# Sinking Cities

Adaptive Architecture for Rising Sea Levels

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Committee:
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**Abstract**

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Though the Duwamish River has been through many significant changes since its glacial creation thousands of years ago, it has remained a source of food, travel and trade for those residing in the Duwamish Valley and greater Seattle area. Previous developments of the economy and local industries have led to regrading and rerouting the river; permanently altering the landscape of the valley. Like many urban waterways worldwide, industrial activity along the Duwamish River has led to an ecological crisis of polluted waterways and excessive greenhouse gas emissions contributing to anthropogenic climate change. This thesis explores amphibious architecture as an adaptive response to rising sea levels in Seattle and worldwide to preserve habitation and regenerate damaged ecosystems, while cultivating climate and environmental literacy.

# Acknowledgments

I would like to recognize that my home, our university, and my thesis take place on the unceded lands of the Coast Salish People including the Duwamish, Stillaguamish, Tulalip, and Muckleshoot tribes. I believe it is important to recognize the displacement, colonization and erasure of the Coast Salish's culture, homes and land. Growing up on the lands of the Snoqualmie Tribe has shaped my connection to nature and is what has inspired me to be so passionate about preserving our environments and our connection to place, leading to this thesis.

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Thank you Rob Corser and Rob Pena for you continued patience and guidance through this thesis.

Thank you to my family for the continual support you have provided, you are my favorite cheerleaders.

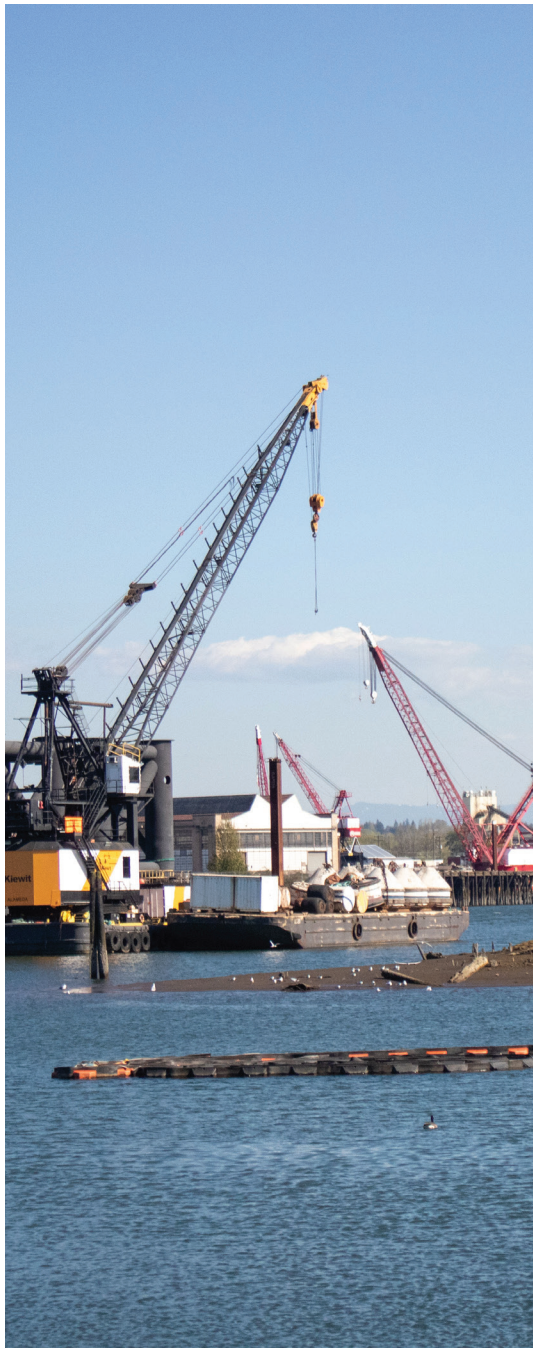
Thank you to my cohort for always being there (studio), and providing the moral support and laughs through every all nighter.

# SINKING CITIES

## ADAPTIVE ARCHITECTURE FOR RISING SEA LEVELS

NATALIE GUNN

Master of Architecture Thesis | Spring 2021



# 00 CONTENTS

# 01 INTRODUCTION

# Introduction

Global temperatures have been rising since even before the discovery of the greenhouse effect in the mid 1800's, and exponentially so in the most recent century. Initiated by the Industrial Revolution, the world, our country, and more specifically the built environment have been making significant contributions to the climate and pollution crisis we are in today. The consequences of this have resulted in increased average temperatures, more extreme weather patterns, rising sea levels and polluted environments. Sea levels globally have risen an average of 9 inches since 1880 and have been accelerating at an aggressive pace the last few decades.

This has caused a spike in high tide flooding, more deadly and destructive storm surges, disrupted land and water ecosystems and contaminated freshwater sources.  In addition, the rise in sea levels disrupts local, migrating, and global sea life that depend on a steady ecosystem to survive. It is time to recognize that the built environment is contributing to climate change at a rate faster than it is able to address the issues that are causing it and is therefore left to mitigate the effects of climate change rather than adapting

and regenerating. This thesis proposes a series of structures on the Duwamish River that will demonstrate ways to adapt with changing sea levels in a manner that fosters regeneration and stewardship.

# 02 FINDINGS

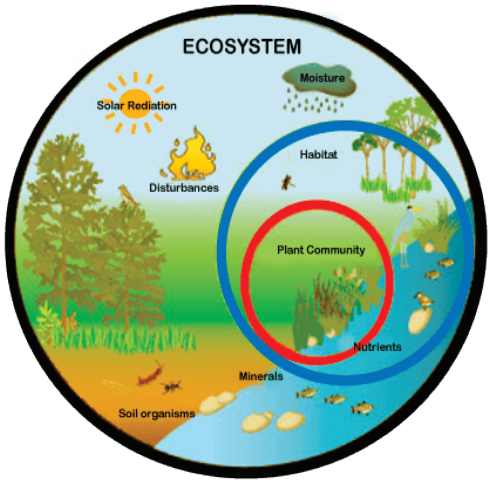
# Climate Change

## Anthropogenic Causation

Embodying the common characteristics of traditional climate change, anthropogenic climate change has the same effects, but attributes its main causation to humans. Over 97% of climate scientists agree with this theory, recognizing while the earth will inherently go through climate variability, human influences have the most dominant effects. While industrialization can be blamed for climate change, for the sake of this thesis I have broken it down into two main categories: destruction of natural habitats and pollution. Combined, these two elements have helped contribute globally to higher temperatures, more extreme weather patterns and rising sea levels

## Environmental Destruction

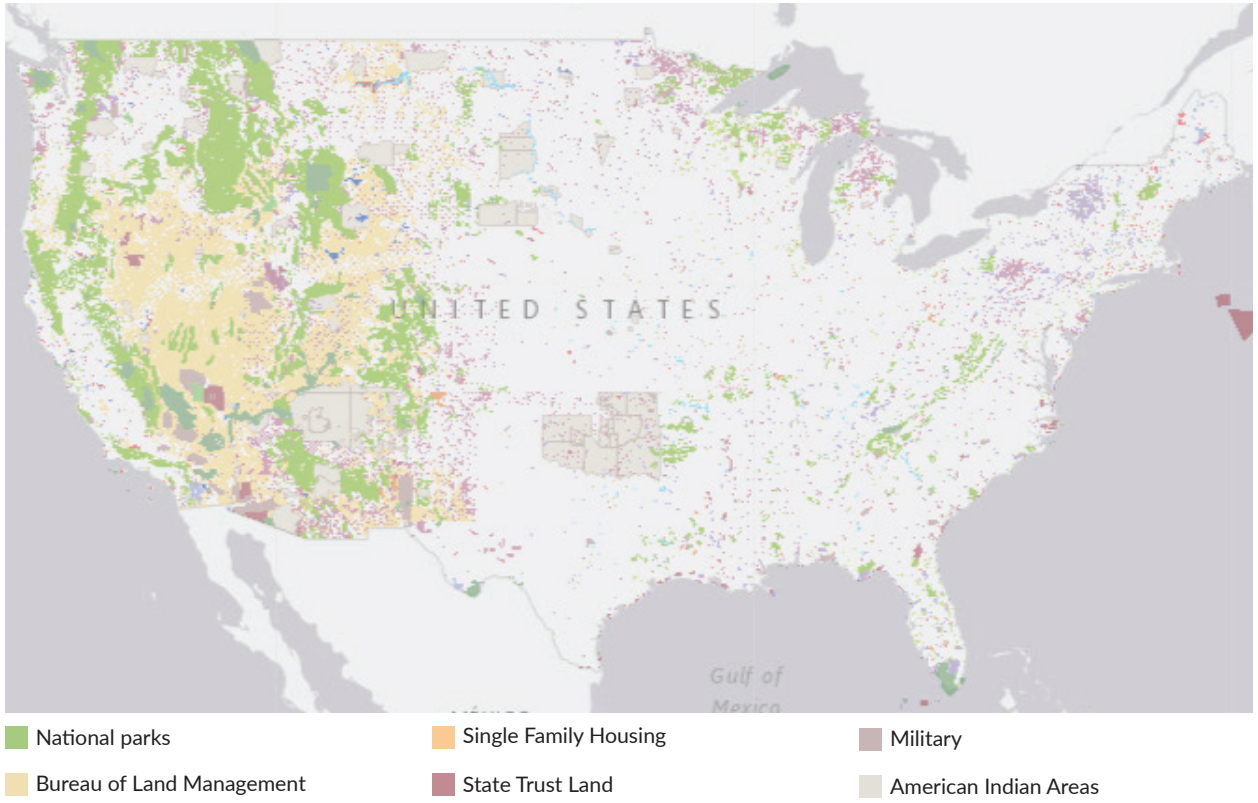
Ecosystems are a holistic system that relies on each component to do its part in keeping it healthy and running. Forests, rivers, riparian buffers, wetlands and other natural spaces are fundamental to a cohesive, self-sustaining ecosystem and healthy planet. When cities grow to accommodate housing, manufacturing, agriculture and other necessary




2.1 (Top Image)
Deforestation practices disrupt ecosystems, which can take decades to recover from

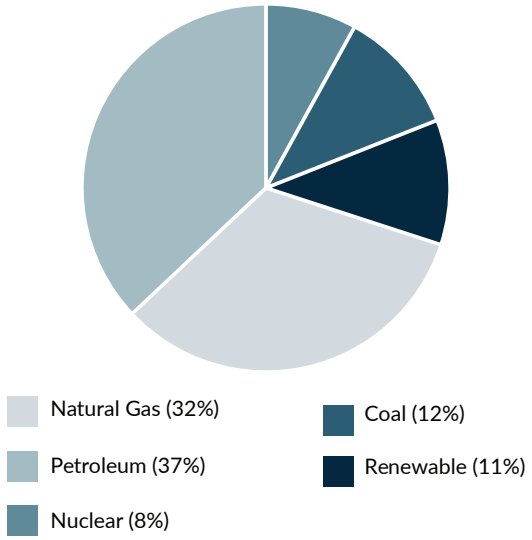
2.2 (Bottom Image)
Ecosystems are all interconnected, relying on each part to run smoothly

components; natural landscapes are destroyed in order to make room. While this may seem inconsequential, removing even one aspect of a landscape can completely alter the whole ecosystem and how it functions. Deforestation, regrading, and mining are all methods used to further develop our communities, however the level of damage we are causing to our environments are having a direct impact on our climate. It is vital to protect our natural landscapes as they help clean our air and water as well as regulate temperatures and climate.




2.3
Map of “protected” lands in the United States of America by land designation

Over the last 2 decades, the United States alone have lost over 24 million acres of natural areas. Currently, only 15% of our land is protected as designated national parks, but scientists have declared that to make a significant difference in climate change we would need to have at least 30% protected by 2030. While all protected land is significant, it is important to recognize that while the United States will delineate a lot of land as "protected", unless it is considered "protected wilderness", like national parks, the land can still be built on or developed on.

