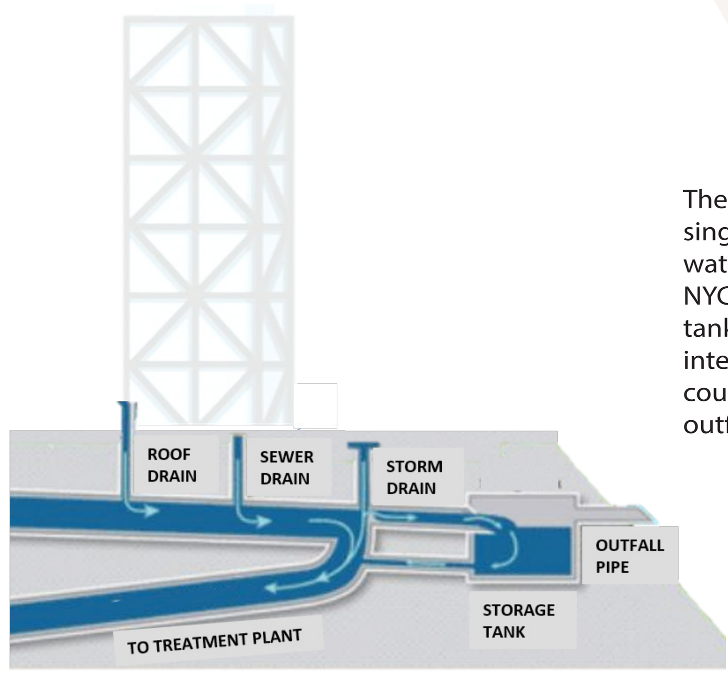
TANK

A CSO tank would retain overflow water during rain events until the treatment system has capacity to handle in the days after a rain event.

+
- tanks can be constructed and installed in pre-cast concrete sections
- simpler connection to exsiting CSO outfalls
- easier access for maintenance and operation in comparison to tunnels
- can be integrated into berm structure

−
- may require pumping to send water back to sewer system for treatment depending on elevation
- larger in-water footprint

The diagram to the right demonstrates a CSO tank storage system. Combined sewer flows travel towards the CSO outfall during wet weather, but are diverted to the storage tank before discharging. Flow that cannot be sent directly to the treatment plant is stored in the tank until the wet weather event is over.



The team wanted to create single structure solution to the water management issues in NYC. The team decided on CSO tanks, which would become an integral part of the structure and could easily connect to existing outfalls.

the belt

FINAL CONCEPT

the belt is a sea level rise-resisting, water quality maintaining, asset securing structure, which will preserve Manhattan with the protection it needs from the force that is water. *the belt* will hold Manhattan together throughout the effects of climate change in the city, while also providing over 30 acres of new coastal greenspace and potential commercial/residential area to be developed by the city. *the belt* will be an innovative solution to the water management issues that exist in New York City.

CSO STORAGE

Calculating the CSO storage would require the team to understand the hydrology in lower manhattan, along with existing and projected rainfall data.

