Floodable Urban Landscapes for a Resilient City:
Potential for the City of Seattle

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Abstract

Floodable Urban Landscapes for a Resilient City: Potential for the City of Seattle

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Landscape Architecture

As a professional project for Seattle Public Utilities, this thesis explores the potential of the urban landscape to act as an integral component of the water infrastructure system as a climate adaptation strategy that simultaneously creates dynamic, multifunctional public open spaces. As an investigation in support of SPU's Integrated System Plan, this thesis explores the following questions:

- What can examples of floodable spaces beyond the context of Seattle teach us about how effectively they deliver functional drainage performance along with usable open space?
- How could Seattle benefit from this concept?
- What might be priority locations for floodable spaces in the City of Seattle?
- How might a concept for floodable spaces in the Aurora-Licton urban village demonstrate how recreational space can work in tandem with drainage function for climate resilience, ecological health, and quality of life improvements?

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Thank you to my family and friends for your encouragement from afar, and lastly, thank you to Ben for your steadfast support and love throughout these three most trying years.

TERMS and ABBREVIATIONS

SPU: Seattle Public Utilities
DWW : Drainage & Wastewater
LOB: Line of Business
GSI : Green Stormwater Infrastructure
BGI: Blue-Green Infrastructure
ROW: Right-Of-Way
CIP: Capital Improvements Project
SPR: Seattle Parks & Recreation
DSA: Drainage Systems Analysis

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INTRODUCTION

The relationship between U.S. cities and their waterways, while one of great potential, has often been one of dysfunction. Urbanization and its associated land cover transformation has severely impacted the hydrology of the places to which it has spread. The transformation of undeveloped watersheds - normally an extensive, interconnected system - into fragmented and disconnected segments is a primary cause of urban flooding, a frequent natural hazard in urban environments[1]. Flooding is also the most damaging natural hazard in cities - with annual losses averaging over $40 billion globally[2], floods can cause economic and environmental damage, displace populations, destroy property, and take human lives. While human civilizations have historically enjoyed many benefits as a result of proximity to water, living with water safely and productively requires planning for it: time and time again, destructive floods reveal that there is a relationship between urban configuration and vulnerability to adverse impacts from extreme weather events[3].

The hard, impervious, static and unresponsive character of urban surfaces - concrete, asphalt, brick, and the like - are unable to absorb and attenuate water flows as were the porous land surfaces they replaced, such as forests, prairies, wetlands, or floodplains. In urban environments, the inherent ability of the landscape to accomodate water has largely been eliminated by development.

The impacts of urbanization on the hydrologic cycle have created problems of quantity as well as quality. The ubiquitous network of impervious surfaces that characterize the typical urban landscape, as well as the rapid conveyance of rainwater from these impervious surfaces by piped underground drainage systems, has led to measurable degradation of surface water bodies in urbanized contexts worldwide[4].

Figure 1.1

Such urban infrastructure appears to have been planned and implemented without consideration of the intrinsic relationship between land and water. Rather than allowing rainwater that falls from the atmosphere to earth to infiltrate into soil or be evapotranspirated by plants as it would under undeveloped land conditions, impervious surfaces and the piped systems that drain them are effectively "stormwater superhighways" that rapidly transport rain water, along with any pollutants in its path, into rivers, streams, and oceans[5].

This system enables increased flooding during storms, prevents natural recharge of groundwater, and increases flow volume and speed. It also causes erosion of stream banks and terrestrial soil, and as a result, increases sedimentation in streams and floodplains. Impervious surfaces and piped, centralized stormwater systems enable chemicals, metals, excess nutrients, and bacteria from human activity to enter waterways, all of which have negative biological consequences for aquatic organisms there and the terrestrial organisms that depend upon them[5]. Urban land use, water quality degradation, altered flow regimes, and urban flooding are interrelated phenomena arising from the ways in which urban and suburban developments have fundamentally altered the hydrologic cycle.

In the 21st century, there are many fundamental challenges facing our existing water infrastructure systems and the organizations that manage them. However, these seemingly insurmountable challenges also represent opportunities to reimagine the entire system.

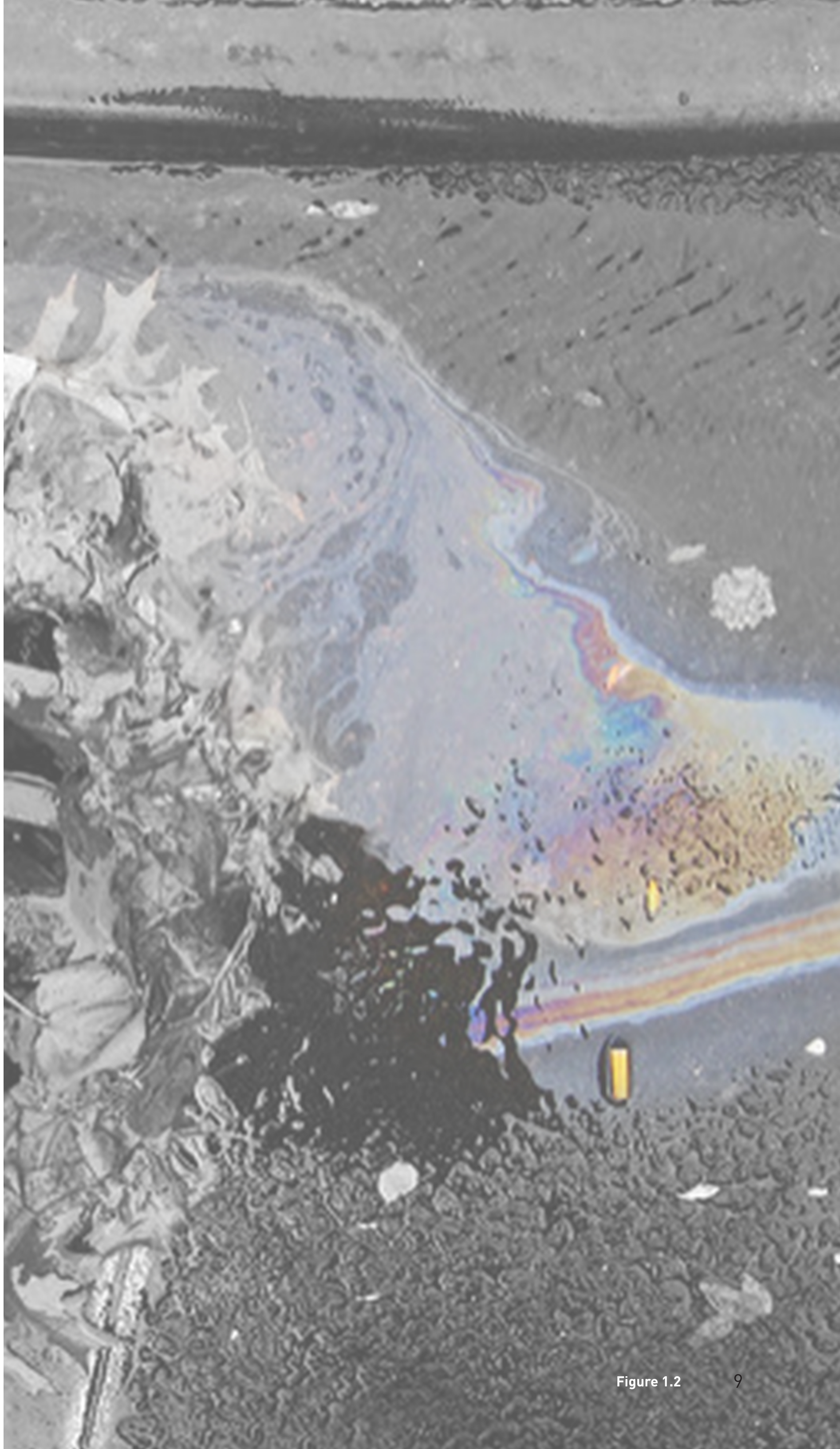


Figure 1.2

GLOBAL CLIMATE CHANGE

The environmental challenges spawned by urban and suburban development patterns are now compounded by the onset of global climate change, a direct result of anthropogenic carbon emissions into the atmosphere since the Industrial Revolution. In a 2009 study published in the journal *Science*, Tripati, Roberts, and Eagle found that atmospheric carbon dioxide levels have not been as high as they are today for at least the past 800,000 years, well before the advent of human civilization or even the evolution of Homo sapiens[6]. The comparatively stable planetary conditions under which our species evolved have been fundamentally and inexorably altered.

Without transformative action towards both mitigation and adaptation, human settlements around the planet face the prospect of increasingly frequent and severe disasters such as floods, droughts, wildfires, extreme storms, and sea level rise in the coming years[7].

URBAN ENVIRONMENTS & INFRASTRUCTURE in the 21st CENTURY

Cities, many of which are sited on coastlines, river mouths, estuaries, or deltas, are uniquely vulnerable to the impacts of climate change, and they have the most to lose. Urban environments are now home to the majority of the global population and most include the majority of the world's built assets and economic activity[8].

Planners and designers of cities and their infrastructure have historically looked to the past in order to plan for the future, a concept known as stationarity. As a result, legacy water infrastructure systems in place today were designed according to the hydrologic patterns of the past 100 years that are no longer a reflection of our hydrologic future.

In the paper *Stationarity Is Dead: Whither Water Management?*, P.C.D. Milly writes, "Stationarity - the idea that natural systems fluctuate within an unchanging envelope of variability - is a foundational concept that permeates training and practice in water-resource engineering....in view of the magnitude and ubiquity of the hydroclimatic change now under way...we conclude that stationarity is dead and should no longer serve as a central, default assumption in water-resource risk assessment and planning"[9]. This new reality demands a different approach to the design and planning of urban form and infrastructure.

During the 20th century and beyond, water infrastructure has tended towards a large, standardized, monofunctional character, largely hidden from the view and awareness of the dependent public; planned, designed, and implemented with a singular goal in mind[10]. When first installed, water systems in the U.S. were revolutionary, bringing about unprecedented improvements in public health and economic growth[11]. However, today, these systems are aging, inefficient, and vulnerable to failure. According to a 2016 report by the National Infrastructure Advisory Council, water infrastructure in the U.S. as a whole is aging, and will require massive reinvestment, 400 billion to 1 trillion dollars nationally, to upgrade pipes, mains, and equipment, with many assets either close to or beyond their original expected lifespan[11]. Taken alongside climate change projections that suggest a much wetter and less predictable future condition, many have argued that these methods are "no longer affordable or sustainable"[12].

Garnering public support for such massive investments is a challenge as well: water infrastructure assets are so often out of sight, out of mind, reliable (at least historically), and expected to be low-cost. This has created a general under-appreciation of how critical water systems are to society[11].

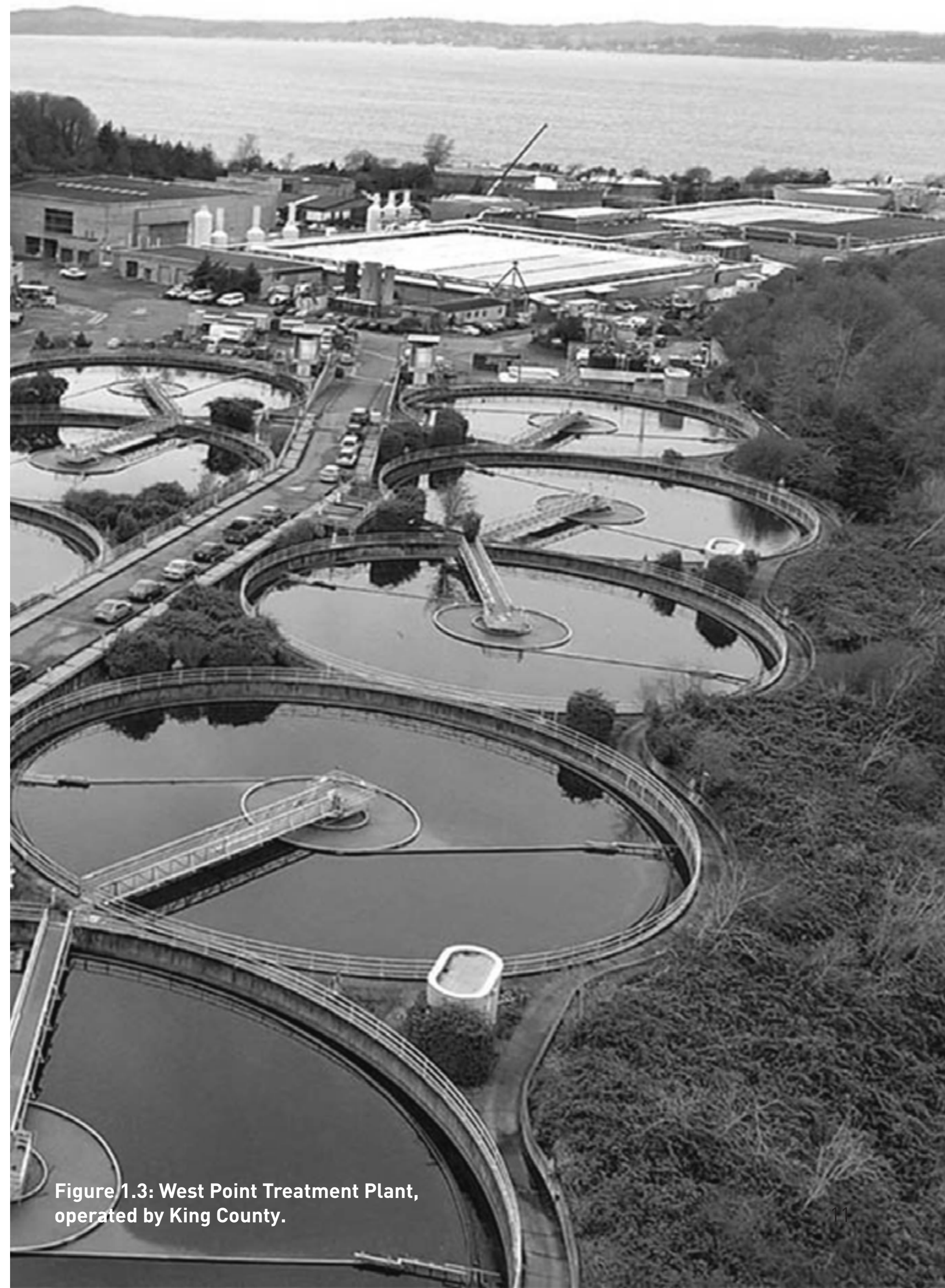


Figure 1.3: West Point Treatment Plant, operated by King County.

In many cases, infrastructure systems have developed out of necessity in response to crisis and failure (Belanger). For example, the Great Seattle Fire of 1889, which scorched 25 square blocks of the burgeoning city, made evident the dire need for a public water system[11].

Beginning in 1902, the U.S. Bureau of Reclamation began funding irrigation projects for farms in the arid West that did not have adequate access to water. Over the following decades, this evolved into the construction of massive water infrastructure projects from which hydropower renevue could be generated and put towards a common fund for farming irrigation. With dams and other water infrastructure projects, the U.S. government essentially bailed out failing farming operations in landscapes that were not suitable for farming in the first place[13].

After the City of Copenhagen, Denmark suffered an extreme rain event with disastrous flooding in 2010, it developed a Climate Adaptation Plan, but it wasn't until after 2011, when two back-to-back cloudbursts caused damages worth between 5 and 6 billion Danish krone, that the City developed their Cloudburst Management Plan and funded the first set of pilot projects that it proposed[14].

something from eco-engineering article here

In our present crisis, the climatic stasis that our infrastructure has been designed for is in a state of complete upheaval at the same time as it is also in need of replacement. This presents at minimum an opportunity and at maximum an imperative to intervene. We must reconfigure our infrastructure systems to return the capacity for flexibility and dynamism afforded by the presence of water and the landscapes it engenders as urban adaptation to the effects of climate change and increase resilience to extreme events.

Figure 1.4: Severe flooding on the streets of Copenhagen, Denmark.

GREEN INFRASTRUCTURE and LOW-IMPACT DEVELOPMENT

Green infrastructure and other innovative water management strategies hold great promise for addressing some of the aforementioned compounding challenges simultaneously - of designing flexibility, adaptability, and therefore resiliency, back into urban environments as a climate adaptation strategy that also improves urban quality of life.

As first described in the text *Green Infrastructure: Smart Conservation for the 21st Century,* Benedict and McMahon define green infrastructure as "an interconnected network of green space that conserves natural ecosystem values and functions and provides associated benefits to human populations"[15]. The term green infrastructure as defined here emphasizes areas of open spaces or natural areas that are interconnected and managed intentionally for their inherent benefits to people as well as the environment.

The US Environmental Protection Agency defines green infrastructure in more narrow terms as a natural-systems approach to water utilities, focusing more specifically on the urban hydrological issues it can address[16]. Often referred to as green stormwater infrastructure (GSI), this is in contrast to traditional mono-functional gray stormwater infrastructure.

Similarly, LID, or low impact development, offers a comprehensive, technology-based approach to managing urban stormwater, an "innovative, alternative approach that strategically integrates stormwater controls into multifunctional landscape features where runoff can be micromanaged and controlled at the source"[17]. In this approach, nearly every urban landscape or infrastructure feature, such as roofs, streets, parking lots, sidewalks, and green space, can be repurposed as multifunctional, incorporating the detention, retention, and filtration of water.

Figure 1.5 : High Point Redevelopment, a GSI project by SPU.

The main objective of this design approach is to mimic the pre-development hydrology of a site or area, restoring the balance between infiltration, storage, groundwater recharge, and evapotranspiration through the use of techniques that evaporate, filter, and detain runoff[17]. Replicating pre-development hydrology has been shown to produce significant positive effects on stream stability, habitat structure, base flows, and water quality in receiving waterbodies.[17] Water is managed in decentralized, small, cost-effective landscape features on a "local" scale, as opposed to the models of convention: large conveyances of water, typically concealed underground in piped systems, to large, centralized facilities for treatment. This is accomplished by reducing impervious surfaces, creating functional grading, open channel sections, and bioretention/filtration landscaped areas[17]. Bioretention areas include ponds, stormwater wetlands, sand filters, bioswales, and rain gardens.

The benefits of LID and GSI strategies are as numerous as the problems that impervious surfaces create. They improve water quality by capturing the initial flow of stormwater and minimize the accumulation of toxins flowing into waterways via ground filtration, act as a method of flood control, and can, if desired, restore the native vegetation of the region and increase biodiversity while simultaneously creating new habitat for other types of native biodiversity, such as insects and birds[18]. They disconnect impervious areas from downstream waterways, increase groundwater recharge, and protect natural wetland systems from storm events by reducing storm flow velocities as compared to pipe systems. Multifunctional landscaping elements also have lower capital costs than conventional piped systems[18].

Additional benefits of LID and GSI include the improved appearance of developed sites, the absorption of noise, providing a wind break, and reducing the urban heat island effect[19].

A broader concept of green infrastructure has evolved as it has been applied to urban environments. In a definition that applies to all scales and varieties of human settlements, Tzoulas et al. defines green infrastructure as comprising "all natural, semi-natural and artificial networks of multi-functional ecological systems within, around and between urban areas, at all spatial scales"[20].

In the paper "Urban Green Infrastructure for Climate Benefit: Global to Local", Nancy Rottle defines urban green infrastructure (UGI) as a set of five systems, social, biological, hydrological, circulatory, and metabolic, with the goal of demonstrating that appropriately designed and situated UGI interventions are multifunctional, capable of delivering overlapping benefits in several, if not all, of these aforementioned categories, similar to the way that intact ecological systems deliver multiple interrelated ecosystem services[21].

In the age of climate change, green infrastructure takes on ever greater relevance for its ability (in some cases) to both mitigate greenhouse gas emissions and serve as a set of adaptation measures to buffer against the impacts of climate change, such as increased precipitation, higher temperatures, air pollution, etc[21].

In terms of hydrological climate change impacts, green stormwater infrastructure (GSI) can be especially effective in adapting urban environments to storms of increasing frequency and intensity. By allowing rainwater to infiltrate

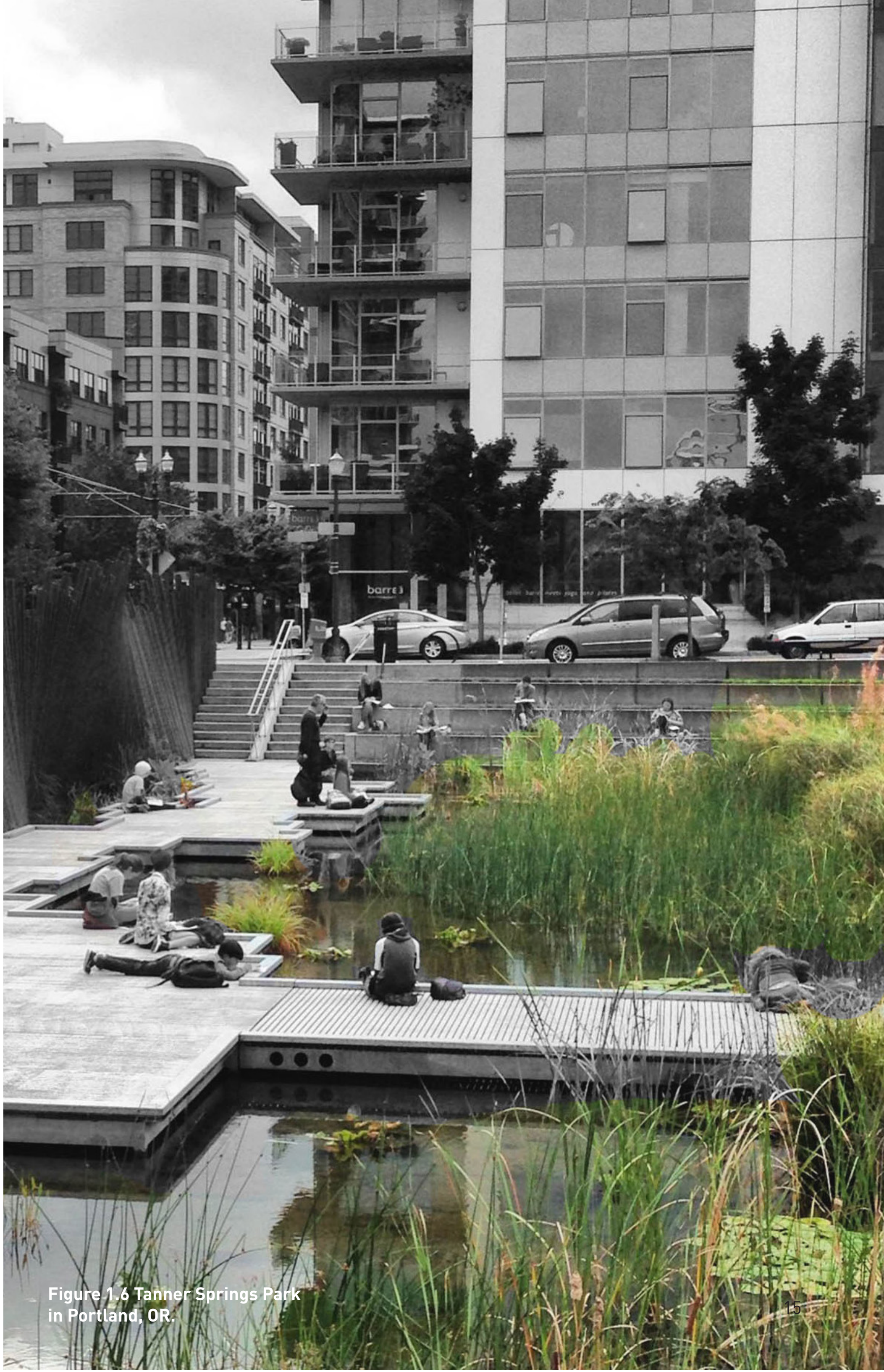


Figure 1.6 Tanner Springs Park in Portland, OR.

where it falls, GSI can help cities accommodate increasing precipitation volumes during storm events, reduce pollution to receiving waterbodies, and mitigate flooding. For example, a series of bioretention swales constructed by Seattle Public Utilities (SPU), a project known as SEA Streets, was found to reduce runoff by 99%, diverting pollutants that would otherwise be picked up from impervious surfaces from reaching Puget Sound[22]. Allowing runoff to infiltrate or to be retained for a period of time, rather than enter the sewer system, alleviates the pressure on this system and makes more space for excess flows in extreme storm events to avoid sewer backups and combined sewer overflows into waterbodies.
Green infrastructure is an effective approach in addressing myriad environmental problems, especially in urban environments. Floodable spaces, while certainly included within the category of green infrastructure, could be considered as representative of an approach that takes the concept a step further, in that it is a larger-scale intervention than a swale, rain garden, or bioretention planter, for example. This concept is explored in greater detail in the following section.

As a professional project for Seattle Public Utilities Drainage and Wastewater System Planning, this thesis makes the case for the utilization of a floodable public realm as a beneficial tool in the green infrastructure toolbox that can more effectively address the problems associated with urban flooding from increased precipitation as a result of climate change while simultaneously catalyzing multiple benefits for the community in which it is sited.

Figure 1.7

DEFINING **“FLOODABLE SPACE”**

“Floodable space” describes a wide variety of spatial interventions. For the sake of clarity, I define floodable spaces in this thesis as **designated areas that are intentionally designed with the capacity to periodically accommodate floodwaters in order to prevent flooding elsewhere, and that simultaneously accommodate other functions, such as usable open space.**

Floodable spaces offer many potential benefits as multifunctional space. Aside from their primary functions of mitigating flood risk while simultaneously providing open space, floodable spaces may, depending on their design, also improve water quality, mitigate the occurrence of combined sewer overflows, contribute to infiltration and groundwater recharge, create wildlife habitat, and make water a more visible component of the public realm, with the potential benefits of higher quality of life and for public exposure and awareness to be educational. Some floodable spaces receive surface water flows from their immediate surroundings to keep runoff from reaching the sewer or drainage system, while others may provide an above-ground stormwater storage facility and receive flows from the underground drainage system in a significant storm event. Some are dry the majority of the time, only taking on water in heavy events; others accommodate some amount of water at all times, but have the capacity to hold floodwaters from heavier, more extreme events as well. The case studies in the following section illustrate the variety of forms and functions that floodable spaces might take on.