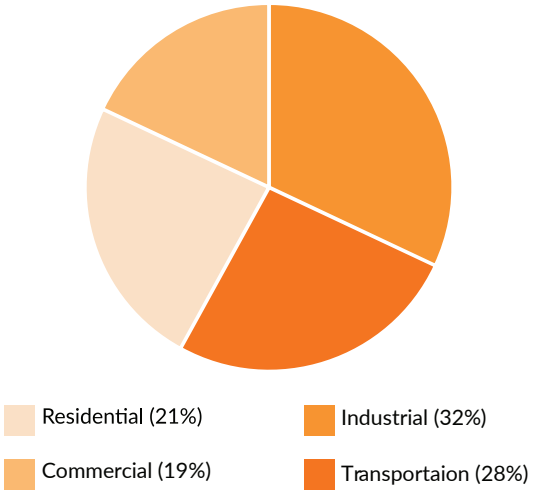



2.4
Sources of Energy Produced in the United States

### Pollution By Fossil Fuels

While it may be expected that the earth's temperature will inherently rise on its own, our use of fossil fuels has drastically expedited the process. Fossil fuels are natural resources found within our land and beneath our oceans, but that does not mean they are sustainable materials. Including oil, coal, and natural gas, fossil fuels and other nonrenewable sources such as nuclear power are the common methods to convert fuel into energy. These materials are typically burned to produce heat which is converted into energy or refined into fuel.

When these fossil fuels are burned, greenhouse gases are created. Including carbon dioxide, methane, water vapor, nitrous oxide and chlorofluorocarbons, these gases collect in the atmosphere and trap heat. The more fossil fuels used for energy, transportation, and manufacturing, more earth warming greenhouse gases are released into the environment. The built environment, mainly comprised of the commercial and residential sectors, uses




2.5
Energy Consumption by Building Type in the United States

40% of the energy consumed and accounts for 34% of CO2 greenhouse gas emissions the United States produces annually.

### Pollution By Industrialization

Polychlorinated Biphenyls (PCBs) are a series of man-made chemicals that were widely used in the manufacturing of plastics, rubbers, paints, paper and a wide range of equipment in the mid 1900's. Unfortunately, it was found that PCBs were linked to multiple serious health conditions including cancer, immune disorders, endocrine disruption, and reproductive and fetal complications, and behavioral problems in children. Known as forever chemicals, when these pollutants are ingested, inhaled or absorbed, they never break down in our bodies, leading to higher concentrations and more significant health problems. These serious health effects in conjunction with poor containment and disposal of PCBs were a leading cause of banning PCB production in 1979 in the Toxic Substances Control Act.

Unfortunately, even with the ban on PCB production, it was too late for many areas within the country that had already been severely contaminated. Many communities near manufacturing or industrial districts had accumulated dangerous levels of PCBs and other pollutants through the years. To make matters worse, because of PCBs durability, it is not easily broken down in the environment. This means that PCBs end up cycling through the environment contaminating the water, air and eventually the food that we eat. In many areas that have been affected by high levels of pollution there are warnings against eating

certain species of seafood; to protect residents form accidentally consuming PCBs and other poisonous contaminants.

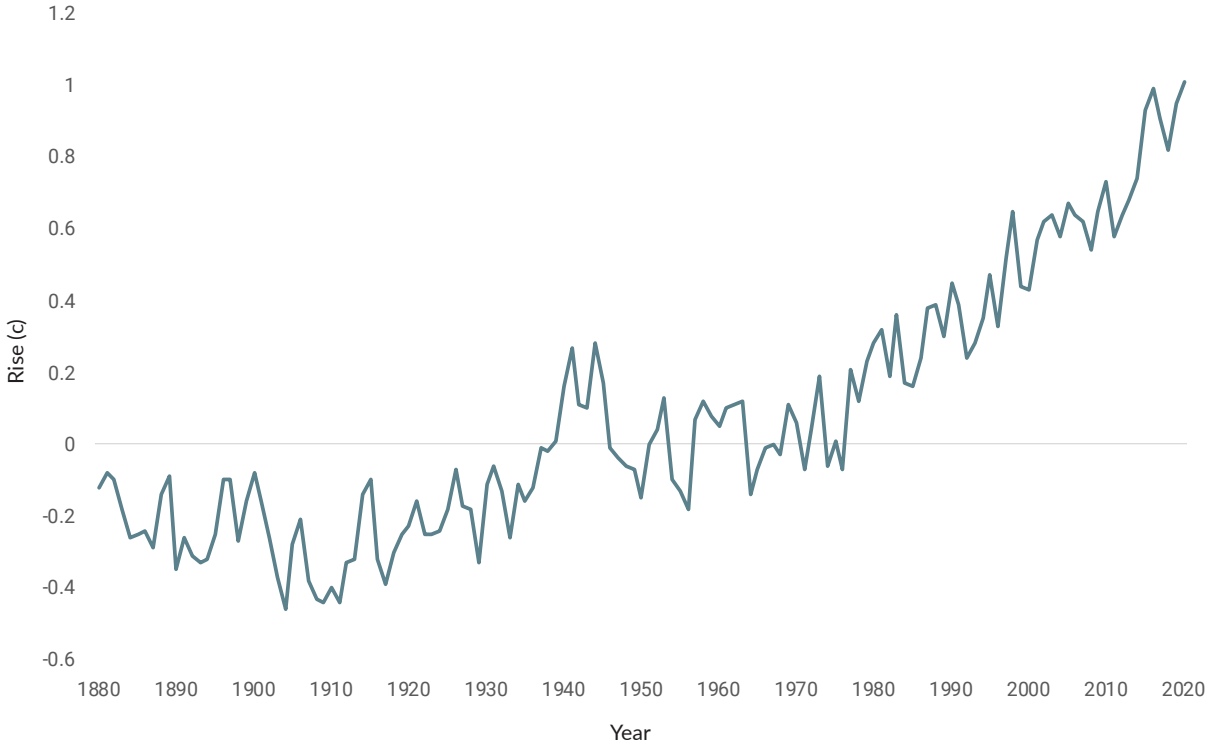
2.6 Diagram of how pollution enters into the environment. Pollution can come from many different sources.

## Sea Level Rise

While there are many factors that contribute to sea level rise, global warming is the biggest component. The ocean is vulnerable to the rise in global temperatures because it absorbs 90% of the Earth's heat caused by greenhouse gases.  The rise in temperatures is melting glaciers, which are melting faster each year; and causing thermal expansion of water. Unfortunately, even if in the next 50 years we, as a collective planet, managed to reduce pollution, switch to renewable resources and lower levels of consumption, the already elevated global temperature will continue to melt glacial sheets and cause ocean thermal expansion. As water covers 71% of the Earth's surface, it is one of the largest influences of life on this planet; as temperatures rise, marine ecosystems have and will continue to bear the brunt of rising temperatures.

Over the last 150 years the average global temperature has gone through consistent cycles of increased and decreased temperatures which have lead many people to believe that we are not in a true climate crisis. However, the current trend is showing a consistent rise in temperature with no indication that it will slow or fall. Since 1975, global temperatures

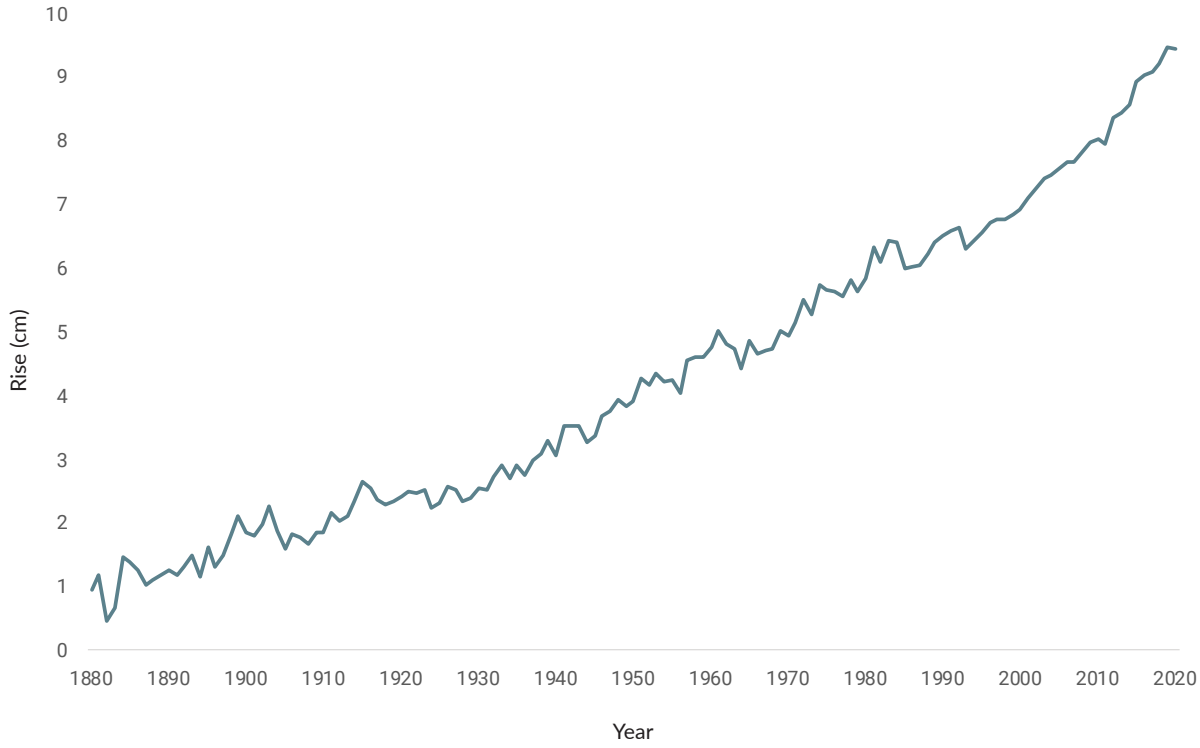
have risen 1 degree Celsius, or 33.8 degrees Fahrenheit. When looking at sea level rise, there is a more aggressive trend of upward growth, slowly accelerating to 9.5 inches over the last 150 years.




2.7
Average global rise of temperature in degrees Celsius from 1880 to present.

Research done in 2018 outlined the amount of sea level rise that will occur along the coastline of Washington state. Their data inputs and outputs are based on the levels of representative concentration pathways (RCP), which are values based on levels of greenhouse gases, emissions, and other factors of pollution that set pathways for scientists to be able to predict the amount of warming and its effects that could occur. Researchers

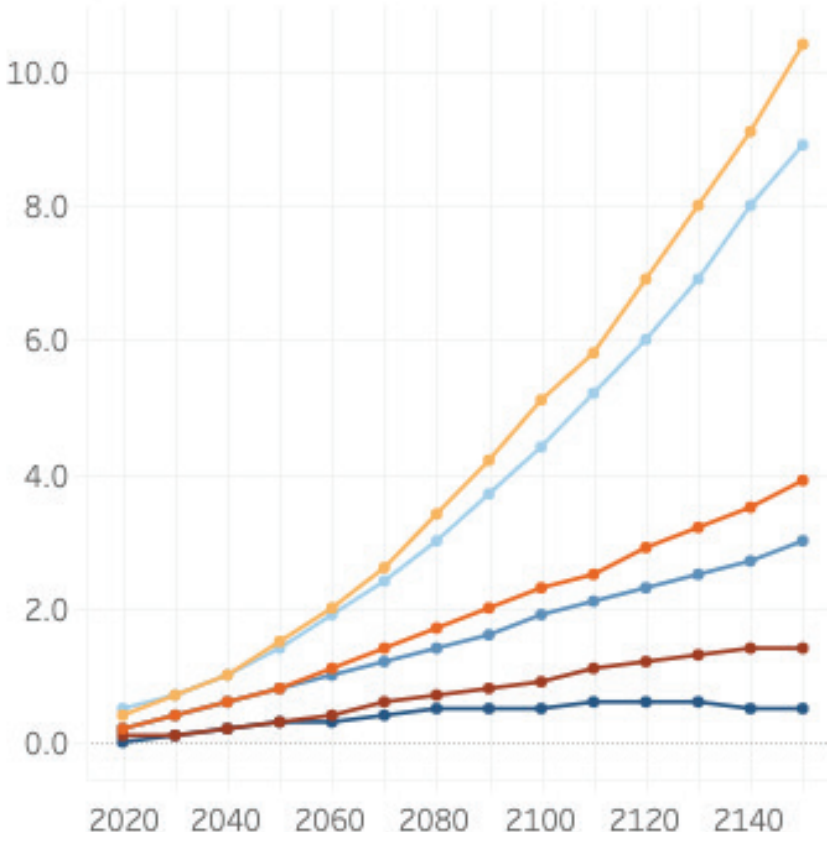
2.8
Average global rise of sea levels in centimeters from 1880 to present.




believe we are currently around a RCP7 which represents a medium to high level of emissions, with low levels of mitigation. The research done shows if we maintain RCP7, by 2150, there is a 99% probability that water in Seattle will rise about 1 foot but could potentially rise up to 10 feet within the next one hundred years.

