ENHANCING LEGACY | ENGAGING PROCESS:
PHYTOREMEDIATION AT GAS WORKS PARK

HAILEY MACKAY

A thesis submitted
in partial fulfillment of the
requirements for the degree of

Master of Landscape Architecture

University of Washington
2016

Committee:
Kenneth Yocom
Thaïsa Way
Sharon Doty

Program Authorized to Offer Degree:
Landscape Architecture

© Copyright 2016
Hailey Mackay

University of Washington

Abstract

Enhancing Legacy | Engaging Process: Phytoremediation at Gas Works Park

Hailey Mackay

Chair of supervisory committee:
Professor Kenneth Yocom
Department of Landscape Architecture

This thesis proposes the use of plants to remove hazardous wastes from soil and water, a process known as phytoremediation, as a promising alternative to traditional methods of toxics clean-up. This project focuses specifically on designing phytoremediation for Gas Works Park, a beloved city park and former manufactured gas plant, located in Seattle, Washington. Today the park, a 20 acre promontory jutting 400 feet into Lake Union with 1,900 feet of lake-front shoreline, maintains many of its original structures as well as water and soil pollution generated by 50 years of coal-gas manufacture. Since its completion in 1976, maintenance and monitoring crews at the park have struggled to contain the contamination that remains beneath a soil and clay cap. Forty years of intense recreational use and heavy seasonal rain storms have degraded the soil cap, exposing contamination, and requiring intermittent re-capping efforts. Physical evidence of toxic sediments leaching into the adjacent lake and seeping up to the surface of the park soils has been documented through continuous testing and monitoring activities. Residual pollutants on site have been respectively identified as toxic, carcinogenic, and mutagenic. These contaminants present a serious health risk for park users and the sensitive lacustrine environment surrounding the park. This project utilizes the burgeoning scientific field of phytoremediation to design strategies that remove and mitigate remaining contamination at the park and simultaneously create new user experiences. Experiences created by phytoremediation strategies are intended to educate visitors about the park's history and engage them in the future of its clean-up. This thesis aims to further awareness of phytoremediation technology as a viable design tool and spark an honest dialogue about mitigating toxicity in public space.



Hailey Mackay and Richard Haag during a tour of the Cracking Towers, 2016

ACKNOWLEDGMENTS

This project was supported and enriched by many minds.

Thanks to my thesis committee, Ken Yocom, Thaïsa Way and Sharon Doty, for their flexibility and wide range of input. Each committee member played an integral role in my process and their overall collaboration was professionally instructive and academically enlightening. Thanks also to Roark Congdon for his indomitable enthusiasm in helping me navigate the world of three-dimensional modeling, Nancy Rottle for being a constant source of support and inspiration and Vanessa Lee for her unrivaled administrative prowess.

Thanks are also due to Richard Haag for his incredible contributions to the discipline of landscape architecture, and his generosity in providing personal insights to this project. Thanks also to the Seattle Parks and Recreation Department and the Washington State Department of Ecology for their transparency and participation in this project. Forty years of hard work and cooperation have made Gas Works Park an icon of great landscape design, one which will persist far into the future.

Immense thanks to my peers, in three years of graduate education,
I have been continuously supported and inspired by each of you.
I have seen this group of students approach the vast field of landscape architecture with unending curiosity, enthusiasm and generosity.
Thank you all for being my community.

Finally, inexpressible gratitude to my family – Patricia, Don, Kellan, Jeanne, Christopher and Trudy – for their unconditional love and continued support of my life pursuits. Thanks also to the Mak family – Alice, Jim, Eric, Louise and Nigel – for technical support and winter breaks in Honolulu.



CONTENTS

CRITICAL STANCE 1

LITERATURE REVIEW 7

Post-Industry:
A Paradigm Shift
Biophilia:
Toward a New Nature
Phytoremediation:
Mechanisms for Regeneration
Gas Works Park:
A Legacy of Progress

CASE STUDIES 21

Elizabeth City, NC
Spring Valley, DC
Ford River Rouge
Houtan Park
Landschafts Park
Social Acceptability

SITE ANALYSIS 35

Location + Views
History
Stakeholders
Park Uses
Regulation
Research + Monitoring
Soils, Hydrology, Contaminants
Contaminants of Concern
Exposure Mitigation
Synthesis

DESIGN METHODS 67

The Site Framework
Form + Process
Phytoremediation
Remedial Mechanisms
Plant Profiles
Planting Strategies

DESIGN CONCEPT 97

Phytoremediation as Design
Conceptual Forms
Phased Implementation
Planting Overlay

DESIGN SCHEMATIC 105

Site Plan
Let's Go for a Walk!
Sections + Diagrams
Vignettes

SELECT BIBLIOGRAPHY 125

APPENDIX 127

CRITICAL STANCE

Post-Industry, Toxicity Flows

As early-industrialized nations continue to export manufacturing industries, post-industrial landscapes are increasingly common. The presence of large stretches of land in disuse are commonly regarded as waste after their respective industries have moved away. Regardless of the type of manufacturing that took place on site, many post-industrial sites contain contamination that may permeate soil, water and existing structures. Deep levels of contamination complicate the process of reusing these sites so most are abandoned, regarded as toxic and therefore unusable. These landscapes occupy large tracts of land, comprising hundreds of thousands of miles of likely polluted soil and water around the world. The practice of discarding post-industrial landscapes is due not only to the threat of toxicity and the sheer size of these sites, cleaning up these sites for reuse is also perceived as too costly. However, the cost of not remediating these sites may be much higher. As a post-industrial site is left to linger, often abandoned, contaminant plumes in soil, water and remaining structures seeps and spreads beyond the site's boundaries. These plumes often contain toxic, carcinogenic and mutagenic compounds, posing serious threats to human and environmental health.

In order to assess the risks of post-industrial sites in the United States the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) was drafted in 1980. This act recognizes the serious nature of health threats posed by industrial pollution, creating a branch of the Environmental Protection Agency (EPA) focused on assessing and cataloguing contaminated sites. Due to the toxic pollutants present, commonly petroleum and coal byproducts CERCLA, also known as Superfund, "provides a broad federal authority to respond directly to releases or threatened releases of hazardous substances that may endanger public health or the environment".[1] The Superfund program identifies problem sites by testing contaminant levels and locations to determine a site's threat level and map specific locations of concern. Sites assessed and catalogued as the most threatening are placed on the Superfund National Priorities List. This list is updated regularly and currently represents 1,323 of the United States' most contaminated Superfunds.[2] Not included in this list are over 450,000 post-industrial sites not yet officially recognized, these landscapes are commonly referred to as brownfields.[3]

Almost more alarming than the health risks present at these unrecognized sites is the sheer magnitude of land consumed by industrial pollution. These massive tracts of wasteland have local and global health implications. As the world's population grows, many countries are developing land that previously performed essential services such as food production, water and air filtration. Land use, human and environmental health are increasingly jeopardized as landscapes offering essential environmental services are diminished and contaminated sites continue to fester unresolved – often leaching toxins into adjacent areas. The combination of derelict post-industrial sites and rapid expansion of urban areas contributes to large scale challenges such as climate change and local issues like water quality and temperature regulation. Broken environmental systems present on post-industrial sites are a symptom of larger systemic environmental crises developing around the world. Issues of water, soil and air quality as well as climatic disasters are nested issues, connected by diminishing natural resources. It is my critical stance that in light of pressing climatic and environmental issues and due to the volatility of post-industrial sites, merely assessing and cataloging these sites is no longer enough. Now more than ever it is incumbent upon landscape professionals to innovate functional solutions that unlock and revitalize the contaminated resources present on post-industrial sites.

In the past three decades landscape theorists, designers and scientists have begun to study contaminated sites more critically in terms of productive remediation. These sites represent a physical threat and a cultural discussion concerned with how past human actions have shaped the present and how present human actions will shape the future. In the face of global climate change and rapid urbanization, humans are beginning to evaluate the history of behavior that precipitated our current environmental situation. As available land, water and other resources decline globally, we confront the proliferation of landscapes of waste as sites where precious resources have been contaminated.

The process of rehabilitating contaminated post-industrial sites is multi-faceted and complex. Histories of industry and economy, lost traces of local ecology, hydrology and geology, and the very real danger of toxic substances, converge on these sites and require the collaboration of diverse disciplines to holistically achieve rehabilitation. Interdisciplinary, site specific and historically cogent approaches to post-industrial sites are required for effective rehabilitation and sensitive redesign. Historians, toxicologists, plant biologists, site engineers, ecologists and landscape practitioners are just a few of the disciplines essential to understanding and transforming these sites.[4] Transformation in this context means rehabilitating toxic areas using plants to remediate toxicity, create biomass for novel habitat and provide basic environmental services such as water and air filtration. Site specific treatment would determine the ultimate reuse of a site after rehabilitation- be it urban, rural or wild.

Consumer. Environmentalist. Citizen.

Traditional methods of toxics clean-up involve invasive and often hazardous techniques. Digging to remove and transport contaminated material to hazardous waste facilities simply transmits the problem to a designated area. Similarly, covering over contamination in place with clay, a technique called capping, only slightly displaces the problem because contaminants underground must be constantly monitored and controlled to prevent leaching. The use of plants to remediate contamination allows toxicity to remain below ground and utilizes plant roots to prevent leaching. The living body of the plant provides an indicator of toxicity through its growth above ground, precluding digging and contaminant exposure. The ability of plants to slowly remediate contamination, stabilizing a site's environmental conditions in the process, can be viewed as a catalyst for post-industrial transformation. While these sites have been alienated from their ecological and hydrological origins, those processes represent an underlying framework for rehabilitation. Phytoremediation, the use of specialized plants to absorb or otherwise mitigate pollutants, is a quickly developing field that can address the complexity of physically rehabilitating contaminated sites. Plants can also address the emotional recalibration of a contaminated site and its history through creating a new kind of landscape.[5] Hybrid landscapes thick with communities of phytoremediation plants that can absorb and degrade pollutants, actively removing contamination over time, can reveal processes at work – below ground mitigation signaled by the growth of vegetation above ground.[6]

To appreciate the opportunities presented by post-industrial sites an "assets approach"[7] is crucial. Understanding the value post-industrial landscapes still hold is essential to facilitating their rehabilitation. The vast derelict lands created by industry offer sites for experimentation, adaptive reuse and regeneration. The ubiquity of these sites makes them ideal grounds for experimentation and adaptive management. While they may often be perceived as leftovers, science can capitalize on these sites' disturbed conditions to further research of phytoremediation and its relative effectiveness. Another important consideration for the evaluation of contaminated landscapes is a biophilic[8] lens that views plants and other organisms as key components to landscape regeneration and reuse. First coined by E.O. Wilson in 1984, "biophilia" refers to an intrinsic link between humans and other organisms. Since its conception, biophilia has become associated with the documented mental and physical health benefits afforded by proximity to natural settings and systems such as water, trees and wildlife.[9] Combining an assets approach with a biophilic perspective unlocks the potential value of post-industrial sites through remediation using plants that reestablish some natural functionality.

An assets approach, imbued with a biophilic lens, also facilitates an understanding of how phytoremediation can be used to rehabilitate sites that lack any trace of their previous ecology, while protecting human and environmental health in the process. The concept of phytoremediation, using plants' natural processes to extract and degrade contaminants in soil and water[10], contributes to a deeper understanding of how plants, trees and other organisms like mycorrhizae and fungi can restore defunct sites and promote human health in relationship to the environment.[11] Associated with this approach is a conception

of nature as both a human construction and an essential entity that connects humans to their environments.[12] This view regards humans as intrinsically natural creatures and thus, our processes and creations as necessarily existing within and as a part of nature.[13] This is not a notion of nature that holds native ecosystems above novel ecosystems.[14] This concept of nature views the human environment as a heterogeneous grid, systemic issues being associated not by species but by the extreme dominance of one species over another. More specifically, this view of nature holds biodiversity as a key functional component without discriminating between species origins – only the services those species may provide to a larger system.[15] In this way, species that provide the highest benefit to a given system or situation are prioritized above species that may not provide vital functions. This stance is not dictated by conservation, restoration or preservation practices but is an amalgam of all three. It is an amalgam of practice that holds paramount the environmental needs of a specific site shaped by human activity.[16] This concept is an aggregation of landscape theories, pulling from Alan Berger's *Drosscape,* Neil Evernden's *The Social Creation of Nature* and Elizabeth Meyer's 'Uncertain Parks' as well as Marris, Lugo and Pearce's discussions of novel ecosystems. An assets approach to post-industrial sites with a biophilic lens, and an indiscriminate view of nature, forms the personal perspective that informs my research and pervades my design methods.

Keeping this perspective in mind, I posit that landscapes created by human production and consumption are a part of nature and a manifestation of human culture. In this position I align with landscape theorists Mira Engler[17] and Elizabeth Meyer[18]. Engler and Meyer propose that the ways in which we decide to reclaim post-industrial sites reveals as much about our culture as the industries that created such landscapes. Thus my view of post-industrial contaminated landscapes functions as a mirror of our values as a collective culture.[19] Meyer furthers this idea when she identifies a culture that abhors the environmental implications of these sites while simultaneously perpetuating lifestyles that create them. Meyer terms this identity as "consumer as environmentalist-citizen".[20] It is this culture that I seek to address in advocating phytoremediation design for post-industrially contaminated sites. While I agree with Meyer's and Engler's positions that careful consideration, sensitivity and generosity are due in the reclamation and redesign of post-industrial landscapes, I posit that "reclaim" is not the appropriate terminology. For what are we taking back that we didn't already consider ours? Instead, I use terms such as rehabilitate, remediate and reuse. Terms I feel are responsive to the actions called for on such sites. Sites whose histories of human intervention are as contested as their consumer products are beloved.

Why Gas Works Park?

The ground-breaking work done by Richard Haag & Associates at Gas Works Park in Seattle, Washington in the 1970s marked a paradigm shift in the way people relate to landscapes contaminated by industry. The guiding concept of the park has been in conflict for decades, at once cherished and despised. When Rich Haag first approached the former coal and oil gas plant in the 1960s he saw the rusting machinery as artifacts, essential to the site's character, revealing the history of its pollution. Although Haag began remediating the pollution left in the soil, air and water, by over 50 years of gas plant operation, he retained several of the original structures as sentinels of the site's past. The design of Gas Works Park, as well as the bioremediation techniques used to begin cleaning pollutants on site, were innovations that shifted the focal point of the City of Seattle toward a new hybrid landscape.

To this day, Gas Works Park acts as a highly visible symbol of the City's values and culture. Gas Works Park represents a city of consumer-environmentalist citizens. Valuing both the natural and the urban, most Seattleites love and support their local post-industrial park. Many of these citizens do not know that the contamination created by the now statuesque towers still lies buried beneath their feet. In the minority, are those who feel the polluted past of the park is too hazardous to be overlooked. Since the park's conception, there has been a small contingent of Seattleites who remain uncomfortable with the perceived lack of transparency surrounding the park's past.

It is my assertion that Gas Works Park's beloved and contested duality,

merged with its industrial past, make it the perfect grounds for continued remediation using plants. The pollutants that continue to surface from beneath clay-capped soils and the toxic sediments that are slowly leaching into the adjacent lake represent symptoms of a need for continued remediation. Phytoremediation is an empirically proven method to safely, efficiently and cost-effectively remove pollutants over an extended period of time. Plants have the added benefit of providing amenities above ground as they remediate below ground. On this site, plants would have a tri-fold purpose; to remediate pollutants in subsurface soil and water, facilitate education of the remediation process above ground, and create a new user experience in a familiar place. I believe that using plants is the best way to continue to remediate Gas Works Park, revitalizing a beloved city park and an international icon both physically and symbolically.

While I am a firm proponent of using phytoremediation to address resource contamination, it is important to take note of practical considerations. Phytoremediation is not simple to implement correctly. Phytoremediation is as complex as the site it seeks to remediate and must be used with due consideration. The primary reasons phytoremediation is not widely used today are the long time scale associated with using plants to degrade toxic pollutants and the limited number of published field studies available. While phytoremediation is an expanding field that is quickly developing, methods that have been tested in field trials and used in case studies are not always published and can be difficult to access. In order to carry out research and design that utilizes phytoremediation correctly, I have had to rely on the available data, largely based in lab studies. For precedents and case studies I only reviewed projects that have been built and sufficiently monitored, providing documented evidence that can be re-created.

In closing, my stance as a designer and engaged citizen is that phytoremediation and ecology offer the ultimate solutions to many human-created problems, globally and locally. I value both quantitative empirical evidence and qualitative experiential evidence as equally important to informing holistic design that functions physically and performs socially.



REFERENCES

1.) EPA, “Cercla,” United States Environmental Protection Agency.

2.) “Superfund,” United States Environmental Protection Agency, http://www2.epa.gov/superfund.

3.) “Brownfields,” United States Environmental Protection Agency, http://www2.epa.gov/brownfields.

4.) Justin B. Hollander, Niall Kirkwood, and Julia L. Gold, *Principles of Brownfield Regeneration : Cleanup, Design, and Reuse of Derelict Land* (Washington: Island Press, 2010).

5.) Krinke, Rebecca. “Overview: Design Practice and Manufactured Sites,” in *Manufactured Sites,* ed. Niall Kirkwood (London, New Yrok: Spon Press, 2001).

6.) Cook, Rachel. “Phytoremediation of a Petroleum-Contaminated Shallow Aquifer, Elizabeth City, Nc: Planting Methods and Preliminary Results” (North Carolina State University, 2008).

7.) Berger, Alan. *Drosscape: Wasting Land in Urban America*, 1st ed. (New York: Princeton Architectural Press, 2006): pg. 239.

8.) Wilson, Edward O. *Biophilia.* (Cambridge, Mass.: Harvard University Press, 1984).

9.) E.O. Wilson and Stephen Kellert, ed. *The Biophilia Hypothesis.* (Washington , D.C.: Island Press, 1993): pg. 21.

10.) United Nations Environment Programme, “Phytoremediation: An Environmentally Sound Technology for Pollution Prevention, Control and Remediation,” *Newsletter and Technical Publications: Freshwater Management Series No. 2* (2015), http://www.unep.or.jp/Ietc/Publications/Freshwater/FMS2/1.asp.

11.) Kirkwood, Niall. *Manufactured Sites : Rethinking the Post-Industrial Landscape* (London; New York: Spon Press, 2001).

12.) Evernden, Lorne Leslie Neil. *The Social Creation of Nature* (Baltimore: Johns Hopkins University Press, 1992).

13.) Berger, *Drosscape: Wasting Land in Urban America,* pg. 239.

14.) Pearce, Fred. *The New Wild: Why Invasive Species Will Be Nature’s Salvation* (Boston : Beacon Press, 2015).

15.) Ariel Lugo and Eileen Helmer, “Emerging Forests on Abandoned Land: Puerto Rico’s New Forests,” *Forest Ecology and Management* 190 (2003).

16.) Niall Kirkwood and Kate Kennen, *Phyto: Principles and Resources for Site Remediation and Landscape Design* (New York, NY: Routledge, 2015).

17.) Mira Engler and Center for American Places., *Designing America’s Waste Landscapes*, Center Books on Contemporary Landscape Design (Baltimore: J. Hopkins University Press, 2004).

18.) Meyer, Elizabeth K. “Uncertain Parks: Disturbed Sites, Citizens and Risk Society,” in *Large Parks*, ed. Julia Czerniak and George Hargreaves (Cambridge, Mass.: Princeton Architectural Press ; in association with the Harvard University Graduate School of Design, 2007): pg. 59-85.

19.) Engler and Center for American Places., *Designing America’s Waste Landscapes,* 123.

20.) Meyer, “Uncertain Parks: Disturbed Sites, Citizens and Risk Society.” pg. 64.

LITERATURE REVIEW

Post-Industry: A Paradigm Shift

While post-industrial sites are generally considered serious public health risks, it is equally important to understand them as assets. An assets approach considers the valuable resources and services these landscapes might offer rather than merely the inherent dangers.[1] In his 2006 book *Drosscape*, MIT urban design professor Alan Berger posits a view of contaminated landscapes that accounts for our waste as a part of the nature of human development, "Humanity's fantastic growth has inevitably confronted us with commensurate wastelands. Drosscape, far from marking failure, testifies to previous urban successes and establishes design challenges for its continuance".[2]

In forming a positive perspective of landscapes so often perceived through shame and terror, Berger helps us to reimagine waste landscapes as 'drosscapes', a term that implies "that dross, or waste, is scaped, or resurfaced, and reprogrammed for adaptive reuse"[3] allowing these places to be considered as opportunities instead of black holes. In his definition, Berger categorizes drosscapes as sites of destruction and potential but is careful not to confine this term to a specific meaning or use. In his unpacking of these complex sites, Berger forges a set of eight design standards that help reframe a broad range of waste landscapes as drosscapes. Although not created specifically for contaminated lands, many of these standards apply to the reconsideration, and ultimately rehabilitation, of contaminated sites. As a body, his list of standards declares that drosscapes are foremost "a natural component of every dynamically evolving city", which require designers to shift thinking toward "complex interactive and responsive processing", and place the designer as "the consummate spokesperson for the productive integration of waste landscape in the urban world".[4]

In her 2007 essay, 'Uncertain Parks: Disturbed Sites, Citizens, and Risk Society', landscape architect, theorist and critic, Elizabeth Meyer, gives weight to Berger's ideas when she calls for honest, generous and just treatment of post-industrial sites. Meyer calls for treatment of these sites that goes beyond mere 'scaping', treatment that questions the culture that created what she terms 'disturbed sites',

> "[These sites] have been disturbed by new processes – interrupted and interfered with – and that alteration disturbs us, makes us uneasy…This term also resonates with contemporary theories of ecological science that recognize the significance of disturbance regimes within successional processes and ecosystem dynamics."[5]

Meyer goes on to quote Iowa State University professor of landscape architecture, Mira Engler, who has written on the role waste landscapes can play as a mirror reflecting our collective culture of production, consumption and waste.[6] Meyer and Engler emphasize critical issues of toxicity, safety and responsibility, calling not only for safety through remediation but also for exposure and self-awareness by allowing sites to maintain elements of history. Using Meyer's term 'disturbed sites' also recalls an important facet of the processes that have taken place on contaminated sites, the processes that continue to shape the site, and the processes that are necessary in order for rehabilitation and reuse. As Meyer suggests, the ecology of these sites has been irreversibly altered, but instead of a natural succession after disturbance, these sites require intervention to be recolonized by functioning ecology. Many sites have been so disturbed that intervention is required in order for anything to grow there at all. The introduction of new forms of ecology, ones resilient to toxicity, is necessary to begin shifting these sites from scenes of disturbance to landscapes of succession and remediation. Meyer and Engler's ideas can be read in conjunction with Berger's drosscape tenets, enriching the concept of drosscapes with a more holistic perspective of post-industrial design. If we acknowledge contaminated lands in their entirety and accept the history and toxicity of these sites as our own, we can still find value in the potential of remediating these places for reuse. As an act of healing and learning, exploring a landscape's past as part of its present, holds enormous promise for its future.

This thinking arose from a larger narrative of shifting paradigms, regarding how toxic sites are considered and thus how they may be treated and reused. Niall Kirkwood, professor of landscape architecture at the Harvard Graduate School of Design, has been at the forefront of

this conversation within landscape architecture practice. In collaboration with others, Kirkwood has published three books on the topic of post-industrial reclamation, the first in 2001 titled *Manufactured Sites: Rethinking the Post-Industrial Landscape*. These publications, as well as the articles and presentations that followed, triggered the beginning stages of a shift in landscape theory and practice. In her overview of post-industrial reuse case studies for *Manufactured Sites*, University of Minnesota professor of landscape architecture, Rebecca Krinke, identifies the adaptive reuse of contaminated industrial sites as a paradigm shift in the production of designed landscapes, "Manufactured sites reveal a paradigm shift…land is seen not simply as inert matter or a commodity, but as a dynamic web of living systems".[7] Krinke surveys case studies included in the book, ranging from planting poplars on capped landfills to the landscaped redesign of inactive coal-gas plants, and describes the adaptive reuse of structures and the use of plants for remediation as a revelation in post-industrial design.

> "Remediating or enhancing the ecological functioning of the site, and making this process visible to the participant, is a new way of addressing the designed landscape…to build landscapes that question dualities of nature/culture and past/present, and engage those who participate in the site with these questions."[8]

Krinke understands the remediation and programmatic actions found in these case studies as the first steps towards a more acute confrontation of our society's landscapes of production and consumption.

University of Copenhagen professor of landscape architecture Ellen Braae reaches a similar conclusion in her 2015 book *Beauty Redeemed*. Although from a different perspective, Braae describes post-industrial landscapes "both as mirrors of society and places of remembrance".[9] She posits that these sites represent a new cultural heritage and a new sustainability founded in adaptive reuse of materials and resources. By transforming post-industrial sites and honoring their histories through adaptive reuse, Braae also argues that the rehabilitation of post-industrial landscapes marks a paradigm shift in contemporary perspective. She puts forth a series of frameworks that call for site specific approaches addressing the complexities of these landscapes through convergence and coherence of methods and disciplines. Braae also stresses the importance of how we view, discuss and ultimately think of these landscapes. She calls for a shift in aesthetic and ecological perspectives which will ultimately embrace sites generically seen as waste, "We must develop our aesthetic view of these ruins if we are to build a future from them and on top of them. This is where we find the new sustainability".[10]

When drosscapes are considered simultaneously as disturbed sites, reflections of our human culture and hosts for new forms of ecology, a praxis toward creating meaningful spaces that inform future land use begins to develop. There are growing numbers of projects which begin to address drosscapes, reimagining contaminated sites for positive reuse with varying degrees of legibility. These sites begin to expose the shifting paradigm which Braae and Krinke discuss, a confluence of shunned history and social conscience, aggregated toward redefining these sites as assets and essential pieces of our lives. The rehabilitation of which is well within our grasp. The preservation and reuse of existing materials and the introduction of unique plant communities on these sites are the raw matter, which if implemented properly, can kick start reconsideration of damaged lands by local and global communities alike. Select case studies that follow this review help to illustrate the varied approaches and interpretations of this paradigm shift, ranging from post-industrial parks to retrofitted factories still manufacturing goods.

Toward A New Nature

The adaptive reuse of post-industrial structures, paired with the reintroduction of plants on site, has become an increasingly common strategy for rehabilitating post-industrial sites for human use. Select interventions, from a spectrum of utility and aesthetics, respond specifically to the site they seek to remediate. The restructuring of relics in the landscape and in the consciousness of society requires a strong counterpoint, or series of counterpoints, with which to frame history and ameliorate contamination. Case studies and literature speak

to the power that plants harbor in this kind of restructuring. Study of the positive benefits of nature, or naturalistic settings, on the human psyche has been in practice since the 1980s, with new studies still being published today.

In 1984 Roger S. Ulrich published groundbreaking research on how views from hospital windows may effect patients' recovery from surgery. Ulrich found that of 46 patients studied from 1972 to 1981, the 23 patients with window views of trees and other natural settings recovered more quickly and required less pain medication than the 23 patients with window views of a brick wall.[11] The results of this study are often cited as evidence that humans benefit from nature and naturalistic settings, spurring further dialogue among environmental psychologists and landscape practitioners about human relationships to space. The publication of this study in 1984 coincided with the conception of the term biophilia[12]. The simultaneity of these, different but now synonymous, theories is indicative of paradigm shifts occurring in several disciplines at once. Ulrich's study, and many studies that followed, sparked an important conversation in environmental psychology that continues today.[13]

The theory of biophilia, first proposed by naturalist and biologist E.O. Wilson in 1984, suggests that humans possess an intrinsic need for interaction with and exposure to natural elements such as plant life, clean water and fresh air. In other words – humans are drawn to other organisms and the processes of interaction between organisms.[14] Wilson's notion posits that in order to maintain or reestablish healthy connections with our environments, we must first acknowledge the processes that shape such environments and enable the proliferation of plant and animal communities. "…instinct is in this rare occasion aligned with reason…to the degree that we come to understand other organisms, we will place greater value on them…".[15] His ideas resonate on a multitude of levels, both environmental and humanistic, and form the basis for modern environmental stewardship.[16] In 1993 E.O. Wilson published *The Biophilia Hypothesis*, coauthored with Yale University professor of social ecology, Stephen Kellert. Featured in this encompassing review of social and environmental science and theory is a chapter by Roger S. Ulrich on the findings of landscape preference studies in support of the biophilia theory that he summarizes as,

> "the strong tendency across different groups and cultures to prefer unspectacular or even mediocre natural scenes over urban settings lacking nature; the pattern for certain broad classes of natural content (vegetation, water) to elicit more positive responses than artificial contents; and the central role that natural versus human- made content appears to play in perceptual categorization of physical environments."[17]

Due to the large amount of published research on this topic in the nearly thirty years since the introduction of Wilson's theory, the notion of biophilia has been supplemented by other, coinciding theories that address the health impacts of human relationships with nature. Many studies, in both social and earth sciences, have corroborated Wilson's rhetoric with results exhibiting positive human health effects from exposure to elements such as trees, water and vegetation.[18] One example of this type of research is the work of University of Michigan psychology professors Rachel and Stephen Kaplan. The Kaplan's research focuses on the nuances of how exposure to certain environmental features can have positive physiological and psychological effects on humans. In one study Stephen Kaplan cites prose from an essay by Frederick Law Olmsted as an explanation of what his research seeks to unveil,

> "[natural scenery] employs the mind without fatigue and yet exercises it; tranquilizes it and yet enlivens it; and thus, through the influence of the mind over the body, gives the effect of refreshing rest and reinvigoration to the whole system."[19]

Imbedded in this notion of innate human connection to nature is a loaded question, what *is* nature? Studies from Ulrich, the Kaplans and others show that positive or restorative responses to natural settings are not limited to the experience of wilderness. In fact, many of these studies use urban vegetation and water systems, or urban ecology, to test responses to and associations with nature.[20] The comparisons or

controls for such studies tend to be urbanized areas lacking any natural form or function, like Ulrich's brick wall. Overall findings suggest that, when comparing responses to human development with and without natural components, the former caused stress and fatigue while the latter restored a sense of well-being.[21]

In the last decade, a focus on urban ecology and climate change in many environmental fields has spurred discussion about the concept of new nature or "novel ecosystems". The words "nature" or "natural" and "ecology" often bring to mind pristine systems in wilderness like national parks and forests. But when nature and ecology are considered in the urban context or the context of post-industrial sites, the meaning of those words and the images they conjure begin to change. As urbanization expands, humans become more dependent on urban notions of nature, making places like city parks and greenways increasingly important. Recognizing human affinity for natural settings removed from wilderness is key to the valuation of urban greening efforts. But while the importance of urban ecology has found a footing in mainstream design rhetoric, restoring ecology to post-industrial sites still lags behind. However, in light of what we know about the benefits of urban ecology, it stands to reason that if a tree offers therapeutic effects not afforded by a brick wall, many trees could offer immeasurable benefits in place of contaminated waste. In this vein, reintroducing ecological processes on contaminated sites provides both functional and psychological benefits. While psychological and physical adaptations to urban ecology may be underway, these adjustments to considering ecology and nature on post-industrial sites must be augmented by the necessity for resilience, survival and remediation in a toxic context. Despite misgivings about the risks of replanting post-industrial sites, there is ample evidence to suggest that plants are a powerful tool for remediation.[22] Many plants can not only survive in hazardous or disturbed conditions but will also thrive and over time, create their own autonomous ecological systems that do as much to clean and contain pollution as they do to supplant the appearance of barren wastelands.[23] While these new ecological systems may divert from traditional notions of nature, they may also be the future of the contemporary environment.

In their respective texts, environmental journalists, Emma Marris and Fred Pearce call for a reevaluation of traditional ideas about what constitutes ecology and what we consider "natural" in an anthropogenic world. They call to question the current role of conservation in the age of climate change and the urban environment, positing that new, more robust, forms of ecology are superseding traditional notions of ecosystems in the urban environment. These hybrid systems have been termed "novel ecosystems" as they represent communities of organisms unseen or unacknowledged until recently. Arguments to embrace novel ecosystems stem from the convergence of several increasingly urgent topics; climate change, species extinction and migration, and rapid urbanization. In her 2011 book, *Rambunctious Garden*, Emma Marris, defines novel ecosystems as,

> "…new, human-influenced combinations of species that can function as well if not better than native ecosystems and provide for humans with ecosystem services of various kinds – from water filtration to carbon sequestration to habitat for rare species."[24]

Marris posits that it is these types of ecosystems that are becoming increasingly important to acknowledge as valid forms of ecology. Not only from a conservation stand-point but also in terms of design, particularly in environments that have been degraded.

Fred Pearce, expounds Marris' claims in his 2015 book *The New Wild*. Pearce claims that non-native species should be understood as inherently natural, as travelers of the world whose geographical limits are dictated only by the humans who transport them and the conditions they require to survive. He pushes this theory further by specifically addressing species considered invasive or naturalized, so successful in foreign climates that they out-compete many native species. While he acknowledges the rampant succession of introduced species he uses the resilience and success of these interlopers as a qualifying characteristic

of biological value in the face of global climate change. “Alien species may be scary sometimes. But they are nature at its best, and in the twenty-first century they may be its opportunity for revival after the damage done to it by humans”.[25] Pearce also advances Marris’ definition of novel ecosystems, positing that it is the combination of often self-selected native and non-native species that create self-sustaining hybrid ecosystems “- composed of new combinations of native species and species introduced by humans, but where the system itself does not depend on humans to keep it going”.[26]

Neither Marris nor Pearce makes these claims in a vacuum. Among many others, both authors cite the work of Ariel Lugo, ecologist and director of the International Institute of Tropical Forestry in Puerto Rico, as pivotal evidence for the viability of nonnative species to form productive novel ecosystems. Lugo has found that in combination with native species, many so-called alien plant species can form diverse, productive ecosystems from barren agricultural fields and plantation sites. After sugar plantations in Puerto Rico were abandoned by locals for work in factories, the compacted and nutrient poor fields were colonized first by hardy introduced species, creating microclimates habitable by native species where they otherwise would not have been able to thrive. One charismatic native species in particular benefitted from the successional reforestation of sugar plantations. The coqui frog, placed on the endangered species list after massive deforestation, has now rebounded and continues to proliferate in the new hybrid forest systems that have successively replaced abandoned plantations in Puerto Rico.[27]

Another example of this type of hybrid-ecosystem success, are Lugo’s study of pine plantation understories. As much by chance as by research and investigation, Lugo found that the biomass, diversity and nutrient efficiency in the understories of non-native pine plantations exceeded that of the sparse and quickly disappearing native forest systems in Puerto Rico.[28] Although such hybrid systems may contain unfamiliar species alongside those cherished for generations, these new ecologies show that success is not created by distinctions between native and non-native species. Ecology has proven that it places value only on function, resilience and adaptation.[29]

An example of the power of novel ecosystems in the Pacific Northwest (the climatic region of this thesis) are the findings of Jud Isebrands, member of the International Poplar Commission and commercial poplar grower. Isebrands found that dense poplar stands, grown from cuttings to mitigate groundwater pollution in Washington State, created lush habitat after only a few years of growth. The microclimates created by the rapid tree growth allowed understory species to colonize the stand and provided habitat cover for wildlife. Additionally, the rapid root growth of the trees enhanced the microbial community in the soil – contributing to the degradation of pollutants in the soil and water table.[30]

The ability of plants to adapt to difficult growing conditions and a changing climate using resources only available through proximity may provide the back bone for the future of what we consider “nature”. If considered alongside the theory of biophilia, Lugo, Marris and Pearce’s arguments for embracing novel ecosystems reveal the latent potential of using plants to remediate post-industrial sites. If novel ecosystems can be formed on post-industrial sites through introducing specialized native and non-native species, selected or encouraged specifically for the services they offer, the remediation of these sites can begin in earnest. Reintroducing plant species to these landscapes enables their transition into another phase of history. The presence of thriving ecosystems on these sites could not only enable the clean-up and stabilization of contamination on site, it could also begin a shift in perception needed to foster human connection and stewardship to places that have been historically shunned. By embracing new forms of ecology we can begin to construct productive narratives of cleansing and healing on post-industrial sites through the application of a range of plant species.

Phytoremediation: Mechanisms for Regeneration

Phytoremediation and bioremediation are the application of specialized

organisms such as plants, trees and microbes to absorb, break down and remove organic and inorganic chemical pollutants in soil and water.[31] As relatively new fields, technological advancements in phytoremediation and bioremediation are improving, particularly in the last decade with the implementation of biological engineering.[32] There are, however, gaps in funding that limit the diversity of scientific studies and the extent of those studies.[33] Despite this, there is a great deal of work that has been done around the use of plants (phyto) and microbes (bio) to extract organic and inorganic pollutants from elemental resources (remediation). These processes have been studied in lab and field trials in order to understand and catalogue the mechanisms behind an organism's ability to remediate polluted resources at remarkably lower costs than traditional methods of toxics cleanup.[34] Traditionally used methods for post-industrial remediation tend to be costly and can be hazardous, sometimes with unpredictable outcomes. The most stable of these is known as "dig and dump", whereby contaminants are removed using heavy equipment, transported to a hazardous waste landfill and disposed of through burying, or capping. Other methods, using chemicals and in-ground systems to treat soil and water contamination often have limited uses and can have unintended consequences such as overheating soils or exacerbating existing pollution.

The *International Journal of Phytoremediation* and others, such as *Current Topics in Plant Biology*, publish current, peer-reviewed studies of phytoremediation technology. Papers featured are often published by plant microbiologists, including Dr. Sharon Doty at the University Washington, Dr. Jud Isebrands formerly of the United States Forest Service, and Dr. Lou Licht of EcoloTree. Dr. Doty's lab at the University of Washington researches the improvement of phytoremediation performance through biological engineering to enhance naturally occurring endophytes, internal microbial symbionts that assist plants with water and nutrient exchange. Her lab has found that endophytes, communities of microorganisms inside plant's living tissues, greatly assist the rate of contaminant absorption, storage and degradation and have been shown to make plants more resilient to toxic and generally stressful growing environments.[35] Dr. Licht and Dr. Isebrands operate small commercial phytoremediation businesses respectively. Their projects are primarily focused on using specific clones of poplars and willows to remediate a variety of sites and contaminants. While the work of Dr. Isebrands and Dr. Licht remain largely unpublished, there is significant circumstantial evidence to support the effectiveness, safety, cost-efficiency and viability of phytoremediation.[36] While I will not overlook unpublished case studies and findings in the field, it should be noted that published peer-reviewed findings represent ideal evidence while unpublished works are problematic to cite and hinder the advancement of the field, particularly for use in large-scale public works projects.

In recent years, the success of phytoremediation studies, both published and unpublished, and the apparent viability of phytoremediation for managing contaminated sites, has brought these processes to the attention of landscape architects and designers as a promising tool for landscape design. In their 2015 book *Phyto*, Niall Kirkwood and landscape architect Kate Kennen create a contemporary framework and user's guide for phytoremediation as functional landscape design. Kennen and Kirkwood use graphic illustrations, case studies and design templates to highlight implementation of phytoremediation on a range of sites that address nuanced contamination in a variety of scenarios. They outline the history of the field, its opportunities and weaknesses, and diagram the mechanisms and relationships necessary for understanding the complexity, and potency, of this quickly advancing technology.

A range of pollutants may be remediated using plants, each contaminant requiring a mechanism that particular plants are specialized to provide. Many plants have evolved to survive in harsh conditions, developing the abilities to maintain a competitive edge against predators, disease and environmental stress. Mechanisms occurring in plants for water and nutrient absorption can, in some specialized species, assist in the uptake and storage or chemical decomposition of many organic and inorganic pollutants. Dr. Licht has implemented successful, site scale,

phytoremediation projects across the U.S. using primarily poplar and willow clones to absorb and break down chemical pollutants. Dr. Licht recently completed projects in Washington State using poplar clones to clean waste water for the town of Coupeville on Whidbey Island and implementing a mixed tree cap to prevent chemicals from the Duvall Landfill from leaching into surrounding areas.[37]

There are eight mechanisms of phytoremediation that are typically expressed as autonomous processes, although many of them are parts of one system and may occur simultaneously. Different species of plants have adapted to specialize in one mechanism or combinations of mechanisms to suit particular biological needs such as defense against predators, maximizing nutrient use or surviving drought. These mechanisms are referred to as phytodegradation, phytoextraction, phytovolatilization, phytohydraulics, phytostabilization and rhizodegradation. The range of mechanisms, applications and uses of phytoremediation technology enhance the potential for using phytoremediation as a tool to create landscape design that responds to and enhances its environment. There are a veritable plethora of sites across the U.S. where phytoremediation could be implemented as a long term, low cost and low maintenance strategy to mitigate the environmental and public health hazards presented by contaminated sites. Implementing phytoremediation on post-industrial sites would set in motion the rehabilitation of these places and increase their potential for reuse. One site, of particular relevance in discussions of post-industrial reuse, began its journey toward remediation nearly forty years ago and today, continues to engage generations of scientists and designers in its rehabilitation and reuse. Gas Works Park, an icon in a progressive city and a precedent for many post-industrial redesigns, stands today as a symbol of regeneration – a site whose history tells us that anything is possible.

Gas Works Park: A Legacy of Progress

Gas Works Park represents the parent of post-industrial reuse projects. A 20.5 acre promontory that juts 400 feet into Lake Union, with 1,900 feet of shoreline, the former manufactured gas plant site is highly visible from many of the hills that characterize Seattle's landscape. After more than a decade of public controversy over what to do with the deeply contaminated former manufacturing plant, the construction of a truly unique park was begun. The park's designer and most active advocate, landscape architect Richard Haag, began by saving as many of the original structures as possible to maintain what he referred to as the most 'sacred' aspects of the site.[38] While these towers have become a cherished landmark to many, they also speak to the toxic history of the site and deeper processes of the founding of the city at large. The site's contamination from half a century of coal gasification and several major oil spills during its time as a heating oil plant were the next critical issues to be addressed on site by Haag.

A radical practice in the 1970s, Haag used a variety of organic matter and bacterial microbes to begin remediating soils polluted with polycyclic aromatic hydrocarbons and other petroleum byproducts across the park. He did this by tilling and aerating the soil and adding mixtures of leaf litter, human bio-solids, sawdust and microbial mixes often used to improve soil fertility for farming. Where there had once been a toxic wasteland, Haag's innovative techniques transformed the landscape. Where only oil slicks and rubble had existed the year before, now sprouted grasses – eventually covering the landforms Haag would create in a lush green patina. Though hard won, the radical landscape Haag was able to create through his sensitivity to its history and post-industrial conditions, marked the beginning of a shift in sensibility which is today a well discussed topic. This shift has, in fact, come to be understood as an underlying paradigm shift occurring across disciplines. As landscape historian Thaïsa Way writes in her 2015 retrospective of Haag's work and life,

> "Methods of bioremediation and phytoremediation are being tested in a wide range of landscapes and spaces and are taught in landscape architecture and ecological design programs in many universities. What was once considered terribly risky by Seattle is now considered appropriate and necessary at many sites around

the world. Haag's groundbreaking work opened that door…"[38]

Richard Haag's treatment of Gas Works Park, both in structure and land, was a triumphant precedent for future generations of designers around the world. The bulk of literature on Gas Works Park and the work of Haag himself speaks amply to the significance of his actions at the former gas plant. However, results from consistent monitoring of buried wastes still lingering underground from the site's industrial days speaks to a need for reassessment of the park's current health. In conjunction with the Seattle Parks and Recreation Department (SPD) and the City of Seattle, the Washington State Department of Ecology (WSDOE) has, over the past 30 years, maintained consistent monitoring of the site's soils and groundwater through several series of wells and borings. Additionally, WSDOE has conducted sediment sampling from Lake Union in the immediate sediment area around Gas Works Park. These studies show conclusively, and in great detail, that some areas of the park have maintained a deep layer of toxicity which rests above the site's subsurface glacial till, in some places at or below erratic groundwater levels. Similarly, there is evidence that suggests these underlying toxic materials have continued to leach into the adjacent sediments of Lake Union, *(please see illustrations on pg. 14-15).*

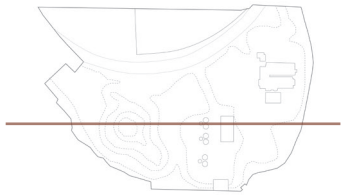
Despite scientific evidence that suggests Gas Works Park is in need of new interventions to prevent continued leaching and possible contaminant exposure, using phytoremediation at the site is believed to be unappealing, or even alarming, to park users.[39] Many public space stewards believe that phytoremediation would be rejected by park users or viewed as an encroachment on the park experience, especially where tree growth could intrude on views of the lake. Studies done by Ellen Weir, in her doctoral dissertation for the School of Environmental and Forest Sciences at the University of Washington, suggest otherwise.

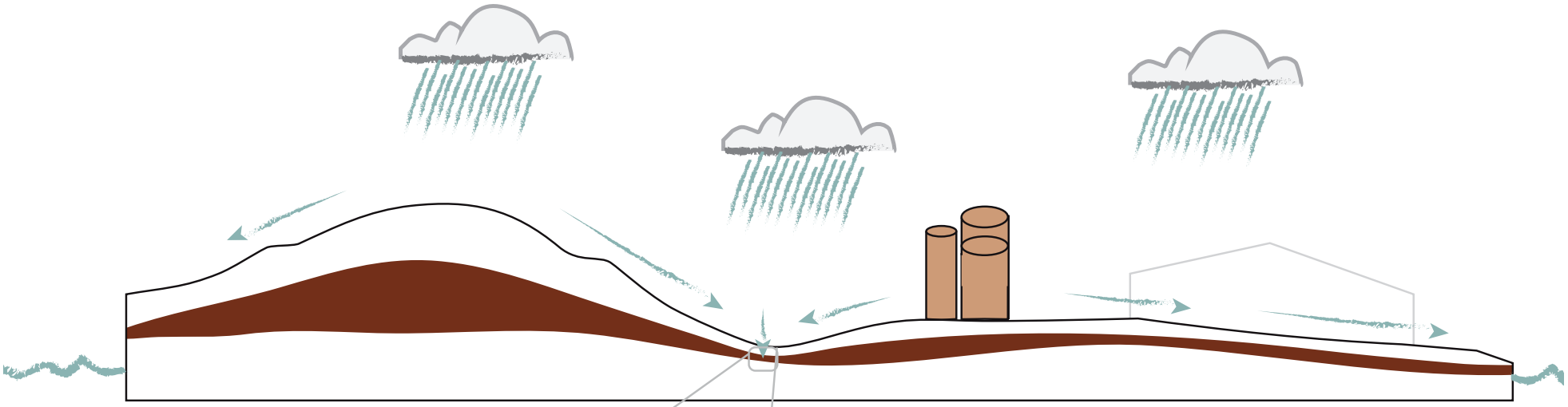
Weir's doctoral research focused on the social barriers, perceived and real, between successful phytoremediation of contaminants at an already established, and well-loved, park. She conducted focus groups of nearby stakeholders and surveys of park users to understand public perceptions of Gas Works Park and to assess public reaction to the possibility of using phytoremediation to continue cleaning the site. Her findings were overwhelmingly positive.[40] She found that the attitude of the neighborhood, and the majority of the park users, embraced the idea of phytoremediation at the park – partially for the love of the landmark and partially due to ethical considerations regarding environmental and human health concerns. In addition to supporting the idea of phytoremediation on site, Weir found that participants were eager to propose their own ideas about the best way to implement phytoremediation in terms of user experience and design,

> "Evaluations of phytoremediation at Gas Works Park were overwhelmingly positive. One notable observation was focus group participants' enthusiasm for the use of phytoremediation. Without any prompting for suggestions, participants volunteered ideas for ways to promote phytoremediation and increase acceptability."[41]

Many focus group participants agreed on the most important recreational functions of the park and described areas where phytoremediation plantings would inhibit use. Of primary concern were maintaining views from Kite Hill, the great mound at the west edge of the site, and use of the Prow area at the south tip of the site for site seeing and events. Other considerations were sports played in the central field area north of the Cracking Towers and pathway circulation. Without solicitation, focus group participants made suggestions for how social acceptability of phytoremediation interventions could be improved. Many participants suggested interpretive signage, making users aware of the park's history and the purpose of phytoremediation plantings. While some participants were concerned about the human health impacts of pollution at the park, most of the participants seemed to care more about environmental impacts on the lake. Weir cites generally ecocentric feelings, ie: nature-centered values, of the group as a good predictor of acceptability of phytoremediation.