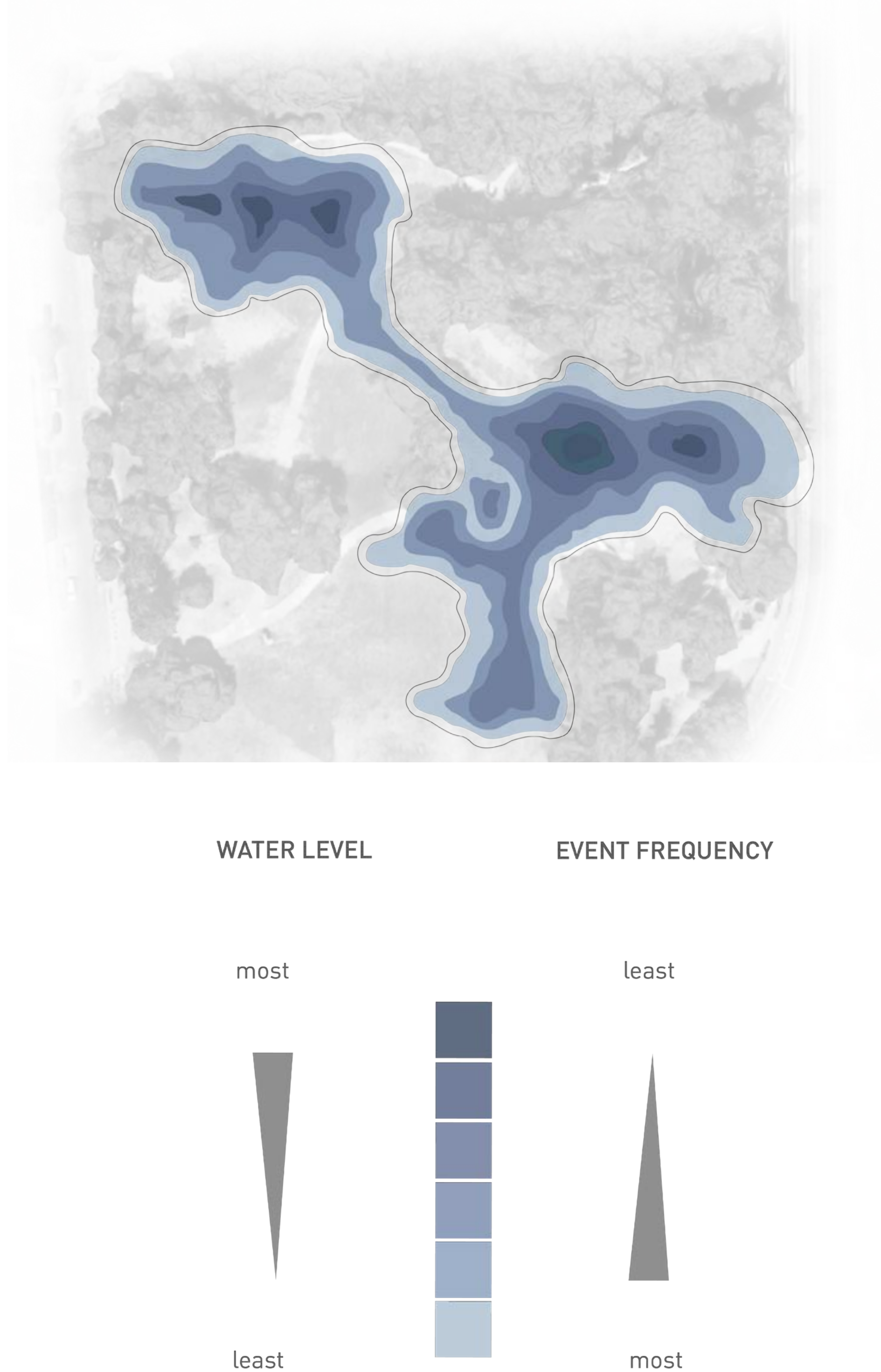


Figure 1.8

Copenhagen's Cloudburst Management Plan

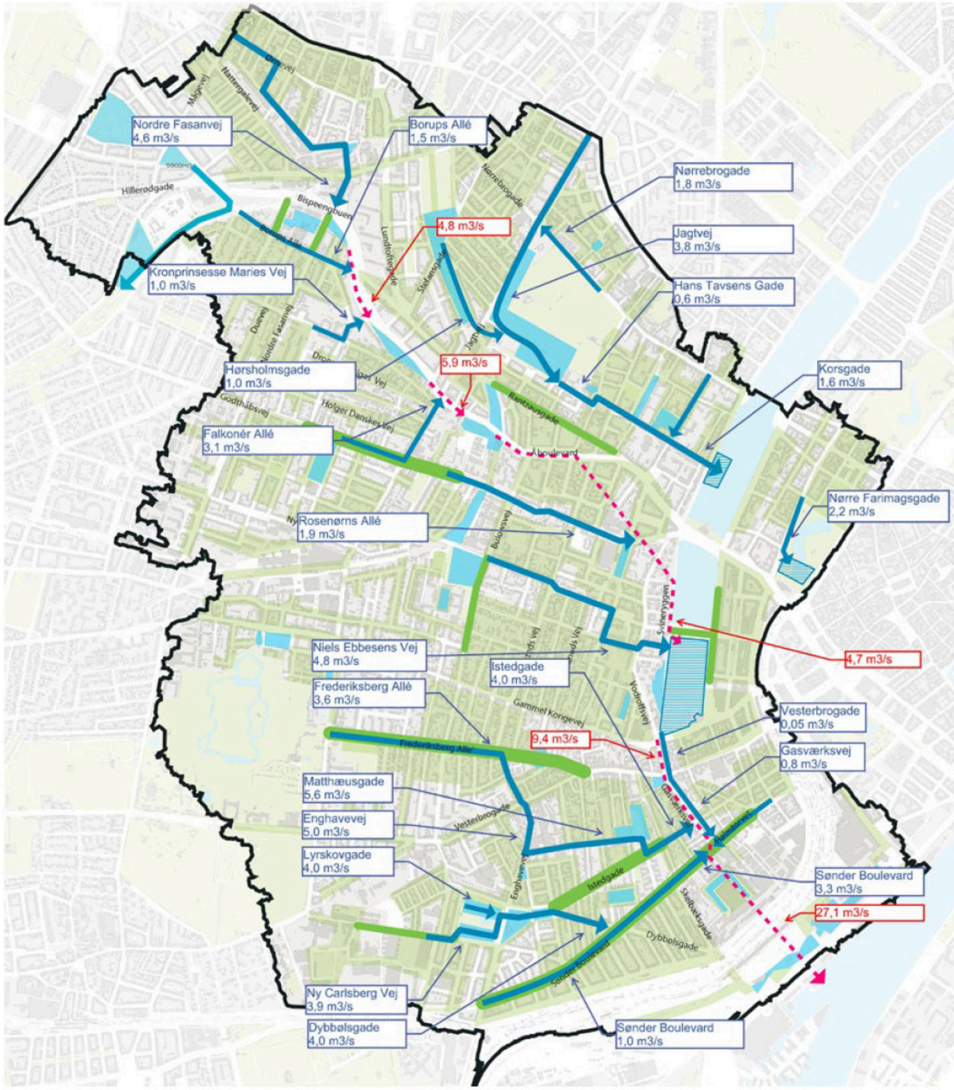
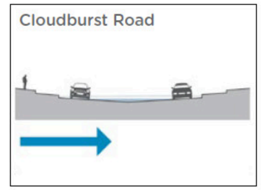
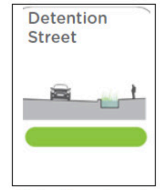


Figure 1.9: The Copenhagen Cloudburst Plan and Toolbox.

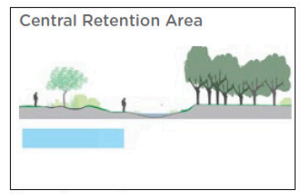


Cloudburst roads are used to channel and direct cloudburst water. These streets can be formed with a unique V-shaped profile and raised kerbs to ensure water will flow in the middle of the road, away from the buildings - contrary to standard engineering practice. Channels and swales can be established along road edges so that water runs in urban rivers or green strips. Cloudburst roads may also be combined with Cloudburst piping below the surface to create tool synergies.

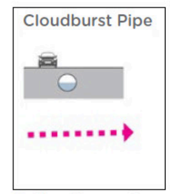


Detention streets are streets that are typically located slightly upstream of vulnerable low-points. In these streets there should be a detention volume established to handle stormwater before reaching the more vulnerable points downstream.

Green streets are proposed as upstream conections to all Cloudburst roads. The green streets should be established with a combination of small-scale channels and stormwater planters or permeable paving. Stormwater should be collected, delayed and then channeled towards the Cloudburst roads.



Central retention areas are proposed in the squares and parks where it is possible to delay stormwater, so that Cloudburst roads can be established in smaller dimensions. The central retention elements can be, for example, open depressions in the parkland or lowered seating areas. Alternatively, they can be established as underground storage such as soak-away crates or rain gardens. Central retention elements will typically be placed in connection with adjacent Cloudburst roads.



A Cloudburst pipe handles rainwater in the same way as Cloudburst roads. This is placed just below street level to ensure connection to other surface solutions. This solution is used if there is no useable space for aboveground solutions.

Location: Copenhagen, Denmark

Published in: 2012

Created by: City of Copenhagen & Ramboll

Copenhagen's Cloudburst Management Plan engages adaptive measures that mitigate pluvial flooding while also making the city more green and blue by managing rainwater at the surface. The plan came in response to a devastating series of storms between 2010 and 2011 that cost the city 3.8 billion Danish Kroner in damages. The projects realized as a result of the plan will prepare the city for 100-year storm events, whereas the existing sewer system is only capable of handling 10-year storm events.

The goal is to plan for and invest in actions that both protect the city from extreme flood events and relieve pressure on the sewer system during regular rain events. Ideally, urban flood adaptation measures will involve solutions that make the city greener and bluer by draining rainwater at surface level.

Implementation is estimated to cost 5-6 billion Danish Kroner, but given the cost of damages from the aforementioned events, "recommendations point to using the money on preventing floods rather than on repairs once the damage has been done"[14].

In light of climate change, Copenhagen is expected to see more storms of this scale, more frequently, in the future. The Danish Meteorological Institute defines an extreme rain event as 15 mm of rainfall within a 30-minute timeframe.

As a coastal city, Copenhagen must also contend with the prospect of rising seas. In combination, these two scenarios present enormous challenges, and the interventions designed to address them will need to vary from from area to area in adaptations that are context-specific.

Based on detailed flood mapping and risk analyses, the Cloudburst Management Plan forms the basis for specific mitigation efforts as well as general city administrative planning. A partnership approach involving city administration, utility companies, and the public will be essential for successful implementation.

While surface solutions that can can catalyze multiple benefits are preferred, this is not feasible everywhere in Copenhagen. In the absence of opportunities to store water at the surface level, subterranean tunnel solutions will be utilized.

Originally, the plan recommended that rainwater be evacuated by draining it to places where flooding would cause minimum disruption, such as parks, sports grounds, and open spaces, with the idea that these floodable spaces would store water until the drainage system had recovered capacity to receive these flows.

However, subsequent extreme rain events and calculations have shown beyond question that this approach is inadequate to prevent pluvial flooding in certain areas of the city. New studies show that mitigation actions should include measures in which waters are led out to sea via roads, canals, urban waterways, and subterranean tunnels as well. However, the potential environmental impacts of this approach have not been studied.

Flood mitigation strategies and city districts were prioritized by taking both flood risk and the potential for synergies with other projects such as road renovation, new urban development, etc. into account. Essential factors considered include areas with high flood risk, areas in which adaptation measures would be easy to implement, and areas where pluvial flood waters could be drained to localities where they won't cause damages, such as adjacent to the harbor.

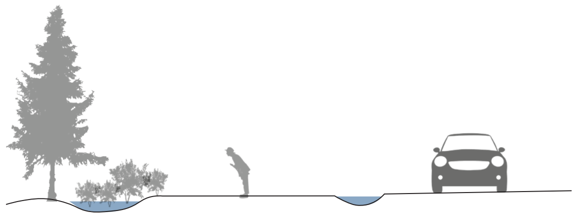
Ongoing development or renovation projects that could be done in conjunction with flood adaptation projects were also taken into consideration, as well as areas where synergistic effects could be gained. The city was divided and prioritized by water catchment area, after which each area was assessed for risk, potential for implementation, coherence with ongoing urban development projects, and synergistic effect. Each basin received a weighted ranking, with solutions that allow for multifunctional spaces that involve green recreational space being preferred where possible. Over 300 citywide pilot projects have been identified[14].

What can the City of Seattle learn?

SPU has recognized the need for planning efforts like Copenhagen's Cloudburst Management Plan to address the myriad challenges of urban water management in the age of climate change, as reflected by the Integrated System Plan. However, as Seattle is about ten years behind Copenhagen in their planning process[25], there are lessons to be learned in terms of plan evolution over time. The Cloudburst Plan's recommendations were revised when studies of more recent storm events revealed that the original, strictly surface solutions approach would be insufficient, and subterranean solutions would be necessary to address the scale of the problem. In this way, Copenhagen took advantage of extreme events that transpired after the plan was drafted, leveraging them to recalibrate their recommendations and impress upon city administration and the public that there is a dire need for a flood mitigation plan at a time when destructive flooding was fresh in people's minds. For Seattle, this is a lesson on the merits of structuring the plan as an open, evolving entity that exists in an iterative relationship with pilot projects and recent analyses that can help to continually improve and refine its capacity to address the challenges of an uncertain future.

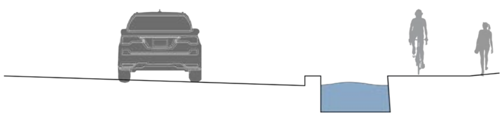
Figure 1.10: Tasinge Square, one of the first projects built as part of the Cloudburst Management Plan.

Green Street



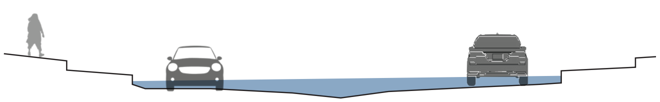
Green streets are proposed as upstream connectons to all Cloudburst roads. The green streets should be established with a combination of small-scale channels and stormwater planters or permeable paving. Stormwater should be collected, delayed and then channeled towards the Cloudburst roads.

Retention Street



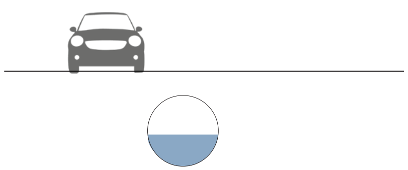
Retention streets are streets that are typically located slightly upstream of vulnerable low points. In these streets there should be a detention volume established to handle stormwater before reaching the more vulnerable points downstream.

Cloudburst Street/Blue Street



Cloudburst roads are used to channel and direct cloudburst water. These streets can be formed with a unique V-shaped profile and raised curbs to ensure water will flow in the middle of the road, away from buildings - contrary to standard engineering practice. Channels and swales can be established along road edges so that water runs in urban rivers or green strips. **Cloudburst roads may also be combined with Cloudburst piping below the surface to create tool synergies.**

Cloudburst Pipe



Cloudburst pipes handle rainwater in the same way as Cloudburst roads. **These are placed just below street level to ensure connection to other surface solutions.** This solution is used if there is no useable space for aboveground solutions.

Central Retention

Central retention areas are proposed in the squares and parks where it is possible to delay stormwater, so that Cloudburst roads can be established in smaller dimensions. The central elements can be, for example, open depressions in parklands or lowered seating areas. Central retention elements will typically be placed in connection with adjacent Cloudburst roads.

Figure 1.11: Cloudburst Toolbox Strategies

Benthemplein // Benthem Water Square

Figure 1.12: Benthemplein Water Square

Location: Rotterdam, Netherlands

Built in: 2013

Designed by: Studio Marco Vermeulen & De Urbanisten

The Water Square combines water storage with improvement in the quality of urban public space. It is the world's first largescale water plaza, offering rainwater storage at street level.

This approach renders the financial investment in technical infrastructure doubly valuable by creating opportunities to add environmental quality and identity to central spaces in neighborhoods while also providing sufficient water storage to address the impacts of climate change[23].

FLOODABLE SQUARE

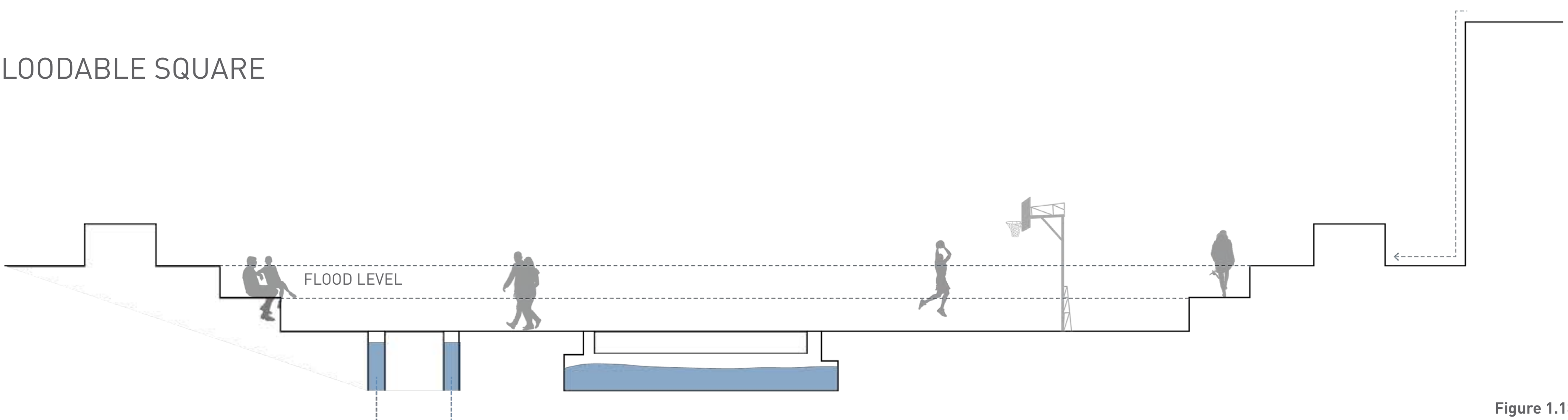


Figure 1.13

De Urbanisten first conceived of the water square typology in 2005 for the International Architecture Biennale Rotterdam "The Flood"[23]. Over the following two years, the group carried out what they labeled as "research by design" on the concept of a water square, after which it became official Rotterdam policy in 2007.

How it works/what it does:

Of the three main basins within the watersquare, two allow for infiltration and groundwater recharge, while the third holds water for a maximum of 36 hours before discharging. The design goal is to reduce the frequency of combined sewer overflow events during rainstorms. The hope is that "by separating storm water gradually from the black water system with each invention, the entire system step by step moved towards an improvement of the overall quality of open water in the city[23].

Most of the time, water square will be dry and in use as a recreational space to "sport, play, and linger"[23]. In heavy rainfall, however, collected rainwater will flow visibly and audibly into the watersquare from an identifiable point in its middle. The intention of the design is that the square will flood gradually. Additionally, rainwater is collected in separate clean water system from surrounding public spaces and roofs to the water square, where it will be held until it can be safely discharged into the nearest waterbody.

The designers engaged in a participatory process with the local community, holding three workshops to discuss possible uses, desired atmospheres, and how stormwater might influence the square. They found consensus around the idea that the square should be a dynamic place for young people with lots of space for play, but with space reserved for quiet, green, intimate places as well.

Another common desire was for water to be "excitingly visible"while running over the square," which manifested in the inclusion of a water wall and rain well[23].

What can the City of Seattle learn?

As land costs rise and water management challenges become more pressing, multi-use public spaces are increasingly a logical response. Designed in collaboration with local communities, municipalities may find park/infrastructure hybrids to be an economically, socially and ecologically viable option. This strategy could be considered as a potential CSO mitigation tool. In a more general sense, the principles behind this project align with DWW Integrated Planning efforts to plan future infrastructure investments that provide the greatest community value.

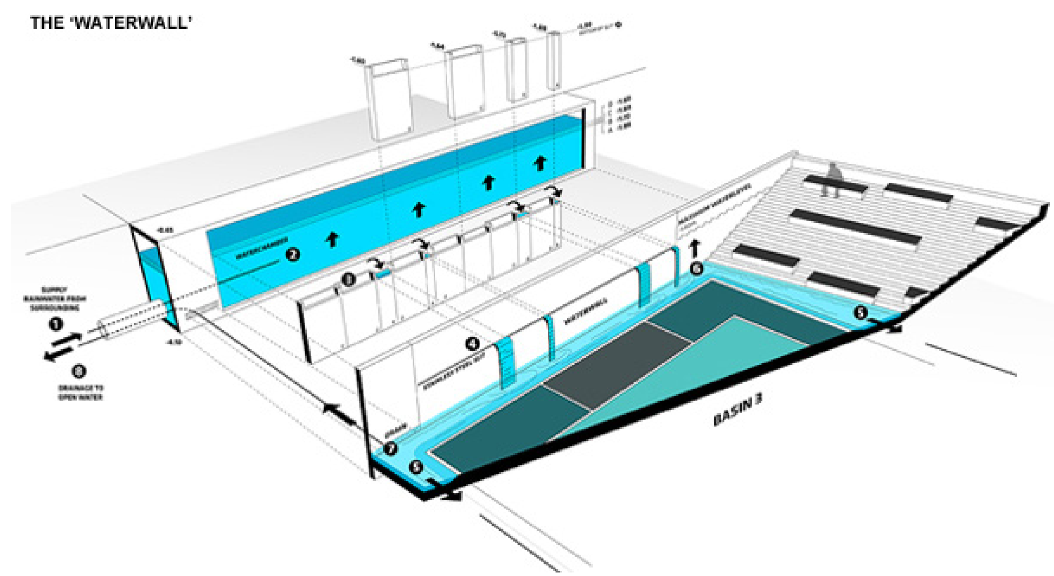


Figure 1.14

Hans Tavsens Park & Korsgade Street

Figure 1.15

Location: Copenhagen, Denmark

Design: 2016 - present

Designed by: SLA

SLA's winning proposal for the Nordic Built Cities Challenge, The Soul of Nørrebro, addresses today's water challenges through "a new model for city development"[24]. The design proposal presents a scalable framework based on co-creation with the community, dialogue, and a nature-based design approach to shared public space. It simultaneously addresses physical, social, and cultural challenges facing 21st century Copenhagen, and in this way, can serve as a model for many other cities today facing similar challenges. The Soul of Nørrebro proposal, which includes a redesign of Hans Tavsens Park as well as the connecting roadway of Korsgade, "uses nature to solve some of today's hardest urban challenges while increasing the life quality of people"[24].

Throughout its life, Hans Tavsens Park has served multiple needs, transforming from a plague cemetery to the city's first user park in the early 20th century. In this way, the

CENTRAL RETENTION // RETENTION STREET

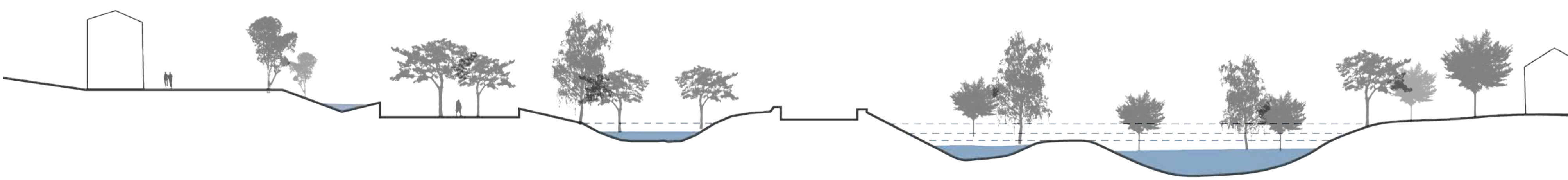


Figure 1.16

designers view a Hans Tavsens retrofit for climate adaptation as just another phase in the life of this **"chameleon-like" public space**[24]. The proposed design frames excess water as an opportunity rather than a problem, invoking a "new Nordic type of nature-based climate adaptation based on principles and processes of nature." City nature for climate adaptation creates the opportunity for "complementary solutions"[24]. Solutions include redirecting and containing cloudburst rainwater to avoid flooding and filtering both runoff and lake water while at once creating new, attractive, and more livable urban space, and improving neighborhood quality of life.

How it works/what it does:

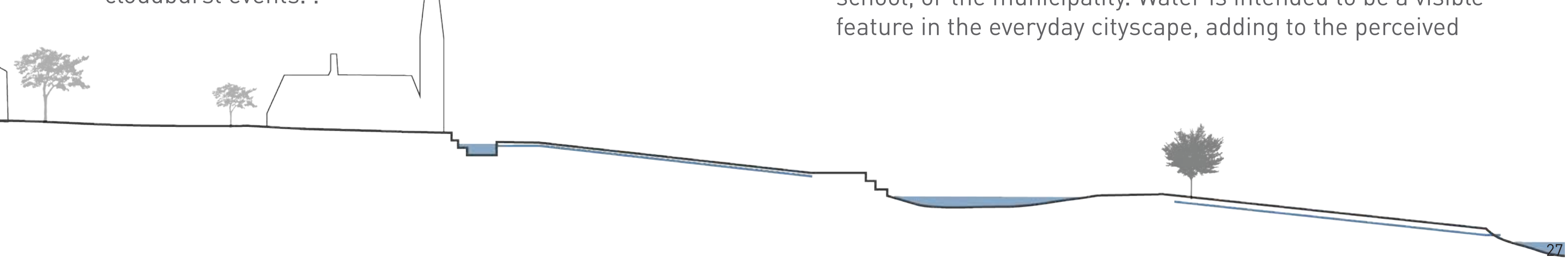
A central part of the design is the collection, cleansing, and reuse of rainwater, be it everyday rainwater or from cloudburst events, in the irrigation of the park's vegetation and the creation of new urban spaces. The park will be capable of retaining and delaying a total volume 18,000 cubed meters, collecting cloudburst water from higher ground and purifying it before it is discharged[24].

The storage volume is achieved by reprofiling the park terrain into a series of hills and depressions. In the western portion of the park, two areas with cleansing biotopes are established for the everyday rain, and an area that is primarily designed to receive rain from the upstream cloudburst plains, so that this rain can be delayed in smaller areas. Water is only intended to fill the larger areas of the park in extreme cloudburst events. .

The drainage to the park from the Nørrebro Park's cloudburst branch will occur through a proposed lowering and reprofiling of Jagtvej, outside Nørrebro Park School[24]. Excess water will be led down Korsgade through filtration biotopes to be cleaned before discharging into Peblinge Lake. Korsgade will be transformed to feature a rainwater element that will collect everyday rains from adjacent sidewalks and roads. This rainwater element involves a circular purification system that purifies both rain water and lake water before discharge, meandering between stepping stones and cleansing biotopes towards the lake. The street is also broken up by spaces with cobblestones that are intended help reduce vehicular speed[24].

In very large events, rainwater will be directed on the surface from the park through Hans Tavsens Street and Korsgade out to the lake. This function requires the re-alignment of these streets into a v-shaped profile including a gutter, a cloudburst road. This allows both the road and gutter to funnel water from these streets and other connecting streets out into the lake. Only in extreme events (1000+ event in current climate) is collected water not cleaned before being discharged. During dry periods, lake water will also be pumped through the biotopes to be filtered in a continually self-cleaning circuit.

Filtered runoff will be collected from roofs and stored in underground tanks to be used in the immediate vicinity of where it fell, either for irrigation by residents, by the adjacent school, or the municipality. Water is intended to be a visible feature in the everyday cityscape, adding to the perceived



value of the area while making new sources of water available for irrigation, improving the local microclimate, and creating a new series of public spaces. Increased rainwater volume is treated as a resource in the area's urban hydraulic cycle.

What can the City of Seattle learn?

This project is another great example that resonates with DWW Integrated Planning efforts to plan future infrastructure investments that provide the greatest community value. Hans Tavsens, Korsgade and the new space created at Peblinge Lake provide improved, connected urban spaces that simultaneously enhance quality of life and drainage function.

One important distinction between how Copenhagen frames this project's multiple benefits and how a municipality like Seattle might do so is in the treatment of such a project's capacity to "increase the value of the area". With affordability becoming an ever greater concern in Seattle, rather than touting the ability of a such a project to increase a neighborhood's value, Seattle's approach would necessitate a set of anti-displacement strategies to accompany such urban improvements, especially in neighborhoods that are home to the most disadvantaged and vulnerable members of our city's population.

The diagrams illustrate the distribution of the rain water in different rain scenarios.