Recent studies have unveiled that Washington State will actually be one of the worst places affected by sea level rise compared to other USA coastal states and territories due to its amount of shoreline. A predicted minimum of 24 billion dollars would be required to

protect public infrastructure. With a threat of this magnitude including public and private loss of property, money and ecology; there is a desperate need for a feasible solution that can mitigate the damage of what will be lost to climate change. In 2017 Seattle completed the new seawall that should last at least 75 years, it is meant to protect the downtown Seattle shoreline from damage and restore salmon migration routes and improve the ecosystem of Puget Sound. While the new sea wall will help protect downtown against the rising waters; it is neither a permanent nor long term solution to global sea level rise.

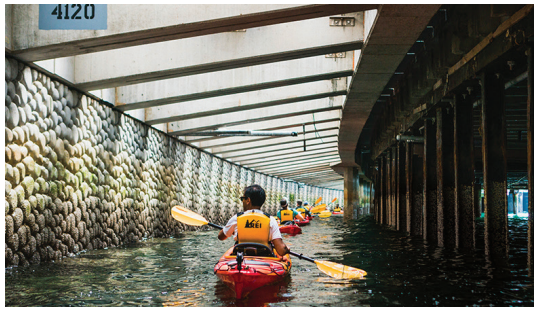



2.9
Graph showing potential sea level rise outcomes (in feet) based on representative concentration pathways, by probability.

# Architecture + Water

2.10
Hoover Dam holding back the Colorado River in the Black Canyon

Architecture and water have had a long relationship throughout history. Even before modern materials and engineering allowed for the infrastructure we have today, humans have been spanning, interacting with and controlling the flow of water for centuries. While the forms and sophistication may have evolved throughout the years, the typologies have remained the same, and can be refined into three main categories: dams, boats, and bridges. The development of modern cities has relied on these forms to protect, preserve and grow their boundaries. Dams, boats and bridges have become the foundation for modern design in and around water.




2.11
The new sea wall in Seattle holds back the water in the Puget Sound, protecting the city from erosion

## Dams, Bridges, + Boats

Dams function to block or restrict the passage of water through an area by spanning the width of an opening around the water. Using materials such as concrete or earth fill, humans are then able to utilize the water to suit their needs better. Often, damming a river can cause social and physical changes in the area affected. Upstream of the dam, land will become flooded creating lakes or reservoirs; this can provide recreational activities but

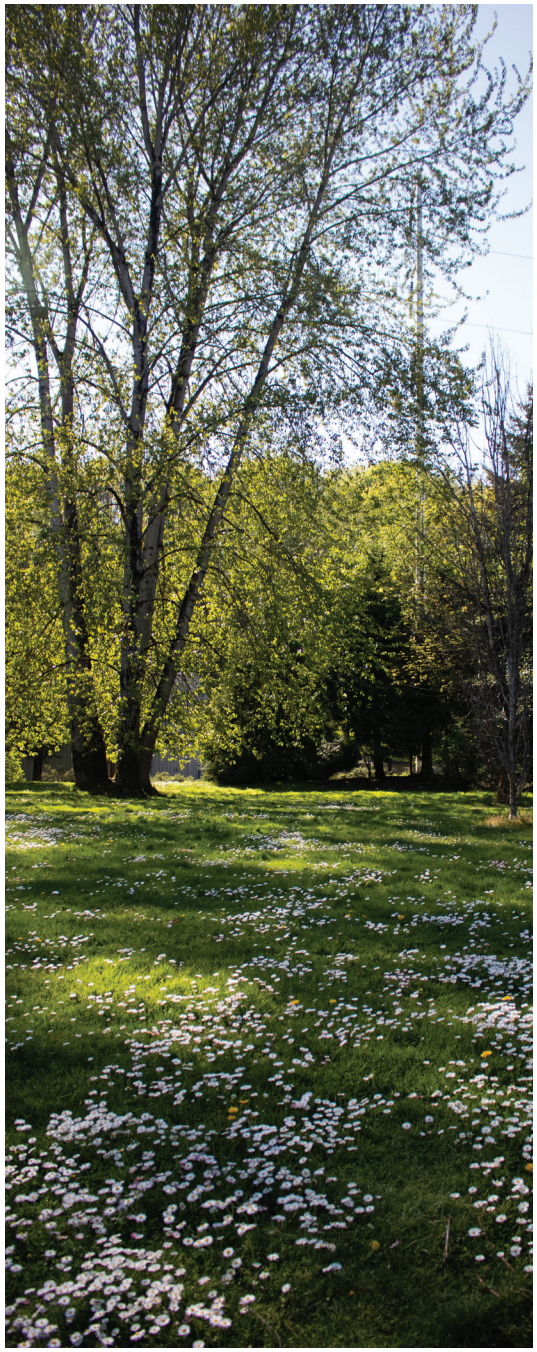
may also displace communities that were on located close to the water. Beneath the dam, drought can occur and migrating fish such as salmon can be cut off from their spawning routes. Dams also generate clean energy and allow for easier water collection and storage for irrigation. Similar infrastructure to dams are levees, sea walls and dikes.

Bridges are able to span across space, typically bodies of water or landscapes that are impassable. Bridges allow cars, trains, pedestrians, and almost any form of transportation to travel across them, connecting one place to another. With the exception of floating bridges, an advantage of a bridge is that water traffic is typically not affected as boats can still travel beneath, allowing for two different modes of transportation to work together. Utilizing different methods of engineering and accounting for each bridge's individual needs, bridges can use suspension, trusses, and arches to span across water. With bridges, the focal point is the center, where it sits above the previously impassable space. Similar forms are piers and docks, where the end of the structure is the destination.

2.12
Washington SR 520 has the longest floating bridge to bring people across Lake Washington to Seattle

Boats are able to travel to places outside the reach of bridges and dams. Not restricted by as many structural limitations as dams and bridges, boats can transport goods and people across the globe by floating across bodies of water. To be able to travel to different places, motorized boats rely on the use of fuel; small boats typically use gasoline or diesel, while larger vessels such as cargo ships typically use "bunker fuel" or heavy oil fuel. Other buoyant vessels can include self-propelled boats such as canoes and kayaks, and barges.

2.13
Boats come in many different forms, including houseboats



# 03 RESPONSES

## Constructed Wetlands

As pollution and waste disposal have become a bigger problem over the last couple of decades, researchers have begun to look at alternative methods to treat wastewater. Wastewater can come from many different sources including sewage, agriculture, and manufacturing. While conventional wastewater treatment methods are successful in filtering and purifying wastewater, it relies heavily on the use of mechanical and chemical systems to do the job.

Artificial wetlands and natural systems mimic the same processes of conventional treatment systems, but typically require less energy, maintenance and sometimes cost. These systems utilize microorganisms and plants to help breakdown and remove pollutants instead of relying on chlorine or other chemicals. A benefit of using natural methods is their ability to be integrated into landscapes and buildings, while still functioning as a treatment system for almost any type of wastewater.

3.1
Traditional wastewater treatment facility

3.2 +3.3
Constructed Wetlands

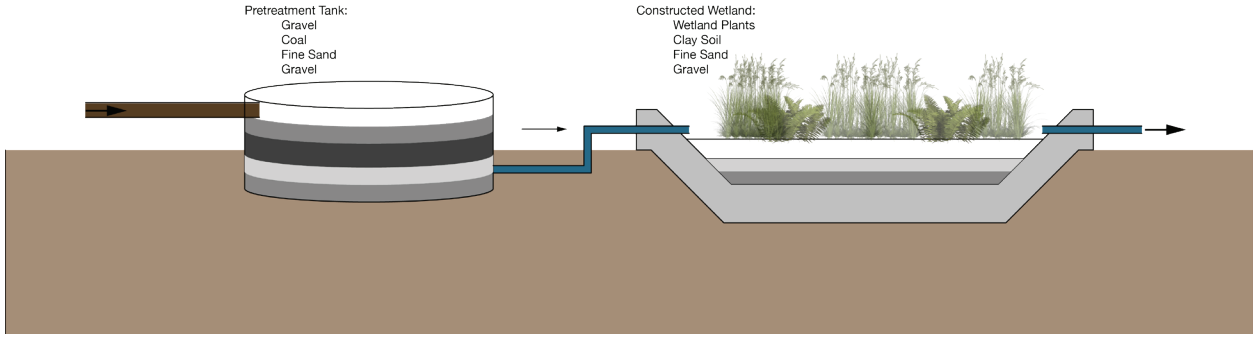
## Constructed Wetlands

Mimicking the process of natural wetlands, constructed wetlands use minimal materials to filter out pollutants from water. If done properly, a constructed wetland can hold up to 3 cubic feet of water per one square foot of land; one acre of wetland can hold about 1 million gallons of water. This ability to hold so much water works well with the vegetation within the wetlands to help slow and filter the water as it flows through. Strategically placed wetlands can act as both a pollution filtration method and a flood mitigation strategy to lower flood heights and the potential for flood damage.

With varying layers of aggregate, soil in a concrete or impermeable basin in the ground, the wetland utilizes resilient plants to help clean the water. It is able to withstand multiple sources of water pollution, including storm water runoff, domestic and agricultural wastewater, coal mine drainage, petroleum refinery waste, compost and landfill leachates, fishpond discharges, and pretreated industrial waste waters.  When used in municipal settings, polluted water is first sent through a pretreatment stage in a tank that catches any large sediment or particles with coal, gravel and sand. Once roughly filtered, the water flows into the wetland basin with layers of lay, fine sand and gravel topped with plants.

Studies conducted on constructed wetlands have shown that they can be up to 91% effective in removing PCBs and up to 94% effective in filtering out other pollutants

such as polycyclic aromatic hydrocarbons, depending on their construction setup and flow method.  With such high filtration performance and low maintenance and cost constructed wetlands are a effective, natural, alternative wastewater treatment method.




3.4
Diagram of constructed wetland

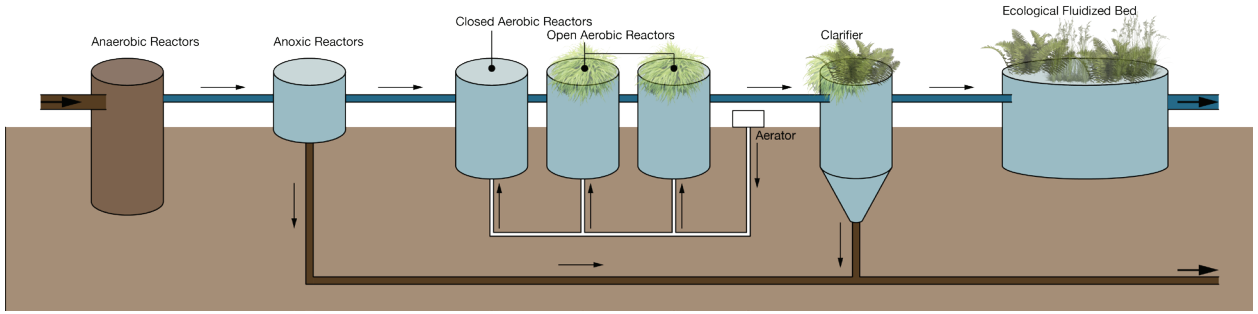
## The Living Machine

Utilizing a series of tanks and a diverse spectrum of living plants and organisms, The Living System, created by John Todd, is a tertiary treatment system for wastewater. Sent through a series of different types of tanks; waste water's bacteria, nitrogen, ammonia, and phosphorous is removed.  This process can be completed in as quickly as 3 days and have been designed to process as much as 80,000 gallons of wastewater per day.  The Living Machine can operate virtually anywhere, utilizing a variety of greenhouses, tanks and leach fields depending in the scope of each project.

3.5 + 3.6
The Living Machine

First, wastewater is sent through a rough screening to remove any large debris and sediment from the anaerobic tanks. Then, in the aerobic stage microorganisms, bacteria

and fish are used to capture sludge and organic matter in the water until it is finally sent to the ecological fluidized beds, which operate similarly to constructed wetlands. This process utilizes a whole ecosystem designed to break down the wastewater to be clean enough to either release back into the environment or to be recycled as non-potable water.




3.7
Diagram of The Living Machine

## Buoyant Architecture

Designing buildings and structures that interact and work with the rising sea levels is increasingly becoming a better option. Developing design based on the principles of dams, boats, and bridges, there has been a rise in buoyant architecture that mimics both function and design aspects of boats and bridges.
These design solutions have included either floating architecture or a newer technique, amphibious architecture.