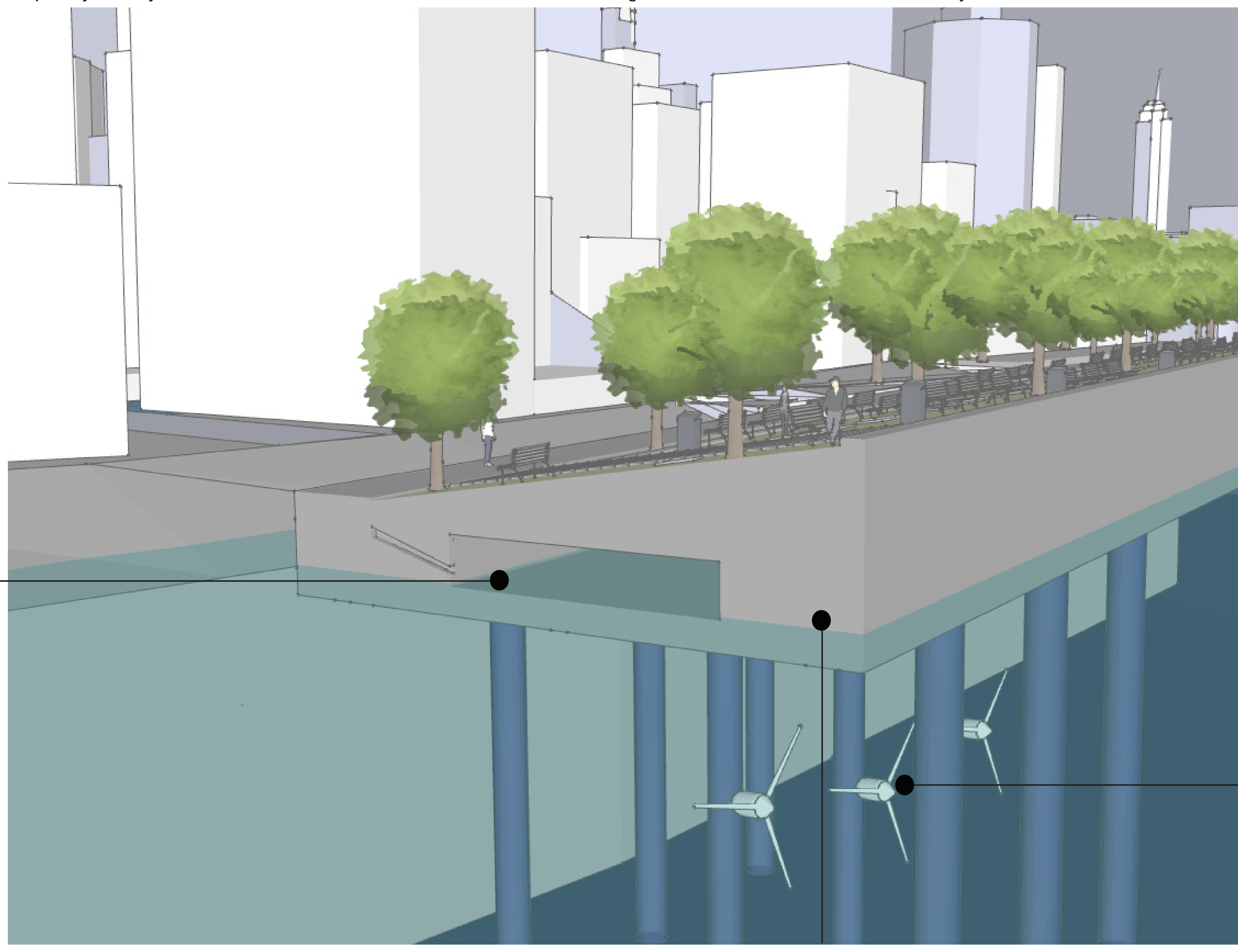
-IDF CURVES: The team utilized NYSWERA IDF (intensity-duration-frequency) curves to analyze 24-hour storm events for 2, 5, 10 25, 50, and 100 year storm return periods, utilizing Manhattan rain guage data.

-DRAINAGE AREAS: The team then utilized Manhattan ESRI drainage area maps (below) and existing outfall locations to determine the stormwater quantities that would fall on our project site during a 24-hour rain event for the 2,5,25,50, and 100-year storms. Value enginering lead the team to plan for a 50-year storm, which would result in a 9-inch per 24-hour rainfall event.