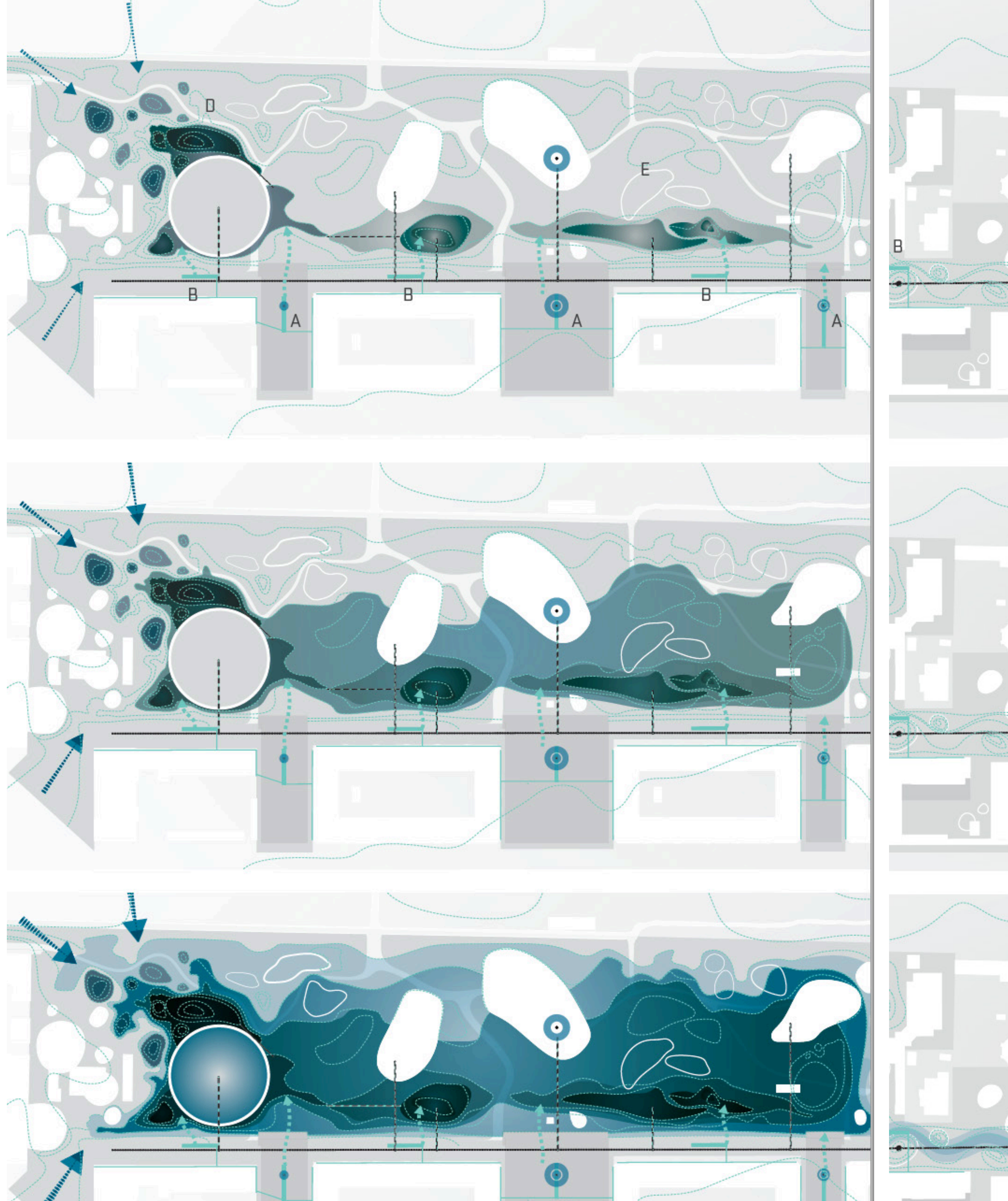
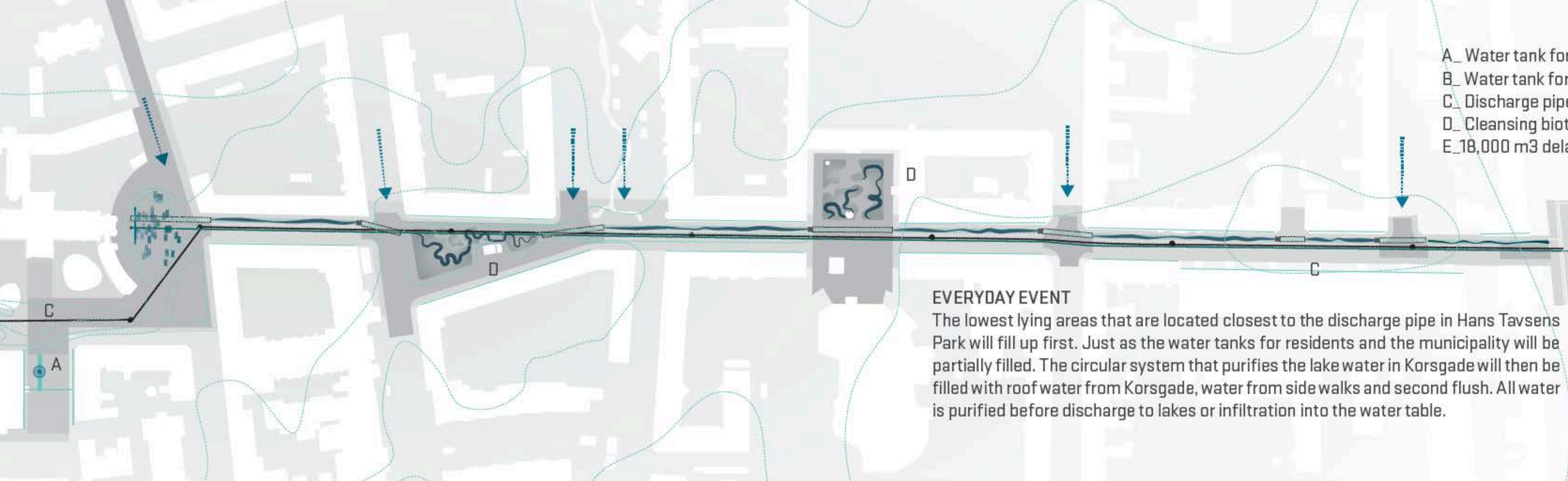
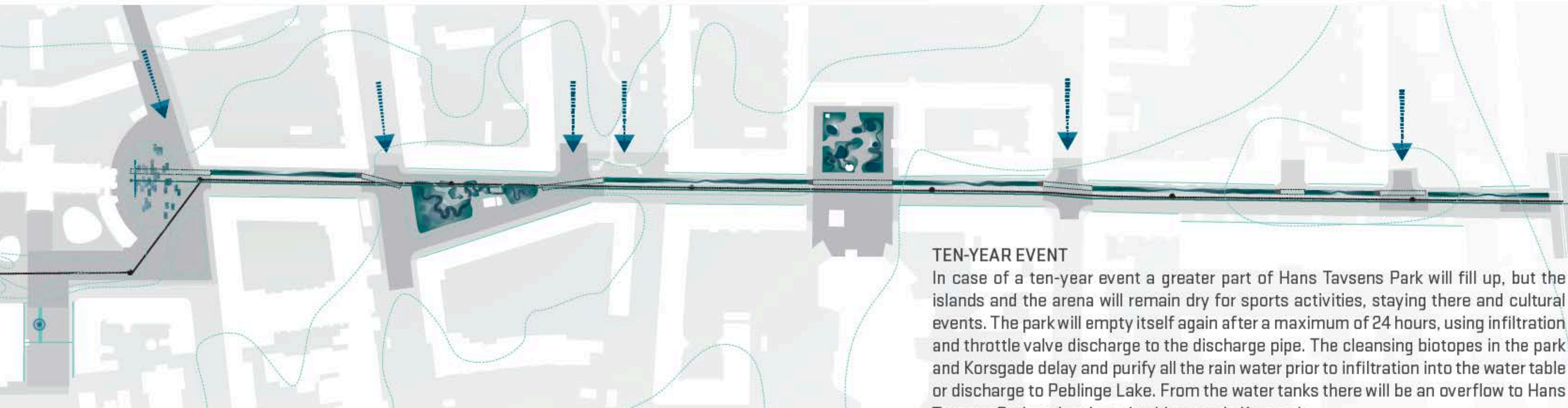


Figure 1.17



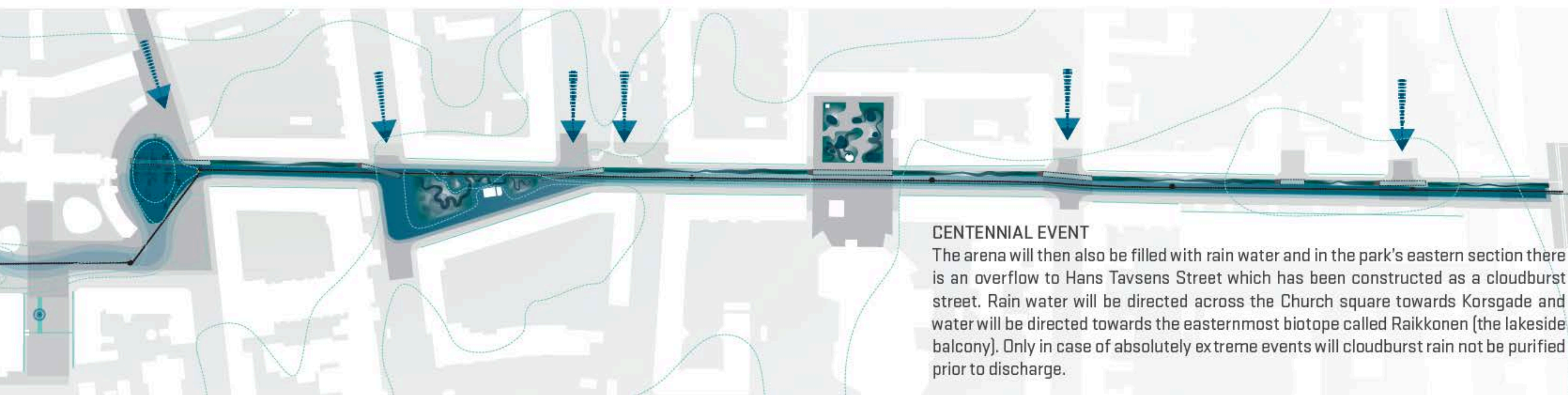
EVERYDAY EVENT

The lowest lying areas that are located closest to the discharge pipe in Hans Tavsens Park will fill up first. Just as the water tanks for residents and the municipality will be partially filled. The circular system that purifies the lake water in Korsgade will then be filled with roof water from Korsgade, water from side walks and second flush. All water is purified before discharge to lakes or infiltration into the water table.



TEN-YEAR EVENT

In case of a ten-year event a greater part of Hans Tavsens Park will fill up, but the islands and the arena will remain dry for sports activities, staying there and cultural events. The park will empty itself again after a maximum of 24 hours, using infiltration and throttle valve discharge to the discharge pipe. The cleansing biotopes in the park and Korsgade delay and purify all the rain water prior to infiltration into the water table or discharge to Peblinge Lake. From the water tanks there will be an overflow to Hans Tavsens Park or the cleansing biotopes in Korsgade.



CENTENNIAL EVENT

The arena will then also be filled with rain water and in the park's eastern section there is an overflow to Hans Tavsens Street which has been constructed as a cloudburst street. Rain water will be directed across the Church square towards Korsgade and water will be directed towards the easternmost biotope called Raikkonen (the lakeside balcony). Only in case of absolutely extreme events will cloudburst rain not be purified prior to discharge.

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2 Literature Review

The analysis and conceptual design presented in this thesis is grounded in a body of literature on topics and theories such as environmental planning, landscape urbanism, flood resilience, and multifunctionality in the urban environment. The ideas and concepts discussed herein serve to inform the development of a framework for citywide analyses to identify priority locations for floodable spaces in Seattle, as well as a neighborhood-specific application of the concept to a particular locale.

Environmental Planning: Design with Nature

Environmental Planning facilitates decision-making about land development that takes environmental, social, political, and economic factors into consideration with the goal of developing a holistic framework that acheives sustainable outcomes[1]. 20th century landscape architect Ian McHarg was one such proponent of a more environmental approach to planning, arguing that development should not occur like "wallpaper…unrolled on the landscape", without regard for landscape features and processes, but rather in response to them in order to maximize societal benefits[2]. His 1969 text *Design with Nature* was a widely influential work, the principles of which can be found in fields and applications from coastal zone management to environmental impact assessments, brownfield restoration, river corridor planning, community development, and zoo design[3]. *Design with Nature* argues that modern human settlements should be planned and organized in accordance with natural process, and proposed a system of landscape and land use analysis that has influenced both the philosophy and methodology of this thesis.

Through case studies, McHarg demonstrates how and why natural processes must be considered in planning processes, as "changes to parts of the system affect the entire system… natural processes do represent values and…these values should be incorporated into a single accounting system"[2].

By integrating the natural sciences into planning, expanding the view of an area under study to include a "layer cake" of geological, hydrological, ecological, and biological factors and interactions, in addition to the typical social and economic considerations, a more holistic picture of suitability comes into view[2]. This allows for more advantageous uses, adjacencies, and synergies to be created. With regard to the positioning of open spaces within development, McHarg advocates for the identification of "discrete aspects of natural processes that carry their own values and prohibitions… it is these that should provide the pattern, not only of metropolitan open space, but also the positive pattern of development…nature performs work for man - in many cases this is best done in a natural condition - further that certain areas are intrinsically suitable for certain uses while others are less so"[2].

Just as the physical realities that govern the functioning of the planet have not changed, McHarg's proposed approach to planning and development remain relevant. However, in the fifty years that have passed since the writing of this book, examples of irresponsible development in the United States abound. The challenges of the 21st century, especially in the urbanized environment, demand a strategy that shares these philosophies, but takes a more intensive approach to planning in which natural process must be reintroduced or reclaimed rather than simply maintained or preserved.

Landscape Urbanism

Other, more recent theories about the organization of urban form bear the influences of the principles laid out in *Design with Nature.* In *Landscape as Urbanism,* Charles Waldheim posits that the best way to organize cities is through the design of the landscape, rather than through the design of its buildings. This represents a theoretical frame in which landscape "supplants architecture's historical role as the basic building block of urban design[4]. Similarly, Landscape architect Elizabeth Mossop writes that "the most permanent and enduring elements of cities are often related to underlying landscapes - geology, topography, rivers, harbors, climate - and this suggests there should be a relationship between the underlying structures (topography, hydrology) and the major structuring elements of urban form, such as the use of catchments as the basis for physical planning and regulation"[5]. In their text *Green Infrastructure: Smart Conservation for the 21st Century, Benedict and McMahon* propose green infrastructure in urban or suburban settlements as capable of providing a framework for growth in which such spaces are designed to shape urban form and determine the most logical areas for development vs. those best preserved and maintained for ecological functionality[6].

However, the structure of urban form that these voices advocate for conjures an image of a undeveloped landscape on which a city has not yet been built. In practice, to apply these concepts requires a re-organization of urban systems already in place.

In *Landscape as Infrastructure,* landscape architect and urban planner Pierre Belanger proposes the concept for which the essay is named, arguing that the way we think about landscape should be reframed as a "sophisticated, instrumental system of essential resources, services, and agents that generate and support urban economies"[7]. Arguing for a decentralized, regional, synergistic approach in which "the urban-regional landscape should be considered as infrastructure," Belanger asserts that **phenomena such as eutrophication, combined sewer overflows, sediment contamination, water shortages, and seasonal flooding "can no longer be perceived as isolated incidents but rather as part of a large, constructed hydrological ecology that is entirely and irreversibly connected to the process of urbanization"[7].** A re-examination and re-organization of resource flows at the scale of the landscape-organized region, such as a drainage basin, for example, can create "new efficiencies and new spaces" when urban systems are designed to be"tightly integrated into regional land-based resources"[7]. In this way, Belanger argues landscape-based strategies have the greatest potential to solve multiple urban problems simultaneously.

In *Landscape as Urbanism*, Charles Waldheim holds up landscape as the medium most relevant to and capable of addressing 21st century urban problems[4]. He defines landscape urbanist practice, a relatively new theory of urban planning, as one that rejects the "camouflaging of ecological systems within pastoral images of "nature"' and states that instead, the practice "recommends the use of infrastructural systems and the public landscapes they engender as the very ordering mechanisms of the urban field itself, shaping and shifting the organization of urban settlement..."[4]. He offers this new theory of landscape urbanism as a medium through which ecological performance as well as the creation of lively public space can be accomplished.

Such ideas support the case for a city structure that reflects the inherent values represented by landscape processes, values derived from the functions they perform, such as the management of surface water. While development has already been "unrolled like a wallpaper...on the landscape" in many American cities, reconstructing or re-introducing elements of landscape form and function represents a logical adaptation strategy to the changing physical conditions of modern times[2].

A 'landscape first' approach has the potential to make our cities more resilient to flooding while also affording a multitude of other side benefits when applied to urban water management. In the words of Ramboll, an engineering, design and consultancy company founded in Denmark, "Hydraulics rule - stormwater management is the backbone of urban planning"[8]. This statement might be revised for an American context to read, "stormwater management can be and should be the backbone of urban planning as a 21st century adaptation strategy." As many cities around the world have found, multifunctional public spaces integrated with water systems, including floodable spaces, offer elegant solutions to the challenges that climate change presents to urban environments.

A Multifunctional Public Realm

Public space has long played a critical role in urban life, often acting as a structuring layer of urban form, creating the central identity of a city. Public spaces, depending on their design and context, enable spatial continuity and legibility of a cityscape, reinforce societal norms, and serve as venues for the exchange of ideas[9]. These are spaces in which "the tension between the physical proximity and moral remoteness of city dwellers"[10] is on display, where the diversity inherent to urban life can mix and cross-contaminate, places that enable community life, "offering services with wide-ranging benefits with tangible and intangible values"[9].

Often designed to be flexible, adaptable, and multi-functional, a number of characteristics typical of urban public spaces lend themselves particularly well to a new type of multi-functionality: **as spaces for flood resilience as a climate adaptation strategy.** The incorporation of flood resilience measures into urban public space offers myriad potential benefits, such as increased financial and spatial efficiency, connectivity, quality of life improvements, risk diversification, and opportunities for education and engagement. Each will be explored further in this section.

Spatial/Temporal and Financial Efficiency

While public spaces are an integral part of the urban experience, rapid urban expansion can work against cities' best efforts to preserve or acquire them[11]. Meanwhile, the necessary replacement of aging, mono-functional grey water infrastructure is increasingly costly (Center for Sustainable Infrastructure). In their paper "Urban Floods and Climate Change Adaptation: The Potential of Public Space Design When Accommodating Natural Processes", Maria Matos Silva and Joao Pedro Costa argue that grey drainage infrastructure, such as large, out-of-sight subterranean retention tanks, are only useful occasionally during the year in times of significant rain events[13]. However, other flow control measures, such as bio-retention basins, rain gardens, or other visible surface solutions, while still serving their primary function, can also be utilized as public recreational space that is available for year-round use[13]. Such doubling of functions should be considered when accounting for the increasing costs of repairing and upgrading existing grey infrastructure assets, especially to upsize those systems in response to the projected effects of climate change[13]. In cities that are becoming increasingly privatized, expensive, and dense, there is an argument to be made for the integration of flood resilience infrastructure, a cost which cannot be avoided, with a functionality such as public open space that can provide benefits to the community full-time.

Aesthetic and Quality of Life Improvements

To the extent that multifunctional public spaces incorporating flood resilience strategies feature natural green infrastructural elements such as vegetation, a range of aesthetic and public health benefits can also be afforded. This further contributes to the overall value of flood-adapted public spaces. An incontestable of research now attests to the human benefits of nearby nature in urban environments[14]. Time spent in or observing nearby nature and green spaces has been found to relieve stress, alleviate mental fatigue, increase attention capacity, and decrease the severity of symptoms in those suffering from depression, Attention Deficit Disorder, etc., just to name a few[14].The community benefits of green infrastructure in the public realm also include improved walkability and traffic calming, less property crime, and contributions to place identity, all of which improve overall urban quality of life[15].

Connectivity

Both water infrastructure systems and public spaces often consist of an extensive physical network (third Silva paper), a commonality that, if unified, can catalyze more benefits than in isolation. Elizabeth Mossop writes of “an obvious synergy between the need to create networks of open space to serve social needs and new approaches to open systems of urban water management[5]. An oft-noted, although older, example of such a synergy is the Emerald Necklace in Boston, designed by Frederick Law Olmsted and Charles Eliot in the 19th century, in which a connected network of pathways and parks also functions as a stormwater detention system that addressed significant drainage and water quality issues caused by urbanization while simultaneously addressing the need for better leisure and recreation opportunities for a growing population[16].

As primary causes of urban floods can often be attributed to the fragmentation of natural watersheds, which in their unaltered state function as a single interacting system, it follows that to return the system to a state of interconnection will contribute to the flood resilience of urban landscapes[9].

While it is not always the case that public spaces are interconnected, those that are interconnected offer the opportunity for increased physical activity and well-being among urban dwellers in the form of trails, paths, or bike routes[14], which add to the livability and desirability of urban environments[17]. Networks of open space also hold the potential to function as habitat corridors for urban biodiversity, the likes of which are far better served via connected spaces than fragmented ones[18]. Silva states that “public space offers the advantage of a decentralized and expansive means to tackle flood management”[13]. The potential synergies between water systems and open space systems offer an argument for creating linkages between fragmented public spaces in the urban environment, perhaps catalyzed by, for example, a need to overhaul an aging drainage system in a given area.

Risk Diversification

Another beneficial aspect of integrating the extensive physical network of flood management infrastructure with public spaces is risk diversification - by investing in adaptation strategies in the public realm that supplement traditional mono-functional approaches, the risk of failure is dispersed across redundant systems, reduced overall[9]. This is in contrast to a single, centralized, mono-functional infrastructural component, such as, for example, a single wastewater treatment plant that serves an entire city. Should it fail, the consequences are far greater than that of a more distributed, redundant, and resilient system.

Opportunities for Education, Exposure, Awareness, & Engagement

The integration of flood resilience strategies into visible public spaces, as opposed to disguised underground, out of sight and out of mind, creates an opportunity for a publicly funded asset to be exposed and shared, generating a greater public awareness around the presence of water in cities[19]. When infrastructure is hidden, its existence is often forgotten or taken for granted by the majority of the population, and thus, any failure of this system will be largely unanticipated by the public. The invisible nature of critical infrastructure can often lead to a false sense of safety[19].

By contrast, solutions in the public realm can improve awareness around temporal urban water cycle dynamics and improve understanding of the potential for risk, as well as generate greater awareness around local impacts of climate change[19]. The public visibility of flood management infrastructure may also serve to promote "a certain sense of responsibility and appropriation" should the public grow to feel an attachment to such spaces[19]. A sense of attachment and responsibility for one's community spaces, and hopefully by extension, one's neighbors, is an essential aspect of a resilient community[20].

Opportunities for Interdisciplinary Designs & Integrated Solutions

The challenges presented by climate change, population growth and urbanization are increasingly forcing flood management strategies to move beyond the siloed approaches of the previous century and take interdisciplinary approaches to urban infrastructure challenges. A naturally arising benefit of this reality is that, in general, the more interdisciplinary and integrated the planning and design process is for a given intervention, the more likely it is to feature multiple functions[9].

An integrated planning and design process that involves multiple stakeholders, as well as one that centers public collaboration and engagement, can foster attachment, emotional connection, and a sense of responsibility. In this way, responsibilities around risk, management, and monitoring of flood resilient public spaces can be shared. This is in contrast to a more traditional management style in which a governmental entity carries out actions on behalf of the public with differing degrees of community involvement in the process[19]. This approach proved to be highly successful in the design and implementation of Benthemplein Water Square, in which concerns about the presence of surface water in the urban environment were quelled through a deeply participatory process with the local community, incorporating commonly held desires into the final design[21]. For a concept like a floodable public realm, which has the potential to cause safety concerns, cultivating public understanding through participation is crucial.

Conclusion

The potential inherent in utilizing the landscape as an organizing unit of urban form and the myriad benefits considered possible by building multifunctionality into the public realm not only make the case for the integration of public open space and water infrastructure, but also offer a scaffolding upon which to build a framework for citywide analysis. The theories presented here serve to broaden the scope of my analysis beyond how SPU defines "priority" locations for floodable spaces.

In the following section, I apply principles of landscape urbanism and environmental planning as a significant part of my process through a physical analysis of Seattle's landforms and historical watercourses, seeking to identify opportunities to reshape urban form around water and watery landscapes.

The potential benefits discussed in this section are translated into a spatial inquiry that explores opportunities to support financial efficiency, collaboration with other organizations or partners, and opportunities for connectivity, aesthetic and quality of life improvements. The goal is to identify locations in Seattle that are not only high priority or physically suitable for floodable spaces, but also show significant potential to catalyze benefits beyond flood resilience, and thus, demonstrate how the potential of the concept might be maximized for the greatest possible community benefit.

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3

CONTEXT and ANALYSIS: Seattle in the 21st Century

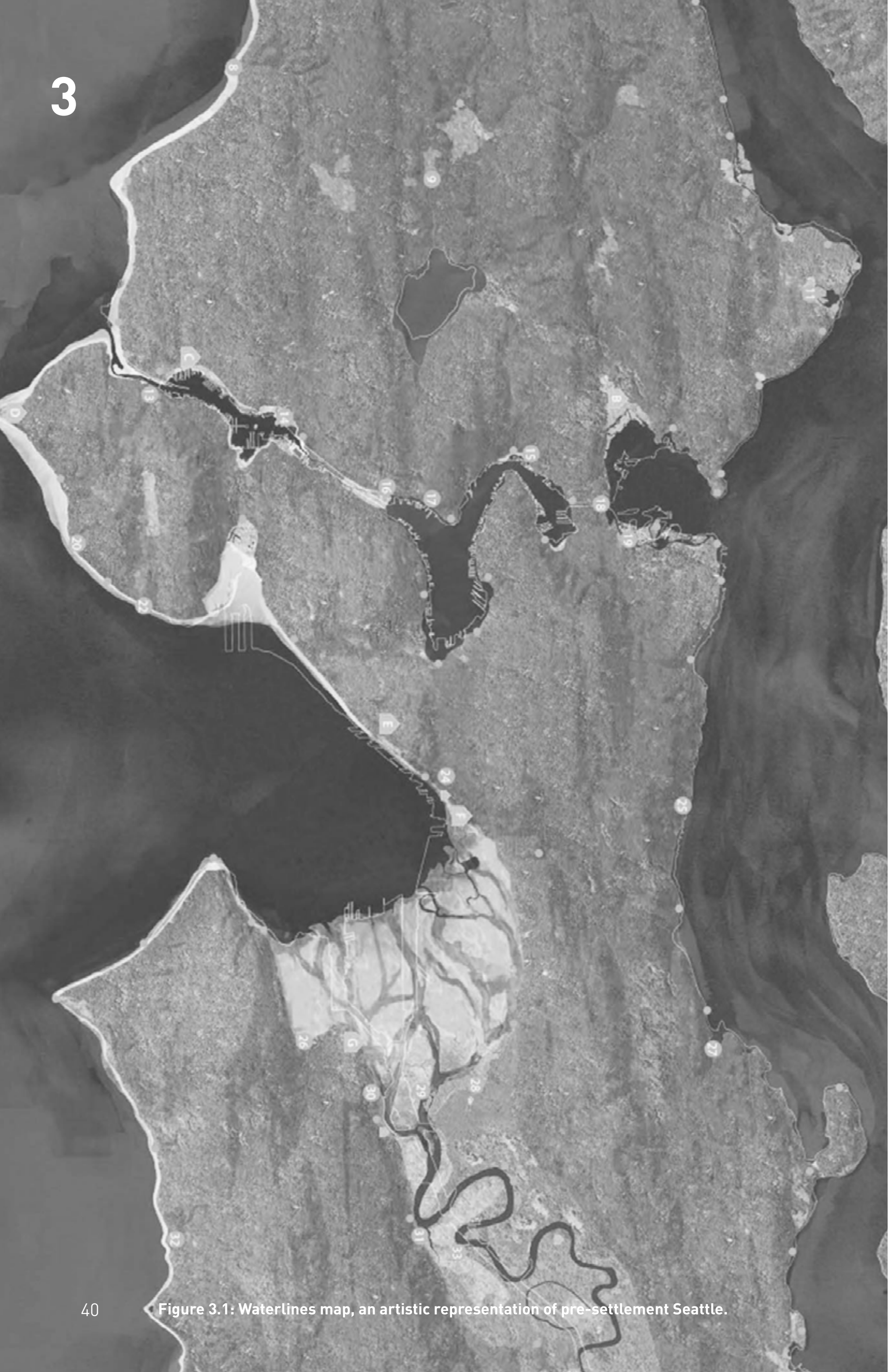


Figure 3.1: Waterlines map, an artistic representation of pre-settlement Seattle.