> *Floating Architecture: a free-floating structure on a body of water that can move freely and is not affected by change in water levels.*

> *Amphibious Architecture: a flood mitigation strategy that allows an ordinary structure to float on the surface of rising floodwater rather than succumb to inundation while remaining tethered to the ground.*

**Precedent Study:**

Floating Office Rotterdam | Powerhouse Company |Ongoing

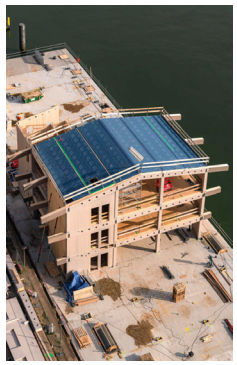
- Carbon Neutral
- Climate resistant
- De-constructible

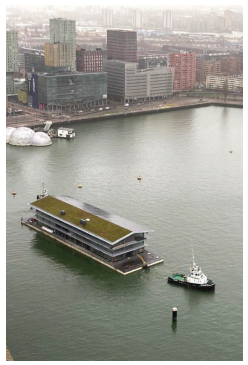
Designed by Powerhouse Company, Floating Office Rotterdam is a floating office in Rotterdam for the Global Center on Adaptation that will be carbon neutral and is meant to function off-grid. If sea levels rise due to storms or flooding, and eventually climate change, the three story 3,700 square meter office will float rather than flood. The timber structure has solar panels and a water-based heat-exchange system installed to help it sustain self-sufficiency and carbon neutrality in operation. The building is meant to be a hub to promote planning, investment and technology to mitigate climate change. While it is meant to be an office space, there are still community areas including a restaurant, outdoor terrace and swimming pool. Because of its unique position on the water, the building is capable of being moved to different locations, this feature is amplified by the building's connection to the street scape being a boardwalk.

## Floating Architecture

Floating architecture is permanently placed in water, using a buoyant foundation to stay afloat. While this typically may not seem like the most intuitive design approach, when it comes to rising sea levels, it may be the only way to keep buildings along a changing coastline. Floating architecture may have similar building systems to traditional land construction; however, they need to be set up differently as they are not tied into typical city utilities. Inherently this makes the floating buildings more self-sufficient, providing ample opportunity to maximize sustainability.

First, by planning for a building to interact with water from the start, you save the trouble of later needing to retrofit or even vacate a building due to changing water levels. This saves money, time and materials. Additionally, because floating architecture is not anchored by a grounded foundation, it is able to be moved around and moored in different locations. This flexibility may reduce seasonal building loads and environmental impact of having a fixed site.

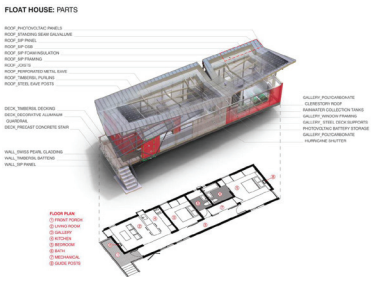


3.8, 3.9, 3.10, 3.11
Floating Office Rotterdam

## Amphibious Architecture

Proposed as an alternative to stilt architecture, amphibious design became widely popular after the devastating Hurricane Katrina. 400,000 people displaced from their homes after 80% of New Orleans was flooded forced architects to think about how to preserve homes in surges of flooding.

Amphibious architecture is able to sit low to the ground except during floods when its buoyant foundation lifts it to float with the changing water levels. As the flood waters recede, the house will lower back to the ground, guided by anchored posts to returning to its original position. While amphibious architecture is certainly encouraged with new construction as needed, it is also possible to retrofit existing buildings with buoyant foundations at a comparable price to preserve the architectural character of existing neighborhoods.




**Precedent Study:**

FLOAT House | Morphosis | 2009

- Amphibious
- Prefabricated
- Affordable

FLOAT House focuses on its performance as an amphibious house in three ways, affordability, buoyancy and sustainability. Its design was a response to the destruction caused by Hurricane Katrina in 2006, and can operate as an annual net zero energy system and is rated LEED Platinum. Utilizing highly efficient appliances and construction materials it is able to lower the resident's utilities consumption and reduce the house's life cycle costs. Solar panels on the roof, a rainwater collection system and geothermal heating via a ground source heat pump aid in its self-sustaining mission. Off-site prefabrication is utilized for most components of the house, including the foundation made out of foam, fiberglass, and includes the plumbing and electrical lines ready for hookup once it arrives on-site. Located in New Orleans, FLOAT House copies the historic shotgun style house while adding a modern touch.

3.12, 3.13, 3.14, 3.15
FLOAT House

**Precedent Study:**

FLOAT House | Morphosis | 2009

- Communal
- Recycled
- Movable

Focused on filling the food dessert of the South Bronx, Swale is a floating community garden creating public food in public spaces. Sitting on top of a reused construction barge, Swale is able to navigate the New York's waterways and therefore circumvent New York Parks Department's ban of growing and harvesting food from public land. Inspired by edible forestry Swale's plants are comprised of perennial fruit trees, leafy annuals and salt tolerant grasses. Relying on the principles of knowing and trusting each other and working together, Swale has become a successful garden and community gathering place. So successful in fact, that it has made New York Parks Department rethink its policies and is now opening their own public foodway at Concrete Plant Park.

## Barges

Barges have become an important part of trade, acting as a method of transportation for goods within ports. They are designed with flat bottoms, maximizing cargo-carrying capacity and allowing it to travel farther inland through shallower waters. Typically, without motors, barges require a method of propulsion that usually comes from tugboats.

With an average lifespan of 25-30 years, barges move freight around at an unmatched pace. One barge trip can carry 15 times more than a rail car, and an impressive 60 times more than a single semi truck.  Even with the higher number of moved cargo, barges are the safest mode of shipping in comparison to train or truck and has the lowest fuel consumption and carbon footprint in comparison to the amount they haul, and distance traveled.

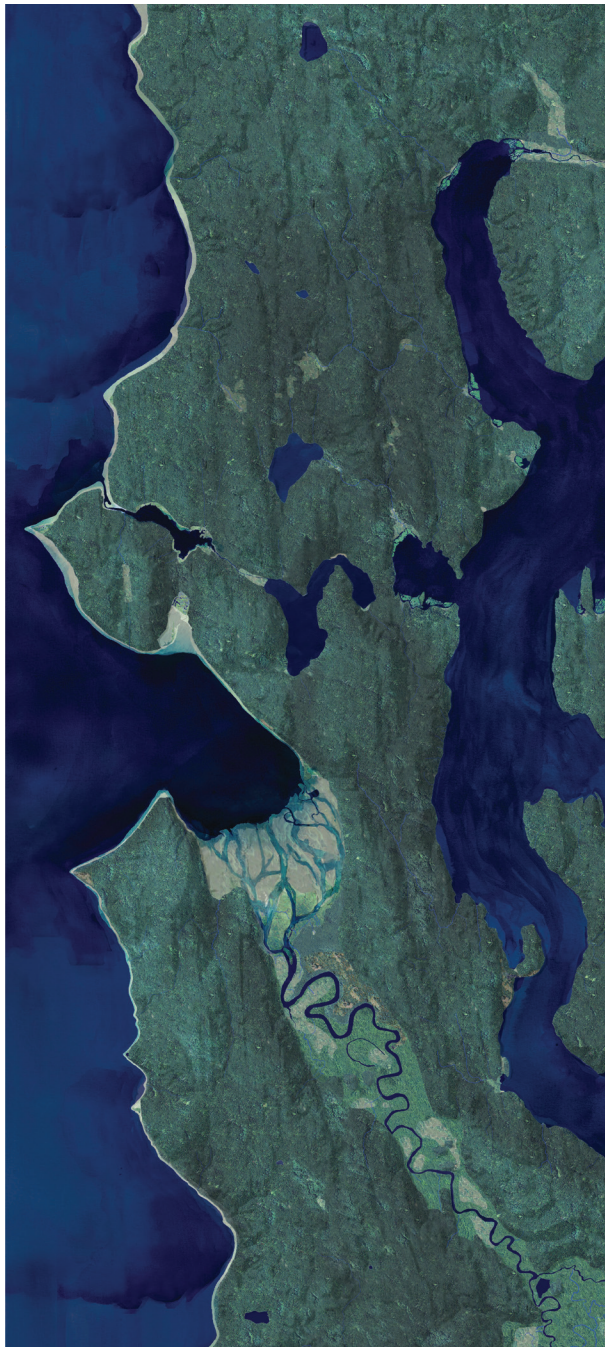
3.16, 3.17
Floating Farms

# 04 PLACE

## Landscape

The Duwamish River was carved first by nature, then by man. An estimated 20,000 years ago, the Cordilleran Glacier outgrew its Canadian borders and started creeping down into the Puget Sound. The weight and force of the glacier easily cut through the topography, and in combination with volcanic mud flows, earthquakes and floods, many of the valleys, lakes and rivers that are in the area today were created.  Winding their way through the Duwamish Valley, there were 5 original rivers that made the Duwamish-Green Watershed. The White River from Mt. Rainier joined the Green River flowing north, and the Cedar River from the Cascades joined the Black River just below the outlet of Lake Washington; together these four rivers flowed together to make the Duwamish River which empties into Elliott Bay. Filled with floodplains, forests, marshes, and tidal flats the valley was home to a diverse thriving ecosystem that the Duwamish Tribe was able to thrive on.

The early 1900's is when the Duwamish River we are familiar with today starts to take shape. The construction of the Lake Washington Ship Canal, including the Hiram M. Chittenden Locks in Ballard was the catalyst. Upon Completion of the Ballard Locks, Lake

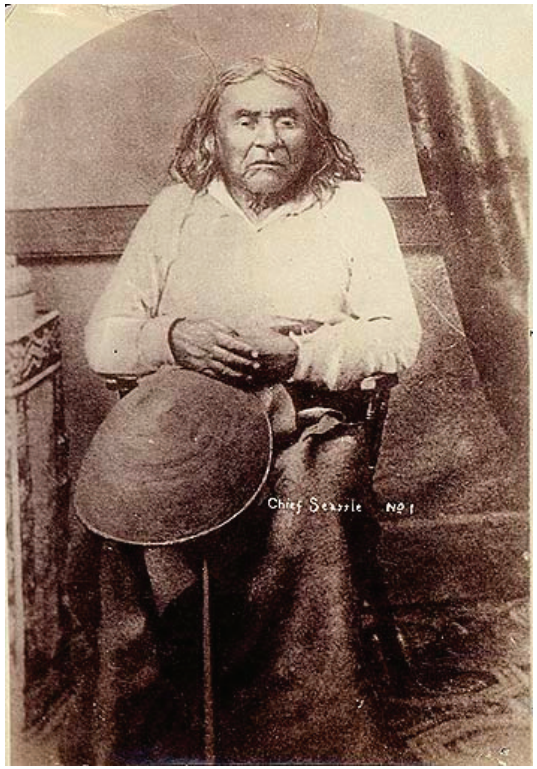


4.1 (Left)
Predicted historic landscape of the Greater Seattle Area before the migration of settlers, regrading, and development.\

4.2 (Right)
Current satellite image of the Greater Seattle Area

Washington was lowered 9ft and the Black River ceased to exist. The remaining Cedar River was rerouted north to Lake Washington and the White River was rerouted south to meet farming needs. The reconfiguration of water routes resulted in an overall 68% loss of water flow for the Duwamish River.  While these changes permanently altered the Duwamish Valley, the biggest change was straightening the channel of the Duwamish River, essentially wiping out the tidal mud flats and replacing it with Harbor Island and a bustling industrial district.

## People




4.3
Chief Seattle, the chief of the Suquamish and Duwamish Tribes during the 1850s when many settlers were moving to the area.

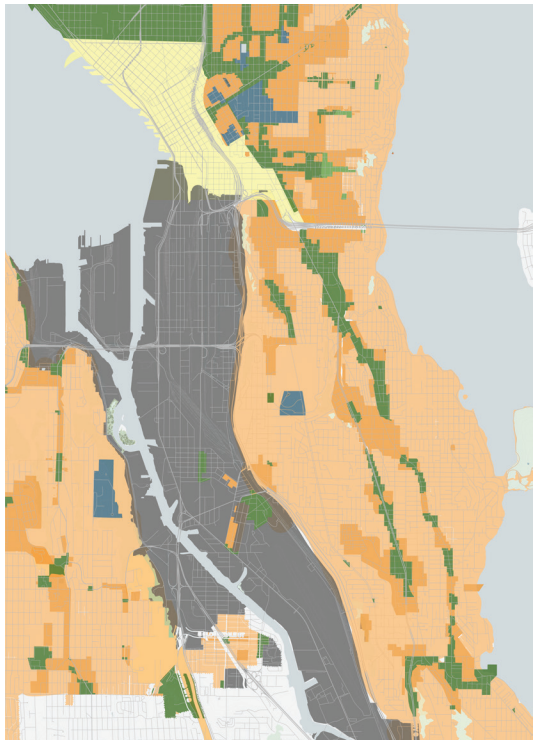
The Duwamish River had been an ecosystem that allowed the Coast Salish to work with the land and live in the area for thousands of years; by 1915, settlers had completely altered the landscape rendering it unrecognizable. These drastic changes affected salmon migration and other food sources for the Coast Salish people, forcing them to adapt to the newly forming landscape.