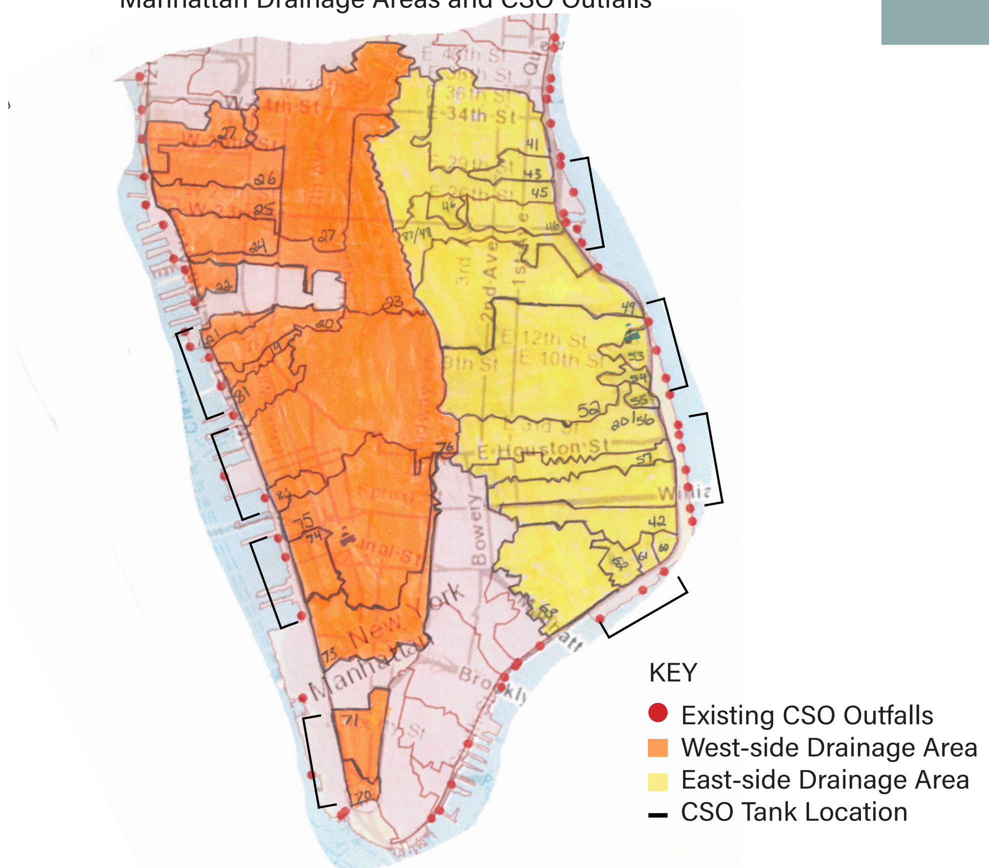
-TANK SIZE: The team calcualted the total storage required for a 50-year storm, separating the east and west drainage areas. Four tanks along each coast will store over 70 million gallons of water per rain event, providing massive alleviation on the existing system.

-CONNECTION TO EXISTING OUTFALL: The 8 new CSO tanks would be connected via pipes to the existing CSO outfalls.

-POST-STORM TREATMENT: After the storm event, the retained water would be fed back into the sewer system, and then conveyed to the wastewater treatment plant. The plant would treat the water to effluent standards and discharge to either the Hudson or East Rivers. Retaining storm event water and not overflowing outfalls could save NY rivers, and provide clean recreational water for long-term use.



Manhattan Drainage Areas and CSO Outfalls



Location	Runoff Coefficient	Total Drainage Area (mi^2)	Storage Required (Million Gallons)	Tank Size (ft^3) (l x w x d)
East	0.85	2.2	32.5	150 x 740 x 10
West	0.85	2.7	39.5	150 x 900 x 10

TIDAL ENERGY

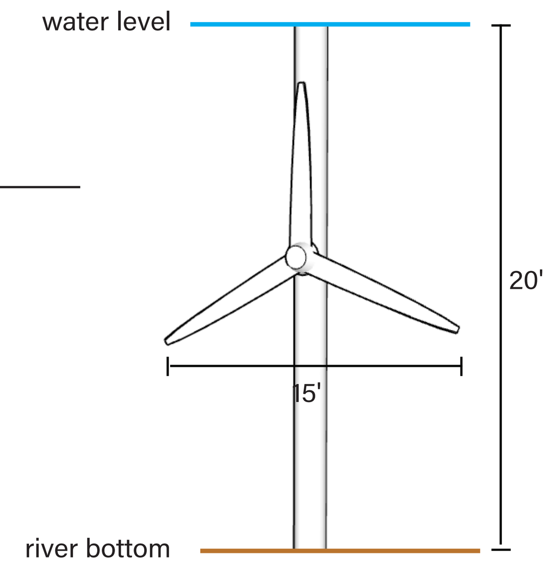
The team saw an opportunity to harness the power of water through tidal turbines, which turn with both the East and Hudson River's current. The tidal energy harnessed will be converted to electrical, and used as an energy generation source in this project.