Figure 3.2: Seattle today.

Seattle is among the fastest growing cities in the United States. From 2008 to 2018, the city has added about 4000 housing units and an average of 7000 people annually[1]. In 2018, home prices grew by 13.61%[2], with the median single family home price reaching $777,000[3]. The Puget Sound population is expected to grow from 4.3 million in 2010 to 6.3 million in 2040[4]. The scale of this development is readily evident to the Seattleite: cranes dot the skyline, traffic has worsened, and single-family homes are replaced by increasingly expensive rows of townhouses at breakneck speed as neighborhoods are re-zoned to concentrate density[5].

Seattle is one of many cities worldwide that must reckon with population growth and increased urbanization while also anticipating the effects of climate change, simultaneous pressures that are unprecedented in scale and scope. In their report State of Knowledge: Climate Change in Puget Sound, the Climate Impacts Group at the University of Washington found that average temperatures in the Puget Sound region have increased over the course of the 20th century, with all but six of the years between 1980 and 2014 above the 20th century average, and projections indicating 21st century warming of at least double that of the 20th century[6]. Future incidences of heavy rainfall are likely to become more frequent and intense, and sea levels are to continue their rise, albeit with great local variability[6]. These impacts have implications for the snowpack and streamflow the region relies on for its water supply.

The Puget Sound region was built on the natural infrastructure supplied by mountain ranges that hold precipitation as snowpack, a reservoir which is released during the dry spring and summer seasons. However, this is changing with the onset of climate change: the snowpack of the Cascade mountains has already

Figure 3.3

Figure 3.3

decreased by 20% since the 1950s[6]. The impacts of climate change also have implications for the frequency and severity of landslides and the frequency and severity of flooding[6].

A report conducted for SPU utilizing 40 years of precipitation data colected at 17 stations reveals that within the City of Seattle, extreme rainstorms have increased in both frequency of occurrence and intensity of a given rain event, a trend that is expected to continue into the future[7]. As land uses that previously allowed rainfall to infiltrate into the ground are converted to the hard impervious surfaces of buildings, streets, and sidewalks, higher volumes of stormwater are conveyed to the drainage system[8]. SPU's drainage system was designed and built during a period of relative climate stability and lower total impervious land area, and it is probable that at least some components of the existing system, such as areas with an informal drainage system of ditches and culverts, will not be capable of accommodating these increasing flow volumes in their current state. If we continue to rely on infrastructure that reflects the relatively stable conditions of the recent past, this is likely to result in a range of adverse impacts, from exacerbated urban flooding problems to impaired water quality in already vulnerable receiving waters such as Lake Washington, Lake Union, or Puget Sound.

A second critical system shaped by the demands of a growing city are Seattle's parks and open spaces. In the words of Seattle Parks and Recreation's (SPR) Board of Park Commissioners, Seattle's parks and green space system is "essential civic infrastructure that contributes to the physiological, ecological, social, and aesthetic quality of our city"[1].

Research now corroborates the intuitive notion that parks are a crucial element in the preservation of the urban community's health, environmental stewardship, social cohesion, and sense of belonging[9]. As Seattle densifies, SPR has sought to maintain the city's high quality of life by setting standards around the proportion of park and open space acreage per resident, as well as for the maximum walking distance a typical resident should be from a park or open space.

In 2017, in response to population growth, SPR proposed to change the citywide acceptable guideline of 3.33 acres per 1000 residents to 8 acres per 1000 residents[1]. That translates into a need to acquire more parks and open space when and where possible, as well as to increase existing capacity[1]. However, the ever-increasing cost of land in Seattle makes these well-intentioned goals increasingly difficult to reach. SPR's Superintendent Jesus Aguirre has acknowledged that, like other expanding cities, Seattle must "think differently about how to create open space and grow our city's access to parks and recreation centers"[1].

In summary, in the near future, population growth and climate change projections indicate that there will be greater volumes of water to manage, and less resources in terms of space and capital with which to manage it. The same is true of the city's public realm, provided by city-owned parks and open space - these areas are becoming socially valuable at the same time as they become more difficult to acquire. Compounding pressures such as these present challenges as well as opportunities to planners, policy makers, and designers of Seattle's built environment, and require that those tasked with the organization and function of the city do more with less: simultaneous and overlapping challenges demand integrated solutions that work to yield multiple benefits at once.

Figure 3.4

PROJECT CONTEXT

Seattle Public Utilities (SPU) recognizes the interrelated challenges that lie ahead as well as the opportunities they represent. This is reflected in the organization's mission of serving as a community-centered utility with the central goals of achieving excellence in core service delivery, increasing affordability and accountability, improving investment value, enhancing public health and environment, ensuring service and racial equity and inclusion, and expanding impact through strong partnerships[10].

As a significant step towards becoming a community-centered utility, SPU's Drainage and Wastewater (DWW) Line of Business is developing an ambitious Integrated System Plan (ISP) which will yield a long-term vision for drainage and wastewater services in Seattle for the next 50 years[10].

The plan aims to address system needs while also providing the greatest possible community value[10]. Achieving such a goal necessitates utilizing essential infrastructure investments to catalyze multiple benefits for the City, such as climate resilience, equity, improved public health, improved aquatic health, and improved public space, accommodation of growth, and cost-saving partnerships[10]. The expanded set of issues that the plan aims to address is in contrast to past drainage and wastewater planning efforts by SPU, in which each was planned in isolation, with a primary focus on regulatory compliance, aquatic resource protection, and flood control[10].

Figure 3.5

CITYWIDE ANALYSIS: Identifying Priority Locations for Floodable Spaces

Through my role as an intern for SPU's DWW System Planning group, I chose to write this thesis in support of the Integrated System Plan, one component of which is the task to identify priority locations for floodable spaces and/or blue streets in the city.

This thesis explores how the concept of floodable spaces applied to the City of Seattle might yield the multiple benefits that the Integrated System Plan aspires to catalyze, and tests a methodology for how potential locations of such multifunctional interventions might be prioritized. In a city that is becoming increasingly dense and expensive, with climate change impacts looming, building multi-functionality into the urban environment, such as making more room for the presence of water, is becoming imperative.

Endeavoring to identify priority locations for floodable open spaces in Seattle involved asking a series of questions.

How is "priority" defined by SPU in this context? (WHY?)

In general, SPU priorities applicable to this analysis include addressing systemic racial and social inequities, addressing threats to human health and safety, and regulatory compliance[11]. Therefore, I first identified areas of the city that are home to the most vulnerable populations, areas of the city in which flooding is a known risk, has happened in the past, or is projected to happen in the future. This process revealed areas of the city that are in need of attention in one way or another.

What types of conditions make a given area suitable for a floodable space? (HOW?)

Once I determined which areas could most benefit from floodable spaces, the next step was to identify areas that are physically suitable for accommodating this function. To answer this, I conducted an analysis of the city terrain to locate low points, enclosed depressions, and flat areas - places where surface water would naturally collect. The locations of historical streams fit into this category as well.These locations indicate where water naturally flowed in the past, thus, depending on the situation, they may prove suitable for accommodating water in the future. Another crucial piece of information in relation to the underground network of pipes SPU operates and maintains - the drainage system. I identified points in the system where flows are converging or are of a higher volume, because these locations indicate places that could be under strain during an extreme storm event, and could perhaps be relieved by some water storage above ground (such as in the case of the Madison Valley Detention Facility, pictured here). Perhaps most essential was locating suitable land uses - such as existing parks and open spaces.

How might floodable spaces do more than solve a flooding problem?

SPU's goal is to become a community-centered utility. This would require utilizing infrastructure investments to bring multiple benefits to communities across the city. To determine how floodable spaces may provide multiple benefits, I identified ongoing projects, by SPU or another city agency, with which floodable spaces may be able to synergize, as well as areas where mutual needs may be met. Another aspect of determining the potential for multiple benefits is urban connectivity: are there areas of the city in which floodable spaces can provide connections between presently disconnected areas of open space, or, in the right-of-way, create separation between bikes and/or pedestrian traffic and vehicular traffic?

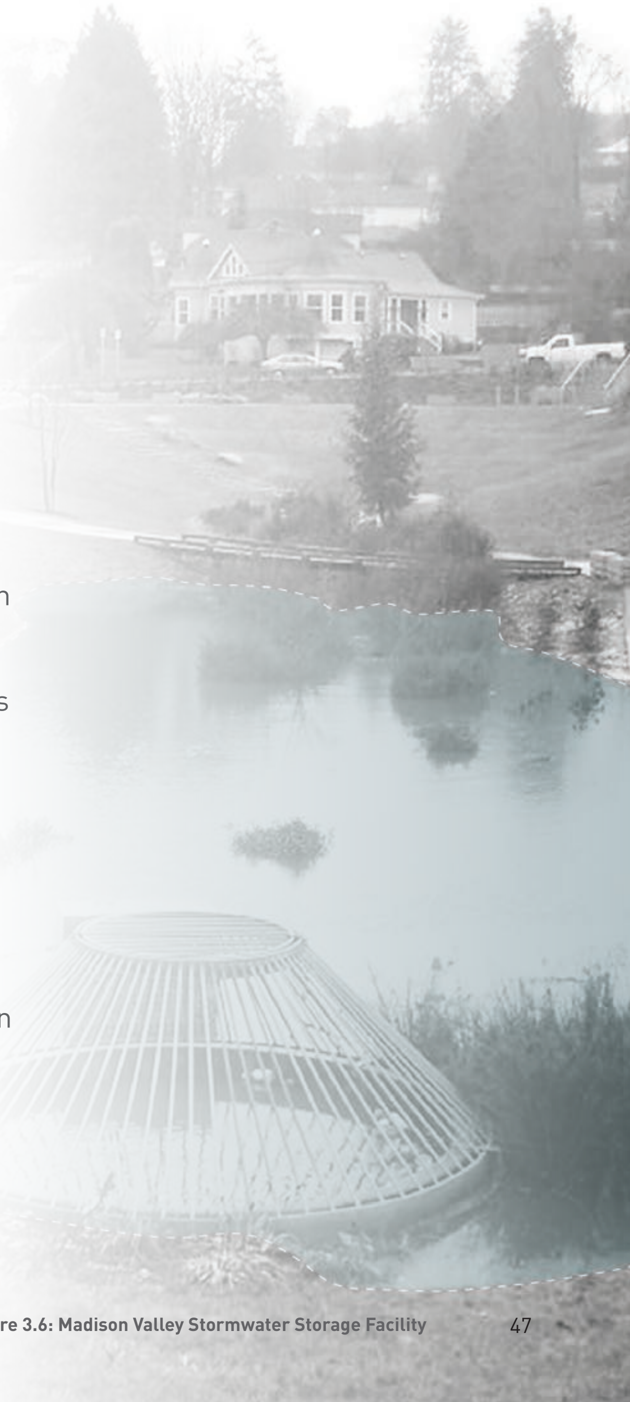


Figure 3.6: Madison Valley Stormwater Storage Facility

CITYWIDE ANALYSIS

Determining Priority Areas for Floodable Spaces

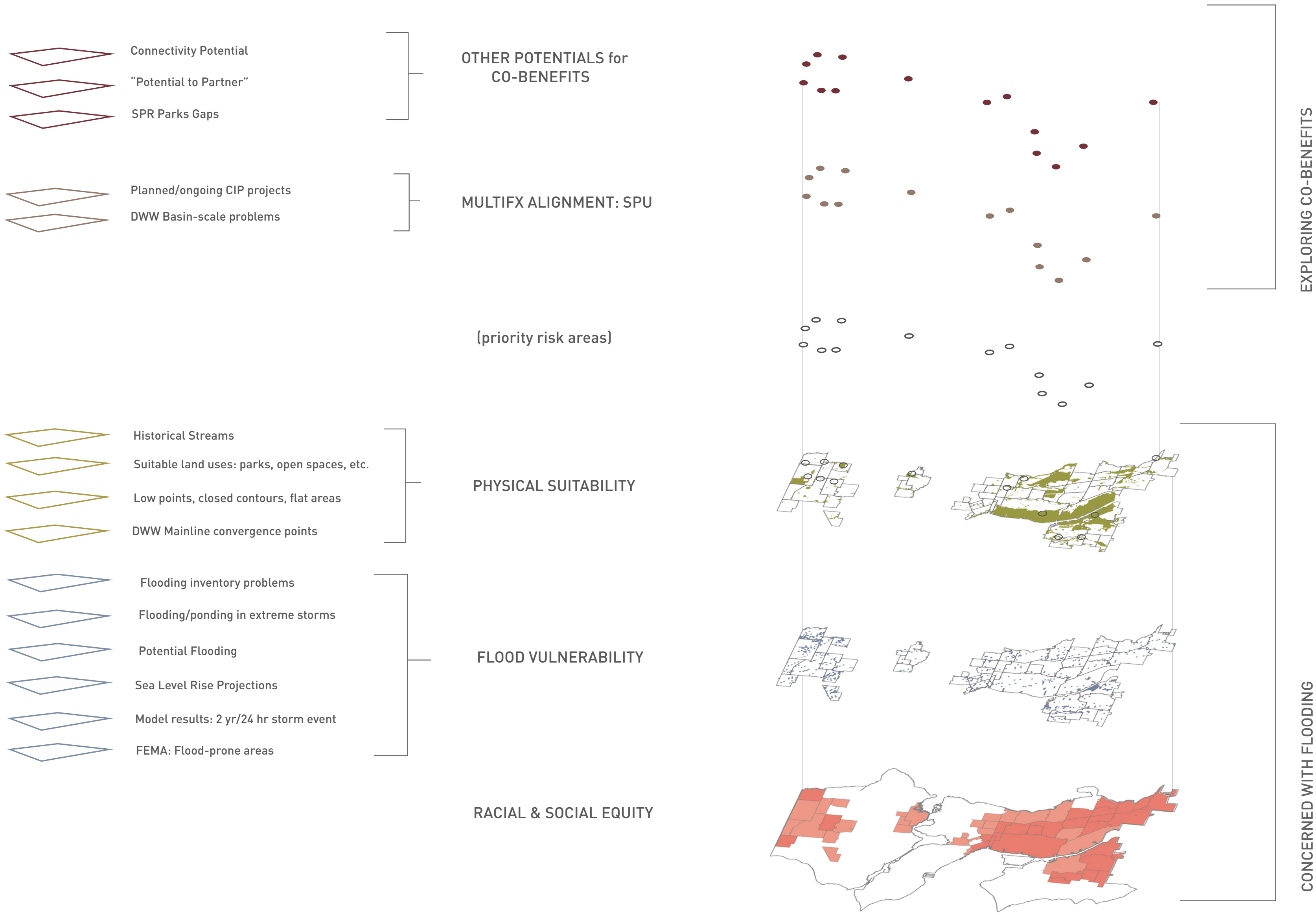


Figure 3.7

ANALYSIS APPROACH

The structure of my analysis represents but one approach to how planning for floodable spaces in the urban environment might be conducted in order to achieve maximum community benefit.

As shown in the diagram above, I divided my citywide analysis into five sets of factors that fall into two groups: those primarily concerned with flooding, and those that investigate the potential for co-benefits. Within the "concerned with flooding" category, racial and social equity and flood vulnerability reveal where the most pressing needs are, while physical suitability factors indicate locations where floodable spaces have the greatest potential to be sited. I used these three map sets to determine what areas in the city should be prioritized for floodable space consideration, the process for which I elaborate upon per map in the following pages. This process yielded a set of fourteen "priority risk areas" for further analysis.

The "exploring co-benefits" category, which includes two maps, "multifunctional alignment at SPU' and "other potentials for co-benefits", were treated differently than the maps in the "concerned with flooding" category. These factors were only analyzed within the fourteen priority risk areas that emerged from the previous "concerned with flooding" category of maps.

My analysis method was partially inspired by Ian McHarg's method for determing suitability as described in *Design with Nature.* This method splits various criteria into categories and assigns a gradation of values to each, from most suitable or valuable to least. In order to analyze the citywide data I'd collected in a systematic way, I assigned each map category a weight, represented in grey scale in the following pages, that reflects the relevance of the data to floodable space applicability and prioritization.

However, my analysis approach differs from McHarg's method in a few key ways. Because I sought to identify **priority** locations, not strictly the most suitable locations, the analysis process is not as straightforward as a most-to-least gradation of suitability. Rather, "priority" implies embedded values, and the weightings of different map categories reflect those values.

In the following pages, I utilize a grey scale version of each map to depict the relative importance - the weight - of the factors depicted. The grey scale maps were not used to conduct the analysis, but rather are a way to visually represent the scoring process I went through **in order to first determine the set of priority risk areas, and second, determine which among those priority risk areas had the highest potential to yield the greatest multiple benefits**. The lower the assigned weight and relative importance of a given factor, the lighter the shade of grey used to depict it. In this way, when the maps are overlayed, the darker shades are representative of the higher scoring areas. On each of the following pages, an example priority risk area is shown to more clearly explain how each map was scored.

RACIAL & SOCIAL EQUITY

The Racial and Social Equity Index is the preferred layer for all of SPU to use in the prioritization of areas of the city for improvements. Produced by the Office of Planning and Community Development, this composite includes three sub-indices: (1) Race, English language learners, and foreign-born shares of the population, (2) socioeconomic disadvantage, measured as shares of the population with an income below 200% of the poverty level, and educational attainment less than a bachelor's degree, and (3) health disadvantage, measured as shares of the population who report no leisure time physical activity, diagnosed diabetes, obesity, poor mental health, asthma, or low life expectancy at birth. All factors were weighted and rolled up into this composite map, which ranks census tracts on a scale of highest disadvantage and therefore highest priority to lowest disadvantage and lowest priority.

For the purposes of this project, only those census tracts with the highest disadvantage and priority and the second highest disadvantage and priority were analyzed.

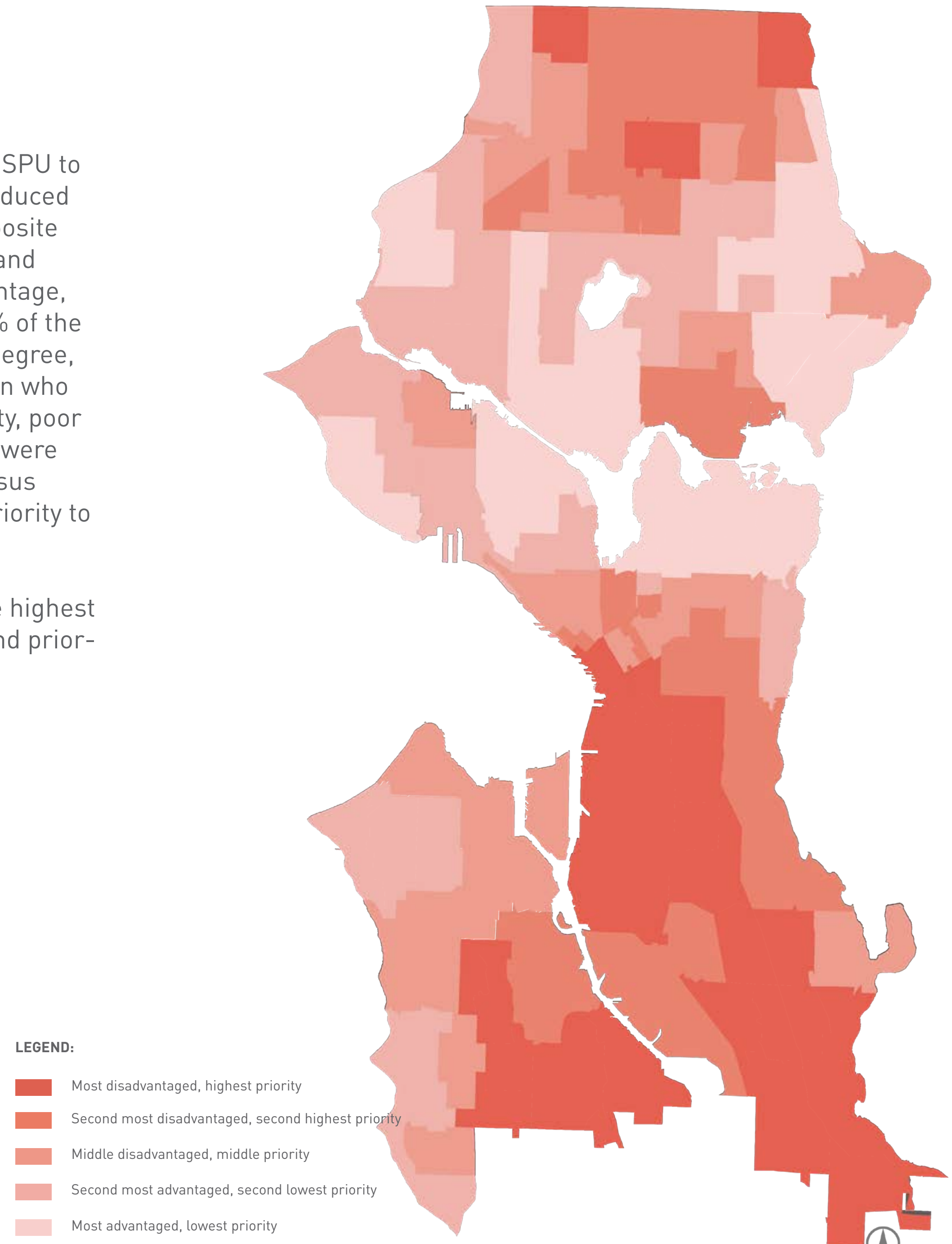


Figure 3.8

Racial & Social Equity: Weighted

Census tracts in the highest disadvantage category are given greater weight and corresponding darker transparency to reflect the increased urgency for action in these areas, as he impacts of flooding on more vulnerable populations have the potential to be more severe than the impacts of flooding on less vulnerable or disadvantaged populations.

Census tracts in the 2nd highest disadvantage category were given a slightly reduced weight and corresponding transparency. The more advantaged census tracts were not considered as a part of this analysis.

Scoring Example

Equity:
(essential)
(weighting: 2x)

Most disadvantaged census tract category
score: 2

Figure 3.9

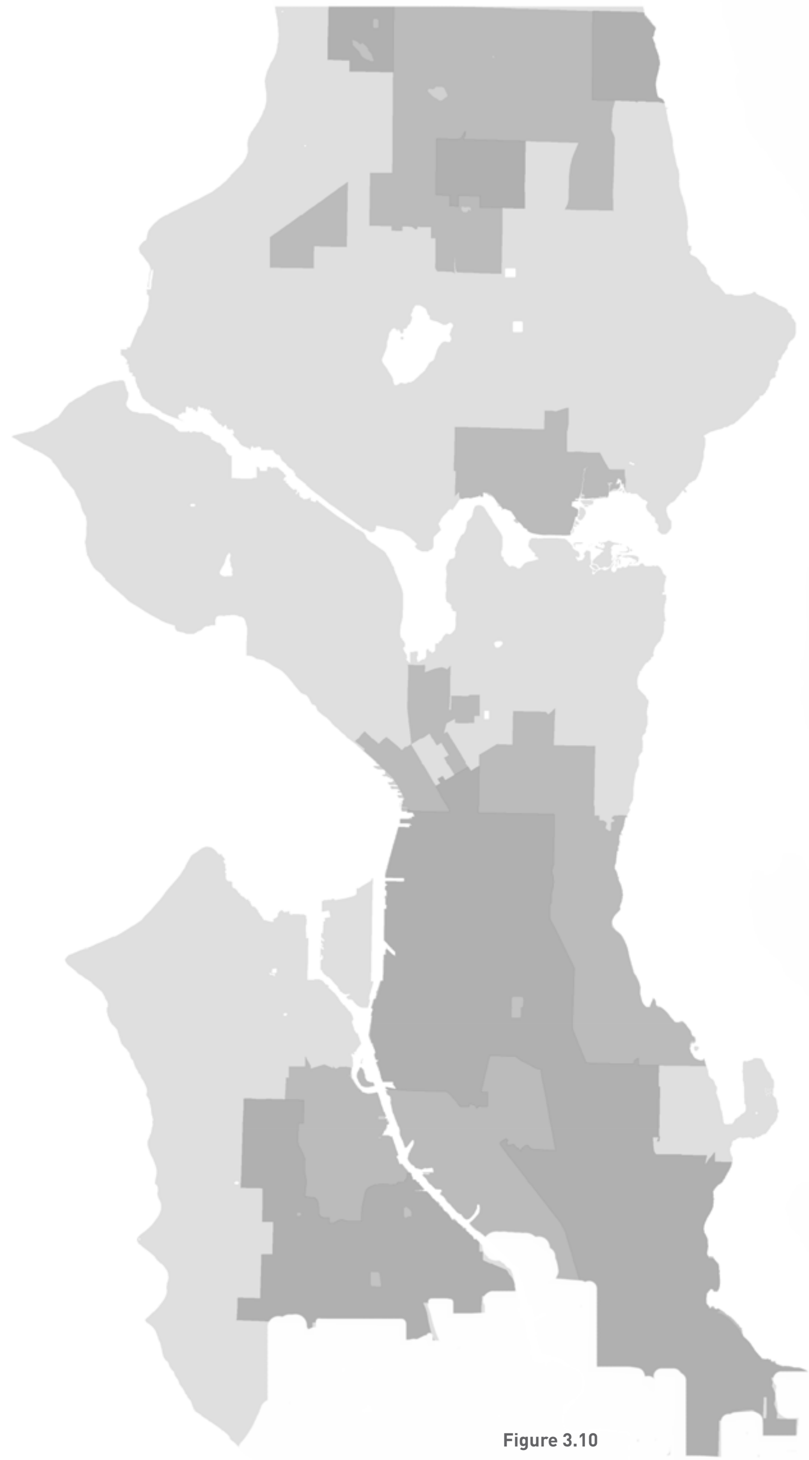


Figure 3.10

FLOOD VULNERABILITY

Identifying areas of high flood vulnerability is at the core of the citywide analysis, as floodable spaces will be sited to address a flooding problem or a risk. Each of the data layers included in this map describe flood vulnerability based either on past events or future projected conditions. I included as many types of flooding datasets as were available to explore what types of patterns or overlaps would emerge amongst them, as the case for intervention may be strengthened in areas where risk of flooding is indicated through multiple sources.

