Cultivating Contamination: Floating In-Situ

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Dedicated to my mother, who will forever
encourage me to grow works
of beautiful utility

University of Washington

Abstract

CULTIVATING CONTAMINATION : FLOATING IN-SITU

Weaving a new materialshed of re-purposed dredge in Seattle's Lower Duwamish Waterway as fill for living sea level rise infrastructure

Sophie M. Krause

Chair of the Supervisory Committee:
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Despite its Superfund designation by the Environmental Protection Agency (EPA) as one of the nation's most toxic hazardous waste sites in 2001, Seattle's Lower Duwamish Waterway (LDW) remains polluted, with a legacy of industrial contaminants persisting in its bottommost sediment.[1] Acknowledging that the permanent removal of this sediment by dredging would provide greater certainty to its cleanup effort, EPA's final Record of Decision (ROD) for the LDW relies on less effective methods, citing the cost of dredging as a limiting factor.[2] Still working to undo the past hundred years of this contamination, the LDW also faces a costly and floodable future from rising sea levels, with frequencies and magnitude of flooding in its lowest lying neighborhood of South Park estimated to increase as annual flooding events are projected to become monthly events by 2035, and daily events by 2060.[3] Analyzing these constraints through the framework of strategic foresight, this thesis presents a design scenario that strategizes how contaminated dredge can be treated and re-purposed as construction fill for creating nearby flooding infrastructure along the South Park waterfront, as a cost-effective driver for optimizing converging waterway projects. Inverting the formula of form -> function -> material amidst a future of resource scarcity and climate change adaptation, this scenario connects the dots between what the LDW has today (treatable dredge) and what it needs for tomorrow (fill for flooding), proposing the design of a hybrid, living floodwall prototype, as landscape infrastructure that is more ecologically and community performative. Re-framing waste as source, and constraint as opportunity, this scenario responds holistically to a world that now asks landscape infrastructure to do more, with less, and at the same time - resiliently. It is a project built on compromise and dirt.

1. EPA Environmental Protection Agency Region 10. Record of Decision Lower Duwamish Waterway Superfund Site. EPA , 2014, pp. 1–181
2 Final Duwamish River Cleanup Plan Fact Sheet. Record of Decision: Final Cleanup Plan Community Fact Sheet. Record of Decision: Final Cleanup Plan Community Fact Sheet, Duwamish River Cleanup Coalition/ Technical Advisory Group, 2015.
3. GGLO Design. "Climate Preparedness: A Mapping Inventory of Changing Coastal Flood Risk." Seattle Office of Sustainability and Environment, 24 Aug. 2015, pp. 1–42., www.seattle.gov/ Documents/Departments/Environment/ClimateChange/2015.08.25_ClimatePreparednessInventory_Sec1.pdf.

CULTIVATING CONTAMINATION : FLOATING IN-SITU

Sophie M. Krauše

SUSPENDED BETWEEN INDUSTRY | ECOLOGY

"Imagine the planet as a big brownfield. Consider it less as a virgin resource (to protect) or a sensitive system (to shield), but rather as a big ball of oscillating waste (to keep moving): materials and fluids in different concentrations whose varying distributions are in constant motion brought upon existing earth processes, accelerated or arrested by emerging modes of production and evolving technological systems, thickened, adjusted, and layered by the human, animal, and vegetal hand. We swim in our shit."

Pierre Bélanger, Ecology 5.0

001

CONTENTS | THANKS

Thank you to my father for encouraging me to let my cerebral horsepower run and for once telling me "if we have the data, let's look at the data. If all we have are opinions, then I guess let's use mine." Thank you to Gerry for encouraging me to stay curious, and for gifting me a copy of the 1977 *A Pattern Language* when I started this program three years ago. Thank you to Holly for reminding me that change is inevitable but growth is optional, and for showing me what hard work looks like. Thank you to my cohort and all of my people here at the University of Washington's College of Built Environments, for collectively making this exploration in landscape architecture a possibility. I would not be where I am if you weren't here with me. And thank you to every single microscopic plant-microbe partnership that makes this entire world a possibility.

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Thesis Committee: Ken Yocom
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003

INTRODUCTION | INTENTIONS

Paddling through the waterway, I surprise a heron successfully stabbing at a fish amidst a backdrop of barges and logs chained to embankments. I spy shipping cranes and things with feathers and scales and a pulse. Waving to fellow kayakers while working to stay in my right of way, my paddle pauses as I float in a sheen past tankards and rigs that demand my focus and an increasingly wide berth. Paddling further ahead, my eyes scan north and west to an urban eddy that straddles the reflective metal of salvaged cars and the opaque murkiness of water that keeps me afloat. Buoyant, but undrinkable. I am kayaking in the lowermost portion of Seattle's Duwamish River, today an infrastructural corridor home to living and

non-living systems that both thrive and survive here. Supporting industry, ecology, and community along the same lifeline, this riverway turned waterway is also home to disparate legacies and convoluted narratives. While my design thinking explores this site primarily through the lens of landscape infrastructure and ecological restoration, being somewhat narrow in its scope, at the core of my vision is the belief that the ecological well being of a place trophically and systematically underpins the cultural well being of the people who live there.

The Duwamish River has been straightened, contaminated, dredged, filled, and developed throughout the past hundred years. From freshwater passageway to an industrial corridor, the lowermost portion of the Duwamish lies just south of downtown Seattle, flowing seaward into Elliott Bay. Contaminated from a century of industrial use, the last five miles of the river, or urbanized estuary now known as the LDW, were designated by the EPA as a hazardous waste Superfund site in 2001.[4] Twenty years later, the LDW is nowhere near clean. Suspended between industrial flows and troubled ecology, the contaminants of highest concern are carcinogenic polycyclic aromatic hydrocarbons (cPAHs) and polychlorinated biphenyls (PCBs), which not only persist but biomagnify within its bottommost sediment. Contact with this sediment, as well as consumption of its resident fish and shellfish, continues to pose serious and inequitable risks to human health.[5] This is both dangerous and disturbing, especially for the communities who most closely live, work, fish, and play here.

In the words of James Rasmussen, Duwamish Tribe member and director of the Duwamish River Cleanup Coalition (DRCC), "if you leave contaminants in the river, they stay here." It's an apt statement for a river whose cleanup history has so far been prone to varying levels of success, failure, recontamination, ownership, agency, and incentive. Most recently in 2014, after unveiling a $342 million dollar cleanup plan ten years in the making, the federal government is determined to continue addressing the site through potentially responsible party (PRP) actions, alongside EPA and Washington state oversight.[6] And according to Dennis McLerran, regional administrator for the district overseeing the Duwamish cleanup, this plan is as aggressive as a Superfund plan can be, representing a "carefully thought through, technically sound approach, that we believe will leave us with the cleanest possible river we can get."[7]

But years of point source finger-pointing, project delays, treatment failures, and the complicated structures and systems of a site juggling government agencies, treaties, tribes, and residents - not to mention that the waterway, as a Port lifeline, cannot stop working - has made cleanup in the LDW historically difficult. Superfund designation was intended to bring a shared, sudden cleansing to a waterway in crisis.

4. Duwamish River Cleanup Coalition, and Technical Advisory Group. "Timeline." Duwamish River Cleanup Coalition/Technical Advisory Group, duwamishcleanup.org/superfund-info/timeline/.
5."LOWER DUWAMISH WATERWAY Site Profile." EPA, Environmental Protection Agency, 20 Oct. 2017, cumulis.epa.gov/supercpad/SiteProfiles/index.cfm?fuseaction=second.cleanup&id=1002020.
6."LOWER DUWAMISH WATERWAY Site Profile." EPA, Environmental Protection Agency, 20 Oct. 2017, cumulis.epa.gov/supercpad/SiteProfiles/index.cfm?fuseaction=second.cleanup&id=1002020.
7.Person, Daniel. "The Duwamish: River of No Return?" Crosscut, Crosscut, 7 Feb. 2018, crosscut.com/2014/07/duwamish-river-no-return.

And while cleanup continues to progress, equitable risk assessment and environmental restoration in the LDW remains slow, while costs and litigation remain high. As with other Superfund sites, the demand for evidence, jurisdiction inconsistency, protection of private parties over the public, costly litigation, and uncertain and technical cleanup complexities have limited the success of its project so far.[8] Mired by processes that for many have been ineffective, inefficient, and unjust, radical change must strategize how the LDW cleanup can do better. Especially if it is to ever reach its restoration goal, of once again becoming a river whose residents can safely live, work, fish, and play here.

With waterway users emphasizing their desire to secure a cleanup of the Duwamish that is "done once and done right," this thesis proposes a design scenario intended to improve, maximize, and ensure the success of current restoration efforts in the LDW. Specifically within a biochemical and economic reality, capable of keeping project goals afloat. Restoration projects in the LDW, as in other urban estuaries, are constantly constrained by industrial use and structural developments in the river and along the shoreline.[9] Nested within the growing city of Seattle, restoring to historical (pre-1900s) ecologic conditions is no longer possible in a system that has undergone such a high level of alteration, and that supports numerous land use types, including industrial, commercial, residential, and urban infrastructures.[10] More so, restoring to these conditions would require returning to an environmental stewardship ethic that for many of us, no longer exists.

What does it mean, then, to develop a design scenario that facilitates cleanup and restoration projects in the LDW, within an increasingly urban and infrastructural context?

Analyzing past restoration projects, current Superfund efforts, and future infrastructure needs in the LDW through the framework of strategic foresight, this thesis finds that incentivizing the biotreatment and reuse of contaminated material as a cost-effective design driver can better link current and future waterway project goals, while facilitating more ecologically mindful and community reflective buildout. It envisions a scenario that allows the LDW to use what it has today, to build what it needs for tomorrow, more adaptively. Richard Slaughter defines strategic foresight as "the ability to create and maintain a high-quality, coherent and functional forward view, and to use arising insights in organizationally useful ways."[11] A future study intent on optimizing a way forward, it is most commonly used within a business or corporate context, embodying the mantra of "carrying out tomorrow's business better."[12] For a waterway cleanup effort currently involving government agencies, state departments, municipal entities, private corporations, universities, local organizations, resident communities, and close to $400 million in taxpayer funded dollars, I will argue that material reuse in the LDW is big business. More so, that working to cultivate contamination in an age of resource scarcity, as our age of mass-disposal transitions to one of mass-re-purposing, will become increasingly big business throughout this century.[13] And especially the next. Proposing a design scenario that works to better organize what the LDW has today, to transition towards what it needs tomorrow, this thinking began by re-conceptualizing the contaminated waterway as a productive materialshed.

What is a materialshed?

Think of the term "watershed," defined as a land area that channels rainfall and snowmelt to creeks, streams, and rivers, and eventually to outflow points such as reservoirs, bays, and the ocean. Now replace the word water with "material." Just as water moves through the land system, so too does material. Within this "shed" concept, designers use the terms watershed, materialshed, sedimentshed, and even wasteshed, to describe material flows through land and water based systems.
- Professor Tobiah Horton, Rutgers Agricultural Experiment Station

As a materialshed, the LDW is rich in contaminated sediment already slated for collection. Representing roughly one quarter of the selected remedy for its Superfund ROD, 960,000 cubic yards of contaminated sediment will be dredged from the LDW, with transport and disposal fees representing much of the overall project's cost.[14]

8. "Superfund: The Shortcut That Failed." PERC, 7 Feb. 2018, www.perc.org/1996/05/01/superfund-the-shortcut-that-failed/.
9,10. Kern, John, et al. Habitat Restoration in an Urban Waterway: Lessons Learned from the Lower Duwamish River. 2015, pp. 1–37, Habitat Restoration in an Urban Waterway: Lessons Learned from the Lower Duwamish River.
11, 12. Hamel, G., & Prahalad, C.K. (1994), Competing for the Future, Harvard Business School Press, Boston MA.
13. Bélanger, Pierre (2007). Landscapes of disassembly. Topos 60 (October):83-91.

While EPA acknowledges that more removal of LDW sediment by dredging would provide more permanence and certainty to its cleanup effort, it is choosing to overwhelmingly rely on less effective methods, citing the cost of dredging and disposal as a limiting factor.[15]

What is dredging?

Dredging is the act of removing silt and other material (or dredge) from the bottom of bodies of water, including harbors and inland waterways. Often focused on maintaining or increasing the depth of navigation channels to ensure the safe passage of boats and ships in urban waterways, dredging to deeper water depths continues to increase over time as larger ships are deployed. Since massive ships carry the bulk of the goods imported into the country, dredging plays a vital role in the nation's economy and is federally required by law. More dredging means more dredged material. The disposal of dredged material is managed and carried out by federal, state, and local governments, as well as by private entities such as port authorities. The U.S. Army Corps of Engineers issues permits for the disposal of dredged material, while the U.S. Environmental Protection Agency provides oversight and authorization. As an earthen aggregate of sediment, dredged material is often re-purposed as a viable material source, or fill, for development and other building projects.
- NOAA, National Oceanic and Atmospheric Administration

Dredge is treatable, however, already being re-purposed in other water bodies as a viable material source like construction fill. As phytotechnologies and bioremediation continue to demonstrate their success in remediating contaminated media, their

applications are becoming more recognizable and widespread, from laboratory to field site. Another upcoming big business, biotreatment can carry contaminated dredge from the output column of one project's spreadsheet, to the input column of another, creating a regionally focused driver for linking waterway projects through their materiality, proximity, and cost.[16]

What are phytotechnologies, and what is bioremediation?

Phytotechnology translates to "plant-technology," representing a set of technologies using plants to remediate or contain contaminants in soil, groundwater, surface water, and sediments. Bioremediation employs the same thinking, but with living microorganisms. While costs of conventional methods to remediate material are easy to estimate, based on known production and disposal rates, conventional techniques are often prohibitively expensive, and not without drawbacks. Generating high amounts of additional wastes, emissions from transport and disposal, they simply replace pollution in one area with pollution in another. Phytotechnologies and bioremediation are frequently shown as promising tools for the remediation of contaminated sites, but their application in commercial operations or field trials is scarce. There is a need to better transfer remediating phyto and biotechnologies to the commercial sector, and to explore ways to improve the economic viability of these technologies.
- A Critical View of Current State of Phytotechnologies[17]

Using biotreatment to re-frame its waste as a resource, more dredging in the LDW would ameliorate its Superfund cleanup while also generating materials for future waterway buildout. With countless ways dredge can be re-purposed and re-built into the LDW, this design scenario will focus on one, increasingly pressing issue: building structures to mitigate sea level rise (SLR). As a low-lying community already facing flooding issues along the waterfront, the neighborhood of South Park is predicted to bear the brunt of SLR in the LDW. Today it faces an even more floodable future from rising sea levels, with estimated frequencies and magnitude increasing in South Park as annual flooding events are projected to become monthly events by 2035, and daily events by 2060.[18] With flood mitigation infrastructure projects taking years to plan and construct, let alone fund, responding to SLR in the LDW requires adaptations (and materials) to be made now. As the narrow, working waterway will require flood mitigation structures to essentially be built into people's backyards, this buildout will require close community inclusion. With residents demanding a cleaner river and more open green space, SLR mitigation in South Park represents an opportunity for envisioning more hybrid, living, landscape infrastructure.

14. "US Environmental Protection Agency. Record of Decision Lower Duwamish Waterway Superfund Site. 2014, pp. 1–181, Record of Decision Lower Duwamish Waterway Superfund Site.
15. Final Duwamish River Cleanup Plan Fact Sheet. Record of Decision: Final Cleanup Plan Community Fact Sheet. Record of Decision: Final Cleanup Plan Community Fact Sheet, Duwamish River Cleanup Coalition/Technical Advisory Group, 2015.
16,17. Conesa, Héctor M et al. "A critical view of current state of phytotechnologies to remediate soils: still a promising tool?." TheScientificWorldJournal vol. 2012 (): 173829. doi:10.1100/2012/173829
18. GGLO Design. "Climate Preparedness: A Mapping Inventory of Changing Coastal Flood Risk." Seattle Office of Sustainability and Environment, 24 Aug. 2015, pp. 1–42., www.seattle.gov/Documents/Departments/Environment/ClimateChange/2015.08.25_ClimatePreparednessInventory_Sec1.pdf.

What is hybrid design?

Hybrid design dispenses with theory and relies on nimble, multi-faceted teams of experts to tackle the complexities of a design challenge. It's a progressive notion about the multi-dimensional craft of "doing things," as well as a reflection on the interconnectedness of all kinds of design within the economic and commercial fabric of society. It balances the skills, talents, and relative strengths of designers to create both physical and non-physical objects, and their refinement, delivery, and relevance within a cultural, social and responsible context. It advances the current range for design thinking by producing tangible, well-crafted solutions to the strategic and difficult challenges designers face in this new and increasingly complicated environment.
- Gadi Amit, New Deal Design LLC

What is living infrastructure?

The idea that living nature is also infrastructure isn't new. But it's now more widely understood to be true. Nature can be harnessed to provide critical services for communities, protecting them against flooding or excessive heart, or helping to improve air and water quality, which underpin human and environmental health. Urban forests, park systems, constructed wetlands, and green stormwater management systems all represent forms of living infrastructure. When nature is harnessed by people and used as an infrastructural system, it is called living infrastructure. Living infrastructure is shown to be more cost-effective than outmoded models of gray infrastructure, and also provide far more benefits for both people and the environment. Nature can be incorporated everywhere to provide many benefits at once.
- ASLA, American Society of Landscape

What is landscape infrastructure?

Landscape infrastructure is an evolutionary approach to strategizing economically and environmentally sustainable multipurpose infrastructure systems, reversing urban sprawl and regenerating our invaluable natural resources. As the world faces an urgent need for new and repaired infrastructure systems, design and planning professionals have the crucial opportunity to re-imagine networks that support multiple uses and functions. Multipurpose infrastructure conserves land, shares the financial load of its development, restores previously overlooked or damaged natural ecologies, and provides public access to much needed open space.
- SWA Group, Designing for a More Livable World

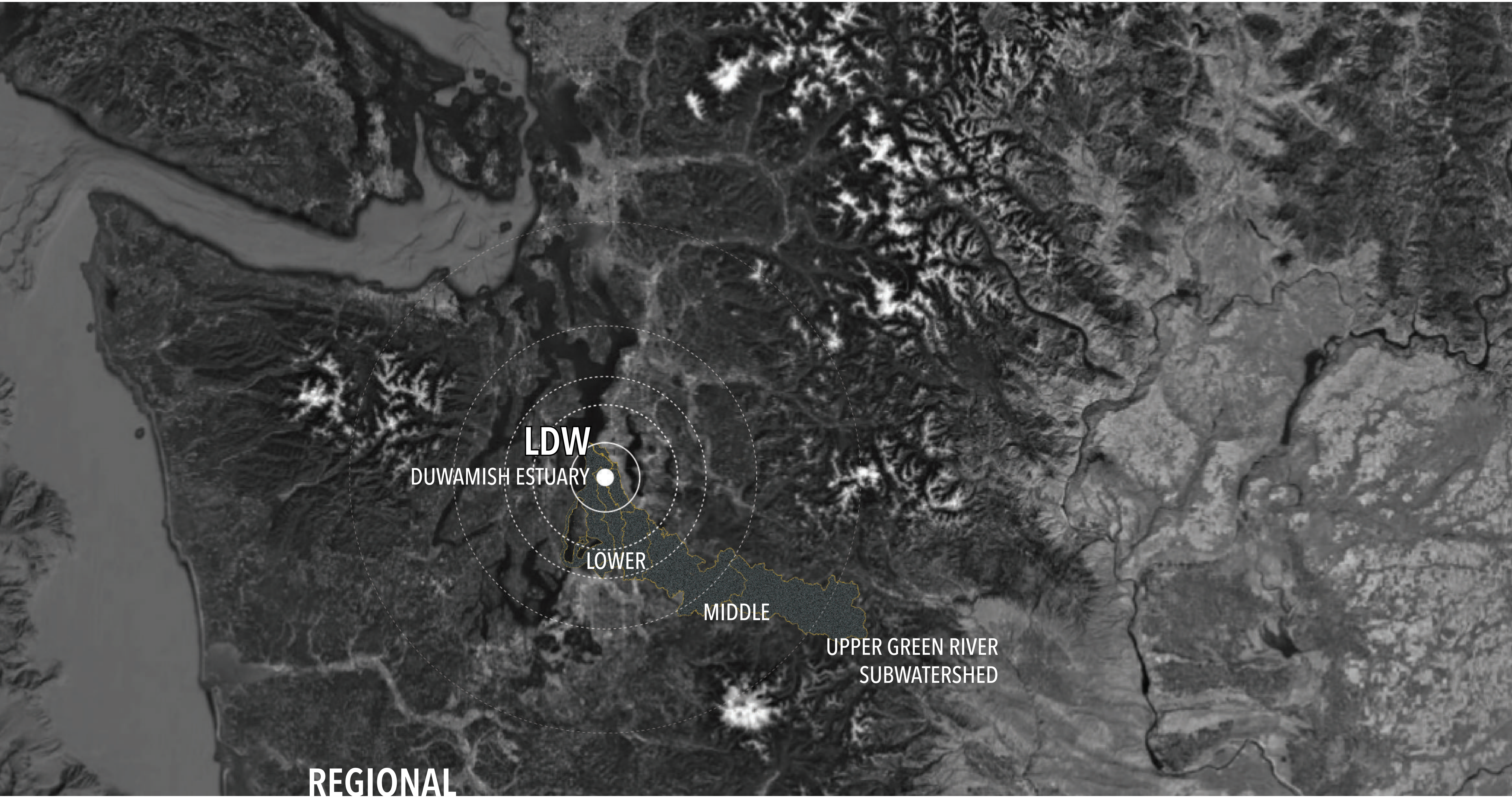
With a focus on finding performance gaps, stakeholder overlaps, and innovation within markets that do not yet exist, strategic foresight represents a fusion of future study. A model for not only strategic business management, but land management as well. Adopting this strategy as a landscape framework, identifying evolving dynamics and emerging issues that will impact project and land use decisions going forward, this thesis explores the following questions as they pertain to cleanup and restoration efforts in the LDW: where are we now, where are we headed, and how can we get there more preferably? How will the LDW transition from its closed, linear, single-purpose landscape infrastructure of today into the open, cyclical, more resilient systems it needs for tomorrow? Not only are these important questions - considering that working with what we have, to build more adaptively, will become increasingly big business throughout this century and the next - these are important questions to envision more optimal answers to, for the people who live here now.

Kees Lokman's Cyborg Landscapes: Choreographing Resilient Interactions Between Infrastructure, Ecology, and Society, proposes that today "we not only have to develop new ways of conceptualizing the environment as a product of complex interactions between anthropogenic forces and biophysical systems, we also have to envision new spatial relationships, [and it is] here, where landscape architects have the capacity (and responsibility) to actively manipulate and choreograph diverse social and ecological processes in order to create more resilient landscapes."[19] Exploring this directive through the LDW, one of Seattle's most developed infrastructure corridors, the following presents a design scenario focused on restoration, resiliency, and a more optimal way forward. As a project built on compromise and dirt, in a world that asks its landscapes to do more with less, it is an attempt to strategize a scenario capable of germinating more lasting and productive change. Even in our most contaminated places.

19. Kees Lokman (2017) Cyborg landscapes: Choreographing resilient interactions between infrastructure, ecology, and society, Journal of Landscape Architecture, 12:1, 60-73, DOI: 10.1080/18626033.2017.1301289

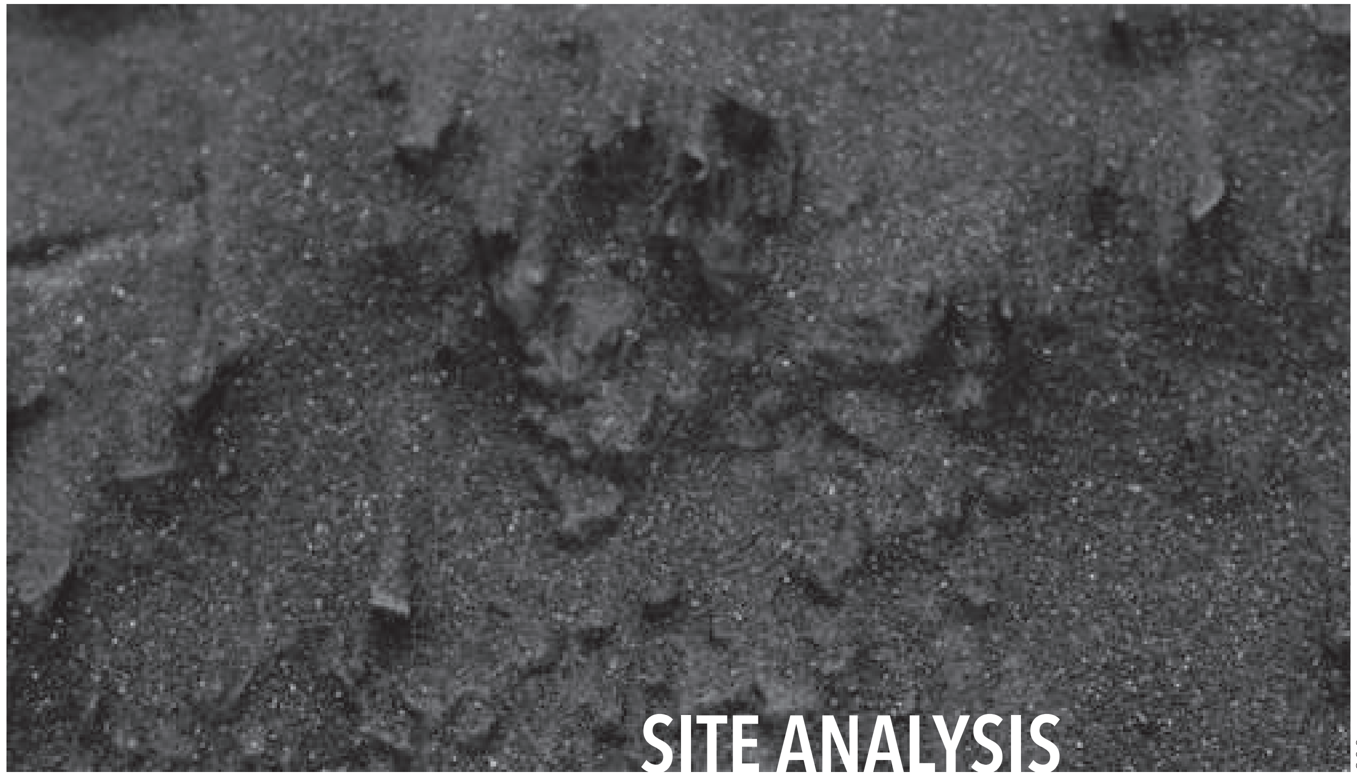
PREFACE

While my design thinking explores this site primarily through the lens of landscape infrastructure and ecological restoration, being somewhat narrow in its scope, at the core of my vision is the belief that the ecological well being of a place trophically and systematically underpins the cultural well being of the people who live there. While economically and ecologically mindful, the scope of my project does not work to fully capture the disparities of the cultural injustices that tell the real story of how the Duwamish Waterway came to be industrialized, contaminated, and in need of restoration. Of longhouses being burned, and of sanctioned, large scale displacement efforts in the name of engineering infrastructure along a river. Specifically with regards to the marginalization of the Duwamish people (among others), the near erasure of the Duwamish River, and the fact that I am currently writing this at an educational institution built on colonized, Duwamish land. Considering the implications of my design speculation in ways that seek, if even partially, to find a harmonious overlap between the stakeholders and powers at be, my intention with this project is to provide a scenario that can collectively continue to help govern the LDW in ways that are more restorative and reflective of community needs.



REGIONAL WATER + SEDIMENTSHED CONTEXT

The water + sedimentshed surrounding the Green and Duwamish River stretch 93 miles from the Cascades to Elliot Bay. These have been separated into upper, middle, and lower portions. This project will focus on the lowermost Duwamish Waterway, an industrialized estuary (LDW).


005

SITE ANALYSIS | 1900 - 2100

Tracing the drivers of materiality, landscape decision-making, and infrastructural change that governed how the LDW was transformed from a riverway to an industrial corridor requiring restoration in the first place, is an important step in strategizing how these same drivers can operate more holistically towards LDW restoration efforts today. Following pathways of its historically industrial use, contemporary use of the LDW is not significantly different. What has changed is the understanding of the waterway's ecological and social risks, alongside increased pressure and responsibility by its contributors in response. Within the LDW, urbanization, land use-land cover change, and landscape

ecology are interrelated.[20] Closely examining this interrelationship can better inform how this site not only re-organizes to reach successful cleanup levels, but how the site and our relationship to it can reach even further, towards building the adaptive infrastructure it needs to face rising sea levels and a future of uncertain ecological realities. Providing necessary feedback for how the LDW - as a lifeline and landscape system - can now weave its materials, functions, and forms to operate more resiliently, the past hundred years of the LDW present a snapshot of what not to do. Following a timeline of expansion decoupled from regional and geophysical flows, these years tell a story of industrial growth at the expense of ecological and cultural livelihood.

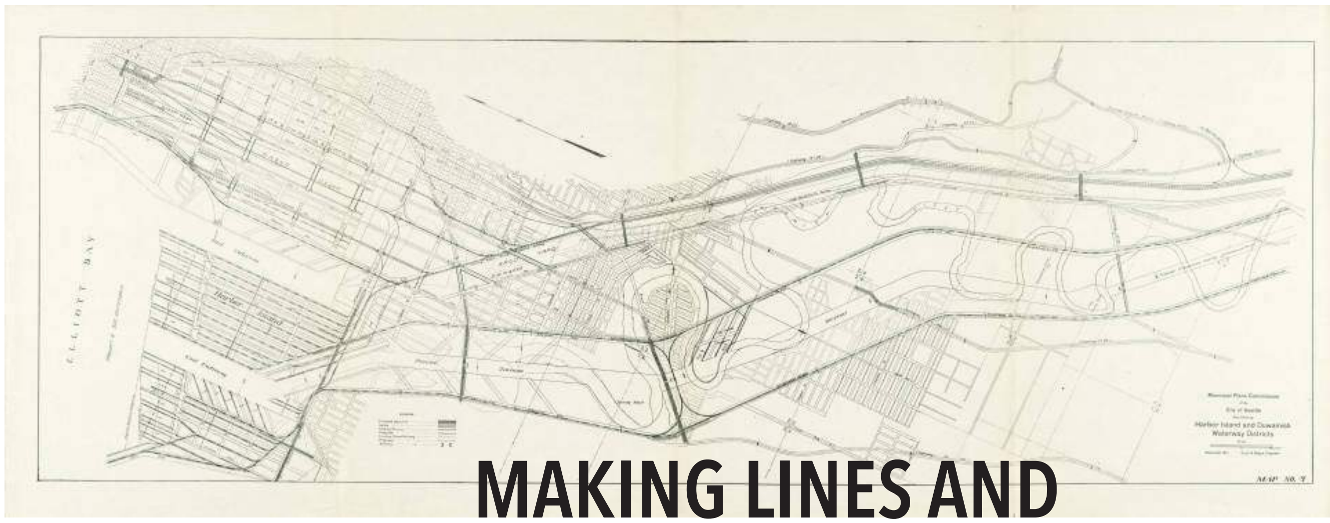
Last Century: A History of Engineered Infrastructure, Industry, and Contamination 1900 - 2000

ENGINEERING INFRASTRUCTURE IN EARLY SEATTLE

Bringing unforeseen patterns of development and technological advancement to waterways like the Duwamish River, the Industrial Revolution championed the idea that the natural world was here to be conquered, exploited, and utilized. Civil engineering efforts gave exacting, formulaic power to the concept of manifest destiny, remaking the landscape through large scale public work projects as settlers drove expansion efforts and organized infrastructure projects across the country. In 1830, the founding statement of the recently formed United States Institute of Civil Engineers was to "harness the great sources of power in nature, for the use and convenience of man."[21] Alongside the science of fluid mechanics and inventions in hydraulic machinery, engineers developed new methods to control, divert, channelize, and dam rivers to better utilize floodplains, prevent floods, irrigate fields, generate power, and improve navigation.[22] Assembling landscapes to hold space for increasingly standardized flows, many of these developments were constructed as single-purpose corridors, largely focused on conveyance.