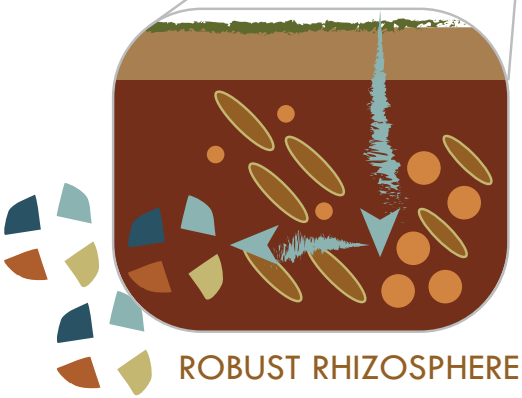
DESIGN INTENT





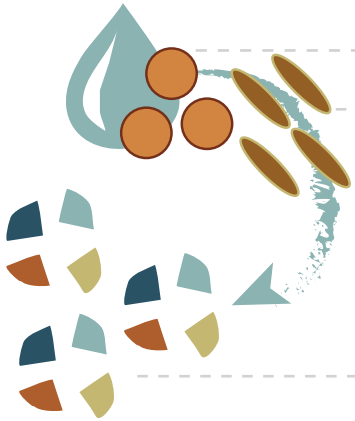
AERATED SOIL





ROBUST RHIZOSPHERE

COMPLETE REMEDIATION



PAHs

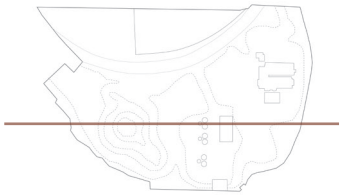
microbes

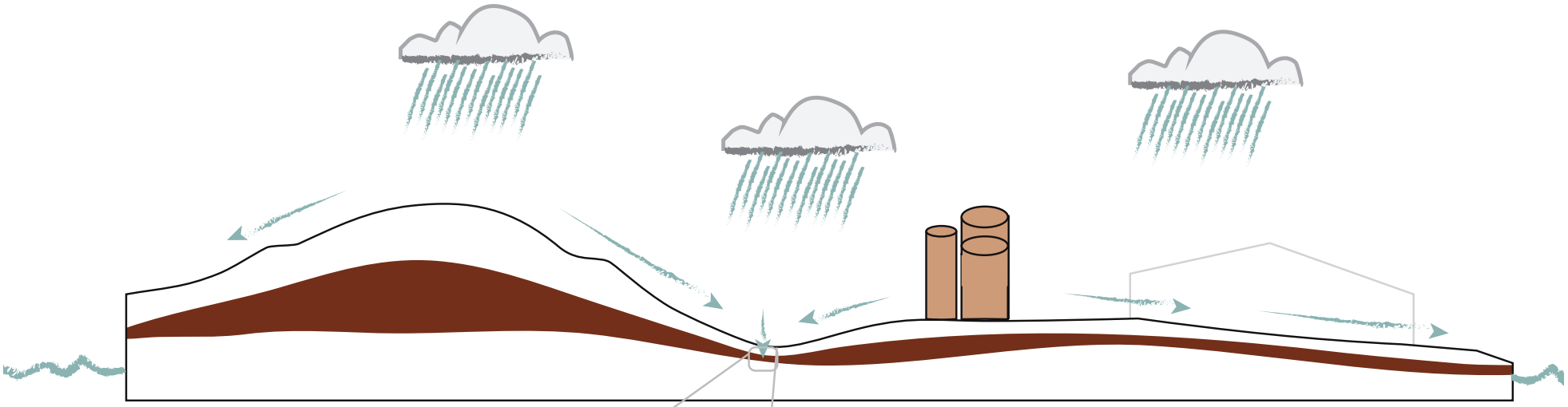
water circulates through soil, aerating and enhancing microbial activity to break down pollutants

PAHs broken down into non-toxic elements

DESIGN REALITY

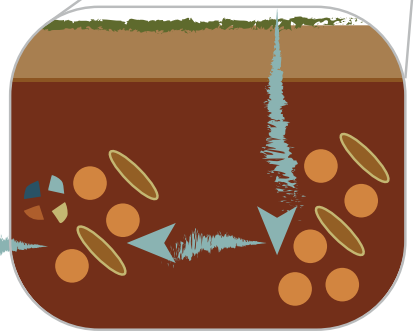
+40 years
of heavy use





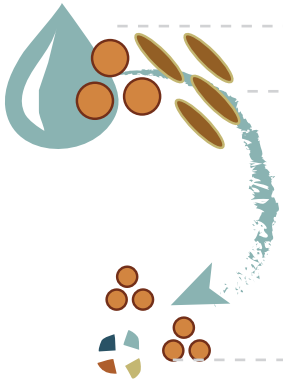
COMPACTED SOIL





WEAK RHIZOSPHERE

LIMITED REMEDIATION



PAHs

microbes

water percolates through soil, soil is compacted by heavy rain + use, water weathers pollutants, becoming contaminated

PAHs primarily weathered by water, only partially broken down

Rationale for Continued Remediation

Literature, studies and interviews discussing Gas Works Park, its contentious history and what its future may hold are beacons of the park's continued significance, to the City of Seattle and the global stage of landscape practice. All discussion of the park, its methods and materials, its users and their ideas and preferences, can be tied back into the larger discussion of rehabilitating contaminated sites. The role of these contested landscapes in contemporary consciousness reflect issues of mental, physical and environmental health. The sheer bulk of knowledge and opinion that has been accrued on Gas Works Park in the last half century continues to mature a paradigm shift in theory, aesthetics and practice.

The expansion of theory, regarding the design and social acceptance of contaminated landscapes, cannot be addressed without a sense of urgency. As our climate changes and our environments begin to shift beyond our control, the ways we reuse our land could directly impact our ability to adapt. Instead of wastelands of rusting rubble leaching toxic plumes, these vast landscapes of inactive industry could be rows of trees, sequestering carbon and absorbing pollutants, or fields of grasses breaking down contaminants lingering in soil and water while providing habitat for a range of species. In light of the changes occurring in our climate and the acceleration of paradigm shifts in ecology, land use and remediation, a strong case can be made not only for the remediation and reuse of post-industrial landscapes but also for the particular use of plants and microbes to remediate such spaces for reuse by people and for creation of habitat. It is this interwoven function, the dual purpose that landscape design must take on in order to adapt, that this thesis proposes is missing at Gas Works Park.

In designing and constructing Gas Works Park, Richard Haag advanced the philosophy of post-industrial reuse considerably, including an interdisciplinary approach towards a landscape that has begun, in many ways, to heal itself. However, in order to continue the process initiated by Haag, more remediation is needed. Embellishing existing forms, using vegetation above-ground to signal remediation below-ground, Gas Works Park could embark on the next phase of its remediation, one which evolves physically over time, revealing the long time scale of the processes necessary to continue contaminant clean-up. Through interpreting the rehabilitation of a post-industrial landscape as a park of constant change, instead of a place of rigorous stagnation, I intend to engage notions of drosscapes, uncertain parks and a paradigm shift in landscape practice, ecology and culture in order to translate history, industry and nature into a refreshed landscape of experience.

Research Questions

What contamination remains on site?
Identify and catalogue the type and severity of contamination that is above EPA cleanup standards and known to be hazardous (toxic, mutagenic, etc.).

Where is contamination concentrated and how deep?
Compile the levels and depths of contamination across the site to look for trends in concentration, depth and spread.

Which plants and in what configuration could be used to continue remediation?
Find and review empirical studies to support species/contaminant specific remediation with consideration to climate, contamination levels and depths. Reviewing studies to understand how the forms of phytoremediation plots effect their effectiveness and outcome.

How could phytoremediation be designed to enhance human experience and facilitate education?
Examine environmental psychology research and design to experiment with forms that visually communicate above ground, remediation occuring below ground.



REFERENCES

1.) Berger, Alan. *Drosscape : Wasting Land in Urban America,* 1st ed. (New York: Princeton Architectural Press, 2006): pg. 239.

2.) Ibid. pg. 241.

3.) Ibid. pg. 12.

4.) Ibid. pg. 239.

5.) Meyer, Elizabeth K. "Uncertain Parks: Disturbed Sites, Citizens and Risk Society," in *Large Parks,* ed. Julia Czerniak and George Hargreaves (Cambridge, Mass.: Princeton Architectural Press ; in association with the Harvard University Graduate School of Design, 2007): pg. 59.

6.) Mira Engler and Center for American Places., *Designing America's Waste Landscapes*, Center Books on Contemporary Landscape Design (Baltimore: J. Hopkins University Press, 2004).

7.) Krinke, Rebecca. "Overview: Design Practice and Manufactured Sites," in *Manufactured Sites*, ed. Niall Kirkwood (London, New York: Spon Press, 2001): pg. 125-149.

8.) Ibid. pg. 148.

9.) Braae, Ellen Marie. *Beauty Redeemed: Recycling Post-Industrial Landscapes* (Basel: Birkhauser Verlag GmbH, 2015): pg. 12.

10.) Ibid. pg. 12.

11.) Ulrich, Roger S. "View through a Window May Influence Recovery from Surgery," *Science* 224 (1984).

12.) Wilson, Edward O. *Biophilia* (Cambridge, Mass.: Harvard University Press, 1984).

13.) Roger S. Ulrich and Statens råd för byggnadsforskning (Sweden), *Aesthetic and Emotional Influences of Vegetation : A Review of the Scientific Literature*, Document / Swedish Council for Building Research (Stockholm: Swedish Council for Building Research, 1985).

14.) Wilson, *Biophilia.*

15.) Ibid. pg. 2.

16.) Ibid.

17.) Ulrich, Roger S. "Biophilia, Biophobia and Natural Landscapes," in *The Biophilia Hypothesis*, ed. E.O. Wilson adn Stephen Kellert (Washington, D.C. : Island Press, 1993): pg. 97.

18.) Roger S. Ulrich and Statens råd för byggnadsforskning (Sweden), *Aesthetic and Emotional Influences of Vegetation : A Review of the Scientific Literature.*

19.) Kaplan, Stephen "The Restorative Benefits of Nature: Toward an Integrative Framework," *Journal of Environmental Psychology* 15, no. 3 (1995): pg. 174.

20.) Ulrich, "Biophilia, Biophobia and Natural Landscapes."

21.) Ulrich and Statens råd för byggnadsforskning (Sweden), *Aesthetic and Emotional Influences of Vegetation : A Review of the Scientific Literature.*

22.) Gupta, Dharmendra Kumar, Plant-Based Remediation Processes, (Heidelberg ; New York: Springer,, 2013)

23.) Doty, Sharon L. "Enhancing Phytoremediation through the Use of Transgenics and Endophytes," *New Phytologist* 179, no. 2 (2008).

24.) Marris, Emma. *Rambunctious Garden : Saving Nature in a Post-Wild World*, 1st U.S. ed. (New York: Bloomsbury, 2011): pg. 112.

25.) Pearce, Fred. *The New Wild : Why Invasive Species Will Be Nature's Salvation (*Boston : Beacon Press, 2015): pg. 151.

26.) Ibid. pg. 153.

27.) Marris, *Rambunctious Garden: Saving Nature in a Post-Wild World:* pg. 113.

28.) Ariel Lugo and Eileen Helmer. "Emerging Forests on Abandoned Land: Puerto Rico's New Forests," *Forest Ecology and Management* 190 (2003).

29.) Pearce, *The New Wild : Why Invasive Species Will Be Nature's Salvation:* pg. 153.

30.) J.G. lsebrands, et. al. "Environmental Applications of Poplars and Willows," in *Poplars and Willows: Trees for Society and the Environment,* ed. J.G. Richardson Isebrands, J. (Boston, MA: CABI and FAO, 2014).ed.

31.) United Nations Environment Programme, "Phytoremediation: An Environmentally Sound Technology for Pollution Prevention, Control and Remediation," *Newsletter and Technical Publications: Freshwater Management Series No. 2* (2015), http://www.unep.or.jp/Ietc/Publications/Freshwater/FMS2/1.asp.

32.) Doty, "Enhancing Phytoremediation through the Use of Transgenics and Endophytes."

33.) Glass, D.J. "International Activities in Phytoremediation: Industry and Market" (paper presented at the Phytoremediation and Innovative Strategies for Specialized Remedial Applications, Proceedings of the 5th International In Situ and On-Site Bioremediation Symposium, Columbus, OH, 1999).

34.) Justin B. Hollander, Niall Kirkwood, and Julia L. Gold, *Principles of Brownfield Regeneration : Cleanup, Design, and Reuse of Derelict Land* (Washington: Island Press, 2010).

35.) Zareen Khan and Sharon Doty, "Endophyte-Assisted Phytoremediation," ***Current Topics in Plant Biology*** 12 (2011).

36.) lsebrands, "Environmental Applications of Poplars and Willows."

37.) Doty, Sharon L. ***Phytoremediation of Organic Pollutants***, ***SEFS 525: Environmental Application of Plants*** (University of Washington2015).

38.) Way, Thaïsa. ***The Landscape Architecture of Richard Haag : From Modern Space to Urban Ecological Design*** (Seattle: University of Washington Press, 2015): pg. 167.

39.) Weir, Ellen. "Assessing the Social Acceptability of Endophyte-Assisted Phytoremediation of Polycyclic Aromatic Hydrocarbons: A Case Study at Gas Works Park" (ProQuest Dissertations Publishing, 2015): pg. 2.

40.) Ibid. pg. 63.

41.) Ibid. pg. 63.



20 *(Ford River Rouge Plant, William McDonough + Partners, 2000)*

CASE STUDIES
lessons from implementation

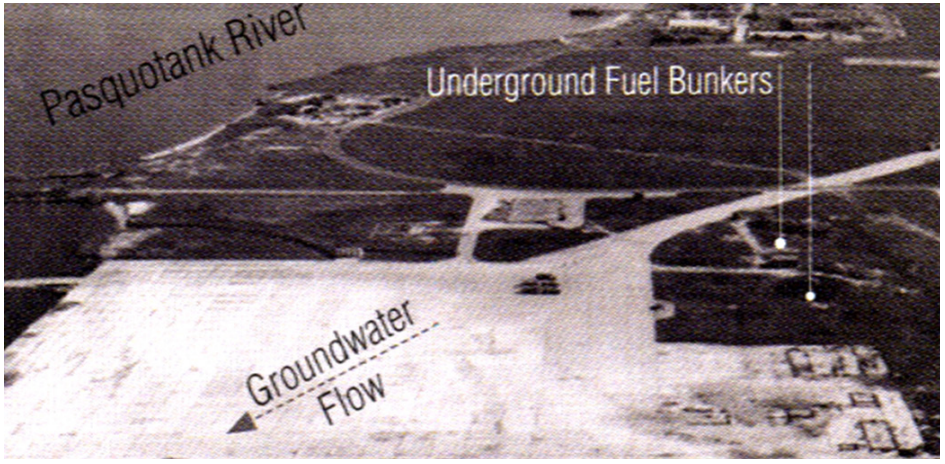
Each case study presented in the following section was selected for its relevance to the effectiveness of phytoremediation, design implementation and user experience, focused primarily on public space. While each case study offers specific lessons, as a whole these projects can be viewed as continued rationale for designing phytoremediation at Gas Works Park. Broken roughly into categories, each project provides detailed insight into one aspect of phytoremediation, ranging from the documented effectiveness of contaminant removal in published research, to the physical forms of designed phytoremediation interventions, to the experience that the combinations of remediation and form may provide. Because phytoremediation design is a complex and site specific endeavor, it is important to review case studies that have been implemented and whose effectiveness and experience over time has been documented. In order to understand how phytoremediation interventions might look, feel and function at Gas Works Park, gaining perspective from a broad swath of practice is essential. These case studies function as instruction and inspiration for this project, providing insight into how practical strategies like phasing, maintenance and monitoring can influence design considerations focused on form, function and experience.

CASE STUDY
PHYTOREMEDIATION: PAHs

U.S. COAST GUARD FORMER FUEL STORAGE FACILITY

Location: *Elizabeth City, NC, USA*
Institutions: *Department of Forestry and Environmental Resources, North Carolina State University, Raleigh, NC*
Time Frame: *2006 - 2007, monitoring on-going*
Primary Reference: *Cook, Guthrie-Nichols, et al. 2014*

Underground fuel tanks on a 5 acre former US Coast Guard fuel farm had been leaking petroleum compounds since World War II. The site is located 490 feet from the Pasquotank River and a plume of polycyclic aromatic hydrocarbons had been identified migrating toward the river through the groundwater. A tree community of hybrid poplars, several species of willow and loblolly pine was established to prevent further groundwater contamination and further spread of contaminants into the river. The groundwater level beneath the site was variable, fluctuating between 4 feet and 9 feet seasonally. Due to this fluctuation the target depth for remediation was between 3 feet and 10 feet below the surface. In 2006, 112 bare-root poplars 4 feet in height and 403 rooted poplar and willow cuttings 3 inches in diameter were installed 10 feet apart in the polluted area. Due to the extremely high levels of PAHs in the soil (testing up to 4436 µg) there was 28% die-off in the first planting. In 2007 new trees were planted including 2,213 poplars, 43 willows and 10 trial loblolly pine. These trees were backfilled with clean soil and their mortality rate decreased to 13%. Within 2 years, soil monitoring showed a 95% reduction in total petroleum hydrocarbons. As of 2013, the last soil and water monitoring recorded for this case study, only one monitoring well remained above North Carolina regulatory cleanup levels for benzene. Measured in 2010, the height of trees planted in the contaminated zone were correlated to the level of contamination present in particular areas. Trees grew taller in areas that showed lower levels of contamination and grew shorter where contamination levels were highest. *(Guthrie Nichols et. al., 2014)*



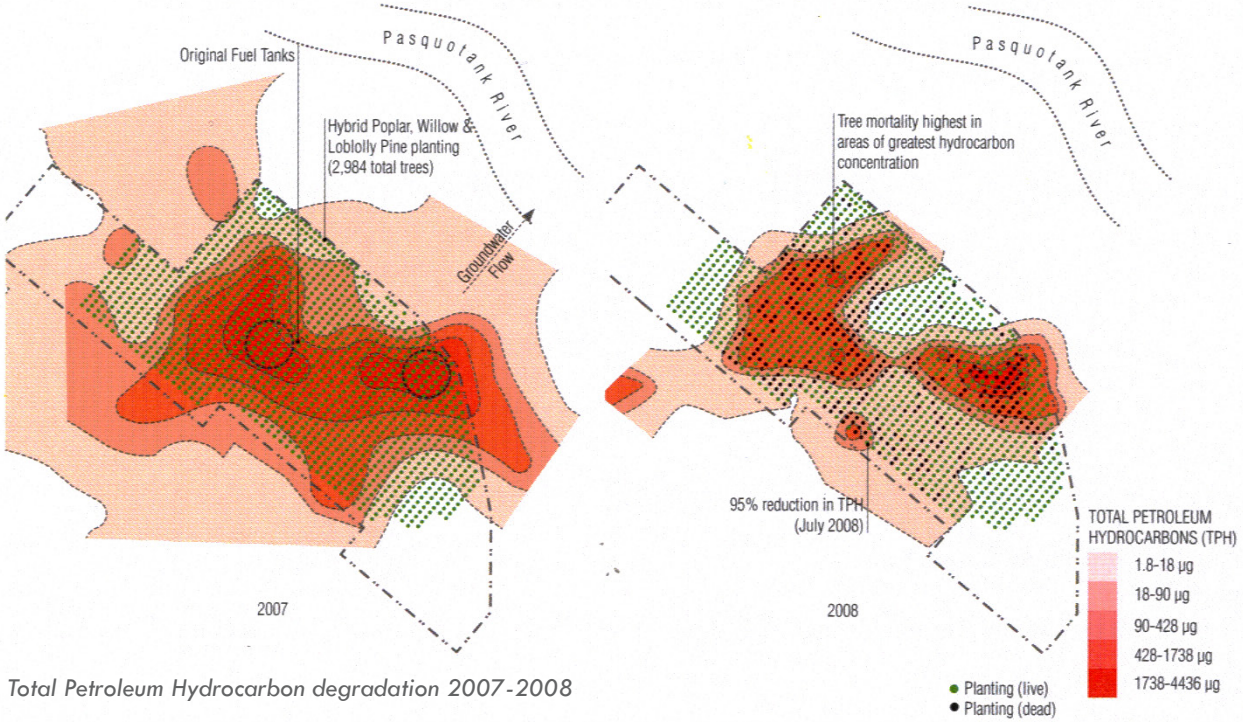
Location of fuel storage in 1942, relative to Pasquotank River. Elizabeth City, NC


Cadets training in newly planted poplar field, area is unfenced and public, 2007

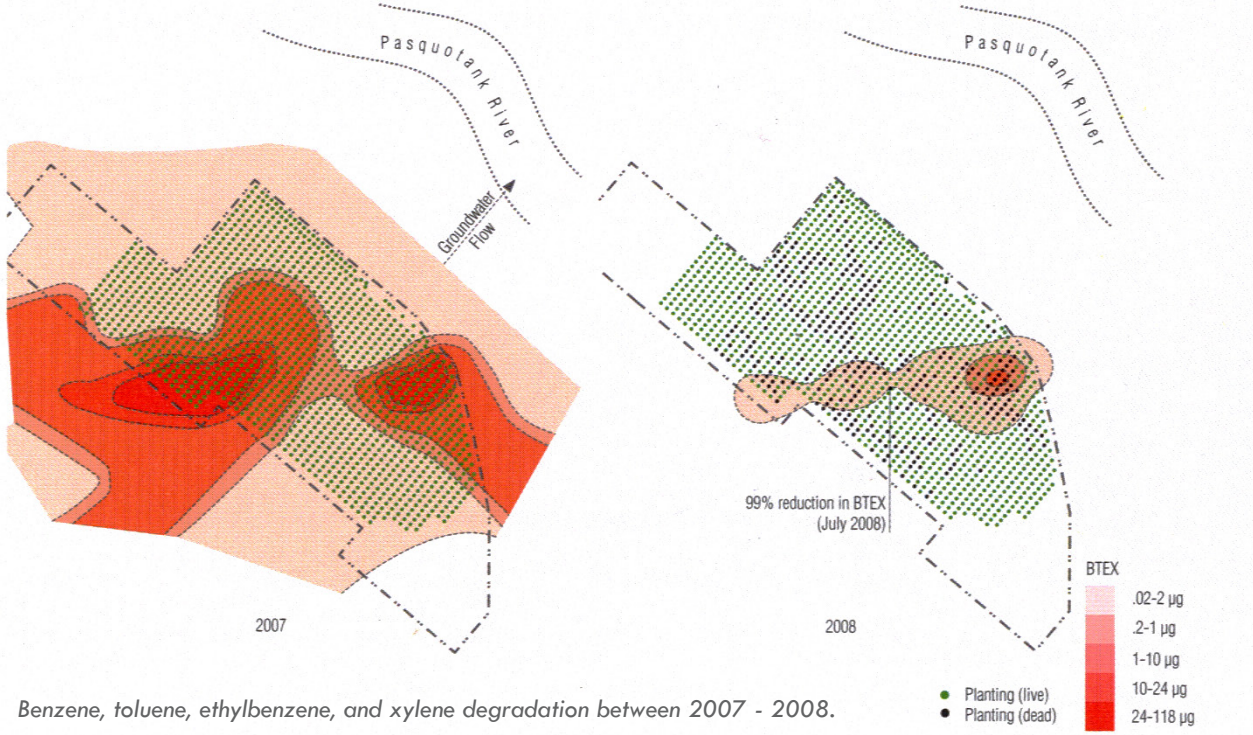


Signs indicating phytoremediation area


Soil gas monitors installed with planting



Total Petroleum Hydrocarbon degradation 2007-2008



Benzene, toluene, ethylbenzene, and xylene degradation between 2007 - 2008.

(All images, Kennen + Kirkwood, 2015)

CASE STUDY
PHYTOREMEDIATION:
Arsenic

SPRING VALLEY FORMERLY USED DEFENSE SITE

Location: *Northwest Washington DC, USA*
Institutions: *US Army Corps of Engineers (USACE), Environmental Protection Agency (EPA), District Department of the Environment, Edenspace Systems Corporation, and Dr. Michael J. Blaylock*
Time Frame: *2004 - 2008*
Primary Reference: *Blaylock, 2006*

An approximately 668 acre former US Military Defense site, Spring Valley is home to 1,600 residences as well as foreign embassies and various commercial properties. The site was originally used to test chemical warfare materials during World War I. In 1993, old explosives were discovered during routine excavation and an environmental investigation was undertaken. Soil sampling across the site revealed about 10% of the area's soils contained high levels of arsenic. Traditional methods, excavating contaminated soil and back-filling with clean soil, was determined too invasive for the residential neighborhood. Phytoremediation plantings using species of the *Pteris*, or brake fern, genus were implemented first in 2004 with 3,000 plants across 3 residences. The operation was expanded in 2005 to include 11 more residences and 10,000 more plants. In 2006, 13 more growing sites were added with a total of 11,000 more ferns planted. Soil was tested and amended with lime and fertilizer if needed before planting, to catalyze the uptake of arsenic by *Pteris*. Consistent soil and plant tissue sampling allowed plants to be removed from soils cleaned of inorganic arsenic. Removed plants found to contain high levels of arsenic were disposed of in a hazardous waste dump, representing a much lighter load than contaminated soil. During the 4 year phytoremediation project most of the sites showed arsenic levels reduced below regulated concentrations by uptake and storage in *Pteris*. However, phytoremediation of arsenic using *Pteris* was not successful for one site in particular so other remediation methods, primarily soil capping, were implemented. *(Blaylock, 2006)*



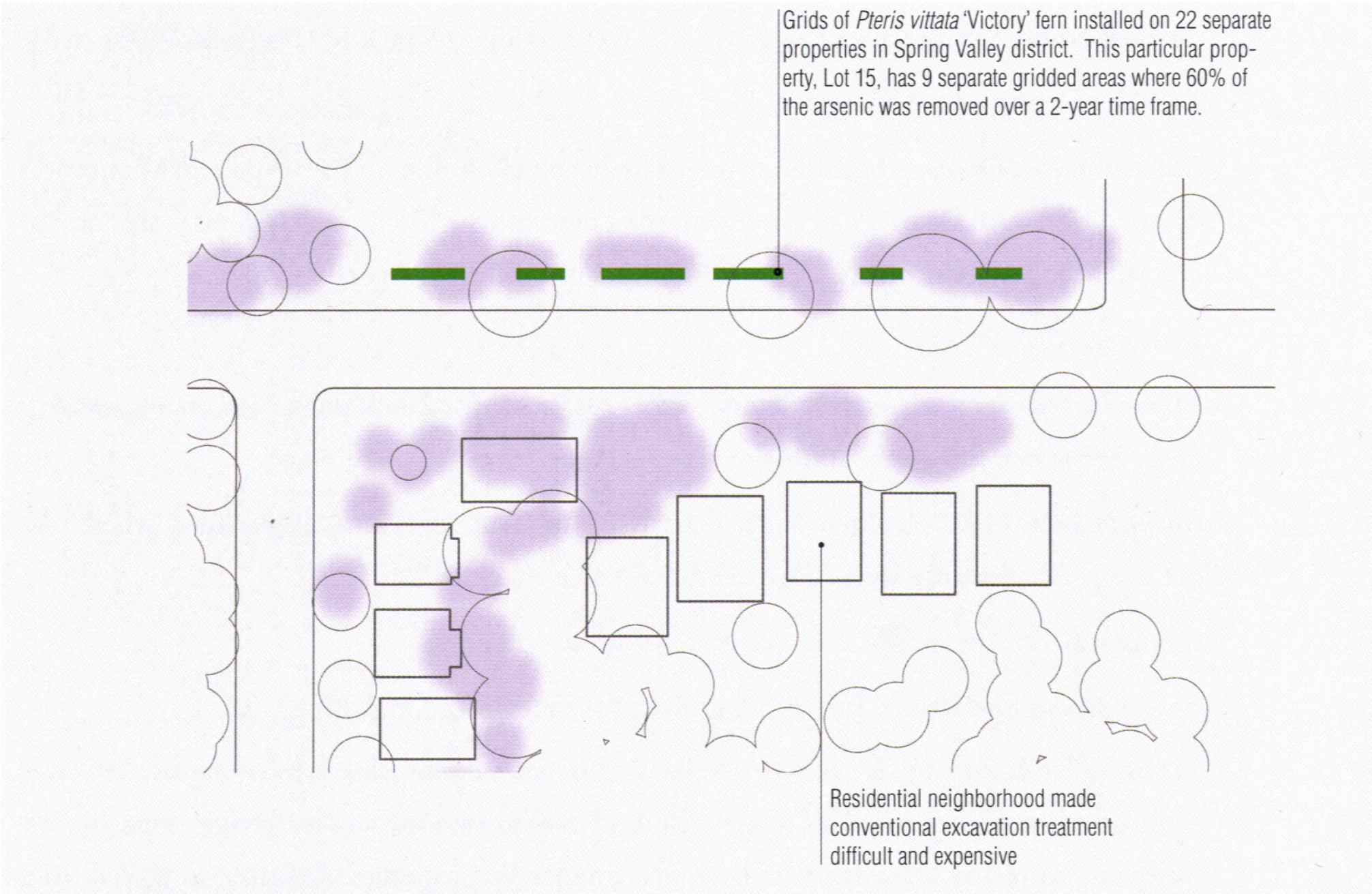
Extraction ferns planted under a residential deck



The extraction fern genus Pteris grows well in shade or partial sun but is not cold-hardy



Extraction ferns incorporated into existing residential landscape plantings



Areas impacted by elevated arsenic soil levels shown in purple, green indicates Pteris plantings
(All images, Kirkwood + Kennen, 2015)

CASE STUDY
DESIGN:
Phytoremediation testing

FORD RIVER ROUGE FACTORY

Location: *Dearborn, Michigan, USA*
Institutions: *Ford Motor Company, Michigan State University and Dr. Clayton Rugh, University of Michigan, William McDonough Architects, and D.I.R.T. studio*
Time Frame: *1999 - 2001, monitoring on-going*
Primary Reference: *William McDonough + Partners, 2011*

After 85 years of car manufacturing, soils at the Ford Manufacturing Center at Rouge River in Michigan were polluted with polycyclic aromatic hydrocarbons. The site underwent redevelopment from 1999 - 2001 to accommodate building and landscape upgrades and the construction of The Ford Center, a museum and tourist destination. Soils under areas in the plant no longer planned for active industrial use were identified as in need of remediation. Instead of typical dig and dump remedial methods, Dr. Clayton Rugh from Michigan State University and Julie Bargmann of D.I.R.T. studio planned phytoremediation testing plots as well as landscapes planted with species tested to be successful remediators. Among the plants tested, about 10 species stood out as effective at accelerating degradation of PAHs and were put into wide use across the site. New England natives *Symphyotrichum novae-angliae, Eutrochium* species and *Amorpha canescens* were among those selected for advanced remediation abilities. Dr. Rugh reported an approximately 50% degradation of PAHs 3 to 5 years after planting. In some cases, Rugh reported as high as 70% reduction in soil PAHs in as little as three growing seasons. This project is unique in several ways; it tests a variety of species native to the region for phytoremediation potential and it tests species on site so that those shown to be effective can be implemented in large scale plantings where needed without changing climatic conditions. This project is not only degrading PAHs in soil, it is also building a plant palette for use across the site.

(William McDonough + Partners, 2011)



Phytoremediation plot using grasses to remediate PAHs (Julie Bargmann, 2000)



Demo plots testing native plant's ability to degrade PAHs in the soil (William McDonough + Partners, 2011)



Many insects and other wildlife were observed using the demo plots (William McDonough + Partners, 2011)

CASE STUDY
DESIGN:
Phytoremediation in public space

HOUTAN PARK

Location: *Huangpu Riverfront, Shanghai, China*
Institutions: *Shanghai World Expo Land Development Company, Turenscape, Peking University Graduate School of Landscape Architecture*
Time Frame: *2007 - 2015*
Primary Reference: *Yu, 2013*

Designed and built on former industrial lands, the approximately 35 acre park was created for the 2010 World Expo in Shanghai, China. Before construction, the site was a linear tract of polluted riverfront land previously used for heavy industry and as a dumping ground. Major issues and concerns on site were the heavy pollution in soil and water, the large amount of remaining debris and an ineffectual flood wall. By creating a series of linear constructed wetlands, filled with annual and perennial plants selected for their abilities to hyperaccumulate or absorb identified pollutants, Turenscape was able to regenerate the landscape. A remarkable improvement in water quality was documented from the topographically highest, most polluted area of the site, to the lowest area of the site. The constructed wetland slows water flow, allowing plants to filter the water. In this case, the plantings perform double-duty, these plants not only effectively filter the water, they also provide seasonal color and texture, presenting striking visual contrast throughout the landscape. The colorful swaths of plantings are a key component of visitor enjoyment at the park. Hosting nearly 600,000 visitors during the 2010 World Expo, the site continues to attract visitors from the nearby city and tourists from around the world. Some of the remediating tracts of plants are harvested seasonally and disposed of due to their uptake of pollutants. Harvesting and replanting creates a seasonal change in the aesthetic character of the park, providing new experiences for park users year-round.

(Turenscape, 2010, 2015 + Yu, 2013)



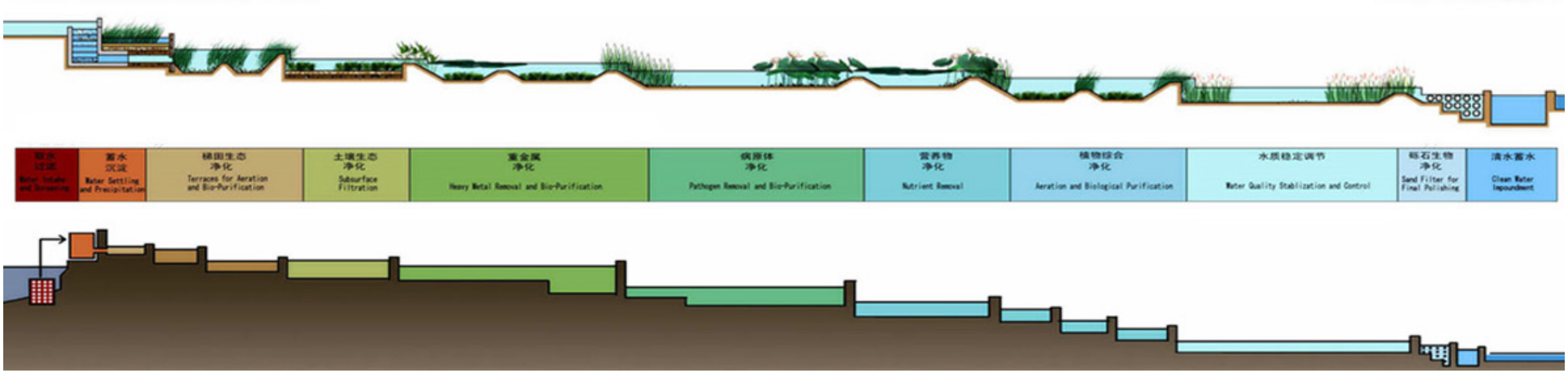
Tall grasses remediate river water and create a unique experience for users



A wide tract of flowering mustard seasonally removes heavy metals from water



Sunflowers seasonally uptake metalloids and provide a pleasant scene



Diagrammatic sections showing water quality improvements through constructed linear wetland *(Turenscape, 2015)*



Site plan from southwest bird's eye view *(All images, Turenscape, 2010)*

CASE STUDY
EXPERIENCE:
Maintenance + Form

LANDSCHAFTS PARK DUISBURG-NORD

Location: *Duisburg, Germany*
Institutions: *International Building Exhibition Emscher Park (federal and local governments), Latz + Partners*
Time Frame: *1990 - 1999*
Primary Reference: *Manufactured Sites, 2001*

Landschaftspark is an interesting case study in this instance because, while it is an internationally renowned project, Gas Works Park was a key precedent for its design. The site was originally a steel manufacturing plant within a heavy industrial district near the Rhine River in Germany. After the steel plant's closure, federal and local government agencies collaborated to create the International Building Exhibition Emscher Park with the goal to revitalize the economy, ecology and social function of the area. Peter Latz and Partners won the park design competition in 1991 with their idea to maintain existing structures and remediate passively using capping and plants. The goal of this concept was to honor the area's industrial past and create new experiences for future users. Latz implemented a variety of planting strategies across the park, each designed to suit the specific needs of particular areas. The most contaminated soils and debris were sealed in existing structures (also heavily contaminated), covered with a soil cap and planted with geometric planting schemes. Geometric plantings were used primarily in areas that featured capping of contaminated material or were planted around structures that were retained from the steel plant. Geometric planting areas are offset by places where natural successional plants have been allowed to colonize and grow-in. Water systems running through the site are cleansed by wetland plantings which help filter the water. Plantings become more naturalistic, often growing in naturally over time, in wet areas of the park and areas where there is no formal programming. The range of planting types require specific maintenance strategies for each area of the park. Some areas are tightly maintained while others are allowed to flourish unabated. *(Kirkwood et al, 2001)*



Water is filtered and cleansed through naturalistic plantings that have developed over time



Partial plan view of the park (All images, Latz + Partners, 1991-2006)



View of tree grid plaza among gas towers



Geometric plantings on capped soils while naturalistic vines grow unmaintained along the walls

CASE STUDY
EXPERIENCE:
Social Acceptability

ASSESSING THE SOCIAL ACCEPTABILITY OF ENDOPHYTE-ASSISTED PHYTOREMEDIATION

Location: *Gas Works Park, Seattle, Washington*
Institutions: *University of Washington, School of Environmental and Forest Sciences*
Time Frame: *2014 - 2015*
Primary Reference: *Weir, 2015*

In her doctoral dissertation, Ellen Weir designed studies to determine the potential reactions of park users to phytoremediation at Gas Works Park. This study responded to two primary factors: a documented need for continued remediation at the park to mitigate residual contaminants and a belief long-held by the Parks Department that park users would respond negatively to remediation plantings. Focus groups and surveys were developed to explore public perceptions of Gas Works Park and to determine reactions to the idea of implementing phytoremediation at the park. Reactions to phytoremediation at the park were gauged using several sociological markers of social acceptability: perception of risk, overall values (ideology), relationship to the site (ownership and participation) and landscape preferences. Because focus groups addressed a small segment of park users, demographic variables were assessed in relation to social acceptability. Focus groups were utilized first and then anonymous surveys were created using focus group results as a guide. Surveys were administered to a larger segment of park users in order to gain a broader swathe of input. All research done in this study was empirically performed and has been peer-reviewed. The results of focus group conversations was overwhelmingly in favor of using phytoremediation at Gas Works Park. Survey results also showed a high level of social acceptability of phytoremediation at the park. Ecocentrism and concern for human and environmental health were found to be significant predictors of acceptability. Many participants offered suggestions for plantings without solicitation.

(All images + information, Weir, 2015)

Emergent Themes...

"Perceptions of phytoremediation were overwhelmingly positive. Responses from focus groups and surveys both indicated that park users would be accepting of the use of phytoremediation at Gas Works Park"

"There was a great degree of interest in phytoremediation and a clear hunger for more knowledge about the process, as evidenced by the high number and intensity of questions about phytoremediation, and readily offered suggestions for ways to implement the technology"

"Focus group participants expressed a great deal of enthusiasm for including a scientific educational component to accompany the implementation of phytoremediation"

"Another participant suggested that maintaining the view is the only thing that would matter in terms of acceptability, saying, 'I think as long as you preserve the view at the top of the hill I do not think people would have a problem with it. Planting trees isn't a conflict of interest'"

(Weir, 2015)

"...the history of the park can provide some information as to the potential risk for contamination. Though many park users do not make the connection automatically, pointing out the history and the pollution could help tie the two concepts together. As mentioned by focus group participants, highlighting that connection could promote acceptability of phytoremediation" (Weir, 2015)

Appendix I: Sample Focus Group Questioning Route

Opening Question: What would you be doing if you weren't here right now?

How often do you visit Gas Works Park?

Why is Gas Works Park important to you?

What other parks do you visit?

What activities do you participate in at the park?

Please talk about the history of Gas Works Park.
- Are you aware of contamination at the park?

Have you talked with family and friends about park contamination?

Do you feel that your activities at Gas Works Park put you at risk for exposure to contamination?
- Are you concerned about risks associated with contamination at Gasworks Park?

What are your thoughts about previous cleanup efforts at the park?

Have you heard about phytoremediation? Please explain.

Are you aware of the natural ability of bacteria to degrade pollutants?

What are your thoughts about using phytoremediation at Gas Works Park (using willow shrubs)?

Of all the things we discussed, what is the most important to you?

Is there anything else you would like to say about the park or phytoremediation?

Sample focus group questions from Ellen Weir

Below is a photo of the type of willow that could be used to clean up the soil at Gas Works Park:



Please indicate how much you agree with each of the following statements:	**Strongly Disagree**				**Strongly Agree**
1. Phytoremediation at Gas Works Park is a good idea.	1	2	3	4	5
2. Phytoremediation would be a good addition to other remediation strategies at Gas Works Park.	1	2	3	4	5
3. Shrubs would make a good addition to the landscape at Gas Works Park.	1	2	3	4	5
4. Phytoremediation at Gas Works Park should be phased, so only some areas of the park have plants at a time.	1	2	3	4	5
5. Phytoremediation at Gas Works Park should be permanent, so the park always has shrubs.	1	2	3	4	5
6. Phytoremediation would make Gas Works Park a more desirable place to visit.	1	2	3	4	5

Extracted page from the survey designed by Ellen Weir and administered to park users

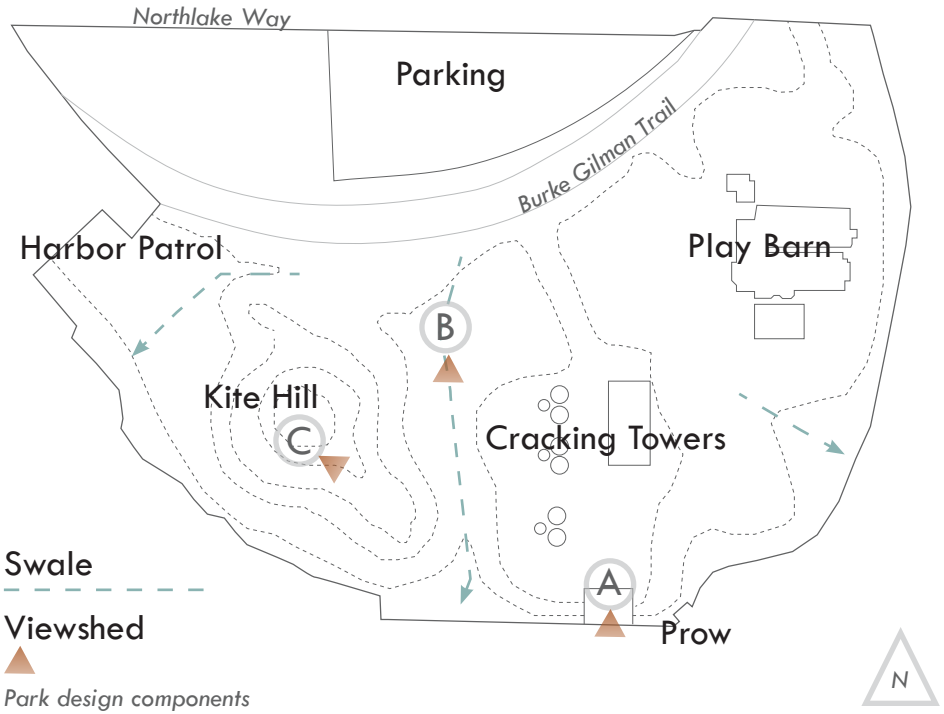


SITE ANALYSIS
beloved + contested

Located in the center of Seattle, lying on the north side of Lake Union, an approximately 20 acre promontory offers panoramic views of the city, the lake and the region. Due to its prime location, the Gas Works Park site was a focal point in the central Seattle area long before the Manufactured Gas Plant was built in 1907. The site has served a range of uses over the last 150 years. First as a traditional fishing area used by Native Americans, then as a recreational area for early European settlers. In the last 100 years, the Gas Works Park site provided early Seattle residents with heat and light in the form of manufactured coal-gas. With the Gas Plants closure and the construction of Gas Works Park, the site evolved into a significant source of both controversy and enjoyment for Seattle residents. While the site still requires intermittent remedial efforts to mitigate contamination lingering from the former Manufactured Gas Plant, the public continues to use the site heavily for a variety of recreational activities and artistic endeavors. Not only a highly visible reference point for the city, the design and treatment of the park has become a symbol of Seattle's progressive spirit. The first post-industrial re-use park in the U.S., Gas Works Park has become a landscape that tells the story of its people- the citizens of Seattle.[1]

LOCATION + VIEWS

The Gas Works Park site is centrally located within the city, just north of Seattle's downtown core. Lake Union, an inland water body connected to the Puget Sound and Lake Washington, separates the site from the downtown area and its adjacent neighborhoods. The 20 acre area protrudes into Lake Union's north end, a land form known as a promontory or "point of high land that juts out into a large body of water".[2] Its lake front location offers expansive views from the site. Views from the south edge of the site, along the shore of Lake Union, look toward the South Lake Union neighborhood and Downtown Seattle area. Views along the east edge of the site look toward the Interstate 5 Freeway Bridge suspended above the lake, the nearby University of Washington campus and the high ridge of the Capitol Hill neighborhood. The west edge of the site looks toward the Highway 99 Bridge, also suspended above the lake, and the prominent hill of the Queen Anne neighborhood. In view along the lake edge are industrial sites, boating and fishing, and several houseboat communities. The north side of the site abuts another steep hill , home to the Wallingford neighborhood that historically provided significant worker housing for the growing industrial zone. The panoramic views afforded by the site's location not only make the promontory an ideal vantage point – they also make this landform a focal point from other look-outs around the city. At any point around Lake Union, from the surrounding hills to the parks, homes and businesses at the lake edge, the Gas Works Park site is clearly visible – today presenting a bright mass of gentle green hills and clusters of burnt orange towers. Views within and around the site also play an important experiential role for visitors. Visitors entering the site from its north side must walk between tall lines of Western red cedar trees and beyond gentle mounds to reach the expansive views of the city. Mounding across the site provides a variety of views as well as a diversity of recreational opportunities. The smaller mounds frame swales that are intended to transport and direct rain water across the site. One very large mound at the western edge of the park – where the site's most toxic remains are buried, rises approximately 60' above the surrounding swales – providing the greatest vantage. The great mound has been named Kite Hill by many park users. From the top of Kite Hill, users can view the city and the rest of the park. Other prominent features, primarily structures retained from the Gas Plant known as the Cracking Towers, occupy the east side of the site, punctuating the low mounds and swales with clusters of rusted machinery – most rising nearly as tall as Kite Hill. The Play Barn, a repurposed machine house, is situated just beyond the Cracking Towers, along with associated features such as the bathrooms, barbeque area and playground. The Play Barn, a large covered area intended for children, is comprised of structures and machinery repurposed from the former Gas Plant, repainted in primary colors. South of the Play Barn and Cracking Towers lies a concrete and brick slab known simply as the Prow. Although much lower than Kite Hill, the Prow is another ideal vantage point to see the city , and offers visual access to the lake edge. Serpentine pathways circulate users into the park from the north, around Kite Hill and back down toward the Cracking Towers, the Play Barn and the Prow.



Park design components



View of Downtown Seattle from the Prow



View of Downtown Seattle from the central swale



View of the Cracking Towers and Capitol Hill from Kite Hill

HISTORY

Gas Works Park's central location has enabled a rich history of use. The site of the former coal and oil gasification plant was centrally located within the city in order to import and export products easily. In 1916 Lake Union was officially connected to Lake Washington to the east and the Puget Sound to the west by the completion of the Ship Canal. The Ship Canal and the Hiram M. Chittenden Locks, which opened in 1934, connected the two lakes with Puget Sound in order to provide transportation for residents and industry. This passage allowed many kinds of industry to develop on the shore of Lake Union, which in turn provided transportation, power and dumping grounds. The Seattle Gas Light Company purchased the site in the early 1900's, and completed construction of the Manufactured Gas Plant (MGP) on site in 1907. The plant converted coal and later oil into gas for lighting and heating the homes of Seattle's early residents[3]. The process of converting coal and oil involved heating it to extremely high temperatures, producing noxious smoke, oil and tar as by-products of the process. Some of the tar was reused on site by the American Tar Company (ATCO) that opened in 1920 and refined the plant's tar for use in making roof shingles and other products.[4] The construction of the Trans Mountain Gas Pipeline in 1954 rendered the Manufactured Gas Plant obsolete and the plant ceased production in 1956. By the time the plant closed its doors, black carbon soot and sticky tar residues coated the surfaces of the ground and equipment. Over fifty years of production left the site polluted above and below ground. Soil, groundwater and near-shore sediments were steeped in oil slicks and tar.[5] In 1963 the City began to purchase the MGP site for reuse as a city park.

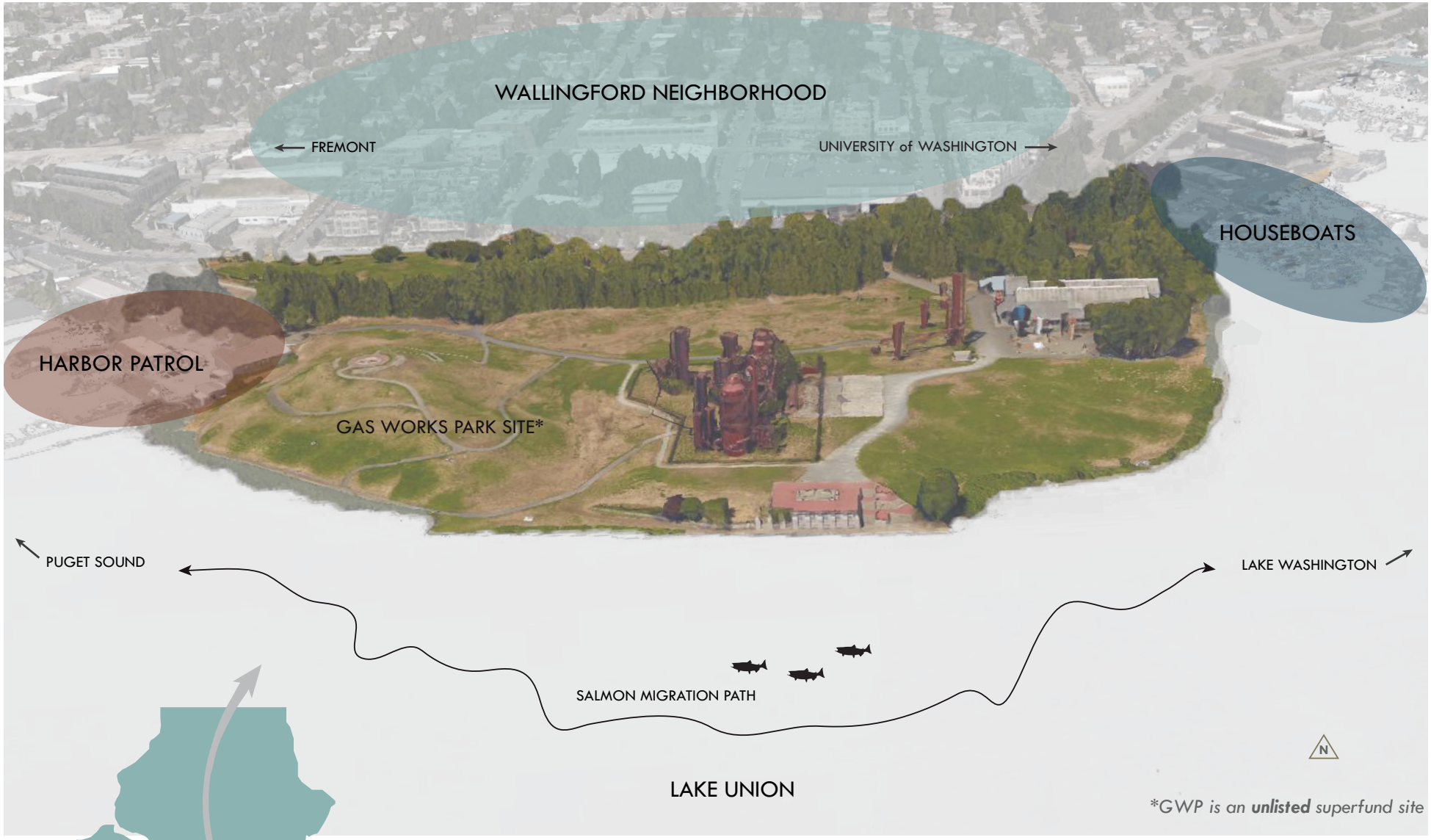
After paying for the site over 10 years (1963-1973) the City of Seattle commissioned Richard Haag to begin working on what would become his legacy park project. In 1971 Richard Haag and Associates (RHA) were officially contracted to design the master plan for the park. Inspired by the history of the site and entranced by its artifacts, Richard Haag proposed a ground-breaking design that would retain many of the park's existing structures. Melding icons of past industry with the city's desire for a pastoral park, Haag created the first post-industrial reuse



Park users view Seattle from Kite Hill, Cracking Towers in the distance



Joggers and walkers utilize pathways through the park





~20 acre promontory

~1,900 ft. shoreline

park to embrace its hybrid nature. In order to make his vision a reality, Haag needed the public to adopt what he termed "new eyes for old"[6]. His thinking was, if he could get the city and the public to see the potential of creating a totally new kind of park, then perhaps they could understand the importance of reusing its existing structures, allowing Haag to design the park in confluence with its past. Although eventually won in 1974, when park construction began, the battle for Gas Works Park was hard fought and continues to embroil occasional conflict over 40 years after its creation. But Haag's flair for innovation did not stop with the park's bold design. In order to create a public space on site, Haag had to contend with contaminated soils and groundwater. Soil and groundwater testing in 1971 revealed that the site was extremely toxic.[7] Once construction commenced, Haag proposed reusing most of the contaminated soil on site by mixing it with organics and reintroducing microbes to begin breaking down the pollutants. A process that later became known as bioremediation, Haag's use of microbes on site was innovative in that it acknowledged and capitalized on natural processes that could begin to deteriorate the extremely robust pollutants that soaked the site. In order to aid the microbial digestion, Haag introduced sewage sludge, sawdust, leaf litter and other organic materials, tilling it into the top soil. Within a few months grass germinated where before nothing would grow.[8] Haag's plan was to spread the new soil mixture across the site, cut out and fill in land forms with rubble from a near-by construction site and cap everything with a layer of clean soil and grass. This process was not only innovative, it was also able to save significant funding that would otherwise have been spent on the disposal of tons of polluted soil.