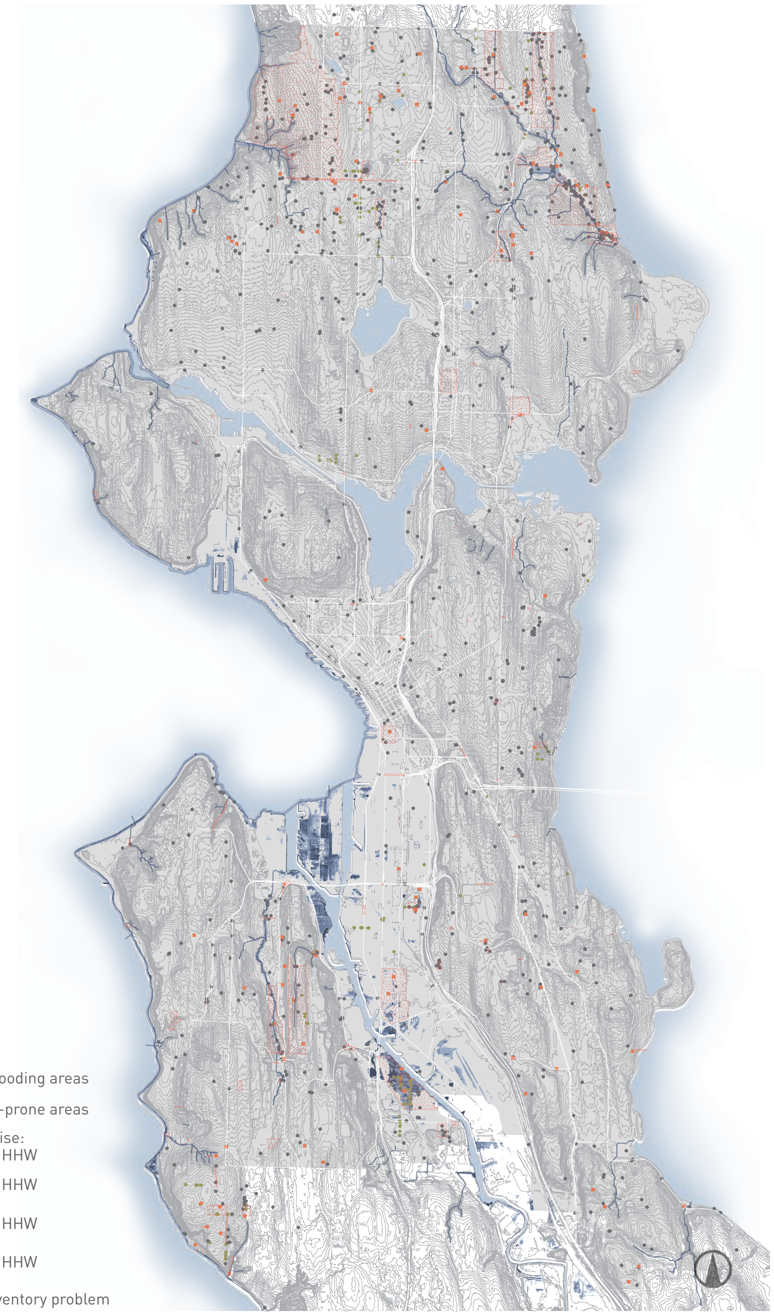
While some of the flooding data layers included are self-explanatory and publicly available, such as sea level rise, there are a few that are only available within the City, and thus require some explanation.

Potential flooding areas displays locations where flooding has been reported by Seattle residents, and multiple City Departments, but with varying levels of information on causes and solutions available. Because this layer was created in 2012, it is of limited reliability, as flood risk in some areas may have already been addressed.

Flooding inventory problems show locations where SPU has confirmed there is a problem in need of investigation as of early 2019, regardless of cause.

Extreme storm impacts areas are based on emergency work orders from the top ten storm events in Seattle, according to SPU's Climate Science Advisor. This data reveals areas that become problematic in major storm events.

The draft model results layer indicates locations in the drainage system that could be expected to back up and impact either the ROW or both the ROW and private property in a simulated 2 year, 24 hour rain event.



LEGEND

Potential Flooding areas
FEMA flood-prone areas
Sea Level Rise:
2 ft above MHHW
3 ft above MHHW
4 ft above MHHW
5 ft above MHHW
Flooding inventory problem
Extreme storm impact areas
Draft Model Results: 2 yr/24 hr event

Figure 3.11

Flood Vulnerability: Weighted

This map category required the most complex weighting process of the five due to:

1) Variable data **reliability**
2) variable floodable space **applicability**
3) variable **severity** of the indicated threat

Given the overall range of variability among the data, I assigned a weight to each individual layer that reflected its level of reliability, applicability, and severity.

For example, flood prone areas denote places that have already experienced flooding and are officially recognized by federal and local governments as at-risk. Therefore, the flood prone layer is reliable, applicable, and indicates a relatively severe threat. Thus, this layer is assigned the highest weight and corresponding darkest transparency.

In contrast, flooding inventory problem locations have not yet been categorized by cause, and thus, this layer in isolation is meaningless for the purpose of identifying priority areas for floodable spaces. Therefore, it is given a low weight.

Because the data is derived from a model and does not reflect real events, the Draft Model Results layer was given a medium weighting and corresponding transparency. Where these data points occur in isolation does not mean much for the purposes of this analysis. However, where they overlap with, for example, a convergence point in the drainage system, may indicate a capacity problem.

Utilizing the boundaries of the most and second most disadvantaged census tracts, I identified areas of overlapping or adjacent flood vulnerability indicators. Areas were scored through an inventory of the

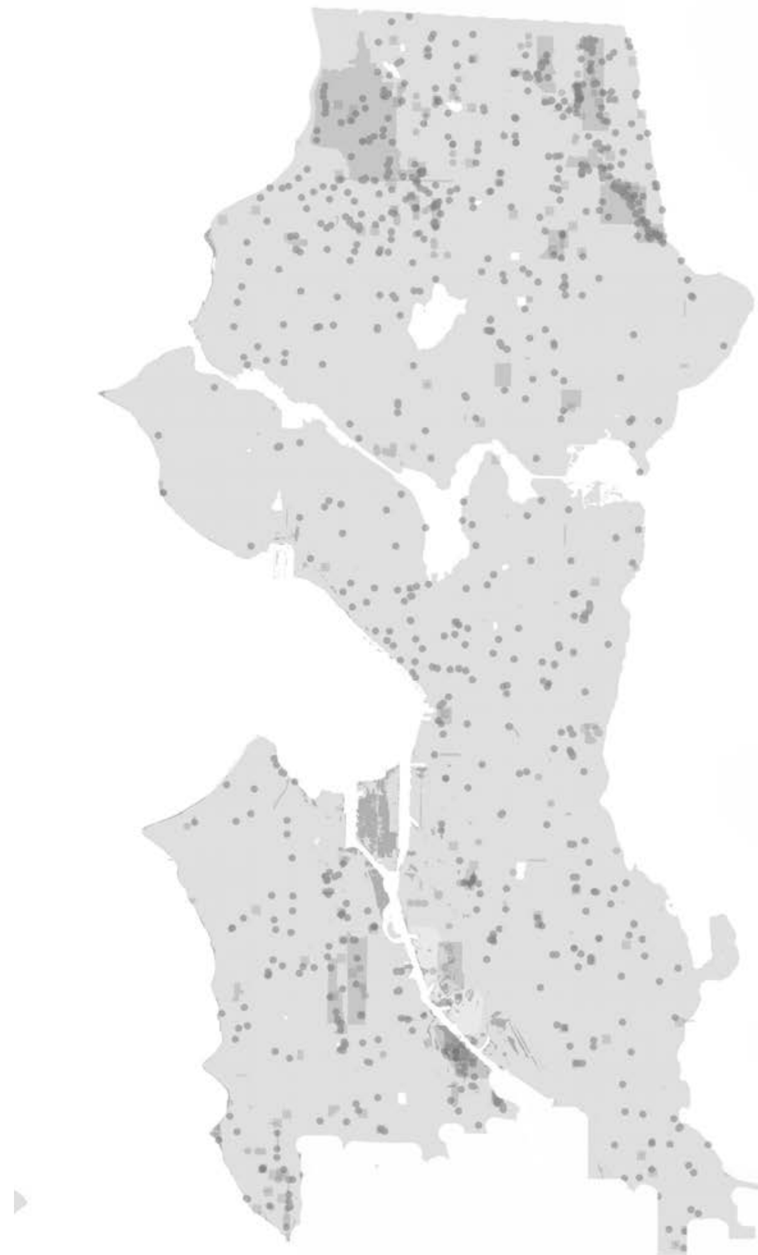


Figure 3.12

number of flood vulnerability indicators present there and the assigned weights were added together for a total flood vulnerability sum.

Lastly, this score was multiplied by the overall map category weighting. As aforementioned, because the primary goal of a floodable space is to address a flooding problem, I deemed flood vulnerability attributes as "essential," and assigned the overall map category a 2.5 weighting - the highest of the three weightings.

.

Scoring Example

Flood Vulnerability
(essential)
(weighting: 2.5x)

Three risk indicators present:
Flood-prone - high - 1.5
Extreme Storm Impact Area - med - 1
Potential Flooding - low - 0.5
1.5 + 1 + 0.5 = 3
score = 7.5

Figure 3.13

Each of the layers included in this map speak to different aspects of suitability for the siting of floodable spaces, concerning land uses, topography, existing drainage system flows, and historical stream paths.

I analyzed the city topography (ten foot contours) to locate low points, enclosed depressions, and flat areas to identify locations where surface water might naturally collect or could potentially be held. It is not surprising that these areas often overlap with both historical stream paths and points of convergence within the drainage system.

The locations of historical streams were included here as they may reveal relationships between historical and current drainage issues. Based on an 1894 map of Seattle, this dataset indicates a significant transformation of Seattle's waterways when overlayed with existing watercourses. Depending on context, places that historically held water may again become ideal places to accommodate water in a wetter, more unpredictable future.

Land uses considered suitable for floodable spaces were limited to existing parks and open spaces. While other types of land use, such as parking lots, could have been considered at this stage of analysis, such potentials were included as part of subsequent phases.

Figure 3.14

Physical Suitability: Weighted

Utilizing the boundaries of the most and second most disadvantaged census tracts, I identified areas of overlapping or adjacent indicators of physical suitability. Areas were scored through an inventory of the variety of physical suitability indicators present there, either 1, 2, 3, or 4.

Physical suitability is an important priority when searching for floodable sites. While it is arguable that it should be considered "essential," I selected to consider it merely "important" because equating it with map categories such as flood vulnerability and equity has the potential to grant priority to an area of lesser need but greater suitability. In accordance with SPU's values, priority will be given to areas most in need. Thus, I assigned this map category a middle weighting of 2.

Scoring Example

Physical Suitability
(important)
(weighting:2x)

Two suitability characteristics present
score: 4

Figure 3.15

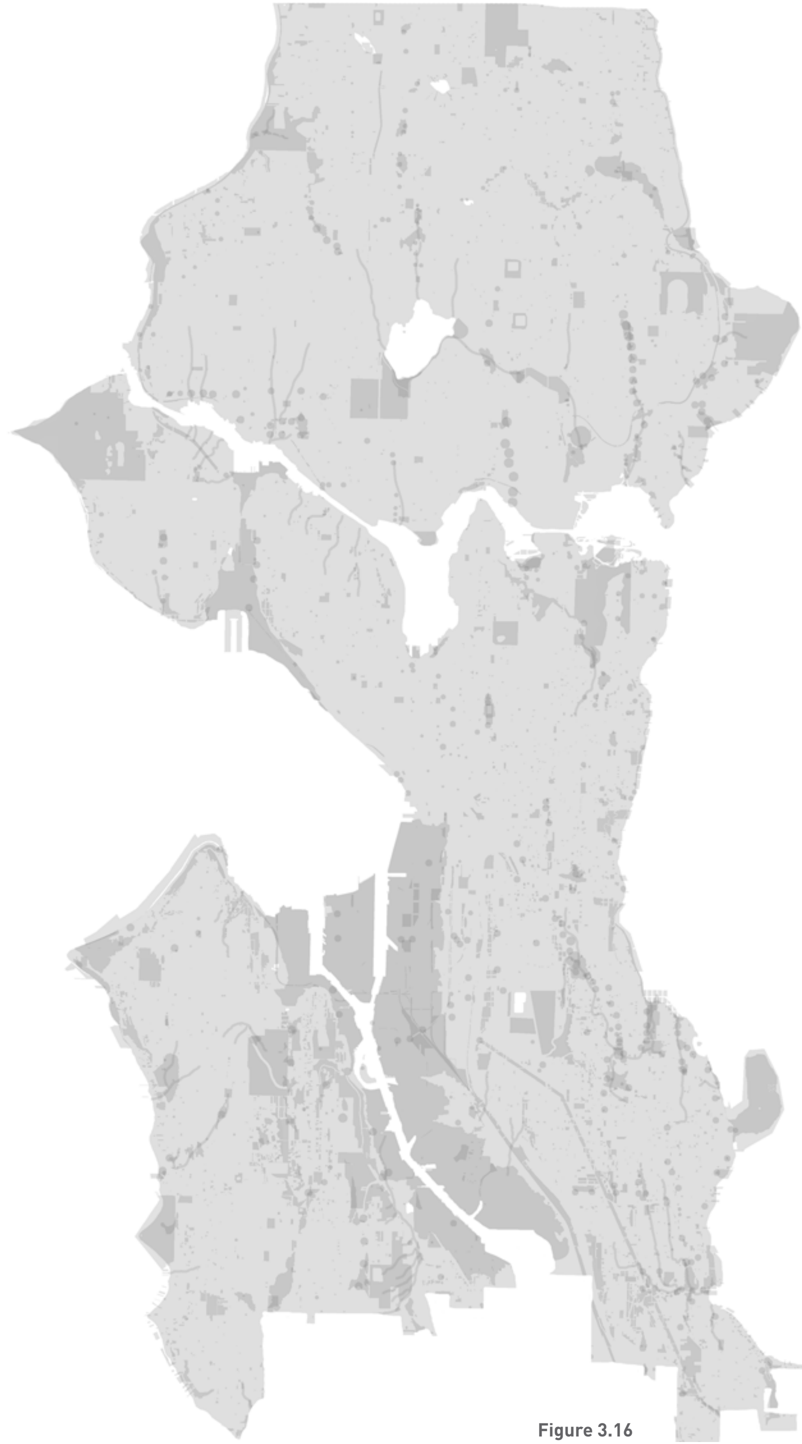


Figure 3.16

As aforementioned, the **drainage mainlines convergence points** layer identified points in the system where flows from multiple pipes are converging and flow volumes are likely high. These locations indicate places in the system that could be under strain during an extreme storm event, and could perhaps be relieved by some water storage above ground, either adjacent to these locations or further upstream.

To identify these locations, I utilized pipe diameter (the larger the pipe diameter, the greater the anticipated flow volume) and location in the drainage basin/proximity to the outfall point, or where it reaches the receiving waterbody. (Areas higher in the drainage basin would likely not have enough flow volume available to be worth intercepting).

Another end goal of this identification process was to overlay these locations with existing flooding problems, a process that could potentially indicate causes of these problems. For example, a convergence point in the drainage system that overlaps with draft model results that show potential flooding in the ROW may indicate that this area of the system is capacity-constrained.

Additionally, areas where convergence points coincide with a low point or closed contour may show potential for water interception at the surface in that location, a place where gravity could be taken advantage of.

I only identified onvergence points in areas with separated drainage systems, because in areas with a combined sewer system, stormwater is already mixed with wastewater, and therefore is not desirable to intercept for my purposes. (Intercepting drainage flows in a combined basin would require a strategy that does not involve the pipes themselves, such as peeling off surface flow to be infiltrated or detained in rain gardens, bioswales, etc.)

Existing SPU DWW Infrastructure, such as retention ponds and GSI, were also analyzed at this stage with the notion that some of these features may cancel out drainage system convergence points and/or topographical low points that I'd previously identified.

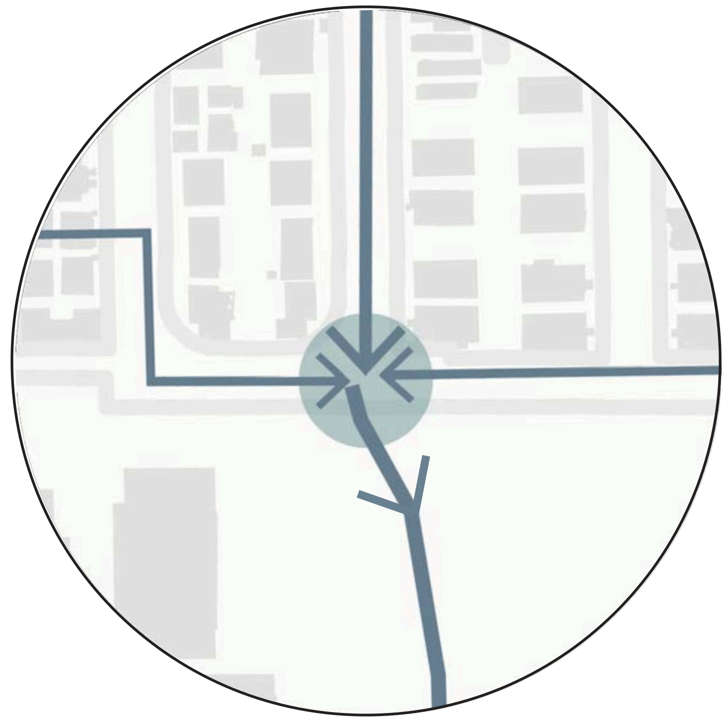


Figure 3.17: Example of a drainage system convergence point. Arrows indicate direction of flow; line thickness represents an approximation of flow volume.

As discussed above, the maps in the "concerned with flooding" category were utilized as a series of filters to progressively narrow down a set of priority risk areas.

I found it necessary to establish a set of minimum requirements to narrow down what areas should progress to the next level of analysis (exploring co-benefits). This simplified the process, and ensured I'd reach my ultimate goal of identifying possible locations within the city to zoom in and explore how the concept of floodable spaces might be applied to a particular area.

In order to advance to the "exploring co-benefits" level of this citywide analysis, areas had to:

1) Be sited in one of the two most disadvantaged census tracts.

2) have at least three out of the six total flood risk indicators present, either overlapping or adjacent to one another.

3) have at least two out of the four total physical suitability indicators present, either overlapping or adjacent to one another.

This set of criteria narrowed my initial set of possible areas to fourteen.

Figure 3.18

MULTIFUNCTIONAL ALIGNMENT AT SPU

The data layers included in this map are part of the "other co-benefits" category of analysis maps, and is composed of two layers: planned or ongoing CIP projects at the City, and basins of concern to SPU's Drainage and Wastewater Line of Business (LOB), like CSO basins, large creek basins, areas draining to the Duwamish River, and capacity-constrained areas.

A priority floodable space location that coincides with a planned CIP project may offer an opportunity to synergize with work already in motion or incorporate floodable spaces into an existing project, which would help to reduce project costs and increase utility and City efficiency overall.

Where a priority floodable space location occurs in a basin of DWW concern might represent an opportunity to do more than just address a flooding issue with a surface solution. For example, if such a location lies within in a basin that drains to the Duwamish River, where water quality is of particular concern, SPU could explore how a floodable space in this area might help improve water quality in addition to providing flood mitigation. In the case of a potential floodable space location within a CSO basin, SPU could explore how such an intervention might contribute to CSO mitigation by keeping water out of the combined sewer system.

These factors are considered to be "other co-benefits" because they do not represent primary motivations for the siting of floodable space, but rather additional benefits they could garner that have the potential to enhance community value and and serve multiple functions.

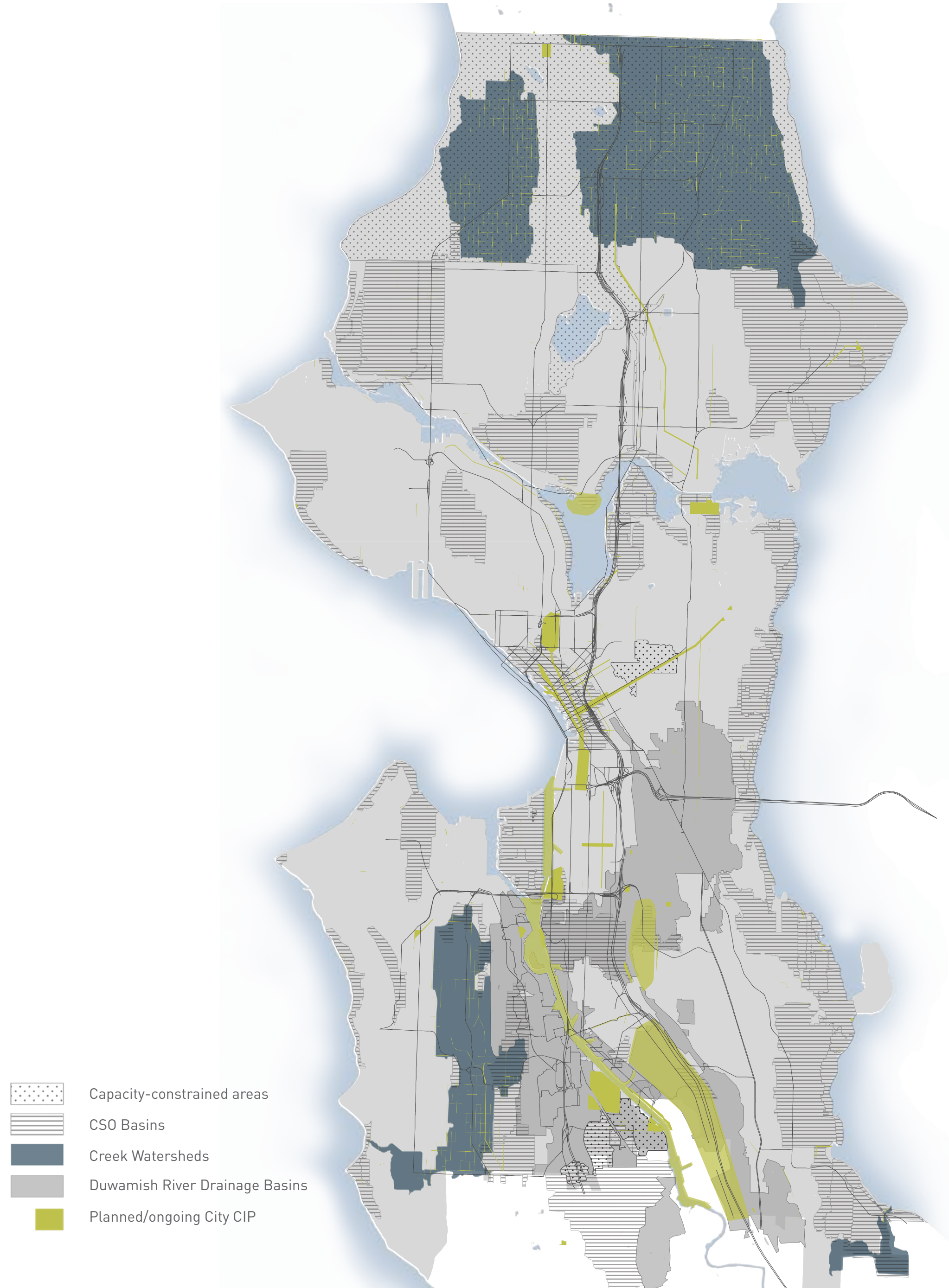


Figure 3.19

Multifunctional Alignment at SPU: Weighted

As discussed previously, map categories that fall under the "exploring co-benefits" umbrella were treated differently than those under the "concerned with flooding" umbrella. I used the boundary of the fourteen priority risk areas that I'd identifed through the analysis of the "concerned with flooding" map set to filter down the the areas included for analysis at the "exploring co-benefits" stage. Within these areas, I noted whether or not planned or ongoing CIP projects were within a quarter mile of each priority risk area, and whether it fell within a DWW basin of concern. In all cases, this was essentially a "yes" or "no", to which I assigned a 1 for yes, and a 0 for no. This score was then multiplied by the overall map category weighting.

Because the parameters included here simply enhance the potential for a floodable space to be more multifunctional and/or provide greater community benefit, I chose to categorize them as "ideal" attributes, and thus assigned this overall map category a 1.5 weighting - the lowest of the three weightings I determined.

Scoring Example

Multifunctional Alignment at SPU
(ideal)
(weighting:1.5x)

Within basin of concern
score: 1.5
(project shown on street near completion: not counted)

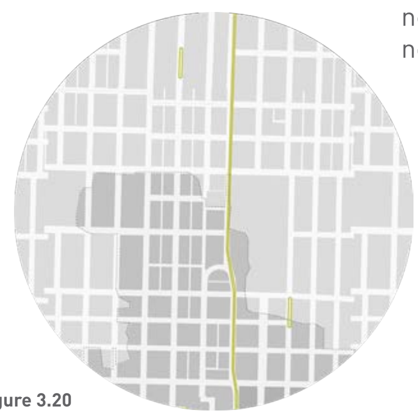


Figure 3.20

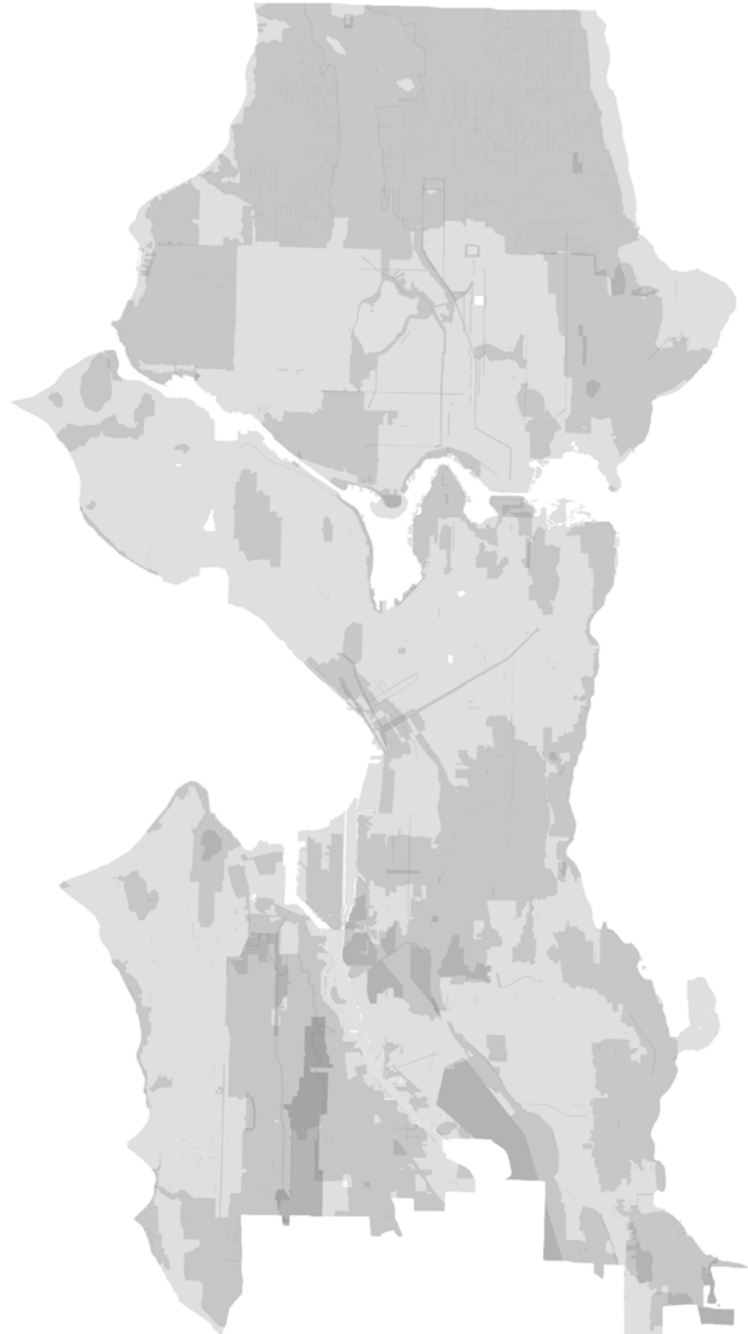


Figure 3.21

OTHER POTENTIALS for CO-BENEFITS

As its name would suggest, this map is part of the "other co-benefits" map category - again, the parameters shown here do not represent primary considerations for the siting of a floodable space, but are factors that might enhance the community value and multifunctionality of such an intervention.