Changes to Seattle watersheds embodied this process, becoming some of the most transformed landscapes of the era, home to a shifting re-organization of land and water features that continues today. The following excerpt, from Coll Thrush's *City of the Changers: Indigenous People and the Transformation of Seattle's Watersheds*, illuminates this process: *Seattle was a bad place to build a city. Steep sand slopes crumbled atop slippery clay; a river wound through its wide, marshy estuary and bled out onto expansive tidal flats; kettle lakes and cranberried peat bogs recalled the retreat of the great ice sheets; unpredictable creeks plunged into deep ravines - all among seven (or, depending on whom you ask, nine or fifteen) hills sandwiched between the vast, deep waters of Puget Sound and of Lake Washington. But built it was, and generations of Seattle's leaders and everyday residents have wrested enormous wealth, comfort, and order out of the dynamic and messy ecology that first confronted the city's founders in 1851.*[23]

20. Mayer, Audrey L., et al. "How Landscape Ecology Informs Global Land-Change Science and Policy." BioScience, vol. 66, no. 6, 2016, pp. 458–469., doi:10.1093/biosci/biw035.
21,22. Williams, Philip. "River Engineering versus River Restoration." ASCE Wetlands Engineering & River Restoration Conference, August 28, 2001, Reno, Nevada. Keynote speech.
23. Thrush, Coll. "City of the Changers." Pacific Historical Review 75 (2006): 1.458–469., doi:10.1093/biosci/biw035



006

MAKING LINES AND FILLING IN THE LANDSCAPE

City-changers have been making lines and filling in the landscape of Seattle since large scale development plans were drafted amidst early American colonization. The Puget Sound Bridge and Dredging Co. played a key role in these plans, "dredging by all methods." Tide lands were filled and waterways were constructed for industrial expansion, often with little to no understanding of its ecological impacts.

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This re-shaping of land and re-directing of water, in an effort to make Seattle "less messy," more linear, and increasingly navigable, required moving literal mountains. Altering land contours in ways that attempted to turn fluid pathways into fixed corridors, the intent was to bring industry and manufacturing in by boat and by rail. This required immense amounts of materials to be rearranged along Seattle's only river, the Duwamish, at the expense and displacement of the Duwamish peoples (among others), who have lived and continue to live as the host peoples in what is now known as Seattle and King County. Their stories tell of the last Ice Age and the Ice Bridge breaking over the Duwamish River, of a productive and tidally influenced estuary running through what is now South-Central Seattle, and of a resource rich landscape flowing seasonally for thousands of years.[24] A dynamically linked geophysical, ecological, and human system, the Duwamish River was not untouched before this period of engineered transformations - it was an essential lifeline, maintaining patterns of settlement through its predominantly natural organization, materiality, and processes.

As land ownership changed along the river in the late 1800s, so too did the emerging practices and technologies sanctioned for re-shaping its use. Trends in societal infrastructure, including the adoption of public agencies and fundable concept of "public works", allowed city-changers in Seattle to begin engineering the Duwamish River to better fit industrial models of economic growth. Bound to these projections, the main task engineers were asked to address was designing and constructing river engineering works to harness resources in the most cost-effective

manner.[25] Earthworks, or human engineered constructions made to modify the land contour, became a dominating force in these resource focused efforts, as natural rivers were viewed as disorganized systems in need of simplification.[26] For the liquid lands of the Puget Sound area, this meant making watery places deeper and less meandering, and shallow places more structural. Perhaps the most notable earthworks endeavor in the area, which helped set the tone and pace of Seattle's development, was the construction of the Lake Washington Ship Canal. Cutting and sluicing through miles of landscape, earthworks demonstrated its ability to take a pathway from Lake Washington to the Puget Sound, once only portage-able, and engineer it to become marine navigable. Accommodating an approximate twenty-foot drop in water level, the making of this East to West canal was spurred by the growing demand for industrial transport and development.[27] Its focus on conveyance heralded as a demonstration of Seattle's progress and coming of age.

With progress becoming increasingly defined by leaders as the passage of larger ships and therefore more trade, this trend of deepening and widening waterways to keep pace with industrial growth persists today. As these patterns of urban growth continued, so too did the tools, technologies, and policies required to keep the industrial promise afloat and accessible. Once constructed, however, these large infrastructural networks were built without plans for how to reorganize after completing their life cycle. In the early 1900s, state-building meant manufacturing and prosperity meant ports - it did not mean climate change and adaptive reuse. Keeping up and holding space for these early advancements required the creation of new landscapes, and the tidal flats at the mouth of the Duwamish River were filled by the Puget Sound Bridge and Dredging Company with approximately 25 million cubic yards of displaced earth from downtown regrades.[29] Completed in 1909, Harbor Island would help pave the way for the continued straightening of the Duwamish River further inland, from meandering to standardized. As Seattle's first municipal harbor, this artificially constructed island carved East and West corridors up into the waterway, coordinating development along its increasingly filled and grid-lined waterfront.

Lowering lakes to empty West instead of South, constructing islands, straightening and armoring rivers, and building flood control infrastructure to prevent all but one of four rivers to flow seaward, within a few decades Seattle became a landscape marked by earthworks and engineered transformations.[31] River engineers, however, were not asked to be river or watershed managers, nor were they asked to consider the ecologic or even long-term consequences of their actions.[32] Consequently, these infrastructural gains came with great although unintended ecological losses.

24. "History of the Duwamish People." Duwamish Tribe, www.duwamishtribe.org/history.
25, 26, 32. Williams, Philip. "River Engineering versus River Restoration." ASCE Wetlands Engineering & River Restoration Conference, August 28, 2001, Reno, Nevada. Keynote speech.
27, 29, 31. Klingle, Matthew W. Emerald City: an Environmental History of Seattle. Yale University Press, 2008.

010

PLACE-MAKING BY MOVING MOUNTAINS OF EARTH

Constructed as a by-product or by-place from the regrades of Seattle's hilliest downtown areas, Harbor Island was built with approximately 25 million cubic yards of locally displaced dirt. Barged and dumped and shaped to form the emerging Port of Seattle headquarters, earthworks became a leading landscape process as Seattle expanded, with excavation projects spurring fill projects throughout the area.

011

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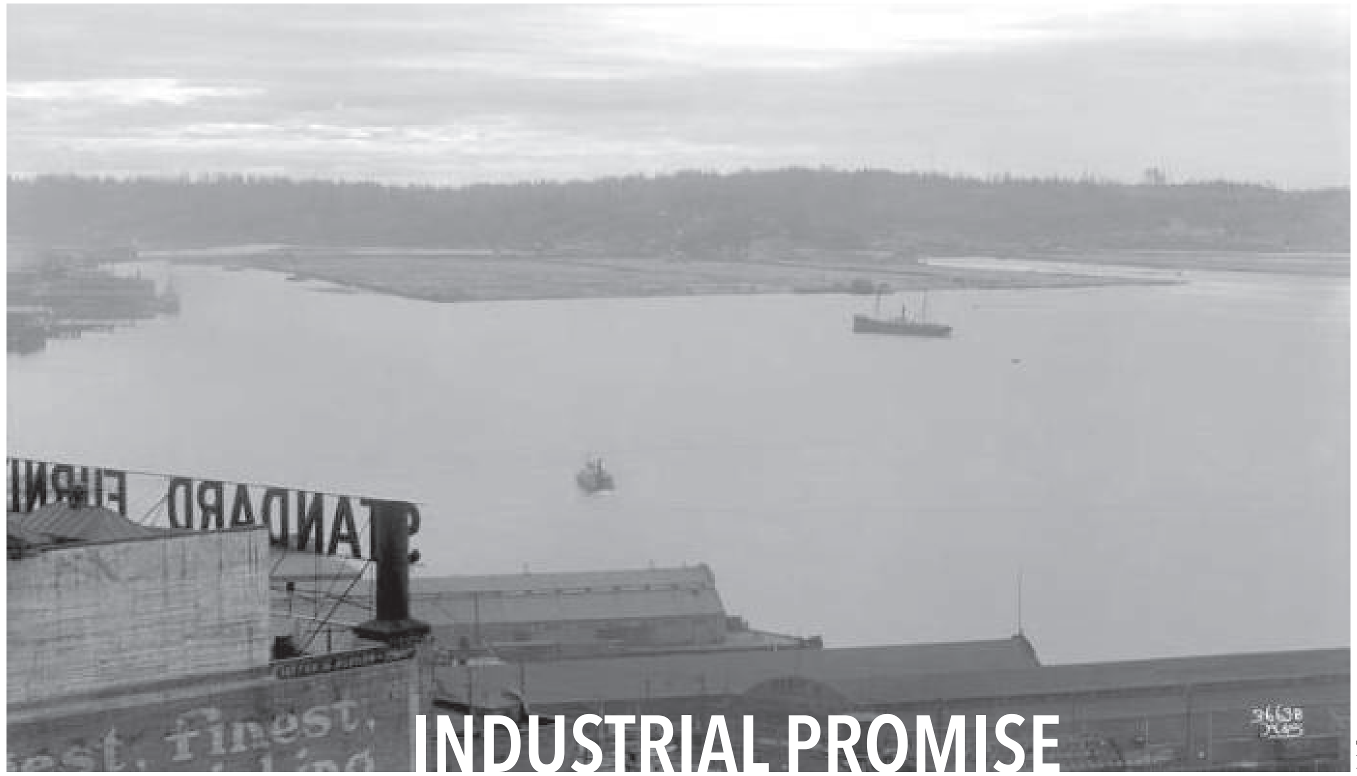

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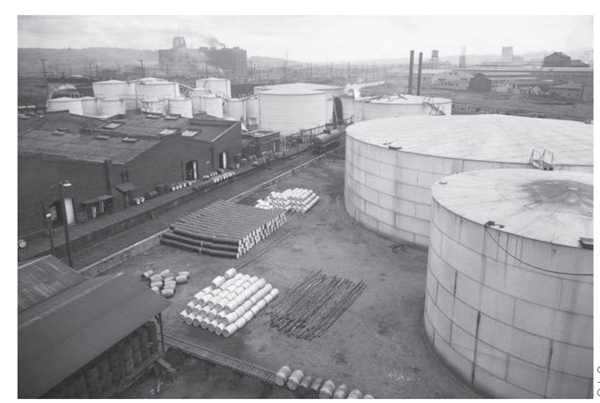
INDUSTRIAL PROMISE
: AN ARTIFICIAL NARRATIVE

Within weeks of its construction, Harbor Island was filled with machinery for the logging, ship building, and petroleum industries. Placed in order to create and demarcate East and West channels, it began as an artificial gateway for increasing navigation and development efforts into the industrializing Duwamish river-turned-waterway. Industry would, and is expected to remain, promised to this area.



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As a result of just a few decades of landscape alteration, approximately 70 percent of the historic watershed was diverted out of the Duwamish River basin, over 90 percent of its historic floodplain was isolated from its river ecosystem, and approximately 97 percent of its original habitat was destroyed. [33] Securing its position within an expanding system of maritime and industrial trade, the Port-focused city of Seattle laid out, filled in, and rearranged its waterways into the Cartesian based corridors it still uses today.

AN INDUSTRY | ESTUARY

After completing its structural transformation into the Port corridor it is today, by 1920 the increasingly navigable river turned waterway began holding space for sequential phases of industrial and commercial development. Bulkheads, piers, wharves, timber, shipping, and manufacturing buildings were constructed and organized around its shoreline, giving way to Seattle's first (and remaining) industrial district. Not to mention the concrete factories, shipping terminals, asphalt plants, and wrecking yards that came later.[34] The Boeing Company, having started in a barn along the river in 1917, expanded its warehouse and plant facilities and by 1936 was beginning to secure its position along the LDW as one of Seattle's economic powerhouses.[35] These industrial gains came with daily operations that would start chipping away at the river's vitality, creating pathways for point source pollution that continues today. In 1945, researchers commissioned by the state of Washington found that Boeing was dumping approximately 500 pounds of generator waste, and roughly 250 pounds of indeterminable but "highly toxic" warehouse solution into the river every day, including a new class of coolant chemicals

lands adjacent to these waterfront pursuits continued to urbanize, runoff from streets and the cars beginning to fill them, discharge piping from more and more houses, the emergence of landfills, and the direct disposal of liquid and solid wastes that go into building a city only intensified.

With much of this urban sprawl and industrial growth occurring at a time when rivers were thought to be self-cleaning, before federal pollution regulations existed or could even begin to debunk the idea that "dilution is the solution to pollution," the waterway was essentially used as a drainage ditch.[37] In the 1950s, this concept became cemented. King County voters approved the creation of an agency to build a regional sewage treatment system around the LDW, installing eleven combined sewer overflows along the river's banks, discharging untreated overflows of sewage and stormwater into the river during heavy rains.[38] As the waterway and surrounding landscape absorbed more and more of these urban transactions, effects of their contamination were beginning to go without notice. It wasn't until the emergence of the environmental movement in the 1960s, however, when pop culture became quasi anti-culture, and activist groups started challenging traditional river engineering projects en masse, that LDW contamination would gain mainstream attention.

HOME GROWN RESTORATION EFFORTS

While effects of the river's exploitation and ecological decline had long been reported and well documented by tribal communities and subsistence fishers, dating back to early post construction decades, (for better or for worse) environmental activism joined these efforts and helped highlight the issue through protests, sit-ins, and marches.

Pamphlets strewn across water resource planning meetings at Seattle's City Hall, read titles such as "The River Killers - how four decades of one government agency's 'public works' has systematically ruined our waterways - and all that lives in or around them," with the depiction of the USACE emblem on a sword being thrown into a river.[39] While top-down dynamics of riverway contamination and the organizations involved in the LDW's deterioration were not yet shifting, bottom-up interest in river restoration was gaining traction, alongside continued pressure for public agencies and responsible companies to start doing something about it.

Throughout the coming decades, small localized efforts began restoring remote patches of natural riverbank wherever it managed to exist. Neighbors, environmental groups, tribal groups, and concerned citizens willing to adopt their own cleanup efforts worked, albeit piecemeal, to restore the river wherever they could.

33. Final Lower Duwamish River NRDA Restoration Plan and Programmatic Environmental Impact Statement. NOAA National Oceanic and Atmospheric Administration on Behalf of the Lower Duwamish River Natural Resource Damage Assessment Trustee Council, 2013, pp. 1–124

37. "The 'Solution' to Pollution Is Still 'Dilution'." Earth Island Journal, www.earthisland.org/journal/index.php/magazine/entry/the_solution_to_pollution_is_still_dilution/.

34, 35, 38. Duwamish River Cleanup Coalition, and Technical Advisory Group. "Timeline." Duwamish River Cleanup Coalition/Technical Advisory Group, duwamishcleanup.org/superfund-info/timeline/.

39. Williams, Philip. "River Engineering versus River Restoration." ASCE Wetlands Engineering & River Restoration Conference, August 28, 2001, Reno, Nevada. Keynote speech.

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AN INDUSTRY | ESTUARY

Then, in the late 1960s, residents of Georgetown and South Park began collectively fighting the area's marginalization, as the city of Seattle attempted to rezone their neighborhoods into an industrially zoned area.[40] Facing eviction and residential buyout, as neighborhoods along the LDW came together, fought for, and won their right from the City to stay in their own homes, one resident claimed, "it was always a struggle to get the rest of the city - environmentally conscious as it is - to care about the river."[41] After decades of finger-pointing and mounting pressure, municipal responsibility began shifting, albeit slowly. As community demands for managing and restoring rivers to sustain ecological and environmental benefits increased, not until the 1990s - roughly one hundred years after the river's alteration began changing its course from an ecologically productive lifeline, to an industrially productive corridor - the city of Seattle started to take responsibility for its actions.

MANDATING A CITY LED CLEANUP

In 1991, Seattle and King County settled with the federal government for damages to public natural resources from LDW's combined sewer overflows (CSO), mandating cleanup at one of its first installed drainage points, the Duwamish/ Diagonal CSO.[42] What began as an isolated cleanup project, this effort would help uncover the true nature, increasing extent, and alarming uncertainty of LDW contamination and approaches for restoration. Over the next few years of project sampling, pollutants were found on site in dangerously toxic levels, most notably within river bottom sediments. Contaminants of highest concern, the persistent cPAHs and PCBs that bind to particles of clay and silt, were also found

to magnify through living tissues, passing through sediment, shellfish, salmon, and the people who subsistence fish or harvest natural resources from the river.

Linked to cancer and banned in the late 1970s, research is still finding traces of PCBs in people and animal tissues around the world, from dense areas of New York City to remote regions of the Arctic.[43] In response to public health concerns, King County submitted a report recommending a cleanup of five acres of these contaminated sediments, adjacent to the CSO, which quickly expanded to seven acres after the project located a contaminated "hot spot" or area of supersaturated toxins, slightly upstream.[44] Findings from this Duwamish/ Diagonal CSO cleanup project, especially its long-term monitoring effort, began to verify what was unfortunately, already known: beyond dirty, the Duwamish is toxic. And beyond toxic, the ability for waterway contaminants to spread and biomagnify through the river's trophic levels is (and remains) an increasingly concentrated problem for those managing and stewarding the LDW. With evidence and pressure mounting on the state of Seattle's only river, its need for taking restorative action was irrefutable.

This Century: Superfund Cleanup, Recontamination, and Restoration 2000 - 2100

DESIGNATION AS A SUPERFUND

In 2000, learning that the EPA was considering the LDW for its Superfund list, the City of Seattle, King County, the Port of Seattle, and Boeing - collectively known as the Lower Duwamish Waterway Group (LDWG) - voluntarily entered into an Administrative Order on Consent with the EPA and the Washington State Department of Ecology (Ecology), requiring the LDWG to conduct a remedial investigation and feasibility study pursuant to the Superfund and Model Toxics Control Act, to investigate the nature and extent of contamination, with the goal of developing remedial alternatives for the in-waterway portion of the site.[45] With contamination undoubtedly being severe enough to warrant a Superfund designation, as part of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), the LDWG was likely hoping to avoid the stigma of being listed, as well as the resulting bureaucratic reckoning of being declared potentially responsible (and therefore compensatory) parties (PRPs). One year later in 2001, unconvinced the LDWG would be able to handle such an extensive cleanup effort on their own, the legacy of 100 years of industrial activity, along with the discharge of 11 combined sewer overflows and 200 storm drains, led the EPA to declare the LDW area a Superfund site, contaminated with over 40 chemicals above recommended levels for human health.[46]

40, 41. Person, Daniel. "The Duwamish: River of No Return?" Crosscut, Crosscut, 7 Feb. 2018, crosscut.com/2014/07/duwamish-river-no-return.
42, 44. Duwamish River Cleanup Coalition, and Technical Advisory Group. "Timeline." Duwamish River Cleanup Coalition/Technical Advisory Group, duwamishcleanup.org/superfund-info/timeline/.
43. US Department of Commerce, and National Oceanic and Atmospheric Administration. "What Are PCBs?" NOAA's National Ocean Service, 18 Sept. 2009, oceanservice.noaa.gov/facts/pcbs.html.
45, 46. EPA Environmental Protection Agency Region 10. Record of Decision Lower Duwamish Waterway Superfund Site. EPA , 2014, pp. 1–181

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HOME GROWN RESTORATION EFFORTS

Small localized efforts continue working to restoring remote patches of natural riverbank along the waterway, wherever they manage to exist. Neighbors, environmental groups, tribal groups, and concerned citizens willing to adopt their own cleanup efforts work, albeit piecemeal, to restore the river wherever and however they can, predominantly through trash removal and native plant restoration.

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Identified as one of the nation's most toxic hazardous waste sites, large-scale cleanup efforts began in a rather complicated and lengthy process. One which is still unfolding today, involving an increasingly entangled toolkit of stakeholders, policies, permits, technologies, successes, and failures. Overseeing this entanglement, specifically actions taken by LDWG and other PRPs, the Duwamish River Cleanup Coalition/Technical Advisory Group (DRCC/TAG) formed the same year LDW was listed, serving as the only collective community advisory group for the cleanup. Working "to protect the river environment, its fish and wildlife, and human health by reducing the levels of river toxins," the DRCC/TAG primary mission is to ensure that achieving this goal is accepted by and benefits the communities who use the river most closely.[47] DRCC/TAG's inclusion in the environmental decision making process remains an integral part of this Superfund project, holding PRPs accountable, making sure sufficient pollution control measures are put into place, and in general, advocating for a complete and lasting cleanup.

Outlining a general strategy for addressing contamination and associated risks in the LDW, EPA developed three main components: 1) early identification and cleanup of the most contaminated areas in the waterway, or "hot spots;" 2) controlling sources of localized and upland contamination to the waterway; and 3) cleanup of the remaining contamination in the waterway, including long-term monitoring to assess the success of the remedy in achieving cleanup goals.[48] Efficacy assessment would soon prove to play a crucial role in cleanup efforts, as PRP methods began bringing about unintended consequences. A murky process involving

complicated machinery, isolating and removing contaminated sediment is costly and difficult, with low visibility and physical control of particulate. Cleaning up what is essentially buried, toxic, underwater sludge requires scraping the bottom of the river and dredging massive amounts of mud, aggregate, and water that then must be contained, sorted, and properly disposed of. While some areas in the LDW of lower contamination can be capped or covered with thin layers of remediating mediums, such as sand to accelerate natural recovery, much of the LDW sediment locations require extensive river bottom removal, often requiring the dredging of three to five feet of sediment beyond bottom elevations.[49]

Cleanup efforts at the Duwamish/Diagonal CSO, the first early action or "hot spot" area, included the removal of 68,000 cubic yards (or 20 olympic sized swimming pools full) of contaminated sediment.[50] All of which was transported to a regional dump, at an extremeley high cost. In addition to dredging, multiple-layered, engineered caps were placed over less contaminated acres, with the intention of isolating remaining chemicals. While project complications from dredging were seen immediately, issues with capping were not discovered until subsequent monitoring. On day three the project shut down due to violations of environmental regulations, reported by the DRCC to King County and EPA, with "messy" dredging operations violating LDW water quality standards. Over the following three months, this project would cause water quality violating plooms of suspended sediments on nearly half of the days dredging took place.[51] In addition, dredging residuals, or contaminated sediments found at the post-dredging surface of the sediment profile, were found to have elevated levels of PCBs.[52] In certain places, it was becoming clear that the very process of removing contaminated sediment was actually exacerbating the situation, despite EPA's acknowledgment that the only permanent cleanup remedy is removal by dredging.

EVOLVING BEST MANAGEMENT PRACTICES

While best management practices for dredging continued to refine and improve cleanup efforts, and the Duwamish/Diagonal CSO project was declared completed in 2004, long term sampling and analysis of dredged and capped locations shows a mixture of reduction and increase levels in total contaminant concentrations.[53] With sampling documentation in capped areas full of phrases like "increased from baseline conditions," "substantial reductions," and "appears to be decreasing over time," it is clear that sediment cleanup in the LDW can be rather hit or miss.[54] Downward trends, however, became prevalent, and in many ways the Duwamish/Diagonal CSO project successfully met its objectives while discovering issues and problem-solving techniques that could be translated to future cleanup areas. However, with monitoring efforts stopped in 2010, and no further monitoring being planned or recommended, there is still relatively little long-term certainty.

47, 51. Duwamish River Cleanup Coalition, and Technical Advisory Group. "Timeline." Duwamish River Cleanup Coalition/Technical Advisory Group, duwamishcleanup.org/superfund-info/timeline/.
48. EPA Environmental Protection Agency Region 10. Record of Decision Lower Duwamish Waterway Superfund Site. EPA , 2014, pp. 1–181
49, 50, 52, 53, 54.. EBDRP. 2015. Duwamish/Diagonal Sediment Remediation Project Final 2010 Monitoring Report. Panel Publication 43. Prepared by the King County Water and Land Resources Division for the King County Wastewater Division and the Elliott Bay/Duwamish Restoration Program.

Extending five miles, although the LDW was not divided into operable units as other large-scale Superfund projects usually are, the EPA and Washington State Department of Ecology (Ecology) declared divided lead-agency responsibility for addressing the site, with Ecology leading upland source control and EPA leading the in-waterway portion.[55] As cleanup efforts moved to other early action areas in the LDW, uncertainty prevailed, with delays requiring the development of new plans to ensure downstream cleanup areas would not be re-contaminated by upstream activity. As different methods and technologies were used to clean up the LDW, site by site, projects encountered issues and setbacks along the way. As pollution contributors began taking more responsibility for their activities, intersecting methods and responding alternatives began a rather slow, drawn-out process, as government agencies and PRPs began juggling varied incentives, specifically rising project costs, with sediment removal and treatment goals.

As contamination became more closely inspected, however, research revealed the true extent of its toxicity and ability to harm human health began highlighting the need for cleanup projects to remove as much sediment as possible, no matter the cost. In 2003 the LDWG began developing a Remedial Investigation Report (RI), investigating the extent, distribution, and risks from their potential contribution to waterway sediments. Released in 2007, this RI includes results of aquatic and sediment sampling in the river, maps of chemicals found at bottom elevations, information on risks to the environment and human health, and identification of ongoing sources of pollution.[56] In keeping with EPA risk assessment guidance, reasonable

maximum exposure estimates were calculated for human exposure scenarios. Using these health-protective exposure assumptions, estimated cancer risks in the LDW were found to be highest for tribal communities.[57] For the tribal seafood consumption scenario, the cumulative risk for all carcinogenic chemicals was 2 in 1,000, with cancer risks for the netfishing scenario and beach play being much lower.[58] In addition, while now known that resident fish and shellfish in the Duwamish were not safe to eat, even salmon passing through the waterway were found to be best eaten in moderation.[59] An alarming statistic, considering the fact that not only do Tribal Trustees have reserved fishing, hunting, and gathering rights (among others) under the 1855 Treaty of Point Elliott in the LDW, but that Trustee Tribes also have adjudicated, usual, and accustomed fishing areas located within actively contaminated areas.[60]

DEVELOPING A COMMUNITY LED VISION

In addition to balancing cleanup treatments and costs with livable health goals, working to ensure the LDW can once again foster ecological and cultural livelihood - especially for user groups affected in inequitable ways - requires community inclusion and feedback that outside influences, and even technical reports, cannot provide. While much of the Superfund inspection had so far involved scientifically quantitative reports focused on environmental sampling and analysis, the LDW was still without an overarching community advising report. Led by the DRCC/TAG in 2009, the Duwamish Valley Vision Map (Vision) was developed through a series of community workshops, interviews, and surveys with over 500 Duwamish Valley residents, tribe members, workers, business owners, industrial leaders, youth, elders, recreational visitors, fisherman, and homeless constituents. [61] The result became an ongoing vision of what the community wanted to see as part of the restoration projects that would take place in their backyard. Offering a roadmap for the work ahead, this Vision continues to guide project efforts towards a more lasting and effective cleanup.

Representing over 10,000 people in the Duwamish Valley and greater Seattle area, the DRCC's Environmental (IN)Justice portion of the Vision Map notes that, "everyone who lives, works, or plays on or near the Duwamish River is affected by the existing pollution and planned cleanup. In fact, everyone in Seattle is affected in some way - by the loss of economic or recreational opportunities; pollution of fish, bird, wildlife species, and habitat; or the taxpayer costs of the cleanup. But the communities overwhelmingly affected are the people - many non-English speaking, low-income, or people of color - who live or work close to the river."[62] Visioning in the LDW community aims to achieve a balance that meets the aspirations and needs of all river users. Minority voices were not lost in this process, but rather upheld to take on special significance, with many of these narratives coming from some of the most vulnerable, or typically overlooked members of the community.[63]

55, 59, 61. EPA Environmental Protection Agency Region 10. Record of Decision Lower Duwamish Waterway Superfund Site. EPA , 2014, pp. 1–181
56. Duwamish River Cleanup Coalition, and Technical Advisory Group. "Timeline." Duwamish River Cleanup Coalition/Technical Advisory Group, duwamishcleanup.org/superfund-info/timeline/.
57,58. Environmental, WindWard. Lower Duwamish Waterway Group Phase 1 Remedial Investigation Final Report. 2003, pp. 1–273, Lower Duwamish Waterway Group Phase 1 Remedial Investigation Final Report.
60. NOAA, et al. Lower Duwamish River Natural Resource Damage Assessment: Injury Assessment Plan. 2018, pp. 1–791–181

Questions leading the Vision project worked to recognize the unintended social consequences of river cleanup, considering how inputs could better manage these impacts moving forward. Examining questions such as, "will a clean river make our community more attractive and lead to rising house prices in our neighborhoods?; do we want condos on the shoreline?; will businesses move into or out of our community as a result of the cleanup?; where will we work in the future?; and how can we prevent being pushed out of our community once we've improved the environment?", this visioning process worked to give the community an important tool for self-determination, instead of cleanup concerns that were being solely answered by reports from outside influences, including developers, investors, and government agencies.[64] With regards to the LDW's Superfund process, the Duwamish Valley Vision Map provides the following, resounding answer to these questions in its concluding statement:

It is the community's vision that the Duwamish River Superfund site will be successfully cleaned up and that people will be able to safely play on its beaches, swim in its waters, and harvest and eat fish, clams, crabs and other seafood from the river. While local governments have suggested that clean up of the Duwamish to the extent necessary to protect the health of subsistence fishers may not be possible, due to the ongoing influx of contaminants from the upper Duwamish and Green River, satisfying this critical aspect of the Duwamish Valley Vision, then, requires a watershed approach to cleaning up and controlling sources of pollution to the lower river. The Duwamish Valley Vision results emphasize the community's desire to secure a clean up of the Duwamish River that is done once and done "right." Community members want to ensure that the clean up employs the strategies and technologies necessary to prevent the spread of contaminants removed from the river bottom, and to take comprehensive measures to control ongoing sources of pollution in order to prevent recontamination of the river after cleanup.[65]

With the Superfund project so far involving year long timelines of mixed proposals and responses, remedial alternatives, sequential vetting processes, and relatively lax cleanup standards - in addition to uncertain best management practices and cleanup technologies to begin with - envisioning projects of this scale to be "done once and done right" is exceedingly difficult. Not to mention costly. While acknowledging that more removal of the site's contaminated sediment by dredging would provide greater certainty to its cleanup effort, EPA cites the cost of dredging as a limiting factor.[66] Shortly after the Duwamish Valley Vision Map and Report was released, the LDWG released a draft Feasibility Study (FS) evaluating the Superfund site within Vision requests, proposing multiple remedial alternatives at reduced costs for EPA cleanup plans. DRCC/TAG determined that all six of these alternatives stopped short of providing enough cleanup to prevent cancer, reproductive, developmental, and other health risks to the people most exposed to the river's pollution.[67]

In response, DRCC/TAG in partnership with EPA and the community held 5 public hearings, 16 public meetings with 1300 attendants, 25 presentations to the community with 2300 submitted comments, and a joint Health Impact Assessment (HIA) with the University of Washington School of Public Health and Just Health Action.[68] Assessing whether the project's remaining burdens would be fair or would impact vulnerable communities in inequitable ways, this HIA provided recommendations to minimize health impacts, maximize benefits, and reduce inequities. Informing and enhancing "equitable, health-aware decision-making at all levels," one of the HIA's primary outputs was to demonstrate health gain as added project value.[69] As part of this added project value, incorporating habitat preservation and restoration was voiced as a necessary component for achieving these gains. Following the cleanup of the area's air, water, and river sediments, preserving and restoring habitat for fish, birds, wildlife and people topped the list of community priorities of what health means for the LDW, noting that "even at sites in use for shipping and industry, shoreline habitat restoration is possible through the replacement of old and often dilapidated waterfront areas with "fish-friendly" piers and loading structures." [70]

62, 63, 64, 65, 70. Cummings, BJ. "Duwamish Valley Vision Map and Report." Duwamish River Cleanup Coalition, 2009, pp. 1–143.
66. Final Duwamish River Cleanup Plan Fact Sheet. Record of Decision: Final Cleanup Plan Community Fact Sheet. Record of Decision: Final Cleanup Plan Community Fact Sheet, Duwamish River Cleanup Coalition/Technical Advisory Group, 2015.
67, 68. Duwamish River Cleanup Coalition, and Technical Advisory Group. "Timeline." Duwamish River Cleanup Coalition/Technical Advisory Group, duwamishcleanup.org/superfund-info/timeline/.
69. "Health Impact Assessment (HIA)." Health Impact Assessment (HIA) - King County, www.kingcounty.gov/depts/health/environmental-health/healthy-communities/health-impact-assessment.aspx.

EPA RELEASES FINAL RECORD OF DECISION FOR WATERWAY CLEANUP

Taking into consideration community feedback, uncertain levels of toxicity in riverway sediment, and the continued use of the river, the EPA began finalizing its remediation project. More than a decade after being designated a Superfund site, in 2014 EPA released its Final Record of Decision (ROD) for the LDW's cleanup, at a cost of $342 million, approximately $37 million more than previously proposed plans.[71] Consistent with its previously developed strategy for addressing contamination and associated risks in the LDW (1: early identification and cleanup of the most contaminated areas in the waterway, or "hot spots;" 2: controlling sources of localized and upland contamination to the waterway; and 3: cleanup of the remaining contamination in the waterway, including long-term monitoring to assess the success of the remedy in achieving cleanup goals), this final record and Selected Remedy focuses on the third component.[72] With plans for implementation starting after cleanup in early action areas has been satisfied, and after upland source control has been minimized, this makes the ROD years away from beginning, let alone completing, the final restoration effort for the LDW.