By reusing the soil and many of the structures on site, Haag created a new vision for public space and set a precedent for using natural processes as a cost-effective alternative to trucking toxic materials to a hazardous waste landfill. To aid sustained microbial digestion of pollutants, Haag regraded the land. Constructing swales and mounds, all surrounding the great mound, now known as Kite Hill. Haag's intent was to use grading to channel rain water so that surface runoff and subsurface flow would percolate through the soils, providing moisture and oxygen to the newly introduced microbes.

The park was completed and opened to the public in 1976. In the next two decades Gas Works Park became an international precedent and a beloved city icon. Locals and tourists alike recreated on its grassy slopes and held events on the waterfront, such as the City's annual Fourth of July celebration, which continues today. Beginning in 1984 the park has been closed intermittently for inspections, due to lingering tar bubbling to the surface in some areas. Superfund, or the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) had been established a few years earlier and new monitoring and cleanup requirements for contaminated sites had been written into law. After initial investigations at the park, the Environmental Protection Agency agreed to keep the site off of the Superfund National Priorities List if Washington State Department of Ecology, the City of Seattle and Puget Sound Energy (formerly Seattle Gas Light Company) agreed to a contract that complied with monitoring and mitigation requirements. Although the park reopened shortly after its closure, this marked the beginning of a long series of monitoring, testing, mitigation and bureaucratic interaction on site.

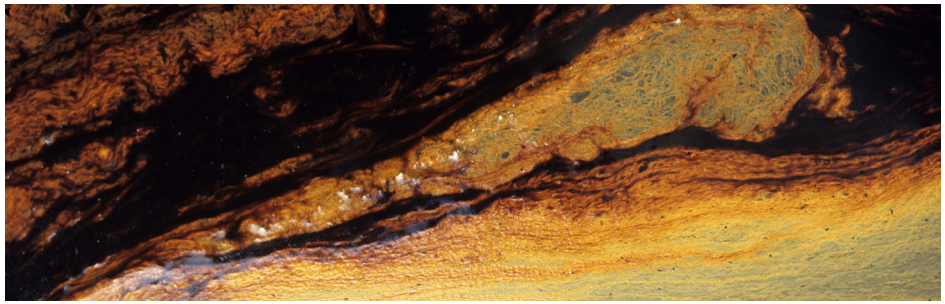
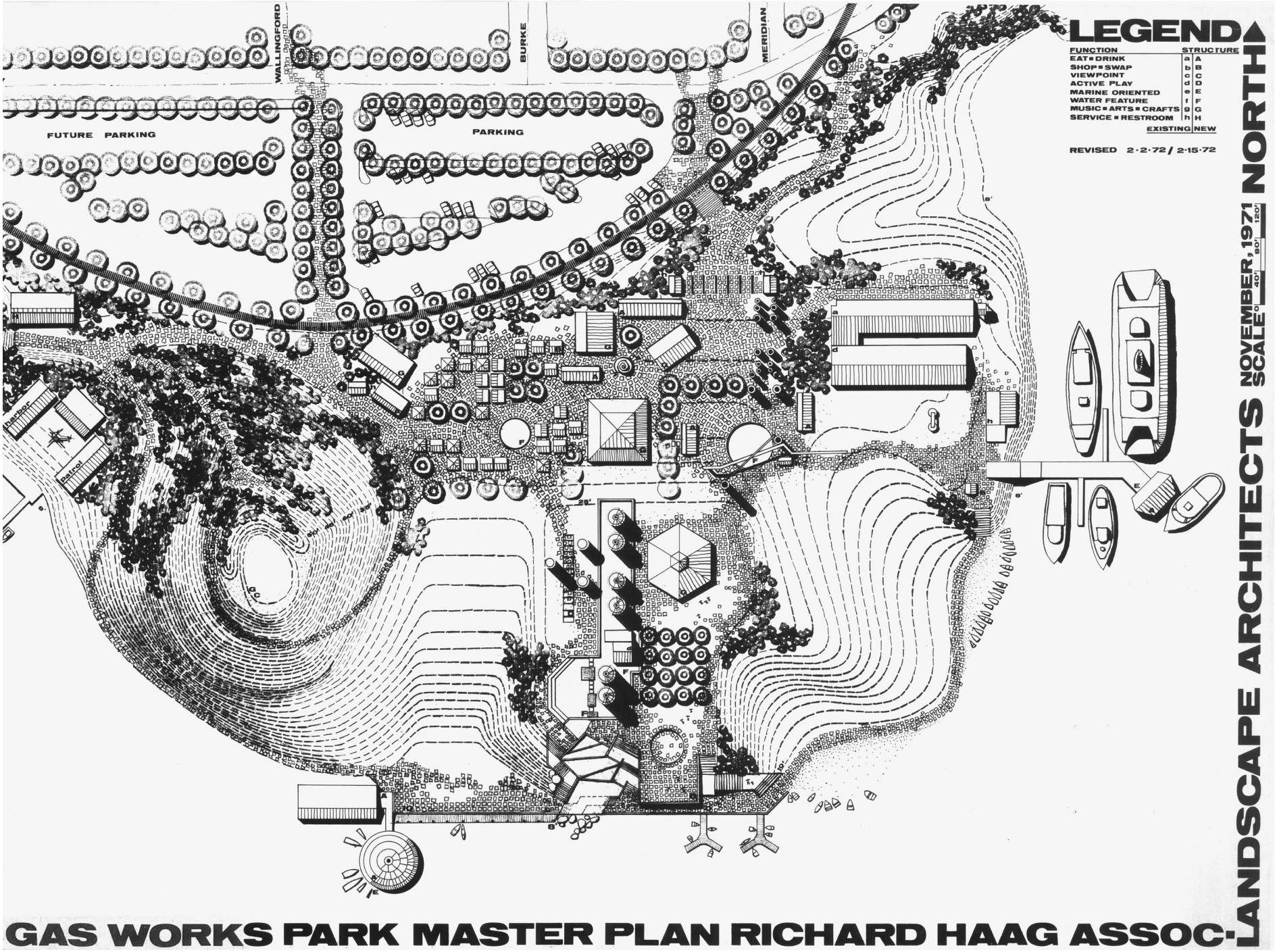


Photo of a tar slick on site, 1970, collection of Richard Haag

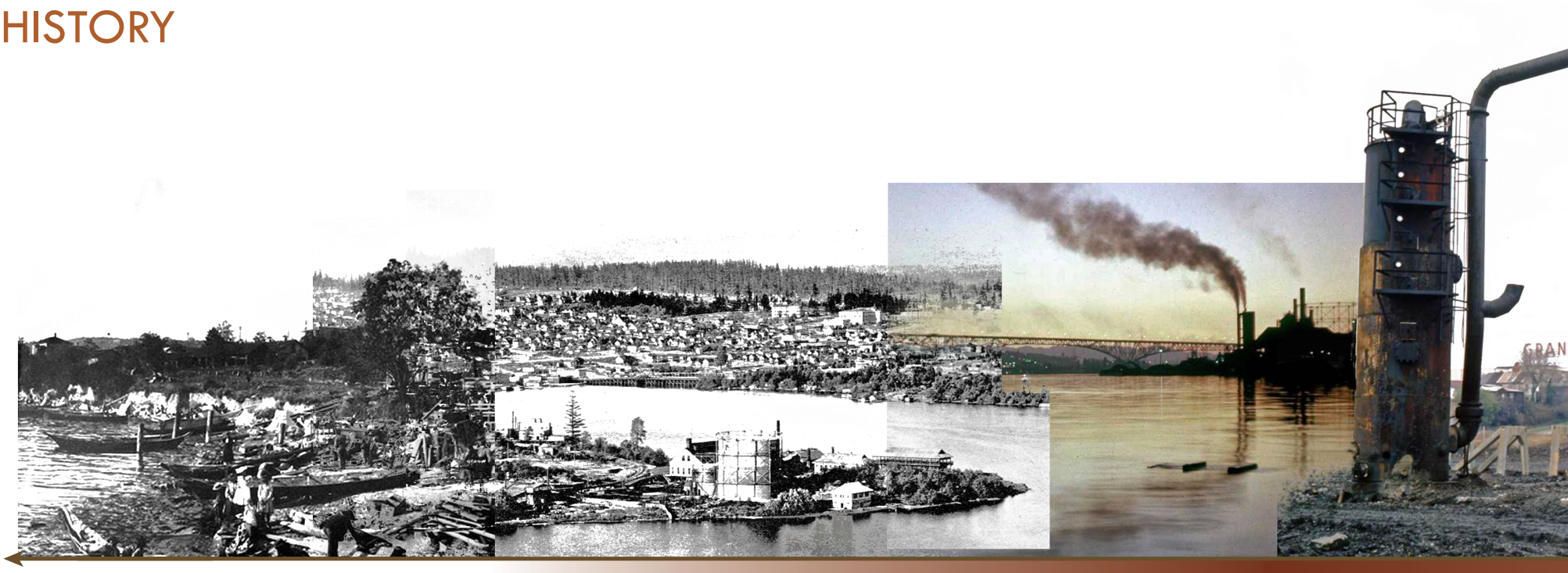


Piles of organic matter on site used for bioremediation, 1971, collection of Richard Haag



Early Gas Works Park Master Plan by RHA, 1971

HISTORY



Pre-1880
Native American fishing village.

1880
Settlers arrive.

1890
City garbage burned on site.

1903
Olmsted brothers propose park for site.

1907
Seattle Gas Light Company builds Manufactured (coal) Gas Plant (MGP) on site

1911
Chittenden Locks constructed, Ship Canal begun

1920
American Tar Company (ATM) begins operations NW of MGP

1937
Manufactured coal-gas plant is updated for oil-gas production

1954
Oil-gas production made obsolete by natural gas pipeline

1956
Manufactured gas plant and American Tar Company close

1963
City of Seattle purchases the Gas Works site land - to be paid over 10 years

1907 - 1956
The shoreline is gradually extended approx. 100' by filling lake edge with debris from construction and plant operations. Soils are polluted by gas plant activities and oil leaks over 50 years.



1971
City of Seattle approves Richard Haag Associates (RHA) master plan for Gas Works Park

1976
Gas Works Park officially opens to the public

1984
EPA starts groundwater and soil testing on site

1988
Initial evaluation of geohydrology, soil and groundwater toxicity published

1999
Cleanup Action Plan and State Enviornmental Policy Act Checklist published

2007
Chemical analysis of NE corner tar and benzene plume

2013
Gas Works Park added to National register of Historic Places

2016
Planning for future sediment remediation in 2017

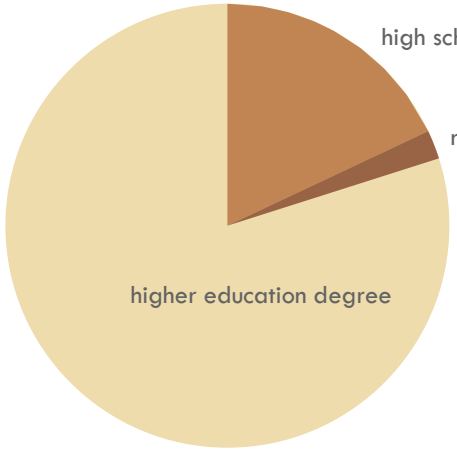
1971 - 1976
Soil and groundwater testing done by Uinversity of Washington found to be deeply contaminated by coal and oil by-products. RHA reintroduces microbes and organic matter, regrades site to begin remediation.

1984 - 2013
Various remediation and monitroing activities to establish toxic “hot-spots” and extent of toxics leaching to Lake Union. Intermitent tar removal and soil capping done around the park to mitigate exposed contaminants.

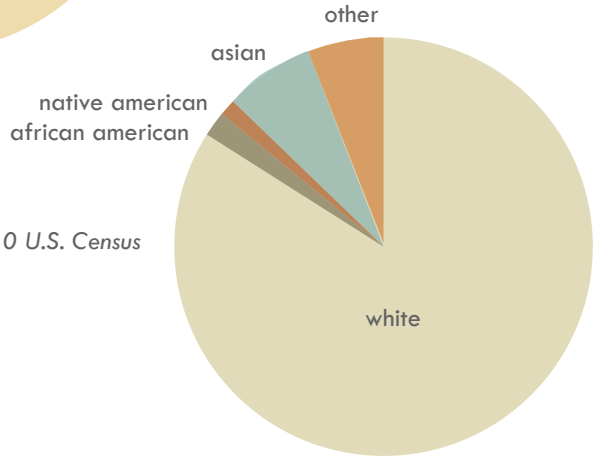
PARK USERS

Patrons of the site range from local users to community groups. Despite vigorous use and affection for the park, public acceptance of the Gas Works has been varied. Concerns for the park vary among park users depending on their particular knowledge and position relative to its history and use. Among the user groups is the park's designer, landscape architect Richard Haag, and the Friends of Gas Works Park foundation, who advocate for stewardship of the park. Their goals involve removing the fence from around the Cracking Towers, restoring the now somewhat derelict children's play area and establishing an on-site "salmon run". Locals, such as residents of the nearby houseboat communities, condominiums and single family neighborhoods generally view the park as an amenity, offering views of the city and recreational opportunities. The closest neighborhood to the park is Wallingford, which bears a historical tie to the site as the home of many of the Manufactured Gas Plant's workers. The neighborhood has changed drastically since the Gas Plant's time and is now home to over 12,000 people, most of whom are relatively affluent, well-educated and white.[9] Recreational users of the park are not isolated to residents however and tend to vary greatly depending on the season and time of day. User groups also represent a range of ages, from children to elderly people, and a mix of tourists and Seattleites alongside Wallingford locals. Another important user group on site is the homeless population, who circulate through the play barn and adjacent covered barbecue area. The covered areas, retained and remodeled structures from the Gas Plant days, offer a unique opportunity of public shelter for some of Seattle's homeless population. While the presence of homeless people may be disputed or viewed as undesirable by some, they represent a consistent contingent of the park's user group. Another important user group are the owners of the site and those legally responsible for its maintenance, use and health. The current owner of the site, the City of Seattle, uses multiple agencies within its governmental body to manage maintenance on site- the Parks and Recreation Department manages seasonal and day to day maintenance while Seattle Public Utilities manages pollutant monitoring and mitigation.

WALLINGFORD DEMOGRAPHICS

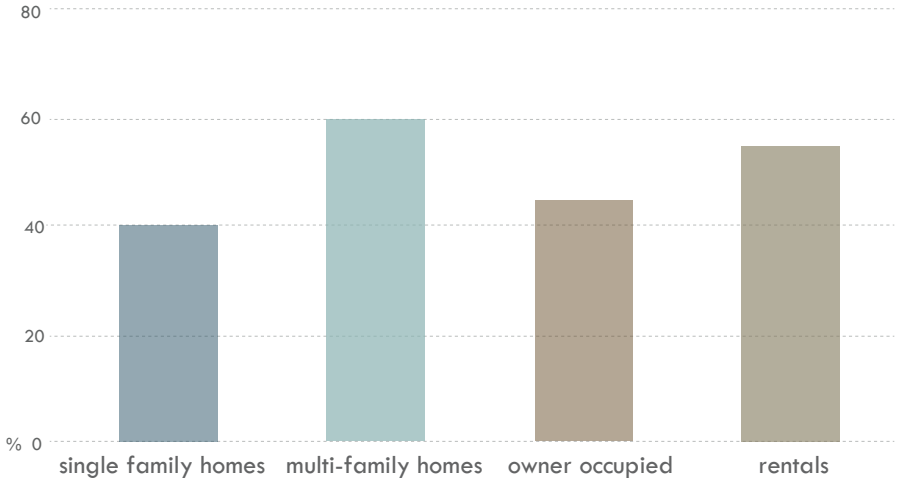


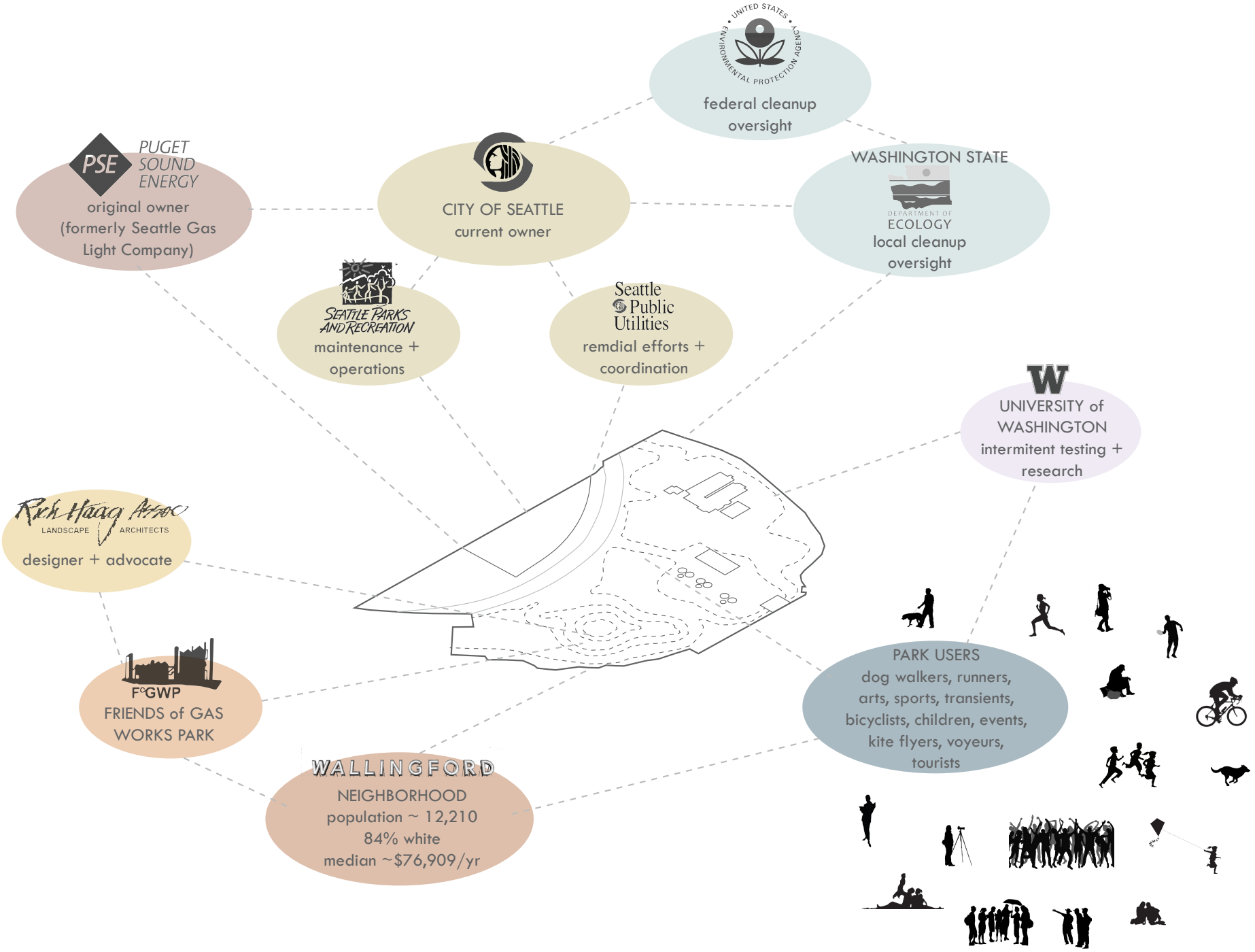
Education
Source: StatisticalAtlas.com



Race
Source: 2010 U.S. Census

Housing
Source: 2013 American Community Survey

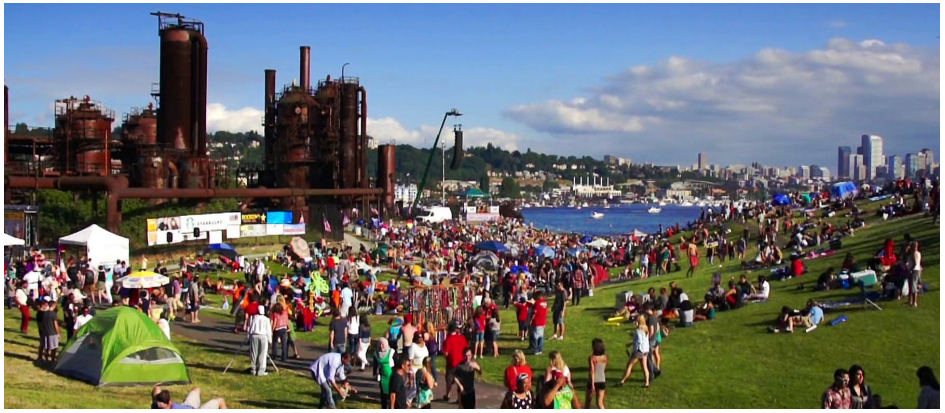




Web of park stakeholders

PARK USES

Overseen by the Seattle Parks and Recreation Department, use of the site, as with users, varies throughout the day and seasonally. The range of activities is one of the reasons the park is so loved by Seattleites and has remained a recreational fixture and a Seattle landmark since it first opened in 1976. However, some areas of the park receive more intense use than others, with the most active areas focused around the pathways and prominent viewpoints, such as Kite Hill and the Prow. These and other prominent features of the park's design shape how visitors use the spaces. The Burke-Gilman pedestrian and bicycle trail runs through the site in an east to west bow, funneling bicyclists, joggers and pedestrians through the park. Many linger and use the paved circuit of pathways for exercise while taking in the view. Dog walking and off-leash dog activities tend to happen most in the generally under-used bowl of grass at the northwest edge of the site. Kite Hill, originally called the great mound, is often crowded with people taking in the panoramic views, flying kites and on sunny days, catching a few rays of precious sunshine. Local and tourist photographers frequent the areas where infrastructure from the Gas Plant has been maintained and where some of the most striking views are afforded. The rusting artifacts are a highlight for many arts groups, attracting art classes and professionals. Other uses of the site include children playing in the play barn area - a repurposed part of the gas plant, cleaned and painted to be an impromptu covered jungle gym. Children also enjoy the sandy playground abutting the play barn and general play throughout the park. Other activities include tours of the park, picnics and barbecues and the annual Fourth of July celebration. Although unsanctioned and technically illegal, nocturnal activities at the park abound. The homeless populations utilize the play barn and covered barbecue areas for shelter and a place to build fires. Local teenagers also use the industrial artifacts at night, throwing parties in the play barn and slipping past the chain link fence that surrounds the Cracking Towers in order to explore. Aquatic users of the site, concentrated just offshore, are the local houseboat communities, kayak groups and rowing shells that launch nearby or from the beach just east of the Prow and aquatic organisms such as salmon and great blue heron.



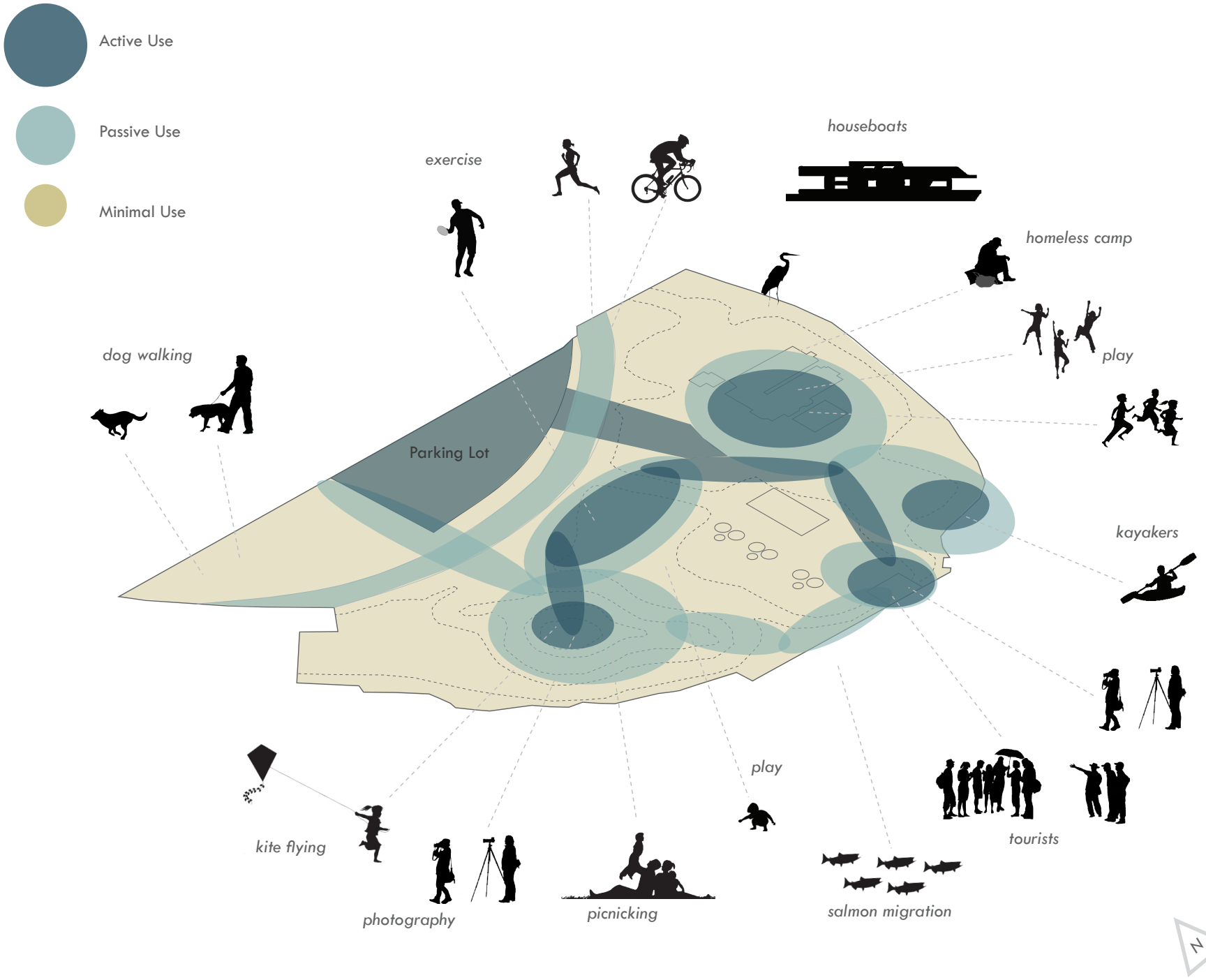
Gas Works Park on the Fourth of July



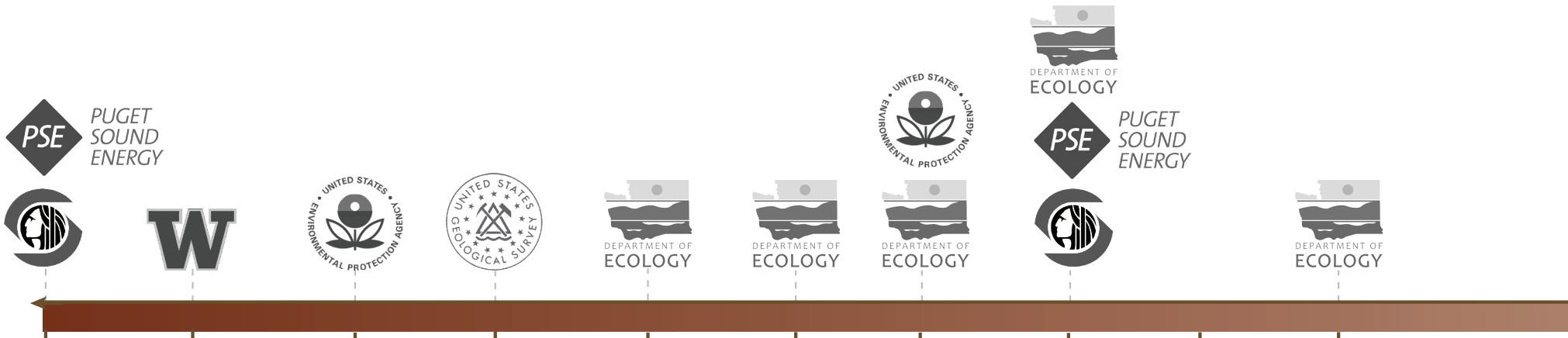
The Play Barn bears evidence of nocturnal habitation



A tent pitched beneath a Play Barn porch provides unique shelter



Sample of the most common park uses



1963
City of Seattle purchases the Gas Works site from Puget Sound Energy

1971
Soil and water toxicity testing begins (Cole & Machno, 1971)

1984
Park briefly closed due to tar seeps, EPA starts groundwater and soil testing on site

1986
U.S. Geologic Survey (USGS) drills soil bore-holes to determine soil stratification and ground water levels

1988
Initial evaluation of geohydrology, soil and groundwater toxicity published (Sabol, et. al., 1988)

1990
Groundwater testing results published (Turney, et. al., 1990)

1996
EPA and WA State Ecology sign Deferral Agreement for GWP cleanup

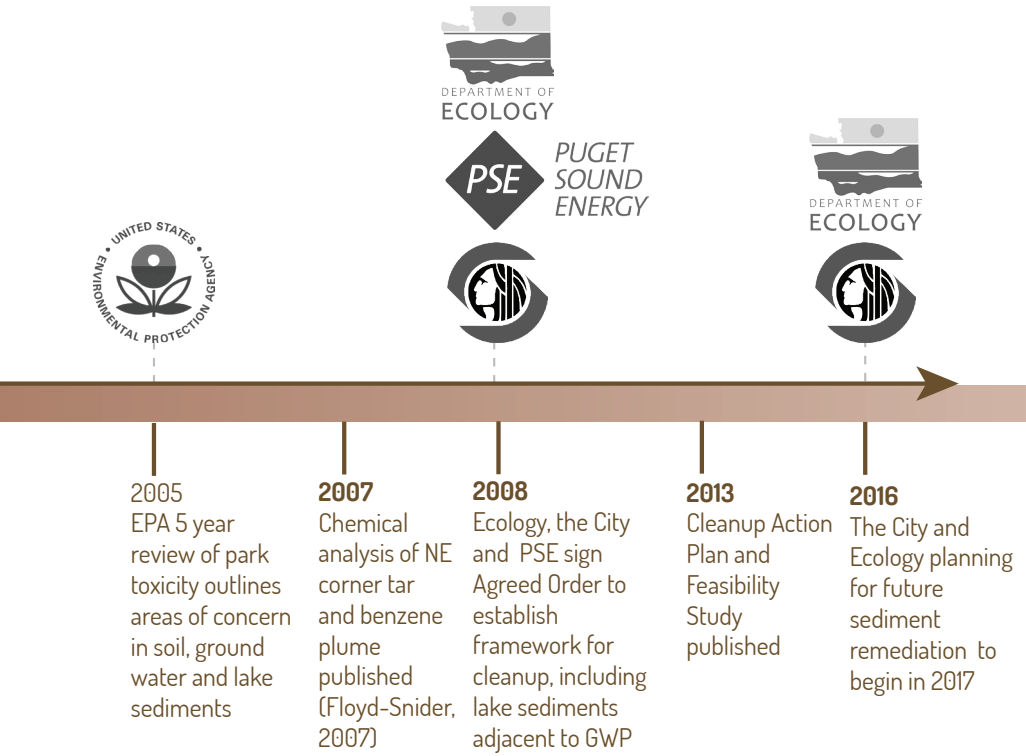
1997
Ecology, the City and PSE sign Agreed Order to establish schedule and scope of cleanup

1999
Cleanup Action Plan and State Enviornmental Policy Act Checklist published

2003
Adjacent lake sediment testing results published (Jack, et. al., 2003)

1984 - 1996
Gas Works Park evaluated for inclusion on the EPA's National Priorities List (aka Superfund). Instead of listing the site, EPA and Washington State Department of Ecology signed a Deferral Agreement that formally made Ecology the regulatory authority overseeing monitoring and respone actions to contamination.

REGULATION



The regulatory framework of the park was originally quite simple, Puget Sound Energy sold the site to the City of Seattle in 1963, with payments to be completed in 1973. Today, despite the official sale of the site, Puget Sound Energy (PSE) is remotely involved in the site's maintenance and cleanup efforts. This is due to the financial responsibility of the original owner of a contaminated site outlined in the Superfund Act of 1980. This act holds the agency that created the pollution on site (generally the industry owners) financially responsible for its cleanup.[10] Since the park was constructed before Superfund was passed, exceptions were made and an agreement reached between the responsible agencies. After soil and groundwater testing was performed by the Environmental Protection Agency (EPA) and the United States Geologic Survey (USGS) throughout the 1980s, an agreement was drafted that would hold Puget Sound Energy and the City of Seattle (City) jointly responsible for the site's health, with the Washington State Department of Ecology (Ecology) as the official governmental body overseeing monitoring and mitigation of pollutants on site. This agreement was officially signed in 1996. Since the original series of post-park construction investigations began in the 1980s, over 30 published scientific papers and articles have documented various monitoring strategies and results across the park. Since 1996, on-going official communications between the City, Ecology and PSE in the form of Agreed Orders and Consent Decrees allow the agencies to form a cooperative network that provides a basis for park maintenance and mitigation planning. On-going testing provides the necessary data to inform remedial investigations and feasibility studies toward the creation of a comprehensive Cleanup Action Plan which has been in the works since 1996. In 1999 the focus area for studies and cleanup was contained to the upland, or terrestrial areas of the park not submerged in water, referred to as the Gas Works Park Site (GWPS). Due to the results of near-shore sediment studies, the focus area was expanded to include sediments referred to as the Gas Works Park Sediment Site (GWPSS). In 2008, the GWPS and the GWPSS were combined into one contiguous study and remediation area, shown as a boundary line encompassing the upland site and adjacent waters. [11]

MONITORING + RESEARCH

Monitoring wells and bore holes pepper the site from several series of soil and ground water testing, starting in the 1980s. Information gleaned from monitoring wells and soil cores has been aggregated over 40+ years to provide a partial but thorough picture of the site's health. Soil, sediment and water samples from both shallow and deep collections have been tested in order to understand the geology and hydrology shaping the site. The first groundwater data was published in 1987 by TetraTech, a firm contracted by the City. In 1988 a study of geohydrology, soil composition, stratification and water flows on site, was published by Sabol, Turney and Ryals for the USGS. In 1990 Turney published another paper outlining the extent of tested groundwater locations. Between 1996 and 2003 several further reports were published by Parametrix and ThermoRetec outlining the range of water levels and soil stratification documented on site. The primary focus of these studies was to determine the actions required by responsible agencies and to establish protocol among agencies for future cleanup. In 2003 Ecology published a study detailing the results of bioassay testing performed in the lake sediments near the park. Bioassays are the use of indicator invertebrates to determine the toxicity of a given medium. These bioassays tested the survival rates of specimens in lake sediments collected near the site indicating the potential impact of relative sediment toxicity on the overall ecological health of the Gas Works Park Sediment Site. In 2005 the EPA performed a 5 year review involving testing of existing monitoring wells and soil bores to determine the park's health and outline the general contaminant areas of concern. In 2007 Floyd-Snider was contracted by the City to test areas of the NE corner of the park where tar had been seen on the surface of the soil and water. Soil collected from boreholes and groundwater collected from monitoring wells showed clear signs of lingering contaminants. In 2013 several publications prepared for the City and Ecology by GeoEngineers outlined the 40+ years of research done at the park and provided over-arching analysis of soil, water and sediment health and pollutant locations. Other testing, prior to 1987, done by the EPA and USGS, has been documented in the aforementioned publications but formal records of this monitoring are scarce.



Tar-like material observed in boring, Floyd-Snider 2007

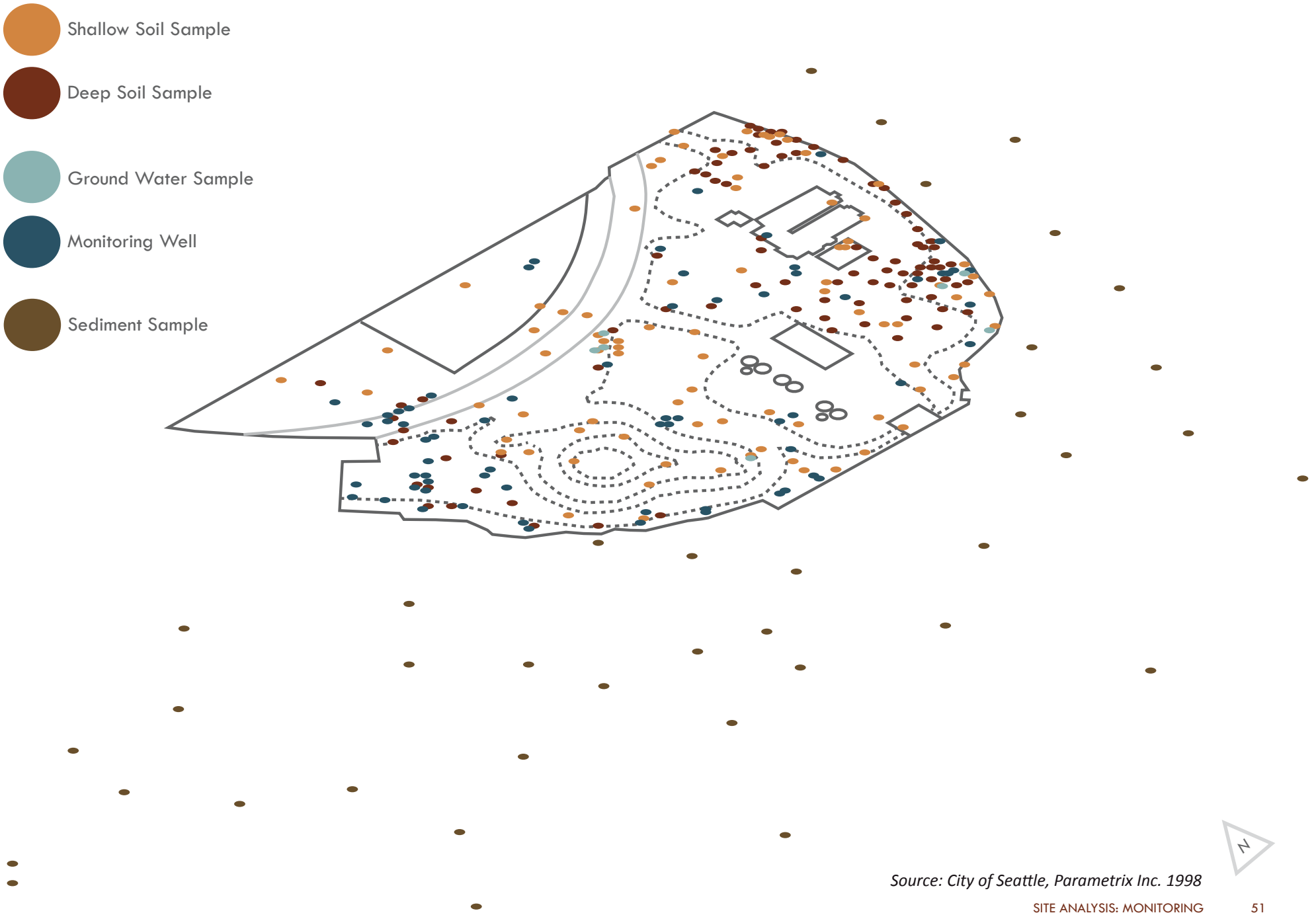


Chemical sheen encountered at groundwater table, Floyd-Snider 2007



Black carbon soot material from boring, Floyd-Snider 2007

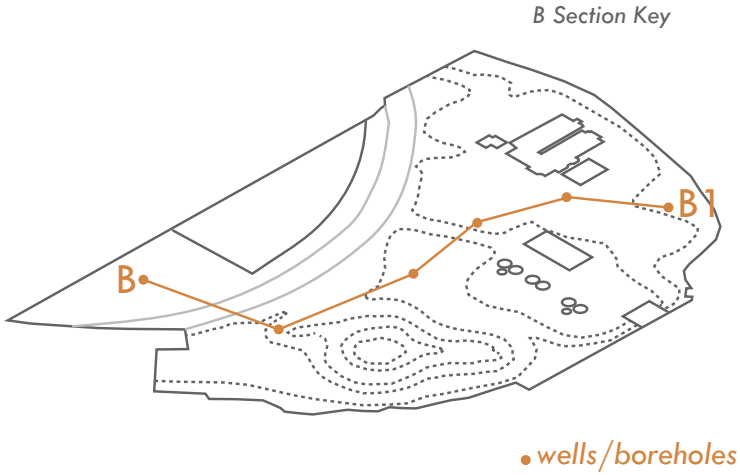
Monitoring well, borehole and sediment sample locations 1984 - 2015

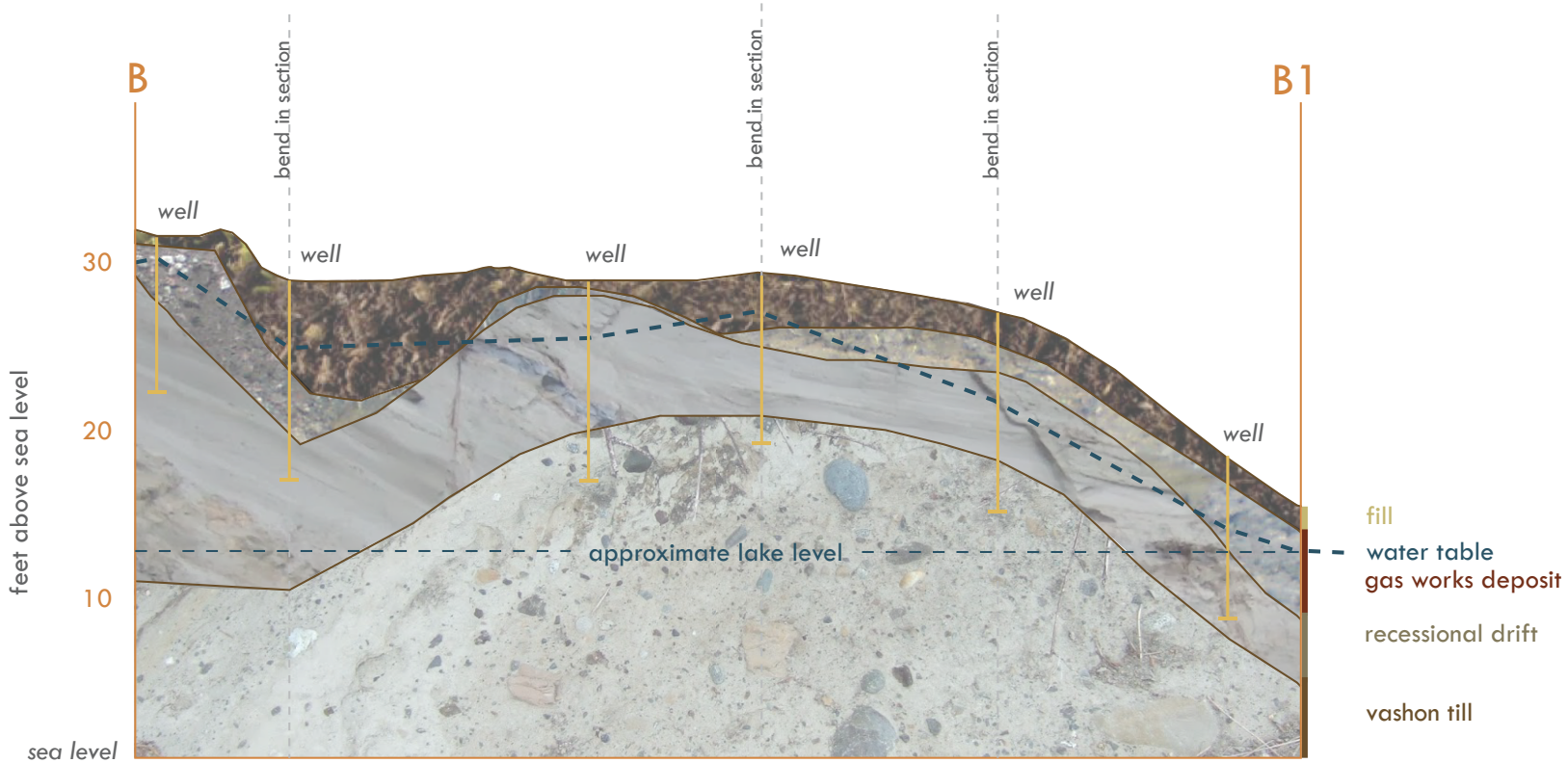


Source: City of Seattle, Parametrix Inc. 1998

RESULTS: SOILS

Soil stratification varies greatly across the site in thickness and location of soil types. However, stratification generally follows a basic pattern with two generalized types of native soils lying beneath two to three types of artificial fill soils from the Manufactured Gas Plant and park construction. Vashon Till is primarily clay and coarse cobble and is the deepest and oldest substrate. A layer of silty-sandy Recessional Drift lies just above the till, thought to have stratified out of the till clay over time. The native soils are overlain with a mix of what has been termed the Gas Works Deposit (containing brick shards, debris, soil stained and mixed with black carbon, tar and oil). A mixture of construction rubble and clean fill soil rest at the top, capping the underlying matrix.[12]

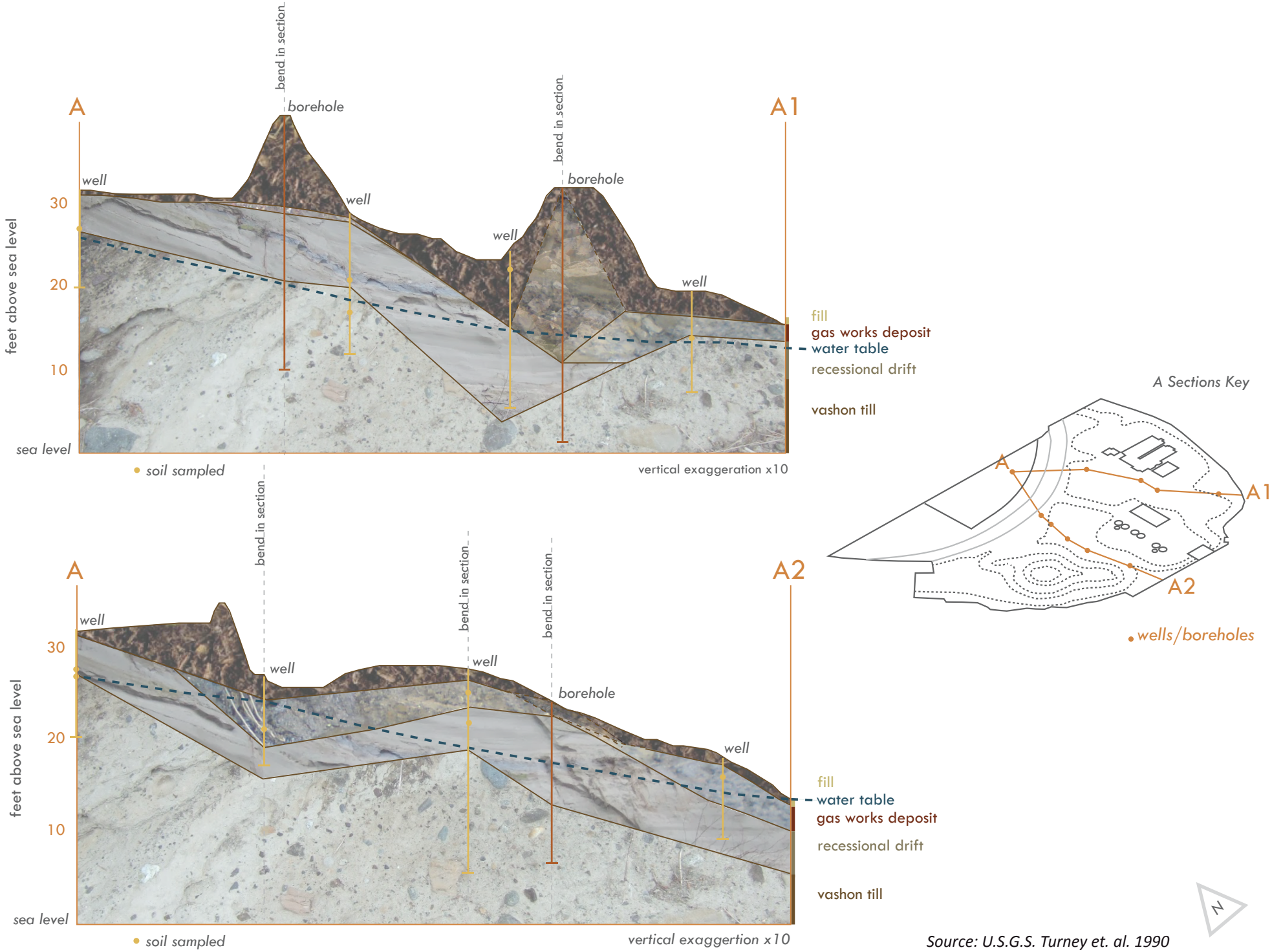




Representative soil section showing typical stratification across various locations

vertical exaggertion x10

Source: U.S.G.S. TetraTech. 1987



Representative soil sections showing typical stratification across various locations