Harbor Island, which was the largest man-made island at the time, became the epicenter of Seattle's port, exporting the goods from the manufacturing companies that were growing along the Duwamish River. Over the years, as these companies grew, they began to pollute the waterways leading to one of the worst superfund sites in the nation.

During this time, the conditions for the Muckleshoot and Duwamish Tribes only worsened. Culturally significant places were destroyed along with their fishing, hunting, and gathering lands. Before 1974, the tribes were even punished for trying to access their previous lands for fishing until the United States v. Washington trial, which supported the tribes' treaty

rights.  However, despite this recognition by the supreme court irreparable damage had already been done, resulting in the displacement of the Coast Salish people as they were pushed further away from their native home.


4.4, 4.5
Duwamish Tribe camps set up on Ballast Island after their homes were burned and they were forced to move to Ballast Island



- Industrial
- Multi-family Housing
- Single Family Housing
- Institutions
- Commercial/Mixed Use
- Downtown

4.6
Zoning map of Seattle and North Tukwila

*See appendix for full list of companies thought to have contributed to the superfund site

## Pollution

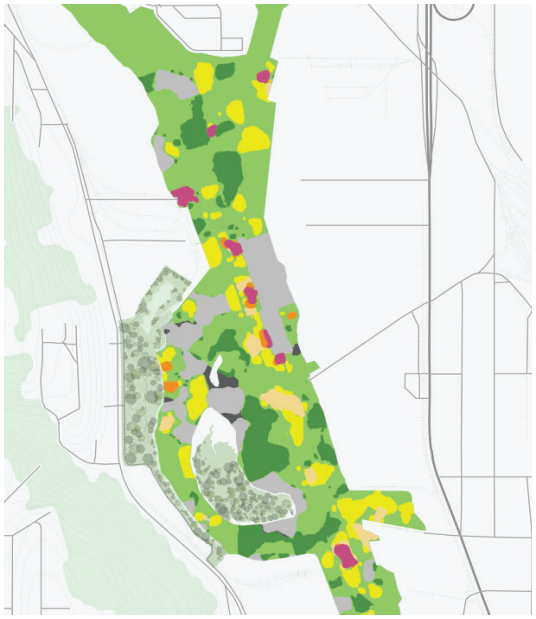
Before the Duwamish River pours into the Puget Sound, it flows through 9 miles of Seattle's industrial district. This industrial zone has been used since the early 1900's starting with lumberyards, steel mills, brick companies and the first Boeing manufacturing plant in 1917. With the start of World War II, industrial manufacturing took off, but the waste management practices remained insufficient. Using landfills and waterways for direct disposal of waste was common practice leading to the pollution levels seen today. Modern, stricter regulations have been put into place to help regulate pollution, however, with continued spills, leaks and illegal dumping, high levels of chemicals and pollutants remain in the ground and river.

In 2001 the Environmental Protection Agency (EPA) distinguished the Lower Duwamish River as one of the worst superfund sites in history making it eligible for federal funding to assist in cleanup. As a part of their clean-up process, the EPA is required to identify and notify all manufacturers or businesses they believe have contributed to a superfund site, in the case of the Duwamish, over 120 notifications were sent out.* From this list

of companies, 14 are required to undergo an investigation by the EPA and be a part of the toxic cleanup plan, 4 additional companies need to undergo investigation and follow a hazardous waste treatment and reduction plan. Lastly, 4 companies; Boeing, The City of Seattle, King County and the Port of Seattle were recognized as the largest pollution contributors and were required to form the Lower Duwamish Waterway Group and make the Duwamish River Cleanup plan. This plan covers 412 polluted acres of the Duwamish River and is estimated to cost $324 million dollars.

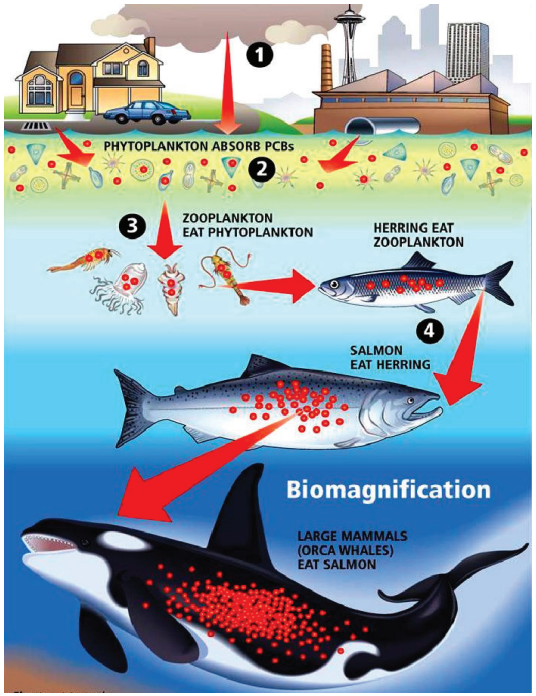
Focusing on polychlorinated biphenyls (PCBs), arsenic, carcinogenic polycyclic aromatic hydrocarbons (cPAHs), and dioxins the LDWG started with their Early Action Areas, which were recognized as the most contaminated areas. The cleanup process includes, dredging up polluted soil along the beds of the river for disposal and capping it off with clean soil to help break down any remaining pollutants that were left behind. Upon completion of the initial Early Action Areas in 2015, approximately 50 percent of the PCB contamination in the river bottom was removed, but a lot of work remains. There is still approximately 177 acres of the Duwamish Waterway that needs cleanup action.

Residents of the Duwamish valley are warned against eating any seafood from the Duwamish River that is not a naturally migrating species. In a process called biomagnification; Crabs, fish, clams and other local aquatic life that feed in the polluted waters, are feeding on organisms that have already be contaminated with pollutants, and as each organism




4.7
Concentration levels of remaining PCB pollutants in the Lower Duwamish Valley after addressing the Early Action Areas in 2015, approximately 50% of contaminants were removed

4.8
Average USA life expectancy is 78.54 years, the average life expectancy in the Duwamish Valley is 13 years lower than the national average.




4.9
Process of biomagnification in an ecosystem

consumes more polluted food, their own levels of toxicity increase. Salmon are one of the only approved sources of food from the Duwamish River as they do not permanently live in the river and only return to spawn. Extended periods of recreation are also not recommended in areas of the lower Duwamish River as exposure over long periods of time poses a risk to health, especially for children. Residents living within the Duwamish valley have been found to have life expectancies 13 years lower than the national average.

## Site

4.10
Historic Seattle landscape with current Seattle outline

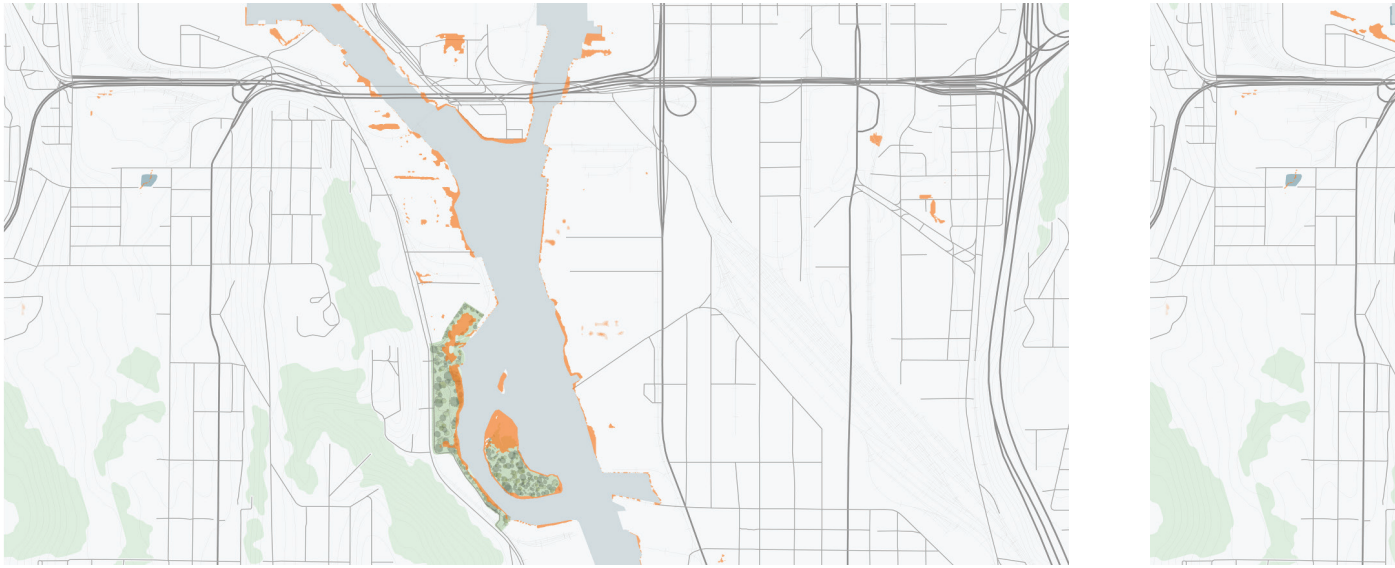
If an outline of the current footprint of Seattle is overlayed on the predicted historic map of the Duwamish Valley, there is a noticeable intersection just south of Harbor Island. Named Kellogg Island, it is the only remaining portion of the original river's route. Because of its historic significance, pollution levels and susceptibility to flooding, It has been selected as the site.