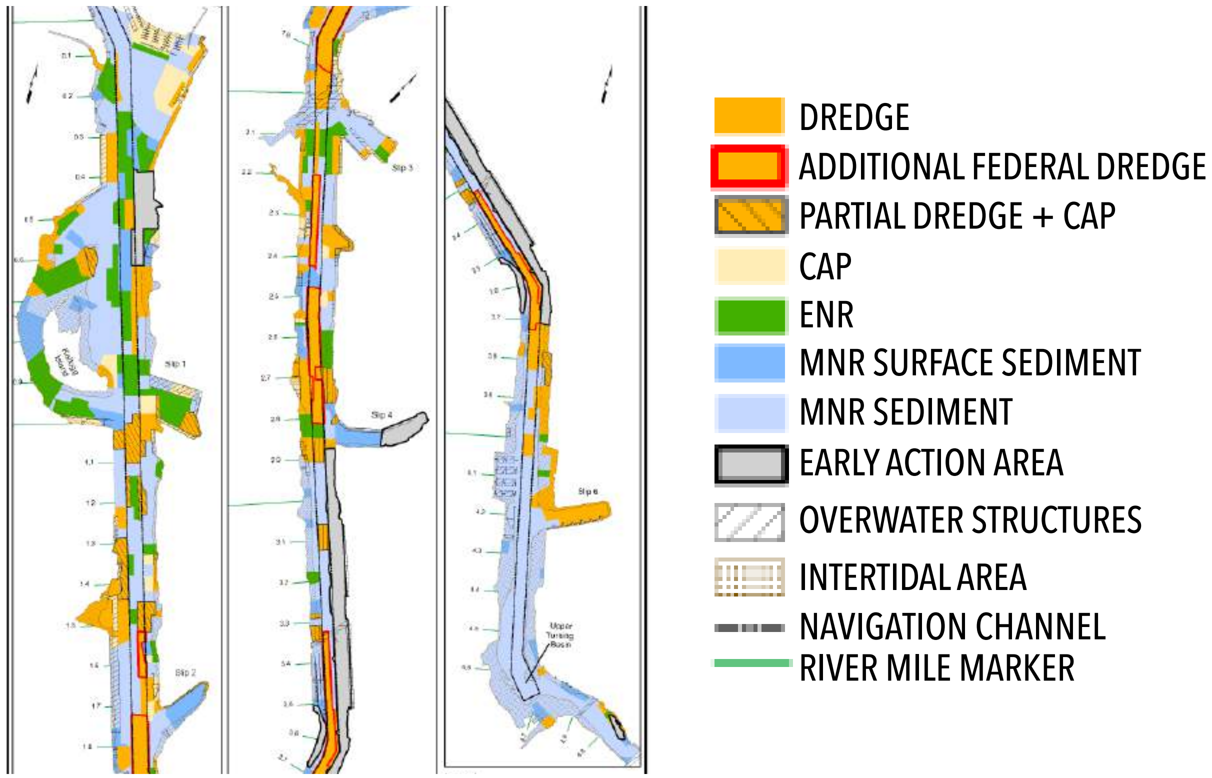
Throughout the next year EPA would negotiate with PRPs, incorporating new sampling methods to determine more up to date toxic sediment levels, jurisdiction areas, and selected remedies. In 2016, EPA presented a timeline with project construction estimated to start in 2020, completion estimated to end in 2027, and the years from 2027 - 2037 scheduled to provide a decade for monitoring the effectiveness of the cleanup.[73] Including a mix of technologies to reduce toxic levels

in the river bottom sediments, the ROD calls for a combination of dredging, capping, enhanced natural recovery or ENR (placing clean material over contaminated sediments), and monitored natural recovery or MNR (relying on natural processes such as burying). Comprising 177 acres of active clean up, the ROD will dredge 105 acres (resulting in 960,000 cubic yards of sediment), cap 24 acres, and employ ENR methods on 48 acres, in addition to employing MNR methods on the remaining 235 acres of non-active cleanup.[74] Declared by EPA to be the most cost-effective proposal that is also protective of human health and the environment, compliant with federal and state requirements relevant to the remedial action, while utilizing permanent solutions and treatment technologies, this ROD outlines a future cleanup that represents the "maximum extent practicable for this site."[75]

DRCC/TAG, however, assesses that while the ROD is "a step in the right direction, it does not ensure a cleanup that will work and last, and more needs to be done."[76] Largely reliant on ENR and MNR methods to reach its environmental and public health goals, the final cleanup plan does not provide a guarantee that cleanup actions will be permanent. While EPA acknowledges that increased removal of contaminated sediment would provide greater certainty that the cleanup will work successfully, concerns about cost of removal and disruptions to cleanup activities have influenced their decision to limit the amount of removal initially required.[77] At the same time, the only cleanup remedy EPA considers to be fully permanent, is removal of contaminated sediment by dredging.[78] There are also are concerns about capping methods as well, with future cap maintenance not effectively outlined within the ROD, although cap disturbances would allow pathways for toxic material left behind to be re-exposed.

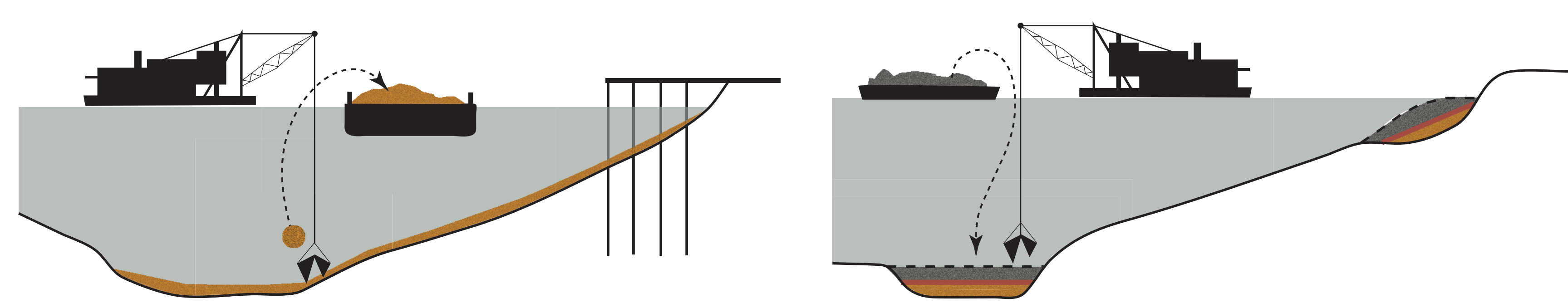
Calling for a more lasting cleanup method and technology use overall, the DRCC/TAG outlines two broad but pivotal ways for increasing the effectiveness of this ROD: maximizing the economic benefits of the cleanup, while ensuring that it achieves environmental justice and health equity.[79] Both of which present their own challenges - and therefore opportunities - for Superfund efforts going forward. While well intended, jurisdictive Superfund "tunnel vision" can have costly, wasteful, and sometimes counterproductive effects for how cleanup projects actually unfold. As a government agency and bureau, EPA is dedicated to a narrow mission: protecting against possible harm from pollution.[80] In the words of Supreme Court Justice Stephen Breyer, the EPA can often have a case of "classic administrative disease" in pursuit of this mission, that arises when "an agency so organizes or subdivides its tasks, that each employee's individual performance effectively carries out a single-minded pursuit of a single goal too far, to the point where it brings about more harm than good."[81]

71, 72, 74, 75. EPA Environmental Protection Agency Region 10. Record of Decision Lower Duwamish Waterway Superfund Site. EPA , 2014, pp. 1–181.
73. Duwamish River Cleanup Coalition, and Technical Advisory Group. "Timeline." Duwamish River Cleanup Coalition/Technical Advisory Group, duwamishcleanup.org/superfund-info/timeline/.
76, 77, 78, 79. Final Duwamish River Cleanup Plan Fact Sheet. Record of Decision: Final Cleanup Plan Community Fact Sheet. Record of Decision: Final Cleanup Plan Community Fact Sheet, Duwamish River Cleanup Coalition/Technical Advisory Group, 2015.
80,81. "Superfund: The Shortcut That Failed." PERC, 7 Feb. 2018, www.perc.org/1996/05/01/superfund-the-shortcut-that-failed/.



EPA FINAL RECORD OF DECISION (ROD): MNR + DREDGE + CAP

DRCC/TAG, however, assesses that while the ROD is "a step in the right direction, it does not ensure a cleanup that will work and last, and more needs to be done."[76] Largely reliant on ENR and MNR methods to reach its environmental and public health goals, the final cleanup plan does not provide a guarantee that cleanup actions will be permanent.



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With the ROD released, EPA and responsible parties are now moving forward, negotiating agreements focused on the design and construction of the cleanup. After which, "responsible parties will work with EPA and the affected communities to design the specifics of the cleanup, and once this design is approved, construction can begin with EPA estimating that negotiations, remedial design sampling, and the design itself will take at least five years to complete, with construction potentially starting in 2020."[82] Somewhat alarmingly, hidden within the fine print towards the end of the document, is the following statement: "agencies anticipate that a technical impracticability (TI) waiver for achievement of water quality requirements would occur, at the earliest, ten years after completion of the construction remedy." [83]

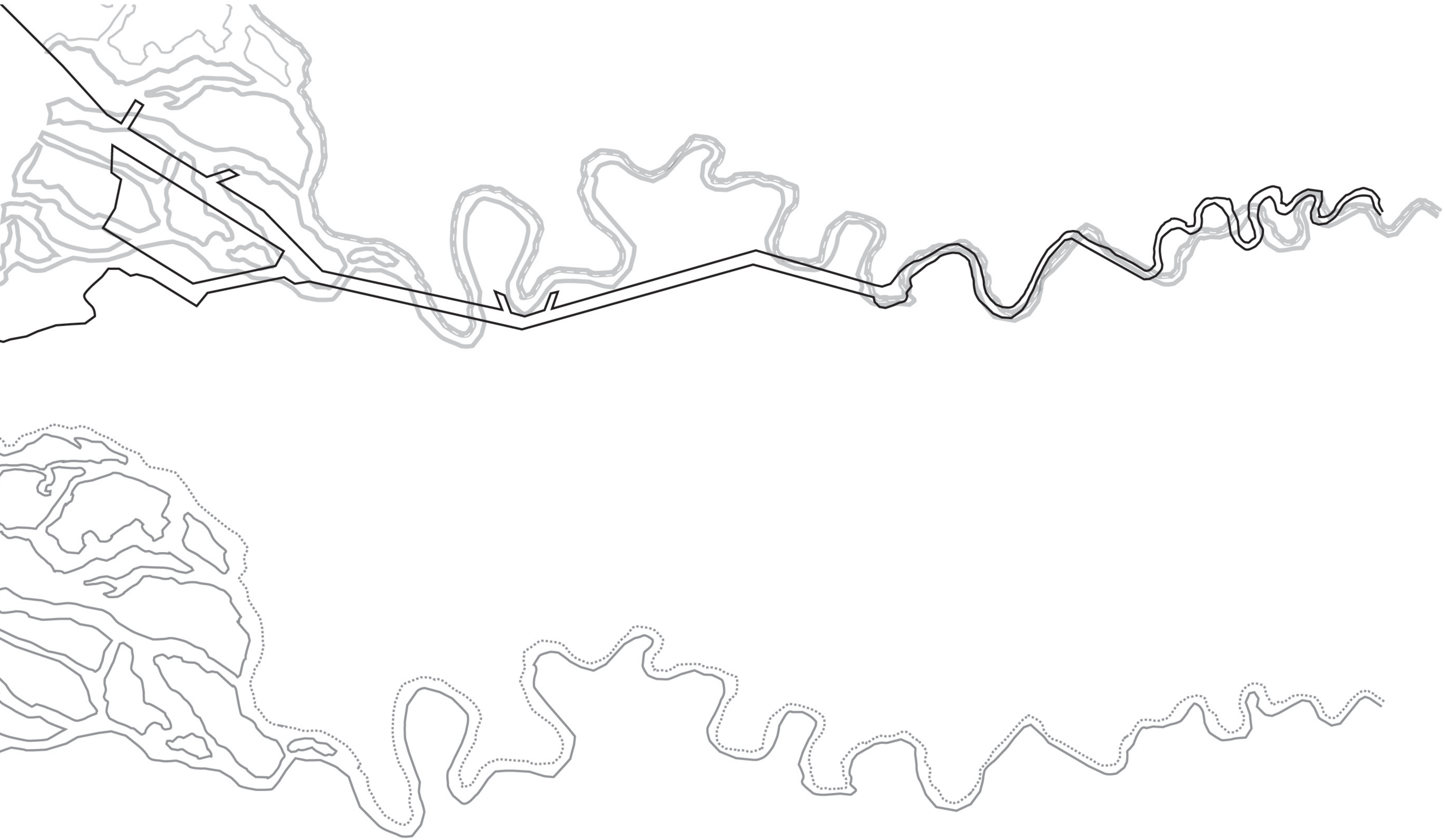
This means that not only are anticipated cleanup levels potentially not achievable under the selected remedy, perhaps being unable to dip below required background concentrations, but that this uncertainty has been signed off on. Going further, EPA admits that the final scope, cost, and success of this ROD may be more or less than the estimate put together. [84]

Continuously mired by processes that for many have been ineffective, inefficient, and unjust, radical change must strategize how to ensure greater performance of cleanup efforts in the LDW. Especially if it is to ever realistically reach its restoration goals, of once again becoming a river whose residents can safely live, work, fish, and play here. With the waterway community emphasizing their desire to secure a clean up of the Duwamish River that is "done once and done right," pushing for the removal of all moderately and highly contaminated sediments (instead of burying them in place under a cap, or relying on "natural recovery), would provide greater health protections, decreased uncertainty, and better assurance that the cleanup becomes permanent.[85] While the costs of removing more of LDW's contaminated sediment may appear greater in the short-term, two potentially significant costs are not included in EPA's final ROD: 1) maintaining and monitoring areas with buried contamination for decades to come, and 2) the future of additional cleanup actions required overall, from a job left unfinished.

"What does it imply when we no longer invent things from the beginning but create them through interaction with what already exists? It is a central question: In what ways can we decode the materials available to us?"

Ellen Brae, Beauty Redeemed: Recycling Post Industrial Landscapes

82. Final Duwamish River Cleanup Plan Fact Sheet. Record of Decision: Final Cleanup Plan Community Fact Sheet. Record of Decision: Final Cleanup Plan Community Fact Sheet, Duwamish River Cleanup Coalition/Technical Advisory Group, 2015
83, 84. "Breaking: EPA Issues Its Record of Decision for the Duwamish River Superfund Site | Science, Law & the Environment | Miller Nash Graham & Dunn LLP." Science, Law & the Environment, 4 Dec. 2014.
85. Cummings, BJ. "Duwamish Valley Vision Map and Report." Duwamish River Cleanup Coalition, 2009, pp. 1–143.



100 YEARS FROM FLUID TO FIXED

The bottom line work shows how the form of the Duwamish Waterway used to flow before Seattle's industrial expansion, according to the Burke Museum's Waterlines project map, which integrates science and historical narratives. The upper line work shows how the Duwamish

TIMELINE OF KEY EVENTS

This timeline focuses on the infusion of industry and related infrastructure along the LDW. Based off of data from the Duwamish River Cleanup Coalition's Technical Advisory Group, it represents how we arrived at a river that is contaminated and in need of cleanup.

1913
Process of straightening the Duwamish River begins, with twenty-five million cubic yards of earth being moved to fill the river bends and deepen the channel for shipping. Now a navigable waterway, the landscape quickly fills with concrete factories, shipping terminals, and wrecking yards.

1917
The Boeing Company is formed and begins production in a barn on the Duwamish River.

1936
The second Boeing Co. is formed, Plant 2, and production is moved to this new site.

1958
King County voters approve the creation of an agency to build a regional sewage treatment system. 11 Combined Sewer Overflows are installed to discharge untreated overflows of sewage and stormwater into the river.

1978
Duwamish Manufacturing Company replaced by Malarkey Asphalt Company, production continues.

1991
City of Seattle and King County settled with the federal government for damages to public natural resources from the city and county's combined sewer overflows. This settlement included cleanup at the Duwamish/Diagonal Combined Sewer Overflow.

1993
Duwamish/Diagonal sediment cleanup project begins, identifying many dangerous contaminants.

1999
After asphalt production stops at Terminal 117, it is acquired by the Port of Seattle.

2000
EPA signs an agreement with the Lower Duwamish Waterway Group - made up of Boeing, the City of Seattle, King County, and the Port of Seattle - to fund investigation of waterway contamination and evaluate cleanup alternatives.

2001
EPA declares LDW a Superfund site, contaminated with 40+ dangerous chemicals.

2003
Five areas identified as "Early Action," based on high risks to people and wildlife in the river.

2003
Cleanup begins at the Duwamish/Diagonal CSO, the first Early Action area. Project is shut down on Day 3, due to violations of environmental regulations reported by DRCC to King County and EPA. Over the following 3 months, due to "messy" dredging and poor operator skill, this project will violate water quality standards measuring suspended sediments on nearly 50% of the days they were dredging in the river.

2004
Partial cleanup of the Duwamish/Diagonal Early Action Area is completed.

2006
Presence of additional PCB contamination is discovered in and around the Terminal 117 site.

2007
Cleanup at elsewhere Early Action Areas is delayed because of recontamination of sites from upland sources of PCBs. With this discovery, there is need to develop a plan for controlling these sources before cleanup begins again. The Department of Ecology, EPA, and Boeing later implement a system that treats stormwater draining into Early Action Areas, allowing the cleanup to proceed.

2007
Port of Seattle determines T117 site will be changed from industrial to a public access habitat site.

2007
Investigation of the extent distribution, and risks caused by toxic pollution in the river sediments is completed. This RI report includes river samples, maps of chemicals found in the river bottom, information on risks, and identification of sources.

2009
The Duwamish Valley Vision and Map is developed through a series of community led workshops, interviews, and surveys with over 500 Duwamish Valley residents. The result is a vision of the community's aspirations, providing a better road map for the work ahead. The Lower Duwamish Waterway Group releases a draft Feasibility Study, evaluating the Superfund site as a whole and proposes multiple remedial alternatives for cleanup.

2010
Final Engineering/ Evaluation Cost Analysis for T117 released to public, outlining approved design.

2010
Potentially Responsible Parties for the cleanup propose six alternatives for the EPA's consideration. DRCC/TAG determines these all stop short of providing enough cleanup to prevent cancer and other health risks to people most exposed to the river.

2013
EPA releases Proposed Plan for the cleanup of the Duwamish River. The University of Washington School of Public Health and DRCC/TAG work together to perform a Health Impact Assessment of the EPA's Proposed Plan. EPA releases an Environmental Justice Analysis of the cleanup option after DRCC/ TAG's request, providing recommendations to minimize health impacts, maximize benefits, and reduce inequities.

2014
EPA's Final Record of Decision on the Superfund cleanup is released.

2016...
City workers remove "the last" of the PCB-contaminated soils from the streets adjacent to T117.

025

STRATEGY | FRAMEWORK

If the last century of this river turned waterway tells a story of what not to do, and the beginning of this century in many ways follows suit, what is the next chapter in working to cleanup and restore the LDW? With decades of stalled deliverables, inequitable efforts by responsible parties, and a sanctioned, yet uncertain future - alongside an ROD that overwhelmingly calls for natural recovery methods within a hazardous toxic-waste site - how many more years will the LDW remain industrially productive, at the expense of its ecological and cultural livelihood? Cleanup efforts are beyond taxed across economical, ecological, and social platforms in the LDW, and now must foresee a way forward through more

cohesive pathways. If the goal is to become a working waterway restored well enough for people to safely use it, project intentions and incentives must couple, re-envision their outcomes, and amplify. An adaptive, win-win design scenario must be employed, that is capable of moving forward towards far reaching goals, through realistic methods.

While the unhindered scope of speculative design can help sites like the LDW reach towards an ideal (and unseen) future, it can become prone to abstract futurism and cure-all technologies.[86] As a forward thinking practice not yet solidified, it can dream. While traditional problem-solving design efforts may legitimize the status quo, speculative design proposals offer necessary alternatives. As a future study, it is good at asking "what if?" But as a practice sometimes unable (or unwilling) to work within the dominant narratives of today, like them or not, speculative design is not as great at answering "how?" Strategic foresight is a similarly focused discipline intent on optimizing a way forward, that provides a systematic and generative approach to the context within which we can make better informed decisions.[87] It can dream, but more pragmatically. Increasingly adopted by deliverable focused design professions, in response to working within stalemated economic, ecologic, and social contexts, strategic foresight offers designers of the built environment a more viable way to re-envision. In the words of Gregor Strachotta, architect and Strategic Foresight practitioner, "we believed the architect to be the person who was capable of influencing society through bringing their vision to bear on the built environment, that the value of the designer was being able to envision preferred futures...but has the profession this changing context, while losing track of its own future and scenarios for getting there?[88]

Intending an optimal future for cleanup and restoration in the LDW, hesitant to lean too far towards either future study framework, perhaps it is speculative enough for me to strategize a contextual scenario where people and projects actually do work together. To determine what kind of futures are probable, preferable, plausible, and possible for the LDW, employing the framework of strategic foresight involves identifying performance gaps within past, current, and future waterway projects, specifically as they relate to outcomes, timelines, and budgets. Finding their overlap, while innovating within markets that do not yet exist, by way of emergent technologies and revolutionary landscape practices. By identifying the dynamics and issues impacting land-use decision making within the waterway at large, applying strategic foresight as a landscape framework allows designers to create scenarios using a combination of insightful tools, which together envision, implement, evaluate, revise (and re-envision) a better way forward.[89] To ascertain how cleanup and restoration in the LDW can more preferably unfold, it is important to analyze what will probably happen, re-framing these constraints as potential opportunities.

86. Haraway, Donna Jeanne. Staying with the Trouble: Making Kin in the Chthulucene. Duke University Press, 2016
87. Hancock, Trevor, and Clement Bezold. "Possible Futures, Preferable Futures." The Healthcare Forum Journal, Mar. 1994, pp. 1–8. PubMed, www.researchgate.net/publication/13166132_Possible_futures_preferable_futures/download
88. "Deft Architects." Deft Architects, deftarchitects.com/.
89. Hancock, Trevor, and Clement Bezold. "Possible Futures, Preferable Futures." The Healthcare Forum Journal, Mar. 1994, pp. 1–8. PubMed, www.researchgate.net/publication/13166132_Possible_futures_preferable_futures/download.

As the final cleanup plan for the LDW, the ROD will dictate the timeline and level of cleanup required, including where and how much toxic sediment needs to be removed, capped, or treated with other alternatives.[90] With weak points in the Superfund system at large having already stalled or hindered much of its cleanup efforts, the finality and success of this new plan remains to be seen. While the selected remedy closely resembles EPA's formerly proposed plan, there are notable changes: revisions of cleanup levels reflecting changes made to Washington's Sediment Management Standards, confirmation that the ROD does not establish cleanup levels for fish tissue, and updated dredge volumes alongside increased cost estimates.[91] This relationship between dredged volume and cost, predominantly accrued from transportation and disposal fees post removal, is an essential part of what hinders overall LDW restoration efforts. While ROD cleanup methods will use a variety of treatments, each with varying levels of success, dredging to remove contaminated sediments is the only remedy EPA considers to actually be permanent.[92] This is alarming, considering that dredging totals only one quarter of the final cleanup plan.

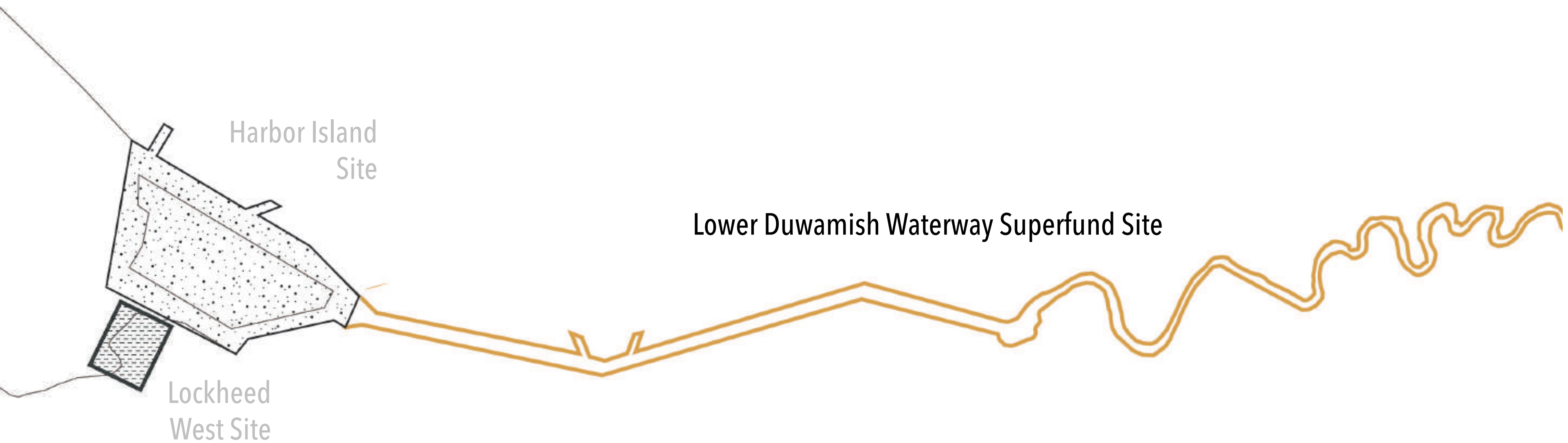
ROD Remediation Guidelines [93]
(25%) 105 acres of Dredging + Disposal
(6%) 24 acres of Capping
(12%) 48 acres of (ENR) Enhanced Natural Recovery
(57%) 235 acres of (MNR) Monitored Natural Recovery

The LDW's ROD calls for the following remedial actions: dredging and disposing of 105 acres of the most toxic sediment, capping 24 acres with an engineered layer of sand, employing Enhanced Natural Recovery (ENR) on 48 of its moderately toxic acres via application of a recovery kick-starting medium, and employing Monitored Natural Recovery (MNR) to its remaining 235 acres.[94] While MNR sounds nice, this means that these areas will receive no treatment whatsoever, and will simply be monitored to control human contact, while seeing if natural sedimentation patterns cover this remaining pollution over time. Despite the majority of acreage in this cleanup plan set to utilize natural recovery methods within a hazardous toxic-waste site, EPA is hopeful. In accordance with cleanup of early action areas, controlling ongoing sources of pollution, completion of the remedies identified in the ROD, and a decade of monitored natural recovery, the ROD for the LDW is expected to result in reducing chemicals posing the most risk in river sediments by 90% or more.[95] With current technologies, best management practices, and overall methods often falling short of cleanup goals, despite decades of work and millions of spending, the effectiveness of this finalized ROD remains to be seen. To see these in a different light, the following sections will outline issues with the ROD's selected remedies, presenting their probable constraint alongside a more preferable opportunity.

THE ISSUE WITH DREDGING + DISPOSAL
Dredging + Disposal (25%) 105 acres
Probable Constraint: Cost of Disposal
Preferable Opportunity: Dredging + Re-purposing

Dredging for the complete removal of contaminated sediment may be the most permanent method of cleanup, but its process is not without negative side effects. While it is assumed that remedial actions implemented by prior projects will address the majority of unsuitable material in the waterway, "there is risk that residual contamination may be present, due to inaccuracies in dredging and construction of the project remedy.[96] Much of its limitation, however, comes not from its removal, but dealing with its disposal. With contaminated dredgings requiring upland disposal, and unsuitable material being transloaded to one of the existing facilities on the LDW to then be disposed of by rail at a landfill, dredging for disposal simply exchanges pollution in the waterway for pollution on land.[97] Although a strong start, disposing of contaminated dredge (still contaminated) via energy intensive rail transportation to a far-away landfill is an increasingly weak finish. Not to mention costly. In addition, this disposal method results in the loss of potential gains from alternative processes also requiring removal, including re-purposing.

90, 92 Final Duwamish River Cleanup Plan Fact Sheet. Record of Decision: Final Cleanup Plan Community Fact Sheet. Record of Decision: Final Cleanup Plan Community Fact Sheet, Duwamish River Cleanup Coalition/Technical Advisory Group, 2015.
91. "Breaking: EPA Issues Its Record of Decision for the Duwamish River Superfund Site | Science, Law & the Environment | Miller Nash Graham & Dunn LLP." Science, Law & the Environment, 4 Dec. 2014, www.sciencelawenvironment.com/2014/12/breaking-epa-issues-its-record-of-decision-for-the-duwamish-river-superfund-site/.
93, 94, 95. EPA Environmental Protection Agency Region 10. Record of Decision Lower Duwamish Waterway Superfund Site. EPA , 2014, pp. 1–181
96, 97. US Army Corps of Engineers Seattle District, and Port of Seattle. Seattle Harbor Navigation Improvement Project. Final Integrated Feasibility Report and Environmental Assessment ed., Engineering, pp. 1–45



MORE DREDGING FOR A MORE CERTAIN CLEANUP

While past proposal plans for the LDW cleanup have worked to include greater certainty through greater dredge removal, all have been turned down in favor of more cost effective, yet less certain remedies. With the direct correlation between volume dredged + disposal and remedy cost, increased incentive for dredge removal + repurposing can help ameliorate the overall cleanup effort.

	LDWG COMBINED KEY	ALTERNATIVE 5C	EPA'S PROPOSED PLAN	ALTERNATIVE 5R
DREDGING + CAPPING AREA (ACRES)	72	104	101	157
ENR AREA (IN ACRES)	65	53	48	0
TOTAL DREDGE VOLUME (CUBIC YARDS)	**630,000**	**750,000**	**790,000**	**1,600,000**
TOTAL COST ($ MILLIONS (NPV)	**$260**	**$290**	**$325**	**$470**
TOTAL COST ($ MILLIONS NON-DISCOUNTED)	$300	$330	$348	$510
CONSTRUCTION TIME FRAME (YEARS)	5	7	7	17

REPURPOSING DREDGE

While dredging objectives vary from widening waterways and deepening harbors to cleanup and restoration efforts, it results in millions of cubic yards of leftover dredged material. Clean dredgings can be put to beneficial use in a variety of coastal and inland waterway landscapes, and have been well documented as an earthen resource for project developers. An aggregate of sediment accumulated at the bottom of a waterway, dredged material can be used for general construction fill, brownfield remediation, landfill capping, and other geotechnical improvements. The adaptive reuse of dredge is becoming an increasingly urgent process for waterway projects to facilitate, because reuse - rather than disposal - has increasingly broad environmental, economic, and societal implications.[98]

As we run out of places to put dredge, while facing increasing transportation costs to get it there, the disposal and placement of dredged material is now considered to be one of the greatest challenges facing today's waterway projects. Even for clean sediment, disposal is becoming an issue. While much of the dredgings from channel deepening in non-contaminated areas of the LDW have been (and continue to be) placed at the nearby Elliot Bay open water disposal site, according to the USACE Seattle District Dredged Material Management Plan, all federal harbor projects where there is an indication of insufficient placement capacity to accommodate maintenance dredging, only looks forward for the next 20 years.[99] This is a relatively short time frame for an increasingly filled-in disposal site, amidst a waterway looking to dispose of millions of cubic yards of future, dredged material, either from navigation needs or cleanup and restoration projects.

As concern over dredging and disposal of waterway sediments increases, unconfined open-water disposal of dredged material from harbors and navigation channels is becoming more closely scrutinized by state and local governments.[100] Across the US, federally controlled waterways are now looking into long-term alternatives to dispose of the more than 230 million cubic meters of dredged material they produce each year, clean or not. Contaminated dredge, often riddled with heavy metals and organics that bind to silt and clay, requires treatment technologies for removing contaminants prior to becoming repurposable. Some of these technologies can be easily added to dredging vessels themselves, minimizing the cost of material handling. Onboard or offboard, treatment methods are becoming increasingly cost effective, as the demand for earthen material spurs the need for re-purposing dredge. In fact, the EPA is currently developing a national strategy to address this issue of contaminated dredge reuse, as this situation intensifies.[101]

Over the last 15 years dredge research, reuse, and experience have demonstrated that re-purposing dredged material can provide added value for local projects. The focus has now shifted to finding more sustained uses for dredged material, as increasingly fixed pathways for coordinating and conveying the supply of dredged material with a concurrent demand.[102] USACE and the EPA's Framework for Determining Environmental Acceptability of Dredged Material outlines ten broad categories of identifiable, beneficial uses for re-purposing dredged material as a manageable and valuable soil resource. From habitat restoration to beach nourishment, aquaculture to agriculture, and construction to material transfer, treated dredge is already being used in a variety of ways. Well known as a material capable of enhancing or expanding port-related facilities, aiding in the reclamation of former industrial brownfield sites as well as commercial development, the use of dredged material often receives local support for its potential benefit to surrounding buildout and development projects.[103]

The first step in assessing the beneficial use of dredged material is to identify the local needs and opportunities for beneficial use in the first place. This involves surveys of activities which may require material with certain characteristics, or surveys of needs for certain future site uses.[104] Using dredge for the reclamation of former industrial brownfield sites and commercial development is a viable option for the industrial lands adjacent to the LDW, as well as any future infrastructure projects requiring construction fill. Contaminated dredge, however, is not yet framed as a readily viable source. When dredged material is lightly contaminated, direct uses and applications may be an option if their environmental risks are low, taking site-specific conditions into account.[105] What does this mean, then, for the LDW's highly contaminated and PCB laden dredge?