Source: U.S.G.S. Turney et. al. 1990



Surface flow in central swale



Pooling in central playfield

Precipitation

Lake Union

Infiltration

Water table

Runoff

Key

- Water
- Soil Cap
- Gas Works Deposit
- Recessional Drift
- Vashon Glacial Till

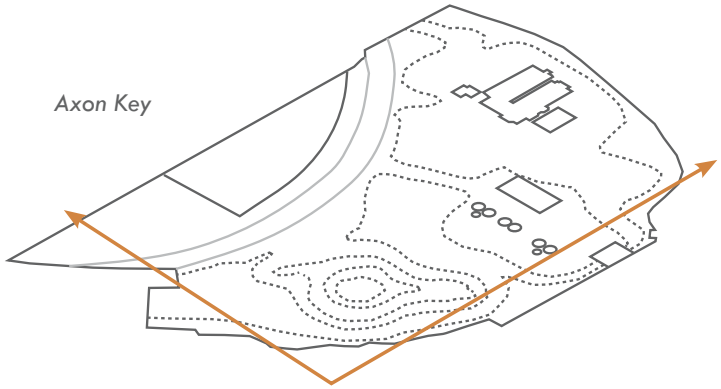
N

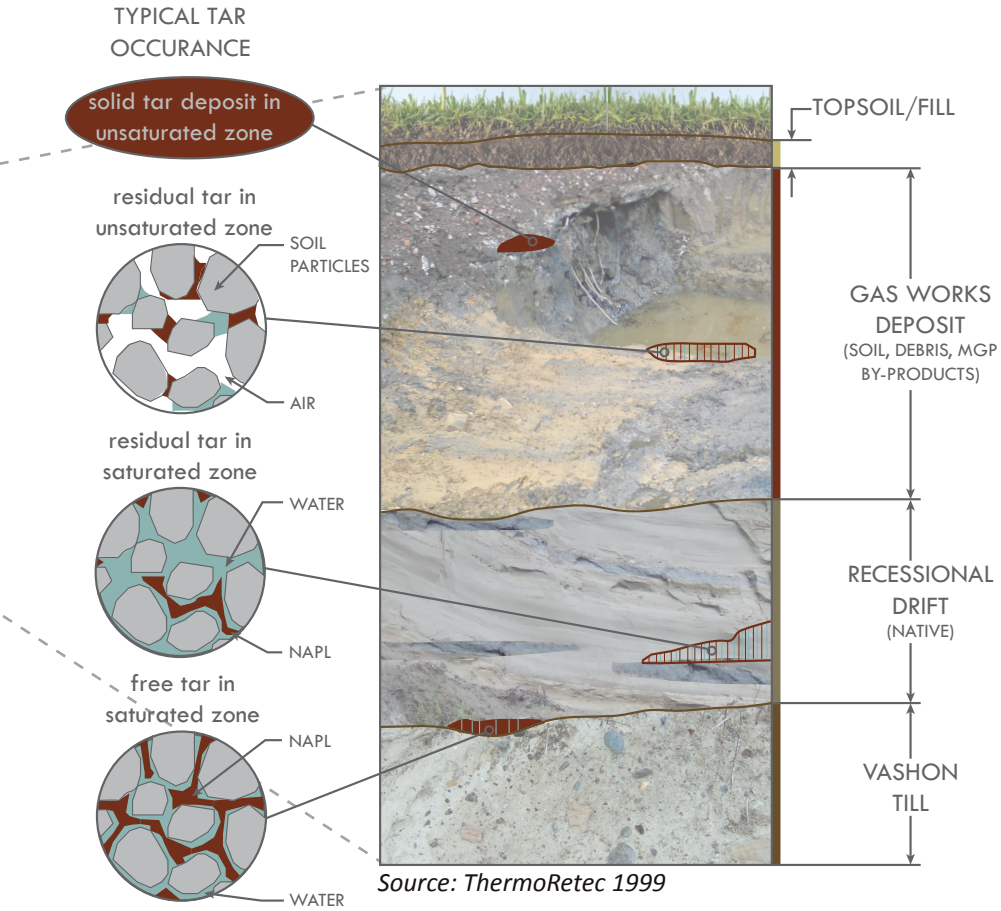
Source: ThermoRetec 1999



Surface runoff drainage into lake

Axonometric soil section shows general stratification and water flow





Source: ThermoRetec 1999

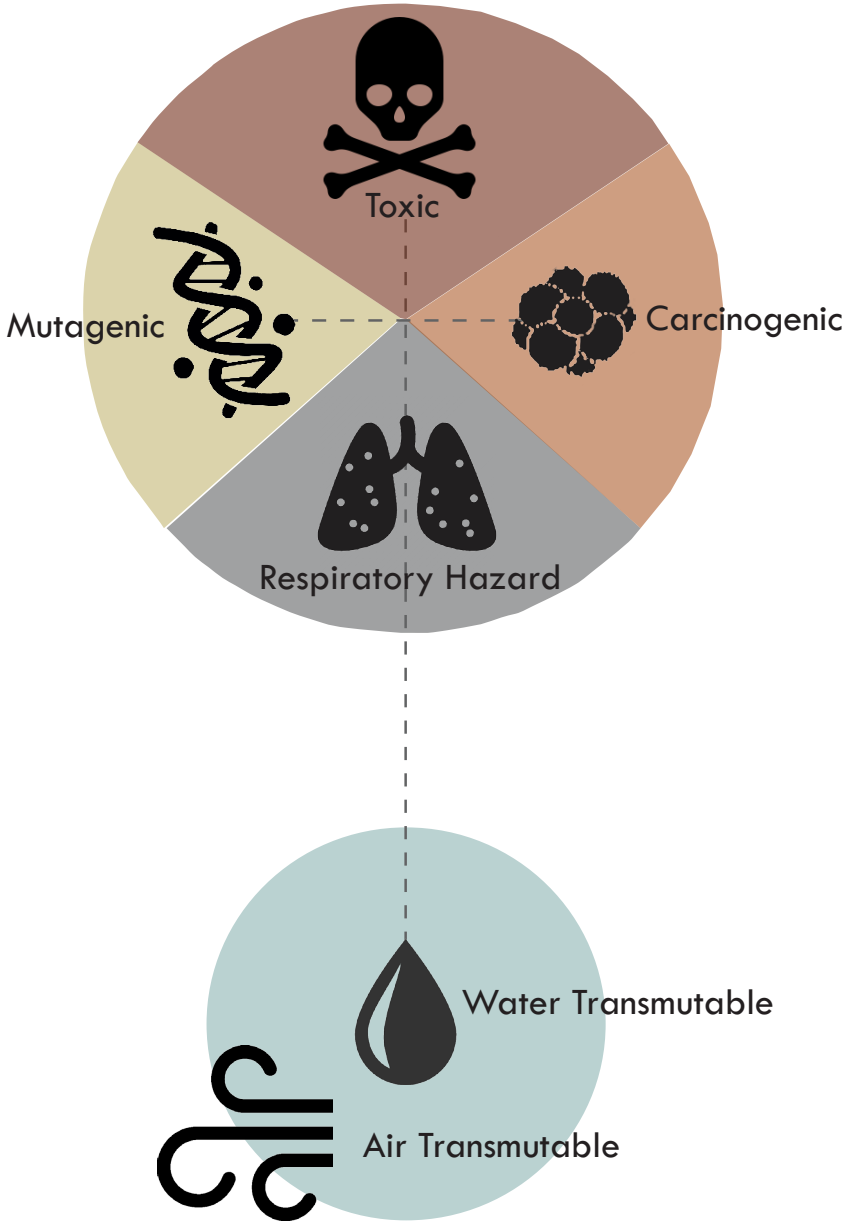
A close-up view of interactions between soils, water and NAPL from the Gas Works Deposit

RESULTS: HYDROLOGY

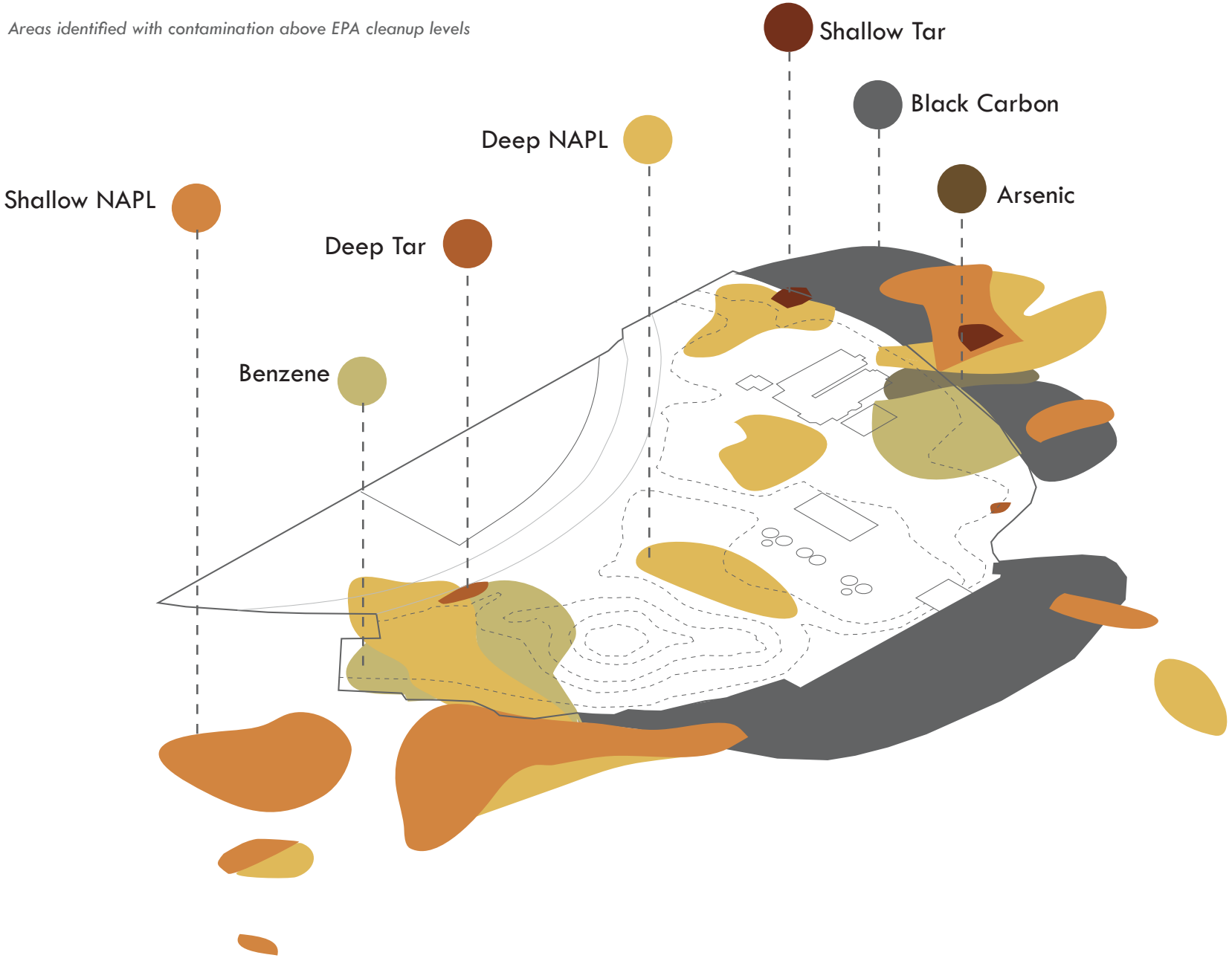
Many monitoring wells, both permanent and temporary excavations, have given hydro-geologists and environmental engineers a fairly concise picture of the water table beneath the park and the seasonal water flows across the site. Additionally, testing of nearby lake sediments has informed speculation of soil and water leaching from the site into the lake. The water table underlying Gas Works Park fluctuates seasonally, often perching above the clayey Vashon Till, for which the depth and thickness vary across the site. Stormwater is also known to wash down a steep hill north of the site and into the park soils. Rainfall and stormwater on site generally infiltrate the cap soils and percolate downward until reaching the water table. The water table tends to be very high in the wet season causing low-lying park soils to become completely saturated. In the dry season the water table has been documented to remain near or above the clay substrate of Vashon Till. Water generally only percolates down to the Vashon Till layer due to the clay's generally low permeability. The high water table and underlying till cause water to run perpendicular to the ground and flow into Lake Union. Water on site generally percolates through the Gas Works Deposit, often perching within the Deposit and maintaining contact. Prolonged, or even temporary, contact with water causes some of the materials in the Deposit to weather - leach into the water and get washed away. Despite early efforts to enhance microbial and hydrologic action on site, over time heavy rainfall and high groundwater have caused much of the lingering pollution on site to contaminate ground water and leach into sediments in Lake Union through subsurface flows.[13] Monitoring wells reveal the interaction between soils, water and remaining contamination. Non-Aqueous Phase Liquids (NAPL) have been found with varying concentrations in groundwater at intervals within each soil layer. NAPL are indicative of contamination from by-products of incomplete coal combustion- tar, oil and associated constituents. These elements, and others, are found in high concentrations throughout the Gas Works Deposit. However, concentrations of specific elements of concern - many associated with NAPL- have been found to vary across the site. [14]

RESULTS: CONTAMINANTS

Extensive testing has clearly concluded that contamination continues to persist beneath the Gas Works Park site. The relative threats that remaining contaminants may pose is determined by the documented concentrations of a contaminant (measured in milligrams per kilogram – mg/kg – in soil or water), its depth and proximity to water. While some compounds found on site may only pose respiratory hazards when exposed to air, others are known to be mutagenic, carcinogenic and toxic. The contaminants found in the highest concentrations are primarily a mix of Volatile Organic Compounds (VOCs) and Polycyclic Aromatic Hydrocarbons (PAHs) as well as the metalloid arsenic. These contaminants originate from several sources, the primary source being the soil layer referred to as the Gas Works Deposit (GWD). A band of soil and debris from the former Manufactured Gas Plant that underlies clean fill soils across the park varying in thickness, the GWD contains residual tar and oil. Other potential sources are the structures remaining from the Gas Plant. Although regularly painting the structures provides an airtight barrier above-ground, many of the structures have underground components that remain polluted. Due to the length of time the contaminants have been in the soil and the wet climate in Seattle, PAHs and VOCs tend to be found on site in weathered forms. PAHs, which generally have a denser and harder to weather molecular structure, tend to be found in the form of Dense Non-Aqueous Phase Liquids (DNAPLs) like oil and tar. VOCs, which have a lighter and less stable molecular structure, are generally found in the form of Light Aqueous Phase Liquids (LNAPLs), similar to gasoline, and tend to be more easily weathered by water or volatilized into the air. Both classes of contaminant are susceptible to warm temperatures- as tar will melt or bubble to the surface of the soil on hot days and VOCs tend to evaporate into the air at high temperatures. Due to their persistence and respective weathering abilities, these contaminants present a threat to air, soil and water quality on site. The documented hazards of compounds found on site range from being deadly if consumed to causing cancer if ingested or introduced into the blood stream in high enough levels. Some compounds can also be respiratory hazards if volatilized into the air in the form of particulates or gases. Mutagenic tendencies, the ability



Areas identified with contamination above EPA cleanup levels

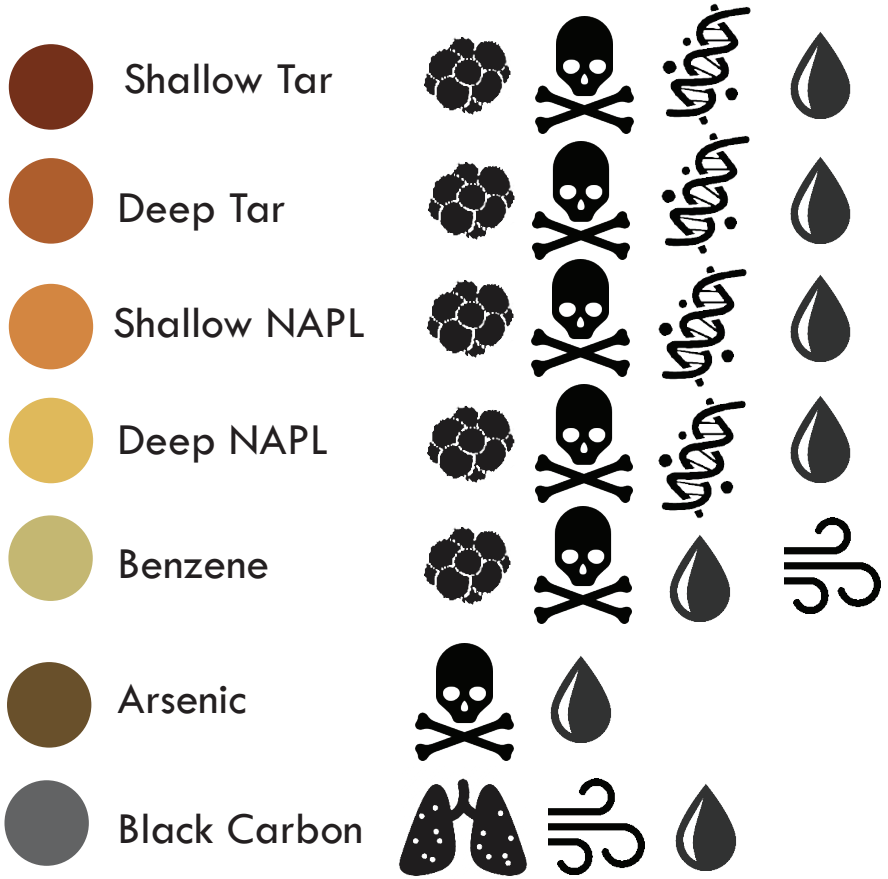


Source: GeoEngineers, Draft 2015

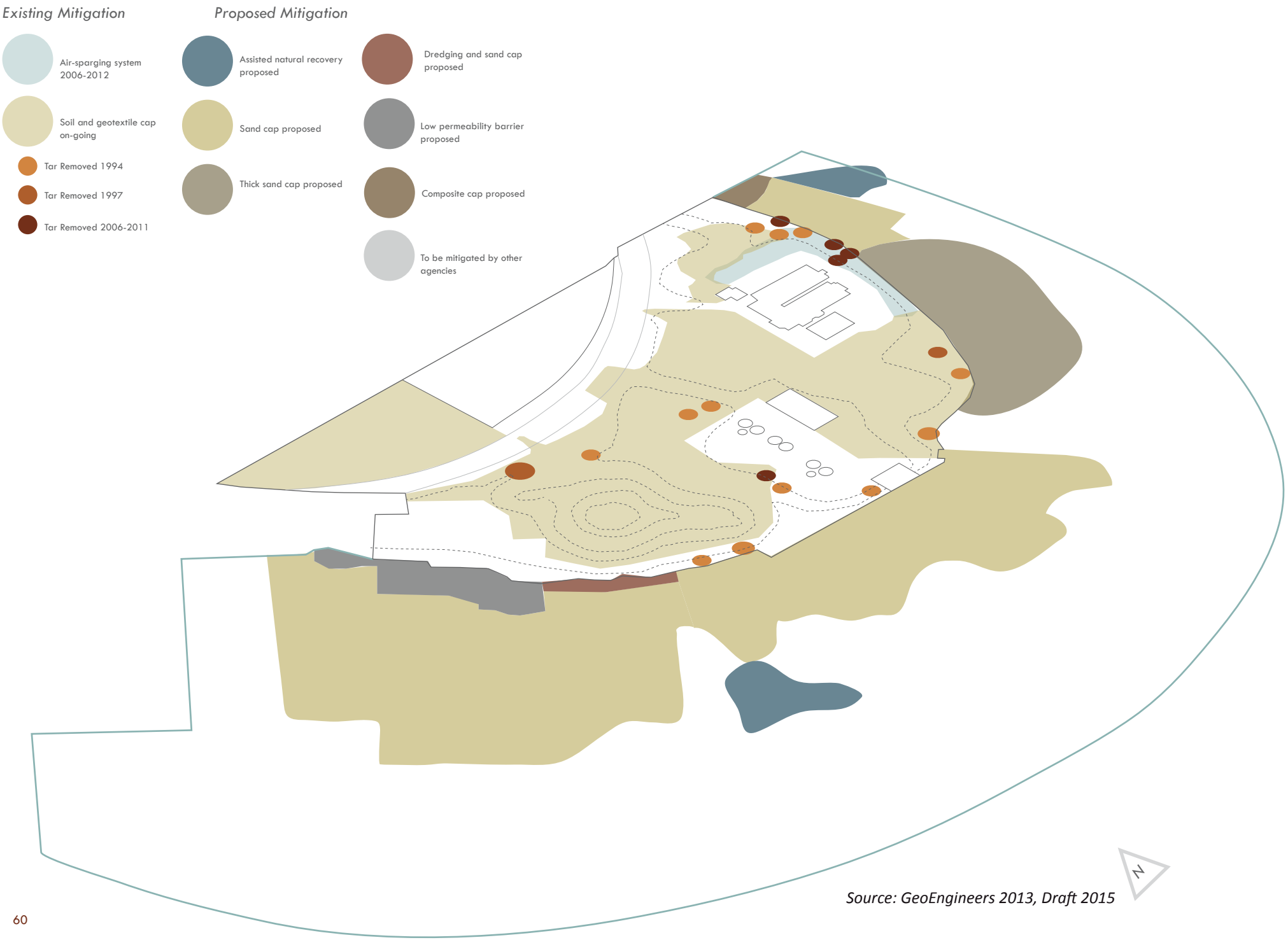
CONTAMINANTS OF CONCERN

of a chemical compound to alter an organism's DNA if introduced into the blood stream, is also of concern. Many of these compounds also have the ability to be moved by water or air through adsorption, binding to water and soil particles without being broken down into another form. This means that many of these substances move relatively freely through soil, water and air depending on their respective volatility.[15] This movement has been documented through cross-referencing lake sediment toxicity testing and soil and water testing in upland areas. A range of human and environmental health concerns are implicated when the breadth of toxicity outlined in monitoring and testing documentation is considered in light of potential hazards.

As outlined in the adjacent table, there are primary classes of pollutants that relate to sub-pollutants found specifically on site. While there have been many different hazardous compounds found on site, those outlined are of the highest concentrations and present the most immediate concern. Many of the pollutants identified on site, such as lead, cadmium and cyanide, were found below EPA cleanup levels or were deeply buried and determined to be stable. The most biologically hazardous compounds found on site are Polycyclic Aromatic Hydrocarbons (PAHs). There are seven types of PAHs found on site, all of these are toxic and carcinogenic, and one is a known mutagen. Benzo(a) pyrene is the densest PAH found on site, it is mutagenic and highly carcinogenic. Benzo(a)pyrene is formed when a benzene ring fuses to pyrene, typical of incomplete combustion of organics such as coal.[16] Because benzo(a)pyrene is a heavy molecule, it is relatively difficult to weather. Naphthalene, one of the lightest PAHs found on site is created by the distillation of coal tar. It is best known as the main ingredient in mothballs.[17] Due to its lightness, it is relatively easy to weather. Benzene is the compound whose fusion to other compounds and to itself forms many of the different PAHs found on site. Benzene is a constituent of crude coal and is highly volatile, a key component of gasoline.[18] Arsenic, although not the only heavy metal found on site, has been identified as a primary concern due to its concentration in a plume at the east edge of the site, between the waterfront and Play Barn. Arsenic is used for many things, its presence on site may be from wood treated for preservation purposes.[19] Black Carbon consists of pure carbon in several linked forms. It is commonly known as soot and it is another by-product of incomplete coal combustion. Although black carbon can be created by incomplete combustion of other materials, such as biomass, its concentrated presence on site is thought to have been generated by the 50 years of soot created by the Manufactured Gas Plant. Black carbon is primarily discussed in climatology as a forcing agent. Black carbon absorbs sunlight, contributing to global climate change. It is also a severe respiratory hazard when suspended in the air. Suspension in water could also be harmful to aquatic life.[20]

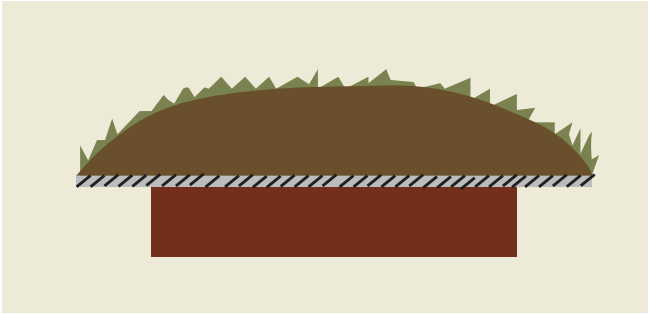


CONTAMINANT CLASS	DESCRIPTION OF CHARACTERISTICS	POTENTIAL SOURCES	POTENTIAL HAZARDS	MOLECULAR WEIGHT /RELATIVE WEATHERING
Polycyclic Aromatic Hydrocarbons (PAHs) 	PAHs are a mixture of several related compounds. Benzo(a)pyrene is the most toxic PAH and naphthalene is the most mobile PAH. PAHs are associated with dense non-aqueous phase liquids (DNAPL).	PAHs are the largest constituent of coal tar. Coal tar is a by-product of heating and processing coal into gas.	PAHs are toxic, seven types of PAHs found on site are also known carcinogens (cancer causing). Benzo(a)pyrene is toxic, carcinogenic and mutagenic (alters genetics of organisms).	The weathering of PAHs depends on their molecular weight. Heavier compounds (benzo(a)pyrene) have more rings (3-6) and are generally less soluble and relatively stable. Lighter compounds (naphthalene) with fewer rings (2-3) can be weathered by water and volatilized easily.
Volatile Organic Compounds (VOCs) 	VOCs are organic chemicals that vaporize easily at low temperatures. Benzene is the most toxic VOC. VOCs are associated with light non-aqueous phase liquids (LNAPL).	Benzene, the primary VOC on site, is a constituent of coal tar which is produced as a by-product of coal gasifciation and a primary product of American Tar Company.	Many VOCs are toxic. Benzene is both toxic and carcinogenic. It is the VOC of most concern for groundwater and air quality on site.	As suggested by their name - VOCs easily change from a liquid or semi-solid state into a more transient state through volatilization into gases or adsorption in water.
Arsenic (Metal) 	An inorganic metalloid chemical element naturally occurring in many minerals.	High concentrations of arsenic are a common by-product of coal-gas manufacturing.	Arsenic is toxic if high levels are ingested or introduced into the bloodstream.	Arsenic can be adsorbed but not absorbed or degraded. It may bind to soil particles or be carried by water but not chemically degraded.
Black Carbon 	Black Carbon (BC) is a particulate component of soot emitted by the incomplete combustion of fossil fuels.	Incomplete combustion of fossil fuels present on site in the form of processing coal into gas.	Fine particles typical of black carbon are a respiratory hazard. Inhalation can cause respiratory disease and cancer.	Weathering and molecular weight depend on the source and type of BC and how it is/has been stored. Most BC is contained in lake sediments near the site.

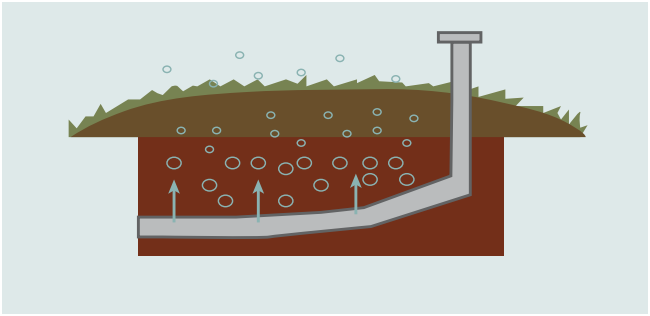


Source: GeoEngineers 2013, Draft 2015

soil cap with geotextile barrier



air-sparging system



tar removal by digging and disposal

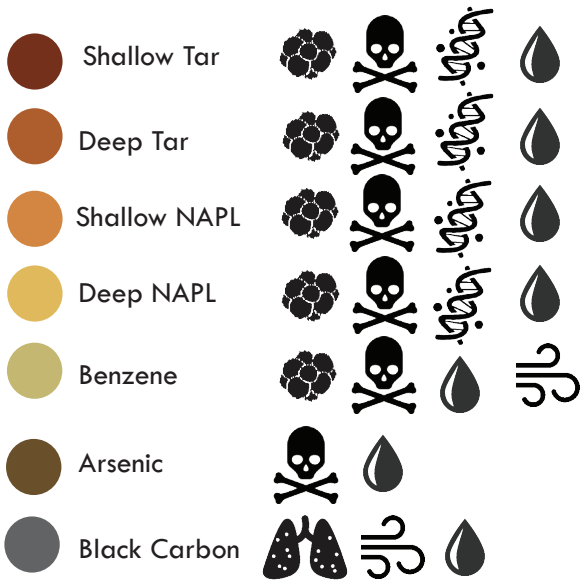


EXPOSURE MITIGATION

Due to the documented levels of contaminants present on site, actions have been taken by the City of Seattle to prevent human and environmental exposure. Since its first temporary closure in 1984, areas of the park have been intermittently closed by the Environmental Protection Agency (EPA), Washington State Department of Ecology (Ecology) and the City of Seattle (the City). At some stages, it has been necessary to close the entire park for short periods of time while mitigation or testing work is performed. The City and Ecology communicate with the public about these closures and the work being done through posted informational signs and mailers sent to nearby communities. The primary mitigation method in areas where pollution has surfaced is soil capping with a geotextile layer beneath the clean soil as an indicator. In the northeast corner of the site and along the eastern shoreline an air-sparging system was placed and utilized between 2006 and 2012.[21] Air-sparging is a mechanism whereby pressurized air is pumped through the soil in order to volatilize contaminants causing them to disperse into the air. This procedure was used to mitigate a benzene plume in the NE corner and shoreline area. Another, more invasive, procedure necessary at a few locations on site is the direct excavation and removal of tar deposits near or directly at the surface of the soil, followed by clean soil capping. The recapping of park soils where they become eroded or pollution becomes exposed is costly in maintenance, as is intensive drilling for soil and water quality testing.[22] Soil and clay caps are typically not considered long-term mitigation solutions without planned efforts to renew or replace the system in phases, as is typically done on landfills. Several forms of sediment capping have also been proposed for the lake sediments. Documents outlining proposals for active charcoal and sand capping, as well as dredging and sand filling, have not yet been finalized or published. However, plans for mitigating any further dispersal of polluted lake sediments are underway. The City and Ecology plan to begin remedial efforts in the sediment areas beginning in autumn 2017.[23] Concern regarding the further leaching of contaminants into the lake from the upland Gas Works Park area is being investigated but potential methods for preventing further leaching remain unknown.

SYNTHESIS

After reviewing the pertinent study results and documentation, it is apparent that actions beyond soil and sediment capping are necessary and reasonable to protect human and environmental health at Gas Works Park. The cost of soil capping and the need to continuously maintain soil caps in order to prevent human exposure to pollutants seems to be, in some areas of the park, unsustainable. Similarly, the excavation of tar deposits risks biological exposure and could jeopardize worker safety. The proximity of harmful pollutants to water in many areas of the park represents the most immediate threat as it poses risks for humans and the lacustrine ecology of Lake Union, including juvenile salmon. These pollutants have also been shown to travel relatively easily, suspended in water, making them a threat to water bodies connected to Lake Union by the Ship Canal. While Gas Works Park is not the only source of pollution in Lake Union, conclusive evidence of heavy pollutants unique to coal manufacture suggest that it has been a significant source of past and current lake contamination. If utilized correctly, phytoremediation technology presents mitigation methods that could provide more resilient protection, mitigation and control of pollutants.

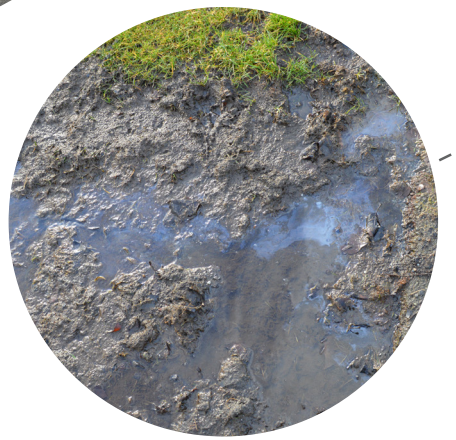




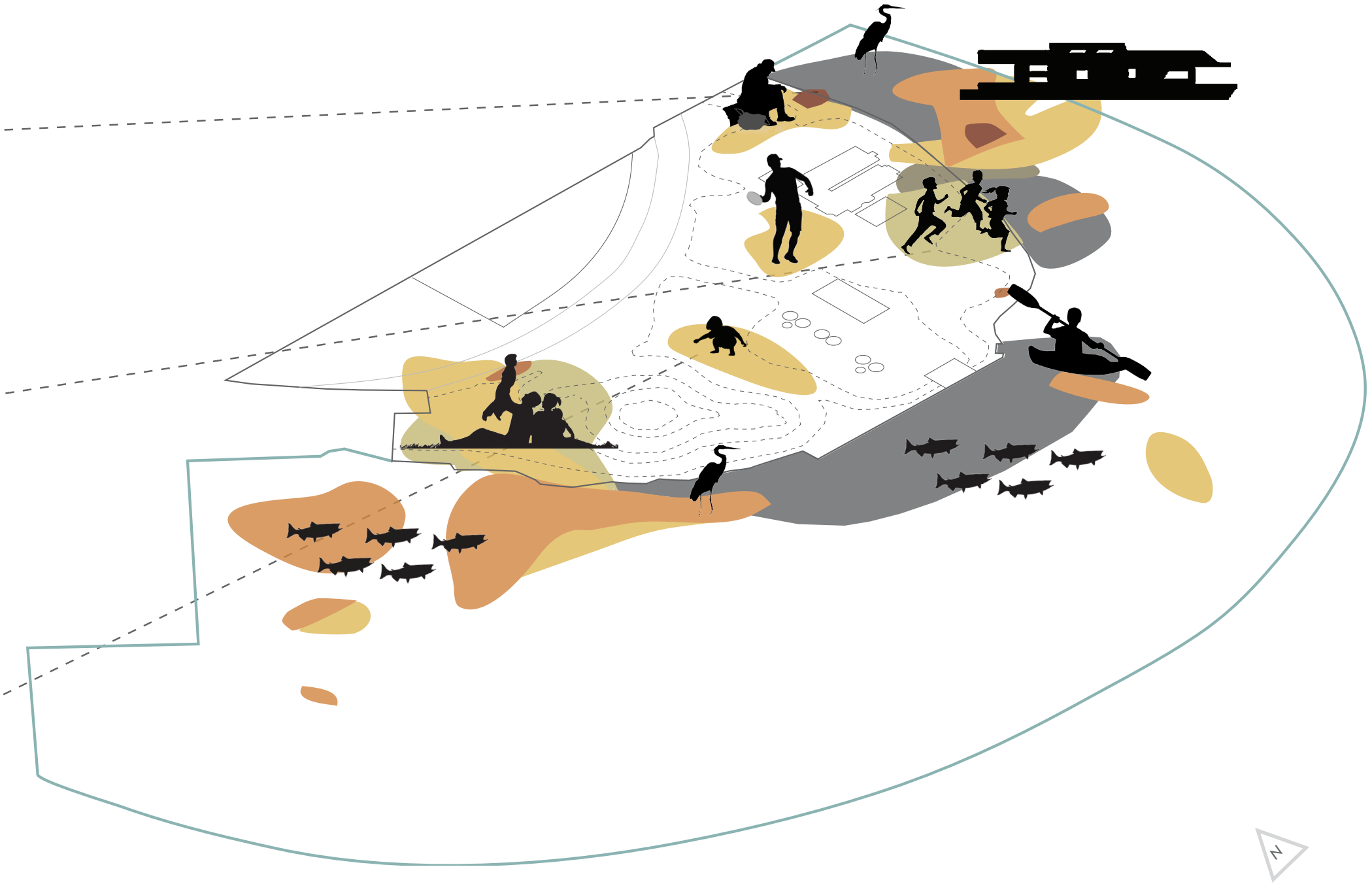
Oily water discharging into lake, NE corner



Children play in the puddles near the playbarn



LNAPL sheen on surface mud in the central swale



Overview of contamination and uses

REFERENCES

1.) Way, Thaïsa. *The Landscape Architecture of Richard Haag : From Modern Space to Urban Ecological Design* (Seattle: University of Washington Press, 2015).

2.) *Merriam-Webster Dictionary of the English Language.*

3.) *The Landscape Architecture of Richard Haag : From Modern Space to Urban Ecological Design*; ibid.

4.) Richard, Michael. *Seattle's Gas Works Park : The History, the Designer, the Plant, the Park, Map & Tour* (Seattle: M. Richard, 1983).

5.) Gary L. Turney, et al., *Ground-Water Contamination at an Inactive Coal and Oil Gasification Plant Site, Gas Works Park, Seattle, Washington,* Water-Resources Investigations Report / US Geological Survey (Tacoma, Wash.Denver, Colo.: Dept. of the Interior, U.S. Geological Survey, Books and Open-File Reports Section distributor,1990).

6.) Way, *The Landscape Architecture of Richard Haag : From Modern Space to Urban Ecological Design.*

7.) Dale Cole, et. al. , "Initial Soil Testing at Gas Works Park," (1971).

8.) Way, *The Landscape Architecture of Richard Haag : From Modern Space to Urban Ecological Design.*

9.) U.S. Census, 2010

10.) EPA, "Cercla," United States Environmental Protection Agency.

11.) GeoEngineers, "Feasibility Study Bridging Document: Gas Works Park Site," (Puget Sound Energy, 2013).

12.) M.A. Sabol, G.L. Turney and G.N. Ryals, *Evaluation of Available Data on the Geohydrology, Soil Chemistry and Ground Water Chemistry of Gas Works Park and Surrounding Region* (Seattle, Washington: Washington State Department of Ecology, 1988).

13.) Turney et al., *Ground-Water Contamination at an Inactive Coal and Oil Gasification Plant Site, Gas Works Park, Seattle, Washington.*

14.) Ibid.

15.) GeoEngineers, "Feasibility Study Bridging Document: Gas Works Park Site."

16.) https://en.wikipedia.org/wiki/Benzo(a)pyrene

17.) https://en.wikipedia.org/wiki/Naphthalene

18.) http://www.cancer.org/cancer/cancercauses/othercarcinogens/intheworkplace/benzene

19.) http://www.who.int/mediacentre/factsheets/fs372/en/

20.) http://www3.epa.gov/blackcarbon/basic.html

21.) GeoEngineers, "Feasibility Study Bridging Document: Gas Works Park Site."

22.) "Supplemental Investigation Work Plan," (Puget Sound Energy, 2013).

23.) Washington (State). Toxics Cleanup Program., "Gas Works Park Update : What's Happening at Gasworks Park?," in *Publication* (Bellevue, WA: Department of Ecology, State of Washington, Toxics Cleanup Program, 2014).



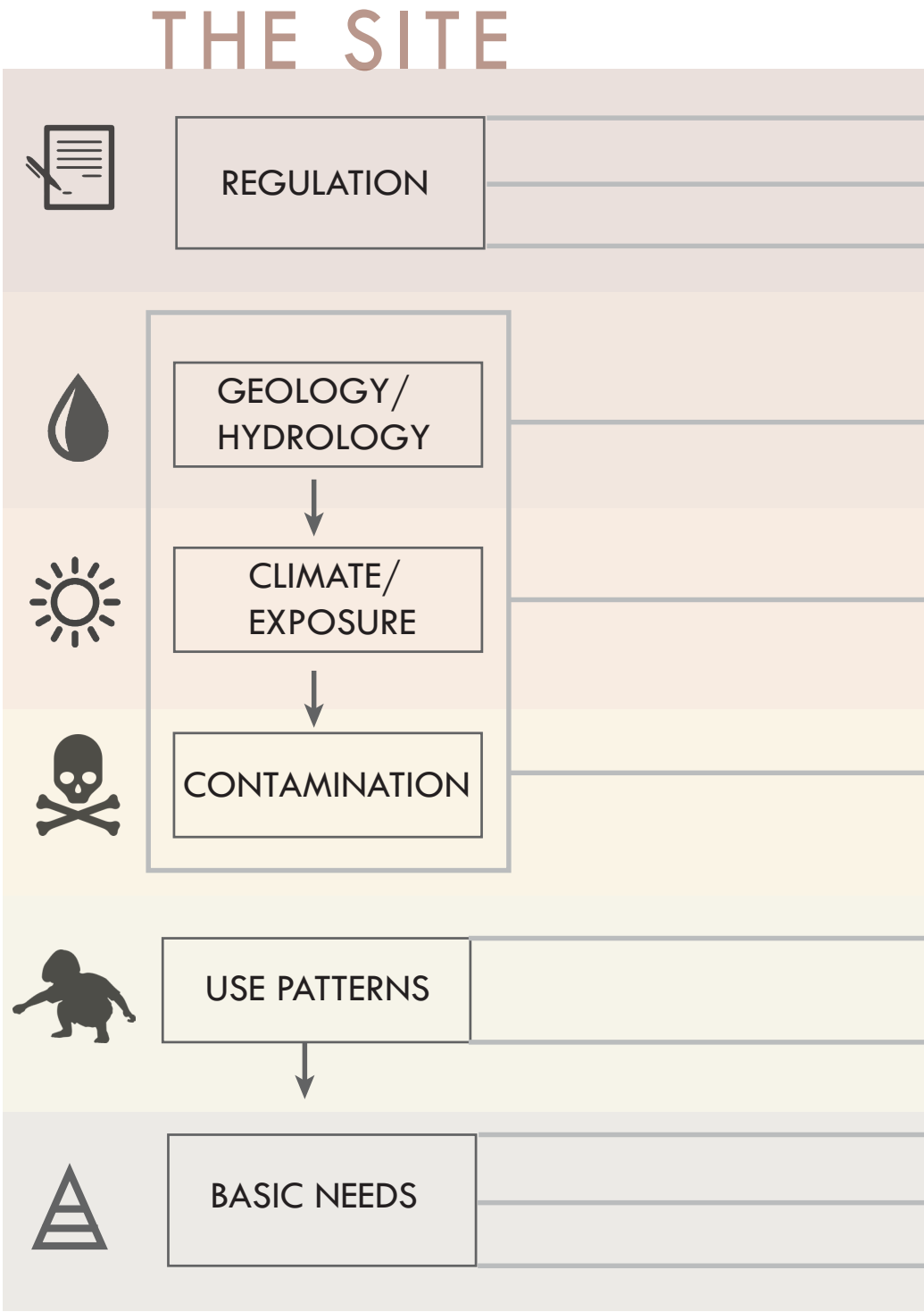
DESIGN METHODS
data driven interventions

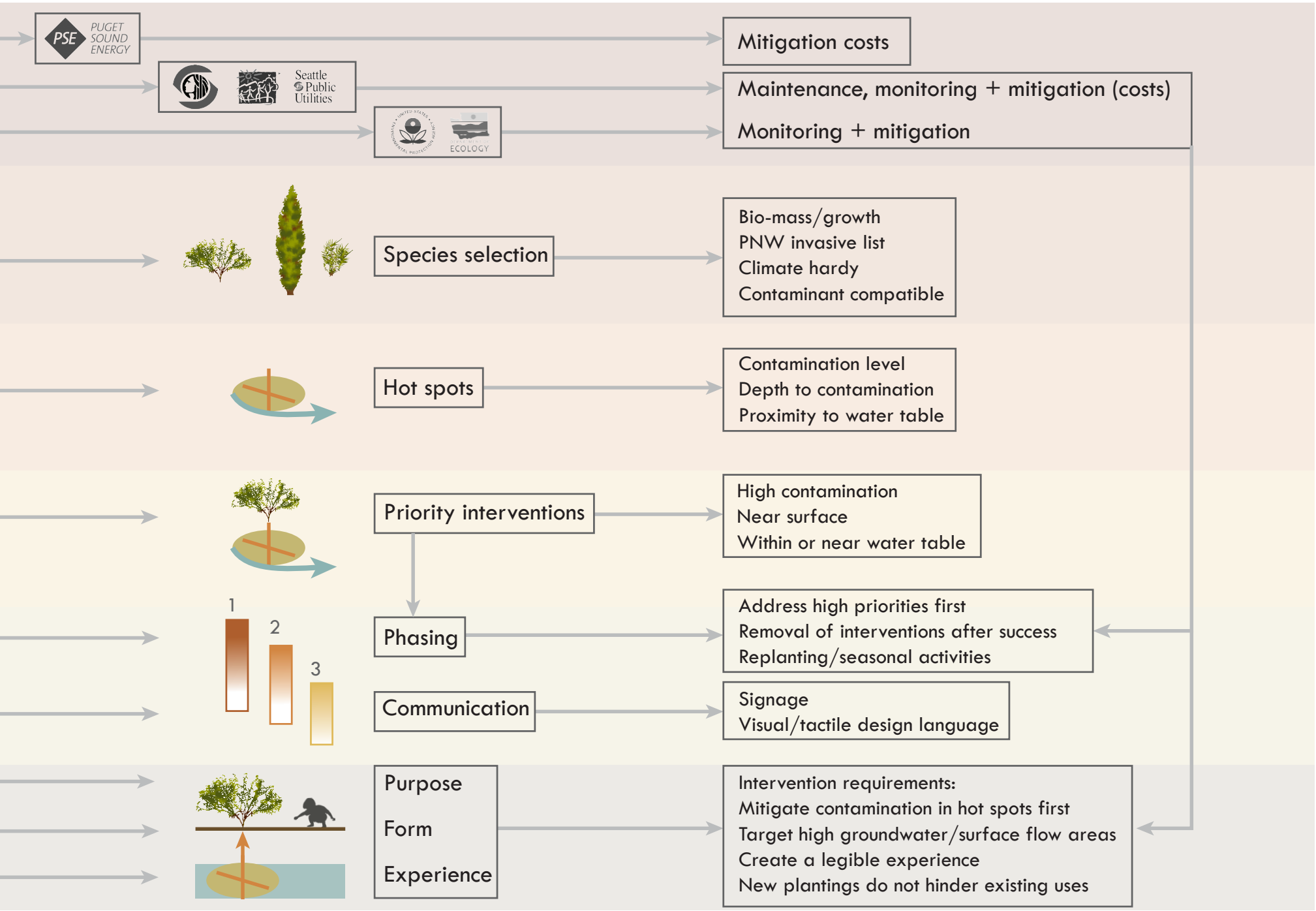
Applying phytoremediation as a means to address pollution at Gas Works Park, i.e. utilizing plants to degrade, absorb and uptake contaminants, is a complex process and cannot be designed for the site without due consideration of social, ecological, and economic forces. To address the complexity of physical forces, hydrology, geology and topography, at play on site, documentation of previous work has been collected and surveyed. Understanding relevant case studies, field studies and other precedents is key to developing optimal alternatives for remediation. Phytoremediation field studies, outlined in the literature review and case studies, document the species and conditions necessary for successful remediation. These studies also test potential phasing and monitoring schemes to be considered.[1] Design precedents, while not exclusively specific to site conditions, provide insight into design methods focused on revealing through form, processes which may not be readily visible.[2] The goal of these design methods is to structure a creative process toward conceptual and schematic design that is both functional and accessible. Ultimately, phytoremediation design for Gas Works Park should illuminate how site specific forms may be enhanced by interventions addressing dynamic processes. Above all, design methods must be site based and site specific for phytoremediation to be successful.

THE SITE FRAMEWORK

Design methods used in this project are intended to prioritize the processes in action on site. A design framework layering stable structures and dynamic processes helps to visualize the complexity of designing site specific interventions. This framework could be considered as a set of filters that constrain and inform site design. The regulatory framework at Gas Works Park involves the EPA at the federal level, Ecology at the state level and agencies within the City of Seattle and Puget Sound Energy (PSE) at the site level. The protocol of bureaucratic structures in place cannot be overlooked as a stable frame for design, one that provides practical grounding for implementation, maintenance and monitoring, which are important components in any phytoremediation project.

At Gas Works Park successful management relies on city agencies as any interventions proposed for contaminant mitigation must be approved and officially implemented through the proper regulatory framework. Within the regulatory structure, alongside implementation and maintenance, phasing and monitoring provide check-points for management, allowing opportunity for interventions to adapt. In this way stable elements of the framework inform actions taken in the dynamic layers of the framework and create a feedback loop for monitoring, maintenance and adaptation. Successful implementation, the reduction in overall contaminants on site, relies on phased interventions and monitoring of interventions to determine optimal strategies. Results from monitoring contaminant levels and microbe concentrations relative to growth at phased intervals directly influence adaptive measures. The ability of interventions to adapt to fluctuating conditions on site relies on the successful implementation of interventions within the regulatory structure, ensuring proper maintenance and monitoring. Here, adaptation means utilizing data from monitoring to promote future success through the movement, removal and replacement of intervention components, adjusting planting strategies in attempts to improve phytoremediation performance and user experience.




PUGET SOUND ENERGY
Seattle Public Utilities
ECOLOGY
Mitigation costs
Maintenance, monitoring + mitigation (costs)
Monitoring + mitigation
Species selection
Bio-mass/growth
PNW invasive list
Climate hardy
Contaminant compatible
Hot spots
Contamination level
Depth to contamination
Proximity to water table
Priority interventions
High contamination
Near surface
Within or near water table
1
2
3
Phasing
Address high priorities first
Removal of interventions after success
Replanting/seasonal activities
Communication
Signage
Visual/tactile design language
Purpose
Form
Experience
Intervention requirements:
Mitigate contamination in hot spots first
Target high groundwater/surface flow areas
Create a legible experience
New plantings do not hinder existing uses

FORMS

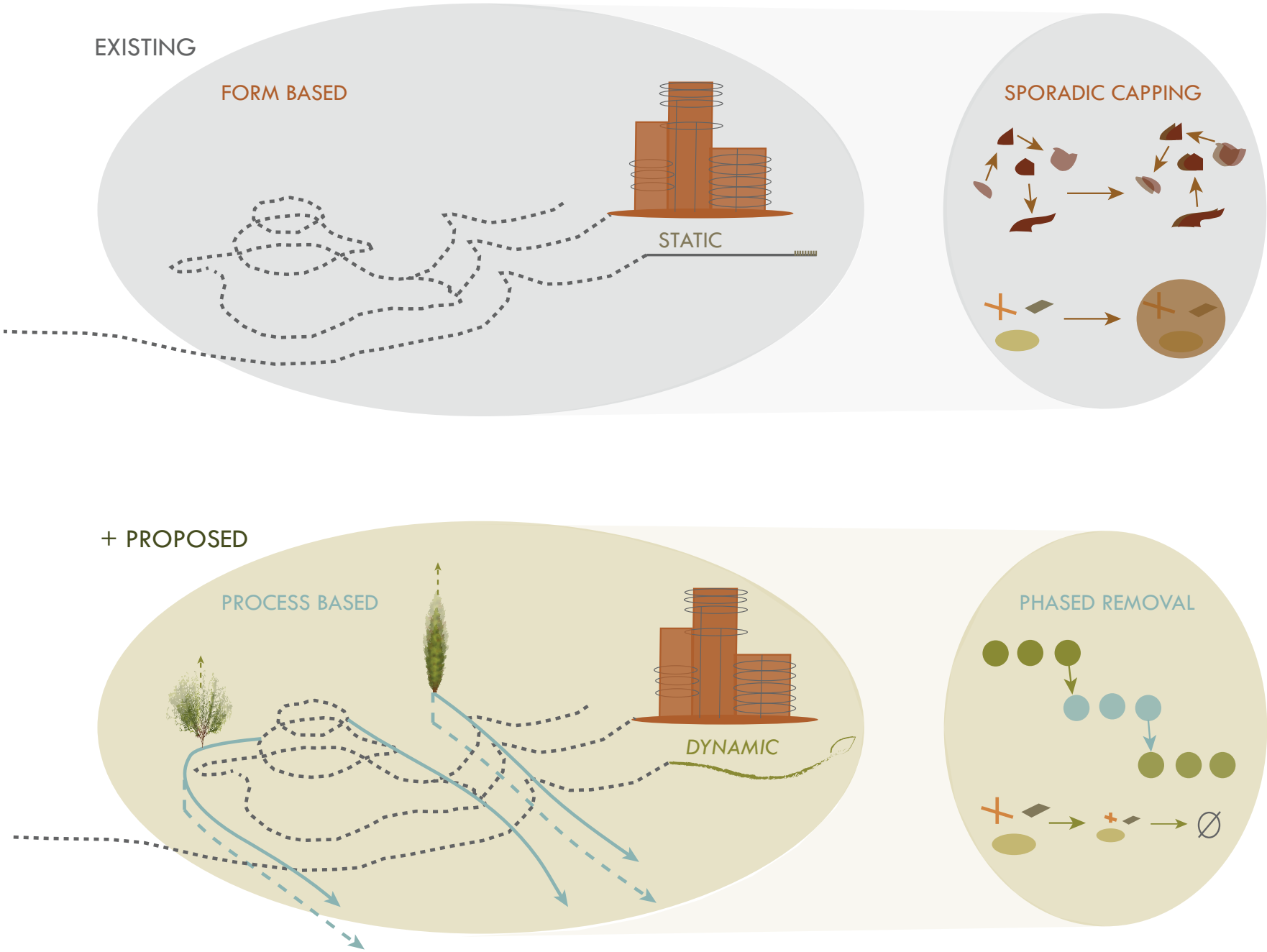
Current user experience at Gas Works Park is shaped by tactile forms woven into and through the landscape. Mounding is a constant presence on site, shaping the way people move through it and experience the views offered. The prevailing visual language uses land forms to accentuate the remaining gas works structures and frame views. This language of form creates a unique user experience focused on the tactile surface of the landscape as viewed from different vantage points. The forms of the topography and retained structures provide a particular set of experiences that make Gas Works Park special.