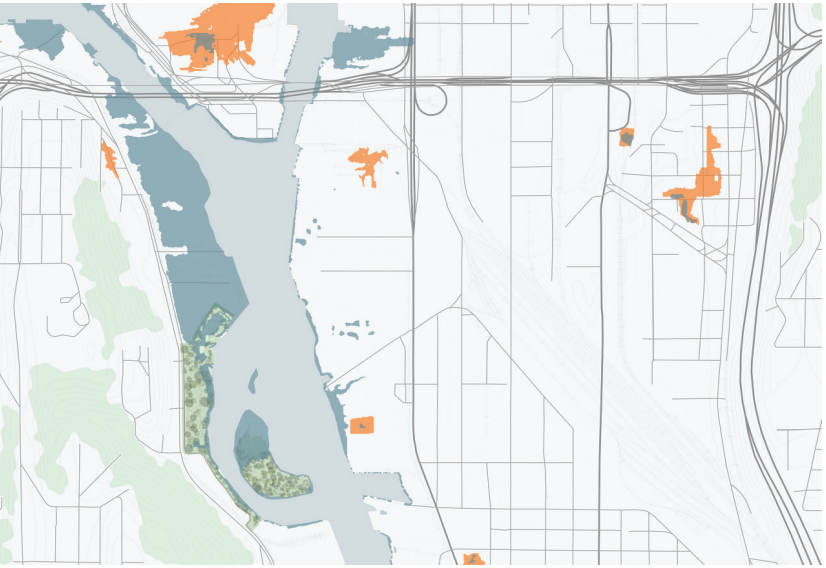
# Local Sea Level Rise

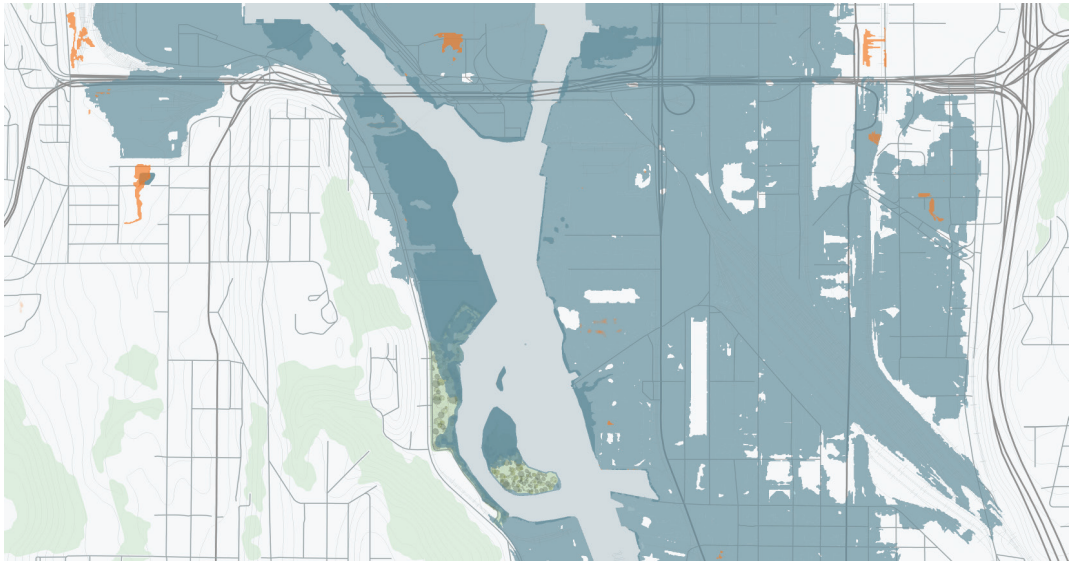
High Tide Flooding

Sea Level Rise

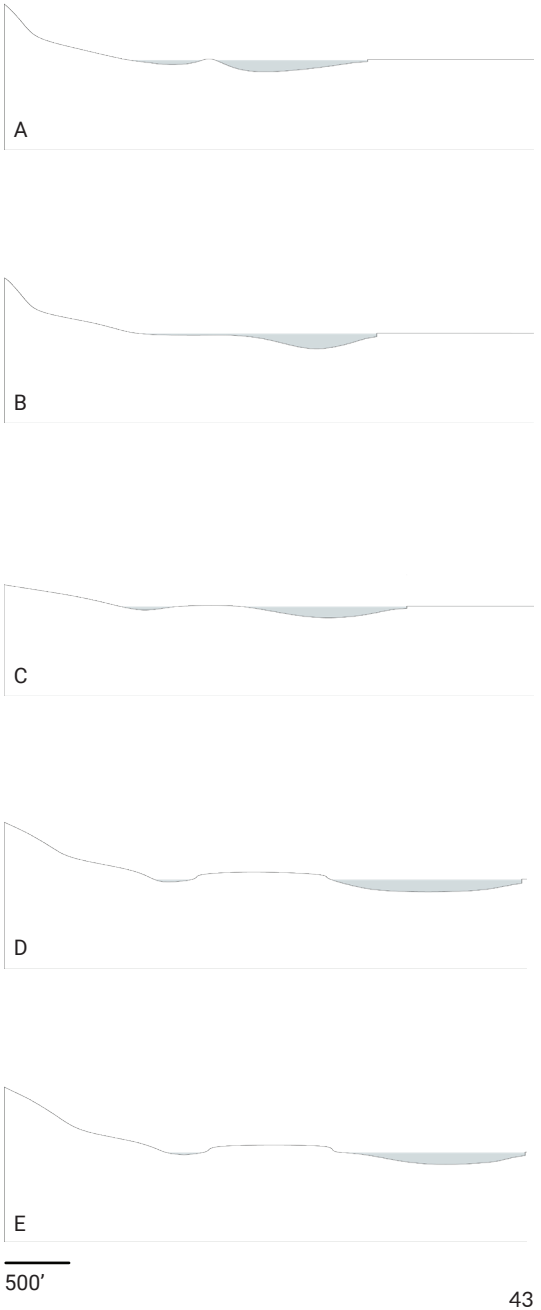
Right to left: 4.11, 4.12, 4.13
A progression of sea level rise at Kellogg Island. Starting with current high tide flooding, 5 feet of sea level rise and finally 10 feet of sea level rise



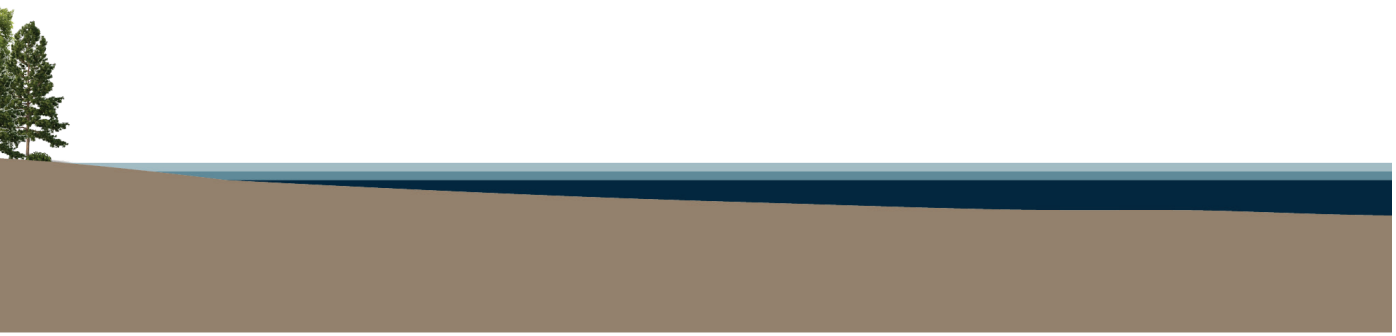




Remembering the mouth of the Duwamish River used to be tidal mud flats, its easy to understand that the area is still very vulnerable to rising water levels. As tides come in and go out, and sea levels continue to rise, the surrounding industrial district will almost start to return to its undeveloped state. At the mercy of the water, the surrounding industrial district as well as other waterfront areas will begin to succumb to the inundation of water.


4.14
Continuous sections cut through the site emphasizing the flat topography. Even with the vertical axis multiplied by 3, the landscpae is still relativley flat



Current sea levels + 10 feet sea level rise

Current sea levels + 5 feet sea level rise

Current sea levels

4.15
Section C, with current sea levels, 5 feet of sea level rise, and 10 feet of sea level rise.

# 05 PROPOSAL

## Center for Rising Waters

Within the next 100 years, it is possible that sea levels could rise up to 10 feet from their current levels. This does not account for high tide flooding, storm surges, or other natural disasters, but rather just the rising levels of the sea as a side effect of climate change. There is no stopping it, as the irreparable damage continues to increase global temperatures and melt glaciers. Land will be lost, buildings destroyed and Seattle's landscape as we know it will change forever. Sea level rise is now inevitable, and the only choice we have now is how we respond to the coming changes.

This thesis proposes amphibious architecture, utilizing barges, that will adapt with the rising sea levels; eventually becoming floating architecture when sea levels have risen too high. Located at Kellogg Island at həʔapus Village Park*, these floating barges will continue to provide public access to the water with recreational areas and provide space of education for the public on pollution and rising sea levels due to climate change. My proposed design intervention is informed by these three guiding principles:

5.1, 5.2
*həʔapus Village Park

*həʔapus Village Park
(Formerly named Terminal 107 Park)

(haapoos, "ha-ah-poos": Name of a small stream draining across a flat on the west side of Duwamish River)

### Adaptation

Sea level rise is inevitable, it's been happening for the last hundred years, and will continue to rise even after we run out of melting glaciers or slow pollution. This thesis proposes a solution that will amphibiously adapt with the coming changes of sea level rise, knowing that as tides rise and fall and seasons change, this proposal will need to be able to adapt through it all to survive the next 100 years.

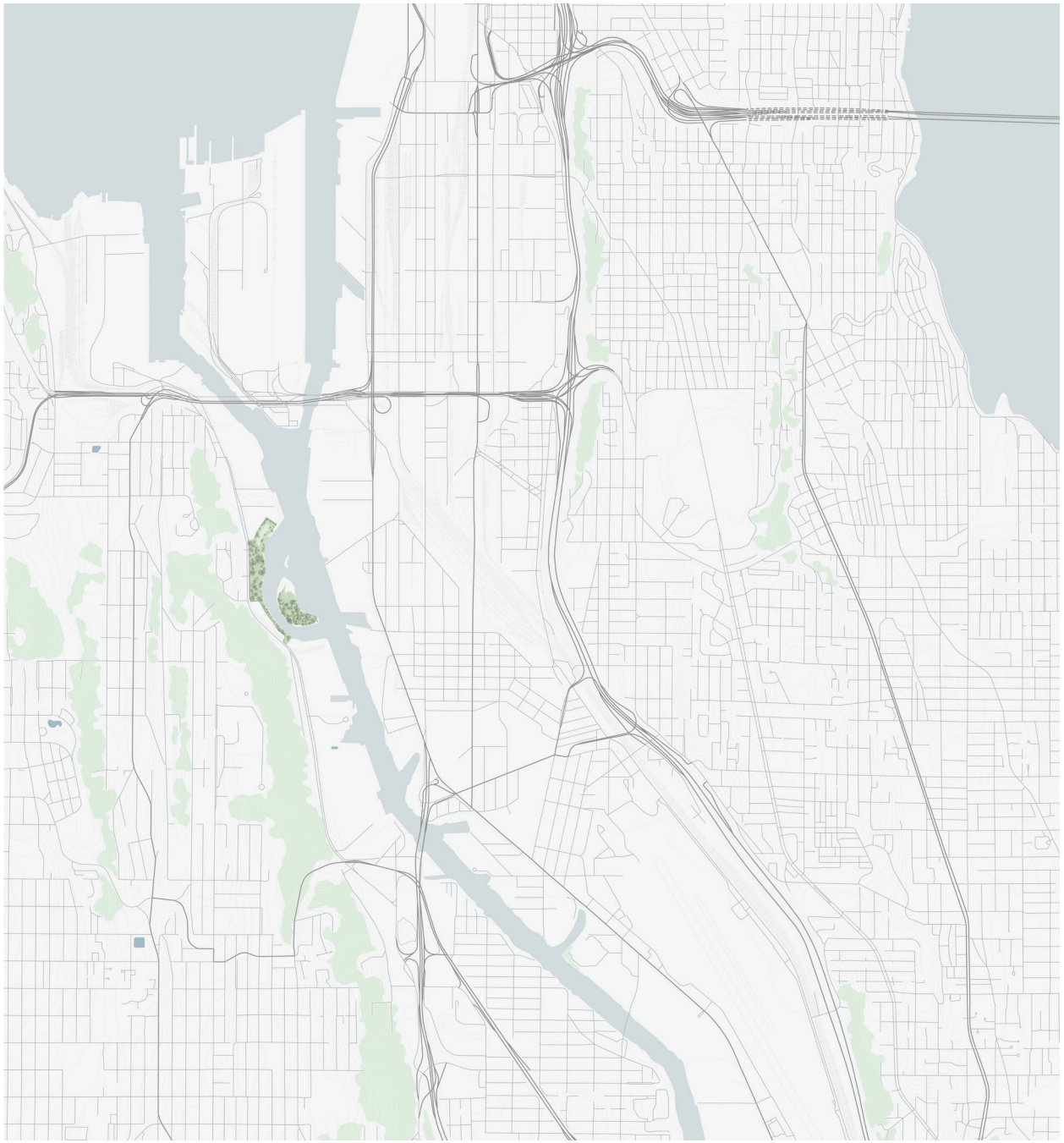
### Regeneration

Kellogg Island was picked as the thesis site not only because it will be affected by rising sea levels, but it also is affected by the surrounding industrial area. Named as one of the worst superfund sites in history, the Duwamish River has the potential to heal from its industrial pollution and become a safer place for people to live.

### Stewardship

Prevention is one of the best ways to keep our planet healthy. This is done through education, outreach, and responsible management. By being good stewards of this thesis, the site, and our planet, we can prevent further damage and move onto regenerating the damage done.