98, 102, 105. International Association of Dredging Companies. Facts About Dredged Material as a Resource. Facts About Dredged Material as a Resource, IADC, 2009.

99. US Army Corps of Engineers Seattle District, and Port of Seattle. Seattle Harbor Navigation Improvement Project. Final Integrated Feasibility Report and Environmental Assessment ed., Engineering, pp. 1–45

100. "Contaminated Marine Sediments: Assessment and Remediation" at NAP.edu." National Academies Press: OpenBook, www.nap.edu/read/1412/chapter/21

101. Zar, H. "Regulatory Strategies for Remediation of Contaminated Sediments." Dredging, Remediation, and Containment of Contaminated Sediments, doi:10.1520/stp16010s.

103, 104. US Army Corps of Engineers, and Environmental Protection Agency. Evaluating Environmental Effects of Dredged Material Management Alternatives - A Technical Framework. 2004, pp. 1–95

Fortunately, phytoremediation and bioremediation represent promising, economic, and ecologically effective technologies that use plants and living microorganisms to remediate heavy metals and other contaminant pollutants from the biosphere: its soil, water, and air.[106] Including contaminated dredge.

As wastes took on an ever more diversified character throughout the last century, so too have our waste treatment technologies.[107] Although not as well recognized as more traditional soil or groundwater based remediation efforts, the notion is the same, and the bioremediation of dredge is beginning to advance as studies begin to identify a wider range of reuses for dredged material, which provide a cost-efficient, sustainable, and win-win scenario for clients, contractors, and communities.[108] While re-purposing contaminated dredge accrues upfront costs and time associated with treatment, it should not be ruled out or overlooked, as cost of treatment when weighed against transportation and disposal fees still makes it more economical.[109]

BIOREMEDIATION

The treatment of contaminated dredge begins with separation and dewatering, isolating usable sand portions from contaminated silt portions. Resulting silt contamination can then be reduced, removed, or immobilized. While some naturally occurring plants and microorganisms already do this, biotechnology companies are now genetically engineering parts of these living creatures, effectively modeling beneficial "super-plants and superbugs," capable of consuming specific parts of contaminants at increased rates and more beneficial byproducts. For example, developing a

microorganism that works to consume PCB particles and break them down as food, creating air and water byproducts carefully measured to support soil growth, rather than anaerobically prevent it. SediMite™ represents one recent and promising treatment, developed by Sediment Solutions, which works to inoculate contaminated sediment with pellets rich with PCB-degrading microorganisms. With new companies and technologies looking to research, develop, and implement their bioremediation products further, sites like the contaminated LDW can help advance these treatment options from laboratory, to field study site, and into practice.

EMERGENT BIOTECHNOLOGIES

SediMite™ bioremediates PCBs using anaerobic microorganisms by first removing chlorines from PCBs, and then releasing anaerobic microorganisms to break down their remaining biphenyl rings.[110] Simply put, it places contaminant hungry microbes within contaminant rich material, in a sort of bioremediation buffet. A 2012 pilot test was used to determine the efficacy of this bioaugmentation in the field, at an overflow pond containing high PCB concentrations. Initial in situ tests in 2.8 sq. ft. caissons achieved 80% reduction in PCBs in the top 6 inches after 990 days, meeting the target level of 50 parts per million.[111] No changes were observed in the untreated sediment. Later in 2015, a Phase II pilot test was used with in situ treatments of 400 sq. ft. plots, achieving a 53% reduction in PCB levels in the benthic zone after 13 months.[112] Although biotreatment takes time, you do not have to pay microbes for their labor, and treatment can be performed intensively on site and in confined areas. Re-envisioning material end products as a driver, cutting costs while actually decontaminating dredged media, successes like these can

dredged media, successes like these can help further incentivize the adoption of biotechnologies.

Land-based biotreatment of contaminated dredge uses constructed treatment cells, much like many of today's wastewater treatment plants. Fortunately, this intensive solid-phase process of remediation can be successfully performed on a minimal footprint, of which the LDW has plenty of in its adjacent, industrial lots. While the USACE and USEPA Framework for Dredged Material Management typically does not consider mechanical biological wastewater treatment processes, because it is doubtful that sufficient organic matter would be available to support biological growth, and because operation of biological systems under the conditions of fluctuating flows and temperatures would be difficult, waterways by their dredging necessity provide sufficient organic matter, and a constant source of water cooling potential.

106. Metallic contamination and its Toxicity, Edition: 2018 (First Edition), Chapter: 15, Publisher: Daya Publishing House A Division of Astral International Pvt. Ltd New Delhi - 110002, Editors: Gautam A., Pathak C., pp.207-229

107. Charlier, R.H.; Finkl, C.W., and Krystosyk-Gromadzinska, A. 2012. Throw it Overboard: A Commentary on Coastal Pollution and Bioremediation.

108, 109. International Association of Dredging Companies. Facts About Dredged Material as a Resource. Facts About Dredged Material as a Resource, IADC, 2009.

110, 111, 112. Payne RB et al. "Mesocosm Studies on the Efficacy of Bioamended Activated Carbon for Treating PCB-Impacted Sediment." Environ Sci Technol. 2017 Sep 19;51(18):10691-10699.

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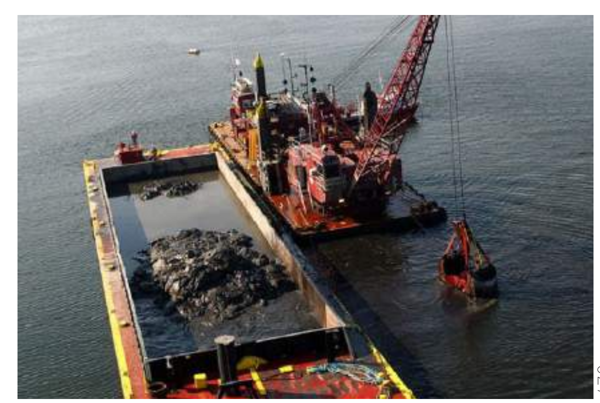
BIOREMEDIATION REMOVES PCBs FROM CONTAMINATED DREDGE

As wastes took on an ever more diversified character throughout the last century, so too have our waste treatment technologies. Although not as well recognized as more traditional soil or groundwater based remediation efforts, the notion is the same, and the bioremediation of dredge is beginning to advance as studies begin to identify a wider range of reuses for dredged material.



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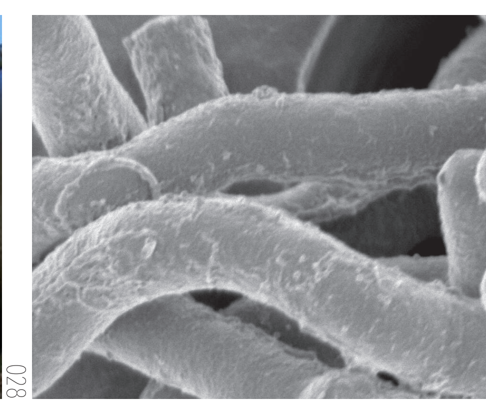

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THE ANNUAL COST OF DOING NOTHING

The market for developing more cost effective technologies capable of bioremediating contaminated dredge within urban waterways in the United States alone is currently hovering around $5 billion.[113] What might be the annual cost of doing nothing? As dredging demands and material supplies shift, more research is required not only to optimize the bioremediation process, but to enhance the applicability and implementation of these growing technologies. While reconciling industrial landscapes through remediation is not new to the practice of landscape architecture, the potential of using transformative bioremediation to build urban form as a large-scale landscape network, that makes the process of remediation part of the urban landscape experience, is still underdeveloped in theory and practice.[114] Moving towards the idea of a more cyclical, urban sedimentshed, the value of dredged material can become a conversational tool that helps foster the acceptance of biotreatment, especially within heavily modified environments where the natural processes maintaining ecosystem functions are highly constrained.[115] Despite these hopeful laboratory and field site trends, phytoremediation and bioremediation must still prove their quantifiable sustainability beyond field scale.[116] Their adoption within large-scale municipal projects, therefore, is becoming increasingly significant.

Meanwhile, as we continue to dispose of contaminated dredge, we are also beginning to negotiate new landscape uses for recovery of this spent material, as we run out of other earthen materials. Under pressure from diminished supplies, there is now considerable interest in removing dredged material from its

confined placement at landfills, to treat and use as a resource for construction material, or topsoil to restore capacity to existing areas, as dredged materials will support desirable vegetation with little input other than fertilizer.[117] Working with a material that hasn't been utilized to its full extent in traditional landscape applications, subject to budget constraints and under-researched public perception, it is time to get creative with the use of contaminated, repurposable dredge. And if dealing with dredged material remains a massive logistical, financial, and environmental challenge for Ports, one that has increasing ramifications for sustainability and resilience, the LDW will need to re-examine how dredged material fits into building its urban forms at large.[118]

THE ISSUE WITH CAPPING

Capping (6%) 24 acres
Probable Constraint: Effectiveness and Trends in Marine Freight
Preferable Opportunity:
Dredging + Re-purposing

Capping works by placing a clean layer of sand and an engineered cap over contaminated sediments, to help bury and contain their risk. Often employed in waterway projects, they are useful in shallow and hard to reach areas, such as around structural elements where dredging is more difficult. Long-term monitoring efforts are beginning to show, however, that capping doesn't always work. Much of what we know about the failures of capping comes from the 2003 Duwamish Diagonal Sediment Remediation project's long-term monitoring efforts, with post-cap sampling data showing that its caps don't always isolate chemicals as planned. Data from cap perimeter stations revealed mixed levels of reduction and increase, and at times even spikes in chemical concentrations.[119] Perhaps more worrisome than caps not fully working, is the global trend in marine freight that threatens to dig past their bottommost elevations in the first place.

DEEPER PORTS, DEEPER POCKETS

Waterway depths in the LDW are in a constant state of flux, as dredging efforts dig deeper and deeper. Focused on maintaining and deepening navigation channels, anchorages, and berthing areas for the passage of boats and ships, this bottom depth continues to increase over time as larger ships are deployed.[120] According to the National Oceanic and Atmospheric Administration U.S. Department of Commerce, since massive ships carry the bulk of the goods imported into the country, dredging deeper plays a vital role in the nation's economy.[121] And when in 2017 foreign trades through U.S. ports were valued at $1.6 trillion, with $527 billion exports and $1.1 trillion imports being moved by waterway bound vessels, an extra inch of water depth in a port can bring in millions of dollars worth of additional cargo.[122] NOAA refers to this concept as "deeper ports, deeper pockets." It is a mantra actively pursued by ports and harbors throughout our coastlines, including here in Seattle, as its Port works to remain competitive in today's international shipping market.

113. Environmental Cleanup Using Plants: Biotechnological Advances and Ecological Considerations, Frontiers in Ecology and the Environment, Ecological Society of America
114. Sleegers, Frank (2010) "Phytoremediation as Green Infrastructure and a Landscape of Experiences," Proceedings of the Annual International Conference on Soils, Sediments, Water and Energy: Vol. 15 , Article 13.
115. Chartered Institution of Water and Environmental Management. Floods and Dredging - A Reality Check. The Blueprint for Water, 2014, pp. 1–25

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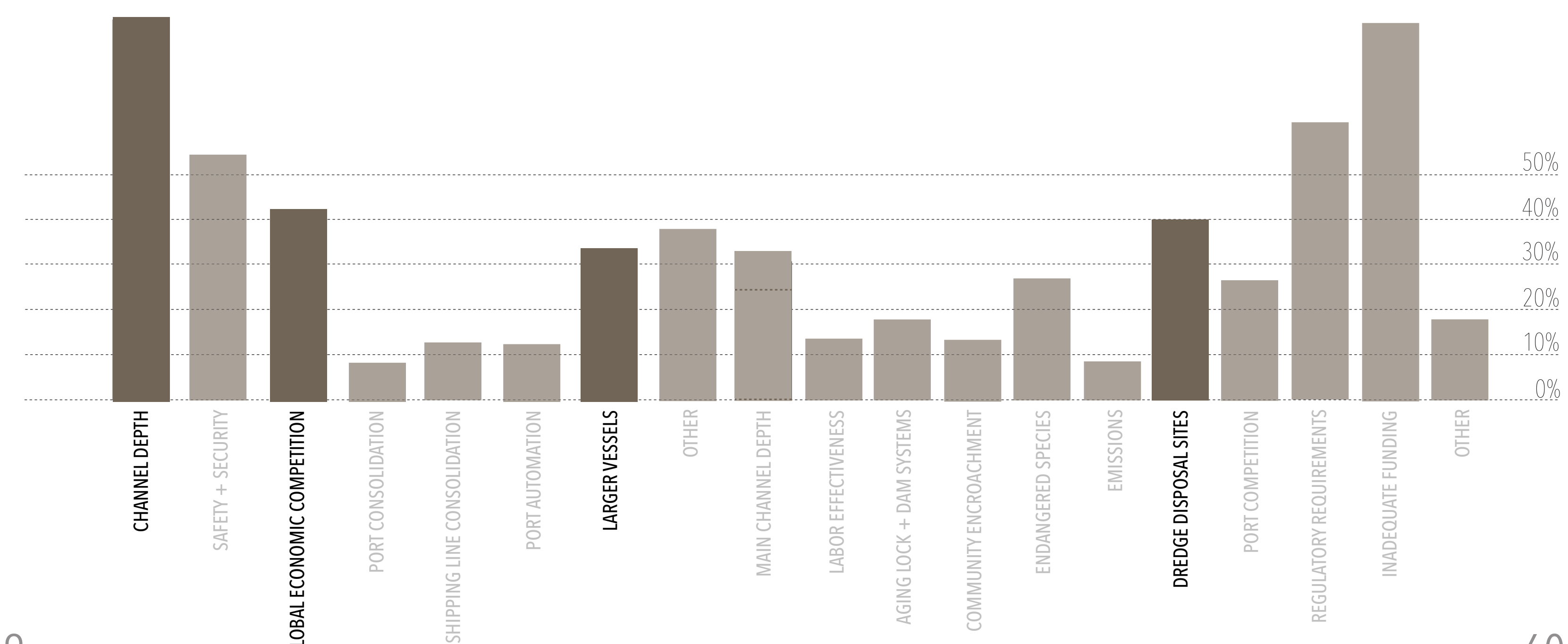
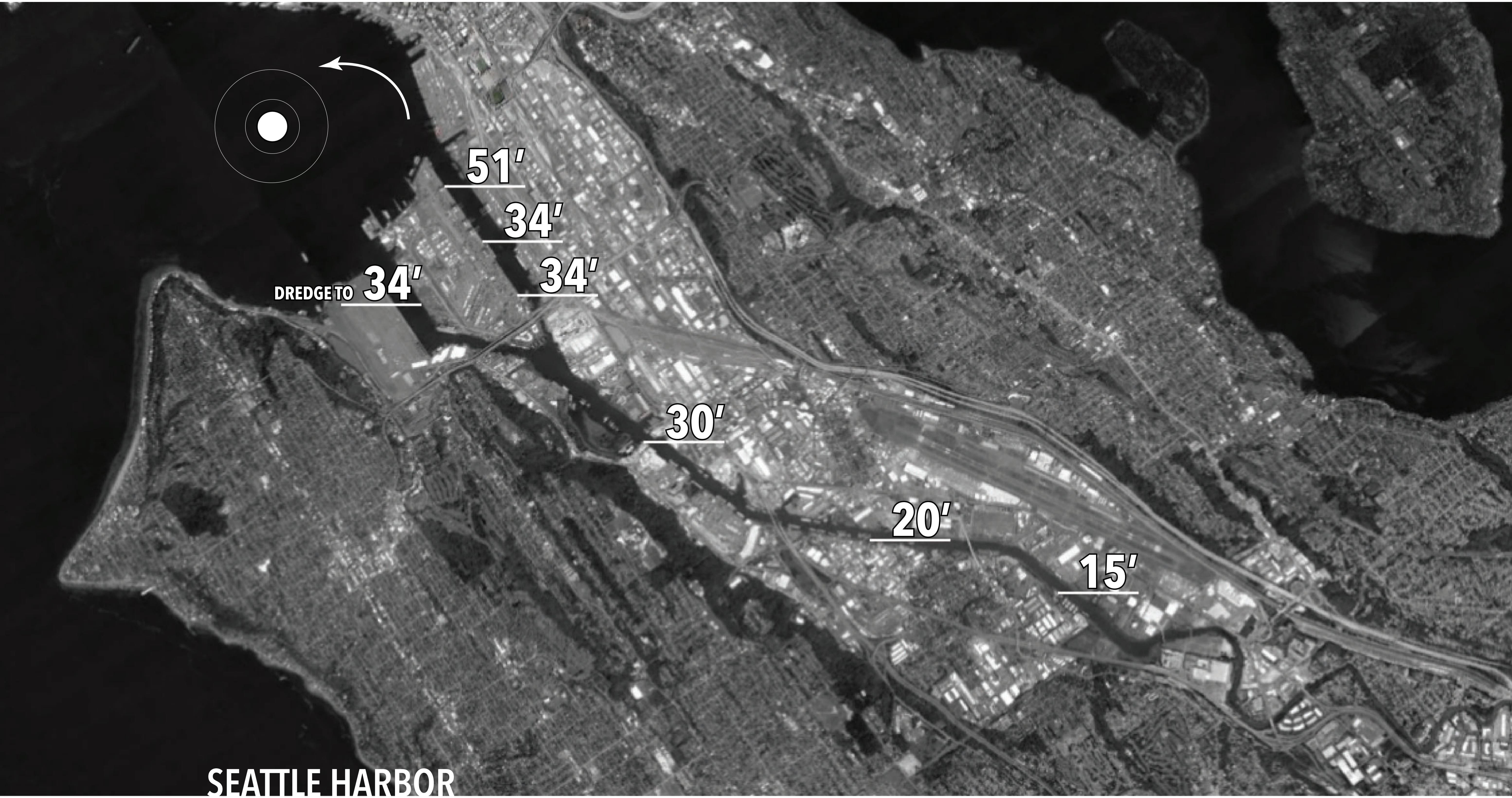
TRENDS + CHALLENGES AT WASHINGTON PORTS

Washington State Department of Transportation recently released a 2018 Trends and Challenges report for all state ports. Close to half cited global economic competition as a driver for larger vessels, deeper channels, and therefore an increase in dredged material and dredge disposal sites. [186]





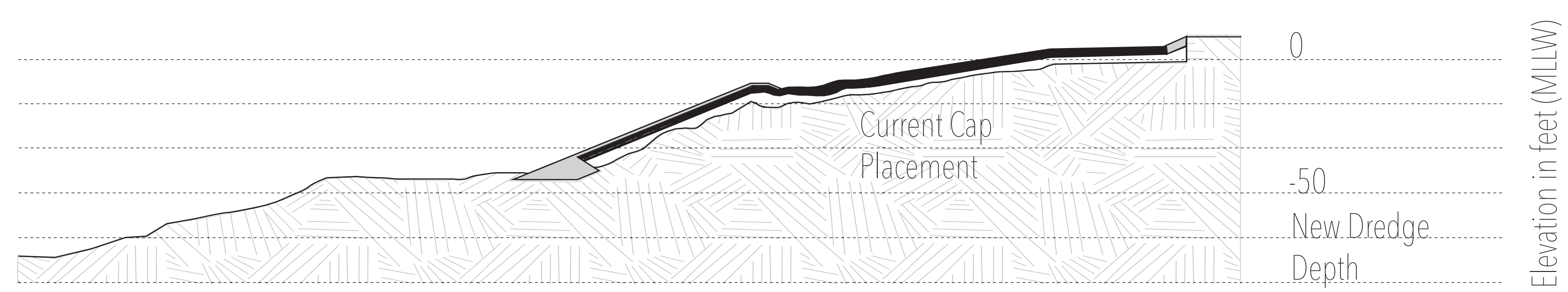
SEATTLE HARBOR NAVIGATION PROJECT DREDGE + DISPOSAL

The Elliot Bay Disposal site is a non-dispersive area 300-360 ft. deep covering an approximate 415 acres. Dimensioned as a 6200 ft. x 4000 ft. ovoid, its disposal zone is an approximate 1800 ft. diameter circle. Non-contaminated dredgings from maintaining waterway depths are deposited here.

031

ISSUES WITH CAPPING
: A FUTURE OF MARINE FREIGHT

Perhaps more worrisome than caps not fully working, is the global trend in marine freight that threatens to dig past their bottommost elevations in the first place. As they work to remain competitive in the international shipping market, "deeper ports, deeper pockets" remains the mantra of making sure Ports can accommdate increasingly larger ships, often digging past placements of environmental caps.



USACE and the Port, dictating dredging needs throughout the LDW as part of the Seattle Harbor Navigation Improvement Project (SHNIP), recently authorized deeper dredging depths with plans to begin digging in 2024.[123] These decisions, informed by the USACE Engineering Manual for deep draft navigation projects, recommend a design channel width of three times the design beam for one-way ship traffic, for a canal type channel such as the LDW.[124] Contracted with the Maersk Shipping Company, which now operates the largest container ship of Triple E-Class vessels to serve a predominantly Asian trade route, the Port of Seattle is expected to be widened approximately 50 feet to serve this new class of design vessels, while adding an additional 150 feet of channel width to each Waterway.[125] As the LDW widens for progressively larger fleets, dredging will work to continuously deepen its channels, with many of these future depths surpassing where engineered caps have been placed or are planned to be utilized.

As part of the SHNIP, the following three alternatives are considered for dredging and the placement of dredged materials in the LDW's East Waterway alone: Alternative 1: No Action - maintain current project depth of -34 to -51 feet MLLW, Alternative 2: National Economic Development (NED): deepen project to -56 feet MLLW, and Alternative 3: Locally Preferred Plan (LPP): deepen project depth to -57 feet MLLW.[126] Alternative 2 and 3 would obstruct current caps and planned placement depths in the area, with some already being set at -51 feet.[127] As river bottom elevations remain in a constant state of responsive fluctuation to engineered dredging manuals, trends in international shipping, and the economic drivers of marine freight - much like the

LDW at large - it is clear that the future of dredging will continue to threaten current and future capping placements.

THE ISSUE WITH NATURAL RECOVERY

Monitored Natural Recovery
(57%) 235 acres
Enhanced Natural Recovery
(12%) 48 acres
Probable Constraint: Ineffectiveness + Uncertainty
Preferable Opportunity: Dredging + ENR

Monitored natural recovery (MNR) is the largest part of EPA's ROD, but also the least effective and least certain remedy. While the long-term goal of MNR is to achieve ecological recovery of biological endpoints in order to protect human health, reliant on the processes of natural sediment burial and the weathering of contaminants to less toxic forms, it is unknown if employing MNR in the LDW will actually provide long-term risk reduction.[128] While at times and in certain locations, the risk of using more aggressive remedies such as dredging and capping may be greater than the risk of leaving sediments in place - effectively stirring up more contaminants - using MNR in the LDW is essentially asking for natural recovery to occur within a toxic hazardous waste site, where contaminants will already be stirred up. Enhanced natural recovery (ENR) is similar to MNR, but uses kick-starting mediums for coverage, to reduce concentration of chemicals in biologically active zones of sediment, in manners that will enhance the potential for ecologically "balanced recolonization," while not causing widespread disturbance to existing habitat.[129] Coupled with dredging, ENR is overwhelmingly preferred as a treatment remedy by waterway users. In response to the ROD, the DRCC/TAG recommends employing ENR on 62% of the LDW's sediment, alongside dredged removal of 38% in its most contaminated areas.[130]

While MNR relies on natural sediment transport patterns to effectively bury its contamination, sediment transport in the LDW quite literally illuminates the thinking that everything, especially contamination, goes somewhere. Particles tracked via luminescent markers were used to help build a picture of how sediment is moving through the waterway in real time. This recent suspended-sediment transport study, prepared in cooperation with the Washington State Department of Ecology and the U.S. Geological Survey, found that the Green-Duwamish River transports watershed-derived sediment to the LDW Superfund site, and that better understanding the amount of sediment moving through the river is essential to the superfunds sediment cleanup process.[131]

116. Environ Sci Pollut Res Int. 2009 Nov;16(7):745-64. doi: 10.1007/s11356-009-0205-6. Epub 2009 Jun 16.
117. US Army Corps of Engineers, and Environmental Protection Agency. Evaluating Environmental Effects of Dredged Material Management Alternatives - A Technical Framework. 2004, pp. 1–95
118. "Dredging Up The...FUTURE." Library.Automationdirect.com, 22 Feb. 2019, library.automationdirect.com/dredging-up-the-future-issue-6-2006/.
119. Water and Land Resources Division, and King County Department of Natural Resources and Parks. Duwamish/Diagonal Sediment Remediation Project Final 2010 Monitoring Report. vol. 43, Elliot Bay/Duwamish Restoration Program Panel, 2015, pp. 1–85
120, 121, 122. US Department of Commerce, and National Oceanic and Atmospheric Administration. "What Is Dredging?" NOAA's National Ocean Service, 6 Sept. 2013, oceanservice.noaa.gov/facts/dredging.html.
123, 124, 125, 126. US Army Corps of Engineers Seattle District, and Port of Seattle. Seattle Harbor Navigation Improvement Project. Final Integrated Feasibility Report and Environmental Assessment ed., Engineering, pp. 1–45
127. US Environmental Protection Agency. Record of Decision Lower Duwamish Waterway Superfund Site. 2014, pp. 1–181
128, 129. Magar, Victor S, and Richard J Wenning. "The Role of Monitored Natural Recovery in Sediment Remediation." Integrated Environmental Assessment and Management, U.S. National Library of Medicine, Jan. 2006, www.ncbi.nlm.nih.gov/pubmed/16640320.
130. Record of Decision: Final Cleanup Plan Community Fact Sheet, Duwamish River Cleanup Coalition/Technical Advisory Group, 2015.
131, 133. U.S. Department of the Interior, and U.S. Geological Survey. Suspended-Sediment Transport from the Green-Duwamish River to the Lower Duwamish Waterway. 2013, pp. 1–34

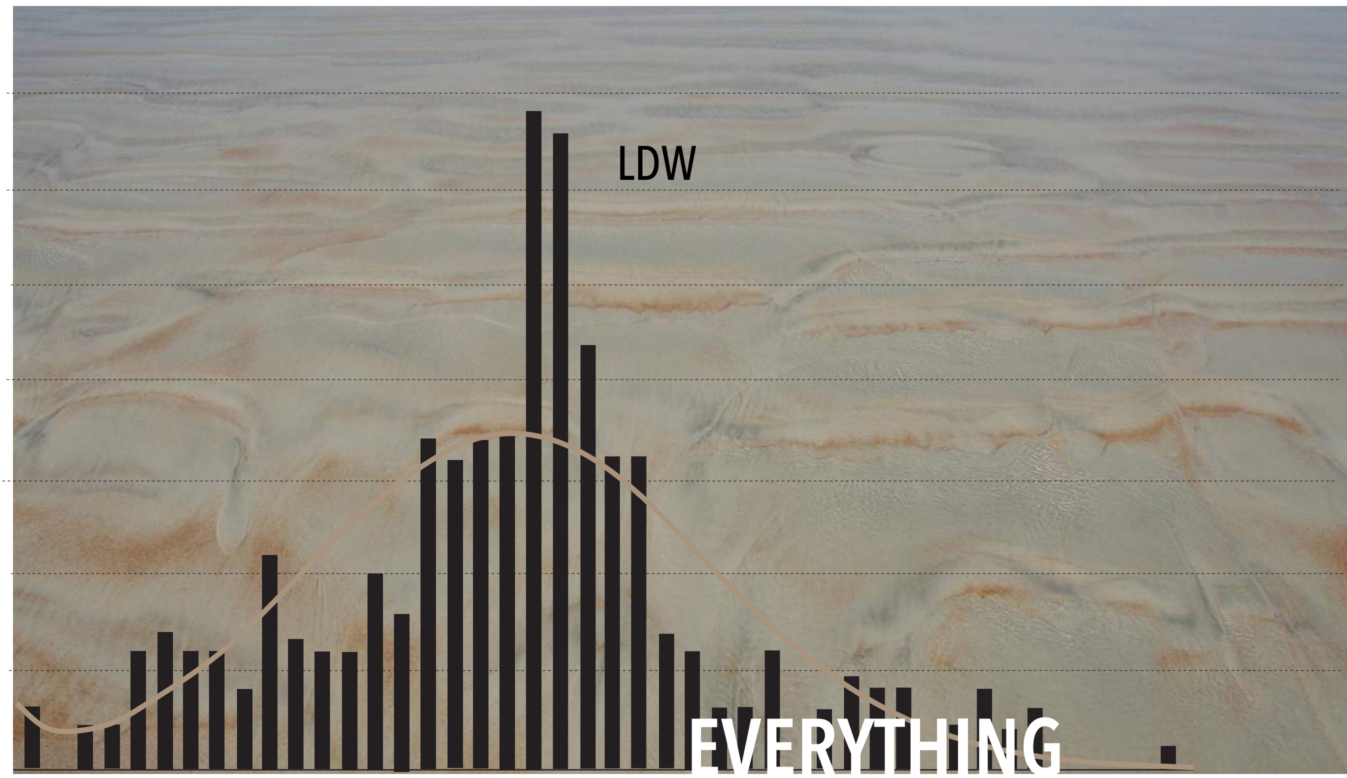
Simply put, sediment is not sedentary, existing in a constant state of flux and fluidity. Hydrologically, the LDW will remain a low-lying body of water, taking in an estimated annual average sediment load now reaching 210,000 tons per year.[132] Washing downstream, sand and silt will continue to gradually fill the LDW, as water flows from high to low and out to sea.

On a geologic time scale, sediment moves from one place to another via erosion and the physical flows of the water columns it swirls, collects, and sinks in. In natural waterways, healthy sediment performs like soil in an underwater forest, providing filtered combinations of nutrients and habitat types for aquatic plants and animals. In our human time scale, channeled through the highly constructed LDW, sediment moves and performs very differently. Flushed through by occasional dam openings, runoff from adjacent construction sites, and pushed through concrete tunnels, sediment moves from one place to another through the infrastructure we allow for it, picking up contaminants along the way. The addition of sediment to riverways above normal levels, especially when contaminated, is a serious issue with considerably negative effects on water quality and habitat. Conversely, the removal of sediment from waterways contributes to poor water quality and decreased habitat, by the very nature of dredging. Despite this industrial and ecological Catch-22, the LDW must not only actively dredge for navigation, but also to remove contaminated sediment with certainty.

132. US Army Corps of Engineers Seattle District, and Port of Seattle. Seattle Harbor Navigation Improvement Project. Final Integrated Feasibility Report and Environmental Assessment ed., Engineering, pp. 1–45

"If 'the shift from one mode [of production] to another,' according to spatial theorist Henri Lefebvre in the last century, 'must entail the production of a new space,' then the transformation of industrial systems (closed, linear systems that produce commodities and wastes) toward urban economies (open, circular systems that cultivate commodities from wastes) should also produce new spaces, and open new geographies. If waste naturally and necessarily charts new scales of influence, how then do we design and direct our future?"