The site's physical forms have also shaped systems that operate below the surface of the park, influencing processes that are influential while often invisible. Phytoremediation design typically focuses on those invisible processes taking place below-ground. These below-ground processes are the crux of phytoremediation praxis, as it is the functions of microscopic soil communities that make phytoremediation possible. A comprehensive phytoremediation proposal for Gas Works Park should communicate the confluence of below-ground processes and above-ground forms. Revealing the functions of below-ground processes as forms above-ground, forms interwoven with the landscape that created the processes, offers benefits beyond remediation. Visual communication, through tactile experience, could also inform user experience of the site. A design process that values the legacy of existing forms while addressing its processes is essential to the success of phytoremediation interventions at Gas Works Park. Developing process based interventions and weaving them into existing forms would allow phytoremediation design to address areas of concern without hampering the landscape's iconic appearance and use.

Designing for the site begins with the levels and locations of contaminants of concern, respective depths of those contaminants and climatic and topographic considerations necessary for selecting optimal phytoremediation species. Empirical and experiential information from case study data play an important role in identifying the best approaches to interventions. Reviewing case studies that bear relevance to specific site conditions allows for a range of perspectives and strategies to be considered, utilizing the most promising toward site specific phytoremediation design. Individual species are selected for their documented performance in field studies mitigating contaminants that are of critical concern at Gas Works Park.

The physical forms of planting interventions should be molded to existing forms on site, playing off of the design language Haag implemented- juxtaposition of curvilinear and rectilinear, framing views with landforms and architecture. Haag's use of landform to control movement and spatial experience, hiding and revealing different areas of the park as you move through it, can be used as a template within which interventions can interact with underground processes and above-ground users. Additionally, interventions that use organisms to address hydrologic and geologic processes present a unique opportunity to engage planning for permanent remediation.

Understanding the design vocabulary currently operating on site as designed by Haag and used by residents for over 40 years is key to developing concepts that enhance or build on the park's existing language. Intertwining existing structure and experience with a new vocabulary, one that brings invisible processes to the surface, is the goal of conceptual development. While the use of interpretive signs may be a preferred possibility, in addition to the visual design concepts, the focus for phytoremediative planting design is to communicate through visual and tactile experience. Other important components to any preferred planting concept are the consideration of project phasing, maintenance and monitoring. These elements impact the physical remediation as well as the experiential success of the design. Current monitoring and maintenance treatment of the site would be augmented by proposed interventions, potentially simplifying the process while making the progress of the park's remediation a more public experience.



Design Language - engaging systems shaped by existing forms

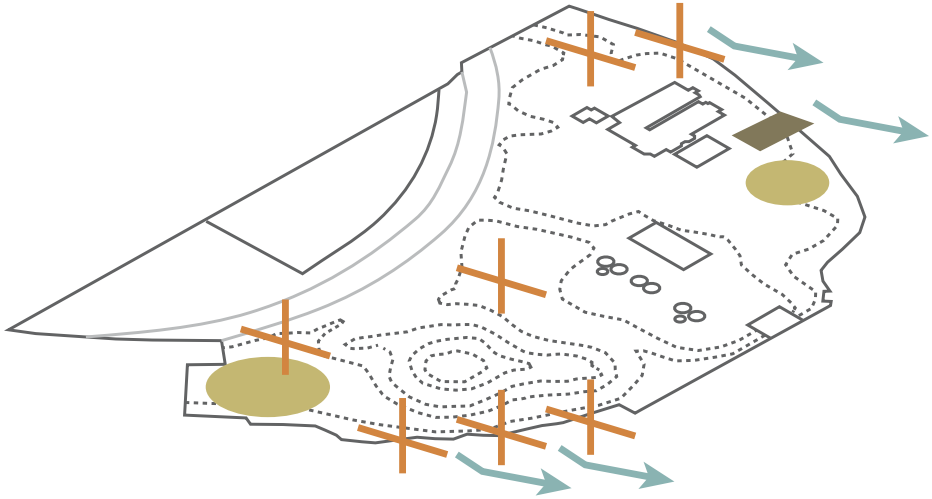
PROCESS

Once plant/contaminant associations and remediation relationships are identified, planting strategies, or “phytotypologies”, can be developed by combining individual plants into schemes that address specific topographic, hydrologic and climatic conditions across the site. These planting strategies, once generally developed, can then be used to create concepts that consider human experience of phytoremediation design, focused on visual communication.

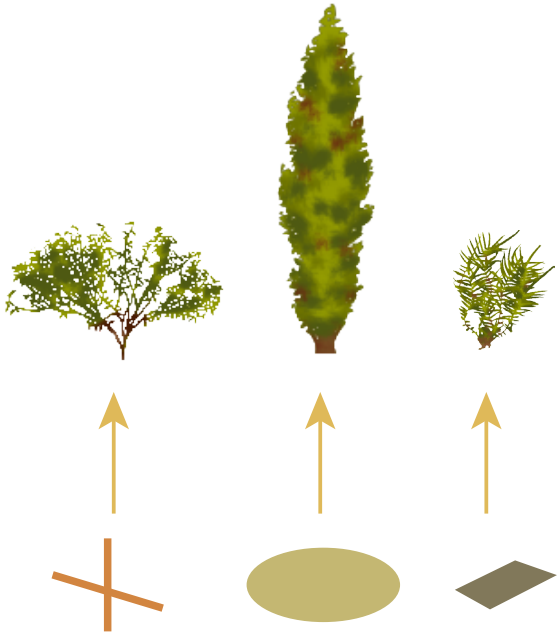
As a process, design methods for this project can be organized as steps - using the site framework as filters for informing and cross-checking each step to ensure its legitimacy before moving forward. Once species, strategies and planting areas have been selected the next step is to make the relationships between species, form, hydrology, geology and contamination visible. Adapting methods developed by the site’s environmental analysts, cross sections of site conditions can be created by interpolating between monitoring wells and boreholes. Hundreds of study holes perforate the site, some have been filled-in after initial monitoring while others remain intact and are still used today to monitor contaminants and water levels across the site. There are three general types of study holes used for monitoring: boreholes that collect soil samples between .5’- 4’ deep, monitoring wells that collect water and soil samples between .5’- 12’ deep, and surface soil samples that collect soils from the top .5’. While each of these monitoring methods provides slightly different results, when viewed as a whole body of information, a relatively clear picture of the varying soils, contaminants and hydrology across the site emerges. Interpolating, or using available data points to infer the data between points, has been used to determine general conditions on site since the mid-1980s and helps site engineers and maintenance crews determine priority areas for remediation.[3] Schematic sections of focus areas can be paired with planting strategies to test out the physical relationships of plantings, contaminants and geohydrology above and below ground. These sections also inform a visual understanding of proposed visual relationships on site.

Once practical relationships are established development of experiential components, finessing intervention design in order to achieve harmony with existing forms and use, can begin to evolve. Through the lens of experiential considerations, intervention design and planning will shift and transform, moving beyond practical phytoremediation considerations to fully engage design.

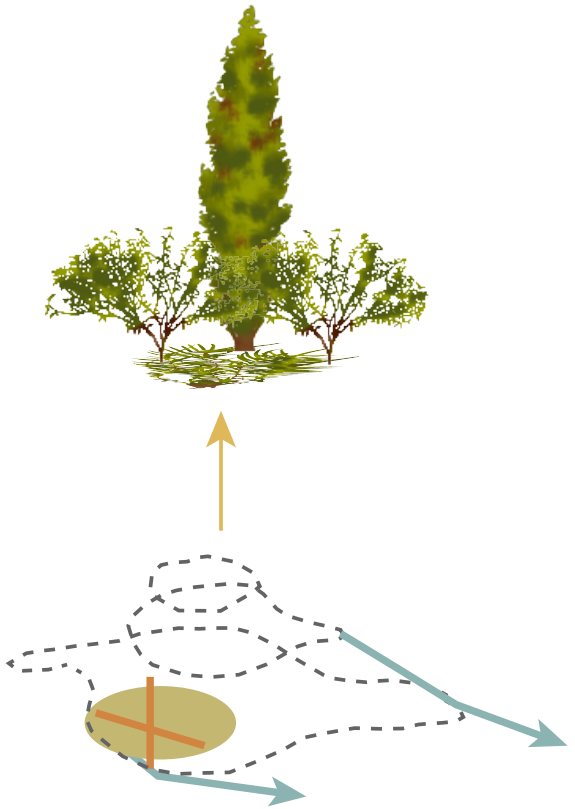
1 The Site: Concerns + Processes + Systems



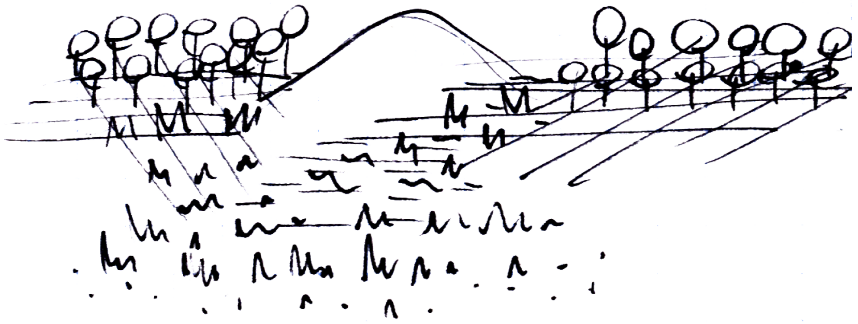
② Identify individual species for contaminant/ location specific mitigation



③ Combine species into planting strategies for maximum benefit in a variety of scenarios



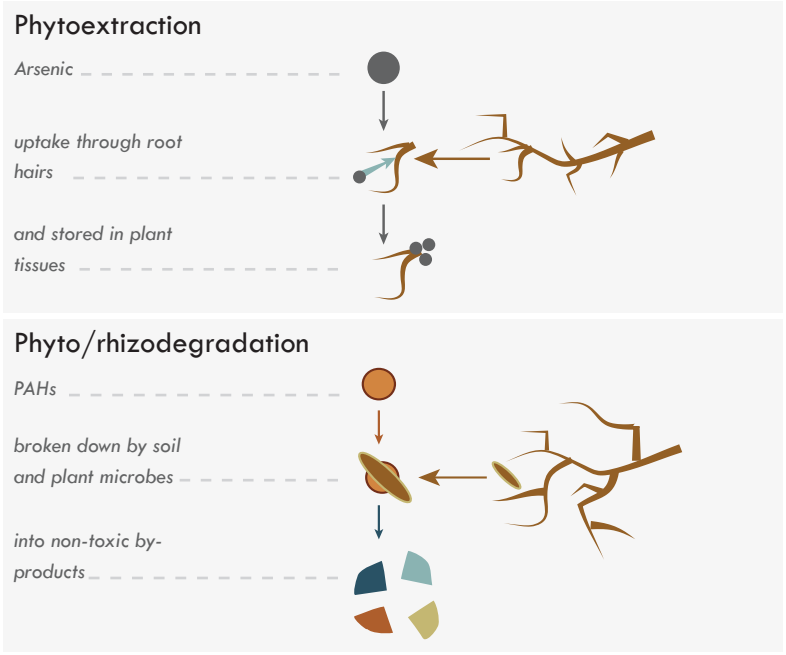
④ Develop concepts that visualize the forms of proposed process based interventions



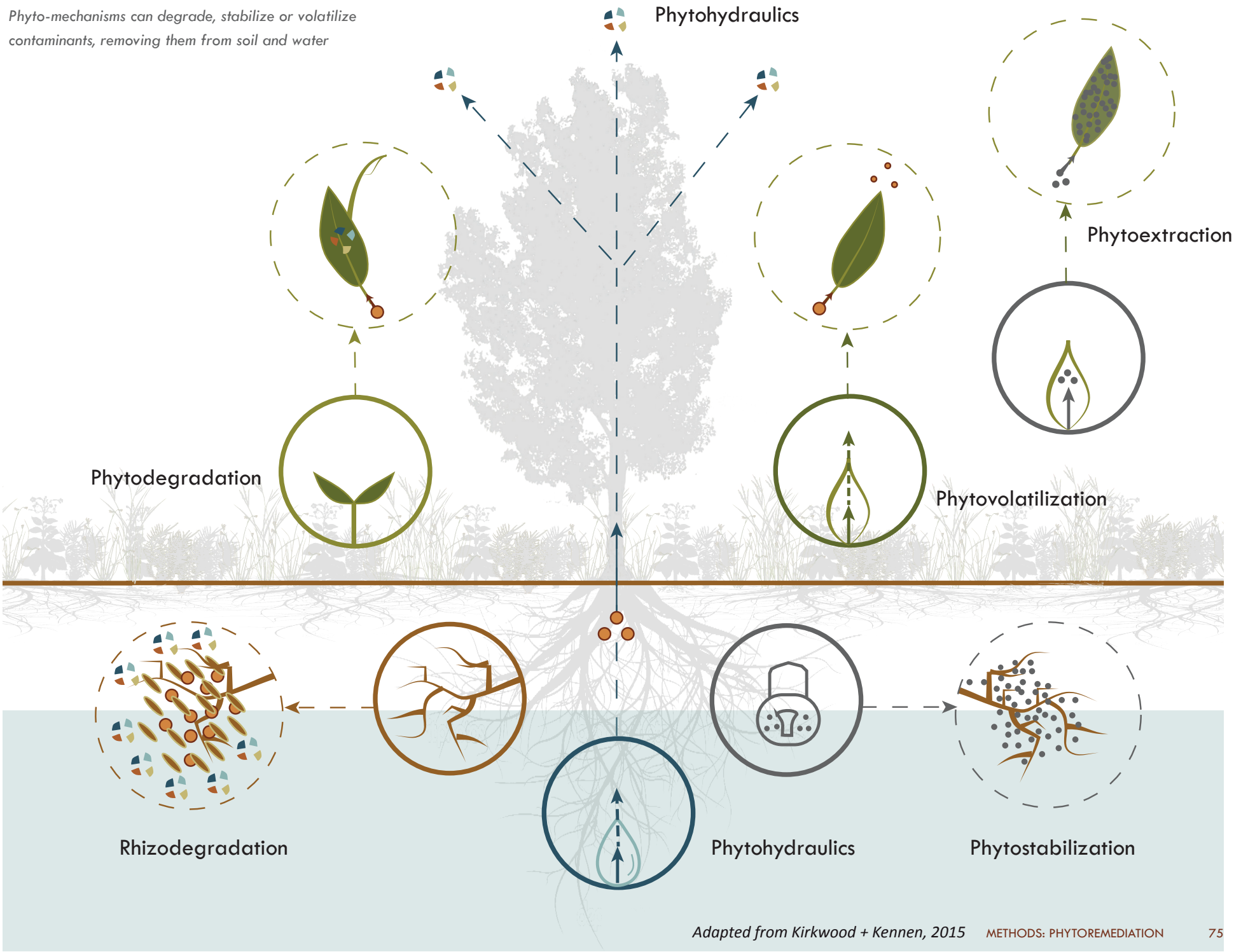
PHYTOREMEDIATION

The associations between specific species, contaminant levels and depths is key to the success of phytoremediation design. The relative root depths and capabilities of these species are suited to particular modes of phytoremediation. The relationships between an individual plant's physiology and introduced or naturally occurring microbes can also aid degradation as well as improve general soil and sediment health.[4] Each species presented in the following plant profiles has been carefully selected for its respective remedial capabilities and its ability to grow well in polluted substrates. The studies that tested each species have also been reviewed for site specific compatibility as well as the plant's cultivation needs and hardiness zones, and Washington State noxious weed and invasive species listings. Each individual plant may have a range of remedial mechanisms depending on its propensity to take up water and nutrients. The overall biomass of the plant (size, foliage mass, root mass and depth) is also an important factor that indicates how efficient a particular species may be at given remedial tasks. Time frames for remediation depend on many factors, the most significant being the type and amount of contamination present.[5] Mechanisms utilized for remediation can also influence the time frame in which a given situation may be mitigated. For example, heavier and deeper contaminants will take longer to degrade or absorb and may require a variety of remediation strategies to fully neutralize the contamination. Lighter and shallower contaminants tend to be more easily degraded or volatilized and fewer remediation strategies may suffice for relatively quick remediation. Inorganic pollutants that cannot be degraded or absorbed present a more nuanced remediation scenario because, although some plants can adsorb inorganic pollutants, they must be biologically available for efficient uptake. A plant with the ability to adsorb and store inorganics, like metals, needs first to be able to access the pollutant. Climatic and geologic conditions may prevent or enable a plant's ability and efficiency in adsorbing inorganics. Phytoremediation mechanisms to be used on site, through species selected for their remedial abilities, are phytodegradation, phytovolatilization, phytohydraulics, rhizodegradation and phytostabilization.

Each of these mechanisms applies to one or more types and depths of contamination and may be utilized by plants concurrently or individually. Phytovolatilization is the process of a plant taking up a contaminant in a liquid or solid state and releasing it as a gas through transpiration. This process does not necessarily degrade the pollutant, rather the compound is simply changed into a gas and slowly released through the leaves. This process generally does not happen rapidly enough to pose air quality concerns. Phytodegradation is the ability of a plant to physically take up and degrade a contaminant, breaking it into smaller pieces and using those pieces to build its biomass, transpiring any remaining components through its leaves. In most cases this process transforms the pollutant's chemical composition so that the composition of the new elements are non-toxic. Phytohydraulics is a mechanism specific to particular species of plants, usually trees, which can soak up and transpire large amounts of water as part of their daily hydration process. The ability of some species to transpire, in the case of willow and poplar between 200 and 800 gallons of water a day, can prevent leaching of contaminants into ground water or prevent contaminated groundwater from flowing off-site.[5]



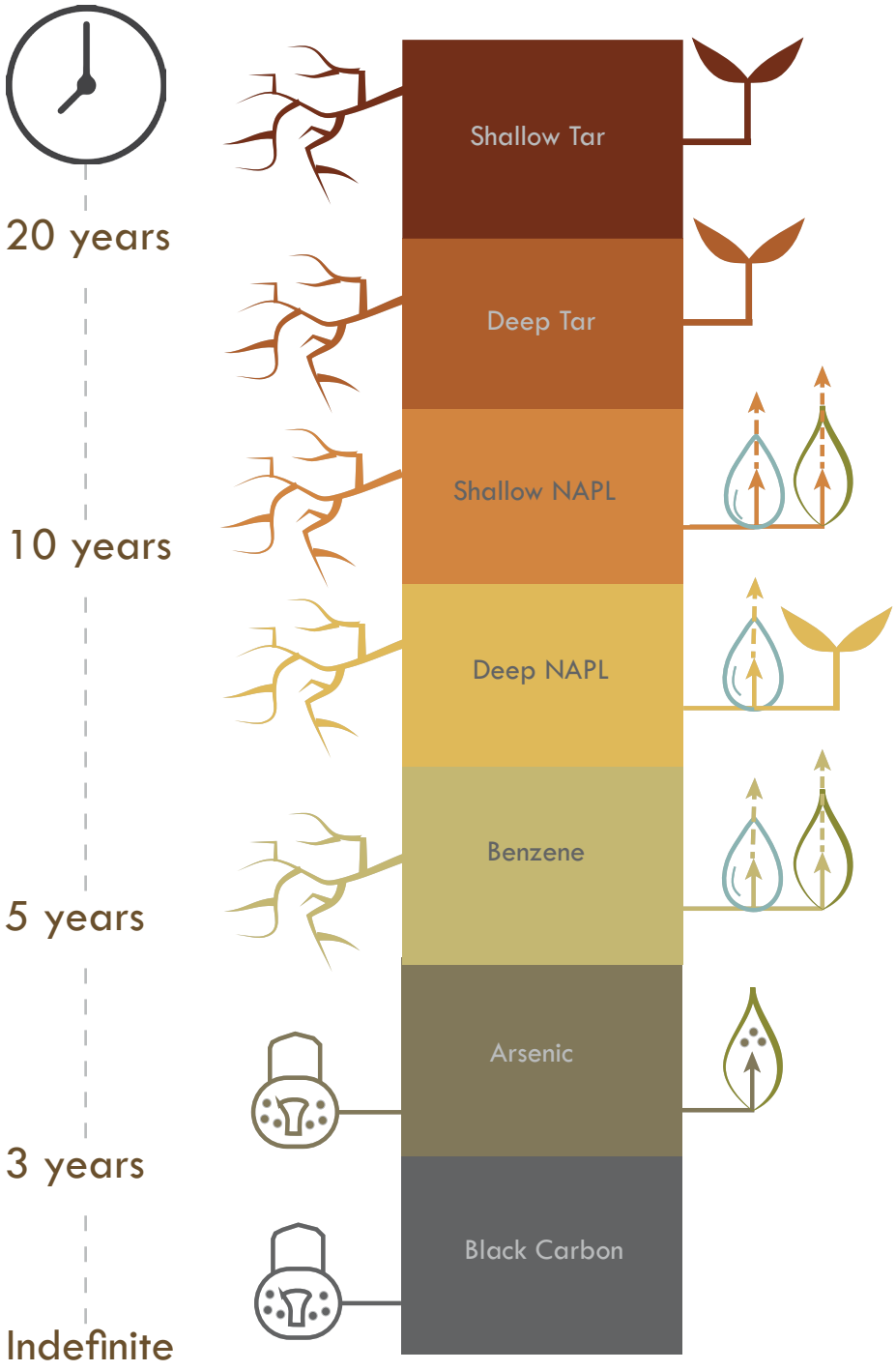
Phyto-mechanisms can degrade, stabilize or volatilize contaminants, removing them from soil and water



Adapted from Kirkwood + Kennen, 2015

REMEDIAL MECHANISMS

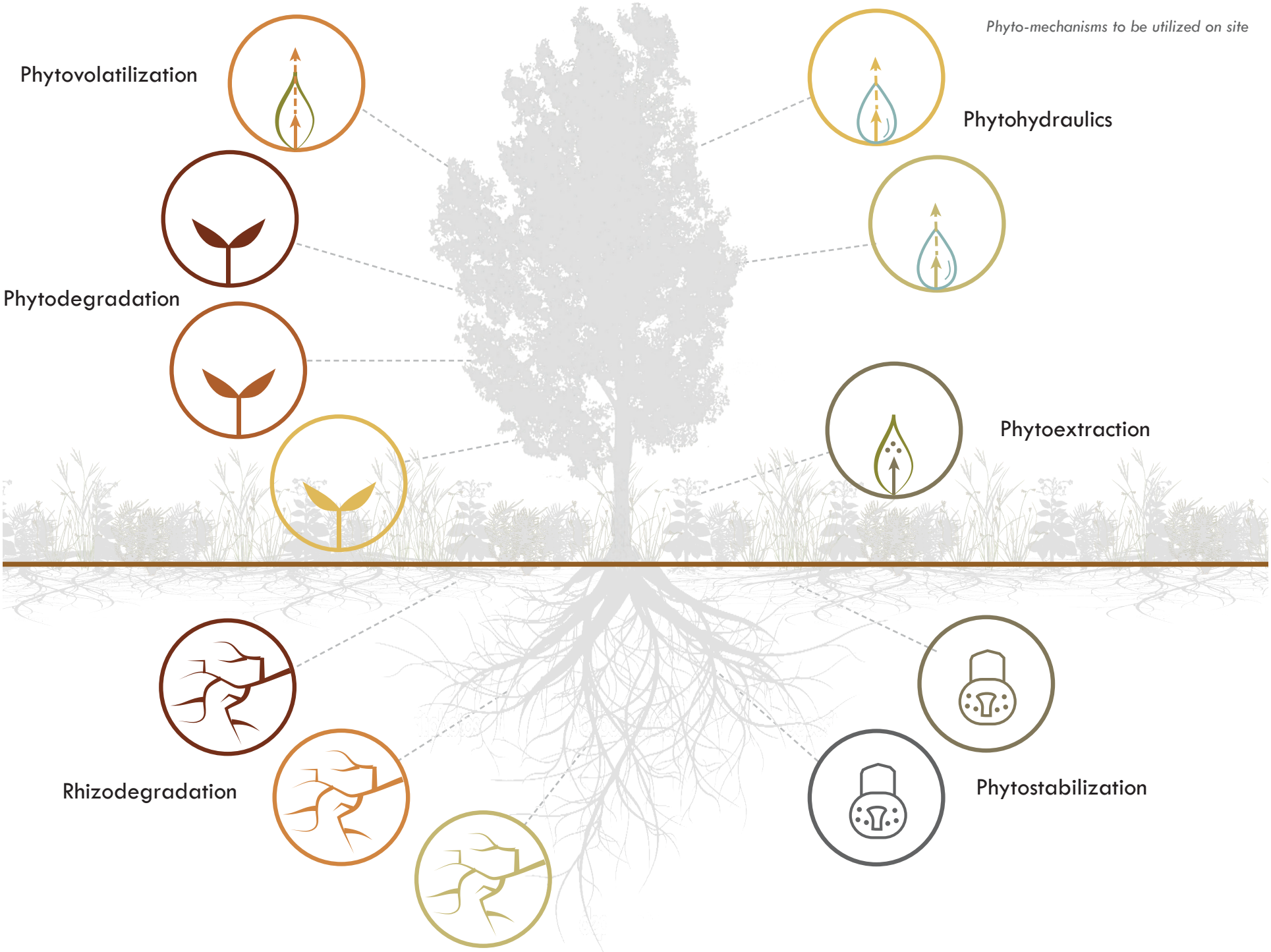
Often, phytodegradation and phytohydraulics operate together, presenting a powerful tool to prevent leaching and degrade contaminants simultaneously. Rhizodegradation is one of the most commonly cited mechanisms for remediation. This process relies on the microbial communities in the soil which are enhanced, or often created by, a plant's root system. Live plant roots aerate the soil, providing essential oxygen circulation and organic matter that microbes need to thrive. Many microbes, which can be introduced or occur naturally, will not only eat the organic matter produced by roots, they will degrade and consume any carbon based matter in the soil, including organic pollutants such as petroleum products.[6] Phytoextraction is an especially unique mechanism only found in specialized plants. It allows plants to physically takeup inorganic contaminants, like heavy metals and arsenic, through their roots and store them in live tissues. The plants can then be harvested and either disposed of in a hazardous waste fill (creating far less material weight than disposing of polluted soil mass) or be incinerated in order to reuse the metals (phyto-mining).[7] Phytostabilization is the ability of plant roots to form fibrous networks underground that can catch and hold contaminants in place, preventing spread or dispersal by water or wind. This mechanism is particularly useful for contaminants that cannot be degraded and are in the form of particulates such as arsenic and black carbon. Phytostabilization can be used to trap many types of contaminants and hold them in place while they are degraded.[8] A visual key, expressing the relationships between species and contaminant mitigation has been developed to clearly state each plant's individual phytoremediation abilities (seen at right). Time is another important component of interventions - each mechanism operating on a different time scale ranging from as little as three years to as long as twenty years or indefinitely. Although contamination is generally not found in the fruit of phytoremediation species, avoiding species with fruit that animals eat is an important consideration. Similarly, pollen in the flowers of phytormediation species apparently do not store contamination, but awareness of how flowering phytoremediation species could impact pollinators is important none the less.



Relative time to remediate

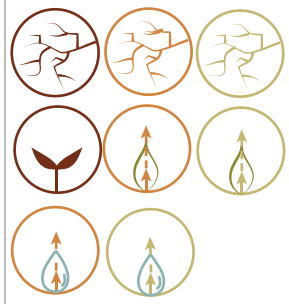
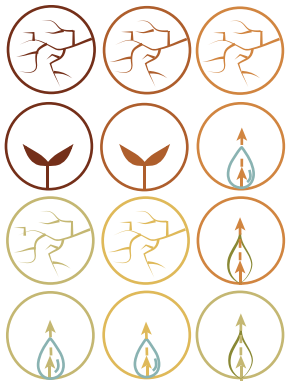
Phyto-mechanism/Contaminant key

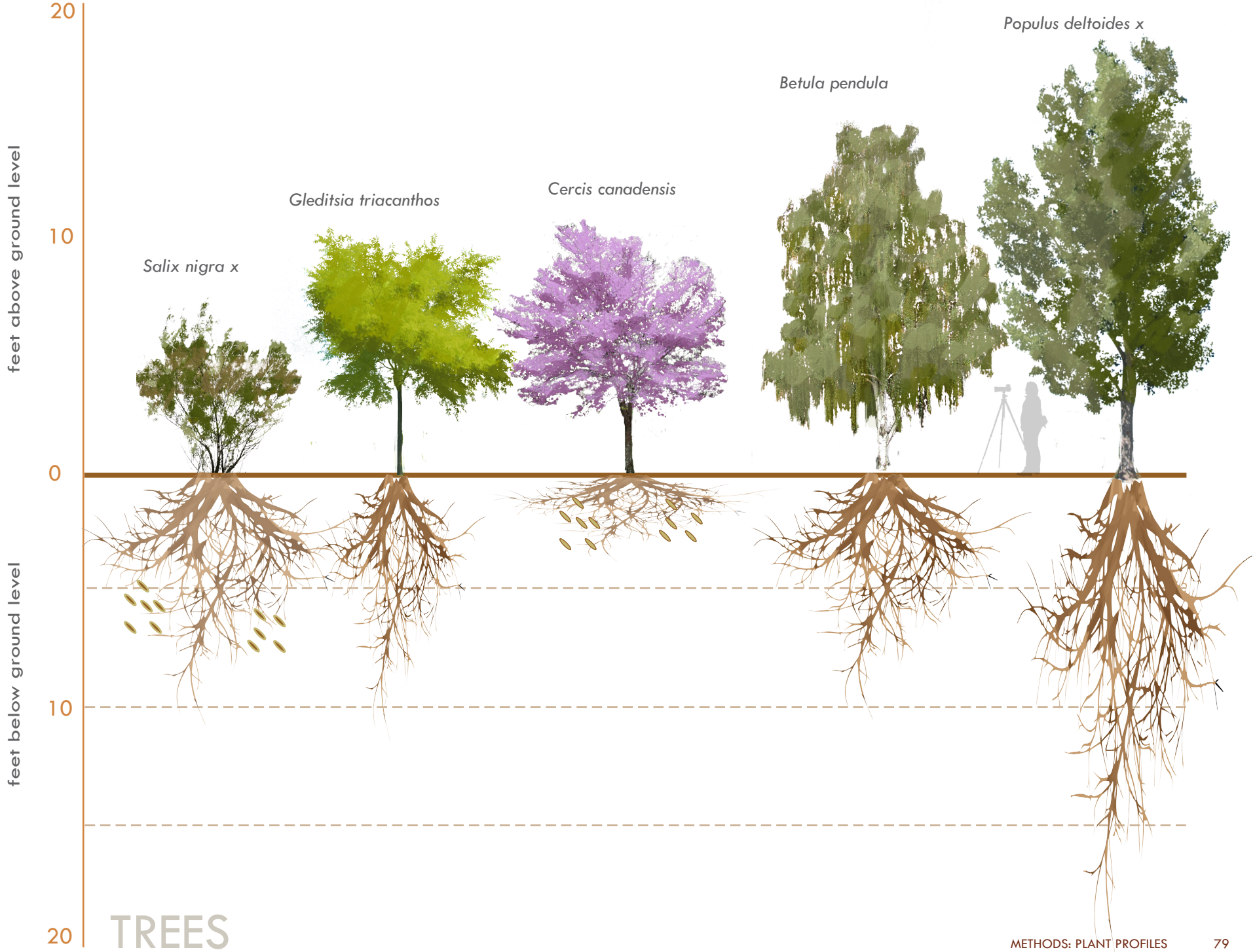
Phyto-mechanisms to be utilized on site

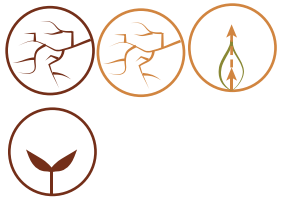


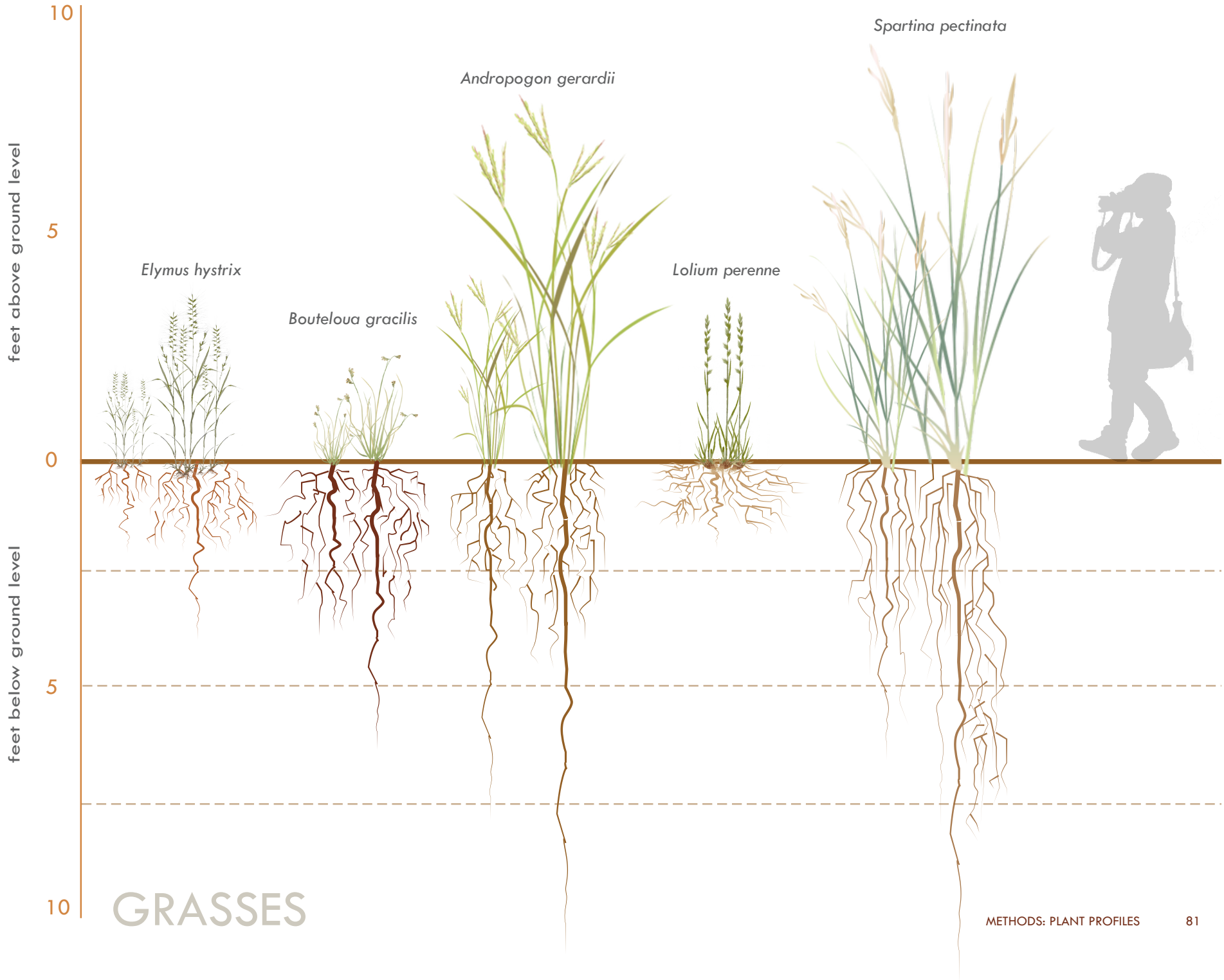
Adapted from Kirkwood + Kennen, 2015

PLANT PROFILES

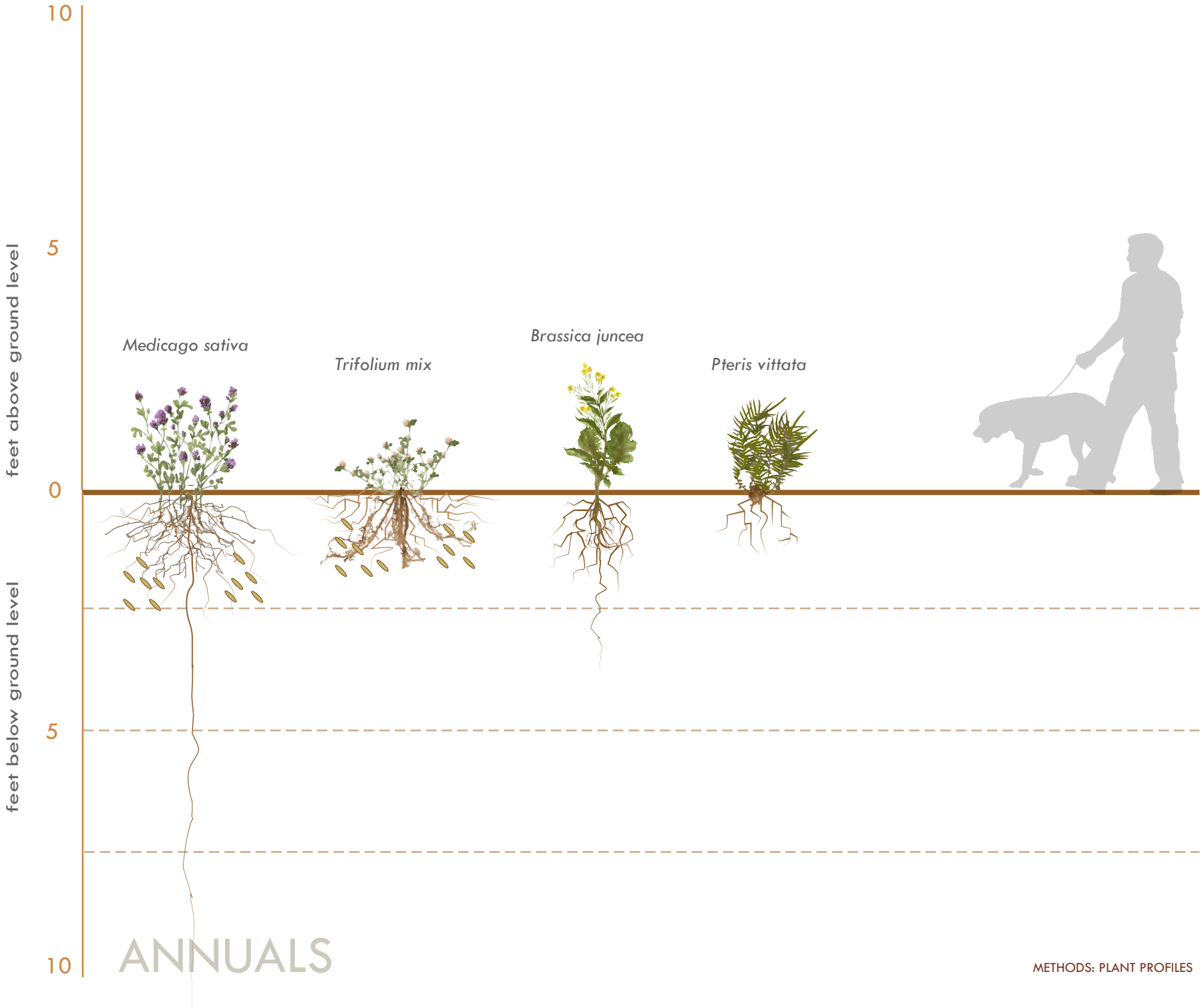
				
Salix nigra x: Black Willow hybrid	*Gleditsia triacanthos:* Honey Locust	*Cercis canadensis:* Redbud	*Populus deltoides x:* Eastern Cottonwood	*Betula pendula:* White Birch
				
Mechanisms: *Rhizodegradation*- shallow heavy/light PAHs, benzene, *Phytodegradation* - shallow heavy PAHs, *Phytovolatilization*- light PAHs, benzene, *Phytohydraulics* - light PAHs, benzene **Size:** 10-20' tall x 5-10' wide **Roots:** 10'+ deep **Cultivation:** zones 2-8, marshy, wetland emergent **Notes:** Fast growing, high evapotranspiration- 200-800 gallons of water a day. Coppices after cutting. Endophyte *Pseudomonas putida* shown to increase degradation capacity. **References:** *Doty & Kahn, 2011. Woodward, 1996.*	**Mechanisms**: *Rhizodegradation*- shallow light PAHs, benzene, *Phytohydraulics*- light PAHs, benzene, deep light PAHs **Size:** 20-40' tall x 10-20' wide **Roots:** 10'+ deep **Cultivation:** zones 3-9, river valleys, plains **Notes:** Deciduous, fast growing, beautiful seasonal foliage, tolerates wet and dry conditions, compaction and pollution. **References:** *Cook & Hesterberg, 2012.*	**Mechanisms**: *Rhizodegradation*- shallow heavy/light PAHs, *Phytovolatilization* - light PAHs **Size:** 10-20' tall x 10' wide **Roots:** 5-10' deep **Cultivation:** zones 4-9, temperate, hardy **Notes:** Deciduous**,** early spring blossoms before leaves emerge. Highly adaptable but intolerant of saturated or compacted soils. In legume family (peas, clover, alfalfa) which are known for nitrogen and bacteria *(Sinorhizobium meliloti)* fixing root nodules. **References:** *Ferro et. al., 1999.*	**Mechanisms**: *Rhizodegradation*- shallow/ deep heavy/light PAHs, benzene, *Phytodegradation* - shallow heavy PAHs, *Phytovolatilization*- light PAHs, benzene, *Phytohydraulics*- light PAHs, benzene **Size:** 30-40' tall x 20' wide **Roots:** up to 100' deep **Cultivation:** zones 4-9, temperate, hardy **Notes:** Fast growing, transpires between 200-800 gallons of water a day. Coppices after cutting. Clone DN34.* **References:** *Burken & Schnoor, 1997. Woodward, 1996. Isebrands, 2014.*	**Mechanisms**: *Rhizodegradation* - shallow heavy/light PAHs, *Phytovolatilization*- light PAHs **Size:** 20-30' tall x 20' wide **Roots:** 11'+ deep **Cultivation:** zones 3-9, deciduous forest **Notes:** Deciduous, roots will grow deep enough to tap water table, first successional species after disturbance due to preference for poor soils. **References:** *Cook & Hesterberg, 2012.* **Poplus trichocarpa (Western Cottonwood) is a PNW native and may be a good additional choice, Miller, 2011.*


20
10
0
10
20
feet above ground level
feet below ground level
Salix nigra x
Gleditsia triacanthos
Cercis canadensis
Betula pendula
Populus deltoides x
TREES

				
Elymus hystrix: Bottlebrush Grass	*Bouteloua gracilis:* Blue Grama	*Andropogon gerardii:* Big Bluestem	*Lolium perenne:* Ryegrass	*Spartina pectinata:* Prairie Cord Grass
				
Mechanisms: *Rhizodegradation*- shallow heavy PAHs *Phytodegradation*- shallow heavy PAHs **Size:** 2'-4' tall x 3.5' wide **Roots:** 3.5' deep **Cultivation:** zones 4-9, western mountainous, edges of woodlands. **Notes:** Perennial**,** also known as *Elymus elymoides*, grows natively in wet, rocky and moderately shady habitats. **References:** *Cook & Hesterberg, 2012.*	**Mechanisms**: *Rhizodegradation*- shallow heavy PAHs *Phytodegradation*- shallow heavy PAHs, **Size:** 6"-1' tall x 1.5' wide **Roots:** 3-6' deep **Cultivation:** zones 3-9, Midwest prairie **Notes:** Perennial, understory in riparian cottonwood forest as well as dry habitats. Can be sod-forming, considered an important soil building grass **References:** *Cook & Hesterberg, 2012.*	**Mechanisms**: *Rhizodegradation*- shallow heavy/light PAHs, *Phytovolatilization*- shallow light PAHs *Phytodegradation*- shallow heavy PAHs **Size:** 3'-10' tall x 6" wide **Roots:** 6-10' deep **Cultivation:** zones 4-9, Midwest prairie **Notes:** Perennial, late-successional after disturbance in prairie ecosystems, drought tolerant, tough/deep sod-forming. **References:** *Cook & Hesterberg, 2012.*	**Mechanisms**: *Rhizodegradation*- shallow heavy PAHs *Phytodegradation*- shallow heavy PAHs **Size:** 3' tall x 1' wide **Roots:** 1.5' deep **Cultivation:** zones 3-9, forest, plains, prairie **Notes:** Perennial, extremely hardy, found to decrease PAH concentrations by 50% or more after less than a year of growth in field trials. Also has high evapotranspiration rate relative to biomass. **References:** *Ferro, Kennedy & Knight, 1997. Ferro et. al., 1999. Allen et. al., 1989.*	**Mechanisms**: *Rhizodegradation*- shallow heavy/light PAHs, *Phytovolatilization*- shallow light PAHs *Phytodegradation*- shallow heavy PAHs **Size:** 6-8' tall x 3' wide **Roots:** 10' deep **Cultivation:** zones 5+, prairie, wet grasslands, wetland **Notes:** Perennial, tolerant of water but not persistent flooding, tough/deep sod-forming roots can spread up to 5-10' annually. **References:** *Cook & Hesterberg, 2012.*


10
5
0
5
10
feet above ground level
feet below ground level
Elymus hystrix
Bouteloua gracilis
Andropogon gerardii
Lolium perenne
Spartina pectinata
GRASSES

			
Trifolium mix: Clover mix	*Brassica juncea:* Flowering Mustard	*Pteris vittata:* Brake Fern	*Medicago sativa:* Alfalfa
			
Mechanisms: *Rhizodegradation*- shallow heavy/light PAHs, benzene *Phytoextraction*- arsenic **Size:** low x spreading **Roots:** shallow sod **Cultivation:** zones 3-11 **Notes:** Self-seeding annual, mix to include *ssp. pratense* (white), *hirtum* (rose) and *incarnatum* (crimson) for optimal coverage, color and remediation. Found to decrease Total Polyaromatic Hydrocarbon (TPH) concentrations by 50% in 2 years. Some species found to hyperaccumulate arsenic. **References:** *Banks & Schwab, 1998. Speir et. al., 1992. Cook & Hesterberg, 2012.*	**Mechanisms**: *Rhizodegradation* - shallow heavy/light PAHs, *Phytoextraction*- metals **Size:** 2' tall x 1' wide **Roots:** 3' deep **Cultivation:** zones 6-11 as annual food crop **Notes:** Annual to be planted in early spring and again in early autumn, to be disposed of after harvesting. Often grown as an edible but cannot be eaten when used for phytoextraction. **References:** *Roy et. al., 2005. Blaylock et. al., 1997.*	**Mechanisms**: *Phytostabilization*, *Phytoextraction*- arsenic **Size:** 1' tall x 2' wide **Roots:** 1' deep **Cultivation:** tropical fern, can be grown as spring/ summer annual in Western Washington. **Notes:** Often associated with limestone habitats - growing on buildings in tropical urban environments. Known as an arsenic hyperaccumulator but arsenic must be biologically available in soil. (Willow with *Psuedomonas putida* may be better choice for arsenic extraction.) **References:** *Wang et. al., 2006. Blaylock et. al., 2008.*	**Mechanisms**: *Rhizodegradation*- shallow heavy/light PAHs, benzene **Size:** 3' tall x 3' wide **Roots:** 10-30' deep **Cultivation:** zones 3-11, prairie, not shade tolerant **Notes:** Can be grown as perennial in some areas, root nodules contain symbiotic bacteria *(Sinorhizobium meliloti)* and supply nitrogen to soil. Found to decrease PAH concentrations in soil by between 10-50% in 6 months. Also has high evapotranspiration rate relative to biomass. **References:** *Komisar & Park, 1997. Pradhan et. al., 1998. Cook & Hesterberg, 2012.*


10
5
0
5
10
feet above ground level
feet below ground level
Medicago sativa
Trifolium mix
Brassica juncea
Pteris vittata
ANNUALS