-The turbines would be 15' in diameter, and would be placed on every other pile along the belt.

-2,500 units would be installed, and would be moved using the 8 knots water velocity of both the Hudson and East Rivers

-Each unit produces 55kW. Both Hudson River and East River flow at a rate of 8 knots, allowing the belt tidal turbines to generate 2100MW/day at a 70% efficieny.

-Electricity generated by the turbines would be collected and stored at a small powerplant on site. The belt would utilize this electricity to power all facilties along the belt. If surplus energy is generated, excess could be sold to Con Edison, the local electric utility, which conveiently has a it's largest NYC plant located at 14th Street on the east side.



SEA LEVEL RISE AND HISTORIC FLOODING PROTECTION

the belt would create a perimeter around NYC, impacting existing structures such as ferry stations, loading piers, and marinas. These facilities would be relocated off the outer edge of the *belt* in order to maintain functionality.

the belt will span the coast of Manhattan from 14th street on the West-side to 14-street on the East-side. During Superstorm Sandy, all of Manhattan below 14th street was left flooded and without power. We've decided to protect the most vulnerable part of Manhattan within *the belt.*

To create the footprint of the belt, we measured existing elevations at the coast line, which varied from EL. 0 to EL. 10. We then used the DFE of EL 14.5' and an average slope of 4%, to find the length of the belt. Below are length dimensions:

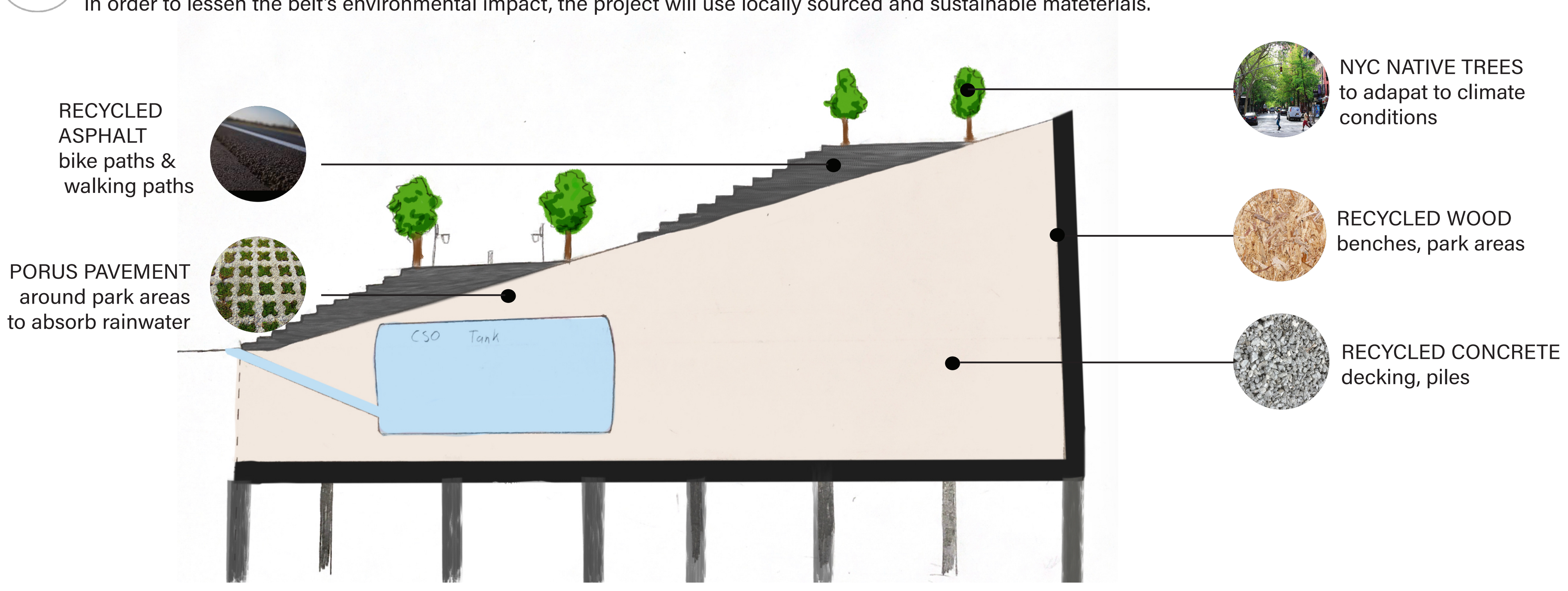
Point ID	Location	Elevation (NAVD 88 feet)	delta (DFE-Elevation)	Berm Length (feet)
1	14th Street-West Side	10	4.5	112.5
2	10th Street-West Side	8	6.5	162.5
3	Pier 25	5	9.5	237.5
4	Brookfield Place	0	14.5	362.5
5	Battery Gardens	7	7.5	187.5
6	Brooklyn Bridge	9	5.5	137.5
7	Manhattan Bridge	7	7.5	187.5
8	Williamsburg Bridge	9	5.5	137.5