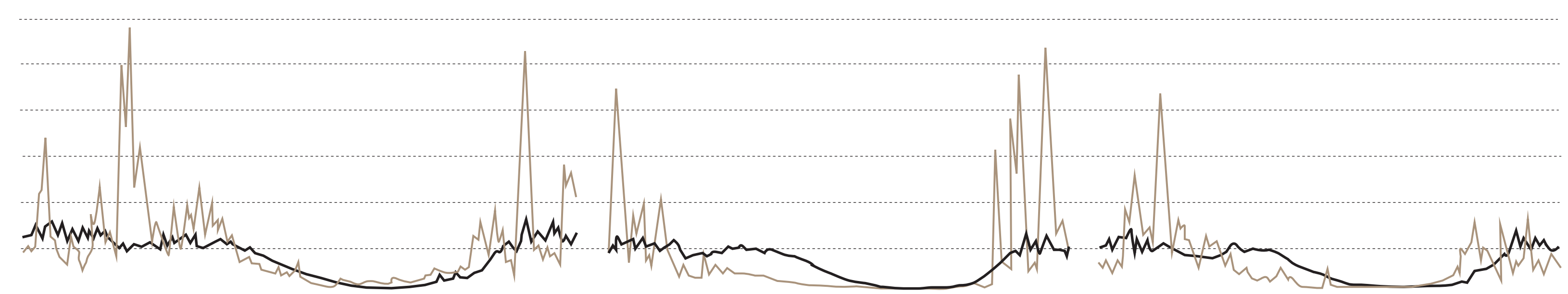
Pierre Bélanger, Ecology 5.0

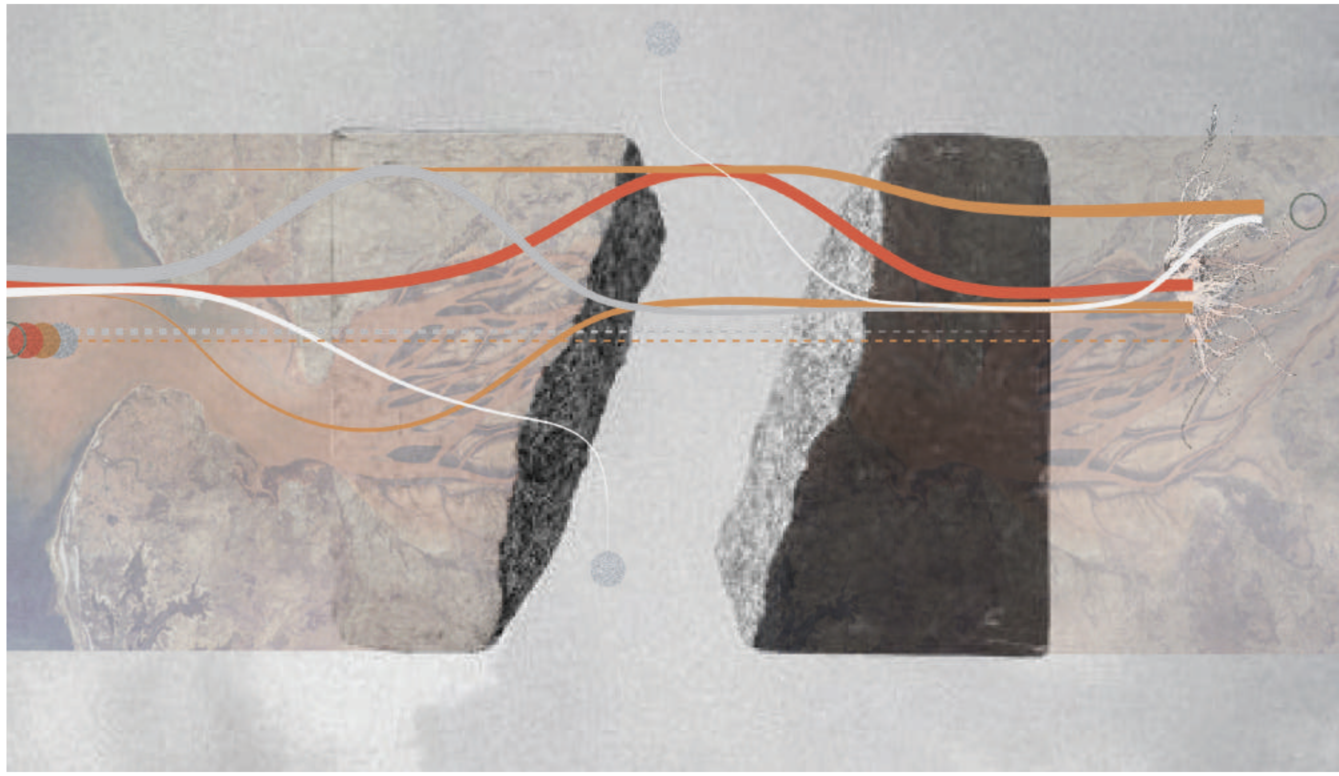


Sophie Krause

EVERYTHING GOES SOMEWHERE

Through our human time scale and infrastructure, sediment makeup and transport is very different than in a natural, geologic context. The above graph shows PCB levels in sediment throughout the Duwamish River mile markers, spiking in the LDW. The adjacent graph compares historic seasonal sediment movement patterns in the LDW in black, alongside current patterns in tan.





Sophie Krause

DESIGN | INSPIRATION

EXPRESSING A PREFERABLE FUTURE INTO A PHYSICAL FORM

Re-framing constraint as opportunity and waste as resource, this design scenario works to weave a materialshed throughout the LDW. Intelligent systems use resources as effectively as possible, to deliver a maximum return for a minimal investment of effort. Incentivizing dredge re-purposing as a waterway necessity and generative source, capable of ameliorating the LDW's current Superfund goals as well as becoming a cost-effective material for future buildout, while the scope of this project focuses on designing for one increasingly pressing issue - building for sea level rise - there are countless, alternative uses for

for dredged material within the LDW. Bringing waste back into the economic loop through technological innovation, redevelopment, remediation, and landscape infrastructure, this thinking can create a system for dredge cycling in the LDW, providing for its future development. While the complexity of recycling and remediation is magnified at today's urban scale in increasingly site-specific ways, two fundamental procedures remain crucial for its decoding, as outlined through the following excerpt *Waste Ecologies, from Landscape of Disassembly:*

Firstly, the mapping of the geography and flow of industrial processes (water coolants, material inputs, energy requirements, emissions, effluents, waste fluids) must occur in parallel with the mapping of urban processes (water courses, surface runoff, sewer outflows, domestic wastes). Secondly, linkages must be designed (using chemistry and biology in combination with geography and transportation) so that waste from one industry becomes fodder for another. With these two procedures, an ecology of waste transactions can be prototyped and a network of industrial exchanges constructed. [133]

Mapping the geography and flow of LDW industrial processes (as a low-lying drainage ditch, already collecting and storing contaminated media), parallel with its adjacent urban processes (as an industrial lifeline, threatened by aging infrastructure amidst rising sea levels), this design proposal will highlight contaminated dredge re-use as fodder for constructing more intelligent flooding infrastructure, capable of increased ecological and community performance.

While the uncertainties of intelligent infrastructure systems include: what will happen in science and technology, the role of business and government, and social attitudes, the following design drivers are known and here to stay: cost, materiality, and climate. Going forward, together these drivers will dictate not only how business is conducted, but how landscape transforms to hold space for its constant, responsive unfolding. In this way, responding to sea level rise represents both calamity - and catalyst - for the advancement of the role of landscape infrastructure along our coastlines and waterways.

"Business is on the verge of a transformation, a change brought on by social and biological forces that can no longer be ignored or put aside, a change so thorough and sweeping that in the decades to come, business will be unrecognizable when compared to the commercial institutions of today. This requires a critical re-evaluation of the overlooked relationship between industry, waste, and urbanism; and a survey of successful industrial ecologies"
- Paul Hawken, the Ecology of Commerce, 1993

133. Bélanger, Pierre (2007). Landscapes of disassembly. Topos 60 (October):86.

FLOODING IN SOUTH PARK: CALAMITY AND CATALYST

Within the context of climate change, natural systems are now changing faster than urban infrastructure.[134] A low-lying landscape built last century atop a liquefaction zone, with industrial organizations, residences, and utility lines laid out in its floodplain, the LDW will require extensive infrastructure upgrades in order to mitigate flooding from rising sea levels. Already experiencing issues with flooding, the waterfront neighborhood of South Park is predicted to bare the brunt of SLR in the LDW, with estimated frequencies and magnitude increasing, as annual flooding events are projected to become monthly events by 2035, and daily events by 2060.[135] The design of these infrastructure upgrades will be confined within the limitations of a narrow, working waterway. Houses are a stonesthrow from the water, and there is not enough space for successfully restoring absorptive marshlands or tidal lands to mitigate flooding without massive relocation. Amidst this distinct line between residentially zoned plots, and a federally managed channel, at its maximum flood mitigating infrastructure could fill an approximate thirty-foot setback from property line and into the LDW. Federal, state, tribal governments, local agencies, NGOs, and private sector interests connected to coastal and inland waterfront communities, possessing a complementary set of authorities and capabilities for protecting coastal and inland waterway systems, will need to work together to determine how this infrastructure performs, and for whom.[136] It is critical that while these structures work to protect South Park homes from flooding, their design develops within a community-led framework, implemented by the residents whose property setbacks

will become construction footprints.

INFRASTRUCTURE REFLECTIVE OF A COMMUNITY VISION

It is inevitable that low lying communities will be exposed to greater risks of flooding from rising sea levels. Responsive strategies will need to mitigate flood prone land through a combination of landscape engineering options, including flood zoning, warning programs, changes in land use practices, and the design and construction of site-specific flood defense structures and operations.[137] Ensuring that this mitigating infrastructure reflects South Park's vision for community development is a critical aspect of this response. As part of the Duwamish Valley Vision, workshops were held in community-identified neighborhood gathering places to discuss incentives residents had for future development projects along the LDW waterfront.[138] Asking what the community of South Park would like to see built in their backyards, residents responded with the following key incentives: protecting homes from flooding, providing more open green space, maintaining access to the waterfront, increasing water quality and habitat for those who fish here, while also supporting waterway industrial and manufacturing jobs.[139] In addition, residents of South Park and neighboring Georgetown, already confronting emerging artist and small business communities, shared concerns that increased development in their neighborhoods would contribute to ongoing gentrification: attracting rising housing prices, dislocating existing lower-income families, and in general forcing a loss of community character.[140] Models of urban greening that produce environmental improvements in the LDW, in order to work sustainably, must concurrently benefit long-term residents in accessible, economical, and equitable ways.

Deindustrialization is not a viable option for the working waterfront in South Park, even along its most residentially zoned areas. Adopting an urban greening approach such as the "parks, cafes, and riverwalk" model of sustainability, which focuses on providing new green infrastructures and spaces for predominantly high-income developments, often goes hand in hand with displacement.[141] A model that better recognizes all three aspects of sustainability: environment, economy, and equity, called "just green enough," aims to implement environmental cleanup and green infrastructure projects that retain and also create living-wage blue-collar jobs.[142] Focusing explicitly on development as it pertains to environmental and social justice goals, as defined by the people most affected by inequitable land use, "just green enough" strategies work to uncouple cleanup and infrastructural development from imposing outside forces. "Just enough," however, does not necessarily mean that green infrastructure projects in the LDW need be passable, or moderate. These retrofits can be coupled in multi-performative ways, as developments that not only reflect infrastructure needs, but community desires.

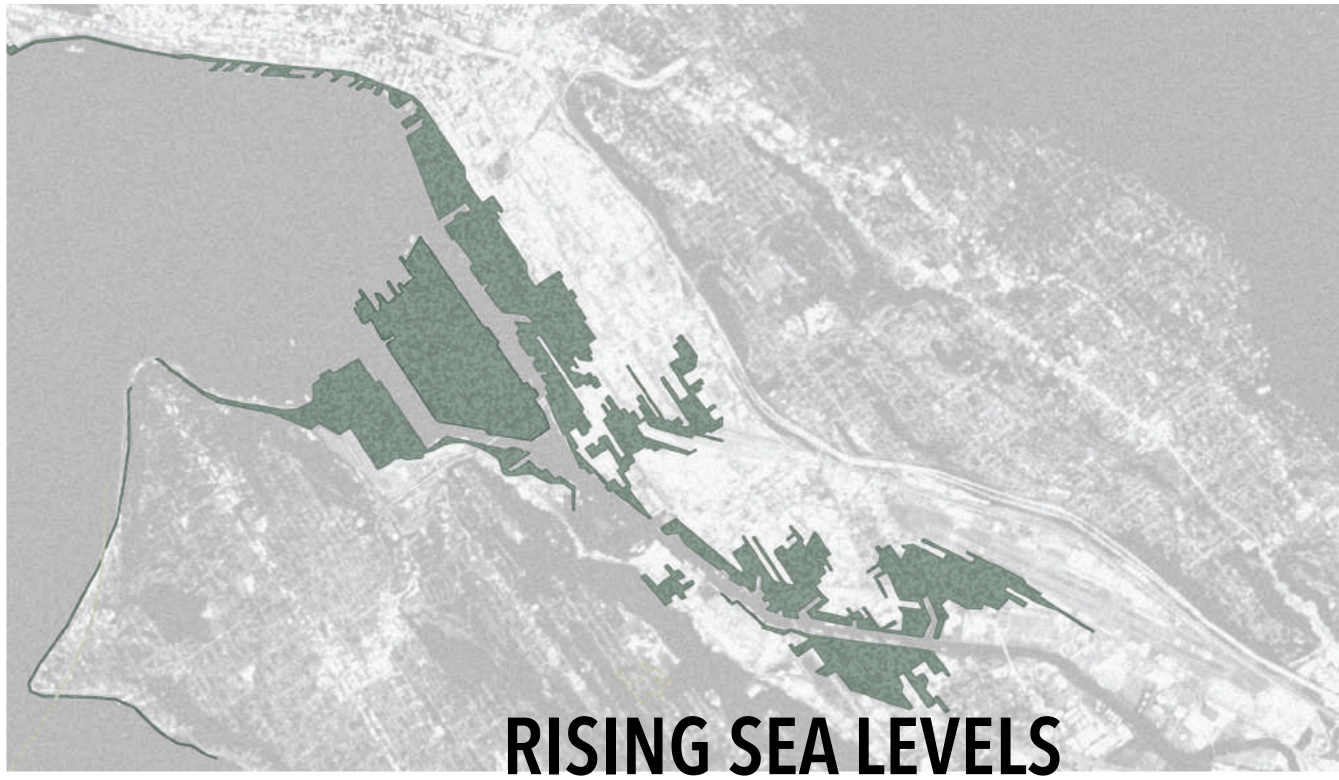
134. "How Cities Are Upgrading Infrastructure to Prepare for Climate Change." Smithsonian.com, Smithsonian Institution, 22 Oct. 2018, www.smithsonianmag.com/innovation/how-cities-are-upgrading-infrastructure-prepare-climate-change-180970600/.

135. GGLO Design. "Climate Preparedness: A Mapping Inventory of Changing Coastal Flood Risk." Seattle Office of Sustainability and Environment, 24 Aug. 2015, pp. 1–42., www.seattle.gov/Documents/Departments/Environment/ClimateChange/2015.08.25_ClimatePreparednessInventory_Sec1.pdf.

136, 137. Army Engineer Research & Development Center. "Developing Best Practices: System-Wide Actions for Coastal Resilience." 2015, doi:10.21236/ad1001635.

138, 139, 140. Cummings, BJ. "Duwamish Valley Vision Map and Report." Duwamish River Cleanup Coalition, 2009, pp. 1–143.

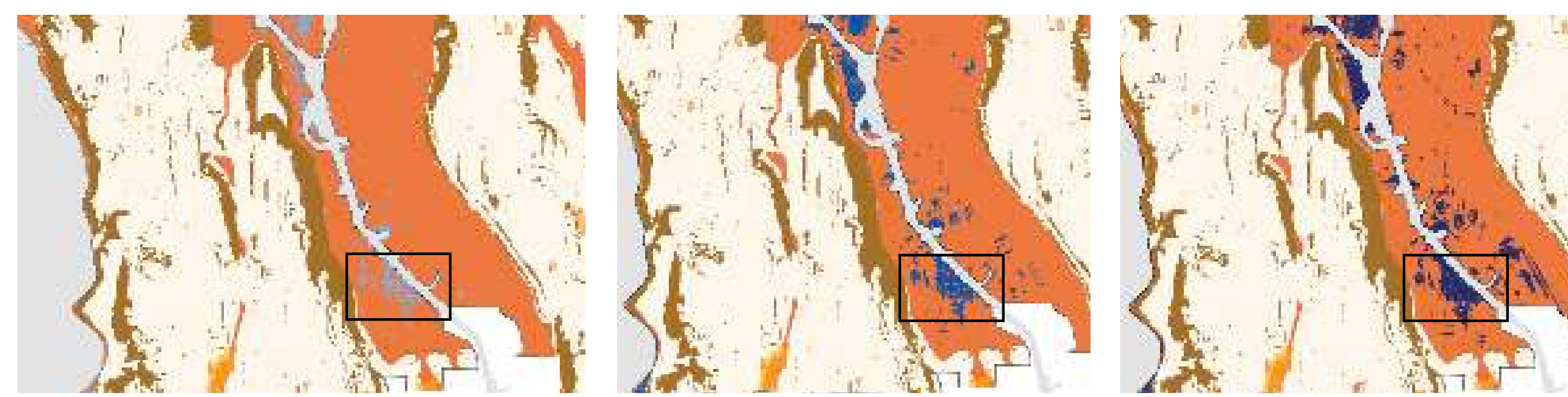
141, 142. Hamilton, Trina. "Can We Green Cities without Causing Gentrification?" GreenBiz, GreenBiz Group Inc., 26 Mar. 2018.



Sophie Krause

RISING SEA LEVELS
: FLOODING IN SOUTH PARK

As a low lying area built on a liquefaction zone, the LDW expects a floodable future from rising sea levels. Already experiencing issues with flooding, the waterfront neighborhood of South Park (bounded by the black box to the right) is predicted to bare the brunt of SLR in the LDW, with increased patterns of flooding for 3, 4, and 5 ft. scenarios.



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RESPONDING TO SEA LEVEL RISE: LIVING INFRASTRUCTURE AS A PRODUCTIVE RETROFIT

Adapting to sea level rise presents challenges - and therefore opportunities - for communities as they work to adopt and implement new infrastructural forms, especially in areas along aging, industrial corridors now overdue for retrofitting. Design is beginning to question the ongoing viability of single-purpose industrial corridors like the LDW, most of which were laid out last century. Many of which have been largely forgotten, are now well past their lifetime, yet in active daily use. Or in the words of Pierre Bélanger, "rarely seen in their longitudinal profile and entirety...until they fail."[143] After years of neglect, and more recently failures, infrastructure has become a major public priority for public investment across the country. And as designers begin to look more closely at landscape-based systems for re-organizing and replacing these spent infrastructures, living infrastructure presents tools for more adaptive buildout.

The effectiveness of designing with nature, integrating living "green" and "blue" infrastructures into our predominantly "gray" systems, is becoming increasingly valued. Living infrastructure has a ways to go, however, specifically when it comes to gaining quantifiable acceptance into our current methods of construction management. In an age of big data, living infrastructure requires close performance monitoring to help quantify the benefits that many of us already know: when we see clean water flowing through wetlands, breathe cleaner air walking along a forested path, and feel cooled off and relaxed while lying in a grassy park, instead of sitting in traffic. Assessing the current efficacy of nature-based vs. artificial waterway

protection demands research to happen today, as our rapidly changing climate requires new and innovative solutions for reducing the vulnerability of coastal and waterway communities to be built tomorrow, in response to an increasingly uncertain future.[144] Data and performance monitoring, therefore, is an integral part of living infrastructure construction, as these new forms work to demonstrate their wide range of value.

Increasingly recognized by the infrastructure powers at be, USACE defines engineering with nature as the "intentional alignment of natural and engineering processes to efficiently and sustainably deliver economic, environmental, and social benefits through collaborative processes."[145] With recent advances in the fields of engineering and ecology, USACE is currently working to opportunize and combine these fields of practice, into a single collaborative and cost-effective approach for infrastructure development and environmental management. How will the thinking of landscape architecture be incorporated, with its aim for ensuring that these infrastructures can generate functional, multi-performative, and livable forms as part of a greater landscape-based system? Landscape architecture is well positioned to re-define land-based infrastructure, presenting an alternative to the reactionary, cultural politics of traditional urban forms, in which "environmental health, social welfare, and cultural aspiration are no longer mutually exclusive."[146]

Capable of translating community needs into physical forms "above ground", landscape infrastructure also focuses on embedding agility, flexibility, and adaptability into infrastructural systems "below ground", so that their lifespans can sustain regeneration much like a living system. Belanger asks us to re-imagine that the environments in which we build have a limited lifespan, and that we no longer train designers to think about ideas, "without the temporalities and materialities of where they come from and where they are going."[147] For USACE, the premise of their current research is that plants can be used as engineering materials, and should be incorporated into engineering projects for optimal performance while maximizing economic and environmental benefits.[148] As a construction material, sediment and the plant communities it can grow in the LDW could not only survive, but also adapt to changing environmental conditions as they go into natural succession. With uncertainty being the new normal, and reliability hinging on positioning infrastructure to operate more adaptively, the adoption of living, landscape infrastructure must become commonplace for today's waterway retrofits. Or, "if the country continues to commit to building last century's infrastructure, we can continue to expect failures of these critical systems and the losses that come along with them."[149]

143. Bélanger, Pierre (2007). Landscapes of disassembly. Topos 60 (October):86.
144. Morris, Rebecca L., et al. "From Grey to Green: Efficacy of Eco Engineering Solutions for Nature Based Coastal Defence." Global Change Biology, John Wiley & Sons, Ltd (10.1111), 16 Feb. 2018, onlinelibrary.wiley.com/doi/abs/10.1111/gcb.14063.
145. Bailey, P. 2014. A Design Manual: Engineering with Nature Using Native Plant Communities.Engineering With Nature. Vicksburg, MS: U.S. Army Engineer Research and Development Center.
146. Landscape Infrastructure Case Studies by SWA: Ying-Yu Hung, Gerdo Aquino, Charles Waldheim, Pierre Bélanger, Julia Czerniak, Adriaan Geuze and Matthew Skjonsberg, Alexander Robinson. Birkhäuser, 2013.
147.Bélanger, Pierre (2007). Landscapes of disassembly. Topos 60 (October):86.
148. Strelzoff, Audrey. "Engineering With Nature." EWN, ewn.el.erdc.dren.mil/.
149. "How Cities Are Upgrading Infrastructure to Prepare for Climate Change." Smithsonian.com, Smithsonian Institution, 22 Oct. 2018, www.smithsonianmag.com/innovation/how-cities-are-upgrading-infrastructure-prepare-climate-change-180970600/.

HYBRIDLY TRANSITIONING FORWARD

Hybridizing living infrastructure with the design of current flood mitigation structures presents a viable path forward, to get from how we build things today to how we can build more intelligently tomorrow. Hybrid design efforts are progressive, mindful about the multi-dimensional craft of "doing things," as well as a reflection on the interconnectedness of all kinds of design within the economic and commercial fabric of society.[150] Thinking hybridly starts with the lofty goal (adaptive, resilient, landscape infrastructure), while using the blueprints, framework, and widely adopted aspects of today's toolkit (rigid, vulnerable, single-purpose structures). Balancing the skills, talents, and strengths of dominant, engineered efforts, hybridizing challenges landscape architecture to create physical and non-physical designs that can be refined, delivered, and relevant within the cultural, environmental, and economic context that,, for better or for worse, currently governs how we build. Hybridly designing more living, landscape-based sea level rise infrastructure in the LDW then, begins by looking at what would probably be built: USACE floodwalls.

USACE FLOOD STRUCTURES: POLICIES AND IMPROVING LIMITATIONS

Defending against rising sea levels and associated flooding along South Park's waterfront requires balancing the needs of an industrial, working waterway with the needs of the people and ecologies living there. Most government flood funding rules prioritize the protection of people and property, with current pressure on funding for flood defense structures to redirect capital focuses towards projects that do not operate at the expense of federally mandated waterway dredging or maintenance activities.[151] Flood

mitigation in the LDW must therefore protect homeowners, while also protecting Port operations.

As this proposal will work to explore, might these flood mitigating structures also hybridly work to restore and protect ecological habitat, while providing open green space for community residents?

Recently, increased environmental concern within construction agencies and greater responsiveness to public opinion have resulted in increasing numbers of flood mitigation projects that are designed, built, and maintained with environmental objectives in mind.[152] Fortunately, USACE planning is beginning to support a more integrated approach to reducing waterway risk and increasing human and ecosystem community resilience, through a combination of natural, nature-based, non-structural, and structural measures.[153]

However, noting that the possibility for long-term saturation of levee and floodwall foundations, together with their specific operation and maintenance requirements, "makes it necessary to exercise caution in the design of landscape planting and vegetation management at these structures," standard USACE floodwall design is cautious about adopting living and plant-based infrastructures.[154] For this to change, USACE is currently calling for future editions of floodwalls to include field studies of vegetation impacts to flood damage reduction structures, and helpful characteristics on the root systems and ecological performances of various species.[155]

WORKING WITH USACE LANDSCAPE PLANTING OBJECTIVES

This includes incorporating landscape planting objectives outlined by USACE, as living systems that should:

1) provide cover to prevent dust and erosion
2) provide ecological benefits, such as improved water quality and wildlife habitat
3) integrate the flood damage reduction system with the surrounding natural and human environment
4) separate activities
5) define zones of use
6) provide privacy
7) screen undesirable features or views
8) accentuate positive features or views
9) create a pleasant environment for human use and recreation.[156]

150. Amit, Gadi, and Gadi Amit. "Beyond Design Thinking: Why Hybrid Design Is the Next New Thing." Fast Company, Fast Company, 30 July 2012, www.fastcompany.com/1656288/beyond-design-thinking-why-hybrid-design-next-new-thing.
151, 152. Nunnally, Nelson R., et al. "Environmental Considerations for Levees and Floodwalls." SpringerLink, Springer-Verlag, link.springer.com/article/10.1007/BF01867197.
153, 154, 155, 156. Army Engineer Research & Development Center. "Developing Best Practices: System-Wide Actions for Coastal Resilience." 2015, doi:10.21236/ad1001635.

PROTOTYPING A LIVING FLOODWALL

Much of the inspiration and precedents for proposing the design of a more livable floodwall borrows from the exemplary efficiency of the natural world. Specifically its pathways that cultivate need for one another through materiality, function, and overlap. Nothing is wasted because everything can be used by something else. Nature makes what it needs where it needs it, and with what it has. While the natural world has had billions of years to weave its materialsheds and responding connective forms, employing this whole systems re-organization into today's urban, infrastructural waterway context - with urgency and synergy - is incredibly difficult. But not impossible. Taking advantage of concurrent waterway project needs, shared material cost, and timely innovation, there are three primary goals for developing a more livable floodwall prototype along South Park's waterfront: 1) assisting current LDW Superfund goals by re-purposing contaminated dredge as cost-effective construction fill, 2) protecting a vulnerable neighborhood from sea level rise, and 3) doing so while challenging contemporary USACE floodwall design, via hybridizing with historic riverway habitat, creating living infrastructure in ways that can be more ecologically and community performative.

As a preliminary model, from which other forms could be refined and developed through actual community led and agency based processes beyond the scope of this project, this prototype offers a conceptual approach for a more preferable future of restoration in the LDW. Strategizing an optimal way forward, it represents an example of how landscape infrastructure can adaptively build more, with less, towards resilience. Connecting the dots

between 100 past years of contaminated sediment and 100 future years of rising sea levels, through a modern day infrastructural retrofit, this prototype speculates a design that is sympathetic to the LDW's context, while capable of enhancing its existing restoration and mitigation efforts. Researched through past and current habitat and restoration projects, biomimetic architecture, and regional waterway success stories, the following sections more closely detail inspirational goals for this design.

STARTING WITH A USACE GRAVITY FLOODWALL

There are four main types of USACE floodwall structures in use today, depending on the characteristics of the structure and surrounding area: gravity, cantilever, buttress, or counterfort.[157] Gravity floodwalls would be used in an area such as the LDW considering its soil profile, retention ability, and structural integrity of its sediment layers.[158] These types of walls have the simplest of structural design elements, relying on sheer mass to weigh down their bottom and better ensure immobility. Taking the form of a right triangle, the bases of these walls are much heavier than their top, partially buried within the ground similar to a large wedge. While the design concept behind gravity floodwalls is simple, they require enormous amounts of material to construct and provide their mass, and the higher the wall the more weight is needed to balance them.[159] Most often, while these walls are considered to be the most stable, they are not employed due to cost of material purchasing for constructing their weighted form.[160] Framed within the materialshed of the LDW however, re-purposed dredge would provide ample, cost-effective material for their construction and use.

Requiring an encompassing concrete mold, USACE currently authorizes the use of aggregate, sediment, and material fill for gravity floodwall mass construction.[161] In addition, as USACE works towards incorporating new landscape planting objectives into their coastal resiliency program, the sheer size of gravity walls provides an adoptable and modular canvas for the introduction, testing, and advancement of more living, planted, landscape infrastructure elements.

PAIRING USACE LANDSCAPE PLANTING OBJECTIVES WITH HABITAT RESTORATION GOALS

FEMA has recently recommended that the National Flood Insurance Program (NFIP) adopt and implement a more modern approach to the analysis of flood risks, that will serve as input to the better assessment of flood insurance, while providing a sound foundation for transitioning towards risk-informed floodplain management that is more environmentally resilient.[162] Pairing USACE landscape planting objectives with lessons learned from habitat restoration projects in the LDW, this conceptual design could simultaneously couple restoration efforts as part of its structural elements.

157, 158, 159, 160, 161, 162. Army Engineer Research & Development Center. "Developing Best Practices: System-Wide Actions for Coastal Resilience." 2015, doi:10.21236/ad1001635.

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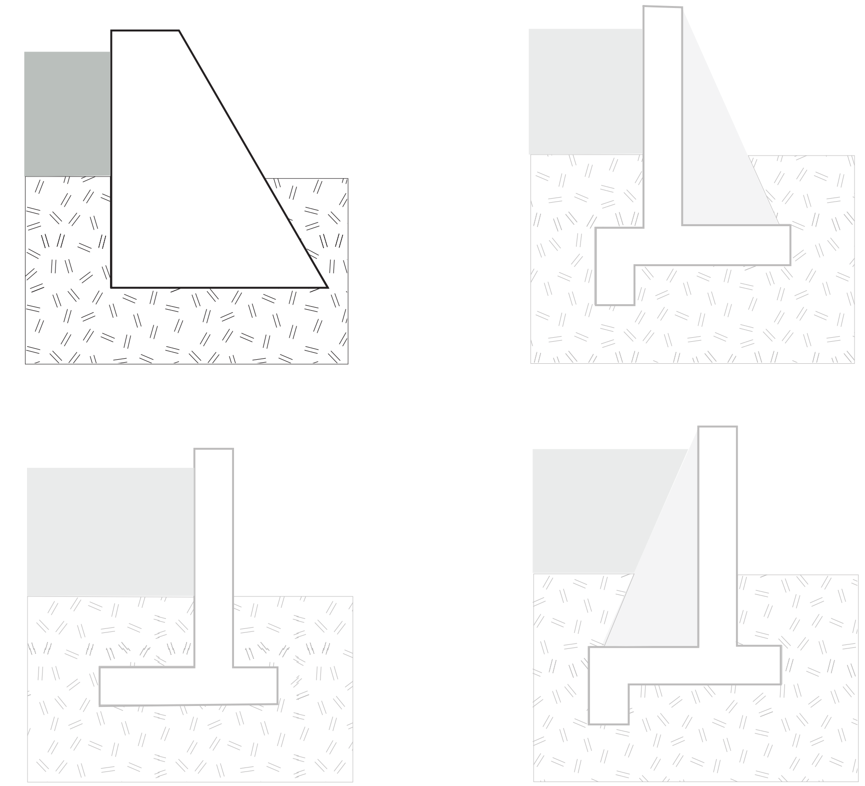
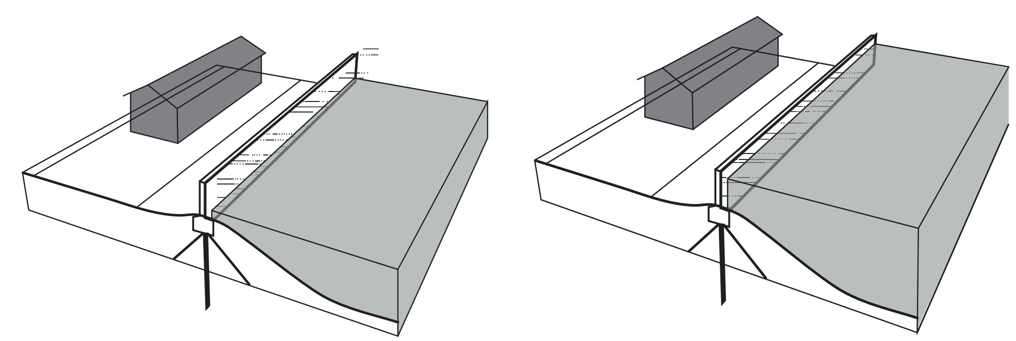
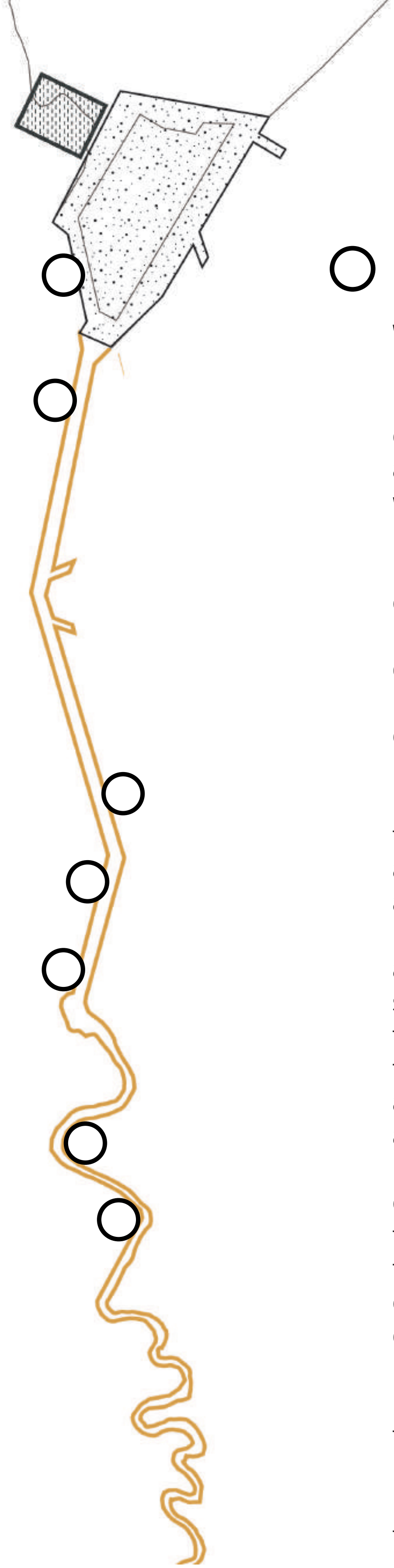
USACE STRUCTURES: IMPROVING FLOOD WALLS

As USACE works to expand their thinking about how floodwalls can provide more ecological and community oriented benefits, living infrastructure and past restoration projects can provide insight into materiality, techniques, and benefits. For an area like the LDW, gravity floodwalls would be used (top left diagram of diagram), requiring cubic yards of material mass for placement and structure. What else can these floodwalls provide?