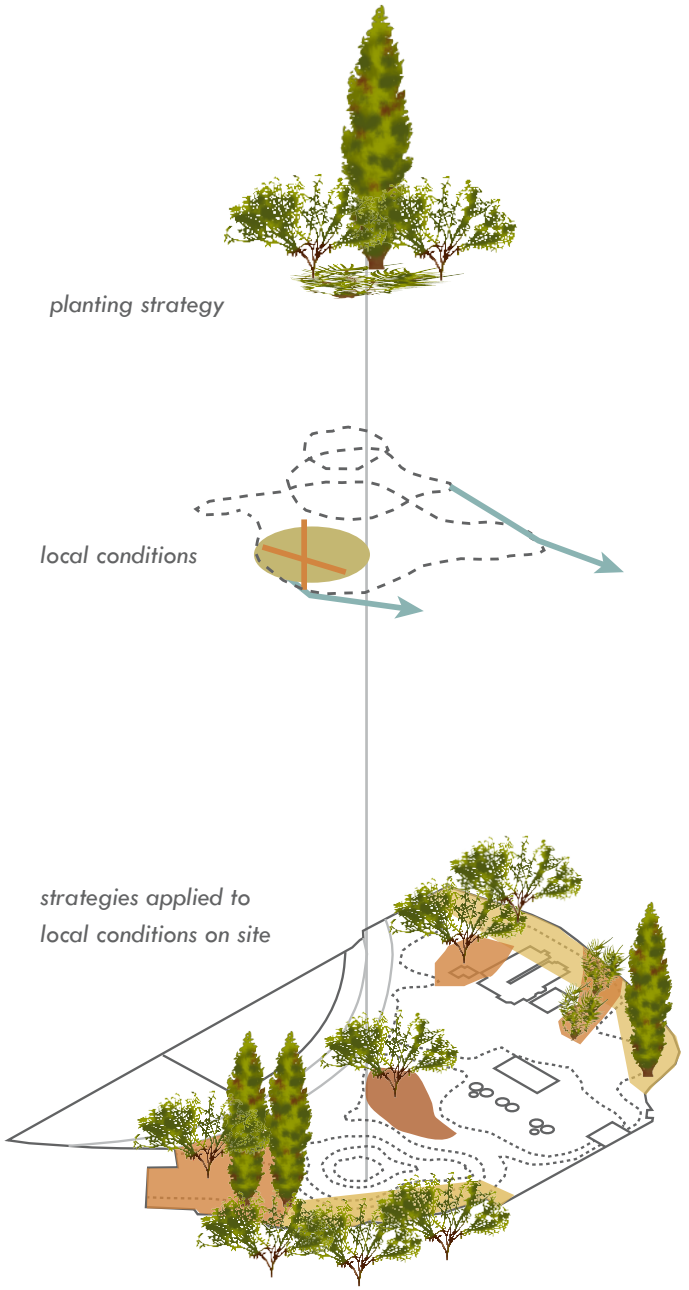
			
Typha latifolia: Tall Cattail	*Scirpus maritimus:* Alkali Bulrush	*Juncus effusus:* Soft Rush	*Scirpus atrovirens:* Green Bulrush
			
Mechanisms: *Rhizodegradation*- shallow heavy/light PAHs, benzene, *Phytostabilization* **Size:** 3-10' tall x 2' wide **Roots:** shallow x spreading **Cultivation:** zones 3-10, wetland **Notes:** Perennial. Shallow thick root mats stabilize suspended solids and particulates in 1-3' of water. Root system increases oxygen and rhizosphere activity. Naphthalene was found reduced between 64-82% in 5 months. **References:** *Mills et. al., 1997. Kadlec, Wallace, & Knight, 1996, 1998. Weissner et. al., 2002.*	**Mechanisms**: *Rhizodegradation*- shallow heavy/light PAHs, benzene, *Phytostabilization* **Size:** 3' tall x 3' wide **Roots: shallow** sod **Cultivation:** zones 5-9, wetland **Notes:** Perennial. Also known as *Bolboschoenus maritimus*. Shallow root mats stabilize suspended solids and particulates. Root system increases oxygen and rhizosphere activity. Found to reduce effluent sediments by 90%. **References:** *Couto et. al., 2012. Kadlec, Wallace, & Knight, 1996, 1998.*	**Mechanisms**: *Rhizodegradation*- shallow heavy/light PAHs, *Phytostabilization* **Size:** 3' tall x 3' wide **Roots:** shallow sod **Cultivation:** zones 2-9, wetland **Notes:** Perennial. Clump forming wetland species. Shallow root mats stabilize suspended solids and particulates. Root system increases oxygen and rhizosphere activity. **References:** *Cook & Hesterberg, 2012. Weissner et. al., 2002. Kadlec, Wallace, & Knight, 1996, 1998.*	**Mechanisms**: *Rhizodegradation*- shallow heavy/light PAHs, *Phytostabilization* **Size:** 2-4' tall x 2' wide **Roots: shallow** sod **Cultivation:** zones 4-8, wetland **Notes:** Perennial. Shallow root mats stabilize suspended solids and particulates. Root system increases oxygen and rhizosphere activity. **References:** *Thomas et. al., 2012. Kadlec, Wallace, & Knight, 1996, 1998.*

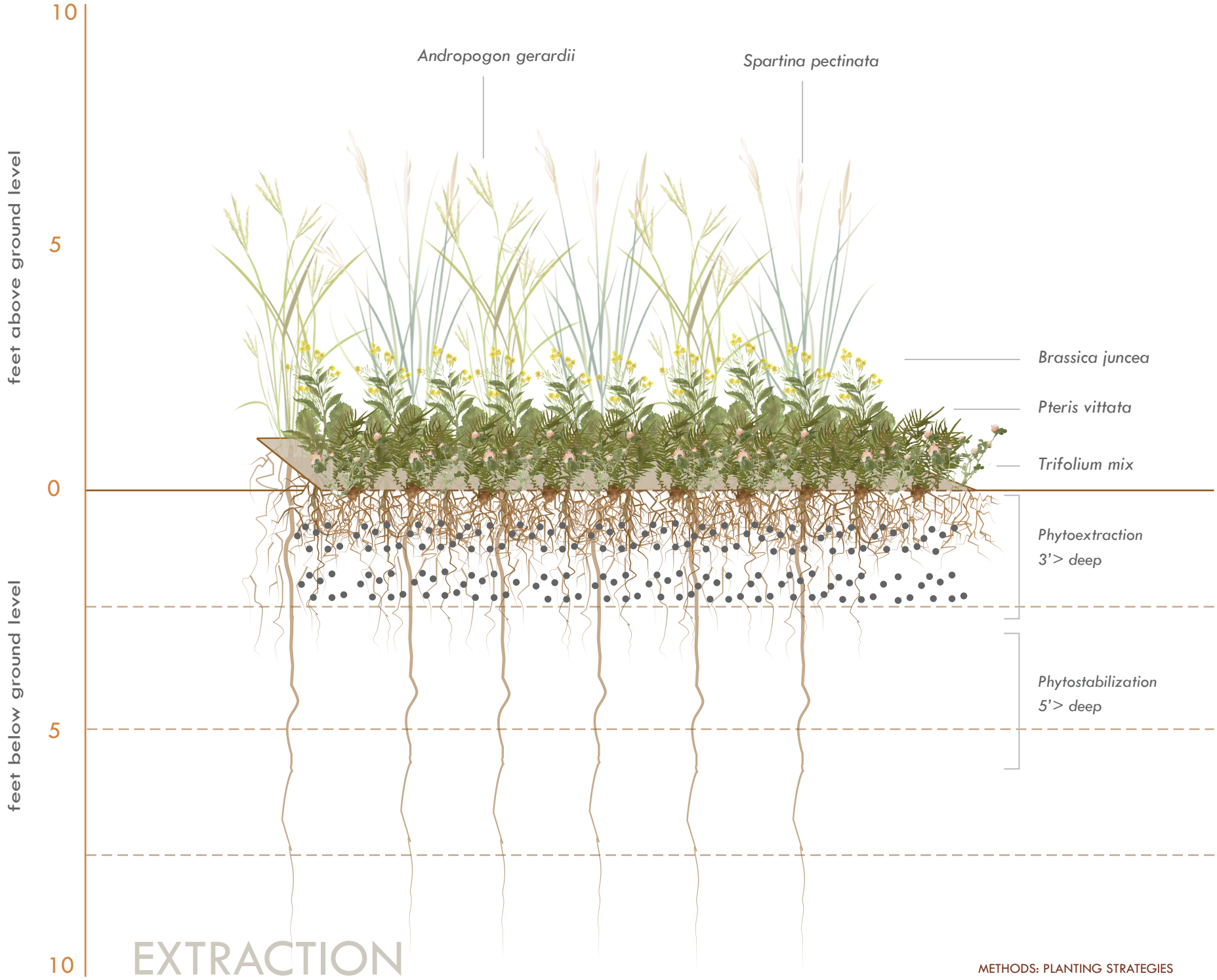

10
5
0
5
10
feet above ground level
feet below ground level
Scirpus maritimus
Juncus effusus
Scirpus atrovirens
Typha latifolia

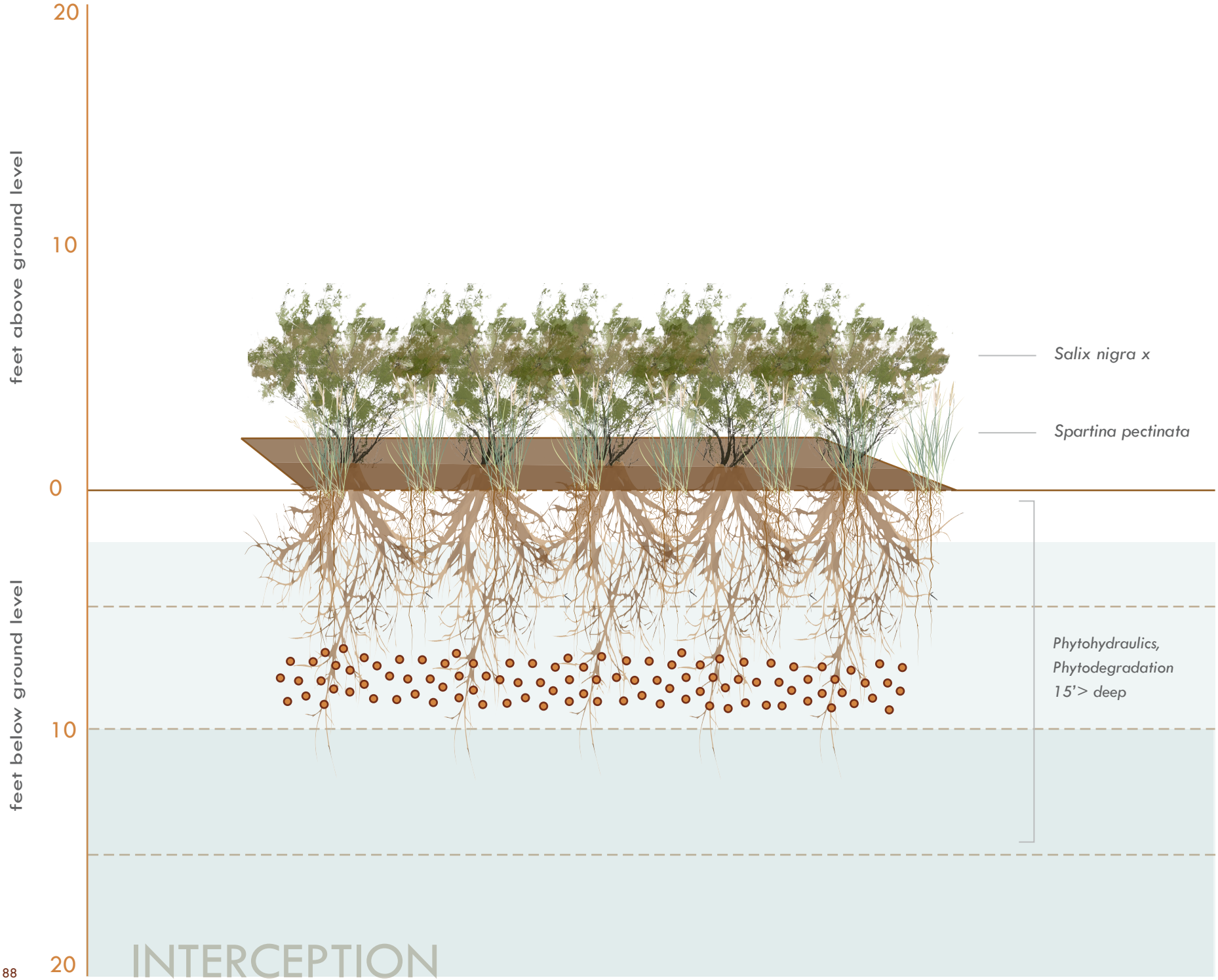
WETLANDS

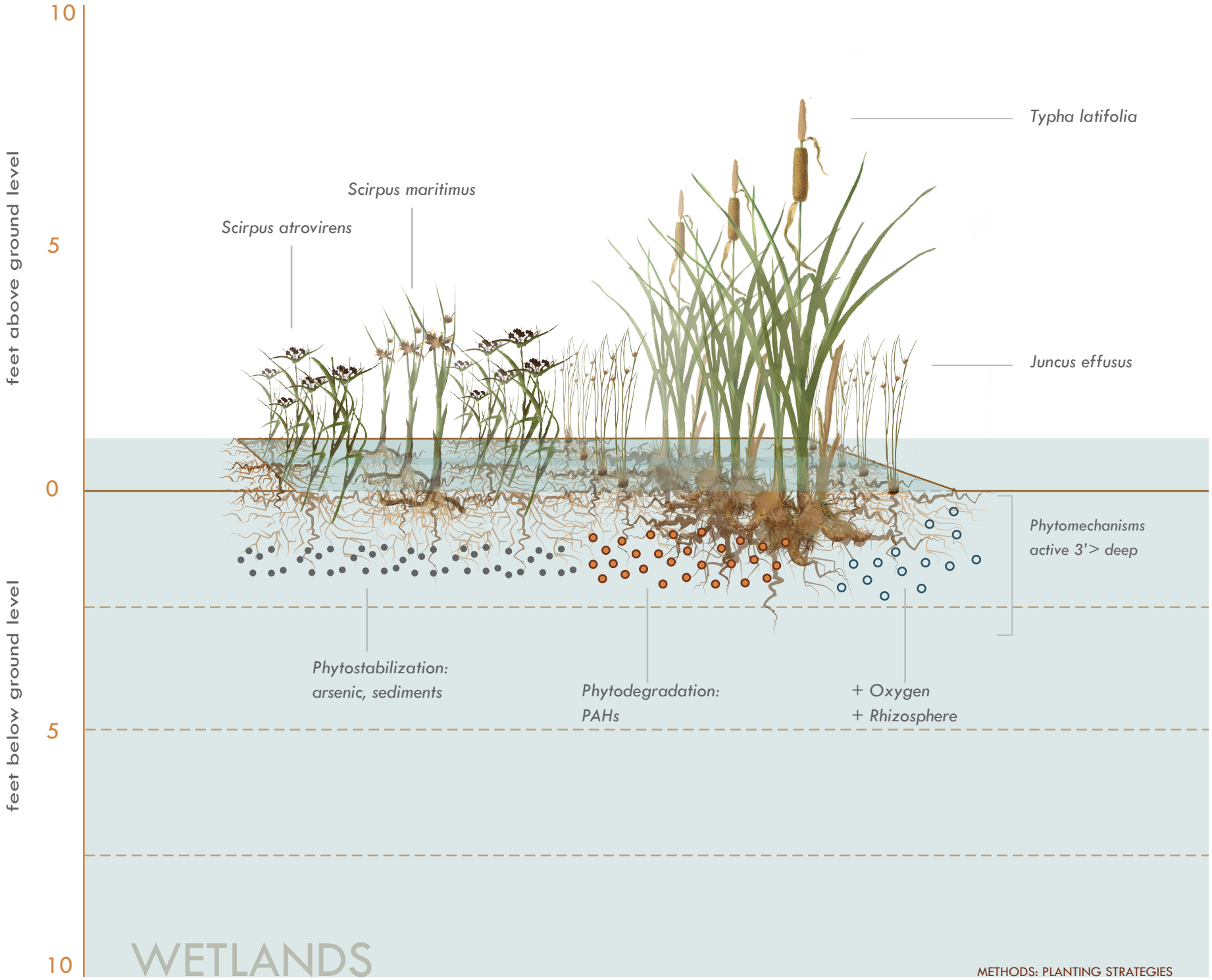
PLANTING STRATEGIES

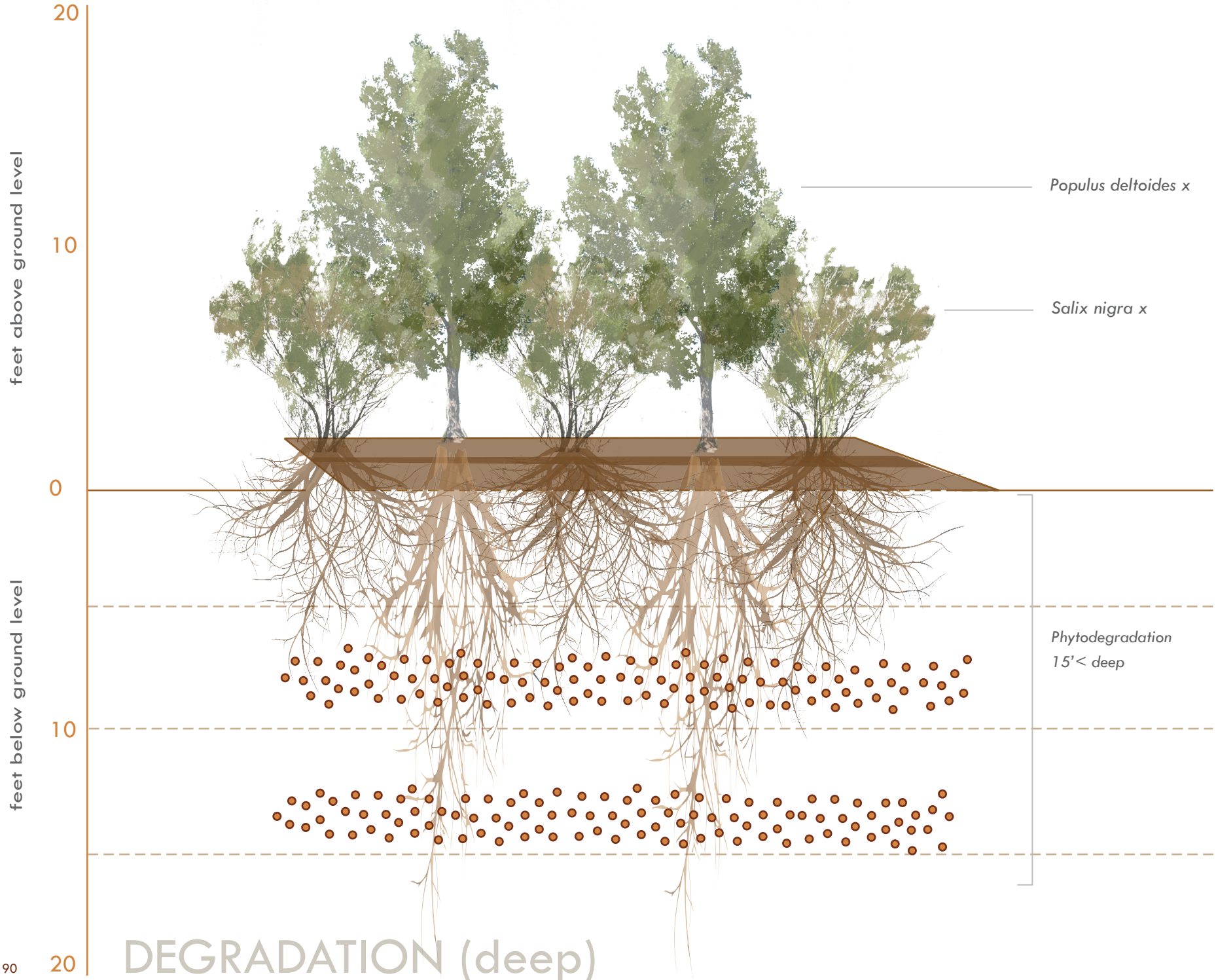
Specific species of plants have been selected and described for their individual attributes as related to climatic and contaminant conditions. These species have been grouped into planting strategies, each with specific purposes aimed at addressing the variety of circumstances on site. Some planting strategies have overlapping functions which are intended to provide an array of options for remediation depending on location specific needs. The extraction strategy utilizes three species documented to extract heavy metals, specifically arsenic, from soil. Due to the possibility of arsenic adsorption in soil and water, two species of grasses with deep, tough root structures were chosen to enhance phytostabilization offered by the extraction species. The interception strategy employs notoriously deep-rooted species with high-evapotranspiration rates and PAH degradation capabilities. This set of species is intended to capture, absorb and transpire contaminants suspended in surface flow and groundwater before they flow off-site (into Lake Union). The wetland strategy combines several wetland species known for shallow, dense matting root systems that increase oxygen circulation and associated microbial communities in near-shore sediments. These root systems are excellent for filtering sediments, capturing particulates, fostering microbial and benthic health and stabilizing inorganic contaminants.[9] The deep degradation strategy is similar to the interception strategy in that it uses primarily deep-rooted, high evapotranspiration species but has added species diversity intended for enhanced degradation capability. The shallow degradation strategy employs primarily shallow rooted species found to effectively degrade light and dense PAHs in surface soils. This particular strategy may be employed in areas more intensely used by people so attention has been paid to aesthetics as well as phytoremediation capabilities. These strategies offer a sampling of the possible configurations for phytoremediation. The physical forms that these planting strategies take on site will be determined in part by the remediation needs of the site and in part by the intended or desired user experience. Aside from effectiveness and aesthetic experience, important considerations to be revisited are monitoring, maintenance, and adaptation regimes.[10]

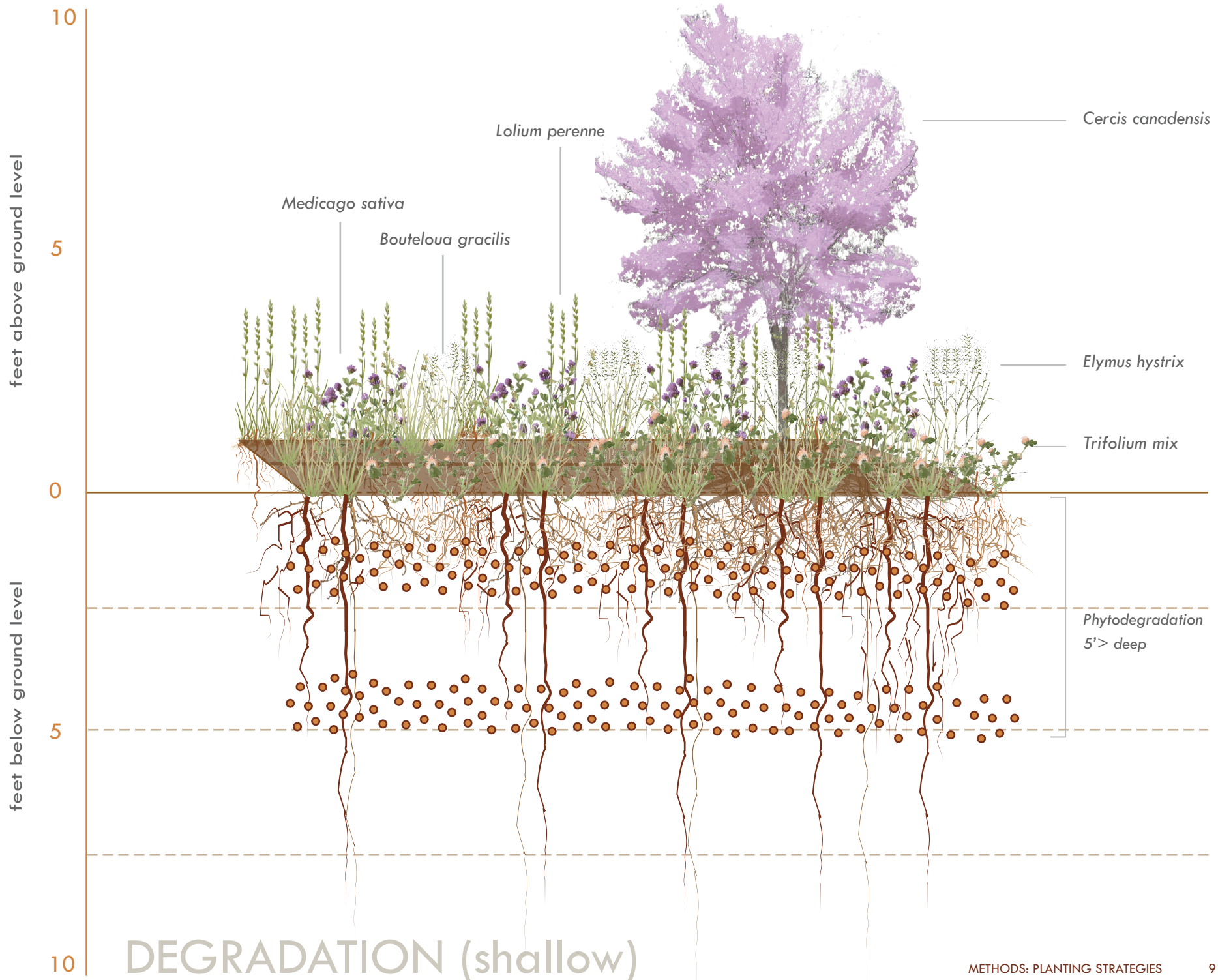



10
5
0
5
10
feet above ground level
feet below ground level
Andropogon gerardii
Spartina pectinata
Brassica juncea
Pteris vittata
Trifolium mix
Phytoextraction
3'> deep
Phytostabilization
5'> deep
EXTRACTION


20
10
0
10
20
feet above ground level
feet below ground level
Salix nigra x
Spartina pectinata
Phytohydraulics,
Phytodegradation
15'> deep
INTERCEPTION


10
5
0
5
10
feet above ground level
feet below ground level
Typha latifolia
Scirpus maritimus
Scirpus atrovirens
Juncus effusus
Phytomechanisms
active 3'> deep
Phytostabilization:
arsenic, sediments
Phytodegradation:
PAHs
+ Oxygen
+ Rhizosphere
WETLANDS


20
10
0
10
20
feet above ground level
feet below ground level
Populus deltoides x
Salix nigra x
Phytodegradation
15'< deep
DEGRADATION (deep)

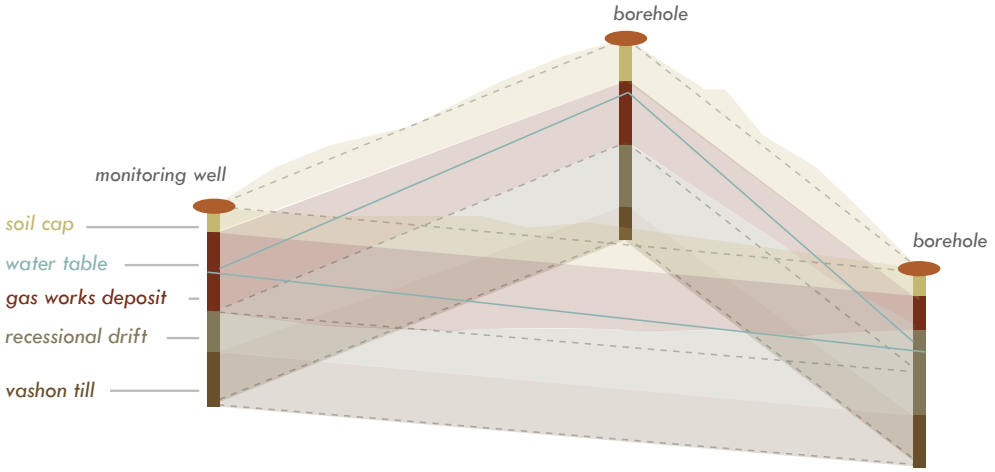


DEGRADATION (shallow)

APPLYING STRATEGIES

Once plants have been grouped into strategies, those strategies must then be overlaid on site. Each contaminated area is overlaid with planting strategies that best suit the area's needs based on contamination type, levels and depths, as well as the geohydrologic and climatic conditions.

To move beyond 2-dimensional overlay, sections drawn between monitoring wells and boreholes are established to provide a snapshot of the conditions below-ground. These sections, interpolated between data points, are used throughout the design process to inform the types, densities and forms of planting strategies implemented. Sections become important tools for visualizing processes and relationships above and below ground.



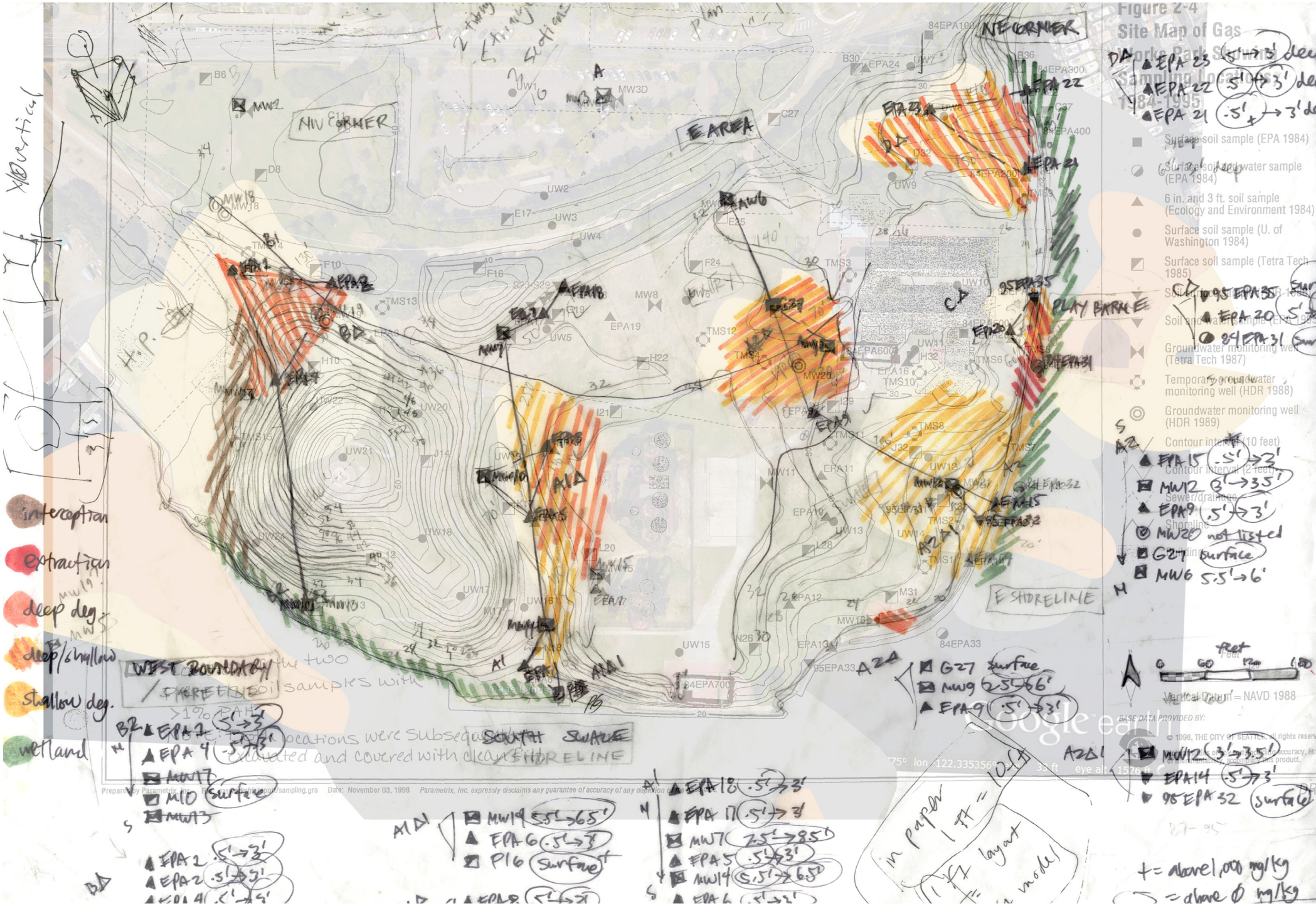
Cross sections of the site can be visualized by connecting the dots between existing monitoring wells and boreholes (interpolation).

Applying Strategies to Contaminated Areas:

Contaminants - type and depth

Soils/hydrology - wetland, midland and upland





Map Overlay: contaminant areas, testing locations + depths, proposed sections through contaminated areas

REFERENCES

1.) See Case Studies: Elizabeth City, NC, Spring Valley, DC, Ford River Rouge and Houtan Park.

2.) See James Corner Field Operations competition entry for Fresh Kills.

3.) Gary L. Turney et al., Ground-Water Contamination at an Inactive Coal and Oil Gasification Plant Site, Gas Works Park, Seattle, Washington, Water-Resources Investigations Report / U S Geological Survey (Tacoma, Wash. Denver, Colo.: Dept. of the Interior, U.S. Geological Survey, Books and Open-File Reports Section distributor, 1990).

4.) Gelvin, S. B. "Agrobacterium-Mediated Plant Transformation: The Biology Behind the "Gene-Jockeying" Tool," *Microbiology and Molecular Biology Reviews* 67, no. 1 (2003).

5.-8.) See: Niall Kirkwood and Kate Kennan, *Phyto: Principles and Resources for Site Remediation and Landscape Design* (New York, NY: Routledge, 2015).

See also the following studies:
Rachel Cook and Dean Hesterberg, "Comparison of Trees and Grasses for Rhizoremediation of Petroleum Hydrocarbons," *International Journal of Phytoremediation* 15 (2013).

Nazare Couto, Clara Basto and Teresa Vasconcelos, "Suitability of Scirpus Martima for Petroleum Hydrocarbons Remediation in Refinery Environment," *Environmental Science and Pollution Research* 19 (2012).

Ari M. Ferro, Steven Rock, Jean Kennedy, James J. Herrick and David L. Turner, "Phytoremediation of Soils Contaminated with Wood Preservatives: Greenhouse and Field Evaluations," *International Journal of Phytoremediation* (2006).

Zareen Kahn, David Roman, Trent Kintz, May delas Alas, Raymond Yap and Sharon Doty, "Degradation, Phytoprotection and Phytoremediation of Phenanthrene by Endophyte Pseudomonas Putida, PD1," *Environmental Science and Technology* (2014) : 12221- 28

Robert L. Knight, Robert Kadlec and Harry Ohlendorf, "The Use of Treatment Wetlands for Petroleum Industry Effluents," *Environmental Science and Technology* 33, no. 7 (1998).

Rachel S. Miller, Zareen Kahn and Sharon L. Doty. "Comparison of Trichloroethylene Toxicity, Removal, and Degradation by Varieties of Populus and Salix for Improved Phytoremediation Applications." *Bioremediation & Biodegradation* (2011).

Hugo Ribeiro, Marisa Almeida, ana Paula Mucha and Adriano Bordalo, "Influence of Different Salt Marsh Plants on Hydrocarbon Degrading Microorganisms Abundance Throughout a Phenological Cycle," *International Journal of Phytoremediation* 15 (2013).

Cedric Kechavarzi, Karin Pettersson, Peter Leeds-Harrison, Laurie Ritchie and Stig Ledin, "Root Establishment of Perennial Ryegrass (L. Perenne) in Diesel Contaminated Subsurface Soil Layers," *Science Direct: Environmental Pollution* 145 (2007).

Sebastian and Suzanne Labelle Roy, et. al. , "Phytoremediation of Heavy Metal and Pah-Contaminated Brownfield Sites," *National Research Council of Canada, Plant and Soil* 272, no. 1-2 (2005).

A. Wiessner, P. Kuschik and U. Stottmeister, "Oxygen Release by Roots of Typha Latifolia and Juncus Effusus in Laboratory Hydroponic System," *Acra Biotechnology* 22, no. 1-2 (2002).

H.B. Wang, and M.H. Wong, et. al. , "Uptake and Accumulation of Arsenic by 11 Pteris Taxa from Southern China," *Science Direct: Environmental Pollution* 145 (2007).

Ronald J. Zalesny Jr., Edmund O. Bauer, Richard B. Hall, Jill A. Zalesny, et al. , “Clonal Variation in Survival and Growth of Hybrid Poplar and Willow in an in Situ Trial on Soils Heavily Contaminated with Petroleum Hydrocarbons,” *International Journal of Phytoremediation* 7, no. 3 (2005).

9.) Robert L. Knight, Robert Kadlec and Harry Ohlendorf, “The Use of Treatment Wetlands for Petroleum Industry Effluents,” *Environmental Science and Technology* 33, no. 7 (1998).

10.) Niall Kirkwood and Kate Kennen, *Phyto: Principles and Resources for Site Remediation and Landscape Design* (New York, NY: Routledge, 2015).



DESIGN CONCEPT
function meets form

The development of a conceptual design for Gas Works Park began with purpose and function. The site framework and planting strategies discussed previously form the basis of an intervention's purpose, the physically functional component of design. Because the primary goal of design interventions is to remediate contamination, forms that express an intervention's function must not hinder or supersede its effectiveness. The secondary goal of design is to create legible experiences that enhance, but do not replace, the existing uses of the site. By connecting contamination below ground to above ground interventions, plant growth becomes a mirror for remediation. The growth of above ground vegetation signals the expansion of roots below ground – improving the soil, degrading contamination and intercepting the water table.

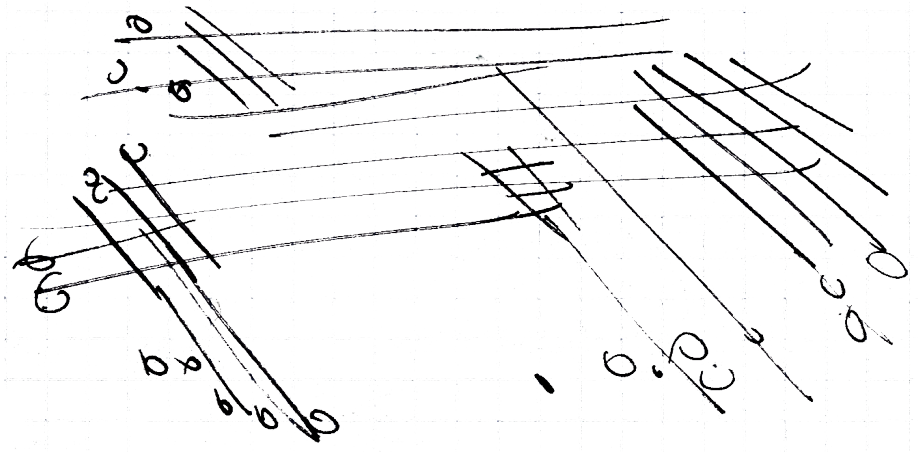
PHYTOREMEDIATION PLOT AS DESIGN

The design concept is based on the form of a traditional phytoremediation plot, a standardized, linear grid of trees. This form is practical for research purposes and provides an interesting and dynamic experience, like walking through a dense bosque or allée of trees. But the phytoremediation grid alone is too rigid to express the range of strategies and the different processes occurring within each intervention. Dissolving the grid – allowing it to break apart, compressing and stretching its pieces into more elegant and adaptable shapes – allows individual interventions to stand out across the site. The underlying grid that connects each intervention – orienting planting strategies on an axis – creates continuity between geographically disparate interventions. In this way, the dissolution of the planting grid becomes a web across the site, connecting and defining each area planted for phytoremediation.

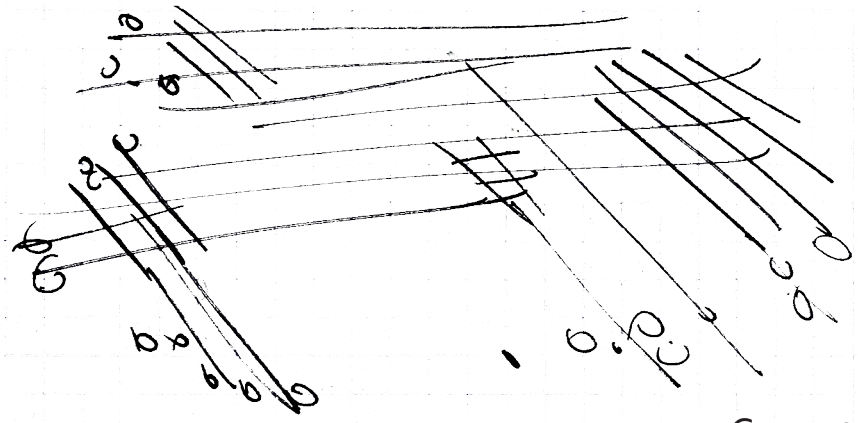

Image: Purdue



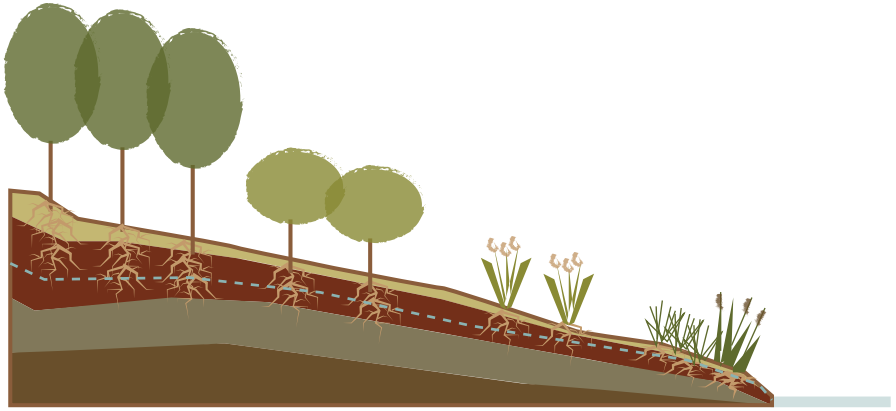
A trend in the relationship between contaminant depth and geology, tending toward deeper contamination in the upland and shallower contamination near shorelines, is an indication of the general nature of contaminant depth and location on site. Following the deep to shallow geologic variation across the site – interventions also range from deep to shallow. Deep rooted strategies perform deep remediation in upland areas where toxicity is up to 10’ deep. Shallow rooted strategies perform shallow remediation in areas closer to the shoreline where remediation is between 6” and 3’ deep.



The plot grid retains its form in areas with deep, heavy contamination where the height of quickly growing poplars and willows indicates the depth and rate of remediation below ground. The goal of visual communication for these, generally upland areas, is to acknowledge the plantings’ purpose, allowing the interventions to stand out and be noticed as they remediate. As interventions begin to transform, moving away from the upland areas towards the shoreline of the park, the grid form begins to dissolve – breaking apart into planting strips. This shape is intended to communicate the changing nature of the depth of contaminants and their corresponding planting types.



Concept



Conceptual Section *relationships between planting depth and height*



Form



Planting

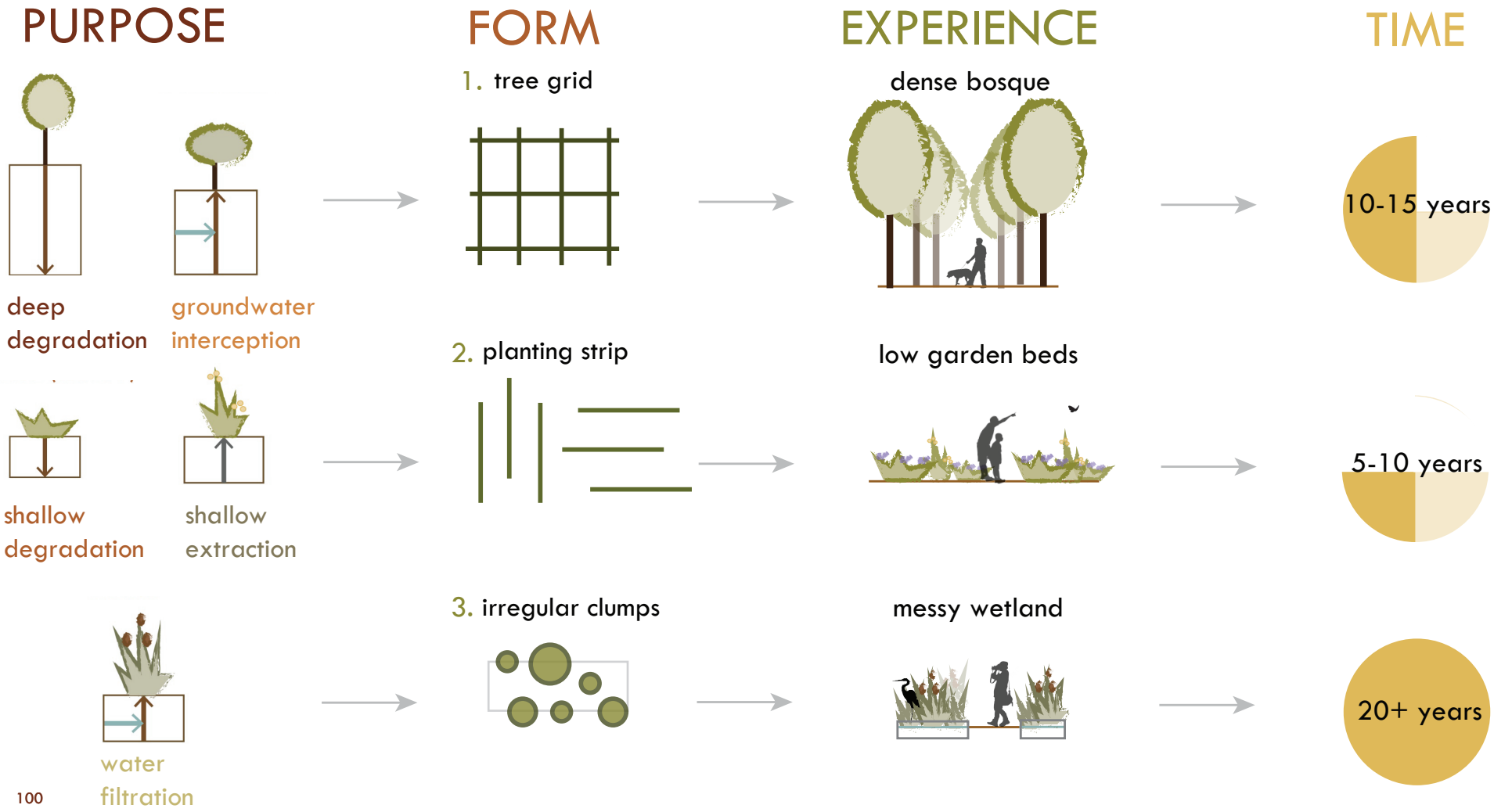
The transformation of the grid into the planting strip also traces the flow of contaminant plumes directed by topography. The full dissolution of the grid into more naturalistic, messier forms at the shoreline is intended to signal a change in the goals of remediation at the shoreline. At the edges of the park the goal of remediation plots is to catch sediments and pollutants in surface and groundwater flow before it seeps off-site. In the upland areas, where interventions are temporary, it is important to communicate the purpose of the interventions as they are in highest contrast to the existing landscape. It is important for the wetlands to blend into the existing landscape over time as these interventions are intended to be an indefinite buffer between the lake and the site.

When considering planting forms that are intended to communicate visually, maintenance becomes an important component. Upland areas planted with grids of tall phytoremediation species require higher levels of maintenance in order to keep sight lines and access for monitoring open. Planting strips in swales may only need intermittent maintenance for monitoring and aesthetic purposes while the wetlands would need very little to zero maintenance. Overall, conceptual planting design relies on variation in planting forms and heights intended to signal the differing life cycles and purposes of interventions, allowing some to stand out while others blend into the landscape over time.

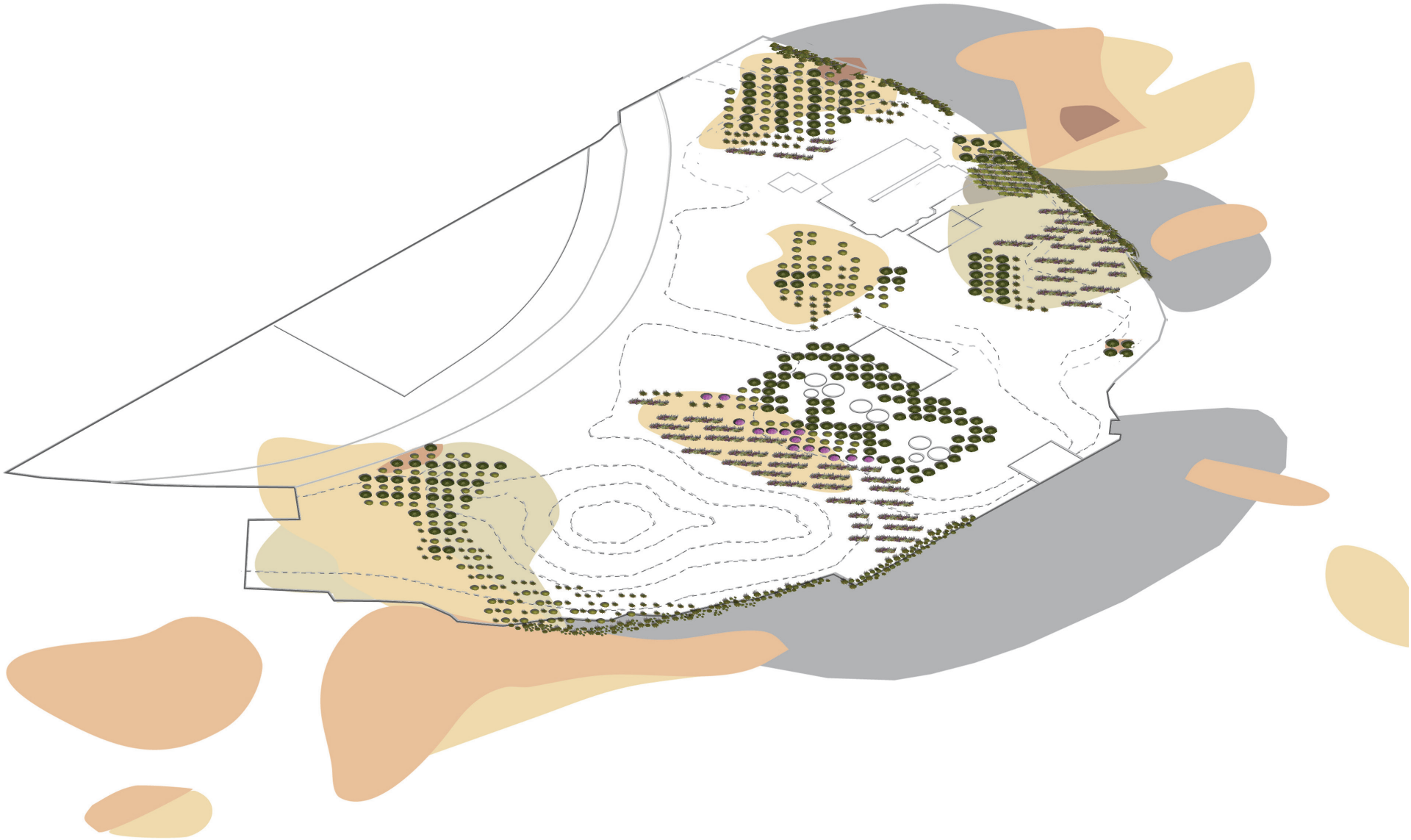
CONCEPTUAL FORMS

Once the primary goal- maximizing planting strategies effectiveness – is established, the secondary goal – describing experience and meaning – becomes the central focus. The goal of shaping planting forms to fit their purpose creates not only a range of forms – but also a range of experiences. The different time frames required for the varying interventions also effects experience. Because many of the interventions are intended to be temporary, with only a few being permanent, phased implementation and removal is key. Communicating time visually on a relatively broad scale is difficult so variations in maintenance and the use of minimal interpretive signs becomes an important consideration.