5.3
Aerial view of Kellogg Island looking south

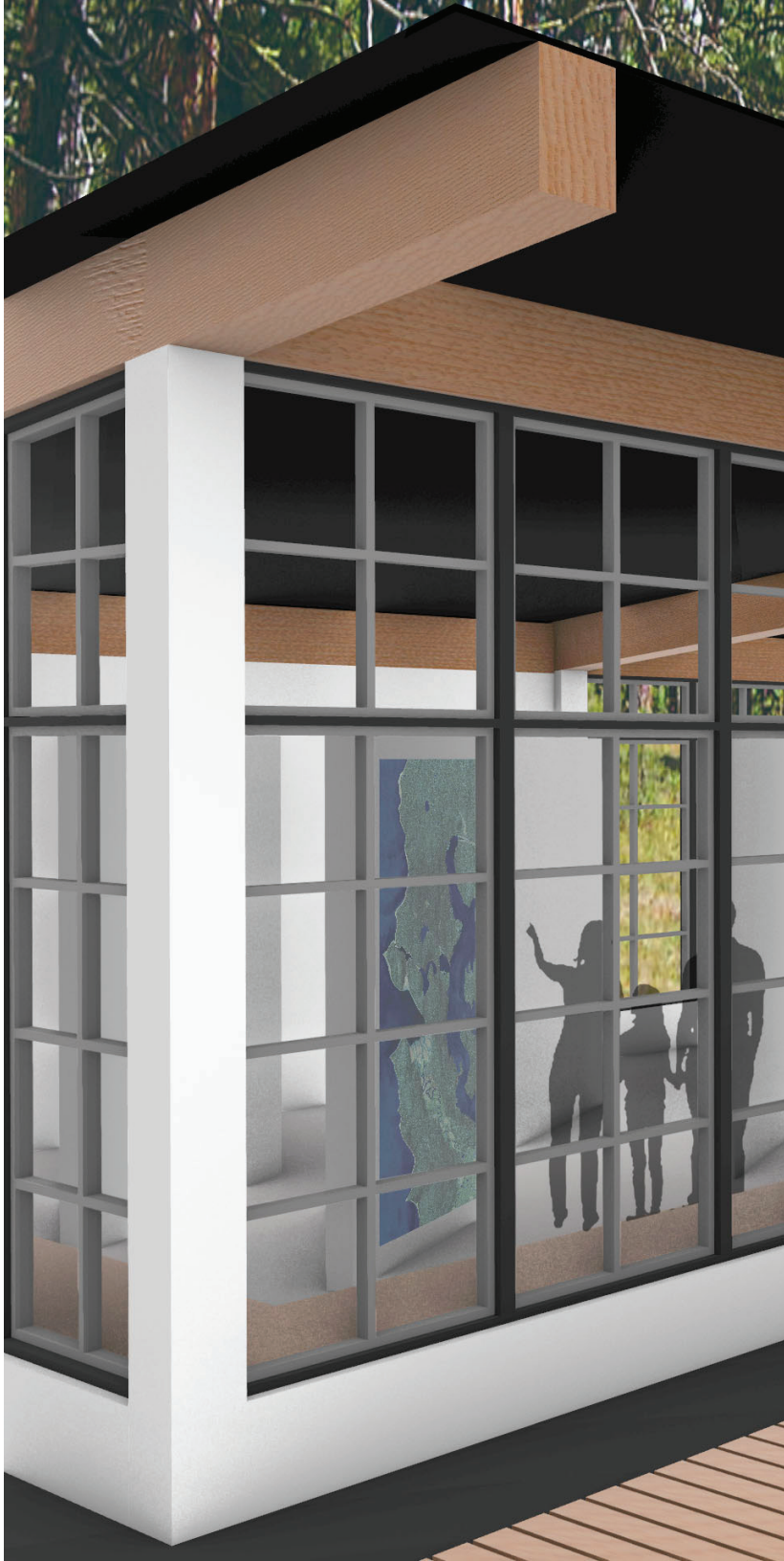


5.4
Vicinity map of the Duwamish River


5.5
Site map of the Center for Rising Waters

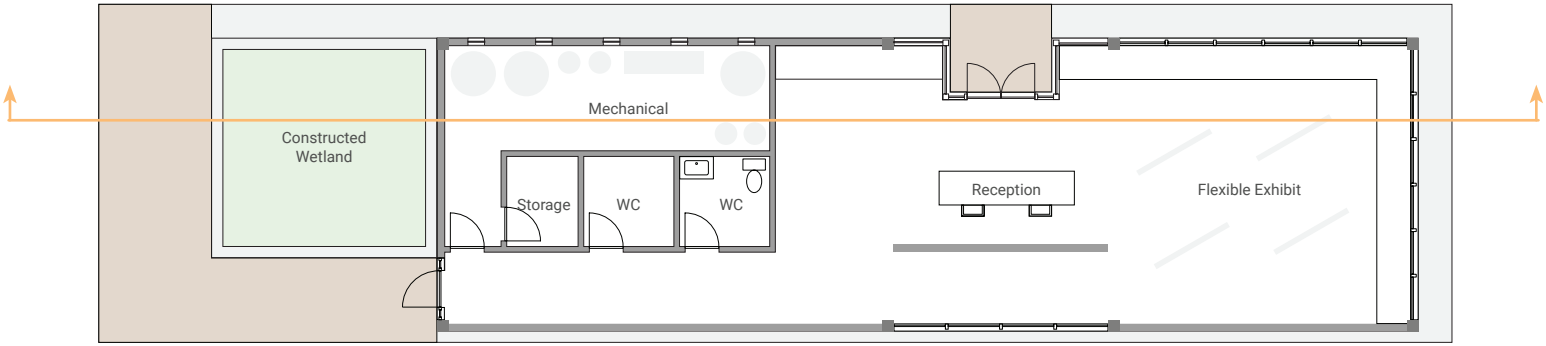
## Welcome Center

Here, visitors get a first glance at what constructed wetlands are and can learn about the history of the Duwamish valley through the exhibit space. The exposed mechanical room includes anaerobic, aerobic and anoxic tanks as done in the living machine to process the water coming from the restrooms. After initial processing, the water is drained into the constructed wetland. Once fully filtered, the non-potable water is stored for recycling with excess being released back into the environment.



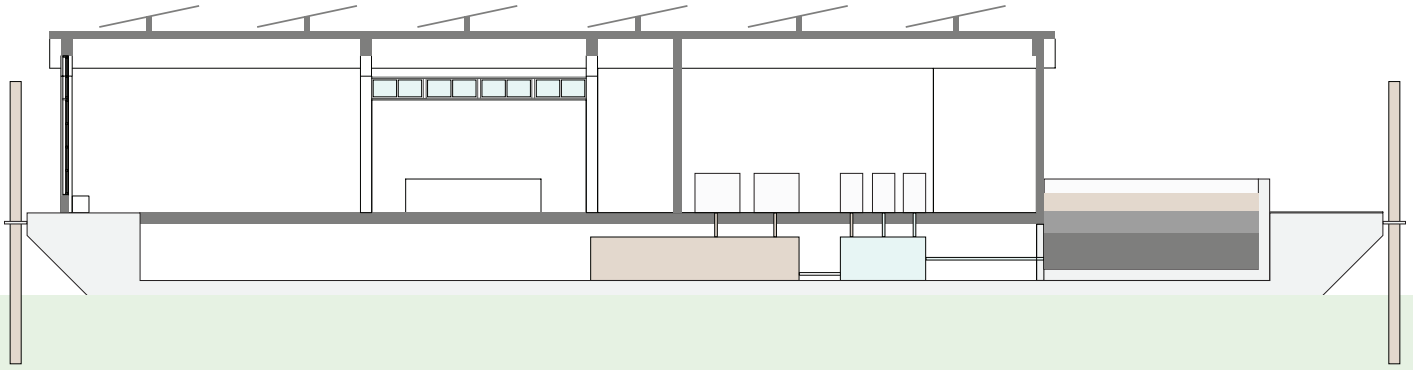
5.6
As the first stop, the Welcome Center is the gateway to The Center for Rising Waters

5.7
Site Plan with the Welcome Center




5.8 (Above)
Plan of Welcome Center Barge with separate education and research space

5.9 (Below)
Section of the Welcome Center showing the mechanical room's Living Machine connect to the constructed wetland to process and filter the wastewater from the restrooms



The welcome center utilizes a hopper barge as an amphibious foundation, anchored by 4 piles at the corners. The location of the welcome center is placed, so it will float once water levels have risen 7.5 feet.

Once inside the center, visitors can check in for self guided tours, learn about the history of the Duwamish Valley or enjoy the scenic view before moving on.


5.10
Inside the welome center visitors can get information from the front desk or read about the area in the exhibit space

## Lookout

To continue, visitors need to cross over the river on an elevated bridge that ends at a lookout.

The lookout allows a moment of rest and stability. It is a point to look north towards downtown Seattle, east at the industrial district or south towards Mount Rainier and be able to see how the environment changes over the next 100 years. The lookout is placed on ground that will flood with 2.5 feet of sea level rise, but because it is fixed and elevated, the lookout and bridge are safe from up to 15 feet of sea level rise.

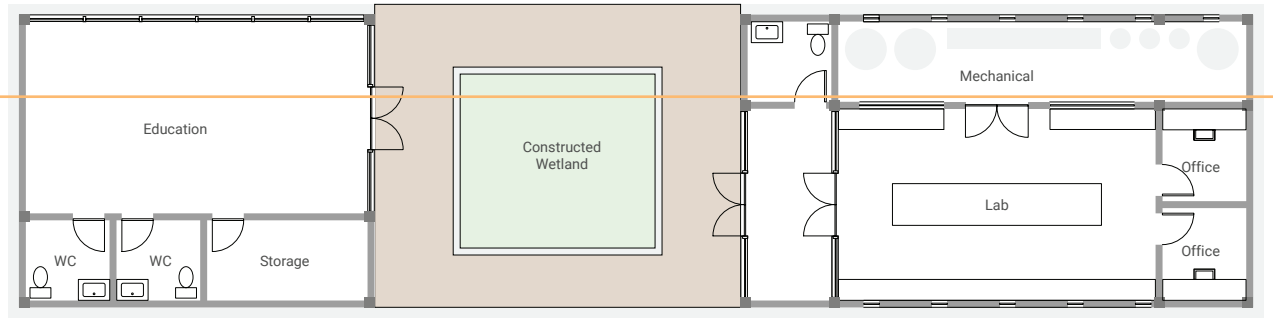
5.11
With almost 360 degree views, visitors can easily watch how the surrounds change around them and sea levels rise

## Stewardship

Back down to the ground from the lookout, 5 ft above sea level, is the Stewardship Barge. Separated by a built in constructed wetland, the barge has and education space on one side and a research space on the other. The flexible education space is regularly used for public seminars and classes where visitors can learn about the causes and effects of climate change, rising sea levels, and how we, as a society can do better to help.

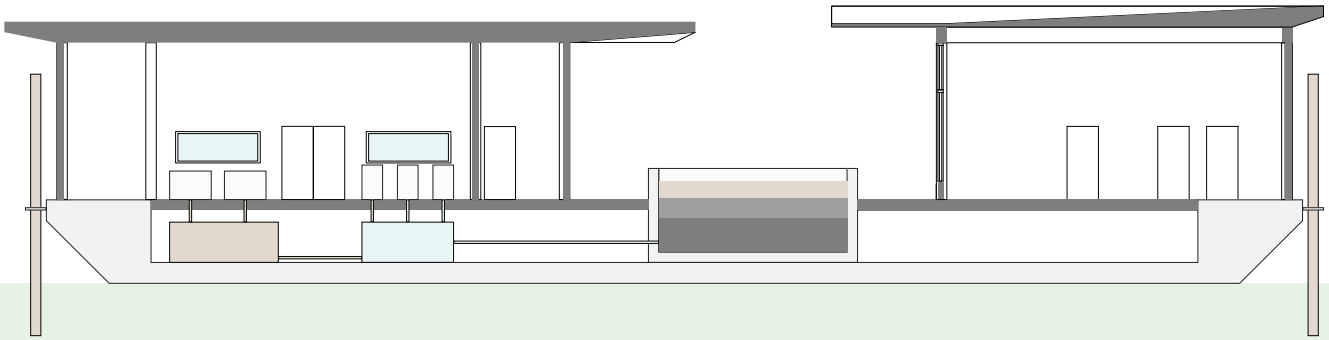
5.12
On the Stewardship Barge visitors can go into the education space on the right for a class that is about to start or look at the Living Machine in the mechanical room attached to the lab to see the current research going on

5.13
Site Plan including the Welcome Center, bridge, lookout and Stewardship Barge




5.14 (Above)
Plan of Stewardship Barge with separate education and research space

5.15 (Below)
Section of Stewardship Barge showing the research lab's Living Machine connect to the constructed wetland



## Research

Similar to the welcome center, this barge also has an exposed mechanical and water filtration area with an adjoining constructed wetland, but it is also in conjunction with the research lab area. This lab space is focused on how we can better utilize systems like constructed wetlands and the living machine, and how those results can be more widely applied to pollution cleanup. The findings from this lab are frequently shared with the public, most often from classes and presentations in the education space.

5.16
Interior view of the research lab. Here scientists work together with plants and living systems to discover and learn more information on pollution clean up

## Regeneration

At the end of the path is a point for future recreation. Today, this space is unable to operate as a safe space for recreation, however it is a point of hope for future potential. As the Lower Duwamish Waterway group continues to clean up the Superfund areas to make the area more habitable, these floating constructed wetland docks can do their part in helping filter pollutants out of the water.