Sophie Krause



RESTORATION IN AN URBAN WATERWAY: LESSONS LEARNED FROM THE LDW

While many groups have worked to restore health to the Duwamish, it wasn't until recently that the advantages of coordinating efforts to pool resources, leverage funding, and maximize restoration effects started to work side by side. In many ways, large scale municipal projects could learn from these localized efforts. Urban waterways are one of the most challenging places to conduct habitat restoration, as restoration in highly developed and commercially important urban zones is complicated and expensive, often taking longer time to schedule and implement.[163] With all waterway projects requiring specific working periods in order to not obstruct Port operations, industrial activity, and fishing activities, the LDW faces a concurrent scheduling conflict between its Superfund projects, restoration projects, and future buildout projects for mitigating sea level rise. All of which could benefit from overlapping incentives. Restoration in the LDW is essential to recover listed species and critical habitats, support commercial and recreationally important fisheries, and restore injured natural resources and lost ecological services to the people who live there.[164] By working more closely together, these efforts could collectively benefit one another, sharing materials, costs, and construction timelines.

Most parcels along the LDW are used for industrial, commercial, or residential purposes, and there is relatively little land available for restoration. In addition, the presence of infrastructure often limits potential restoration projects to a relatively thin strip along the river, which may result in steep project slope designs that could be subject to failure without significant engineering.[165] While it is theoretically possible to increase the width of a restoration site by placing clean fill on shallow subtidal areas to increase intertidal habitat, thereby creating a shallower slope, this is not always viable in the narrow LDW, as it works to maintain navigation within its middle and federally owned thoroughfare. And if the placement of fill in this manner would reduce the amount of aquatic habitat available for net placement, this type of restoration would actually interfere with tribal fishers utilizing their Treaty Rights.[166]

With such constrictive limitations, what does it mean then, to ecologically restore part of a working waterway within an urban context?

Could the LDW actually allow a dynamic river and estuarine system to carve, flow, scour, flood, and recede as it once did? Probably not. Will projects honor the restorative flooding of a riverway, great for all things biodiversity, while hazardous and costly for adjacent businesses and landowners? Certainly not. Trying to restore full naturalness to the LDW today would upset everything, and everyone, that has since filled in the area. Industries, manufacturers, roads, trains, commercial buildings, Port operations, piers, and concrete. People's homes and livelihoods. How far do you go to recreate a natural environment within a waterway that is simply no longer natural? It's a question many restoration specialists and ecologists are grappling with throughout the U.S., with some proposing that the answer is not in restoration as we know it, but habitat enhancement. A new ecosystem type, straddling the necessity of nature with the realities of what it means to operate within an industrial corridor.

Provided the principal goal of ecological restoration in working waterways is to recover habitat function, not recreate the specific habitat structures that previously existed, where can the LDW go from here?

Designing floodwalls capable of habitat enhancement could mitigate rising sea levels, while also helping to restore part of the waterway ecology. Taking from the following lessons learned from habitat restoration in the LDW so far, hybrid living floodwalls could assist current cleanup and restoration efforts by[167] :

1) Fulfilling mitigation requirements for development projects that impact critical habitats
2) Addressing limiting factors to the recovery of Chinook salmon and/or other species protected under the Endangered Species Act that depend, directly or indirectly, on urban estuaries
3) Conducting compensatory natural resource damage assessment (NRDA) restoration to address injury to natural resources and resource services due to hazardous substance releases
4) Restoring habitats and natural resources important in supporting fishing Treaty Rights
5) Providing shoreline access for recreation

163, 164, 165, 166, 167. NOAA Fisheries, and Laurel Jennings. Habitat Restoration in an Urban Waterway: Lessons Learned from the Lower Duwamish River. NOAA, 2015, pp. 1–37

THE DUWAMISH RIVER REVIVAL PROJECT

Twenty years ago a significant habitat corridor was envisioned along the South Park residential shoreline north of the South Park Bridge. The Duwamish River Revival Project, coordinated by the Environmental Coalition of South Seattle (ECOSS), a South park-based business and community assistance organization, gained support and participation of individual shoreline homeowners whose properties would be included in the project proposal.[168] The primary goal was to develop habitat in a built-up urban environment, as a response to the need for more habitat restoration work to be done in cooperation with waterfront landowners. Although never fully constructed, the goals of this project and recognition of possibilities for an urban, residential site in an industrial waterway, provide key insights for future habitat enhancements.

With fewer opportunities for government to buy land along the Duwamish for restoration, most of the land that is left is being used productively for businesses and residences, and any new habitat projects will have to be developed in and around these current land uses.[169] Selecting a stretch of waterway currently without habitat enhancement along a residential corridor of South Park, just north of the South Park bridge, this project's location analysis and focus on new habitat efforts could become suitable for floodwalls, improving what has already been built in the LDW as a habitat migration corridor. Along South Park's waterfront, juvenile salmon in this portion of the estuarine zone are looking for a place to adjust, shelter in the shallows, and dine on a rich food web.[170] Reshaping the shoreline to create refuge and feeding areas, and planting estuarine vegetation and overhanging vegetation

zones, represent some of the improvements recreated habitat would need to provide these services. Concurrently, people living in the area identified the following common goals for their backyard planning efforts: public access, safety and security, water quality, and salmon habitat enhancement.[171]

With the need to develop a model for habitat projects that do not require major government land acquisitions, but serve as smaller "stepping stones" for out-migrating salmon, this project conceptually works to address this challenge, providing the following habitat structures and functions necessary for enhancing salmon habitat, defined by LDW design guidelines:[172]

1) Riparian Woody Vegetation: source of insects, leaves, and wood to the aquatic habitat, providing food production and a source of LWD for predator refuge
2) Estuarine Marsh: holds and creates nutrients in the form of plant material and softer sediments for invertebrates, providing food production
3) Intermediate slope Rip-Rap/Large Woody Debris: substrate for invertebrates and predator refuge, providing food production, predator refuge, and migration corridor benefits
4) Intermediate slope Sand/Gravel: finer substrate for invertebrate production, gentler slopes for predator refuge, providing food production, refuge, and migration corridor benefits
5) Mudflat: finest substrate for highest invertebrate production, gentlest slopes for predator refuge, providing migration corridor benefits

168, 169, 170, 171, 172 . DUWAMISH RIVERFRONT REVIVAL J O N E S - Jones & Jones. www.jonesandjones.com/Projects/pdfs/duwamish-boards.pdf.

"Given the constraints of maintaining the navigation channel and the neighborhood, the size and scope of the project is somewhat limited. For these reasons, the restoration project will be considered more "enhancement of selected attributes" rather than "restoration to a historic condition." This is an appropriate goal given the high degree of urbanization of the site and the surrounding area. The attributes are focused on habitat functions supporting juvenile salmon. Juvenile salmon are particularly reliant on feeding and resting habitat that provides a safe haven from predators as they become acclimated to salt water on their journey out to Puget Sound."

- Duwamish River Revival Project

BOEING PLANT 2 SEDIMENT REMEDIATION PROJECT

One of the larger and more notable restoration projects within the LDW (that did get built), which represents a cleanup effort by a responsible party with a century long track record of contaminating the waterway in the first place, is the Boeing Plant 2 Sediment Remediation Project. When the LDW became a Superfund site, the EPA highlighted several "hot spot" areas of sediment contamination that warranted cleanup before the larger Superfund cleanup decision could be made.[173] Boeing Plant 2 represents one of these areas, located on the east bank of the waterway and constructed in the late 1930s. During World War II, Plant 2 was a major aircraft manufacturing facility. Housing transformers and related electrical and hydraulic equipment, PCBs used to operate these machines were released directly into the waterway. In addition, a wide range of other hazardous chemicals found their way into the soil, groundwater, and sediment, through years of operating as an industrial center.[174]

Also sanctioned as a Resource Conservation and Recovery Act (RCRA) hazardous waste facility, its partial closure from dangerous waste management units is currently being overseen by the Washington State Department of Ecology, with cleanup efforts being managed by the EPA.[175] Slick with oil as well as a governing document game of finger-pointing, this site is subject to the requirements of the Toxic Substances Control Act. Under Administrative Order, Boeing has worked to remove a mile of PCB-contaminated caulking, soils, and groundwater. Boeing began implementation of this sediment cleanup in 2013, completing remediation work over the next three years. Subsequent

investigations, however, have discovered that some of these treated areas are still showing signs of contamination. Area RA8, a paved industrial area, was remediated as part of a 2012 redevelopment project, during which impacted soil was removed and tunnel excavations were backfilled above the water table with crushed concrete, however, recently sampled backfill was found to still contain residual PCBs and other contaminants.[176]

Despite issues like this, Boeing's Plant 2 Sediment Remediation and Urban Waterway Restoration project received the 2016 WEDA Environmental Excellence Award. While this project does represent a major, multi-faceted environmental restoration of a one-mile portion of the Duwamish, which is incredible - it must be held accountable for being credible. In the words of Boeing, this waterfront site has gone "from a camouflaged bomber plant that helped win World War II to an invaluable natural habitat." And in many ways, it has. Yet there is still room for improvement. Perhaps of greatest long-term importance, the Plant 2 project produced many lessons that can help guide future sediment remediation projects within the Duwamish at large. Many of these Plant 2 lessons provide transferability to future projects, including successful demonstrations of: the efficiency of integrated remediation and restoration, the application of dredging without residuals, and the viable alternative of dredge return-water treatment technology.[177]

173, 174, 175, 176, 177. "Hazardous Waste Cleanup: Boeing Plant 2, Tukwila, Washington." EPA, Environmental Protection Agency, 7 June 2019, www.epa.gov/hwcorrectiveactionsites/hazardous-waste-cleanup-boeing-plant-2-tukwila-washington

"Nearly 100 years since the river was straightened, roughly two percent of the original wildlife habitat remains along the Lower Duwamish Waterway in Seattle, Washington. Boeing's habitat restoration project is helping to turn the tide.The company completed the largest restoration project on the Lower Duwamish Waterway in 2014. This achievement – and the example it sets for future restoration projects – is the reason NOAA, the National Oceanic and Atmospheric Administration, honored Boeing with its Excellence in Restoration award. The award is given annually to recognize leaders in coastal restoration who are not only focused on ecological value, but the importance of effective collaboration with project partners. Overall a successful coordination of waterway cleanup in conjunction with habitat restoration."

- Boeing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HABITAT ENHANCEMENT IN A WORKING WATERWAY

Provided the principal goal of ecological restoration in working waterways is to recover habitat function, not recreate the specific habitat structures that previously existed, habitat enhancement methods have been used throughout the LDW to varying degrees of success. When applied to the design of living floodwalls, these enhancements could help add to existing, reconstructed habitat corridors.


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SEATTLE'S LIVING SEA WALL

Seattle's 2017 living sea wall project demonstrates how habitat enhancement can go hand in hand with the replacement of aging waterway infrastructure. As tourists and residents visit Seattle's downtown waterfront, it may not be apparent that they are walking on arguably the largest, most ambitious urban seawall project in the world, that prioritizes habitat for young fish and the invertebrates they feed on.[178] While still allowing for normal commerce and activity above ground, this new seawall includes structures that provide habitat features for encouraging and protecting young salmon to migrate along its constructed shoreline below ground. University of Washington researchers have published an initial analysis of the effectiveness of the new habitat features as part of an ongoing partnership with the Seattle Department of Transportation, finding that adding shelf-like structures extending from the vertical underwater wall helped recruit a greater diversity of organisms such as algae and small invertebrates, which juvenile salmon feed upon as they migrate along urbanized shorelines through Puget Sound, and out to sea.[179]

Adding to the global conversation of how to both protect and restore shorelines, the Seattle Seawall represents the start of an ongoing experiment between infrastructure and ecology. The union between science and management of nature-based coastal structures are still in their early stages, but already showing promise. The big question with urban shorelines, according to Jason Toft, a research scientist at the University of Washington's Aquatic and Fishery Sciences, "is how to protect infrastructure while maintaining stability with sea-level rise and storms - and still try to restore natural processes."[180]

The Seattle Seawall demonstrates that the compromise between structural integrity and habitat enhancement can be made, in ways which benefit both. While long-term data monitoring of the sea wall is in its early stages, we can already see life growing along the wall in ways it previously didn't. For whatever it's worth, it's a start.

BIOMIMETIC TEXTURES: SOFTENING HARD INFRASTRUCTURE

Biomimetic architecture seeks sustainable solutions not by replicating natural forms, but by understanding the rules governing those forms.[181] Intended functions can then be represented and applied through material science, into more suitable forms and building blocks for today's world, such as a tile. A multi-disciplinary approach, when focused through the lens of sustainable design, biomimetic architecture follows a set of principles, not necessarily a stylistic code. Current construction practices require the things we build today to be highly uniform, replicable, and modular, which prevents many of our structures from imitating natural processes. While coastal and marine infrastructure are typically built with little consideration to the nature of the urban marine habitats they generate, this is changing. Studies demonstrate that environmentally sensitive and productive technologies can be applied for ecologically enhancing waterway infrastructure.[182] Previously hard engineering solutions can be softened, while maintaining their structural integrity. While coastal infrastructure such as seawalls or breakwaters add significant amounts of hard substrate for aquatic organisms, they do not support similar species assemblages to those of natural habitats. Steep slopes, low structural complexity, and highly homogenous forms are rarely found in natural habitats.

Approaches are emerging, however, that work to assimilate ecological capacity into the design and construction of hardened waterfronts. Biomimetic architecture is assisting this effort towards more active coastal infrastructure, reducing a structural element's ecological footprint without compromising its operational performance.[183]

178, 179, 180. "Seattle Seawall's Novel Fish Features Are a Potential Model for the World." UW News, www.washington.edu/news/2017/05/18/seattle-seawalls-novel-fish-features-are-a-potential-model-for-the-world/.
181. Dalos, Hosni. A Proposed Biophilic Inspired Redevelopment of People's Park. pp. 1–13, A Proposed Biophilic Inspired Redevelopment of People's Park.
182, 183. "Seascape Architecture – Incorporating Ecological Considerations in Design of Coastal and Marine Infrastructure." Ecological Engineering, Elsevier, 8 July 2017, www.sciencedirect.com/science/article/abs/pii/S0925857417303798?via=ihub.

"After 3.8 billion years of research and development, failures are fossils, and what surrounds us is the secret to survival. Life solves its problems with well-adapted designs, life-friendly chemistry and smart material and energy use. We're basically this very young species, only 200,000 years old. We're one of the newcomers, and we're going through the same process that other species go through, which is, how do I keep myself alive while taking care of the place that's going to keep my offspring alive? There are literally as many ideas as there are organisms. The truth is, natural organisms have managed to do everything we want to do without guzzling fossil fuels, polluting the planet or mortgaging the future. With biomimicry we're able to apply fresh thinking to traditional manufacturing. I wish we, agents of biomimcry, had been at the design table at the Industrial Revolution."

- Selected Quotes from Janine M. Benyus, Biomimicry: Innovation Inspired by Nature

038

SEATTLE'S LIVING SEA WALL INFRASTRUCTURE

Seattle's 2017 living sea wall project demonstrates how habitat enhancement can go hand in hand with the replacement of aging waterway infrastructure. Adding to the global conversation of how to both protect and restore shorelines, the Seattle Seawall represents the start of an ongoing experiment. The union between science and management of nature-based coastal structures are still in their early stages, but already showing promise.

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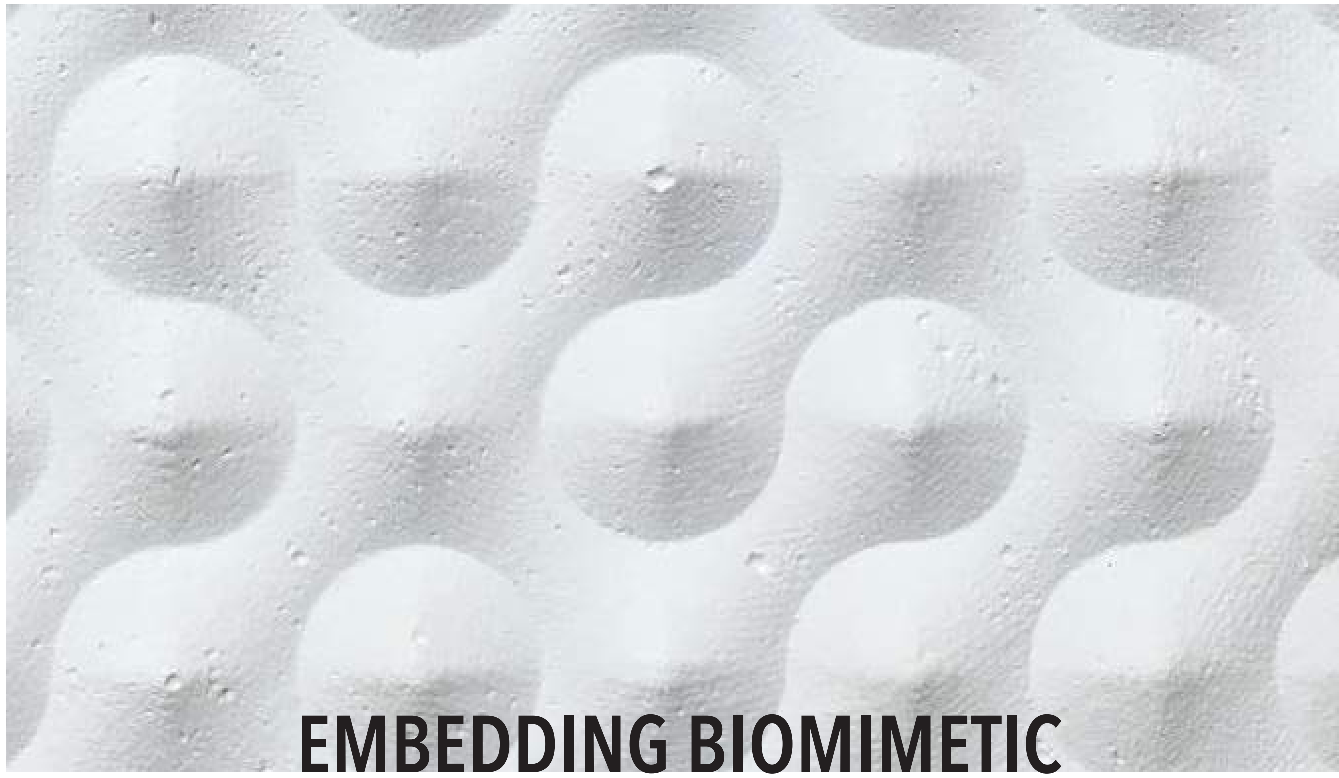
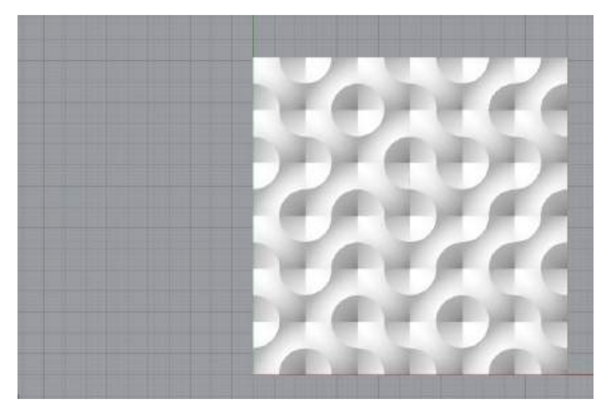
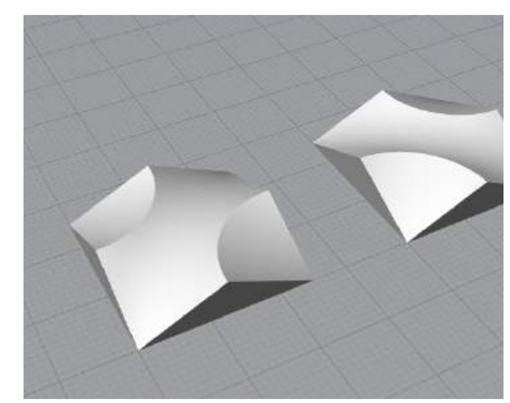


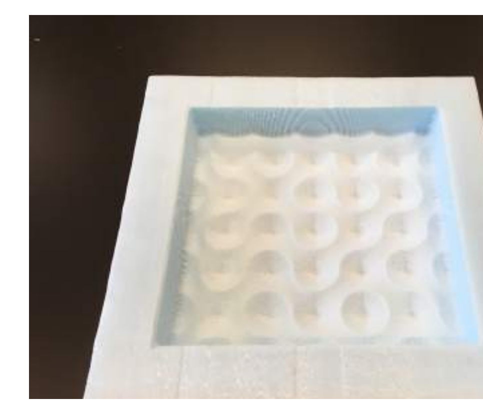
Sophie Krause

EMBEDDING BIOMIMETIC TEXTURES INTO LIVING FLOODWALLS

Biomimetic architecture seeks sustainable solutions not by replicating natural forms, but by understanding the rules governing those forms. Intended functions can then be represented and applied through material science, into more suitable forms and building blocks for today's world, such as a tile. The following represents one such approach for crafting a structural floodwall component, also capable of hosting life.







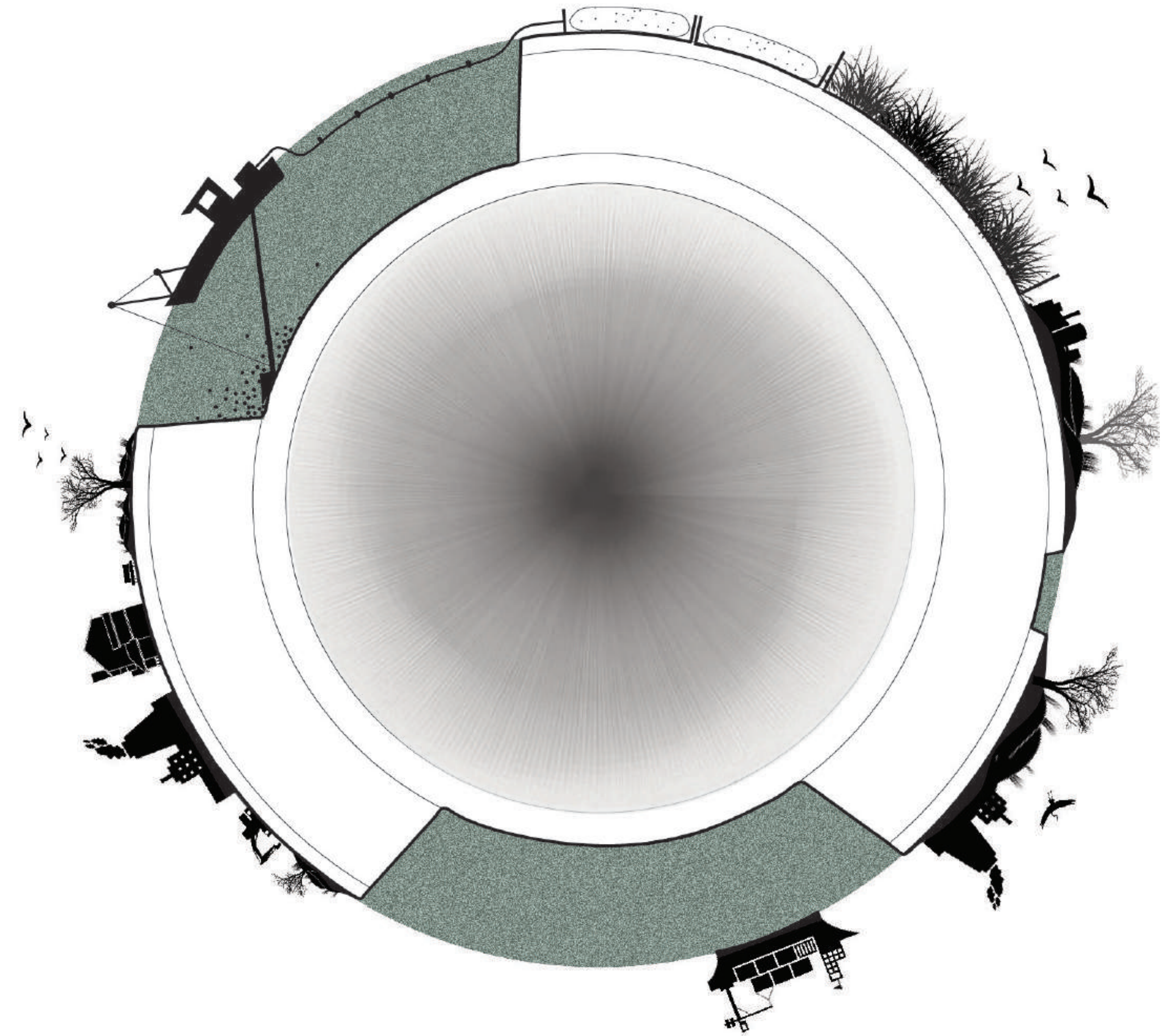
Homogeneously uniform structures are very rarely found in the natural world, yet are commonly constructed within today's urban forms. Concrete, steel, wood, plastic, and many of the other materials often used are essentially formed into relatively smooth and linear, uniform building blocks. Developing a tile formed into a truchet pattern, a mathematical formula developed in the early 1700s by Sebastien Truchet, could create structures that are not rotationally symmetric. This means that they are not uniform after some rotation by a partial turn, and can be used to develop patterns and therefore materials that are similar yet intrinsically random. Imprinting randomness into structural forms can help create micro-habitats for living infrastructure, capable of housing aquatic microorganisms, which can potentially reduce adjacent water temperatures.[184]

As microorganisms intake and excrete during their life cycle, they produce by-products of water and oxygen, which help keep surrounding mediums cool. With water temperature being identified as a possible and probable factor for decline in anadromous and resident salmonid populations in main-stem and tributaries to the Green-Duwamish River, increasing urban waterway temperatures threaten LDW habitat.[185] Fortunately, nature has some ideas for how waterway structures can work to help keep themselves cool.

184, . "Seascape Architecture – Incorporating Ecological Considerations in Design of Coastal and Marine Infrastructure." Ecological Engineering, Elsevier, 8 July 2017, www.sciencedirect.com/science/article/abs/pii/S0925857417303798?via=ihub.

185. Abbe, Tim. Engineered Log Jams: Recent Developments in Their Design and Placement, with Examples from the Pacific Northwest, U.S.A. Natural Systems Design

Weaving it all together:
10 steps for creating a materialshed of re-purposed dredge as fill for living sea level rise infrastructure in the Lower Duwamish Waterway



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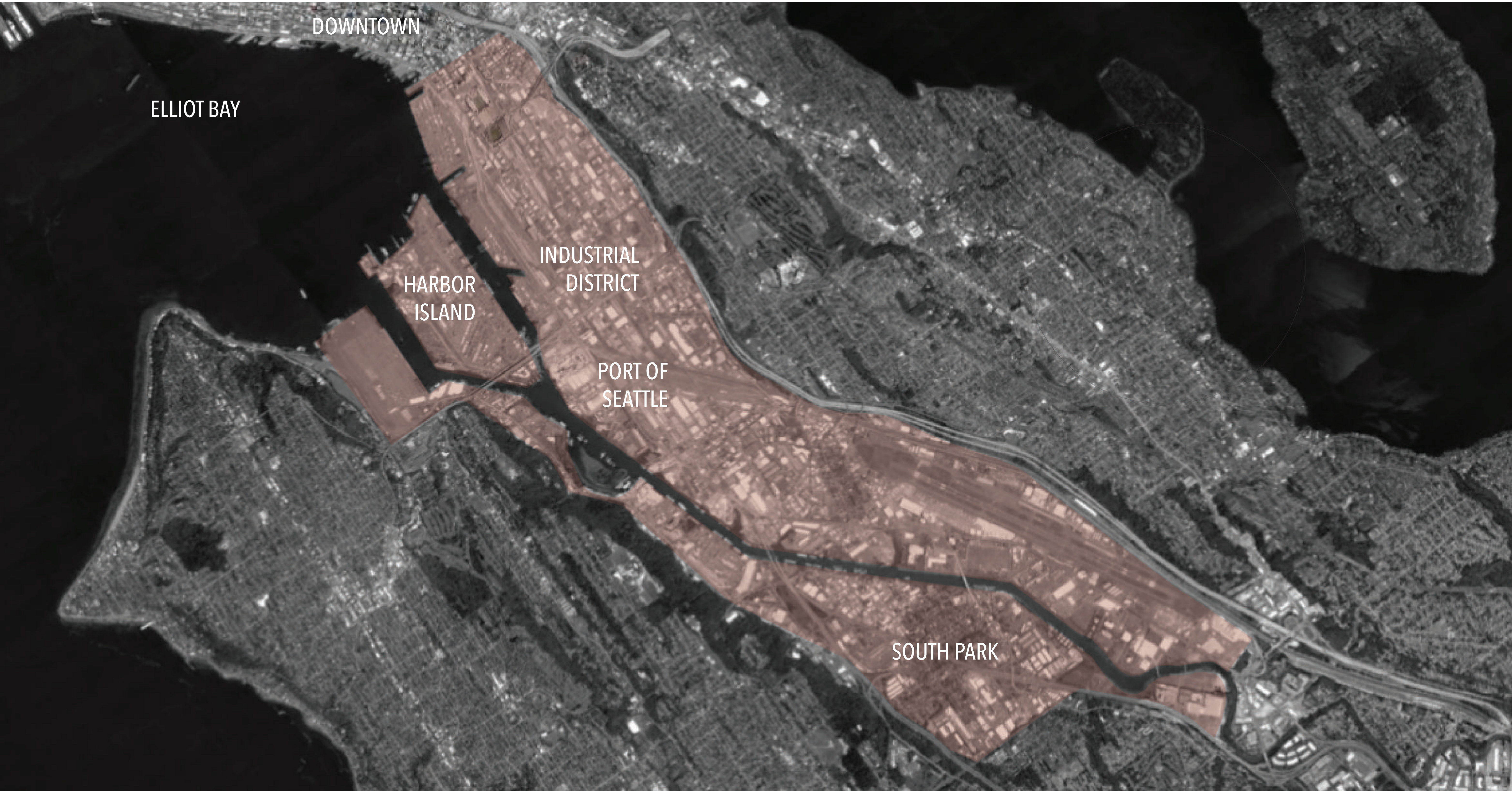
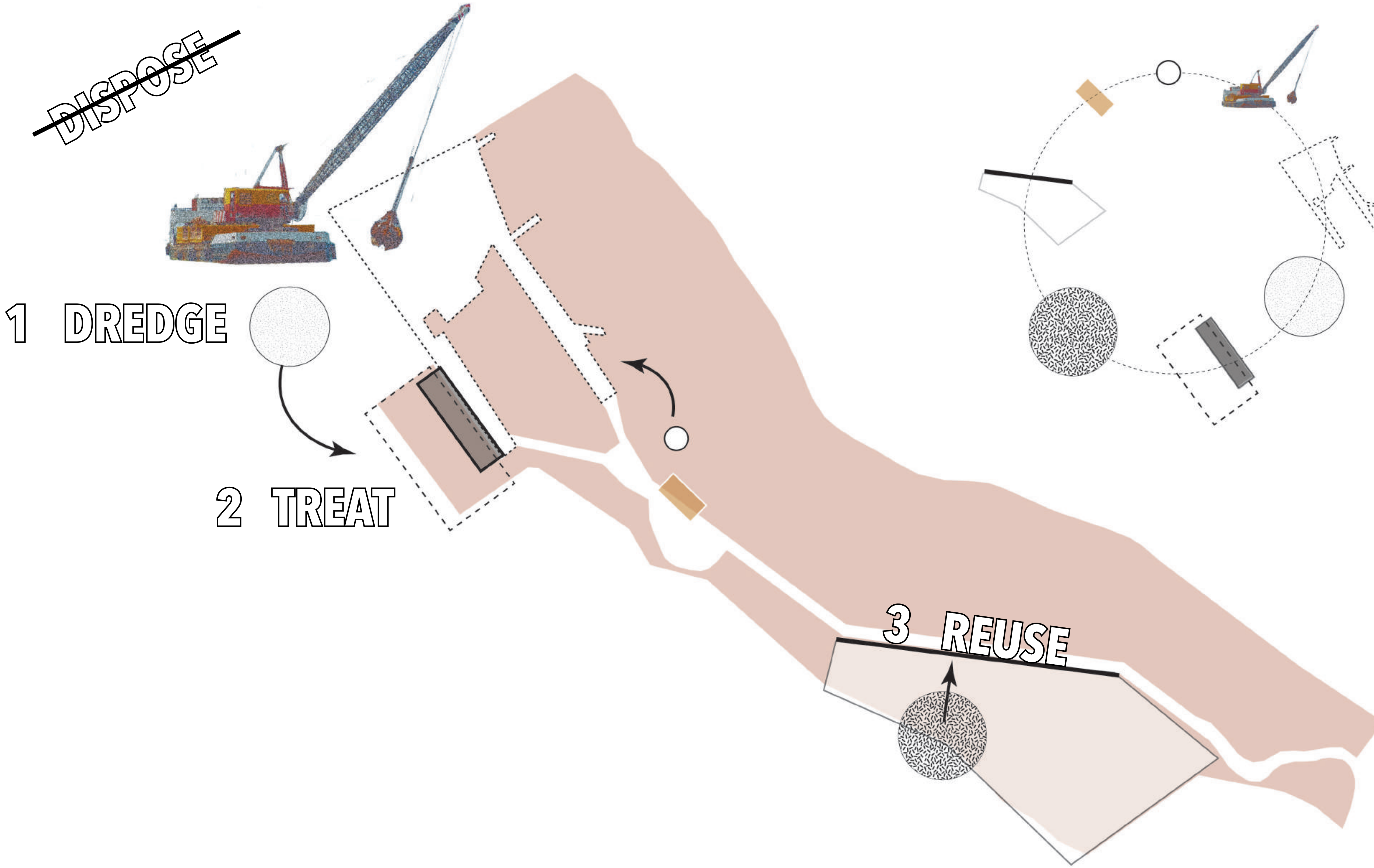