EXPRESSION OF PHYTOREMEDIATION PLOTS IN THREE BASIC FORMS:

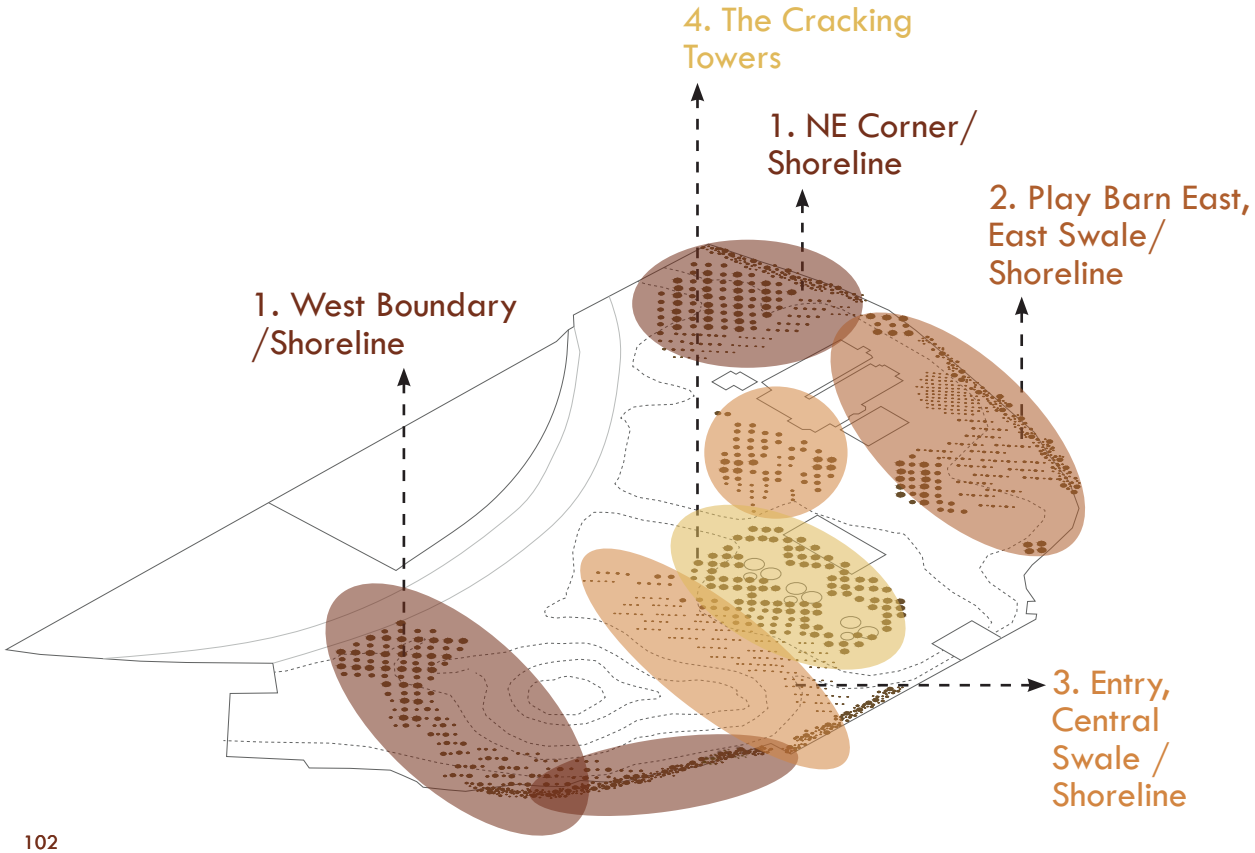


CONCEPTUAL PLANTING OVERLAY



PHASED IMPLEMENTATION

Establishing priority areas for remediation is a necessary consideration for phytoremediation and user experience. Some plantings would perform permanent services like filtration and interception while most of the interventions are intended to be temporary – in place between 5 and 20 years. The value of phasing and temporary interventions is the possibility to learn from early plantings and adapt later interventions, learning which interventions work and which do not work. Additionally, user experience is greatly effected by the temporality of plantings. Interventions like the filtration wetlands would become messy over time, intentionally excluded from maintenance, eventually blending into and softening the edge of the site. Initial phasing time scales are proposed here but monitoring the effects of plantings would determine, in real time, how long each strategy needs to remain on site for complete cleanup.



PHASE 1:
NE Corner/Shoreline + West Boundary

Deep degradation- 4 years to efficiency, 10-15 years total.

Shallow degradation- 2 years to efficiency, 10 years total.

Filtration wetland- 3 years to efficiency, permanent.

PHASE 2:
Play Barn East + East Swale/ Shoreline.

Extraction- 1 year to efficiency, 3-5 years total.

Interception- 3 years to efficiency, 5 years total.

Shallow degradation- 2 years to efficiency, 10 years total.
Filtration wetland- 3 years to efficiency, permanent.

PHASE 3:
Entry, Central Swale/Shoreline

Interception- 3 years to efficiency, 10 years total.

Shallow degradation- 2 years to efficiency, 10 years total.

Filtration wetland- 3 years to efficiency, permanent

PHASE 4:

Cracking Towers,
Deep degradation- 4 years to efficiency, permanent.



PHASE 1

West Boundary - Shoreline
NE Corner - Shoreline

Degradation: 5-15 years
Wetland: Permanent



PHASE 2

Play Barn East
East Swale - Shoreline

Extraction: 3-5 years
Degradation: 5 years
Wetland: Permanent



PHASE 3

Entry
Central Swale - Shoreline

Degradation: 5-10 years
Wetland: Permanent



PHASE 4

The Cracking Towers

Degradation: Permanent

0 5 10 15 20 years

wetlands

wetlands

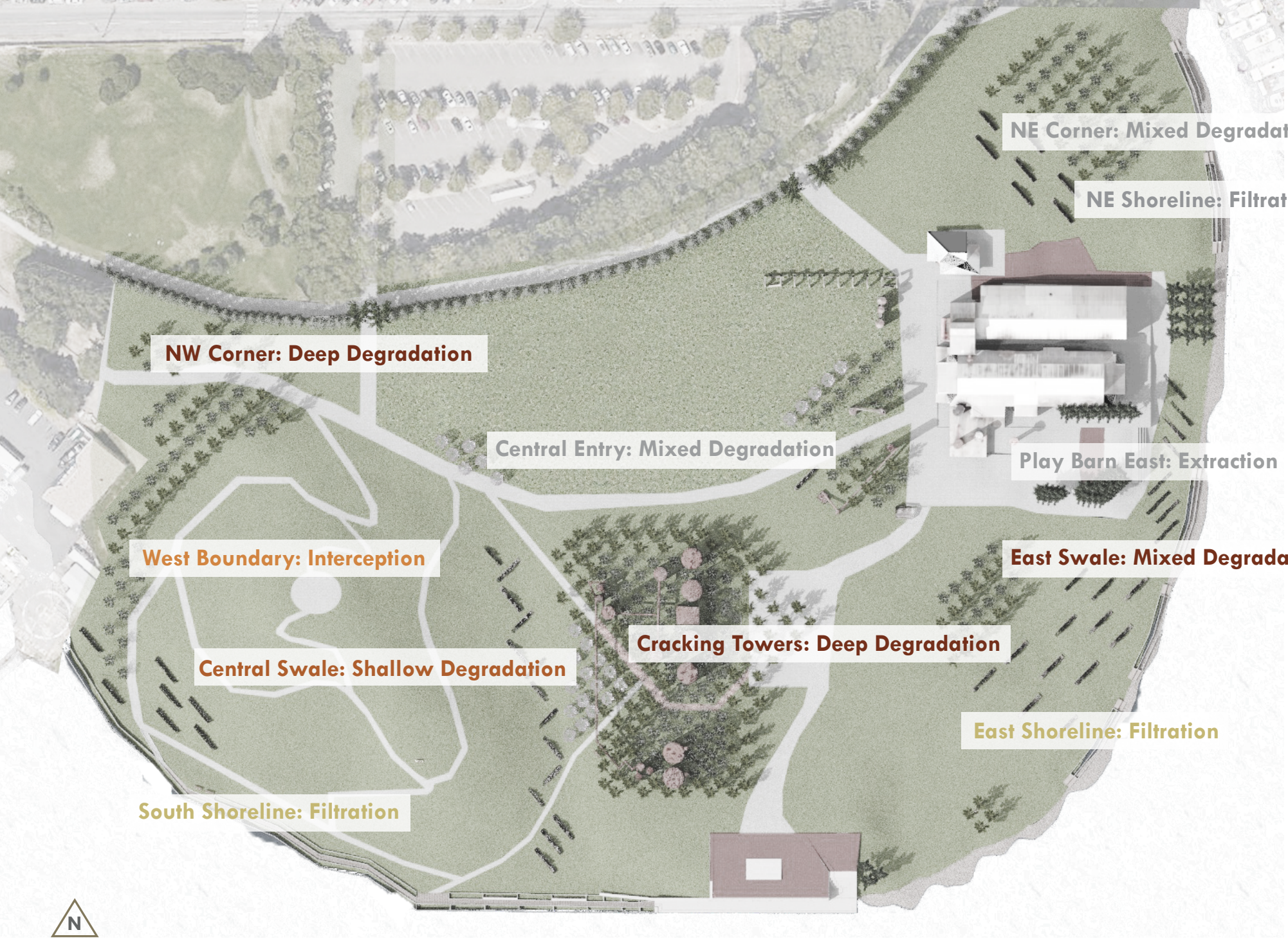
wetlands

wetlands



END

Permanent Interventions
Living Fence:
Deep Degradation/ Interception Tree Stand
Filtration Wetlands:
Shallow Degradation/ Interception


NE Corner: Mixed Degradation
NE Shoreline: Filtration
NW Corner: Deep Degradation
Central Entry: Mixed Degradation
Play Barn East: Extraction
West Boundary: Interception
East Swale: Mixed Degradation
Cracking Towers: Deep Degradation
Central Swale: Shallow Degradation
East Shoreline: Filtration
South Shoreline: Filtration
N

DESIGN SCHEMATIC
revealing relationships

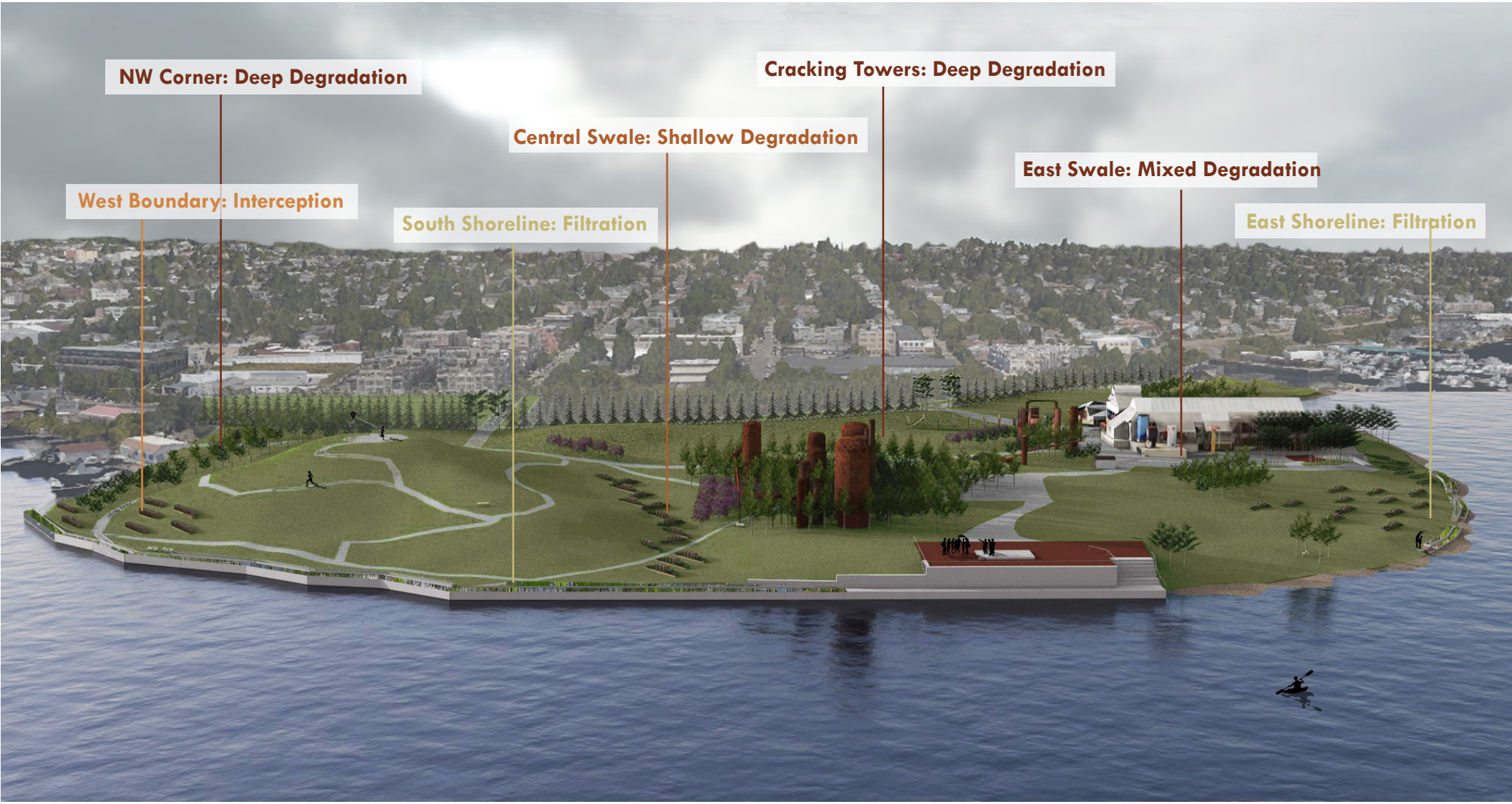
After establishing strategies, giving those strategies conceptual planting forms and establishing an initial phasing plan, it became essential to describe the experience by creating representations of how those interventions would feel. Moving beyond 2-dimensional representation to provide information in 3-dimensions provides a clear understanding of relationships between below ground processes and above ground appearance as well as providing a window into the experience of planting forms, textures and heights. The site's conditions are not shown as phases here, instead the site is envisioned as if all interventions were implemented at once with about 5 years of growth. This provides a picture of interventions as mature plants performing phytoremediation services in optimal conditions. These visualizations are intended to provide a detailed look at selected areas of the park. Visualizations of phasing interventions with broader site sections and triangular slices of planting strategies can be found in the Appendix.



LET'S TAKE A WALK!

Gas Works Park is a relatively large site, in order to explore in detail how planting interventions look, feel and perform, taking a figurative "walk" through part of the park will help envision interventions as a whole system.

PLAN VIEW: WALKING ROUTE



BIRD'S EYE VIEW NORTH

1 NW CORNER: growth + degradation



PLANTING
steep grassy slope (west side of kite hill), water from rain events runs off west toward Harbor Patrol and into lake

USE
Running, walking, western park entry

CONTAMINATION
PAHs - Non-Aqueous Phase Liquids (NAPL), benzene + tar
3' - 10' deep up to 1057 ppm

3' - 10' to gas works deposit

CURRENT

PLANTING
deep mix: *populus deltoides x + salix nigra x*
bare root or live stakes planted 10' o.c.

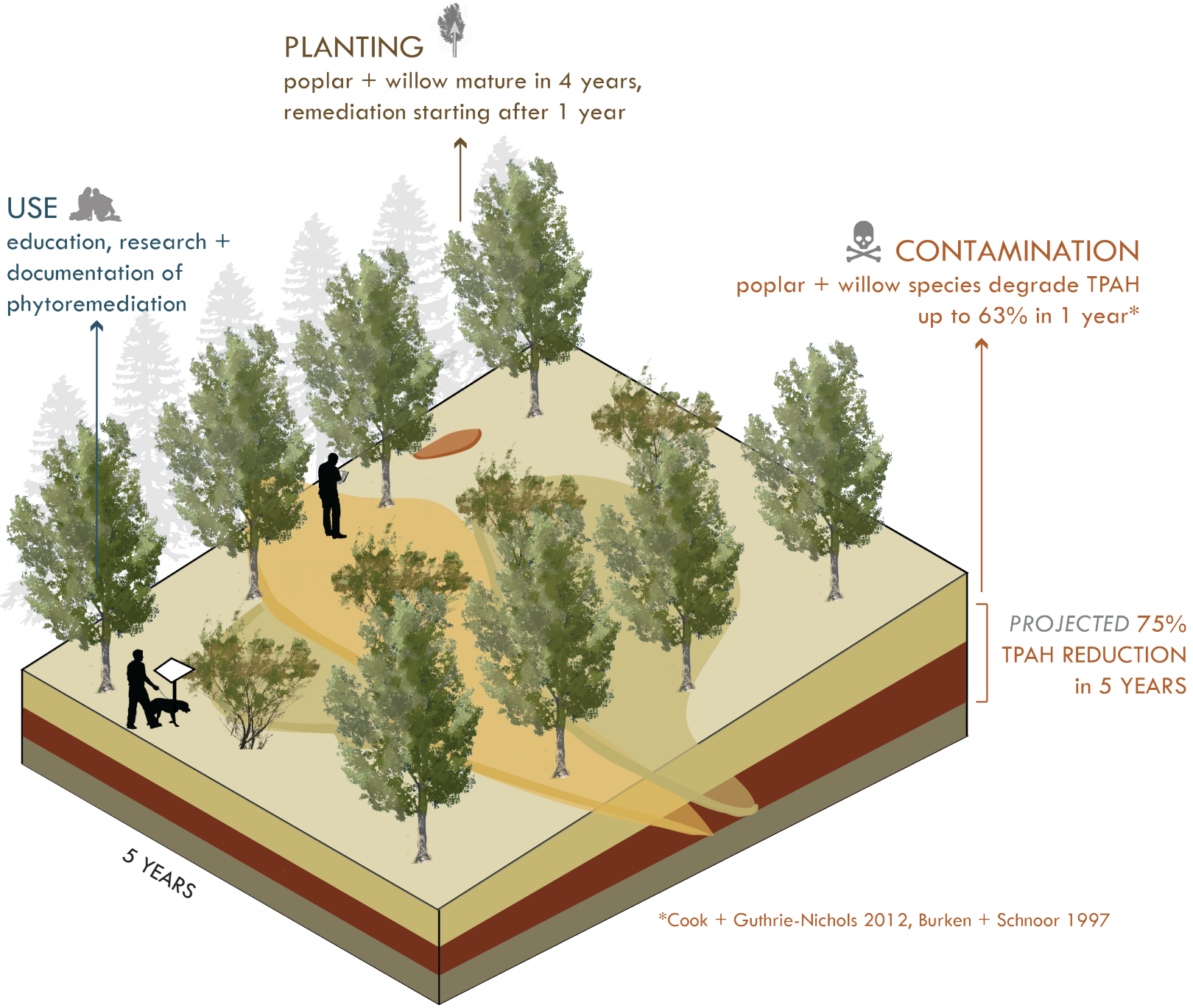
USE
Education, research + documentation of phytoremediation

CONTAMINATION
rooting depth 20'< resistent to phytotoxicity up to 5,000 ppm

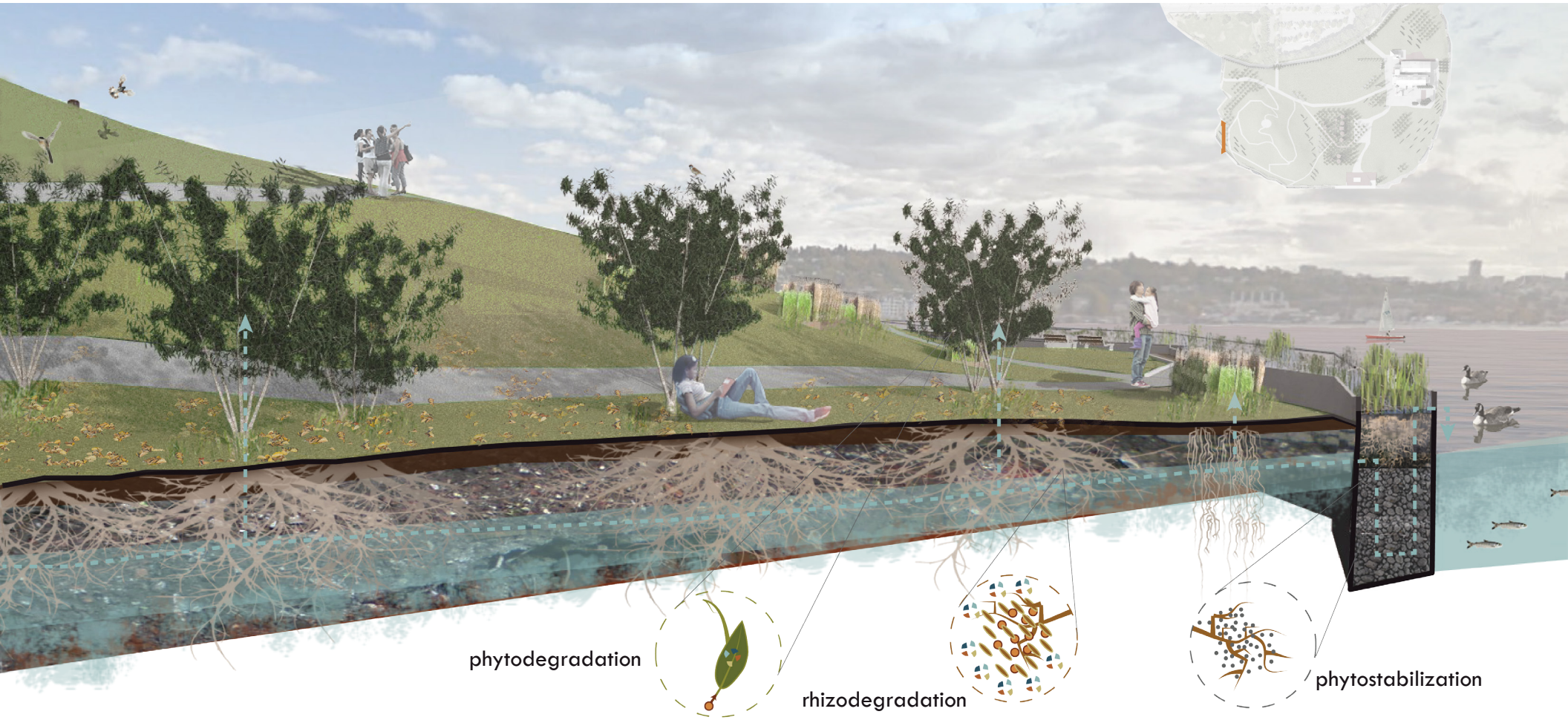
roots 20'<

PLANTING

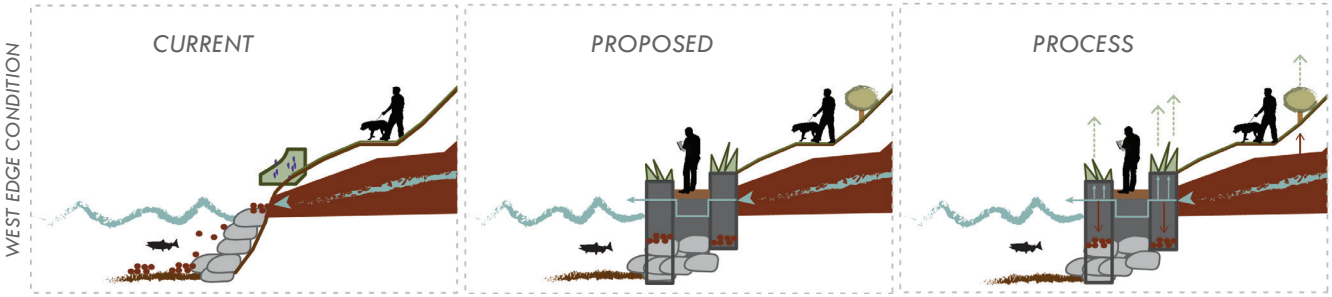
N


PLANTING
poplar + willow mature in 4 years,
remediation starting after 1 year
USE
education, research +
documentation of
phytoremediation
CONTAMINATION
poplar + willow species degrade TPAH
up to 63% in 1 year*
PROJECTED 75%
TPAH REDUCTION
in 5 YEARS
5 YEARS
*Cook + Guthrie-Nichols 2012, Burken + Schnoor 1997

2 WEST BOUNDARY: section looking east



Sections visualize the processes working below ground as a system - intercepting and filtering water, degrading and extracting contaminants. Redundant processes, performed by several interventions, provide system resiliency in case some plants die-off or perform poorly.

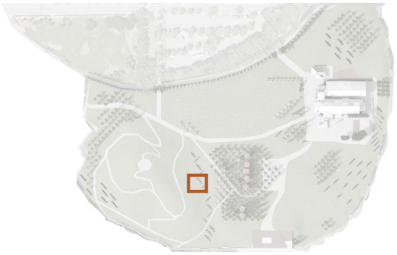


3 SOUTH WETLAND: perspective looking west



Walking along the shoreline boardwalk, between stepped filtration wetlands, views of the lake and the city are framed by lush wetland species. Proximity to the steep slope of Kite Hill and the shoreline hints at the processes being performed by the wetland plants below ground - filtering, stabilizing and degrading residual contamination in water and sediments flowing toward the lake.

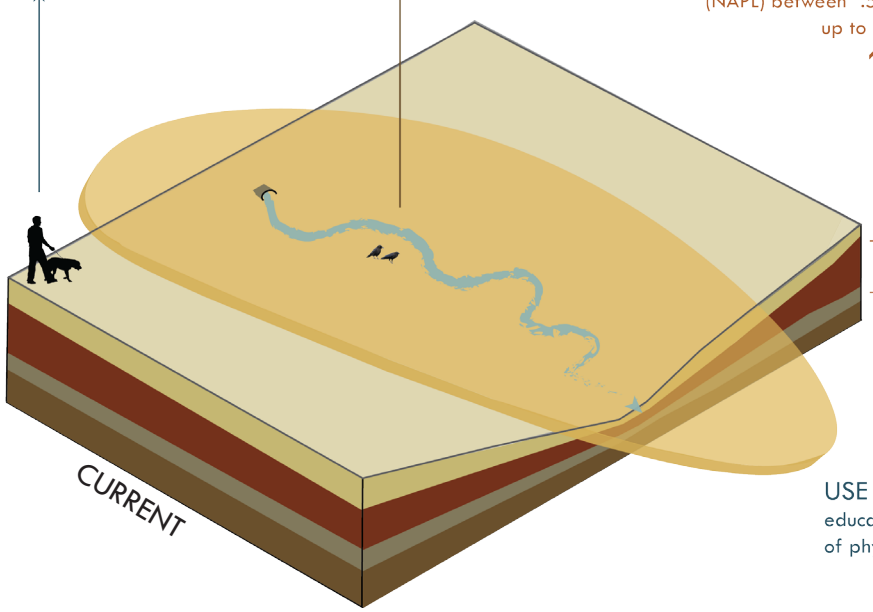
4 CENTRAL SWALE: growth + degradation



USE
viewshed of lake and downtown, walking activities around swale

PLANTING
grass swale carries surface + sub-surface flow from parking lot and rain events into lake

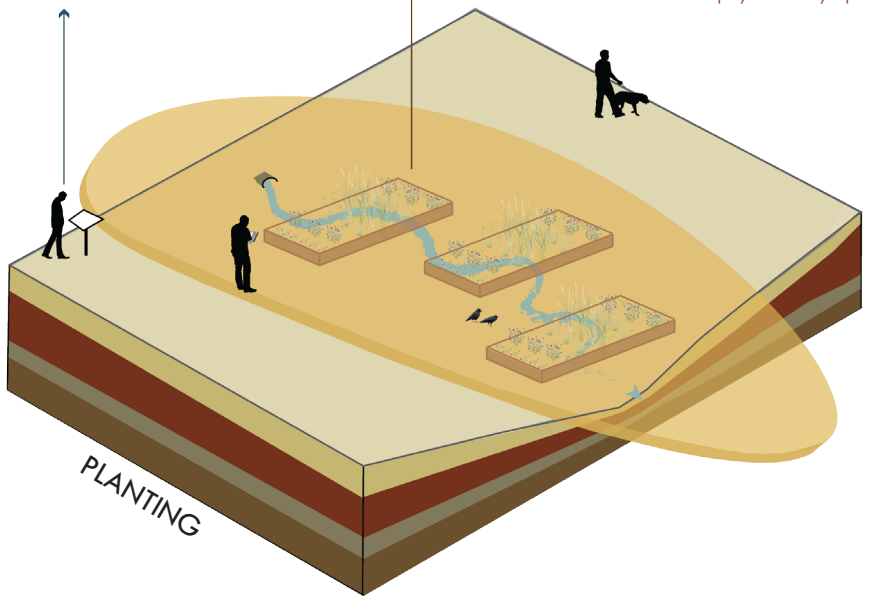
CONTAMINATION
PAHs - Non Aqueous Phase Liquids (NAPL) between .5 - 3' deep
up to 1810 ppm



PLANTING
shallow mix: *grass mix, Medicago sativa, Trifolium mix* plugs planted in 3' wide strips, 10" o.c. or less

USE
education, research +documentation of phytoremediation

CONTAMINATION
rooting depth up to 3' resistent to phytotoxicity up to 5,000 ppm TPAH



PLANTING

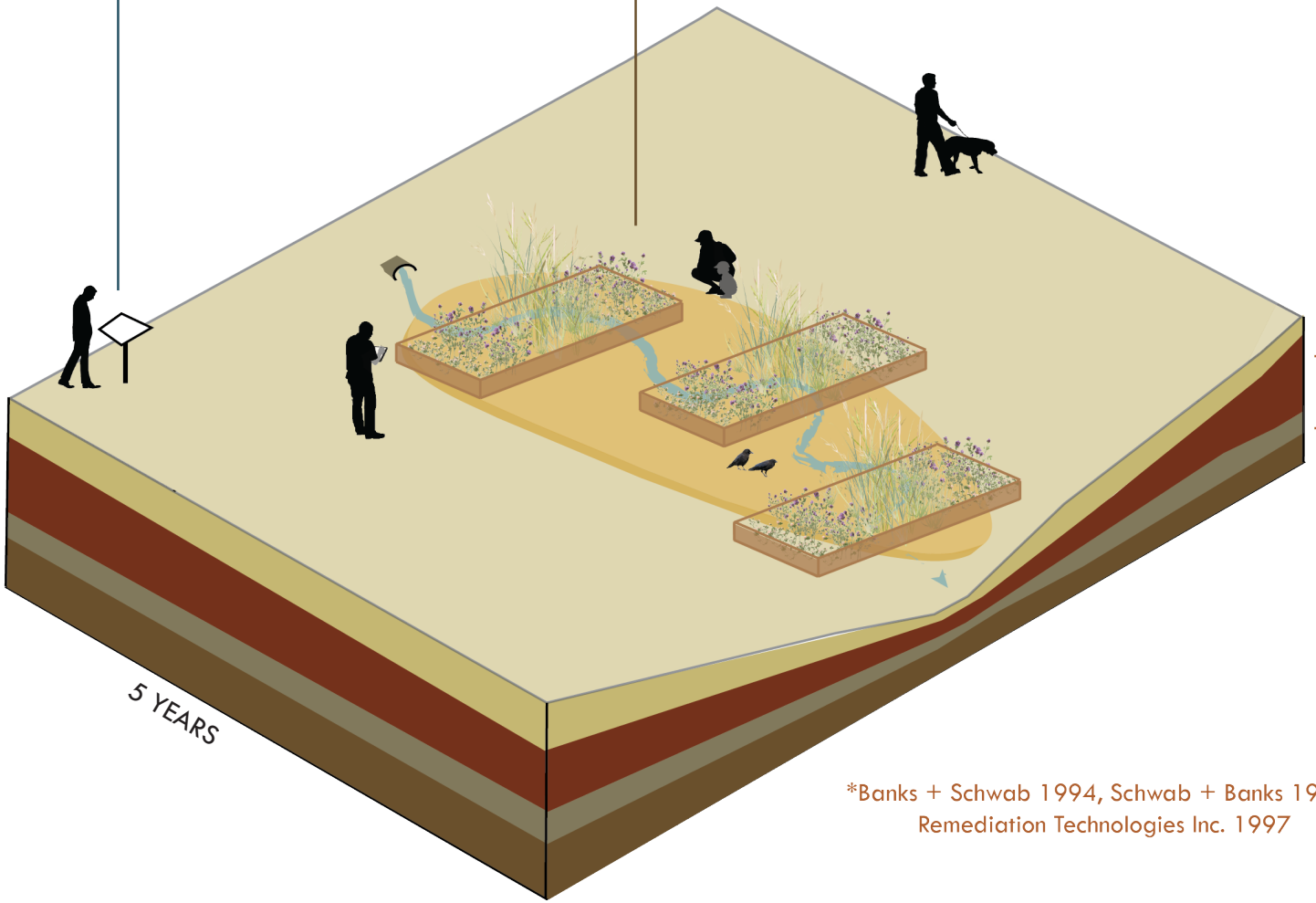
plants begin remediation as soon as 1 year
above ground growth + height an indicator
of below ground root development

USE

education, research +
documentation of
phytoremediation

CONTAMINATION

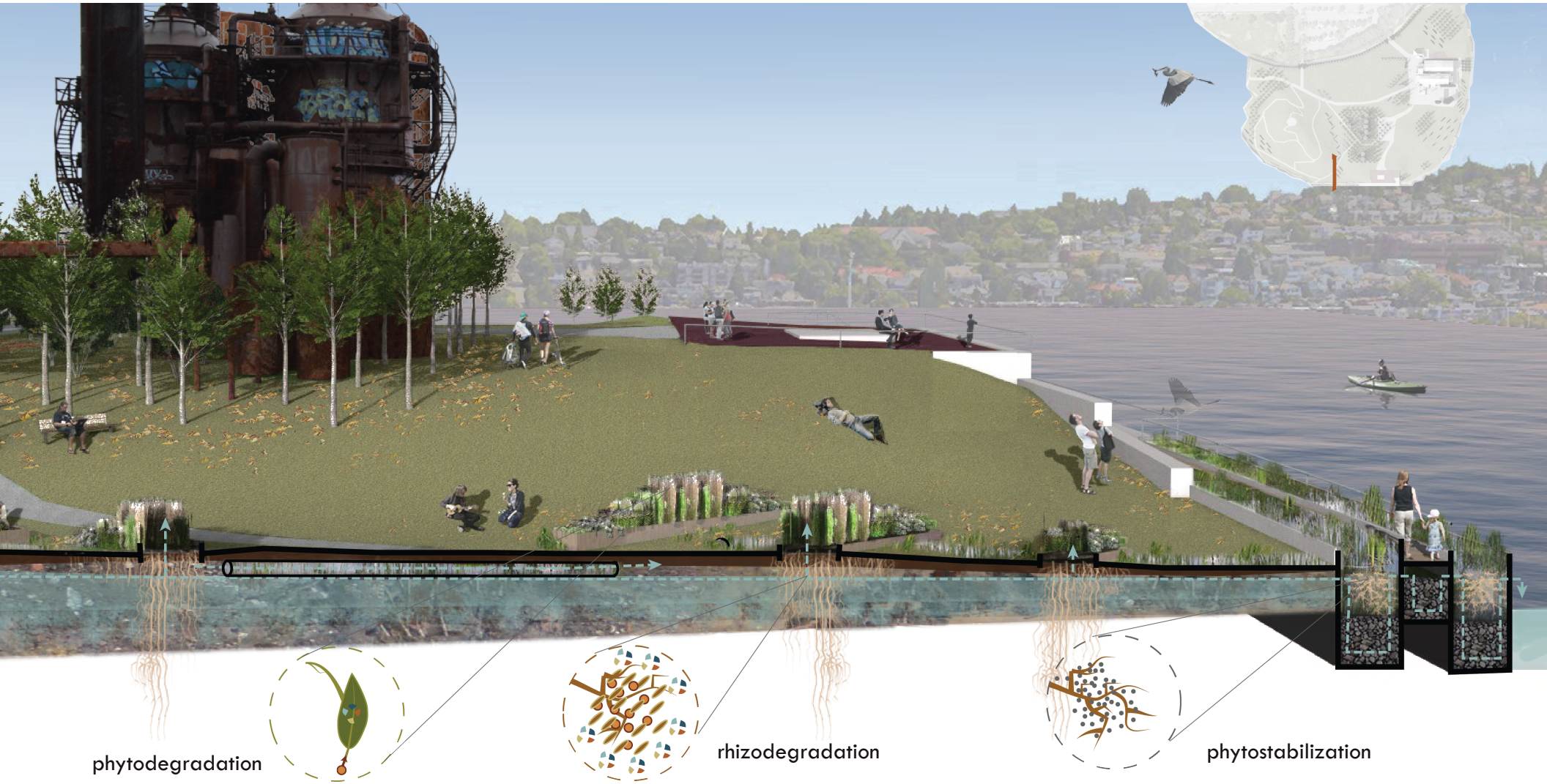
mixed grass + legume species degrade
up to 50% TPAH in 6 months - 2 years *



PROJECTED 50%
NAPL REDUCTION
in 5 YEARS

*Banks + Schwab 1994, Schwab + Banks 1998,
Remediation Technologies Inc. 1997

4 CENTRAL SWALE: section perspective

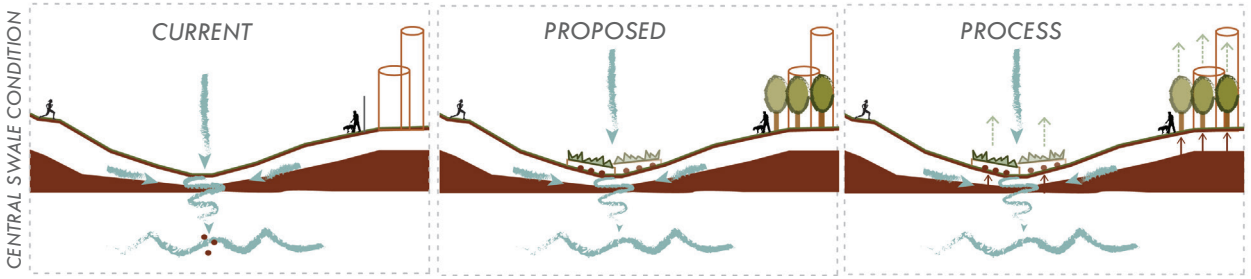


phytodegradation

rhizodegradation

phytostabilization

Sections of the central swale focus on slowing, filtering and capturing as much of the central swale surface and groundwater flow as possible. The staggered shallow degradation beds enhance the rhizosphere and slow water flow. Filtration wetlands at the shoreline finish the cleaning process.



4 CENTRAL SWALE: perspective looking northeast



A brisk walk through the Central Swale towards the Cracking Towers on a rainy day. Water is slowed and filtered by shallow rooted interventions, the deep rooted tree grid frames the towers, beckoning visitors to explore.

5 CRACKING TOWERS: perspective looking east



The experience of the deep degradation area around the Cracking Towers is important to visualize and understand. While there is no data available on the levels and depths of the contamination in the Cracking Tower area - the foundations of the towers plunge deep into the site, indicating residual contamination (created by the towers during coal-gas manufacture) below.

6 CRACKING TOWERS: perspective looking west



The deep contamination below the Cracking Towers would be slowly removed by poplar and willow - the trees roots would also stabilize contamination and prevent further leaching off-site. The height of the trees is not intended to obscure the towers, but frame them - providing a meaningful counterpoint to their form and purpose. The creation of a directed pathway through the towers, bordered by trees, would also provide an experience of the towers that is currently unavailable.

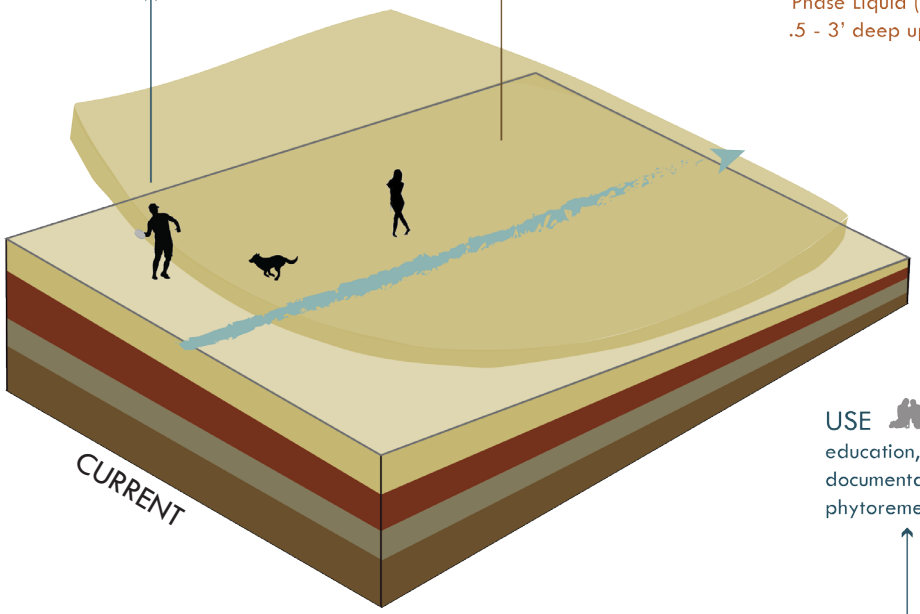
7 EAST SWALE: growth + degradation



PLANTING
open grass field - sloping towards cobble beach, sub-surface water flow into lake

USE
recreation, picnicking, shoreline access

CONTAMINATION
benzene - Light Non-Aqueous Phase Liquid (LNAPL) plume
.5 - 3' deep up to 953 ppm



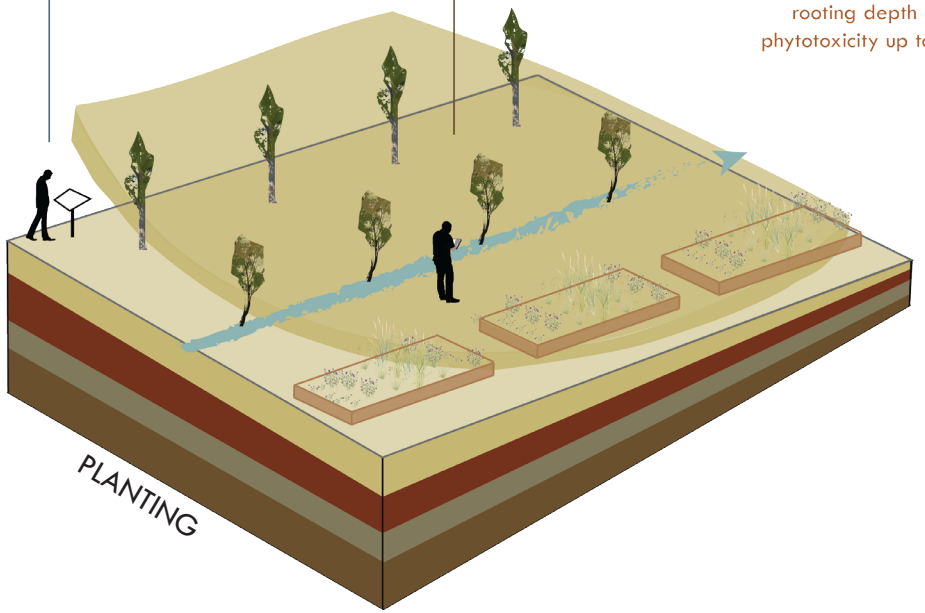
.5 - 3' to gas works deposit

CURRENT

PLANTING
mixed degradation:
Populus deltoides x, Salix nigra x, shallow mix
bare root or live stake grid planted 10' o.c.
shallow plugs in 3' wide strips

USE
education, research + documentation of phytoremediation

CONTAMINATION
rooting depth 3' - 20' resistent to phytotoxicity up to 5,000 ppm TPAH



roots 3' - 20'

PLANTING

N

PLANTING

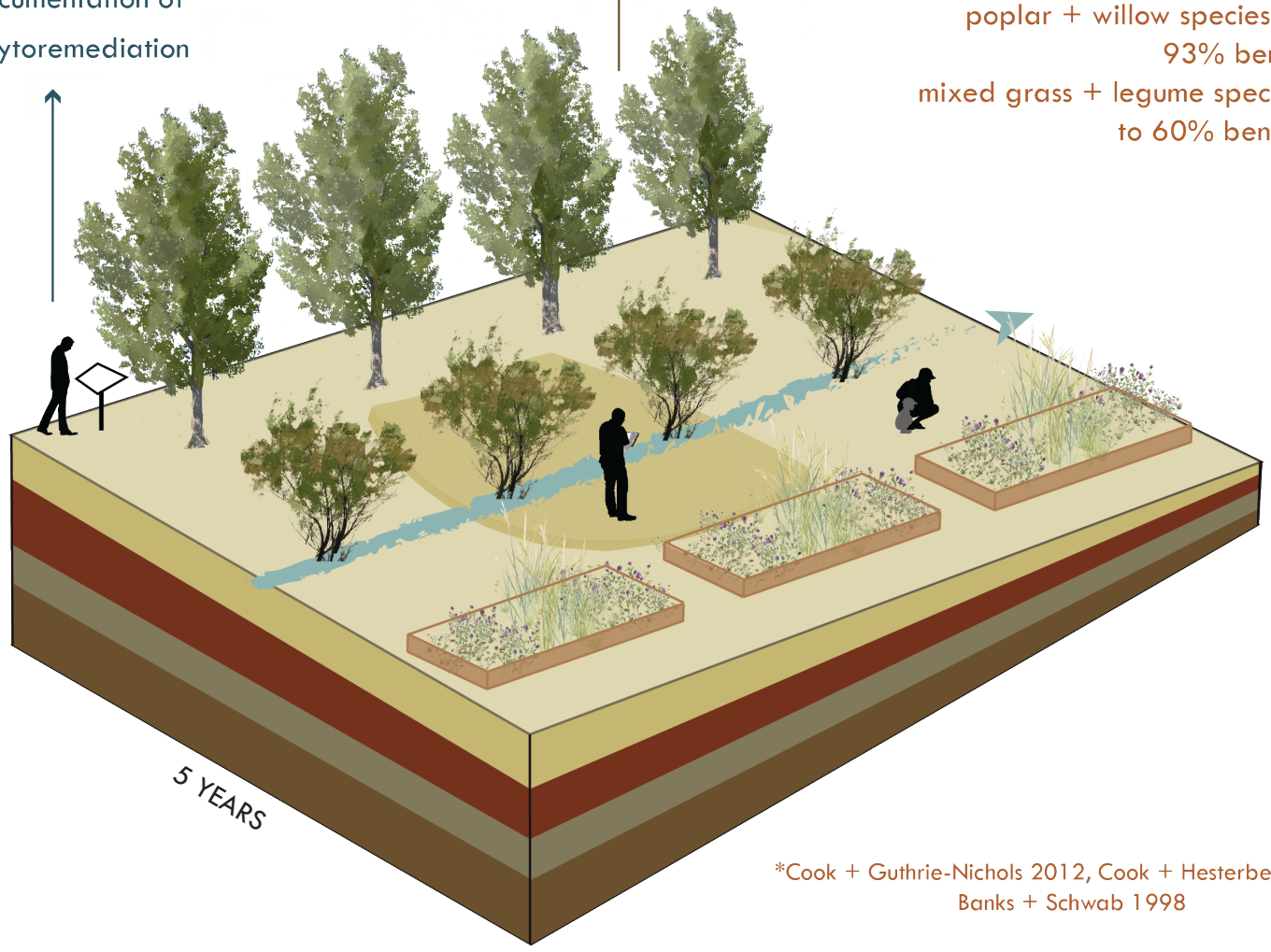
poplar and willow mature in 4 years,
starting remediation after 1 year
shallow mix mature in 1 year,
starting remediation in <1 year

USE

education, research +
documentation of
phytoremediation

CONTAMINATION

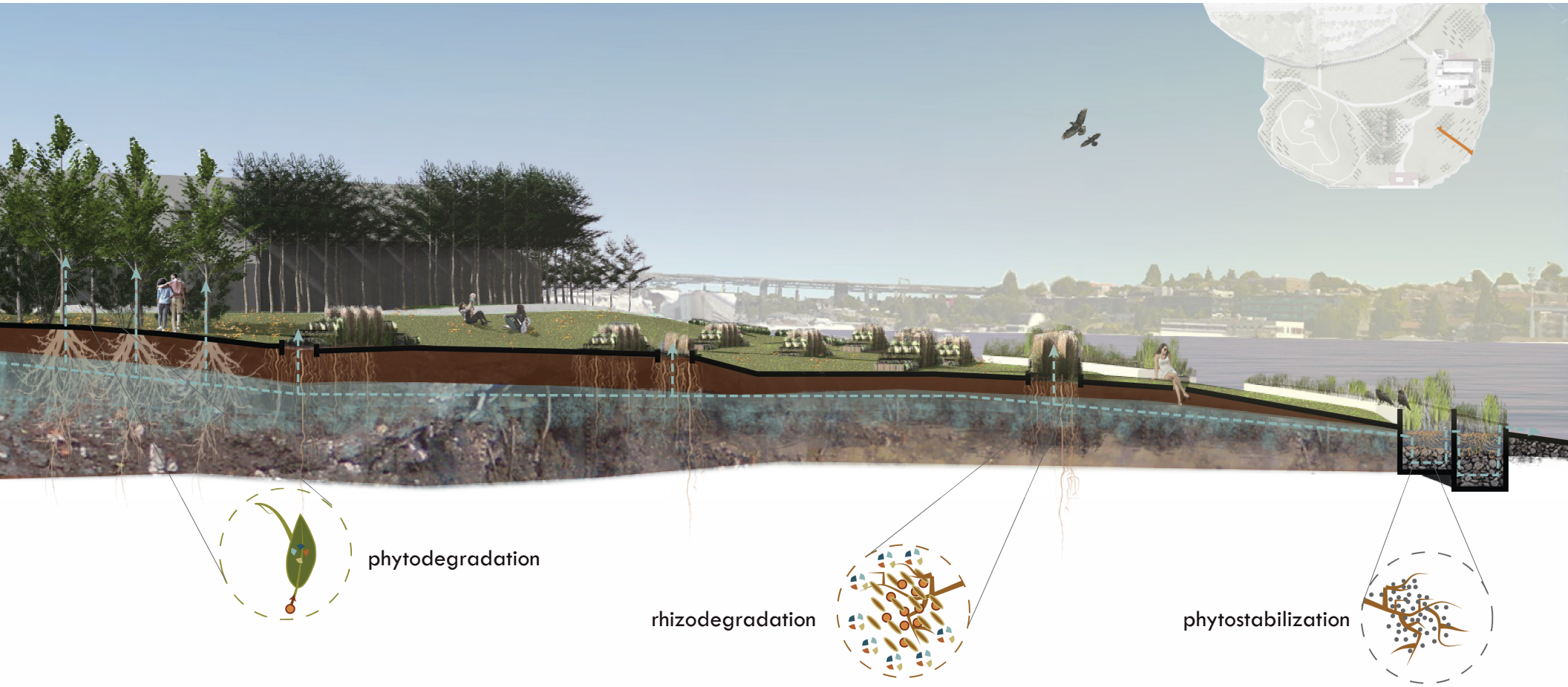
poplar + willow species degrade up to
93% benzene in 1 year
mixed grass + legume species degrade up
to 60% benzene in 2 years

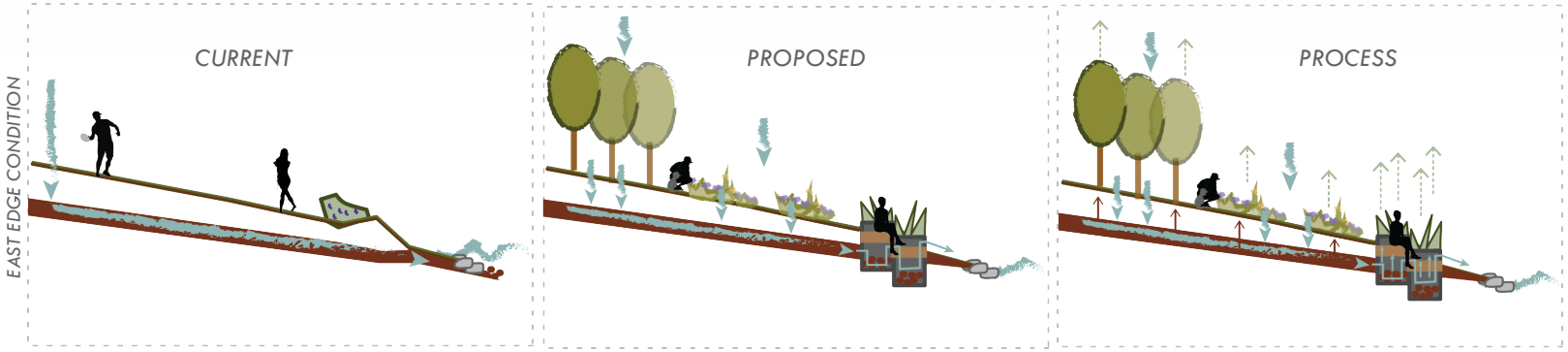


PROJECTED 75%
BENZENE REDUCTION
in 5 YEARS

*Cook + Guthrie-Nichols 2012, Cook + Hesterberg 2012,
Banks + Schwab 1998

7 EAST SWALE: section looking northeast





8 EAST WETLAND: perspective looking northeast



Ending our walk on the east edge of the site provides an early morning view of the aquatic community on the east side of Lake Union. Stepped wetlands create a new experience at the edge. Providing low seating in close proximity to the plants, the wetlands become a valued part of the park - providing habitat for humans and animals while performing remediation and filtration services below ground.