the belt would also utilize a permeable barrier, which would be constructed between the deck and the existing coast line, this barrier would create a waterproof seal around Manhattan, preventing any water from infiltrating into the city.

the belt would create a perimeter around NYC, impacting existing structures such as ferry stations, loading piers, and marinas. These facilities would be relocated off the outer edge of *the belt* in order to maintain functionality.

SUSTAINABLE MATERIALS

In order to lessen the belt's environmental impact, the project will use locally sourced and sustainable mateterials.



ENVIRONMENTAL IMPACT

Construction of *the belt* would impact impact water bodies which serve as a recreational space for New Yorkers and habitats for other species. An Environmental Impact Statement (EIS) would be prepared during the planning phase of the project. An EIS would analyze the impact of the project to all life (both humans, marine life, bird life, etc.) which would be impacted by the construction of *the belt.* The major state and federal agencies shown on the right would be coordinated with, along with local environmental conservation groups to ensure that habitats are protected for all species in the Hudson River, East River and surrounding land.

SECURITY

the belt will be connected to the NYC Department of Environemntal Protection wastewater treatment system, which is considered critical infrastructure. Water stored in the CSO tanks will eventually reach treatment plants, which will treat and discharge the water to the Hudson and East Rivers. Limiting access to only NYC Department of Environmental Protection personnel and other personel will protect the tanks and the water treatment system from any contamination or security threats. Authorized personnel will access the tanks for maintenance through locked manholes, hatches, or other means. These security measures are in place to mitigate CSO discharge in the rivers and protect recreational users, waterways, and ecosystems.

SCHEDULE AND CONSTRUCTABILITY

the belt cost will be constructed in a 5-phase approach. Each segment is estimated to take 3 years to construct. Phases 1 through 5 will all have the same construction work breakdown schedule.

Phase 1 staging area will utilize existing abandoned piers on the west side. After construction of Phase 1, Phases 2 through 5 will mobilize using the finished area from the previous segment as staging area. The piles, pile caps and grade beams will all be built using barges, and the concrete deck will also be constructed via barge, using a concrete plant stationed on the Hudson or East Rivers.

Each phase will be constructed and completed for use by the public while the other segments are being constructed.

Construction duration is estimated to be 15 years. Below is a typical construction schedule for a single phase.