Existing and planned bicycle routes are included here to emphasize the potential synergy between bicycle infrastructure and right-of-way GSI (in this case, floodable GSI). For example, GSI in the right-of-way can function as a median between vehicular and bicycle traffic lanes.

Civic land uses such as churches, schools, libraries, or community centers are also included, as such organizations may have an interest in partnering on funding, implementation, or maintenance and stewardship of a floodable space.

Parks gaps, shown in grey, are places where Seattle Parks and Recreation, according to their walkability standard, is interested in acquiring property for the establishment of new parks. Where these gaps overlap with a flood risk area that has the potential to be addressed through the development of a floodable space, Parks and SPU may wish to partner on the creation of a park/infrastructure hybrid.

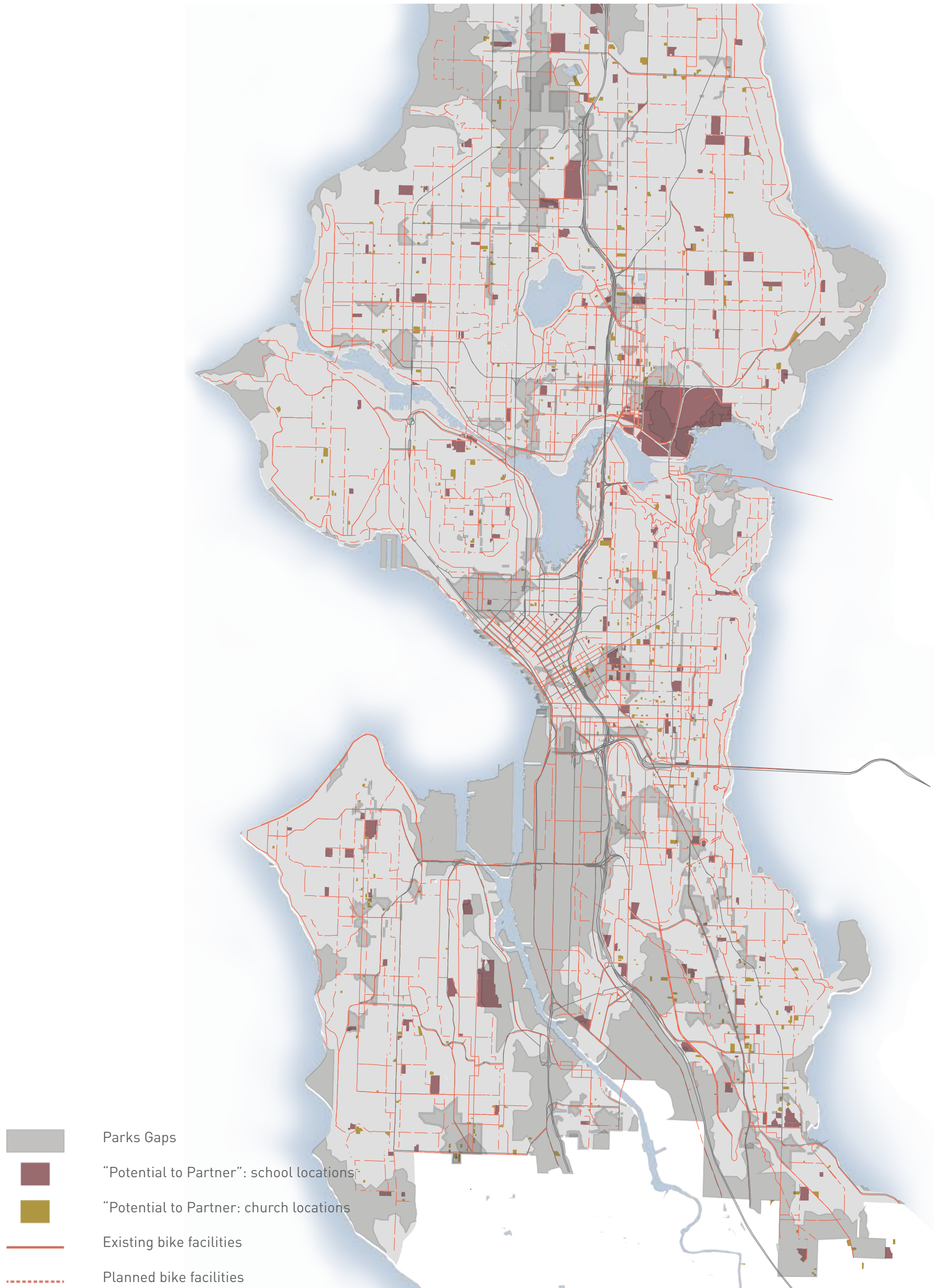


Figure 3.22

In the same way as the "Multifunctional Alignment at SPU" map was treated, because these parameters are attributes that would simply enhance the potential for a floodable space to be more multifunctional and/or provide greater community benefit, I've chosen to categorize them as "ideal" attributes, and thus assigned this overall map category a 1.5 weighting.

Using the boundaries of the fourteen priority risk areas that I'd identifed through my analysis of the "concerned with flooding" map set, I counted the number of occurences of existing and planned bicycle infrastructure, land uses with potential to partner, and parks gaps within a quarter-mile radius of each priority risk area, and added those up to get a score per area that I then multiplied multiplied by the 1.5 overall weighting for this map category.

Scoring Example

Potential for Community Benefits
(ideal)
(weighting: 1.5x)

Proximity of two entities w. potential to partner
score: 3

Figure 3.23

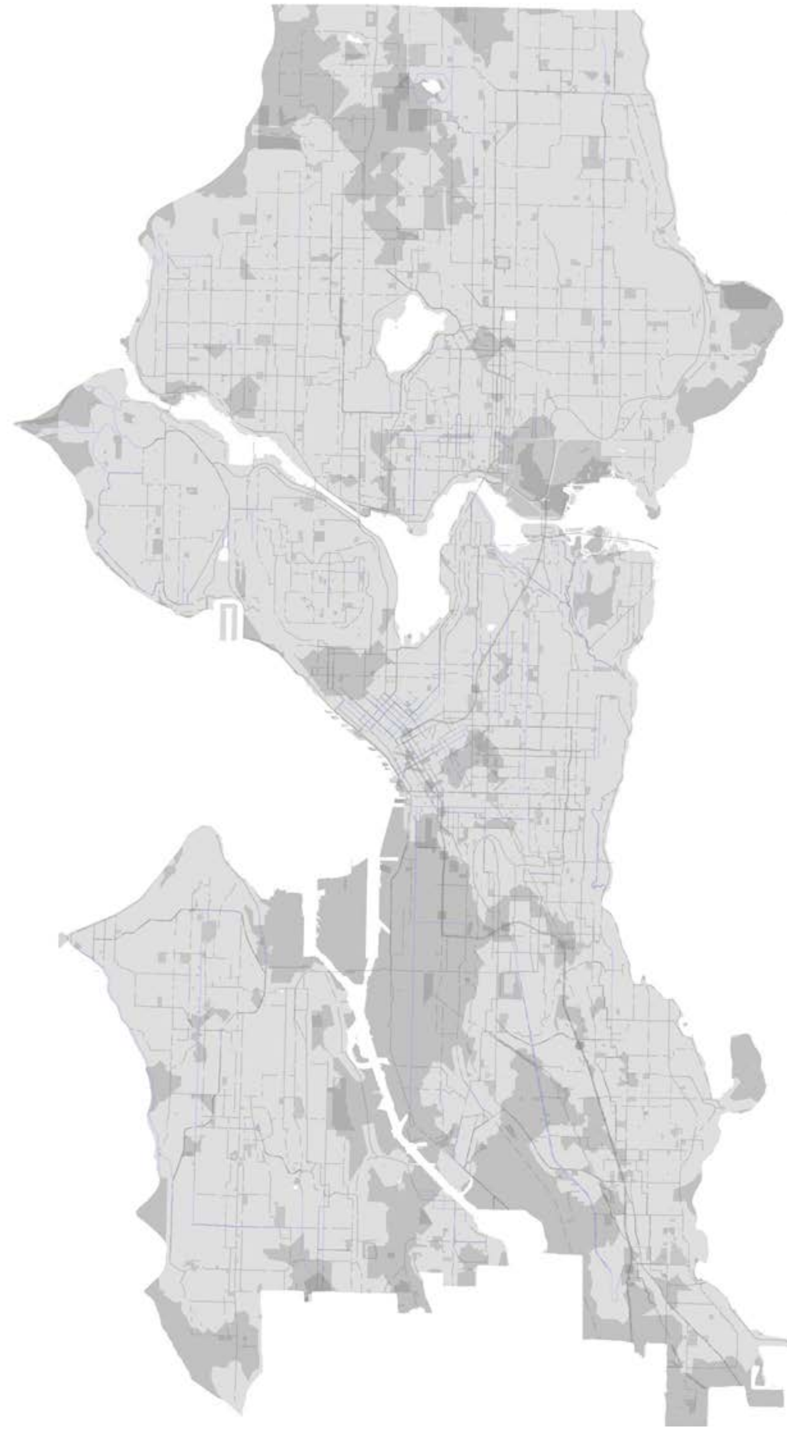


Figure 3.24

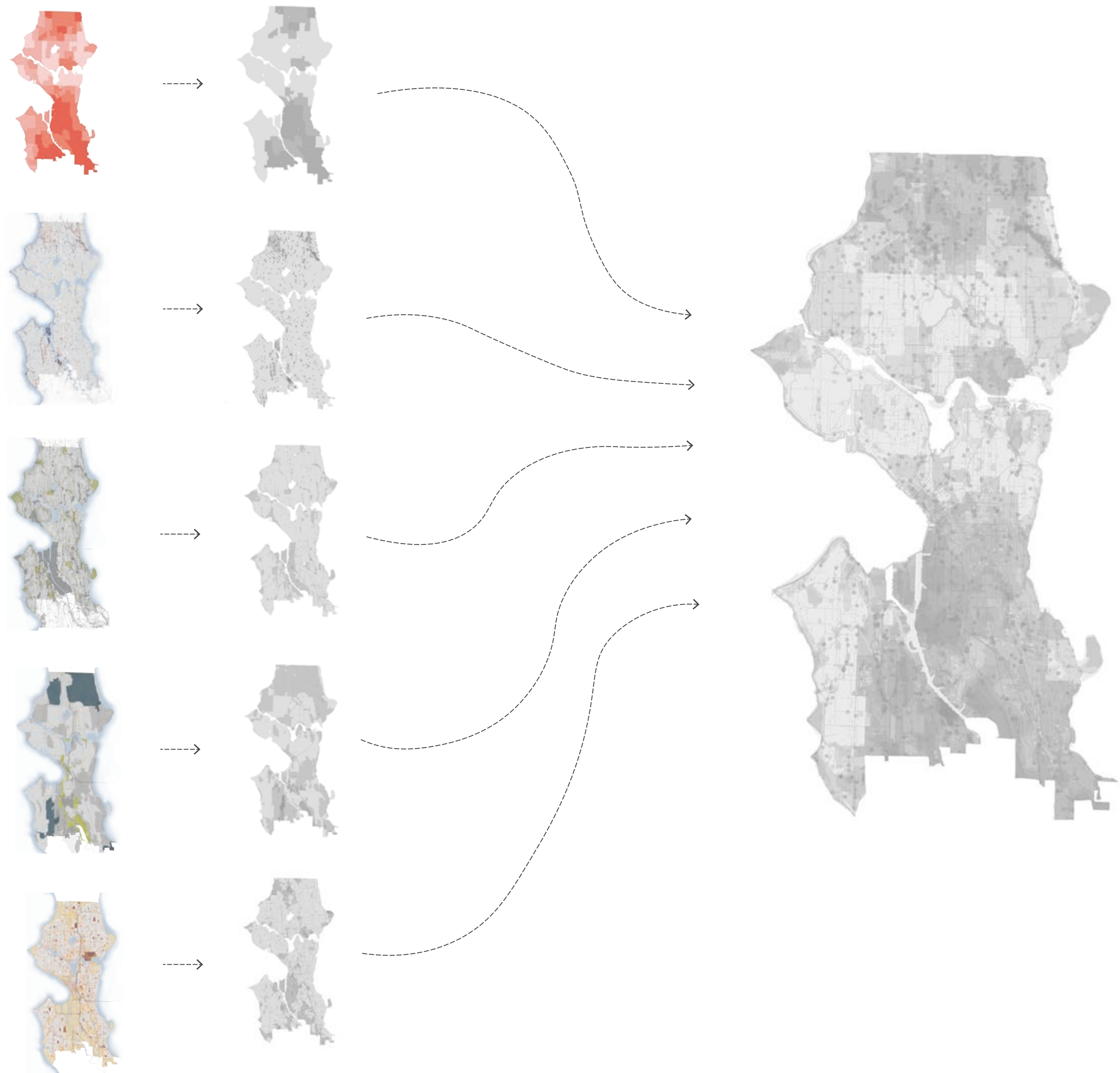


Figure 3.25

SCORING METHOD EXAMPLE: ALL MAPS

Weightings per Map Category

Equity:
(essential)
(weighting: 2.5x)

Flood Vulnerability
(essential)
(weighting: 2.5x)

Physical Suitability
(important)
(weighting: 2x)

Multifunctional Alignment at SPU
(ideal)
(weighting:1.5x)

Potential for Community Benefits
(ideal)
(weighting: 1.5x)

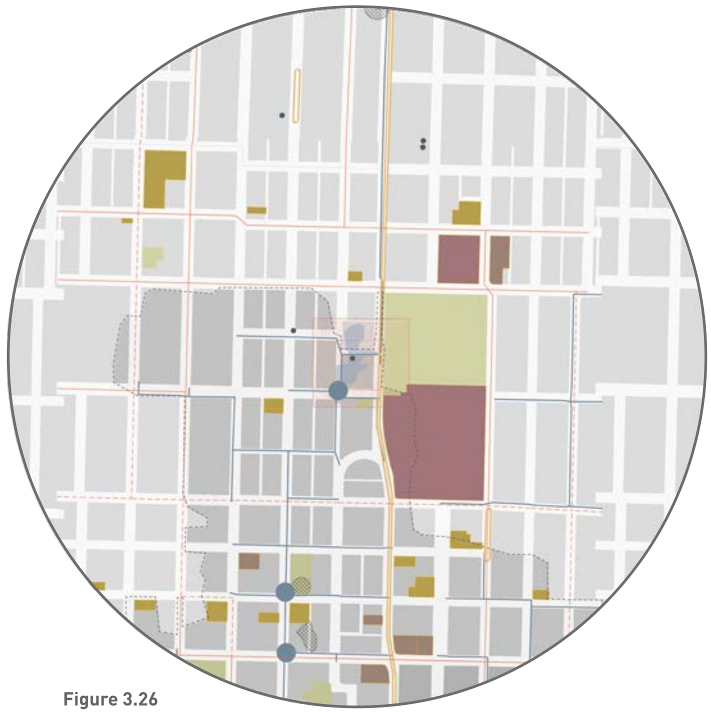


Figure 3.26

(Quarter mile radius around identified risk area)

Scoring: Central District risk area

Most disadvantaged census tract category
score: 2.5

Three risk indicators present
score: 7.5

Two suitability characteristics present
score: 4

Within basin of concern
score: 1.5
(project shown on street near completion, not counted)

Proximity of two entities w. potential to partner
score: 3

Total score: 18.5

Here, all map categories are combined for the example priority risk area, located in the Central District, to more clearly illustrate how the scoring process was carried out.

RESULTS: PRIORITY RISK AREAS

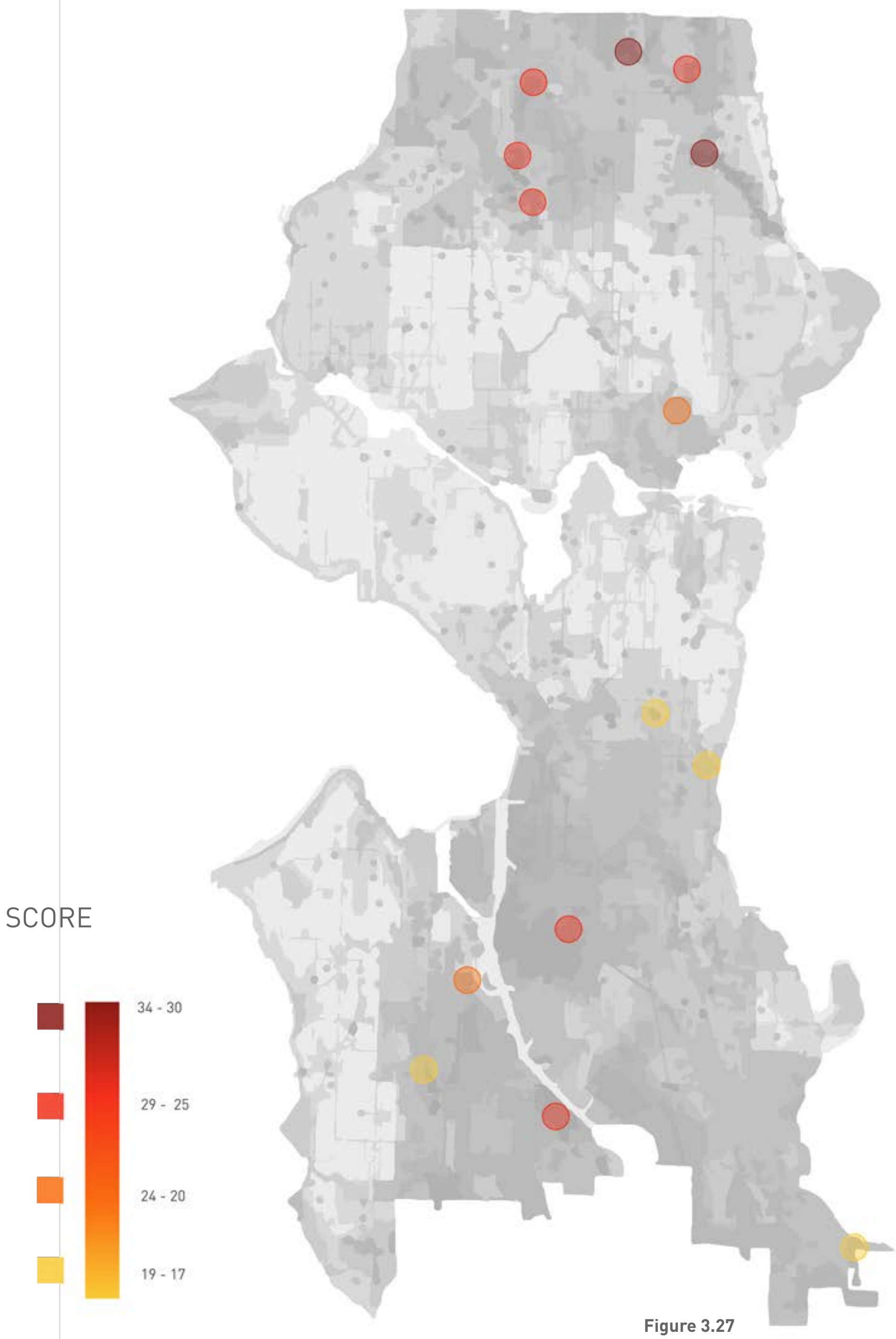


Figure 3.27

After scoring each of the fourteen risk areas per map category, I added them up for a total score per area, which I then ranked highest to lowest. The results are reflected in the map at left.

While each of these fourteen priority risk areas are ripe for an exploration of how floodable spaces might work to address existing flood risks while simultaneously affording multiple community benefits, I ranked them to select one of the highest priority areas in which to play out a floodable space concept.

SEATTLE'S WATER STORY

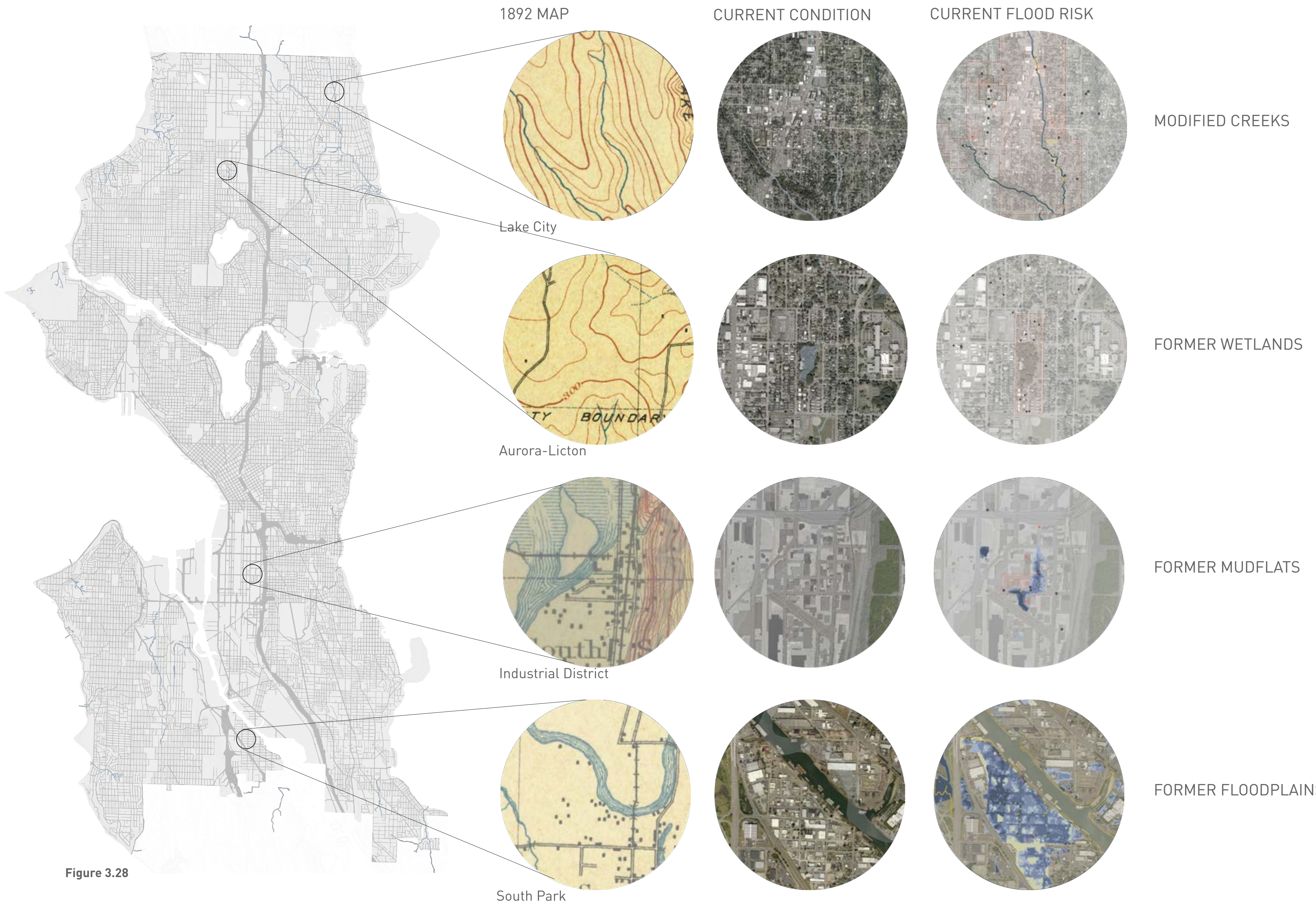


Figure 3.28

Throughout my analysis process and research, I noticed a pattern (that may seem intuitive) in which many of the areas most at risk of flooding are also the ones that have been the most drastically transformed from dynamic and watery landscapes to developed sites. Today they are static places with very little room for adaptability.

Seattle is one of the most heavily engineered cities in the United States[12]. After the arrival of Euro-Americans in 1851, the landscape was transformed in a matter of decades. Hills were leveled, creeks were piped and paved over, replaced by roadways for vehicular traffic. Ponds and wetlands have been filled and built upon, rivers channelized, lake levels lowered and streams disconnected and desiccated.

In a place of great topographic variation, areas of flat or low land were most often utilized by city engineers for vehicular roadways, industrial areas, and the like, because they were deemed more suitable. However, most of the flat lands and low points in Seattle were formed by the presence of water, or at least indicate, geologically, its historical presence. These are places where water was present either all of the time or intermittently. Many of these entities were piped (creeks), filled, (wetlands), or channelized (river), dramatically altering the inherent functionality of these landscapes, if not outright destroying them, and at minimum, taking what was a dynamic, flexible, and resilient system and attempting to contain it in a state of relative stasis. This has not been without consequence, as the clusters of flooding problems in Seattle around transformed waterbodies and former watery landscapes indicate. In the following chapter, I explore the story of one such location in greater detail.

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Figures

Figure 3.1: Waterlines map, an artistic representation of pre-settlement Seattle .Source: Burke Museum.
Figure 3.2: Seattle Today. Source: GoogleEarth.
Figure 3.3: Image modified from https://www.mutualmaterials.com/new-report-details-downtown-seattle-construction-growth/
Figure 3.4: Photo by author.
Figure 3.5: Community-centered utility icons. By author, for SPU DWW PPM Division
Figure 3.6: Madison Valley Stormwater Storage Facility. Figure: Image modified from: http://lakeunioninseattleco.ipage.com/madronaseattle.com
Figure 3.7: Citywide Analysis Representation. Image by author.
Figure 3.8: Racial and Social Equity Index map. Image by author.
Figure 3.9:Weighted Racial and Social Equity Index map scoring example. Image by author.
Figure 3.10: Weighted Racial and Social Equity Index map. Image by author.
Figure 3.11: Flood Vulnerability map. Image by author.
Figure 3.12: Weighted Flood Vulnerability map. Image by author.

Figure 3.13: Weighted Flood Vulnerability map scoring example. Image by author.
Figure 3.14: Physical suitability map. Image by author.
Figure 3.15: Weighted Physical Suitability map scoring example. Image by author.

4 FLOODABLE SPACES in the DENSMORE BASIN

SELECTED FOCUS AREA: DENSMORE BASIN

The Densmore Basin is an area in which an extensive natural drainage system of ephemeral streams, creeks, and groundwater-fed wetlands were replaced by centralized subterranean infrastructure with the onset of urban development.

.

Because three distinct, high-scoring priority risk areas emerged in the Densmore Basin from my citywide analysis, I selected this area as an experimental site in which to test my analysis methodology at a smaller scale and explore how the concept of floodable spaces might be applied to a specific Seattle context.