STEPPING FORWARD, LOOKING BACK

I can't say that this process took me to unexpected places.
The constraints of the site and the medium of phytoremediation provided a clear path for me to follow. In that way, it is difficult for me to see where the needs of the site end and my own design begins. Suffice it to say that the integration of phytoremediation at Gas Works Park feels like a natural partnership.

While my research and design process was deeply informed by the site, Gas Works Park is more complex than I could capture in 100 pages. Similarly, phytoremediation requires implementation *in the ground* to confirm the effectiveness and the experiences I have projected here. So although I am confident in my findings and ultimately in the interventions outlined in this project- it is important to keep in mind the true complexity of urban sites and phytoremediation. This complexity stems from a diverse set of processes that are in costant in flux. Fluctuations of *natural* processes (climate, geohydrology) and *human* processes (development, destruction) as well as fluctuations in scienctific process and academic rhetoric, all have an impact on the potential of this project.

As I look at the site now- sitting ankle deep in a fresh crop of grass on the south flank of Kite Hill- it feels as though I am actually looking back into the past, reflecting on how the park looked before phytoremediation was implemented. I can almost see trees around the Cracking Towers- degrading tar deep below the surface as new leaves rustle in the wind. If I walked to the edge of the park, I might expect to step off the concrete bulk head into lush wetlands filtering park runoff. Despite the reality of the situtaion, these experiences feel so close I can almost trick myself into believing they exist.

In reality, PAHs, benzene and arsenic continue to move through the park underground, seeping into the sediments of Lake Union, and rising to the top of the soil cap, exposed as oily sheens and tar. Additionally, the bureaucratic red tape encircling the site precludes any shift in remedial action in the near future. These conditions present daunting barriers to overcome.

However, looking back at the work of others before me- specifically the impetus that Ellen Weir's dissertation created, acting as a spring board for my own work- I feel optimistic. The continuation of research and design can propel innovative projects forward in order to seek improvements to the health, safety and enjoyment of existing public spaces.

The role students, researchers, and academia in general, play in discussions of contentious spaces, like Gas Works Park, is to create a functional dialogue and general awareness aimed towards eventual action. Those enmeshed in academia are afforded privledges that practicing professionals don't often have- the freedom to pose hard questions and seek alternative answers.

So although the park remains unmarked by any real remedial solutions, the potential power of documents like these- planting a seed that may, one day, incite positive change- feels real.

Understanding the complex physical and political conditions on site, I look back over my shoulder at the park today and step forward to embrace the possibility of how this site could be in the future- a healthy space for all organisms, above and below ground.

- Hailey Mackay, June 4, 2016, from Kite Hill

SELECT BIBLIOGRAPHY

Berger, Alan. ***Drosscape :*** *Wasting Land in Urban America.* 1st ed. New York: Princeton Architectural Press, 2006.

Blaylock, Michael. "Arsenic Phytoextraction: Phase 4 Field Verification Study Spring Valley". *FUDS Operable Units 4 and 5, Washington D.C. (2008).*

Braae, Ellen Marie. *Beauty Redeemed: Recycling Post-Industrial Landscapes.* Basel: Birkhauser Verlag GmbH, 2015.

Czerniak, Julia, George Hargreaves, and Harvard University. Graduate School of Design. *Large Parks.* Cambridge, Mass.: Princeton Architectural Press ; in association with the Harvard University Graduate School of Design, 2007.

Cook, Rachel and Dean Hesterberg. "Comparison of Trees and Grasses for Rhizoremediation of Petroleum Hydrocarbons." *International Journal of Phytoremediation* 15 (2013): 844-60.

Cook, Rachel. "Phytoremediation of a Petroleum-Contaminated Shallow Aquifer, Elizabeth City, N.C.: Planting Methods and Preliminary Results." North Carolina State University, 2008.

Couto, Nazare, Clara Basto and Teresa Vasconcelos. "Suitability of Scirpus Martima for Petroleum Hydrocarbons Remediation in Refinery Environment." *Environmental Science and Pollution Research* 19 (2012): 86-95.

Doty, S. L. "Enhancing Phytoremediation through the Use of Transgenics and Endophytes." *New Phytologist* 179, no. 2 (Jul 2008): 318-33.

Ferro, Ari M., Steven Rock, Jean Kennedy, James J. Herrick and David L. Turner. "Phytoremediation of Soils Contaminated with Wood Preservatives: Greenhouse and Field Evaluations." *International Journal of Phytoremediation* (2006): 289-306.

Engler, Mira, and Center for American Places. *Designing America's Waste Landscapes.* Center Books on Contemporary Landscape Design. Baltimore: J. Hopkins University Press, 2004.

Evernden, Lorne Leslie Neil. *The Social Creation of Nature.* Baltimore: Johns Hopkins University Press, 1992.

GeoEngineers. "Feasibility Study Bridging Document: Gas Works Park Site." Puget Sound Energy, 2013.

Hollander, Justin B., Niall Kirkwood, and Julia L. Gold. *Principles of Brownfield Regeneration : Cleanup, Design, and Reuse of Derelict Land.* Washington: Island Press, 2010.

"International Poplar Commission." http://www.fao.org/forestry/ipc/en/.

The Interstate Technology & Regulatory Council Phytotechnology Team. "Phytotechnology Technical and Regulatory Guidance and Decision Trees, Revised." Washington, DC: Interstate Technology & Regulatory Council, 2009.

lsebrands, J.G. et. al. "Environmental Applications of Poplars and Willows." Chap. 6 In *Poplars and Willows: Trees for Society and the Environment*, edited by J.G. Richardson Isebrands, J., 258-336. Boston, MA: CABI and FAO, 2014.

Kahn, Zareen, David Roman, Trent Kintz, May delas Alas, Raymond Yap and Sharon Doty. "Degradation, Phytoprotection and Phytoremediation of Phenanthrene by Endophyte Pseudomonas Putida, PD1." *Environmental Science and Technology* 48 (2014): 12221- 28.

Kaplan, Stephen. "The Restorative Benefits of Nature: Toward an Integrative Framework." *Journal of Environmental Psychology* 15, no. 3 (1995): 169- 82.

Kellert, E.O. Wilson and Stephen, ed. *The Biophilia Hypothesis.* Washington , D.C.: Island Press, 1993.

Kirkwood, Niall. *Manufactured Sites: Rethinking the Post-Industrial Landscape.* London ; New York: Spon Press, 2001.

Kirkwood, Niall, and Kate Kennen. *Phyto: Principles and Resources for Site Remediation and Landscape Design.* New York, NY: Routledge, 2015.

Marris, Emma. *Rambunctious Garden: Saving Nature in a Post-Wild World.* 1st U.S. ed. New York: Bloomsbury, 2011.

Pearce, Fred. *The New Wild : Why Invasive Species Will Be Nature's Salvation.* Boston : Beacon Press, 2015.

Ribeiro, Hugo, Marisa Almeida, ana Paula Mucha and Adriano Bordalo. "Influence of Different Salt Marsh Plants on Hydrocarbon Degrading Microorganisms Abundance Throughout a Phenological Cycle." *International Journal of Phytoremediation* 15 (2013): 715-28.

Robert L. Knight, Robert Kadlec and Harry Ohlendorf. "The Use of Treatment Wetlands for Petroleum Industry Effluents." *Environmental Science and Technology* 33, no. 7 (1998): 973- 80.

Roy, Sebastian and Suzanne Labelle, et. al. "Phytoremediation of Heavy Metal and Pah-Contaminated Brownfield Sites." *National Research Council of Canada, Plant and Soil* 272, no. 1-2 (2005): 277-90.

Sabol, M.A., G.L. Turney and G.N. Ryals. *Evaluation of Available Data on the Geohydrology, Soil Chemistry and Ground Water Chemistry of Gas Works Park and Surrounding Region*. Seattle, Washington: Washington State Department of Ecology, 1988.

Turney, Gary L., D. F. Goerlitz, Seattle (Wash.). Department of Parks and Recreation., and Geological Survey (U.S.). *Ground-Water Contamination at an Inactive Coal and Oil Gasification Plant Site, Gas Works Park, Seattle, Washington.* Water-Resources Investigations Report / U S Geological Survey. Tacoma, Wash. Denver, Colo.: Dept. of the Interior U.S. Geological Survey, 1990.

Ulrich, Roger S. "View through a Window May Influence Recovery from Surgery." *Science* 224 (1984): 420-21.

Ulrich, Roger S., and Statens råd för byggnadsforskning (Sweden). *Aesthetic and Emotional Influences of Vegetation: A Review of the Scientific Literature*. Document / Swedish Council for Building Research. Stockholm: Swedish Council for Building Research, 1985.

Way, Thaïsa. *The Landscape Architecture of Richard Haag: From Modern Space to Urban Ecological Design.* Seattle: University of Washington Press, 2015.

Weir, Ellen. "Assessing the Social Acceptability of Endophyte-Assisted Phytoremediation of Polycyclic Aromatic Hydrocarbons: A Case Study at Gas Works Park." ProQuest Dissertations Publishing, 2015.

Wiessner, A., P. Kuschik and U. Stottmeister. "Oxygen Release by Roots of Typha Latifolia and Juncus Effusus in Laboratory Hydroponic System." *Acra Biotechnology* 22, no. 1-2 (2002): 209-16.

William McDonough +Partners. "The Making of the Next Industrial Revolution at Ford Motor Company." Ford Motor Company, 2011

Wilson, Edward O. *Biophilia.* Cambridge, Mass.: Harvard University Press, 1984.

Yu, Kongjian, and William S. Saunders. *Designed Ecologies the Landscape Architecture of Kongjian Yu*. Basel: De Gruyter, 2013.

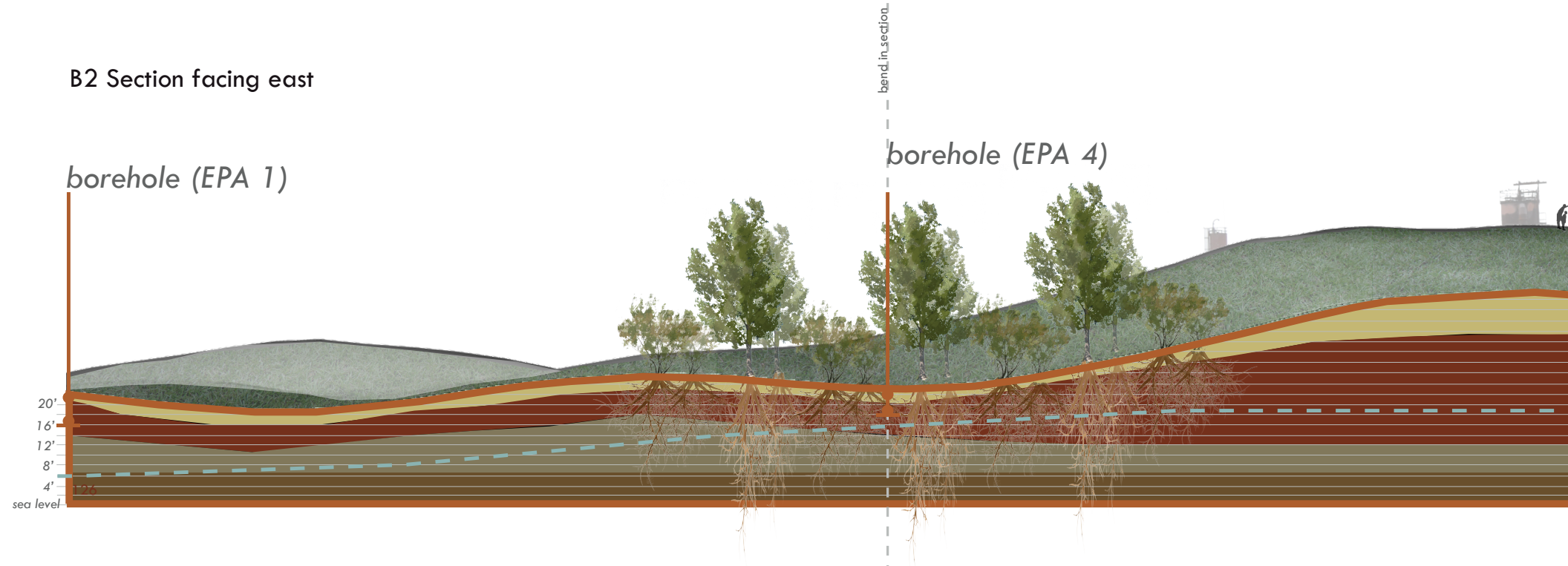
Zalesny Jr., Ronald J., Edmund O. Bauer, Richard B. Hall, Jill A. Zalesny, et al. "Clonal Variation in Survival and Growth of Hybrid Poplar and Willow in an in Situ Trial on Soils Heavily Contaminated with Petroleum Hydrocarbons." *International Journal of Phytoremediation* 7, no. 3 (2005): 177-97.

APPENDIX: SECTIONS + SLICES

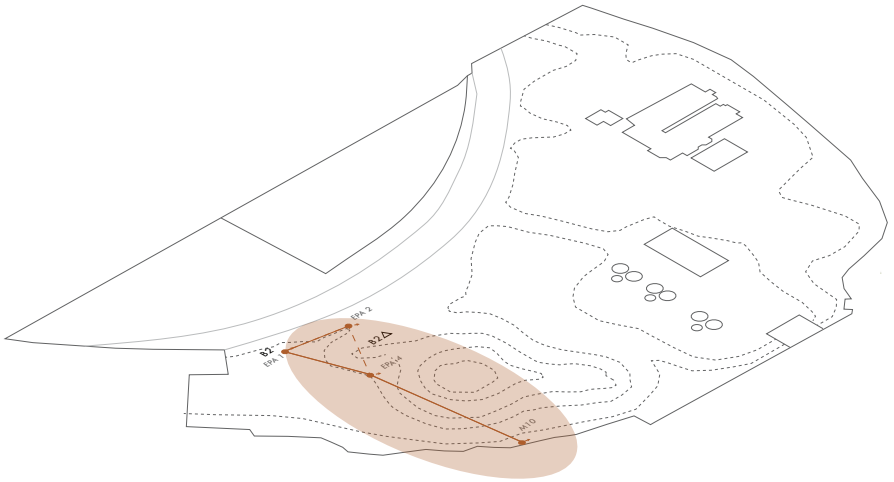
West Boundary - Shoreline (B2)

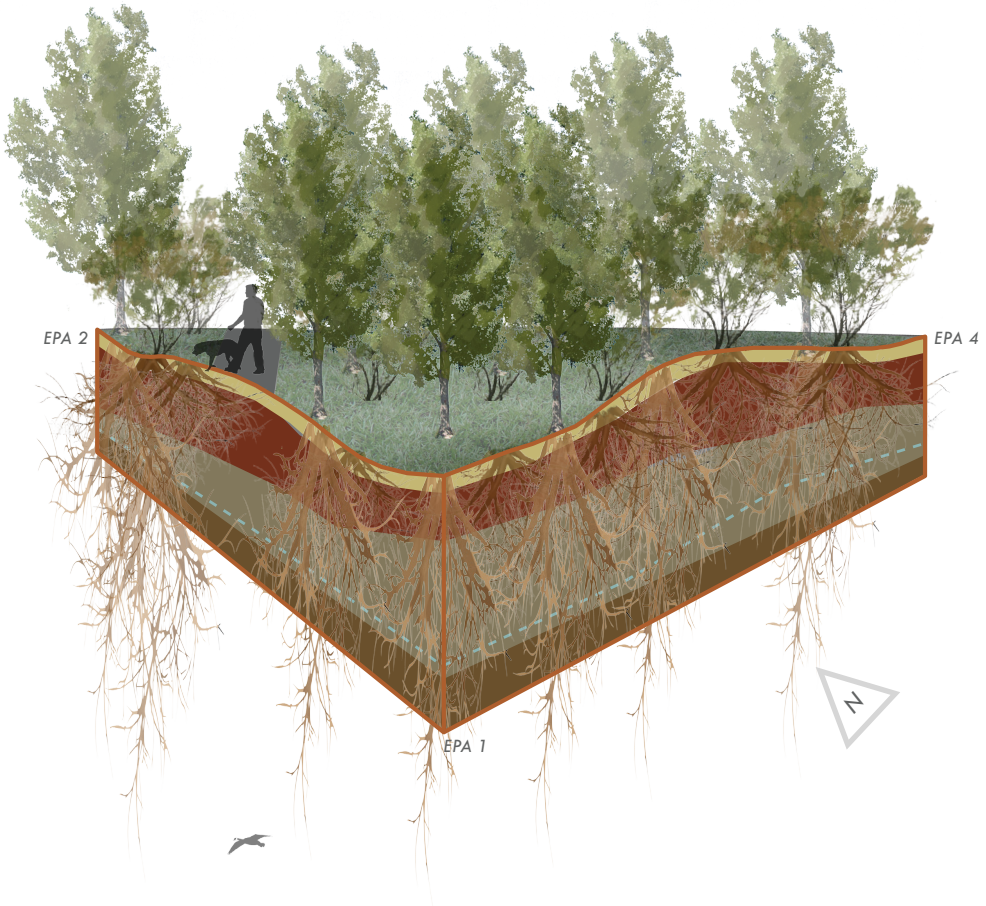
	Contamination	Strategies	Maintenance	Form		Monitoring
Upland	EPA 1: depth .5-3' level 32 mg/kg TPAH, benzene EPA 2: depth .5 - 3' 2 - 214 mg/kg TPAH, benzene	Deep degradation: willow, poplar Purpose: degradation	Clear understory weeds, grass trimming /3 months, maintain form - access	Tall gridded rows Decidous Poplar cuttings 10 ' OC Willow cuttings 5' OC	Type	Soil/water sampling at established locations/depths
Midland	EPA 4: depth .5 - 3' level 36 - 1057 mg/kg TPAH, benzene	Interception: willow, spartina Purpose: hydraulics + degradation	Clear understory /6 months (summer/winter), maintain form - access, cut back willow every two years?	Low planting strips Deciduous/Perennial Willow cuttings 5' OC Spartina plugs 2' OC	Interval	6 months, sample testing for TPAHs, benzene
Shoreline	M10: surface sample level 400 mg/kg TPAH	Wetland: Typha, scirpus a/m, juncus Purpose: filtration + degradation	No maintenance - except potential overwater thinning for salmon habitat	Low naturalistic Clumping Perennial Wetland plugs	Purpose	Data compilation to determine rate + effectiveness of phytoremediation

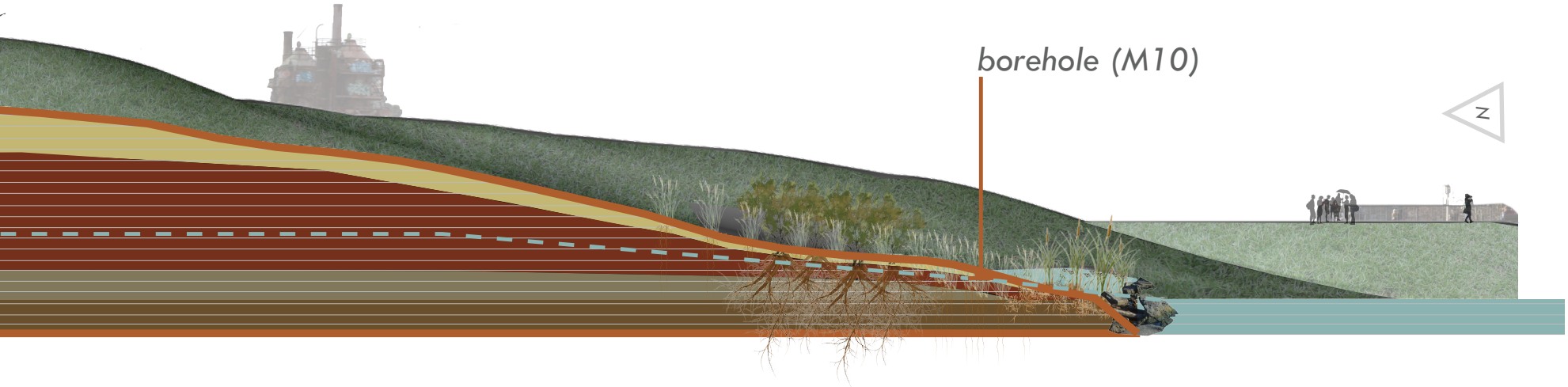
B2 Section facing east



B2 △ looking southeast

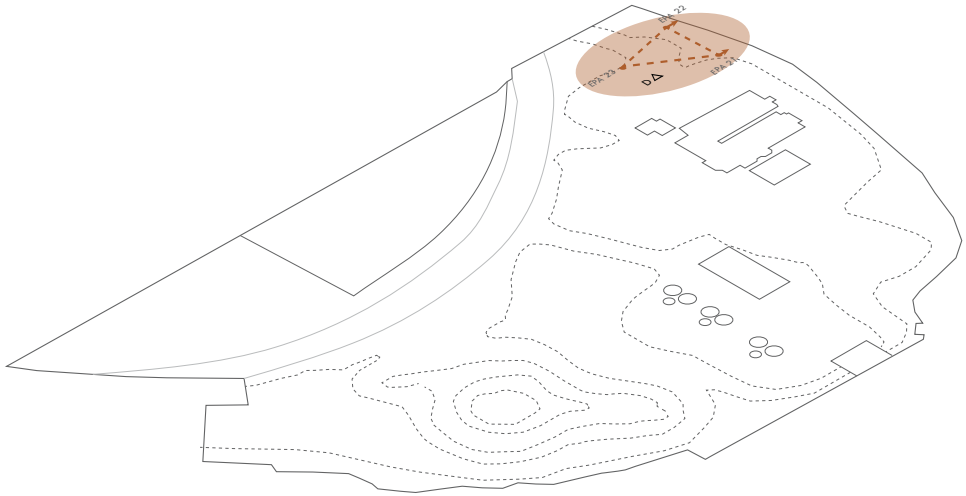


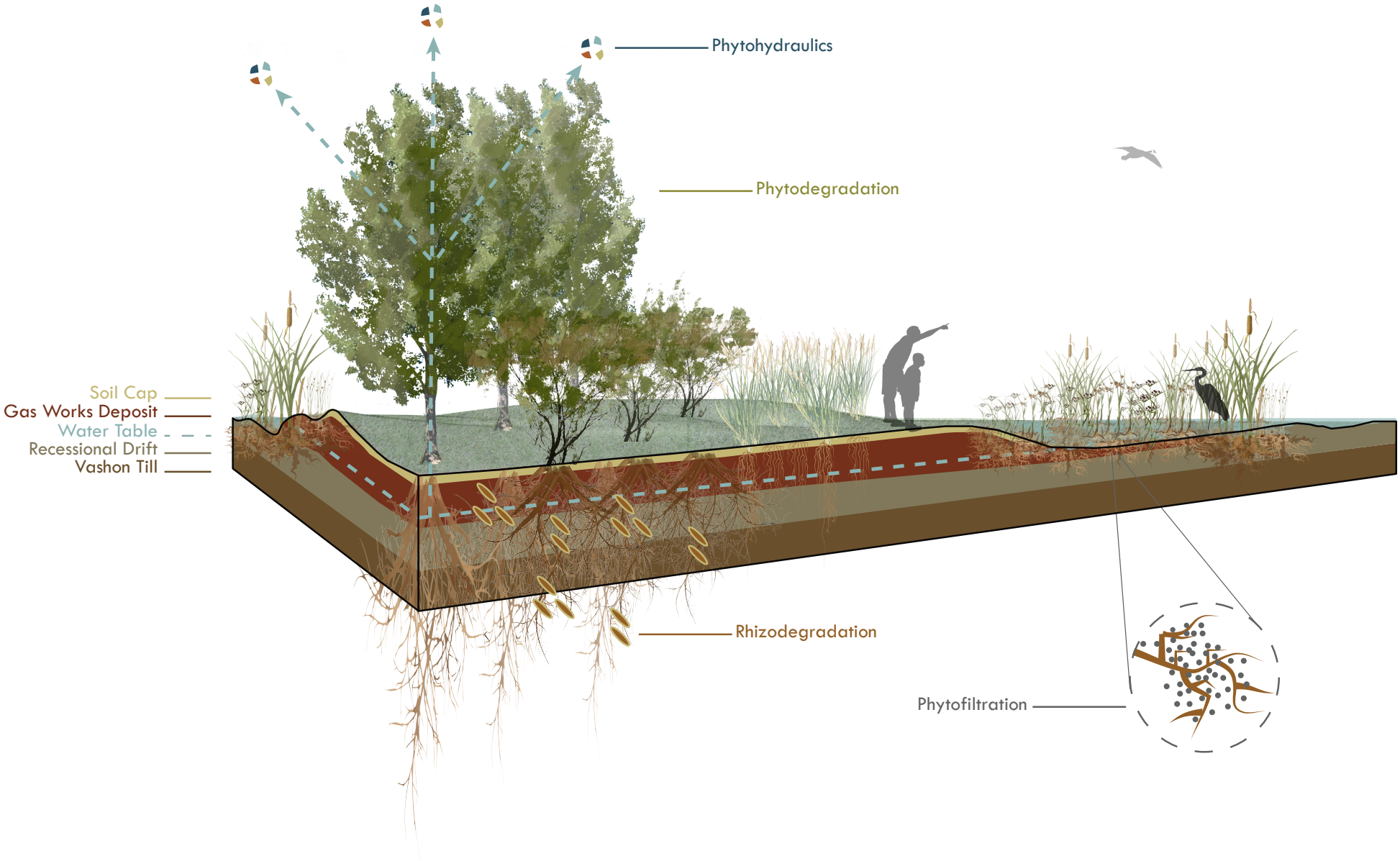




NE Corner - Shoreline (D)

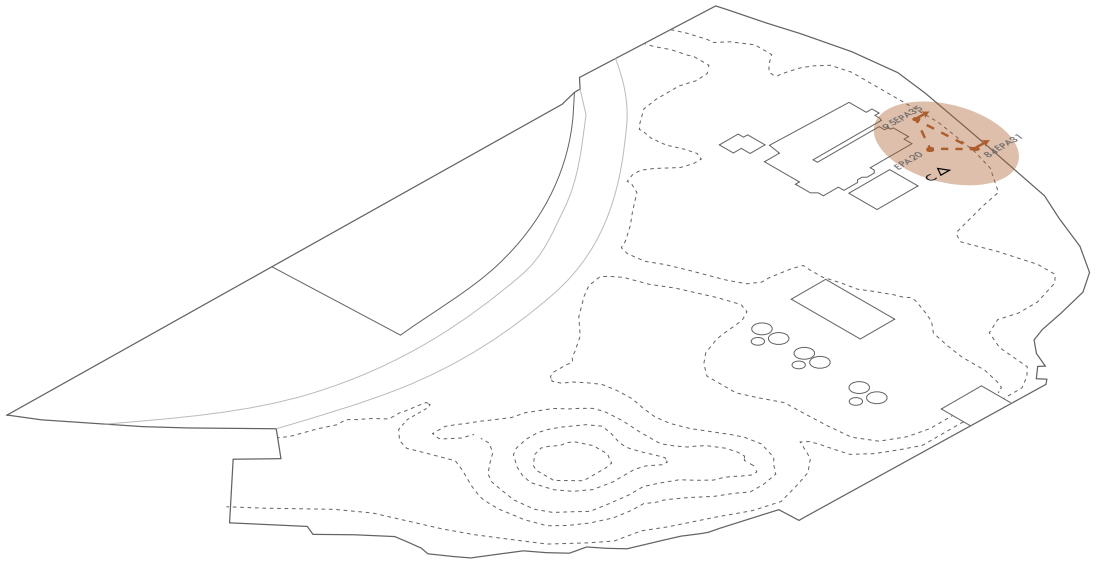
	Contamination	Strategies	Maintenance	Form		Monitoring
Upland	EPA 23: depth .5-3' level 266 - 275 mg/kg TPAH	Shallow degradation: trifolium, medicago, grass mix Purpose: degradation	Edging /3 months, maintain form - access, periodic mowing?	Low planting strips Deciduous/Perennial Shallow mix, 1' OC Spartina plugs 2' OC	Type	Soil/water sampling at established locations/depths
Midland	EPA 21: .5' - 3' level 2299 - .5 mg/kg TPAH	Deep degradation: willow, poplar Purpose: degradation	Clear understory weeds, grass trimming /3 months, maintain form - access	Tall gridded rows Decidous Poplar cuttings 10 ' OC Willow cuttings 5' OC	Interval	6 months, sample testing for TPAHs, benzene
Shoreline	EPA 22: depth .5 - 3' level 376 - .9 mg/kg TPAH	Wetland: Typha, scirpus a/m, juncus Purpose: filtration + degradation	No maintenance - except potential overwater thinning for salmon habitat	Low naturalistic Clumping Perennial Wetland plugs	Purpose	Data compilation to determine rate + effectiveness of phytoremediation

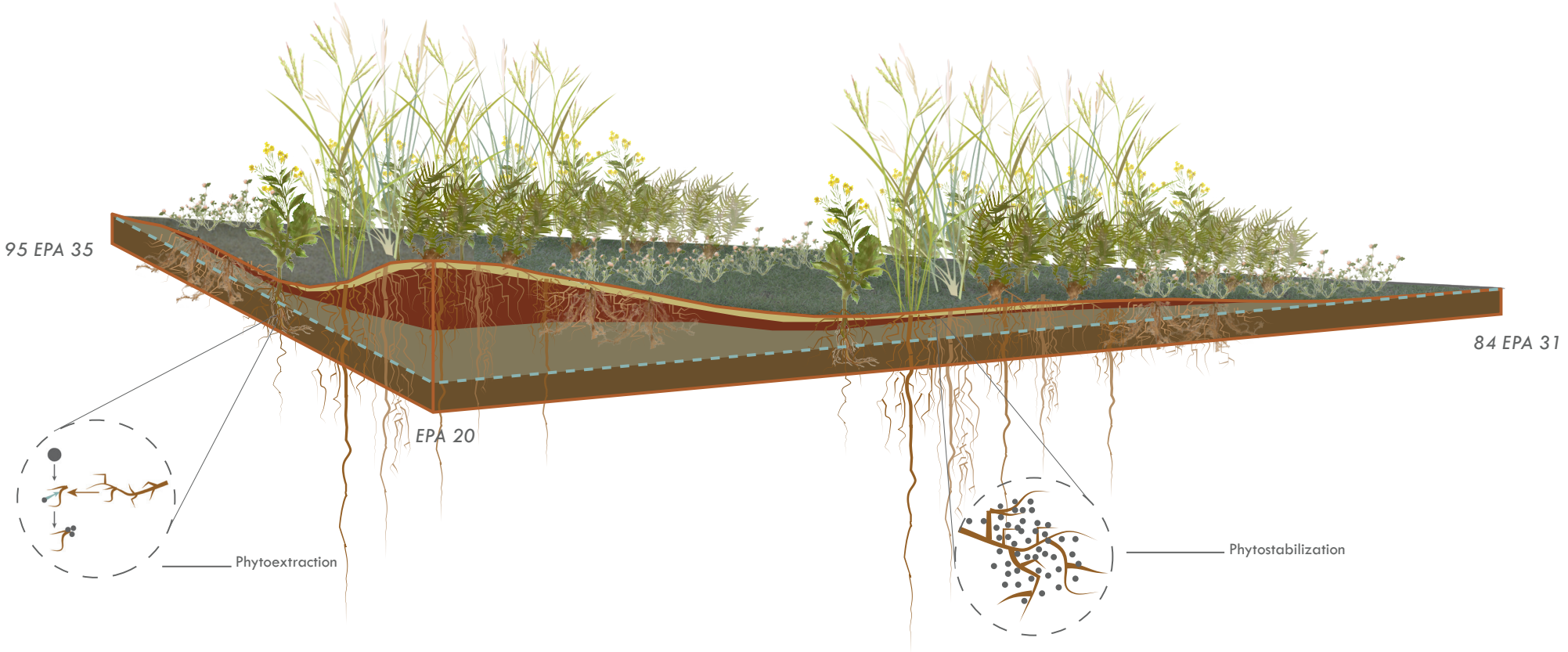



Phytohydraulics
Phytodegradation
Soil Cap
Gas Works Deposit
Water Table
Recessional Drift
Vashon Till
Rhizodegradation
Phytofiltration

Play Barn East - Shoreline (C)

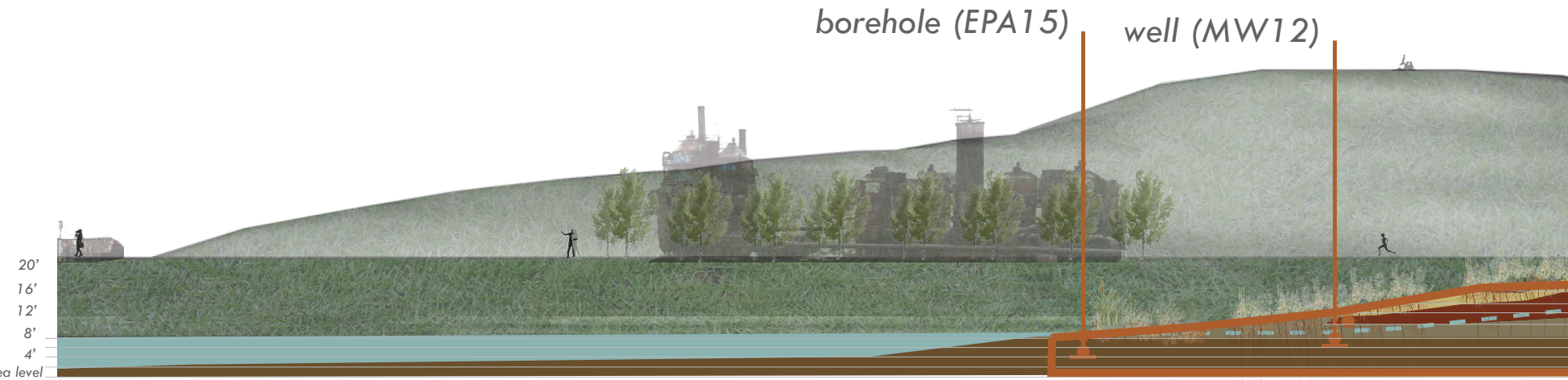
	Contamination	Strategies	Maintenance	Form		Monitoring
Upland	EPA 20: depth .5-3' level 194 - .5 mg/kg TPAH Elevated arsenic	Extraction: brassica, pteris, grass mix Purpose: extraction, stabilization	Edging /3 months, maintain form - access, harvesting (disposal) and replanting annuals twice yearly	Low planting strips Annuals/perennial grass Pteris/brassica, 1' OC grass plugs 2' OC	Type	Soil/water sampling at established locations/depths
Midland	95 EPA 35: surface level 2409 mg/kg TPAH Elevated arsenic	Extraction: brassica, pteris, grass mix Purpose: extraction, stabilization	Edging /3 months, maintain form - access, harvesting (disposal) and replanting annuals twice yearly	Low planting strips Annuals/perennial grass Pteris/brassica, 1' OC grass plugs 2' OC	Interval	6 months, sample testing for TPAHs, benzene
Shoreline	84 EPA 31: surface level 26 mg/kg TPAH Elevated arsenic	Wetland: Typha, scirpus a/m, juncus Purpose: filtration, stabilization + degradation	No maintenance - except potential overwater thinning for salmon habitat	Low naturalistic Clumping Perennial Wetland plugs	Purpose	Data compilation to determine rate + effectiveness of phytoremediation

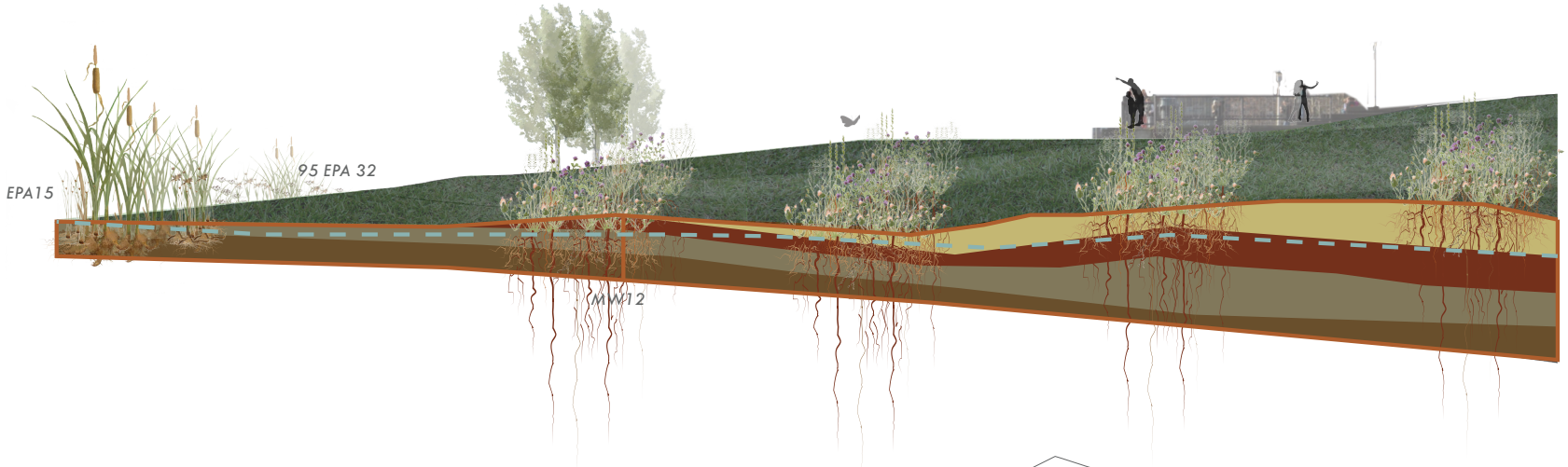


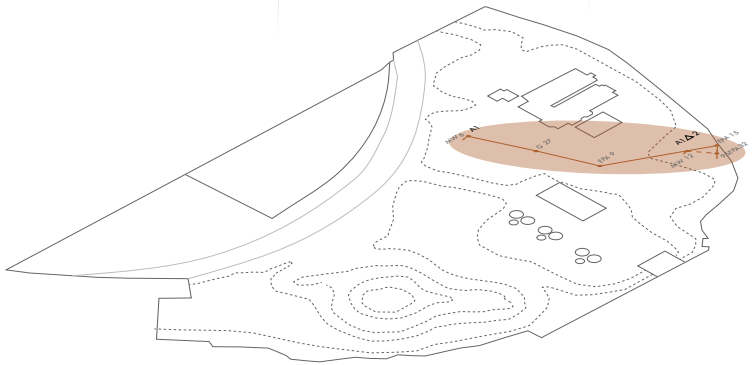

95 EPA 35
EPA 20
84 EPA 31
Phytoextraction
Phytostabilization

East Swale - Shoreline (A1)

	Contamination	Strategies	Maintenance	Form		Monitoring
Upland	MW 6: depth .5.5 - 6' level 176 mg/kg TPAH Groundwater 1.5' down G 27: surface, level 20 mg/kg TPAH. MW 9: deptj 2.5 - 6', level 206 - 36 mg/kg TPAH	Deep Degradation: poplar, willow, spartina Purpose: deep degradation, hydraulics	Clear understory weeds, grass trimming /3 months, maintain form - access	Tall gridded rows Decidous Poplar cuttings 10 ' OC Willow cuttings 5' OC	Type	Soil/water sampling at established locations/depths
Midland	EPA 9: .depth 5 - 3', level 126 - 42 mg/kg TPAH MW 12: depth 3 - 3.5', level 120 mg/kg TPAH	Deep/shallow degradation: poplar, willow, grass mix, medicago, trifolium Purpose: degradation, hydraulics	Edging /3 months, maintain form - access, periodic mowing?	Low planting strips Deciduous/Perennial Shallow mix, 1' OC Spartina plugs 2' OC	Interval	6 months, sample testing for TPAHs, benzene
Shoreline	EPA 15: .5 - 3' level 953 - .5 mg/kg TPAH 95 EPA 32: surface, level 126 mg/kg TPAH	Wetland: Typha, scirpus a/m, juncus Purpose: filtration, stabilization + degradation	No maintenance - except potential overwater thinning for salmon habitat	Low naturalistic Clumping Perennial Wetland plugs	Purpose	Data compilation to determine rate + effectiveness of phytoremediation





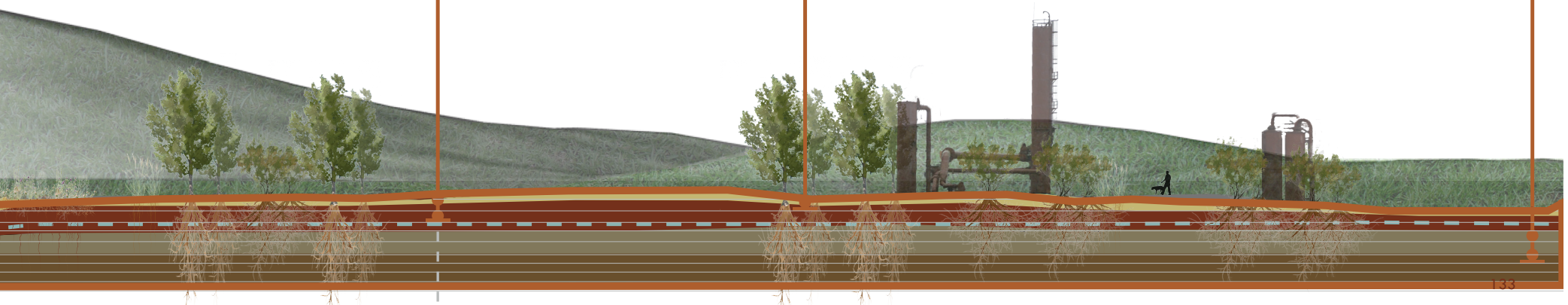


bend in section

borehole (EPA9)

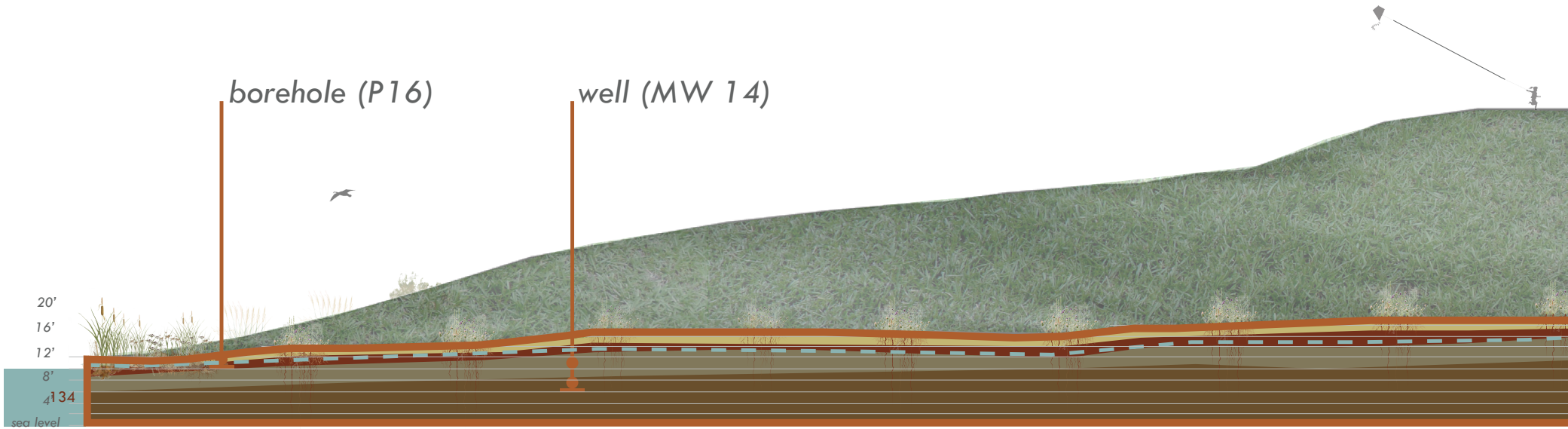
borehole (G27)

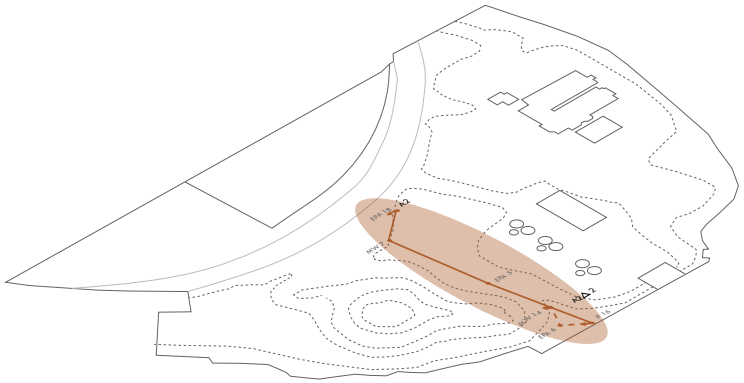
well (MW 6)

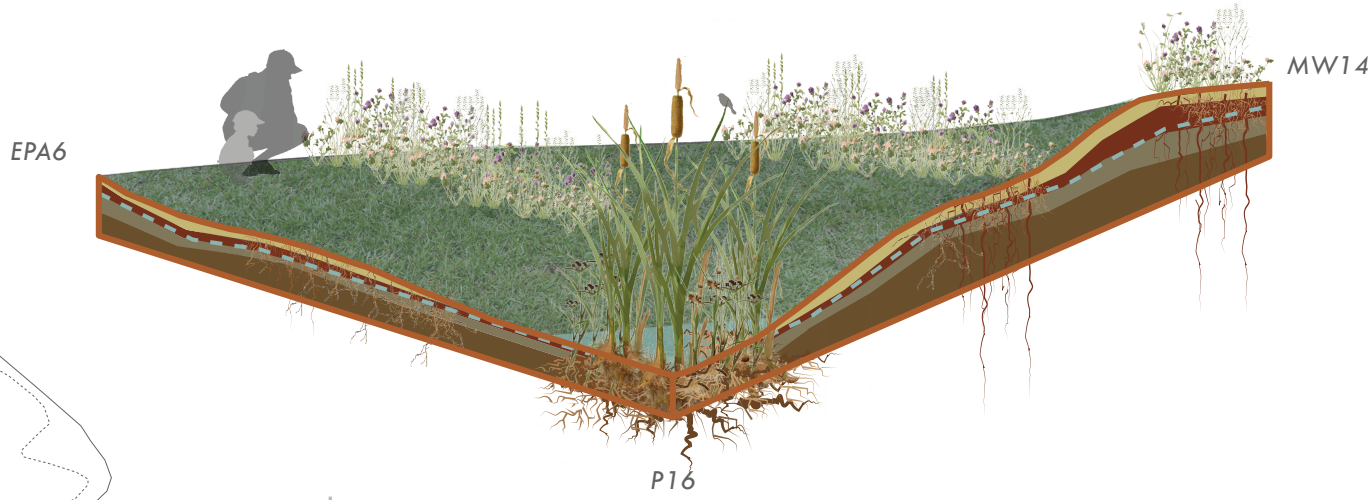


Central Swale - South Shoreline (A2)

	Contamination	Strategies	Maintenance	Form		Monitoring
Upland	EPA 18: depth .5 - 3' level 412 - .982 mg/kg TPAH MW 7: depth 7.5 - 8.5' level 6.9 mg/kg TPAH EPA 7: depth .5 - 3', level 1810 mg/kg TPAH	Deep Degradation: poplar, willow, spartina Purpose: deep degradation, hydraulics	Clear understory weeds, grass trimming /3 months, maintain form - access, except around towers?	Tall gridded rows Decidous Poplar cuttings 10 ' OC Willow cuttings 5' OC	Type	Soil/water sampling at established locations/depths
Midland	EPA 8: .depth 5 - 3', level 467 - 45mg/kg TPAH MW10: depth 3 - 9.5', level 3.3 mg/kg TPAH Groundwater 9.5'	Shallow degradation: grass mix, medicago, trifolium Purpose: degradation, hydraulics	Edging /3 months, maintain form - access, periodic mowing? (for 7/4)	Low planting strips Deciduous/Perennial Shallow mix, 1' OC	Interval	6 months, sample testing for TPAHs, benzene
Shoreline	MW 14: depth 5.5 - 6.5' level 6 mg/kg TPAH Groundwater 4.7' EPA 6: depth .5 - 3', level 114 - 74 mg/kg TPAH P16: surface, level 225 mg/kg TPAH	Wetland: Typha, scirpus a/m, juncus Purpose: filtration, stabilization + degradation	No maintenance - except potential overwater thinning for salmon habitat	Low naturalistic Clumping Perennial Wetland plugs	Purpose	Data compilation to determine rate + effectiveness of phytoremediation







bend in section

borehole (EPA 5)

well (MW 7)

borehole (EPA 18)