STEP 1:
UNDERSTAND THE URBAN WATERWAY CONTEXT



STEP 2:
ENVISION A MORE OPTIMAL MATERIALSHED

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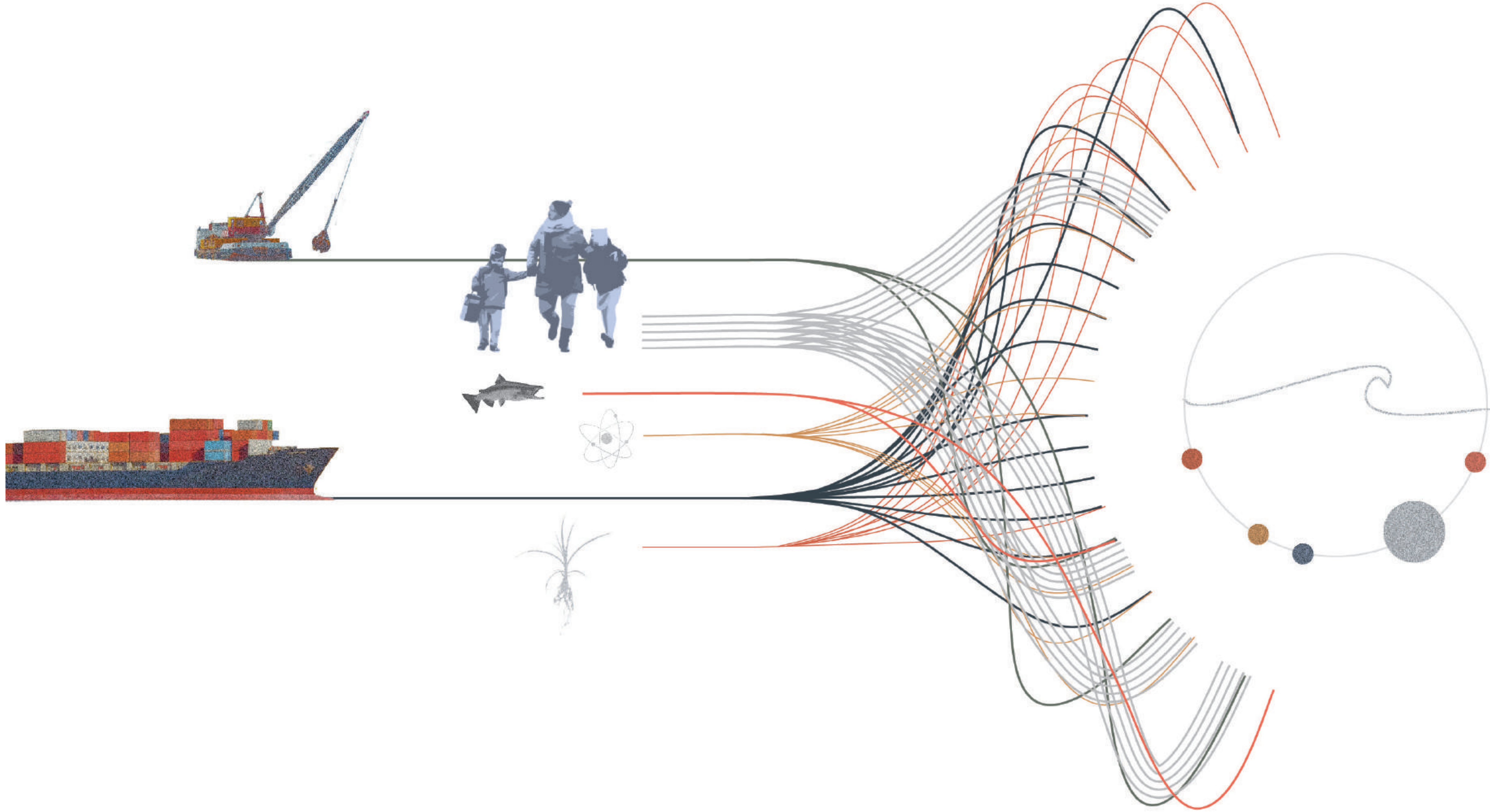
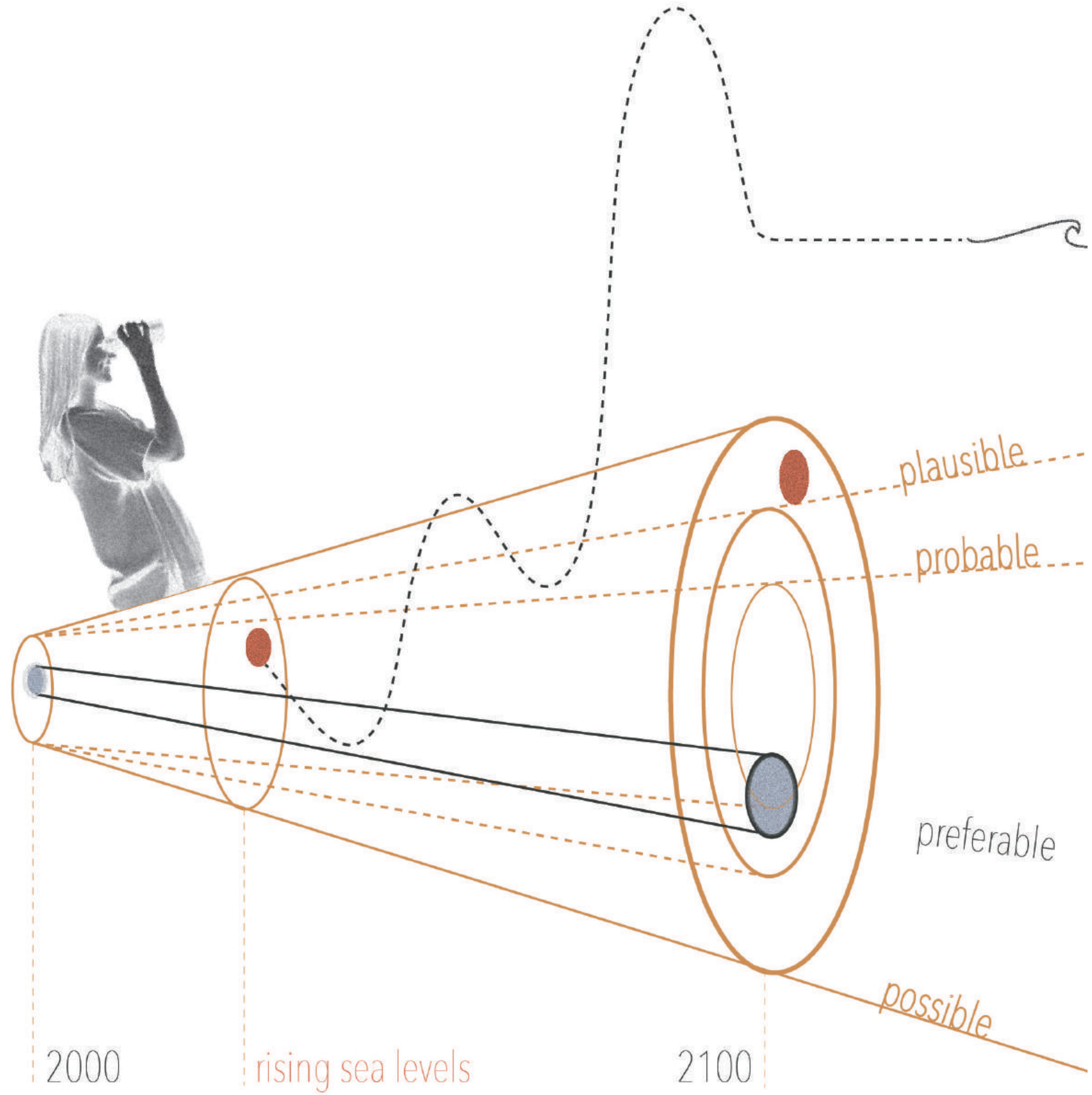


STEP 3:
IDENTIFY HOW TO STAY WITH THE TROUBLE



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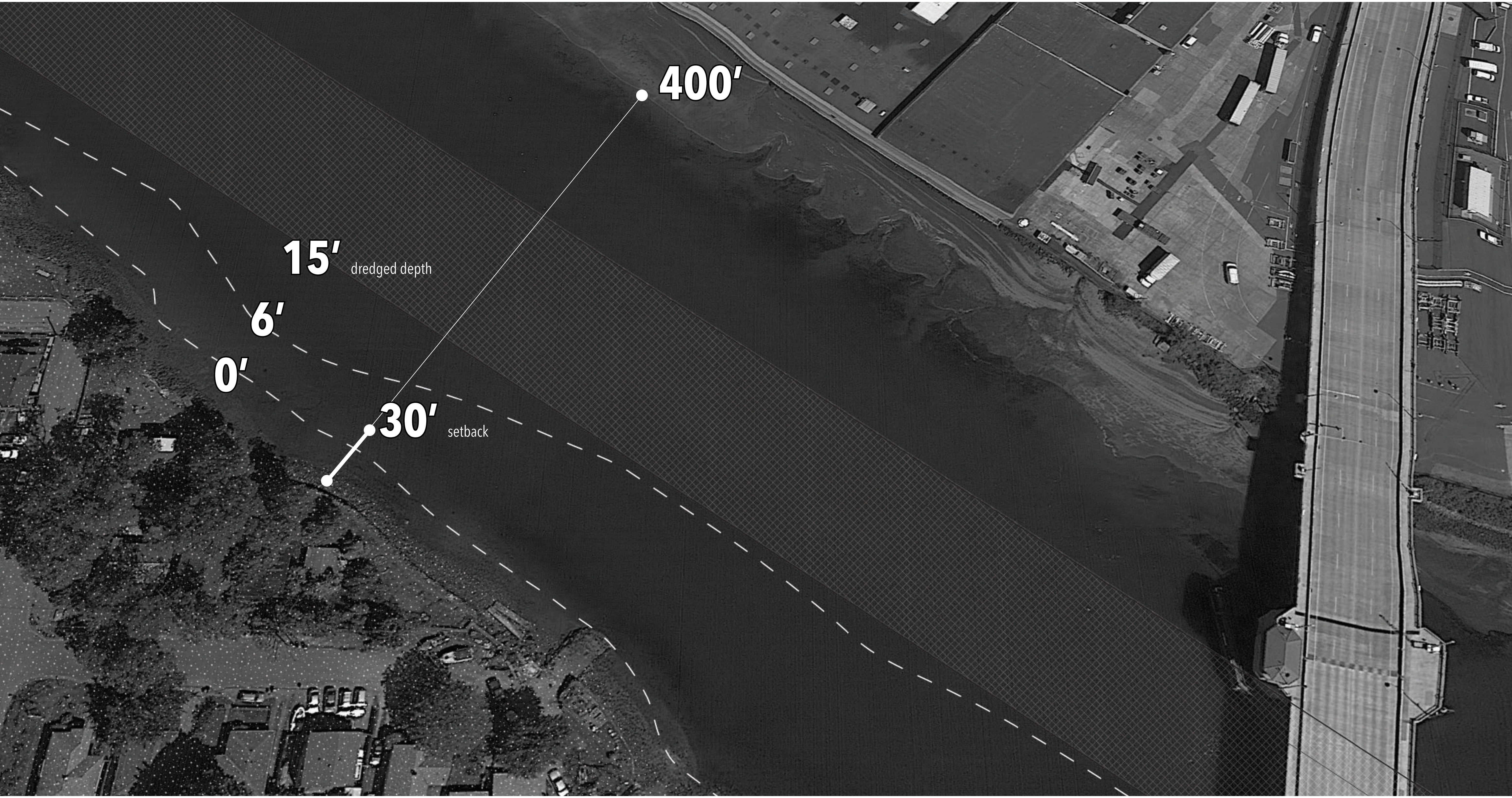
STEP 4:
STRATEGIZE HOW PROJECTS CAN GO FORWARD PREFERABLY



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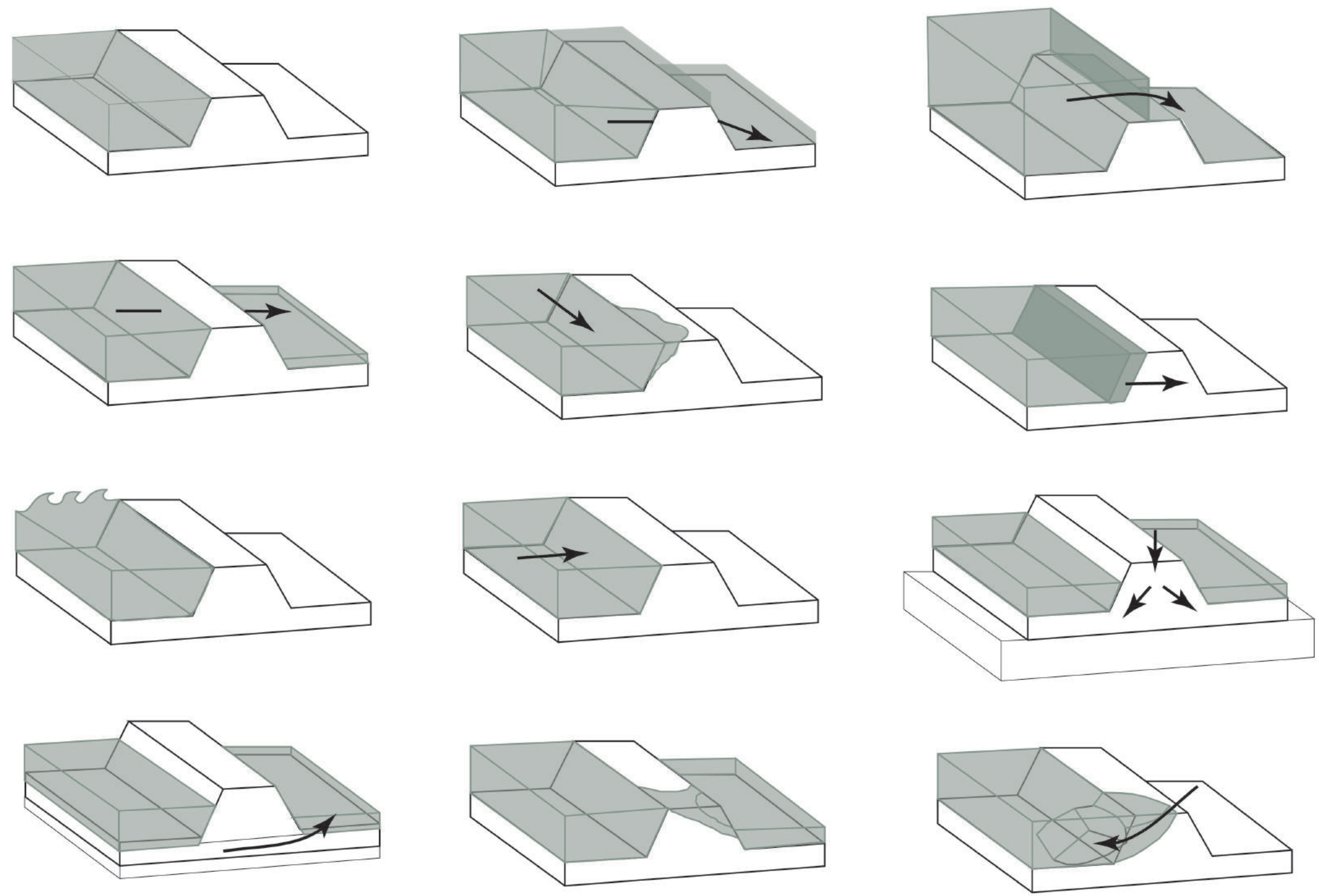
STEP 5:
DREAM BIG, THINK SITE SPECIFICALLY



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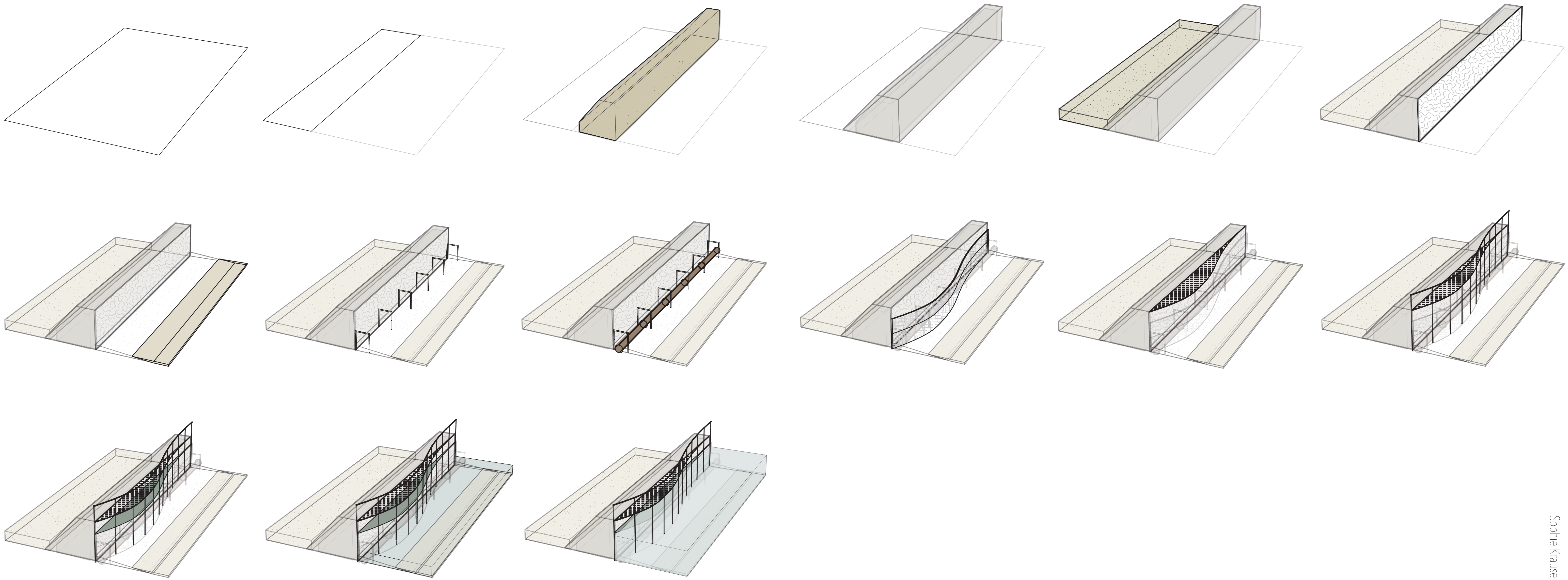
STEP 6:
RESPOND TO CURRENT DESIGN LIMITATIONS



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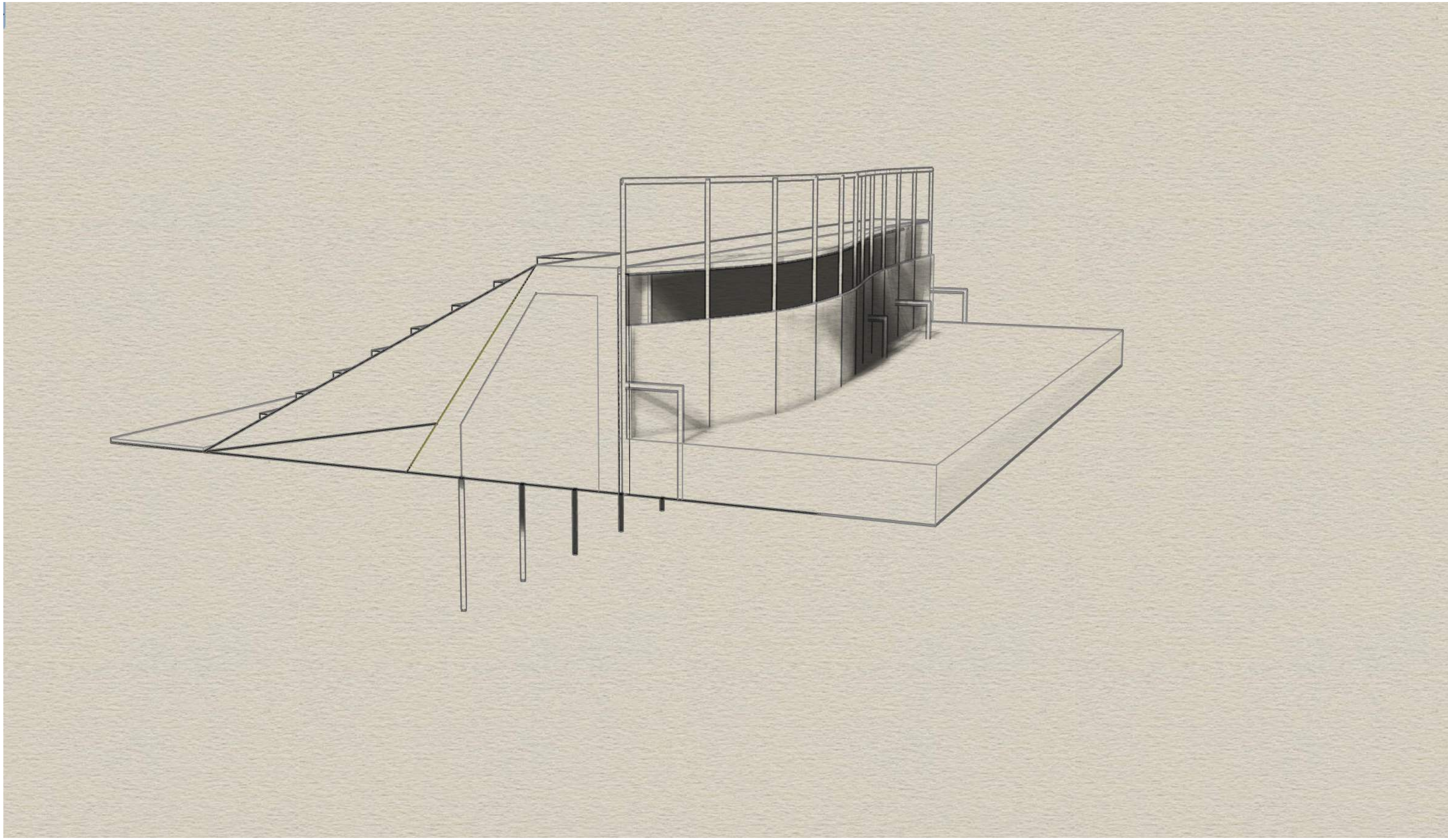
STEP 7:
VALUE ENGINEER A WIN-WIN HYBRID FORM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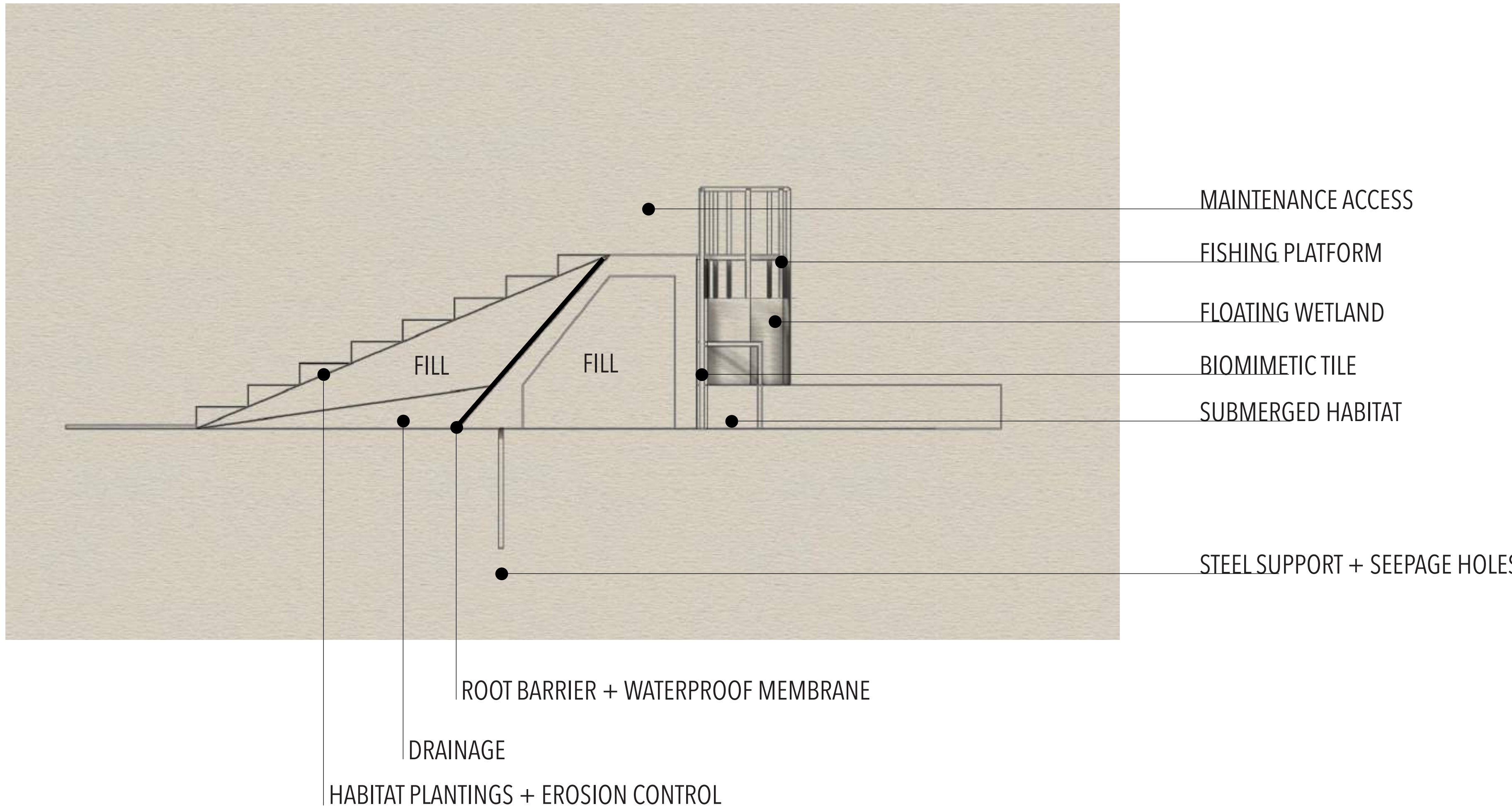
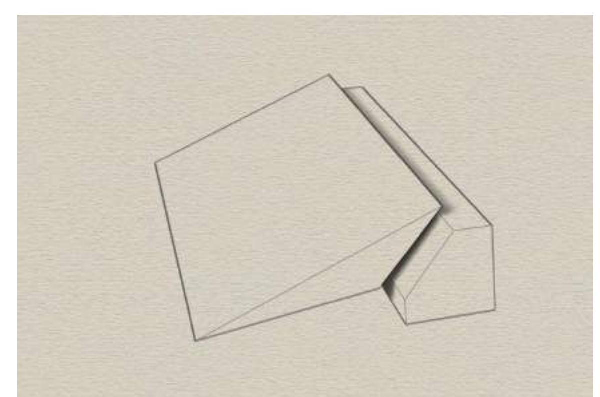
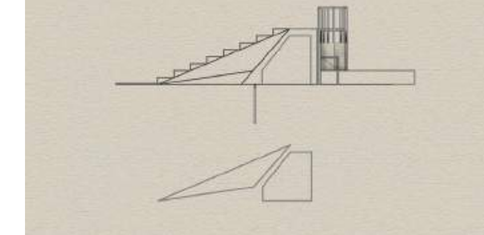
PROTOTYPE: A HABITAT ENHANCING FLOODWALL



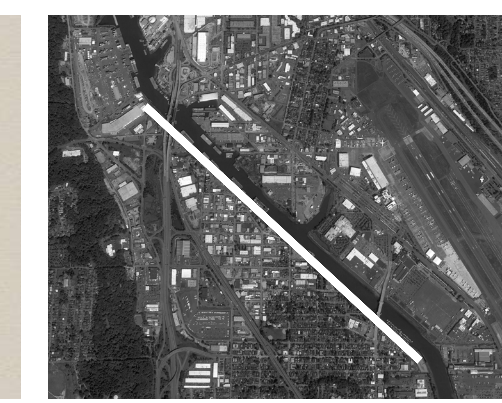
A living floodwall 30 x 50 ft. in dimension can reuse 4,000 cubic ft. of treated fill, while creating 2,000 sq. ft. of waterway habitat. Spread across the entire 9,000 ft. waterfront of South Park, a series of these floodwalls could reuse 720,000 cubic ft. of treated fill, while creating 360,000 sq. ft. of waterway habitat.