While many areas of the city have had their natural drainage courses replaced by underground pipes, the Densmore Basin is an ideal area to explore site and neighborhood-specific applications because it has the potential to generate concepts applicable to other parts of the city.

For example, many of the most flood-vulnerable areas in Seattle are adjacent to a creek, river, or the open water of Puget Sound. Thus, applications of floodable spaces in these areas would be highly waterbody-specific, involving strategies and approaches that would not necessarily be relevant or transferrable to flooding problems elsewhere.

The flood risk in the Densmore Basin, like other areas of North Seattle, has more to do with stormwater management and pluvial flooding. This area is already inherently capacity-constrained in terms of its ability to convey stormwater runoff. Its urban villages are zoned for increased development, which will undoubtedly contribute to this problem. As these issues are likely to arise in other areas of the city in the future, especially other urban villages not adjacent to a major waterbody, the Densmore Basin is an ideal candidate for experimentation with the notion of flexible surface water solutions in the urban environment.

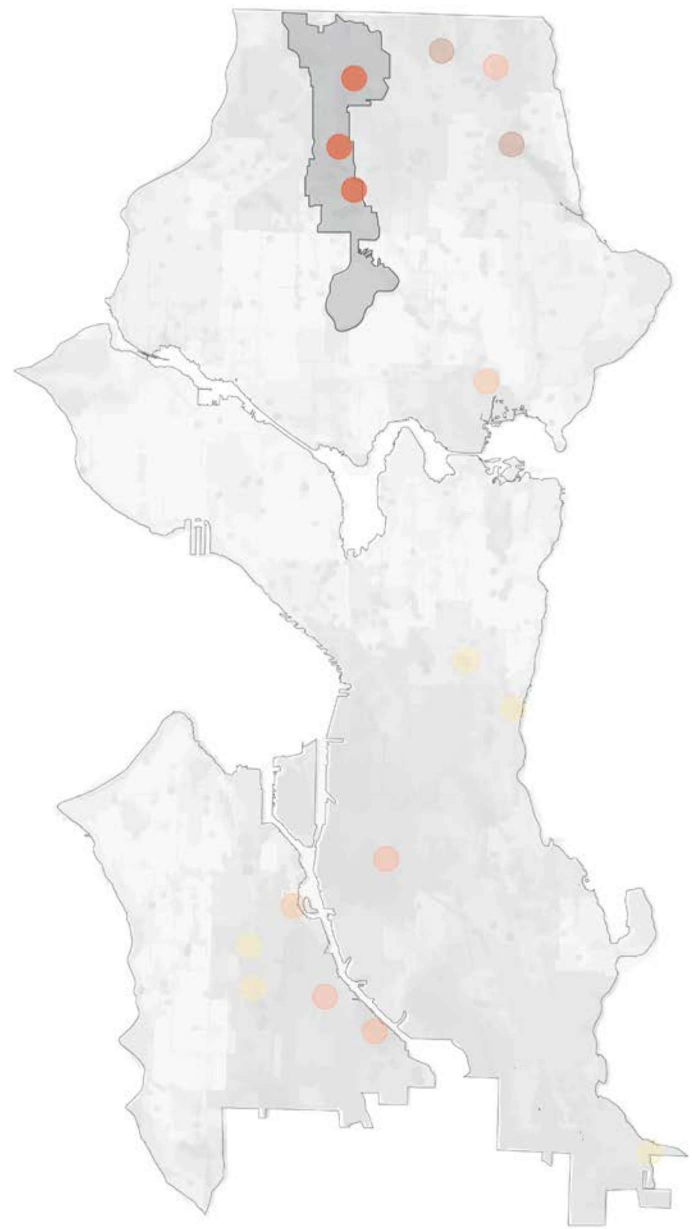


Figure 4.1

BASIN INTRODUCTION

The Densmore Basin is located in the north central area of Seattle and stretches from the northern city limits to Green Lake, sloping from north to south, with a total area of 3.1 square miles. The areas of the basin north of N 85th Street were not annexed by the City of Seattle until the 1950s, and therefore, much of the area's development occurred outside of city jurisdiction[1].

While most of the basin was developed as residential, the length of Aurora Ave N features a significant strip of commercial development. Several schools and public facilities lie within the basin, as well as the Evergreen-Washelli Cemetery, which occupies 100 acres at its center[1]. Before the area was settled, precipitation infiltrated into the ground, evaporated into the atmosphere, or drained through natural drainage courses. As the basin developed, infrastructure was constructed to convey stormwater runoff, replacing most of the natural drainage features[1].

I selected to address the lower portion of the Densmore Basin, which extends from the southern edge of Washelli Cemetery to the northern edge of Green Lake, to which it drains. Here, clusters of flood risk indicators along the spine of a transformed and fragmented creek channel scored high in my citywide analysis but also intrigued me: does the possible interconnected nature of these problems indicate the potential for interconnected solutions here, like the natural drainage system that existed prior to settlement and urban development? To answer this question required additional analysis beyond those parameters examined at the citywide scale - an exploration of the Lower Densmore Subbasin's "water story" through the lens of its natural history, built history, and present challenges.

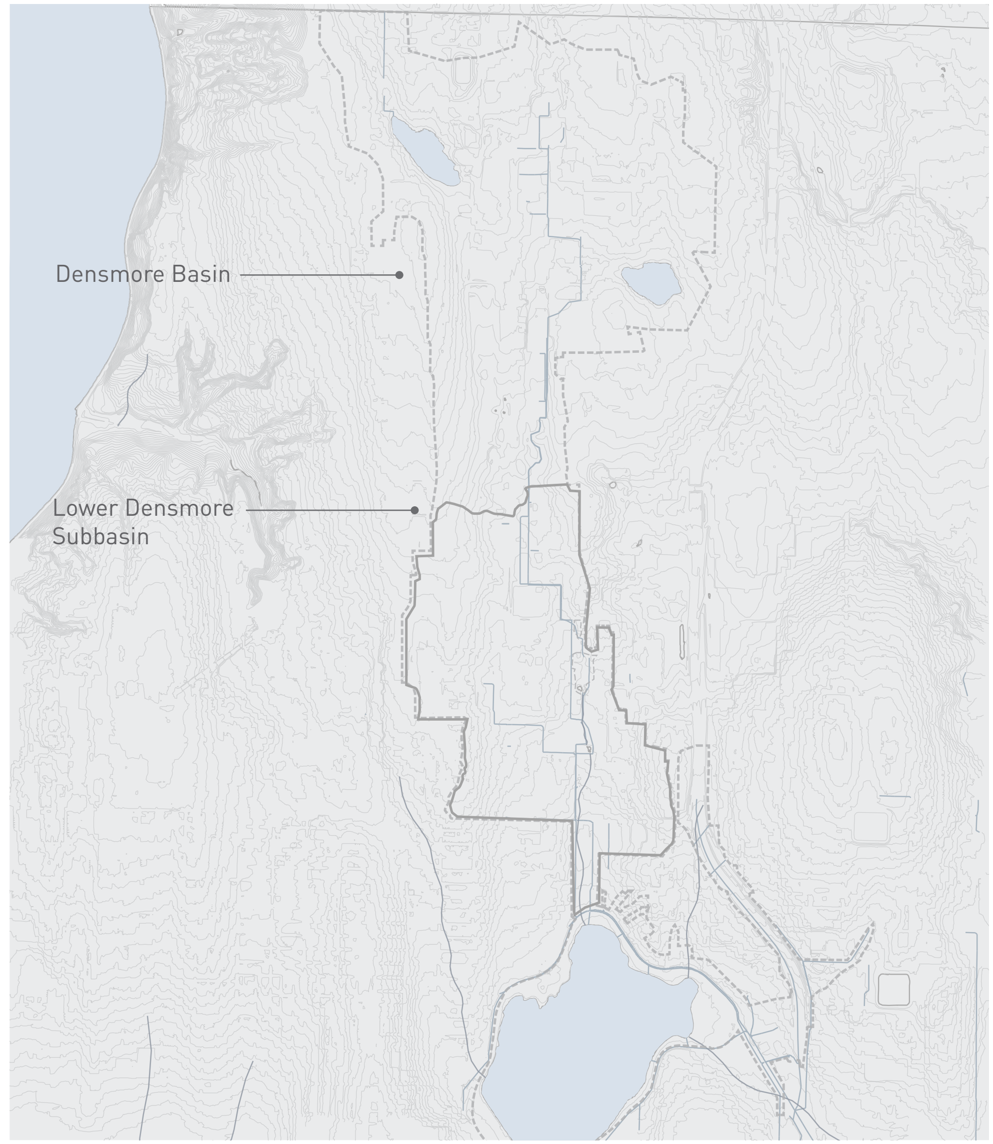


Figure: 4.2

NATURAL HISTORY

An investigation of the area's natural history and geology through both 19th century maps and geological maps reveal that this has long been a watery place[2]. Glacial retreat and advance, which formed much of the Puget Sound region, shaped the lower Densmore Basin into its current topographic and geologic configuration, leaving its signature in the form of linear recessional and advance outwash gravel deposits as well as a long depressional groove[2]. This linear depression, that continues southward to Green Lake, constitutes the low point of the basin to which all water eventually flows, indicated by the path of an intermittent historical stream issuing from Licton Springs to Green Lake. Here, geological deposits mark the historical presence of wetlands in the form of peat deposits beneath Licton Springs Park, as well as beneath the development that has gradually sprouted up around it. Wetland deposits stretch southward from Licton Springs Park to the southern edge of the present day Wilson-Pacific School property[2]. These characteristics of the landscape, though largely hidden from view, continue to influence the hydrologic function of the lower Densmore Basin, and help to provide a clearer narrative of place that may offer clues to both causes of problems and potential solutions.

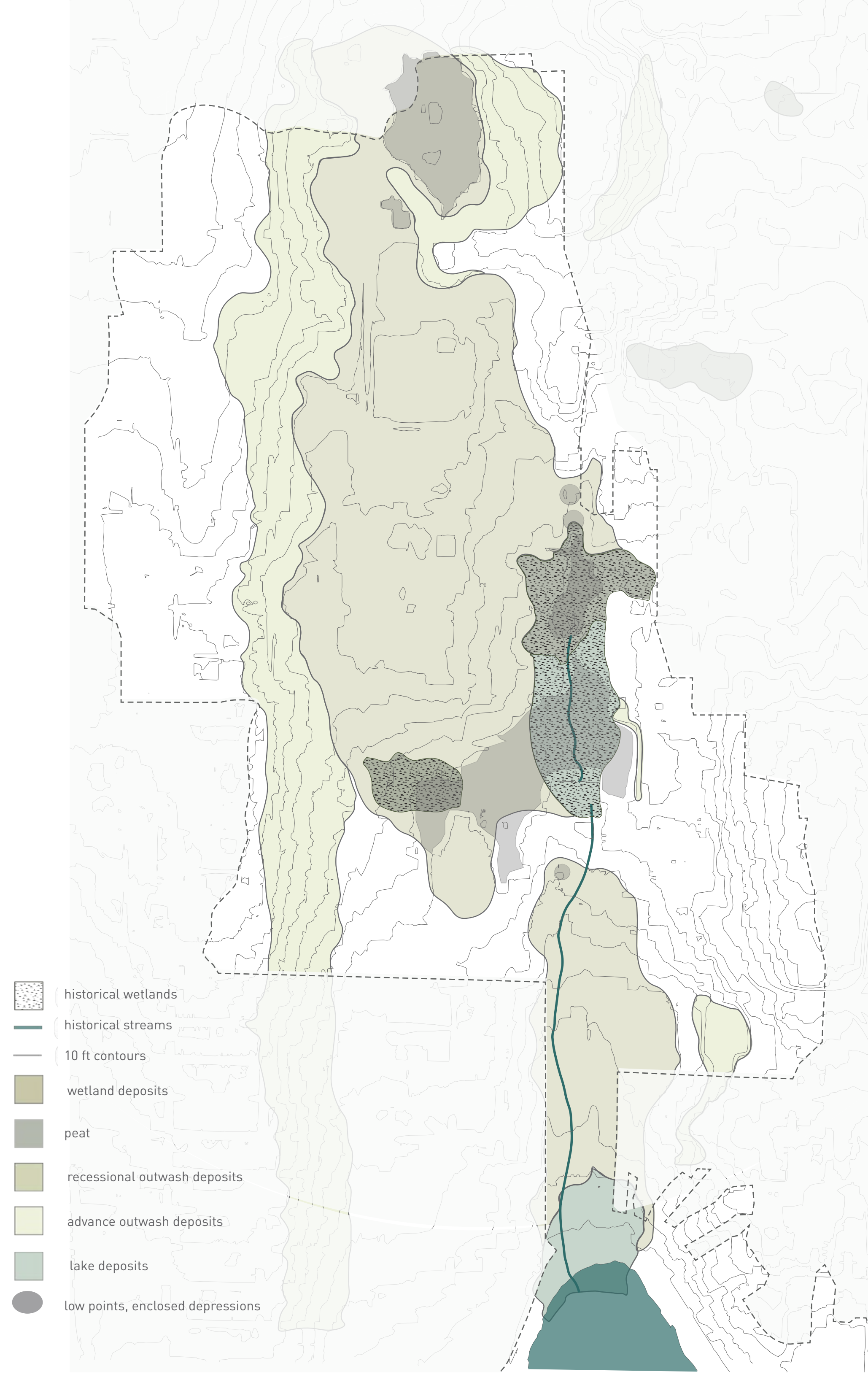


Figure: 4.3

BUILT ENVIRONMENT

As Seattle grew, many of these watery landscapes were supplemented with artificial fill to make them more suitable to build upon[2]. As of 2003, 47% of the basin was covered by impervious land uses, with an expected increase of 30% as a result of increased development[1].

According to Joe Starstead, watershed resource specialist and de facto SPU historian, many of the properties located along the historic creek path and around saturated Licton Springs Park remained "conspicuously undeveloped" until the 1950s and 60s[3].

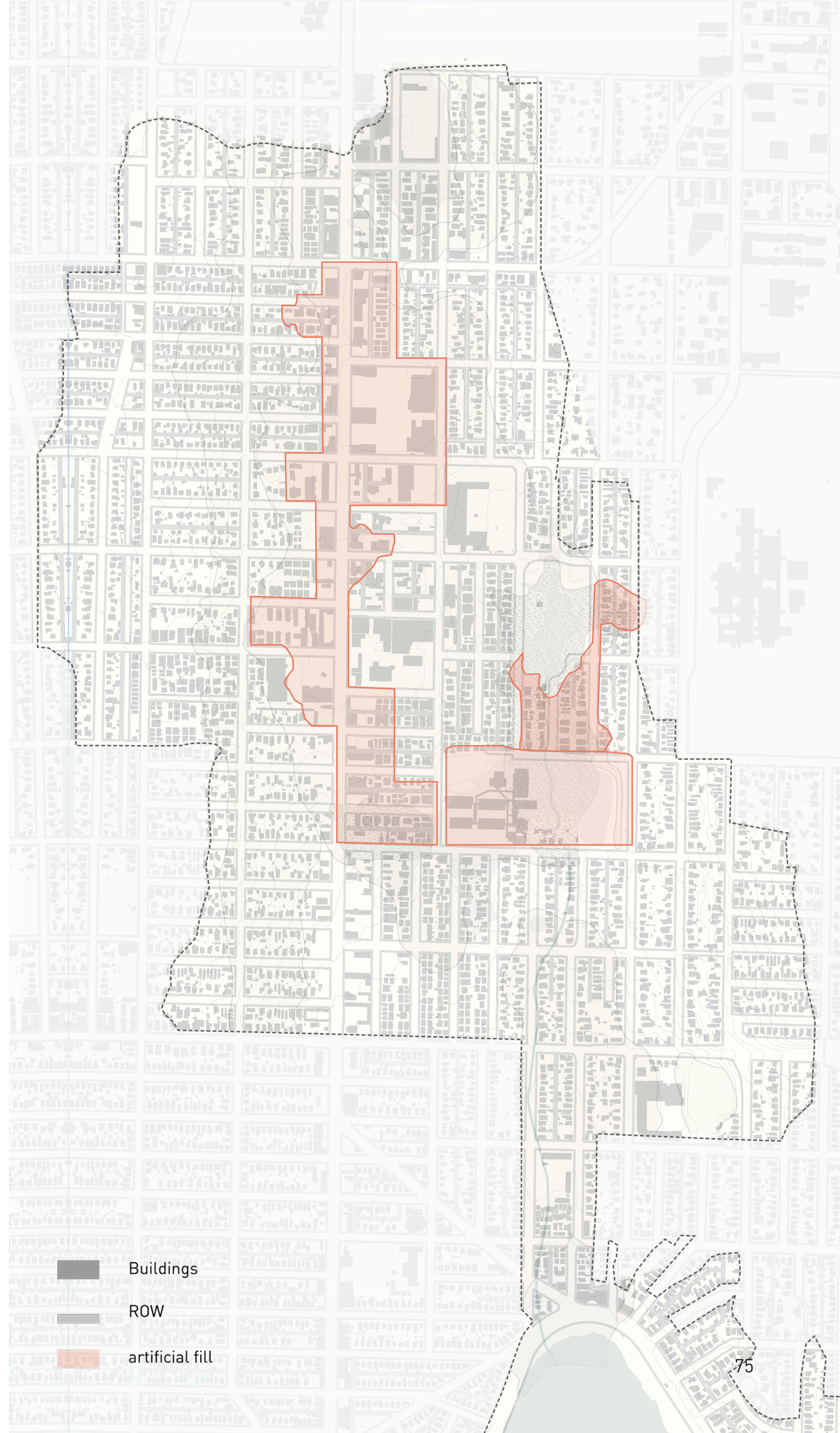


Figure: 4.4

HYDROLOGICAL SYSTEM

The central stem of the capacity-constrained and aging drainage system of the Lower Densmore Subbasin travels north to south.

From beneath Washelli Cemetery, it essentially forms a funnel as it progresses toward Green Lake, with flows from the western part of the basin converging with those from the north and east on either end of Licton Springs Park. Close inspection of the drainage system at the north end of the park reveals a highly complex tangle of pipes and diversion structures[1]. The creek and spring waters receive toxic stormwater runoff from the pipes upstream that are now connected to the creek. Many streets in the northern areas of the basin have no drainage infrastructure, and thus, rainwater that falls there simply runs off, descending upon the drainage mainline running east to west beneath N 105th St. Many crucial segments of the system, such as areas where flows converge, are aging, in a state of decline, and will soon need replacing[3].

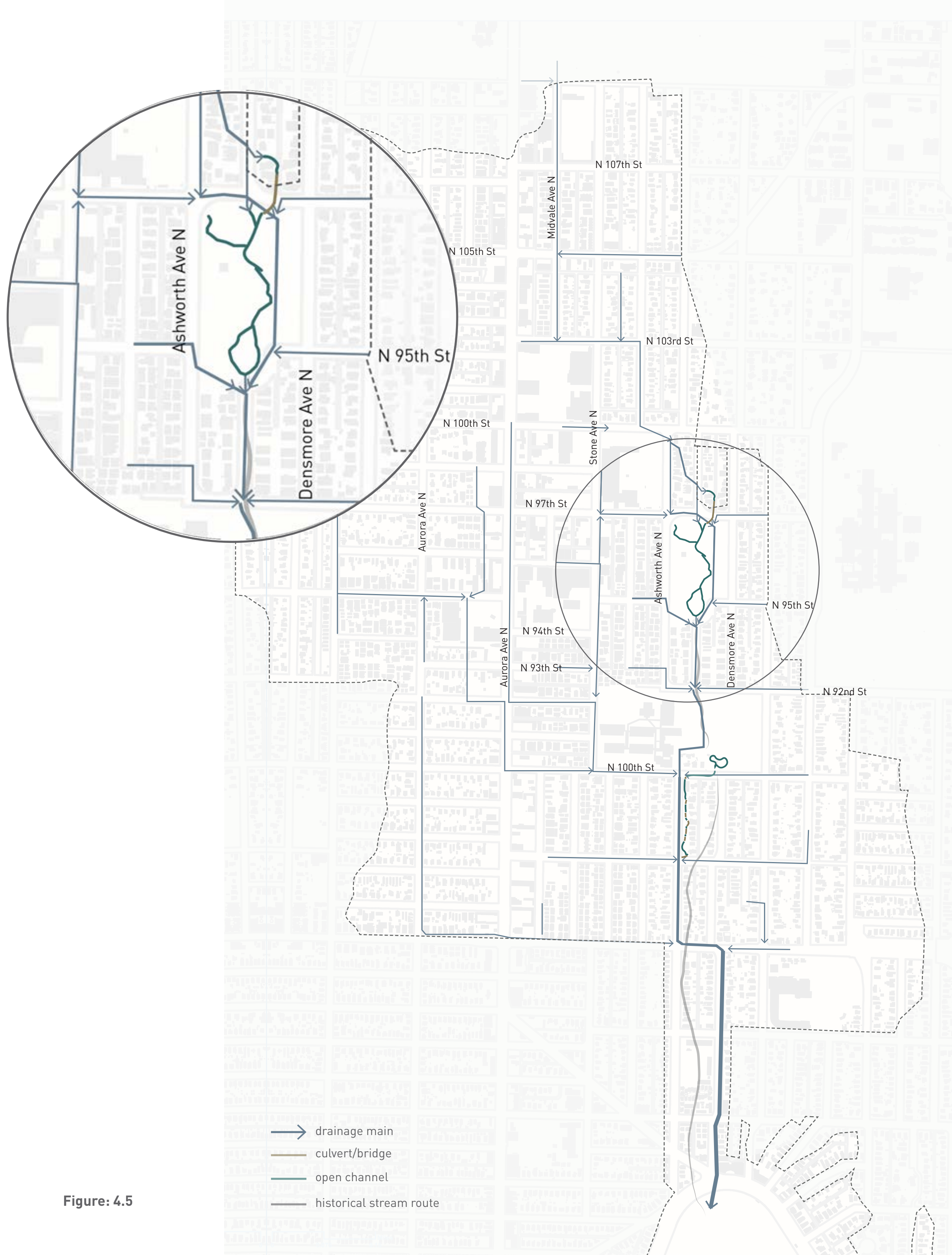


Figure: 4.5

ENVIRONMENTAL VULNERABILITY

Overlaying the clustering of flood risk indicators with the existing drainage system and artificially filled areas reveals what appears to be a relationship between these phenomena. In multiple instances, flood risk indicators coincide with convergence points in the drainage system in which flows traveling from different areas of the basin are merging together.

Flood risk indicators also tend to coincide with areas of artificial fill, especially where they are underlain by peat and wetland deposits. Developed areas underlain by peat are not only vulnerable to flooding, but to peat settlement as well, adding another dimension of risk.

In the Aurora-Licton neighborhood, vulnerability has been built into the urban environment through a failure to recognize the utility of creek and wetland landscapes in their natural state, as well as an ignorance of the impacts resulting from their transformation. In at least two locations, the Midvale Pond vicinity and the Licton Springs Park vicinity, multiple overlapping flood risk indicators reveal important areas for further investigation and intervention.

I explore the character of the Lower Densmore Subbasin on the following pages through four of the five major map categories employed in the citywide analysis. These mapped parameters illustrate why this area emerged as high priority for potential floodable space implementation. Because it was discussed earlier, flood vulnerability is excluded from this next section.

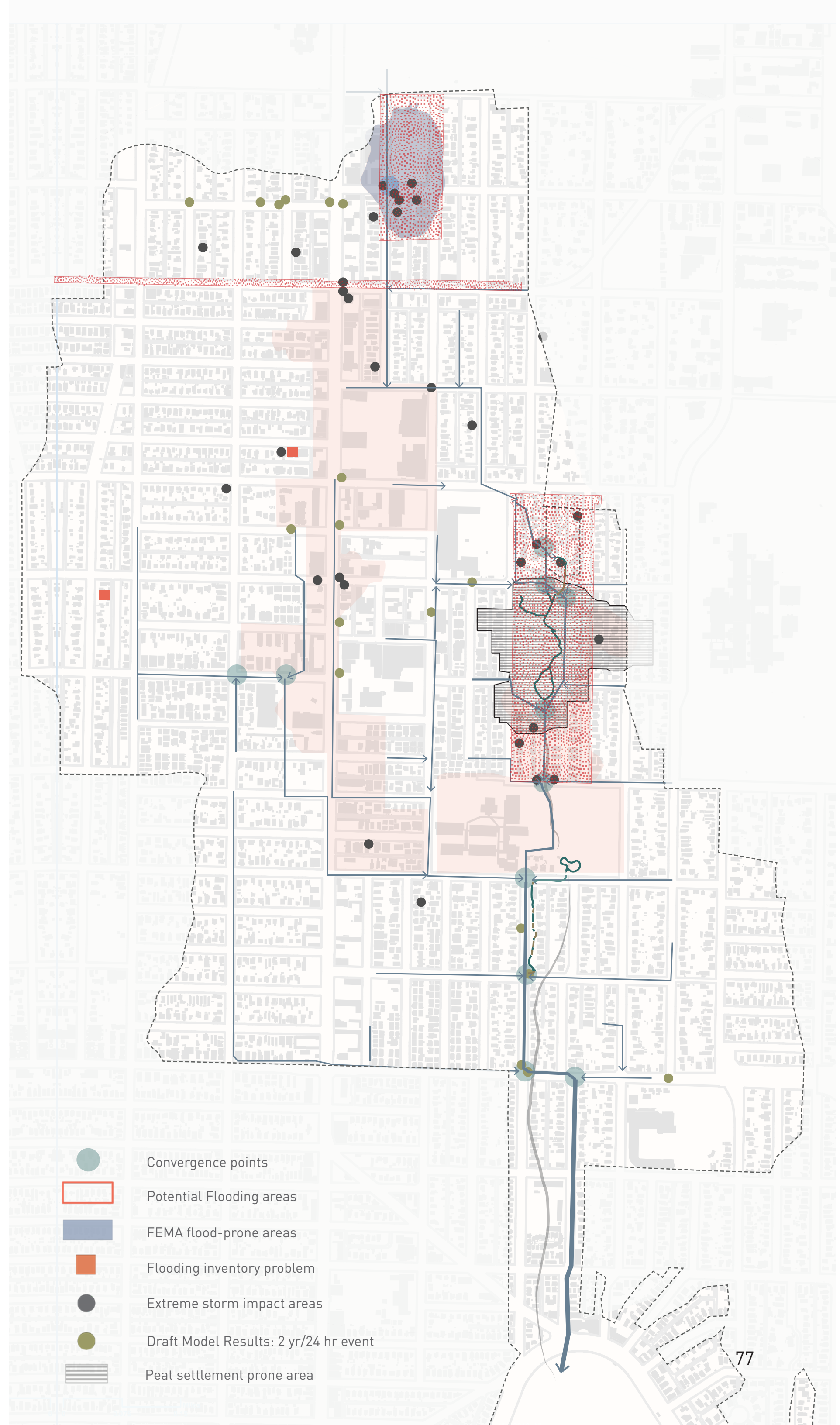
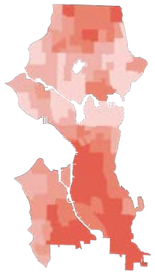


Figure: 4.6

DENSMORE BASIN: District Analysis

Figure: 4.7

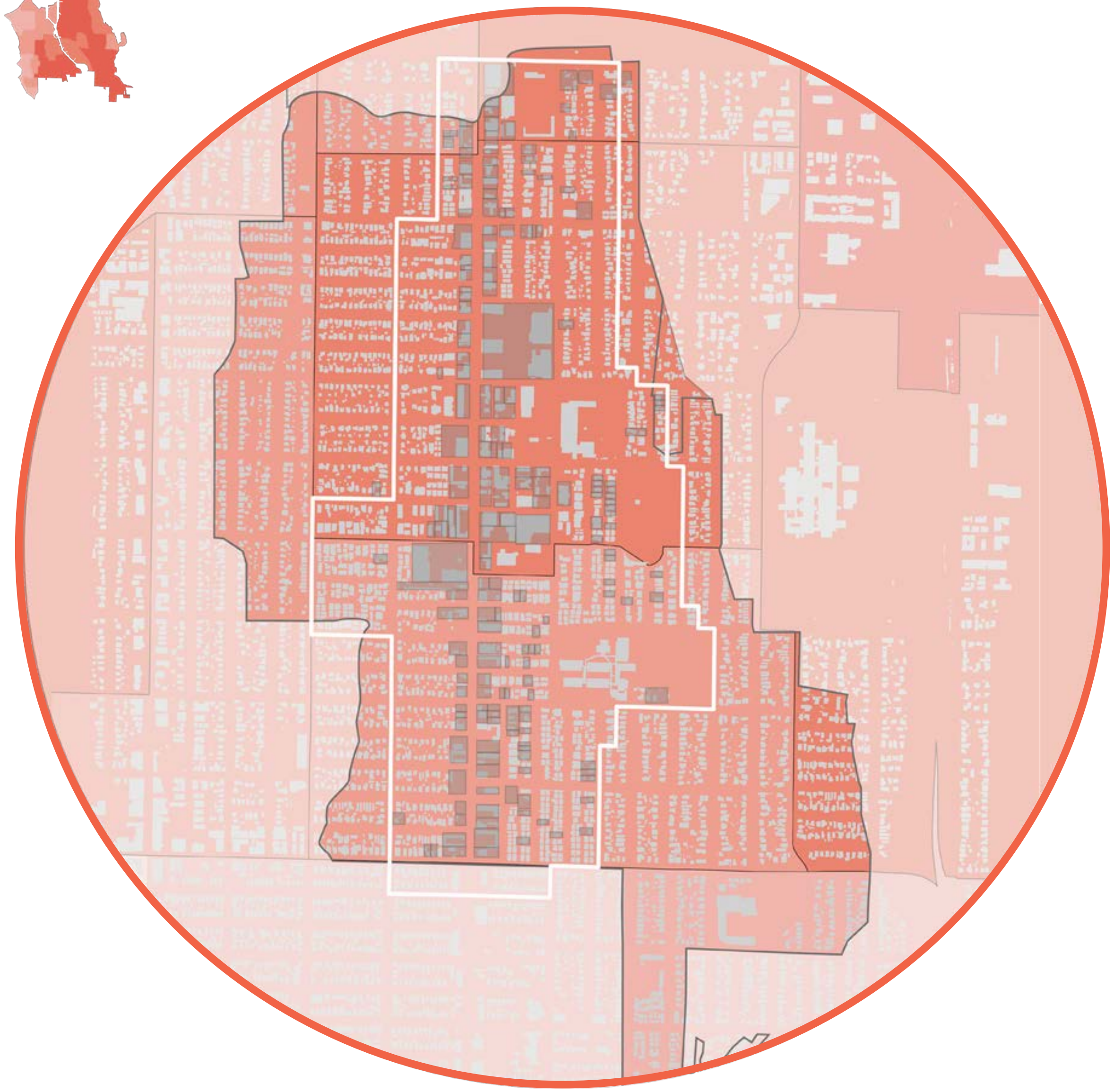
RACIAL and SOCIAL EQUITY



The Lower Densmore basin overlaps with multiple census tracts spanning from the second most disadvantaged to second most advantaged census tract categories. As one moves south toward Green Lake, the census tracts gradually become more advantaged and therefore lower priority, according to the Racial and Social Equity index.