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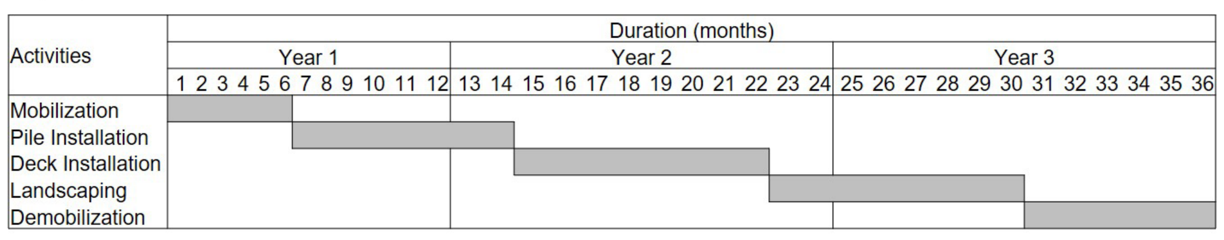

COST ESTIMATE

the belt cost estimate was developed using quantities and unit costs. The cost suggests an approximate value of $12.7B not including soft costs, such as land acquisition, permitting and environmental impact mitigation measures. The costs include labor, materials and equipment. The units that are represented are the average height and width of *the belt.*

Item	Quantity	Units	Cost/Unit ($)	Total Cost ($)
belt structure				
Pile (36-inch diameter drill shaft, 100 ft depth)	18,594	units		
Tidal turbines (15-ft diameter)	2,324	units		
Concrete pile caps and beams (3ft by 2.5ft)	1,859,400	VLF	500	929,700,000
Concrete Deck 1ft thick	258,189	CY	5,000	1,290,945,000
Concrete Retaining Wall (8ft by1ft)	469,333	CY	3,000	1,407,999,000
Berm/Backfill (average 200ft by 8ft)	18,773	CY	2,500	46,932,500
CSO Tank 150 by 800 by 40 (average size)	8	EA	25,000,000	200,000,000
belt landscaping/development				
Total New Land Area Created	300	ACRES		
Landscaping/Recreational Area	90	ACRES	2,000,000	180,000,000
Private Re Development	90	ACRES	250,000	22,500,000
Bike Paths and Circulation	30	ACRES	2,500,000	75,000,000
Public Facilities	90	ACRES	5,555,556	500,000,000
Marine Maintenance and Protection of Traffic (2.5% of structure & landscaping)	1	LS	122,000,000	122,000,000
			Sub-Total Direct Cost	4,962,809,800
Contingency			30%	1,488,842,940
			Sub-Total	6,451,652,740
Contractor Overhead & Profit			15%	967,747,911
			Sub-Total	7,419,400,651
Bonds & Insurances			2%	148,388,013
			Sub-Total	7,567,788,664
Escalation (5 year design, 15 year construction)	4.25%	% per Year	68.25%	5,164,940,085
TOTAL COST				12,732,728,749
Cost/Square Foot (total cost/berm area)	1,056,000	SF		12,057

FUNDING SOURCES

the belt is estimated to cost a $12.7 billon. The team understands that this is a lot for one entity to take on, and so the belt will have to be built via the financial support of many groups. Because the belt will provide NYC with 30 new acres of land for residential, commercial, and recreational use, and also incporates critical water infrastructure, we expect agencies such as United States Department of Housing and Urban Development, NYC Department of Environmental Protection, NYC Department of Housing, NYC Department of Transportation, and private developers to provide funding. All of these groups would benefit from the building of the belt.

Grant programs within the Environmetal Facilties Corporation, such as Green Innovation Grant Program and the Water Infrastructure Improvement Act, as well as the Clear Water State Revolving Fund, the USDA Rural Development Water and Environmental Program, and non-profit foundations such as the Jonson Foundation, Rokerfeller Foundation, and Ford Foundation could all support the construction of the belt.

LESSONS LEARNED

The RFP challenged us to learn about a topic that was unfamiliar to most of the team. Water management and preservation is not something we think about often, however, water management systems are working all around us, 24/7, to provide clean drinking water, treat wastewater, protect us from natural disasters and, overall, keep the public safe. Throughout the project, Team 30 learned about the water infrastructure in NYC and how we could improve water management locally in order to develop our final concept: *the belt.*