5.17
Visitors who have reached the end of the path have ended at the Duwamish River. From there they have a northern view of the suspension bridge that they crossed earlier

# 05 REFLECTION

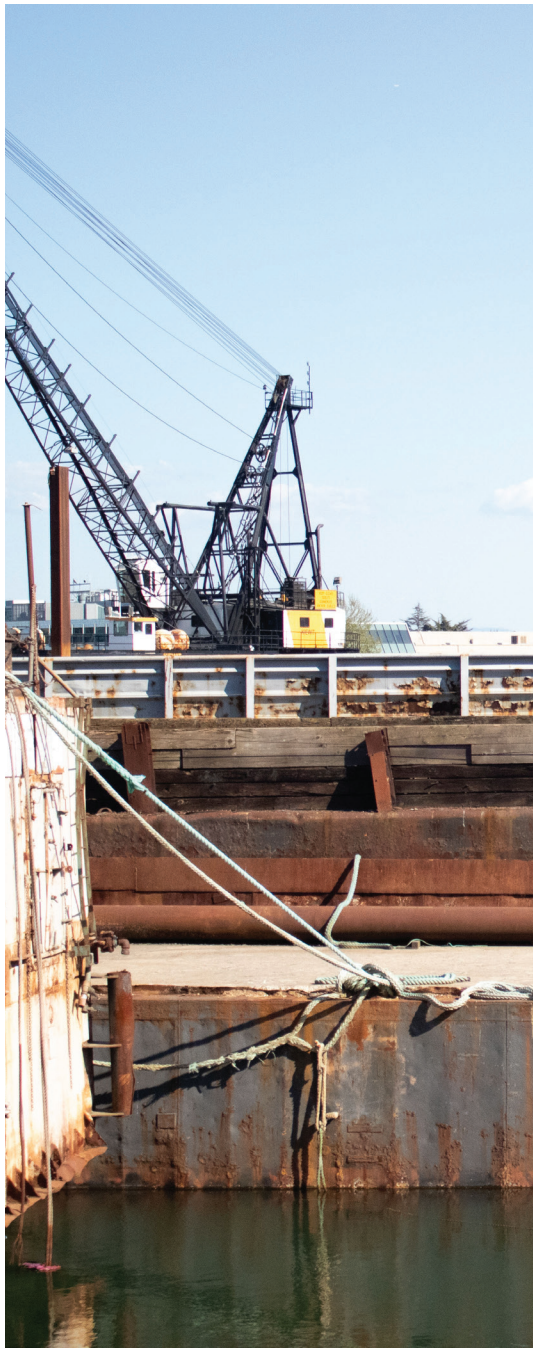
## Concluding Thoughts

The world is in a global climate crisisand we live in a society that doesn't fully recognize the weight and brevity of the situation. This thesis stemmed from my passion for sustainability and love of nature, but recognition that the climate crisis we have been predicting, is one we are now living. The issue of climate change is a multifaceted issue with no one right answer but can be mitigated through interventions of many different scales. As I researched deeper into the issue of climate change, its affects, and the repercussions, the more I focused on adaptive strategies rather than forceful interventions.

Global temperatures have been rising, glaciers have been melting and sea levels have been rising. We, as a society and as a world are inept to handle the scale of climate change. By reframing this change as a catalyst for adaptation to anticipate the coming changes, rather than avoid them, we can preserve more of our homes, environments and communities. Growing up near Seattle, and going to school in the city, makes me wonder if in 100 years sea levels rise 10 feet, will we adapt to the coming changes or ignorantly neglect them until it is too late to intervene at all? Design proposals are only as robust as

the designers are willing to take it, and for a challenge this large, the adaptive strategies need to be pushed.

It is my hope this thesis can provide a better understanding of the climate situation we are in today, and what it means for the future. We cannot fix climate change overnight or heal the damage already caused, but we can first recognize our role in causing it. By reflecting on the processes and mistakes we have made to cause anthropogenic climate change, perhaps we can create adaptive designs that will not further contribute to the climate crisis but rather regenerate the environment and community instead.



# 05 REFERENCES

## Images*

2.1 Deforestation practices disrupt ecosystems, which can decades to recover from
Source: https://www.nationalgeographic.org/encyclopedia/deforestation/

2.2 Ecosystems are all interconnected, relying on each part to run smoothly
Source: https://socratic.org/questions/can-you-define-ecosystem

2.3 Map of “protected” lands in the United States of America by land designation
Source: https://maps.usgs.gov/padus/

2.4 Sources of Energy Produced in the United States

2.5 Energy Consumption by Building Type in the United States

2.6 Diagram of how pollution enters into the environment. Pollution can come from many different sources.

2.7 Average global rise of temperature in degrees Celsius from 1880 to present.

2.8 Average global rise of sea levels in centimeters from 1880 to present

2.9 Graph showing potential sea level rise outcomes (in feet) based on representative concentration pathways, by probability
Source: https://cig.uw.edu/our-work/applied-research/wcrp/sea-level-rise-data-

*Photographs and images are produced by author unless otherwise noted

visualization/#dataviz1

2.10 Hoover Dam holding back the Colorado River in the Black Canyon

Source: https://www.nationalgeographic.org/encyclopedia/dams/

2.11 The new sea wall in Seattle holds back the water in the Puget Sound, protecting the city from erosion

Source: https://www.seattlemag.com/news-and-features/new-seawall-anchors-seattles-waterfront

2.12 Washington SR 520 has the longest floating bridge to bring people across Lake Washington to Seattle

Source: https://wsdot.wa.gov/Projects/SR520/bridge-replacement/home

2.13 Boats come in many different forms, including houseboats

Source: https://tinyhousetalk.com/tiny-houseboat-in-seattle/

3.1 Traditional wastewater treatment facility

Source: https://www.andrealopezv.com/factors-to-consider-in-a-community-wastewater-treatment-plant/

3.2 Diagram of constructed wetland

3.3 Constructed Wetland

Source: http://whix.fiu.edu/WHIX04/GeneralDescription.aspx

3.4 Constructed Wetlands

Source: https://www.mdpi.com/2073-4441/12/6/1665

3.5 + 3.6 The Living Machine

Sources: https://www.toddecological.com/

3.7 Diagram of The Living Machine

3.8 Floating Office Rotterdam

Source: https://www.powerhouse-company.com/for-office

3.9 + 3.10 Floating Office Rotterdam

Source: https://www.avontuura.com/floating-office-by-powerhouse-company/

3.11 Floating Office Rotterdam

Source: https://gca.org/gca-moves-to-worlds-largest-floating-office-a-model-of-self-sufficient-climate-resilient-design/

3.12 - 3.14 FLOAT House

Source: https://www.morphosis.com/architecture/126/

3.15 FLOAT HOUSE

Source: https://www.anthropocenemagazine.org/2018/09/amphibious-architecture/

3.16 Swale floating farm

Source: https://marymattingly.com/html/MATTINGLYSwale.html

3.17 Swale floating farm

Source: https://www.designboom.com/video/swale-floating-farm-new-york-mary-mattingly-a-blade-of-grass-05-30-2017/

4.1 Predicted historic landscape of the Greater Seattle Area before the migration of settlers, regrading, and development
Source: https://www.burkemuseum.org/static/waterlines/project_map.html, Edited by Author

4.2 Current satellite image of the Greater Seattle Area
Source: https://www.google.com/maps

4.3 Chief Seattle, the chief of the Suquamish and Duwamish Tribes during the 1850s when many settlers were moving to the area
Source: https://www.duwamishtribe.org/history

4.4 + 4.5 Duwamish Tribe camps set up on Ballast Island after their homes were burned and they were forced to move to Ballast Island
Source: https://www.duwamishtribe.org/exile-to-ballast-island

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4.9 Process of biomagnification in an ecosystem
Source: https://sites.sandiego.edu/sdpollutiontrackers/2018/04/05/somethings-fishy-about-pcbs/pcb_food_chain_marine_plankton_herring_salmon_mammals/

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# Appendices

## Recognized Superfund Site Contributors

Ace Galvanizing, Inc.
Airgas-NorPac, Inc.
Alaska Logistics LLC
Alaska Marine Lines, Inc.
Ameriflight LLC
Art Brass Plating
Ash Grove Cement Company
Ball Corporation
Basin Oil Co., Inc.
Bayer CropScience LP
Birmingham Steel Corporation
Blaser Die Casting Co.
Boeing Development Center
Boeing Isaacson-Thompson
Boyer Towing, Inc.
BNSF Railway Company
BNY Mellon N.A. – Trust for Giuseppe and Assunta Desimone
Capital Industries, Inc.
CDL Recycle, LLC
CertainTeed Gypsum Manufacturing, Inc.
Chevron U.S.A. Inc.
Chiyoda International Corporation
City of Seattle
City of Tukwila
ConGlobal Industries, Inc.
Container Properties LLC
Continental Holdings, Inc.
Crowley Marine Services, Inc.
Crown Beverage Packaging, Inc.
Crown Cork & Seal USA, Inc.
David J. Joseph Company, The
Delta Marine Industries, Inc.
Douglas Management Company
Drummond Lighterage Co.
Duwamish Marine Center
Duwamish Properties, a partnership
Duwamish Shipyard Inc.
Earle M. Jorgensen Company
Ellis Garage, LLC
Emerald Services, Inc.
Evergreen Trails, Inc.
First South Properties, LLC
Fletcher Challenge Investments Overseas Limited
Fletcher Challenge Investments Overseas Limited
Frank H. Hopkins Family, LLC and Frederick J. Hopkins Family, LLC
Gary Merlino Construction Co., Inc.
General Construction Company
General Electric
General Recycling of Washington, LLC
General Services Administration
Georgia-Pacific LLC
Georgetown Steam Plant
Glacier Northwest, Inc.
Great Western Chemical Company
Halvorsen, Mary Catherine
Hansen, Mark
Holcim (US), Inc.
Hurlen, Harald
Independent Metals Company, Inc.
Industrial Container Services - WA LLC
Insurance Auto Auctions, Inc.
James D. Gilmur
Jorgensen Forge Company
Kaiser Cement Corporation
Kaiser Gypsum Company, Inc.
Kelly-Moore Paint Company, Inc.
King County
King Electrical Manufacturing Company
Lafarge North America, Inc.
Latitude Forty-Seven, LLC
Lehigh Northwest Cement Company
Linde Gas North America, LLC
Lipsett Company, LLC
Longview Fibre Paper and Packaging, Inc.
Long Painting Company
Malarkey, Michael O'Neil
Manson Construction Company
Marcia A. Rodgers Industrial, LLC
Marine Power & Equipment, Inc.
McLeod, Dennis & Patricia
Merrill Creek Holdings LLC
MMGL Corp. (Formerly Schnitzer Investment Corp.)
Monsanto Company
MRC Holdings, Inc.
Norcliffe Company
Northland Services, Inc.
Northwest Container Services, Inc.
PACCAR, Inc.
Pacific Terminals, Ltd.
Philip Services Georgetown
Port of Seattle
PSC, LLC
Praxair, Inc. (Re: Liquid Carbonic Corp.)
Puget Sound Coatings
Puget Sound Energy, Inc.
Puget Sound Truck Lines, Inc.
Puget Sound Tug & Barge Co.
R&A Properties, LLC
Rainier Commons LLC
Reichhold, Inc.
RJ & BA LLC
S. Michael Rodgers Industrial, LLC
Saint-Gobain Containers, Inc.
Scougal Rubber Corporation
SCS Refrigerated Services, LLC
SeaTac Marine Properties, LLC
Seattle Boiler Works, Inc.
Seattle Iron & Metals Corporation
Shalmar Group LLC, The
Silver Bay Logging, Inc.
Simco Properties, LLC
South Park Marina Limited Partnership
Sternco Industrial Properties Partnership
Sternoff Metals Corporation
Swan Bay Holdings, Inc.
The Chemithon Corporation
Trotsky, Herman & Jacqualine
U.S. Army Corps of Engineers
Union Pacific Railroad Company
United Iron Works, Inc.
V. Van Dyke, Inc.
Washington State Department of Transportation
Wells Fargo Bank, N.A.
Wells Trucking & Leasing, Inc.

## Toxic Cleanup Plan Companies

Boeing Isaacson-Thompson
Crowley Marine Services, Inc.
Douglas Management Company
Duwamish Marine Center
Duwamish Shipyard Inc.
Georgetown Steam Plant
Glacier Northwest, Inc.
Great Western Chemical Company
Industrial Container Services - WA LLC
Jorgensen Forge Company
PACCAR, Inc.
Port of Seattle
Reichhold, Inc.
South Park Marina Limited Partnership

## Hazardous Waste Treatment and Reduction Companies

Art Brass Plating
Blaser Die Casting Co.
Capital Industries, Inc.
General Electric

## Lower Duwamish Waterway Group

Boeing Development Center
City of Seattle
King County
Port of Seattle