CREATING WATERWAY HABITAT



REUSING TREATED DREDGE AS FILL



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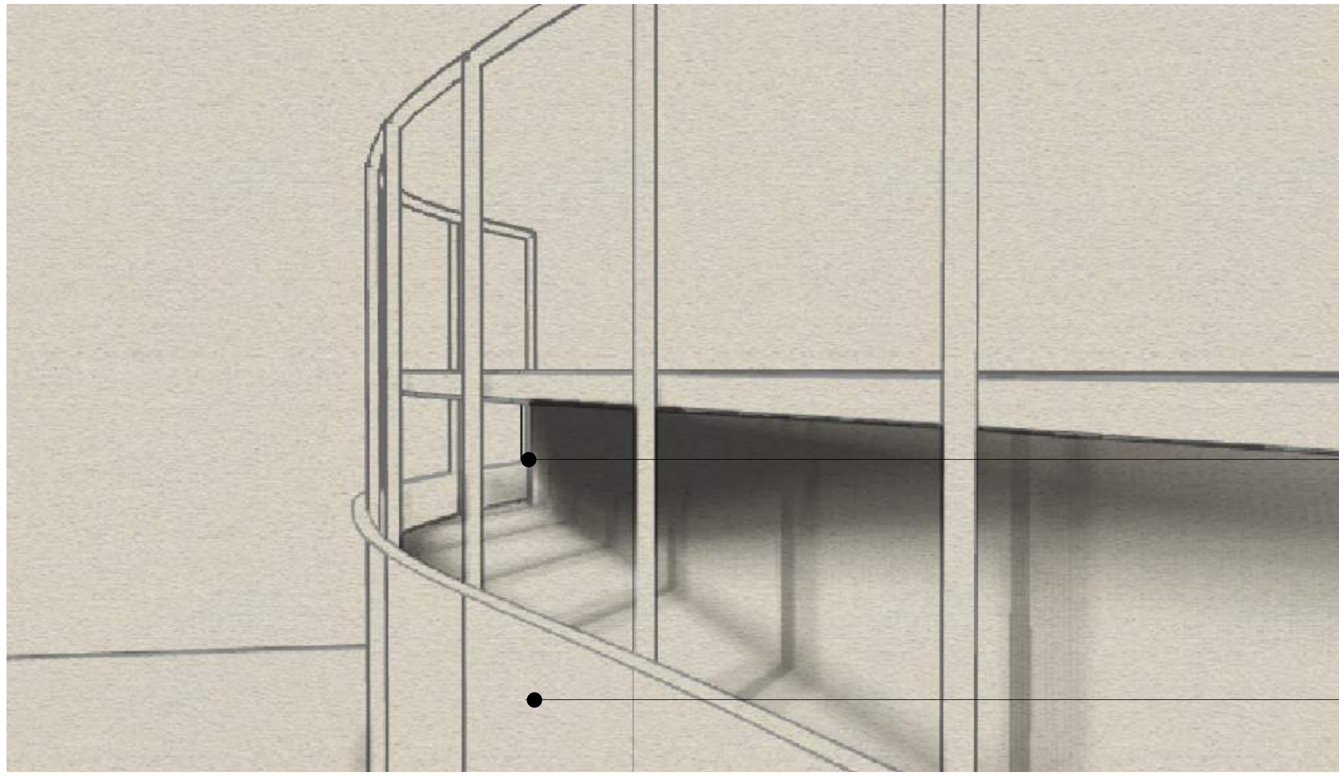
STEP 8:
CREATE A REPRODUCE-ABLE MODULE



Air, water, and habitat quality monitors installed on a sliding track in each floodwall allow restoration ecologists to harvest data in real time, while measuring the performance of living infrastructure. Monitoring can help demonstrate the efficiency of living infrastructure and drive the adoption of more ecological waterway structures.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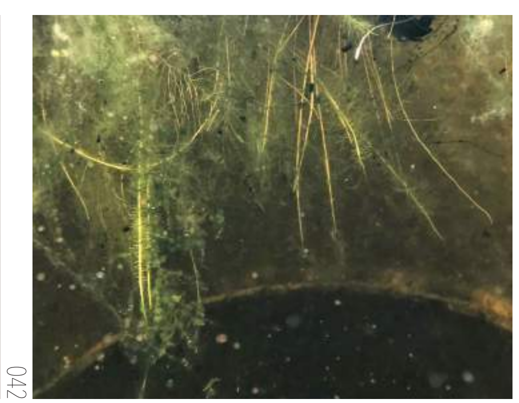
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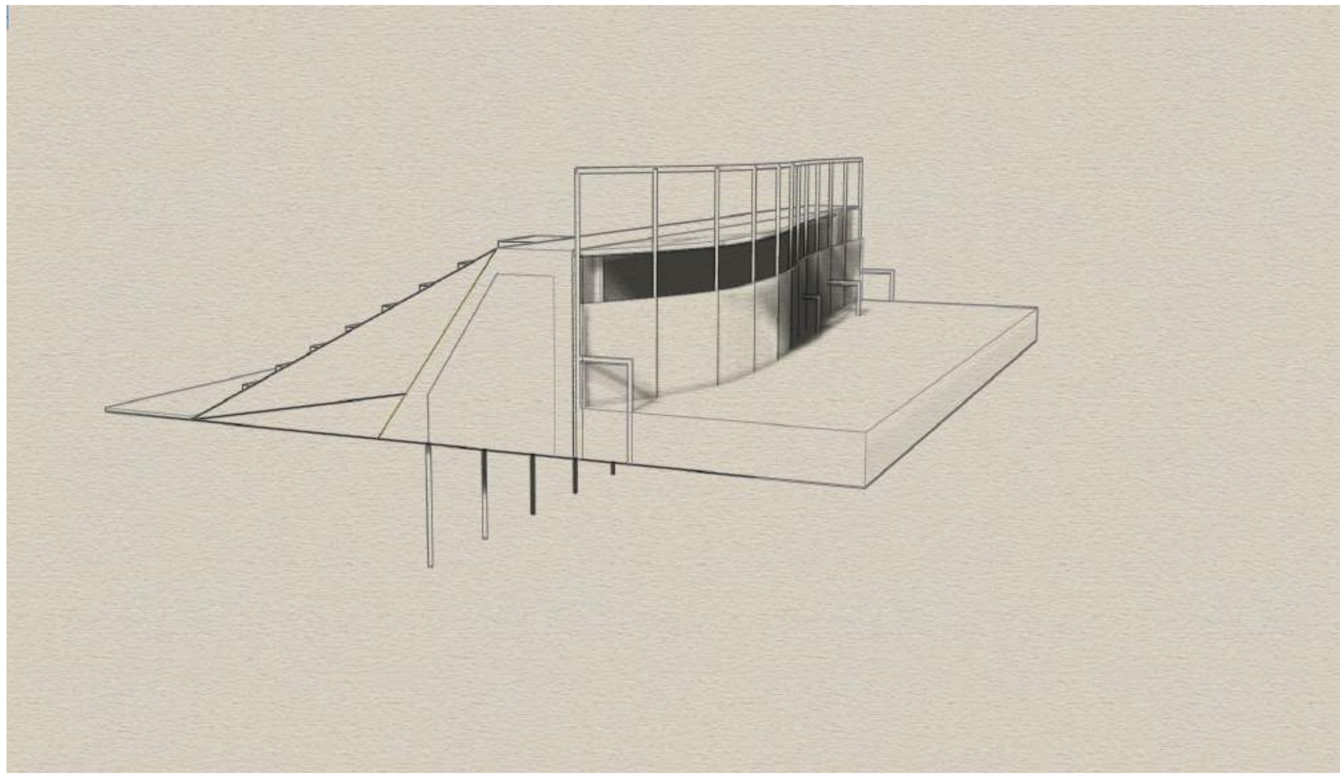
STEP 9:
BUILT-IN TO MONITOR IMPACTS OF HIGH-PERFORMANCE

STEP 10:
ENVISION PROTOTYPE THROUGH COMMUNITY-LED DEVELOPMENT

Sophie Krause



Sophie Krause

CRITIQUE | REFLECTION

"Is our discipline [of landscape architecture] a necessity? Are we closing the gap between ideals and practice? We are not, I promise, saving the world. We don't need playful design proposals; we need high-impact built projects - prototypes for the resilient futures we've been promised."

- Billy Fleming, Design and the New Green Deal

Ecological wellbeing is a progress report. One that graphs our need to change how we plan, design, build, and maintain our relationship with growth, our carrying capacity, and the biosphere. This requires strategizing more optimal pathways for connecting people to place, to each other, and to the natural systems that bring us life. In Seattle's Lower Duwamish Waterway, this requires developing a design scenario capable of facilitating cleanup and restoration projects within an increasingly urban and infrastructural context. In many ways, this scenario attempts to do too much. Re-conceptualizing a toxic waste site as a productive materialshed, re-connecting fiscal and material pathways between a red taped Superfund project and an unseen buildout for rising sea levels, re-imagining USACE floodwall structures with hybrid, living, biomimetic habitat enhancements, while re-organizing an active industrial waterway with a history of environmental injustice to perform as a more ecologically and culturally productive corridor - some might say it is too much. While perhaps the people and other living organisms who call the LDW home might say, it is not enough.

I will say that it is a start. A holistic ~~solution~~ response to a design ~~problem~~ opportunity, within one single industrial waterway in one city, in an environmental and cultural era that is now calling for the radical transformation of how we live atop our entire planet. With the United Nations Intergovernmental Panel on Climate Change warning us that in order to avoid a future of catastrophe, human societies have twelve years to wholly transform the way we use energy and land, making changes on a scale for which "there is no documented historic precedent," trying to "do too much" today might actually be on the verge of doing too little, too late.[187]

Envisioning these changes towards an unforeseen future requires re-thinking projects already in motion, so that they can converge in more generative, multi-functional, and cyclic ways. Scenarios that are increasingly win-win (and less win-lose, or even worse, lose-lose) require re-making lines of inventive connection, or in the words of Anne Harraway, staying with the trouble:

"We - all of us on Terra - live in disturbing times, mixed-up times, troubling and turbid times. The task is to become capable, with each other in all of our bumptious kinds, of response. Mixed-up times are overflowing with both pain and joy - with vastly unjust patterns of pain and joy, with unnecessary killing of ongoingness but also with necessary resurgence. The task is to make kin in lines of inventive connection as a practice of learning to live and die well with each other in a thick present. Staying with the trouble requires learning to be truly present, not as a vanishing pivot between awful or edenic pasts and apocalyptic or salvific futures, but as mortal critters entwined in myriad unfinished configurations of places, times, matters, meanings."[188]

Landscape configurations will hold space for these bold, systemic responses, just as they always have as we work to lay out new definitions, patterns, and processes of urban growth. In addition to new working partnerships between the people and professions tasked with designing the built environment.

187 Billy Fleming, "Design and the Green New Deal," Places Journal, April 2019. Accessed 05 Jun 2019. <https://placesjournal.org/article/design-and-the-green-new-deal/>.
188. Haraway, Donna Jeanne. Staying with the Trouble: Making Kin in the Chthulucene. Duke University Press, 2016.

Fleming asks in his most recent take on Design and the Green New Deal, in which he begins by claiming that if landscape architects want to re-make the world we must start by re-making our discipline, "can landscape architecture be both an instrument of neoliberalism and an activist force in the fights against climate change and for social justice?"[189] Landscape architecture as a single discipline, still working to clarify its capacity for re-making the built environment and not just backyards, surely it cannot. But as a discipline capable of aligning, consulting, challenging, and becoming capable with the national-scale missions of strong-holds such as the Bureau of Land Management, the Federal Energy Regulatory Commission, and the U.S. Army Corps of Engineers - the agencies who collectively control the landscapes we wish to transform - surely it can.

Working towards systemic landscape change by operating through the very pathways that mechanistically contribute to what we're trying to resolve in the first place might not appear radical. Again I will say, it is a start. Fleming goes further, saying that "before we ask the world to view [landscape] as an urgent necessity, we must look at those sites, tools, and structures and re-make our discipline to be more useful, in the moment, for the movements and ideals we aspire to serve."[190] This requires being timely, opportunistic, and at times, compromised. The disciplines working to build (and re-build) infrastructure are in a constant state of responsive evolution, compromising funding, form, and function. This evolution, however, is not blind. Responsive to power, profit, people, and the planet - and largely in that order - those in charge of the built environment will continue to make (and re-make) new infrastructural grounds, organizing how we live from trace paper to something you can walk on.

Natural systems, the ultimate top-down decision maker, will continue to determine where and how this tracing can occur. Zooming out far enough, proposing a design intervention that works to mitigate sea level rise in the LDW by building defensible floodwall structures, albeit habitat enhancing, does not make much sense amidst an uncertain and changing climate. The material, economic, and human capital required to work against a continuously rising sea level - of which conservative estimates are still high - would be better spent retreating from all potential shorelines to begin with. Retreating from the natural forces larger than ourselves, that despite our attempts, we cannot control.

Ideally, design would work with this future of encroaching water. Staying with the trouble by letting it in, making use of its advancement, perhaps even re-situating restoration and agricultural efforts along its floodplains, as we once did, when we had to. Because no matter what we throw at the issue of rising sea levels, as long as we continue to develop in flood-prone areas, they will simply remain floodable. Today, however, disaster recovery efforts seek to re-build shorelines following a single, unified plan, which aims to restore the status quo even if that means putting people, buildings, and infrastructure back into high-risk zones.[191] And it is within these increasingly risk prone zones, where I believe transitional change towards increasingly resilient responses will begin to unfold. Not effortlessly or without calamity, of course, but by necessity. As a catalyst, and transitional retrofitting.

Because if industrial lifelines continue to support our everyday existence, making landscape pathways so scalar that we are now scraping the bottoms of oceans and mining metals from outer space trash, industrial contamination and waste streams as a concept will have to change. And in many ways, it already has. Industrial wastes are being efficiently re-framed as resources around the world, and it's working. Not only functioning in multi-performative ways, but in ways which will help pull this century to the next, spurring new businesses as they work to re-envision new markets.

This speculation of how we will cultivate and capitalize on what we've been framing as industrial contamination will become increasingly big business throughout this century, and especially the next hundred years. Business that will operate through re-defined landscape pathways, just as this model of cultivation has served us since we first began saving seeds and monetizing harvests. How will we capture this value going forward, and for whom? What would a Superfund startup look like? In a world of infrastructural decay, alongside seemingly endless technologic growth, the role of living infrastructure as an urban retrofit will help root us into an increasingly productive next century.

189, 190. Billy Fleming, "Design and the Green New Deal," Places Journal, April 2019. Accessed 05 Jun 2019. <https://placesjournal.org/article/design-and-the-green-new-deal/>
191. Landscape Infrastructure Case Studies by SWA: Ying-Yu Hung, Gerdo Aquino, Charles Waldheim, Pierre Bélanger, Julia Czerniak, Adriaan Geuze and Matthew Skjonsberg, Alexander Robinson. Birkhäuser, 2013.

Designing more livable infrastructure, nesting the micro scale of bioremediation (think microbes), within the larger urban scale (think waterfront), and even larger regional scale (think sedimentshed), becomes a powerful narrative as landscape architecture helps work to upgrade our aging infrastructure, and forgotten Superfunds. With roughly 1,330 Superfund sites across the country, there are many that have been on the National Priority List for decades, their cleanup efforts slowed and limited by expired funding, technical issues, foot-dragging by potentially responsible parties, insufficient community involvement, and a basic lack of current sampling data and the health hazards they pose.[192] Re-envisioning these areas, amidst a future of resource scarcity and climate adaptations, presents a growing opportunity for testing, monitoring, and implementing advances in phytotechnologies and bioremediation, from laboratory to landscape.

Today's relationship between peak, precarity, and place asks designers to build more, with less, and at the same time, better. This push for re-designing landscape systems to be more ecologically productive, sustainable, and resilient is especially true for the single-purpose infrastructural corridors that predominantly organize our cities. Constructed last century and largely forgotten, replacing these aging infrastructures poses an unprecedented challenge - and opportunity - to the engineers, designers, and public work agencies that have previously assumed this responsibility and role of de facto land use managers. As design works to adapt these linear, one track minded thoroughfares towards something more multi-performative and lively, what has always been interrelated - material, cost, and climate - will become even more so.

And the relationship between decline and growth will continue to contribute to our envisioning of new, resilient relationships between infrastructure, ecology, and society, specifically as expressed through material flows and forms.[193]

With millions of cubic meters of material being dredged annually from ports, harbors, and waterways in order to optimize navigation, remediation, and flood management, with disposal and placement of dredged material growing as one of the greatest challenges facing a dredging project, contaminated urban waterways represent a new sort of resource.[194] As this issue worsens it will continue to supply the demand for thinking about these systems holistically. Just as the concept of watershed elevated our approach towards water stewardship and cyclic re-use, spurring our adoption of large-scale wastewater treatment efforts, so too will the concept of the waterway sedimentshed.

Conceptualizing human-made ecosystems that operate in similar ways to natural ecosystems, industrial ecology has some ideas for how to move from a linear to a more cyclical framework. Like natural ecosystems, industrial ecology is in a constant state of flux, where the waste or byproduct of one process is used as an input for another process. When we design for this mutual relationship, benefits include: savings from materials purchasing and waste disposal fees, increased environmental protection, and all kinds of generation, from ecological outputs to income. Current limitations to industrial ecology include: no viable market for materials, lack of support from government and industry, reluctance of industry to invest in appropriate technology, legal implications, and in general, our reluctance to change.[195]

As landscape architecture and land-based systems continue to challenge this thinking, however, and work to demonstrate their value, this will change.

And while updating single-purpose infrastructural corridors to become more ecologically and socially productive is no small feat, neither was moving literal mountains of earth one hundred years ago. As modern society faces high costs (and risks) associated with maintaining waterway infrastructures that have reached their lifespan, their re-configuration must not only be cost-effective, but muti-performative. Their concurrent projects overlapped, maximized, and ensured with the same certainty that future generations will face, being handed landscapes that are essentially a shared biological and cultural inheritance. This presents great challenges alongside opportunities for how design can work to retrofit not only waterway structures, but the thinking that goes into them. And while this project, built on compromise and dirt, might simply strategize a foreseeable way forward for the Lower Duwamish Waterway, floating in-situ between two legacies of risk, again I will say, it is a start.

192. "Superfund: National Priorities List (NPL)." EPA, Environmental Protection Agency, 4 June 2018, www.epa.gov/Superfund/superfund-national-priorities-list-npl.
193. Kees Lokman (2017) Cyborg landscapes: Choreographing resilient interactions between infrastructure, ecology, and society, Journal of Landscape Architecture, 12:1, 60-73, DOI: 10.1080/18626033.2017.1301289
194. International Association of Dredging Companies. Facts About Dredged Material as a Resource. Facts About Dredged Material as a Resource, IADC, 2009.
195. Sustainability Concepts: Industrial Ecology, www.gdrc.org/sustdev/concepts/16-l-eco.html.

SOURCES

"14 Reasons to Invest in Living Green Infrastructure." Latest News, www.smartcitiesdive.com/ex/sustainablecitiescollective/14-reasons-invest-living-green-infrastructure/1159887/.

Amit, Gadi, and Gadi Amit. "Beyond Design Thinking: Why Hybrid Design Is the Next New Thing." Fast Company, Fast Company, 30 July 2012, www.fastcompany.com/1656288/beyond-design-thinking-why-hybrid-design-next-new-thing.

Army Engineer Research & Development Center. "Developing Best Practices: System-Wide Actions for Coastal Resilience." 2015, doi:10.21236/ad1001635.

"Breaking: EPA Issues Its Record of Decision for the Duwamish River Superfund Site | Science, Law & the Environment | Miller Nash Graham & Dunn LLP." Science, Law & the Environment, 4 Dec. 2014, www.sciencelawenvironment.com/2014/12/breaking-epa-issues-its-record-of-decision-for-the-duwamish-river-superfund-site/.

GGLO Design. "Climate Preparedness: A Mapping Inventory of Changing Coastal Flood Risk." Seattle Office of Sustainability and Environment, 24 Aug. 2015, pp. 1–42., www.seattle.gov/Documents/Departments/Environment/ClimateChange/2015.08.25_ClimatePreparednessInventory_Sec1.pdf.

Cummings, BJ. "Duwamish Valley Vision Map and Report." Duwamish River Cleanup Coalition, 2009, pp. 1–143.

"Deft Architects." Deft Architects, deftarchitects.com/.

"Dredging Up The...FUTURE." Library.Automationdirect.com, 22 Feb. 2019, library.automationdirect.com/dredging-up-the-future-issue-6-2006/.

DUWAMISH RIVERFRONT REVIVAL J O N E S - Jones & Jones. www.jonesandjones.com/Projects/pdfs/duwamish-boards.pdf.

Environmental, WindWard. Lower Duwamish Waterway Group Phase 1 Remedial Investigation Final Report. 2003, pp. 1–273, Lower Duwamish Waterway Group Phase 1 Remedial Investigation Final Report.

Hamilton, Trina. "Can We Green Cities without Causing Gentrification?" GreenBiz, GreenBiz Group Inc., 26 Mar. 2018, www.greenbiz.com/article/can-we-green-cities-without-causing-gentrification.

Hancock, Trevor, and Clement Bezold. "Possible Futures, Preferable Futures." The Healthcare Forum Journal, Mar. 1994, pp. 1–8. PubMed, www.researchgate.net/publication/13166132_Possible_futures_preferable_futures/download.

Haraway, Donna Jeanne. Staying with the Trouble: Making Kin in the Chthulucene. Duke University Press, 2016.

"Hazardous Waste Cleanup: Boeing Plant 2, Tukwila, Washington." EPA, Environmental Protection Agency, 7 June 2019, www.epa.gov/hwcorrectiveactionsites/hazardous-waste-cleanup-boeing-plant-2-tukwila-washington.

"Health Impact Assessment (HIA)." Health Impact Assessment (HIA) - King County, www.kingcounty.gov/depts/health/environmental-health/healthy-communities/health-impact-assessment.aspx.

"How Cities Are Upgrading Infrastructure to Prepare for Climate Change." Smithsonian.com, Smithsonian Institution, 22 Oct. 2018, www.smithsonianmag.com/innovation/how-cities-are-upgrading-infrastructure-prepare-climate-change-180970600/.

Landscape Infrastructure Case Studies by SWA: Ying-Yu Hung, Gerdo Aquino, Charles Waldheim, Pierre Bélanger, Julia Czerniak, Adriaan Geuze and Matthew Skjonsberg, Alexander Robinson. Birkhäuser, 2013.

Magar, Victor S, and Richard J Wenning. "The Role of Monitored Natural Recovery in Sediment Remediation." Integrated Environmental Assessment and Management, U.S. National Library of Medicine, Jan. 2006, www.ncbi.nlm.nih.gov/pubmed/16640320.

Matt Drange and Susanne Rust, the Center for Investigative Reporting. "Toxic Trail: the Weak Points in the Superfund Waste System." The Guardian, Guardian News and Media, 17 Mar. 2014, www.theguardian.com/environment/2014/mar/17/toxic-trail-weak-points-superfund-waste.

Morris, Rebecca L., et al. "From Grey to Green: Efficacy of Eco-Engineering Solutions for Nature-Based Coastal Defence." Global Change Biology, John Wiley & Sons, Ltd (10.1111), 16 Feb. 2018, onlinelibrary.wiley.com/doi/abs/10.1111/gcb.14063.

Nunnally, Nelson R., et al. "Environmental Considerations for Levees and Floodwalls." SpringerLink, Springer-Verlag, link.springer.com/article/10.1007/BF01867197.

"Read 'Contaminated Marine Sediments: Assessment and Remediation' at NAP.edu." National Academies Press: OpenBook, www.nap.edu/read/1412/chapter/21.

Final Duwamish River Cleanup Plan Fact Sheet. Record of Decision: Final Cleanup Plan Community Fact Sheet. Record of Decision: Final Cleanup Plan Community Fact Sheet, Duwamish River Cleanup Coalition/Technical Advisory Group, 2015.

Reese, Tom, et al. Once & Future River: Reclaiming the Duwamish. University of Washington Press, a Ruth Kirk Book, 2016.

"Seascape Architecture – Incorporating Ecological Considerations in Design of Coastal and Marine Infrastructure." Ecological Engineering, Elsevier, 8 July 2017, www.sciencedirect.com/science/article/abs/pii/S0925857417303798?via=ihub.

"Seattle Seawall's Novel Fish Features Are a Potential Model for the World." UW News, www.washington.edu/news/2017/05/18/seattle-seawalls-novel-fish-features-are-a-potential-model-for-the-world/.

Strelzoff, Audrey. "Engineering With Nature." EWN, ewn.el.erdc.dren.mil/.

"Superfund Job Training Initiative." EPA, Environmental Protection Agency, 4 June 2018, www.epa.gov/superfund/superfund-job-training-initiative.

"Superfund: National Priorities List (NPL)." EPA, Environmental Protection Agency, 4 June 2018, www.epa.gov/superfund/superfund-national-priorities-list-npl.

"Superfund: The Shortcut That Failed." PERC, 7 Feb. 2018, www.perc.org/1996/05/01/superfund-the-shortcut-that-failed/.

Zar, H. "Regulatory Strategies for Remediation of Contaminated Sediments." Dredging, Remediation, and Containment of Contaminated Sediments, doi:10.1520/stp16010s.

IMAGES

000. Paul Joseph Brown

001. Reese, Tom, et al. Once & Future River: Reclaiming the Duwamish. University of Washington Press, a Ruth Kirk Book, 2016.

002. Reese, Tom, et al. Once & Future River: Reclaiming the Duwamish. University of Washington Press, a Ruth Kirk Book, 2016.

003. Reese, Tom, et al. Once & Future River: Reclaiming the Duwamish. University of Washington Press, a Ruth Kirk Book, 2016.

004. Reese, Tom, et al. Once & Future River: Reclaiming the Duwamish. University of Washington Press, a Ruth Kirk Book, 2016.

005. Reese, Tom, et al. Once & Future River: Reclaiming the Duwamish. University of Washington Press, a Ruth Kirk Book, 2016.

006. "Municipal Plans Commission of the City of Seattle Map Showing Harbor Island and Duwamish Waterway Districts, 1911." Maps and Atlases, cdm16118.contentdm.oclc.org/cdm/ref/collection/p16118coll2/id/37.

007. "Letterhead from Puget Sound Bridge and Dredging Co., 1915." Digitalcollections.lib.washington.edu, digitalcollections.lib.washington.edu/digital/collection/imlsmohai/id/12145/rec/18.

008. "Guide Map of Seattle Showing Tide Lands to Be Filled and Canal to Be Constructed by the Seattle and Lake Washington Waterway Company (1895)." CONTENTdm, content.libraries.wsu.edu/digital/collection/maps/id/115/rec/1.

009. "Guide Map of Seattle Showing Tide Lands to Be Filled and Canal to Be Constructed by the Seattle and Lake Washington Waterway Company (1895)." CONTENTdm, content.libraries.wsu.edu/digital/collection/maps/id/115/rec/1.

010. "Denny Regrade in the Vicinity of 2nd Ave. and Virginia St. Showing the Use of Hydraulic Giants, Seattle, August 20, 1907." Digitalcollections.lib.washington.edu, digitalcollections.lib.washington.edu/digital/collection/panoram/id/86/rec/27.

011. "Self Dumping Scow at the Foot of Battery St. with Load of Dirt from the Denny Hill Regrade, Elliott Bay, Seattle, Washington, May 8, 1930." Digitalcollections.lib.washington.edu, digitalcollections.lib.washington.edu/digital/collection/lee/id/90/rec/42.

012. "Self Dumping Scow at the Foot of Battery St. with Load of Dirt from the Denny Hill Regrade, Elliott Bay, Seattle, Washington, May 8, 1930." Digitalcollections.lib.washington.edu, digitalcollections.lib.washington.edu/digital/collection/lee/id/204/rec/41.

013. "Eastern View on Bell St. from 4th Ave. Showing Regrade Activities, Seattle, Washington, October 1909." Digitalcollections.lib.washington.edu, digitalcollections.lib.washington.edu/digital/collection/lee/id/13/rec/4.

014. "Harbor Island from Downtown Seattle, Ca. 1913." Digitalcollections.lib.washington.edu, digitalcollections.lib.washington.edu/digital/collection/imlsmohai/id/6210/rec/3.

015. "Standard Oil Plant, 1916." Digitalcollections.lib.washington.edu, digitalcollections.lib.washington.edu/digital/collection/imlsmohai/id/5162/rec/17.

016. "S-12. ." WI Coastal Wetlands Assessment Report - Wisconsin DNR, dnr.wi.gov/topic/wetlands/cw/ELSup/index.asp?mode=detail&RecID=1E8E551B34F.

017. "Lumber Mill on Harbor Island, Seattle, Washington, circa 1951-1954." Digitalcollections.lib.washington.edu, digitalcollections.lib.washington.edu/digital/collection/seattle/id/5012/rec/69.

018. Reese, Tom, et al. Once & Future River: Reclaiming the Duwamish. University of Washington Press, a Ruth Kirk Book, 2016.

019. Reese, Tom, et al. Once & Future River: Reclaiming the Duwamish. University of Washington Press, a Ruth Kirk Book, 2016.

020. KUOW STAFF Aug 27, 2018 at 11:48 am. "The Duwamish Isn't Just a River." KUOW, 27 Aug. 2018, www.kuow.org/stories/the-duwamish-isn-t-just-a-river-to-this-lifelong-steward-it-s-part-of-his-family-0b46.

021. Shinn, Lora. "All Hands In to Repair Seattle's Polluted Duwamish River." NRDC, 31 May 2019, www.nrdc.org/stories/all-hands-repair-seattles-polluted-duwamish-river.

022. Walker, Richard. "Reclaiming the Duwamish River: A Conversation With James Rasmussen." IndianCountryToday.com, Indian Country Today, 24 Nov. 2011, newsmaven.io/indiancountrytoday/archive/reclaiming-the-duwamish-river-a-conversation-with-james-rasmussen-Asqa8sSe8kSy5A_r2AQo2A/.

023. "Breaking: EPA Issues Its Record of Decision for the Duwamish River Superfund Site | Science, Law & the Environment | Miller Nash Graham & Dunn LLP." Science, Law & the Environment, 4 Dec. 2014, www.sciencelawenvironment.com/2014/12/breaking-epa-issues-its-record-of-decision-for-the-duwamish-river-superfund-site/.

024. Reese, Tom, et al. Once & Future River: Reclaiming the Duwamish. University of Washington Press, a Ruth Kirk Book, 2016.

025. Reese, Tom, et al. Once & Future River: Reclaiming the Duwamish. University of Washington Press, a Ruth Kirk Book, 2016.

026. Cox, Alissa, et al. "Generating Electricity While Microbes Clean Wastewater – How Wastewater Treatment Plants Could Go from Brown to Green." Envirobites, 4 Aug. 2017, envirobites.org/2017/08/04/generating-electricity-while-microbes-clean-wastewater-how-wastewater-treatment-plants-could-go-from-brown-to-green/.

027. Business Consulting & Solutions. "Maintenance Dredging Morehead City Harbor, Range A & Range B." The Dutra Group | Aggregates, Dredging, & Marine Construction Services, www.dutragroup.com/project-details-dredging-aggregates-dredging-marine-construction.html?id=31.

028. "EcoTube™ Sludge Dewatering Geotextile Tubes - Products." US Fabrics, www.usfabricsinc.com/products/ecotube-sludge-dewatering-tubes/.

029. "What Microbes Are Hiding In Your Microbiome?" Science Friday, www.sciencefriday.com/segments/what-microbes-are-hiding-in-your-home/.

030. "Workboats." Workboats | DSC Dredge, www.dscdredge.com/products/workboats.

031. J.F. Brennan Company, Inc. "Sand Covers and Capping | J.F. Brennan Company." J.F. Brennan Company, Inc., www.jfbrennan.com/environmental/sand-covers-and-capping.

032. GGLO Design. "Climate Preparedness: A Mapping Inventory of Changing Coastal Flood Risk." Seattle Office of Sustainability and Environment, 24 Aug. 2015, pp. 1–42., www.seattle.gov/Documents/Departments/Environment/ClimateChange/2015.08.25_ClimatePreparednessInventory_Sec1.pdf.

033. "Broken Floodwalls Following Hurricane Katrina by Coleen Perilloux Landry." PBase, www.pbase.com/image/127791859.

034. "Boeing: 2014 Environment Report." The Boeing Company, www.boeing.com/aboutus/environment/environment_report_14/3.2_remediation.html.

035. "Heron Eats Fish from Lower Duwamish River Waterway, Seattle, WA, 06-2014." Orange Logic, secure.boeingimages.com/archive/Heron-eats-fish-from-Lower-Duwamish-River-Waterway--Seattle--WA--06-2014-2JRSXLJLN41T.html.

036."Mimicking Mother Nature." U.S. Department of Transportation/Federal Highway Administration, www.fhwa.dot.gov/publications/publicroads/06jan/05.cfm.

037. "Lower Duwamish River Habitat Restoration Plan (LDRHRP)." Port of Seattle, www.portseattle.org/projects/lower-duwamish-river-habitat-restoration-plan-ldrhrp.

038. "Seattle Seawall's Novel Fish Features Are a Potential Model for the World." UW News, www.washington.edu/news/2017/05/18/seattle-seawalls-novel-fish-features-are-a-potential-model-for-the-world/.

039. "Seattle Seawall's Novel Fish Features Are a Potential Model for the World." UW News, www.washington.edu/news/2017/05/18/seattle-seawalls-novel-fish-features-are-a-potential-model-for-the-world/.

040. "Seattle Seawall's Novel Fish Features Are a Potential Model for the World." UW News, www.washington.edu/news/2017/05/18/seattle-seawalls-novel-fish-features-are-a-potential-model-for-the-world/.

041. "Seattle Seawall's Novel Fish Features Are a Potential Model for the World." UW News, www.washington.edu/news/2017/05/18/seattle-seawalls-novel-fish-features-are-a-potential-model-for-the-world/.

042. Water Quality Monitoring System, www.globalw.com/products/wqms.html.

043. "Freshwater Algae." Scottish Natural Heritage, www.nature.scot/plants-animals-and-fungi/algae/freshwater-algae.

044. "Cariboo-Chilcotin - Terry Allen." Terry Allen CaribooChilcotin Gallery RSS, www.allenfotowild.com/Cariboo-Chilcotin/Cariboo-Chilcotin/i-NGvQsGC/.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