Much of the basin overlaps with the Aurora-Licton Urban Village, outlined in white. All urban villages have been upzoned in order to concentrate density and development in designated areas of the city in accordance with the Growth Management Act[4]. Although the basin is nearly fully developed, there are a number of locations in which parcels are not developed to their full zoning capacity at present[1]. This is reflected in the spatial dataset "redevelopment potential", shown here, which depicts the locations of existing properties that are not developed to their full zoning potential, and are therefore likely to be redeveloped in the near future (an existing single-family home in an area now zoned as mid-rise, for example).

Without intervention, redevelopment of some existing land uses may displace current residents, especially more vulnerable populations. However, the discrepancy between the zoning and land use here, especially along or adjacent to commerical Aurora Ave N, may also represent an opportunity for SPU, along with other city agencies, to acquire property for community benefit.



Most disadvantaged, highest priority
Second most disadvantaged, second highest priority
Middle disadvantaged, middle priority
Second most advantaged, second lowest priority
Most advantaged, lowest priority
Buildings
Redevelopment Potential

Figure: 4.8

PHYSICAL SUITABILITY

The sub-basin is also highly suitable for the siting of potential floodable spaces given the amount of low points, flat areas, and enclosed depressions within it, the presence of open space, and the nature of the drainage system that serves it.

The overlaps and adjacencies between these systems offer significant potential to synergize drainage and open space functionality. For example, Licton Springs Park, the only public open space in the Lower Densmore Basin, is topographically lower than the surrounding lands. Additionally, the main trunk of the drainage system passes through it.

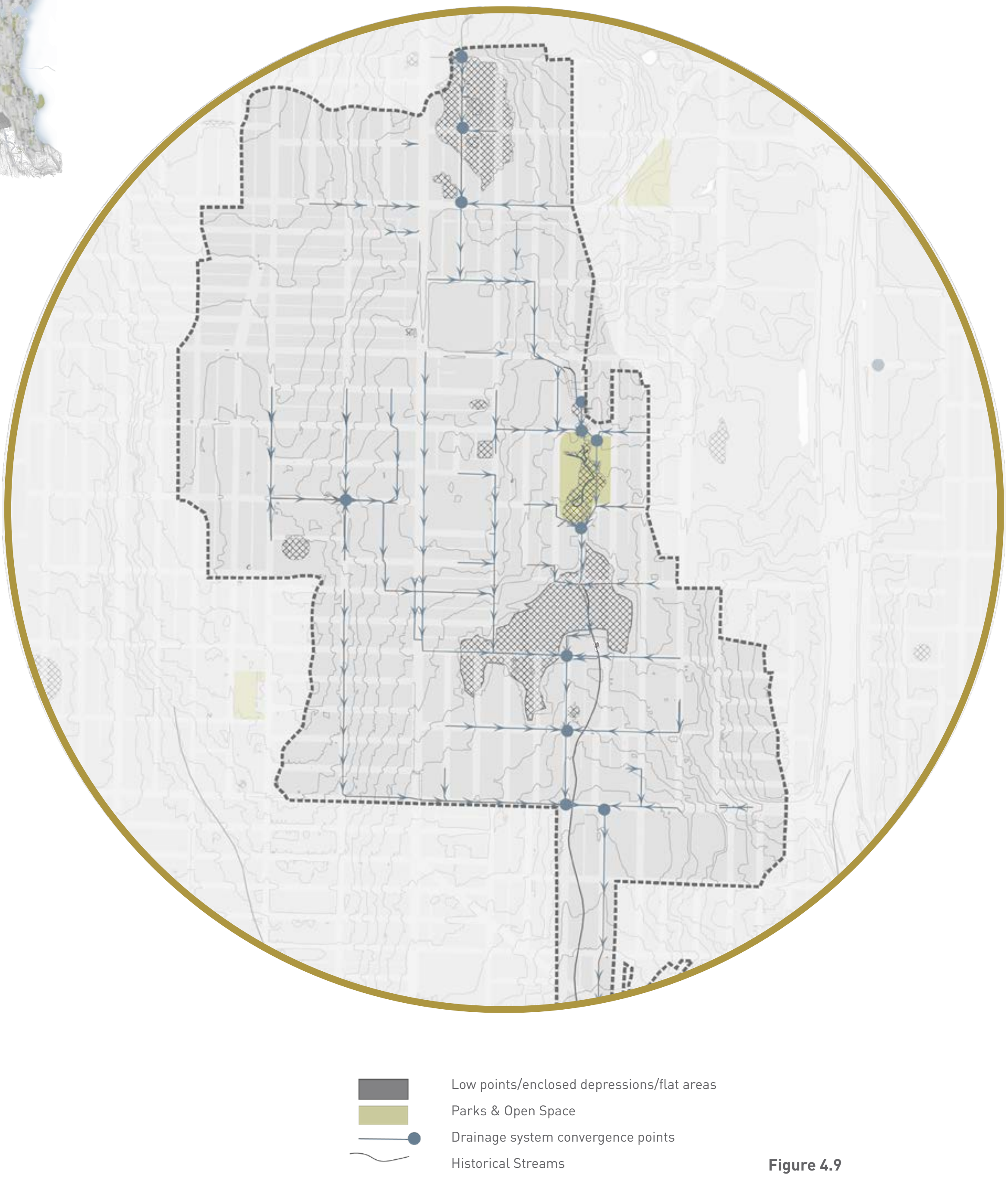
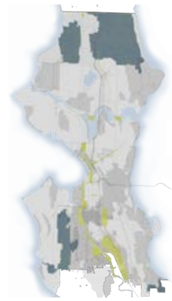


Figure 4.9

MULTIFUNCTIONAL ALIGNMENT at SPU



As previously discussed, the whole of the area is capacity-constrained in terms of stormwater drainage. Like much of Seattle north of N 85th Street, the infrastructure here, which discharges to a King County storm drain, was not designed with capacity to convey runoff from the increased density created by additional development[1].

Given the pressure that increased development and climate change impacts will put on the drainage system, at some point in the near future, SPU will need to address the capacity constraints in this area in one way or another. In terms of the potential to synergize with planned or ongoing CIP work, particular streets in the basin are designated for Natural Drainage Systems (NDS) Partnering. Because NDS Partnering typically takes the form of a GSI project in the ROW, a floodable space intervention in the ROW could represent a new, more intensive approach to NDS Partnering.

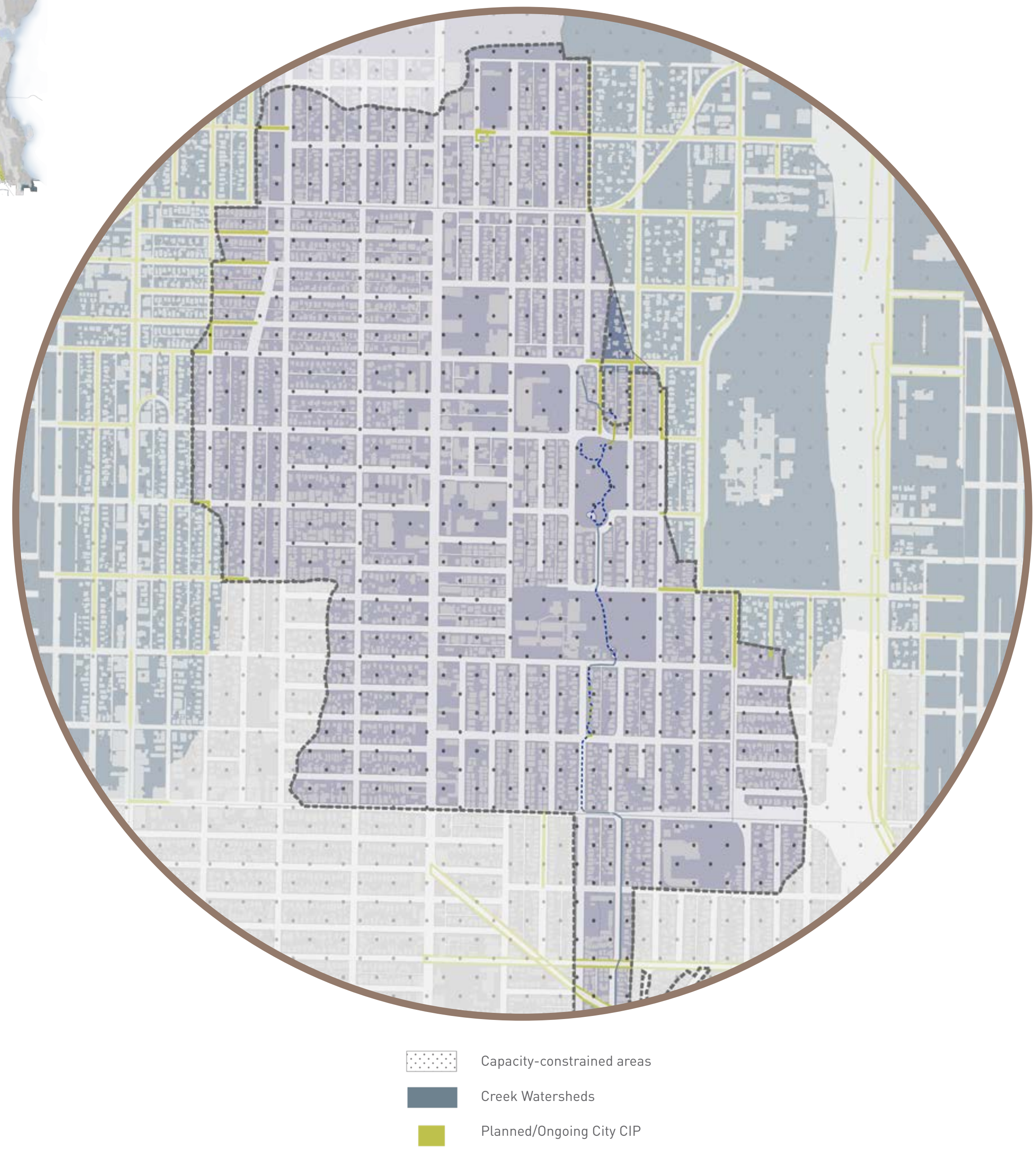
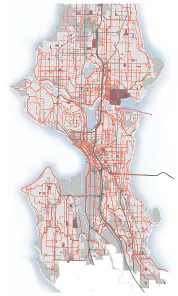


Figure: 4.10

OTHER POTENTIALS for CO-BENEFITS



A large swath of the Aurora-Licton urban village is considered by SPR to be a park gap, as the only public open space in the area is Licton Springs Park along the urban village's eastern edge.

If land acquisition in the neighborhood is feasible, this represents a potential opportunity for SPU to partner with SPR in the development of a floodable open space that might serve community park needs while addressing drainage and flooding issues. Planned bike routes will one day cut through the neighborhood, presenting a possible opportunity to synergize bike lane development with floodable GSI in the right-of-way.

Multiple adjacent land uses in the area, like schools, city-owned property and churches, represent possible partnership opportunities. For example, the Wilson-Pacific School may have an interest in partnering with SPU in the development of a floodable space on their large, low-lying property that could serve as an interactive, educational outdoor laboratory for their students.

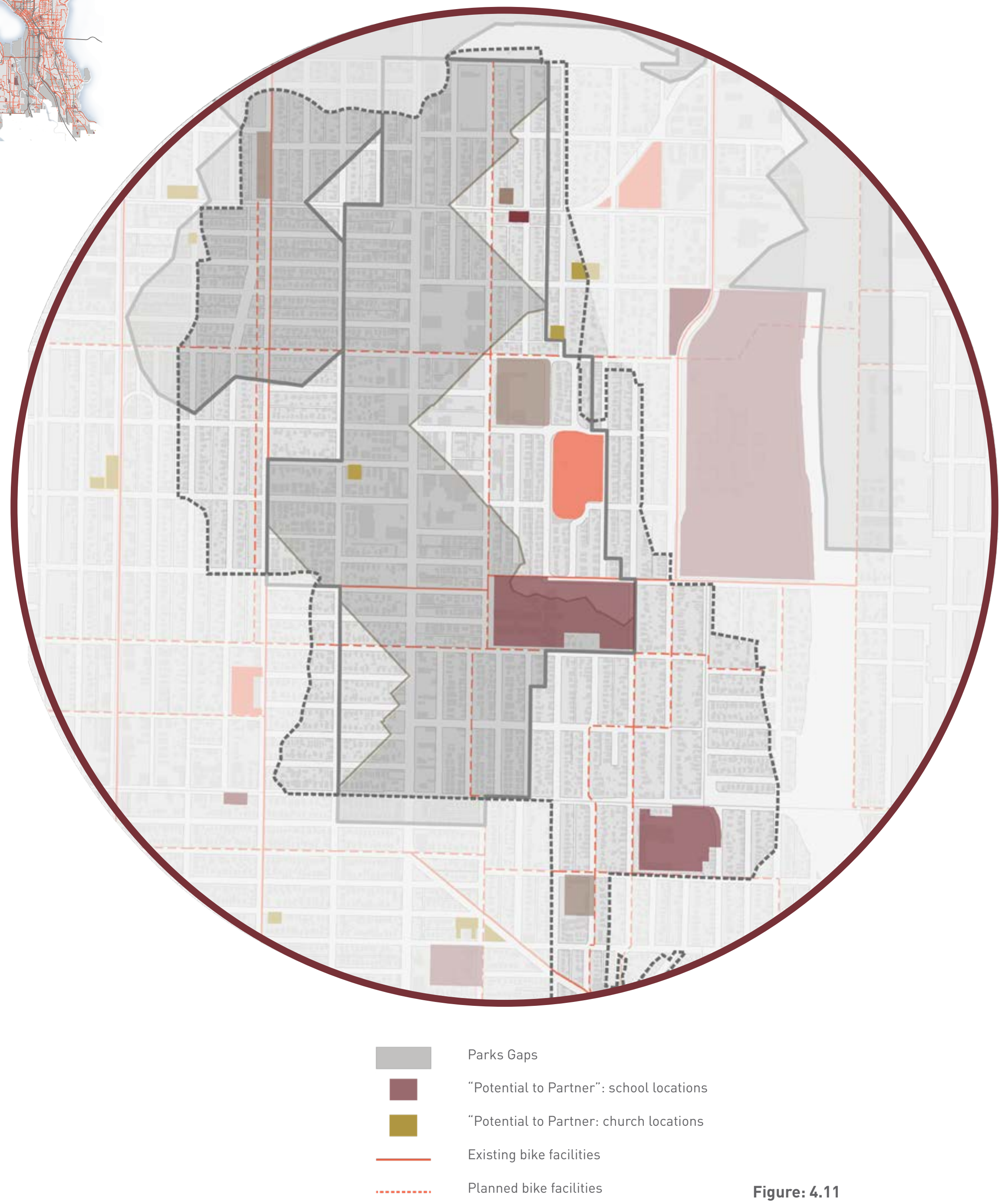


Figure: 4.11

ANALYSIS SYNTHESIS: AREAS OF POTENTIAL

Through my analysis process, I identified a number of sites in which several overlapping factors indicated opportunities to leverage advantageous adjacencies to the existing drainage system.

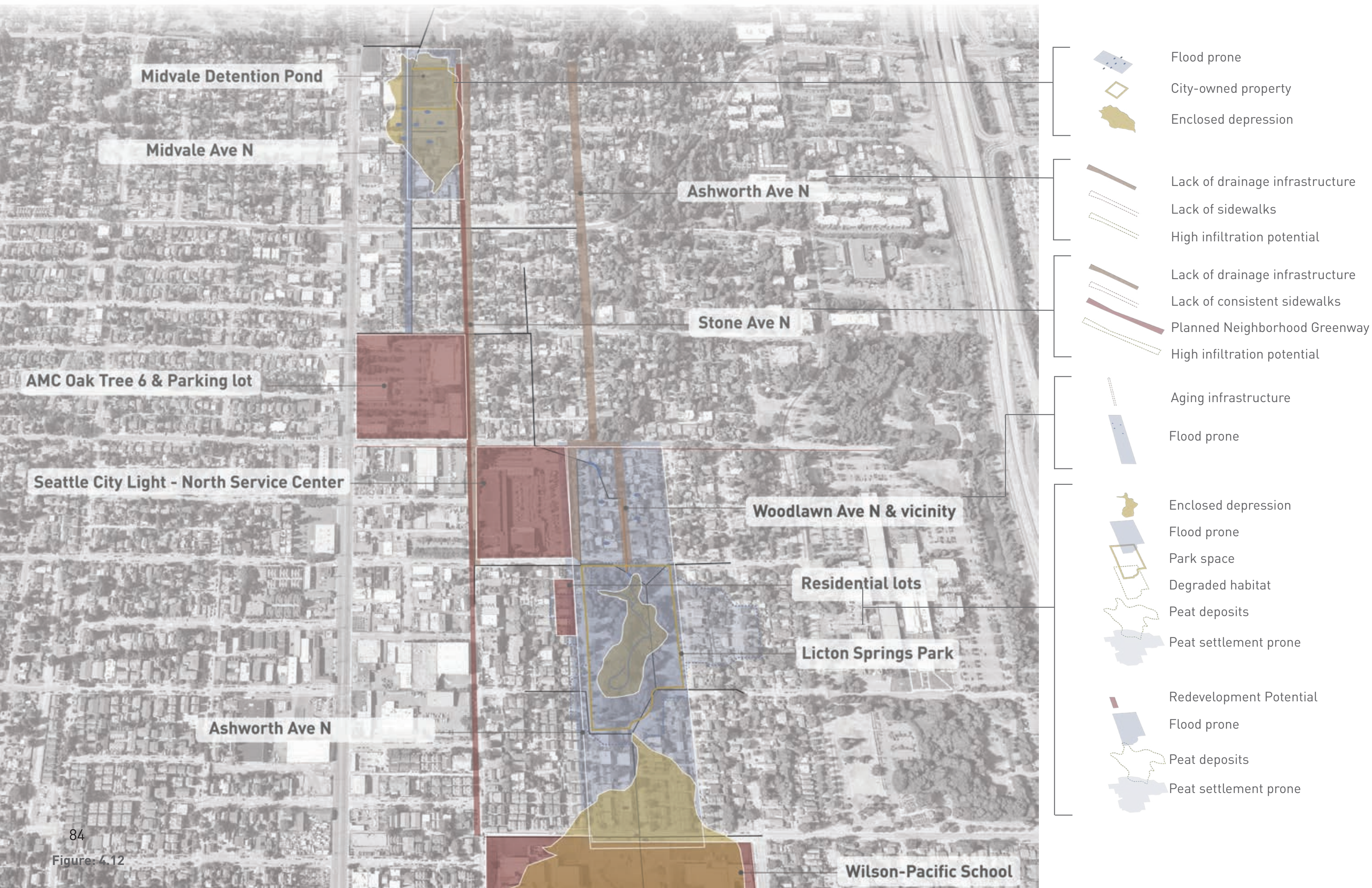
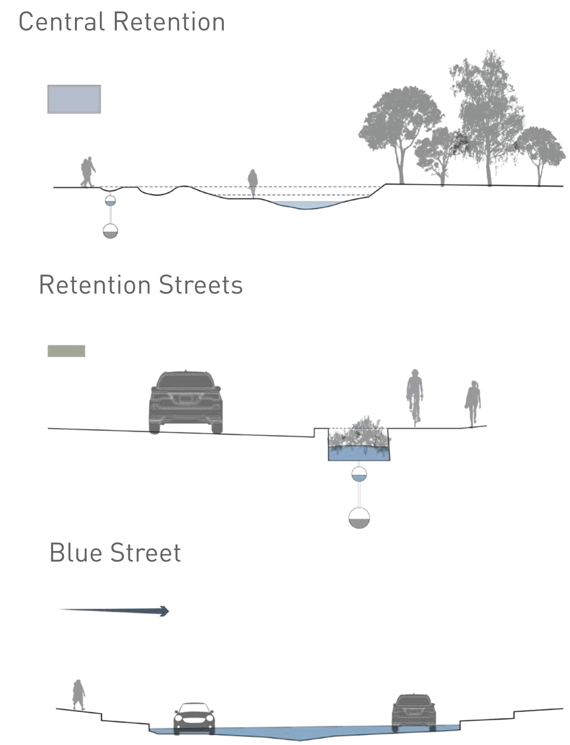


Figure: 4.12

POTENTIAL INTERVENTIONS

I explored the possibilities for interventions in the Lower Densmore Subbasin and Aurora-Licton urban village to be part of an interconnected, floodable surface water system, modeled after Copenhagen's Cloudburst Toolbox strategies and approach. This would function as a surface-level supplement to the existing piped system, building redundancy, flexibility, and flood resiliency into the neighborhood while simultaneously catalyzing other community benefits.

Figure: 4.13



PROPOSED HYDROLOGICAL SYSTEM

EXISTING PIPED SYSTEM

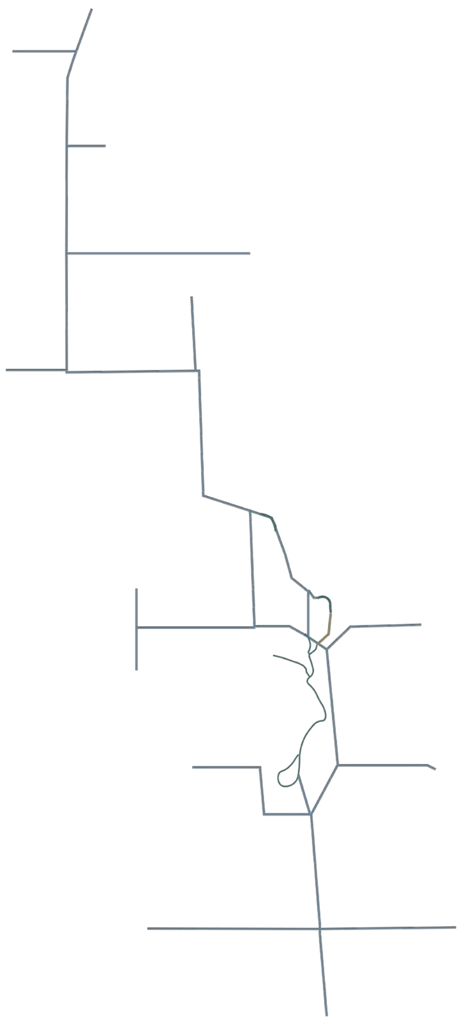


Figure: 4.14

Modeled after the Cloudburst toolbox, my proposed hydrological system for this area employs a range of strategies, utilizing central and local retention areas, detention streets, and blue street elements. It also utilizes the concept of emergency overflow areas, inspired by interventions such as Madison Valley Stormwater Storage Facility. Such strategies were chosen for their applicability to this area due to the dense, low-lying nature of both this basin and the areas of Copenhagen in which these have been applied. Some of these spaces have water present in the majority of rain events; others, only in extreme events.

It should be noted that this proposal is conceptual: rather than designing a system to accommodate a specific volume of water, this is a vision of an overll integrated vision for this area that seeks to illuminate as many different options as possible.

In recognition of the amenities offered through the presence of surface water in the public realm, the goal of this blue-green infrastructure system is to maximize water infiltration and purification, and to keep flows out of the piped system and on the surface whenever possible. However, water priorities change depending on the situation and severity: blue-green infrastructure is intended as the primary stormwater system, but remains connected to the original sub-surface piped system as a backup for instances of very high flow when this first line of defense is overwhelmed.

During more extreme events in which the piped system is also overwhelmed, flows are again directed to the surface in designated emergency overflow areas, such as stormwater parks and blue streets. This layered, redundant system has the flexibility to perform under a range of scenarios, building resiliency into the infrastructural fabric of the neighborhood while simultaneously using surface water to connect public spaces. The overall strategy will be elaborated upon in the following pages.

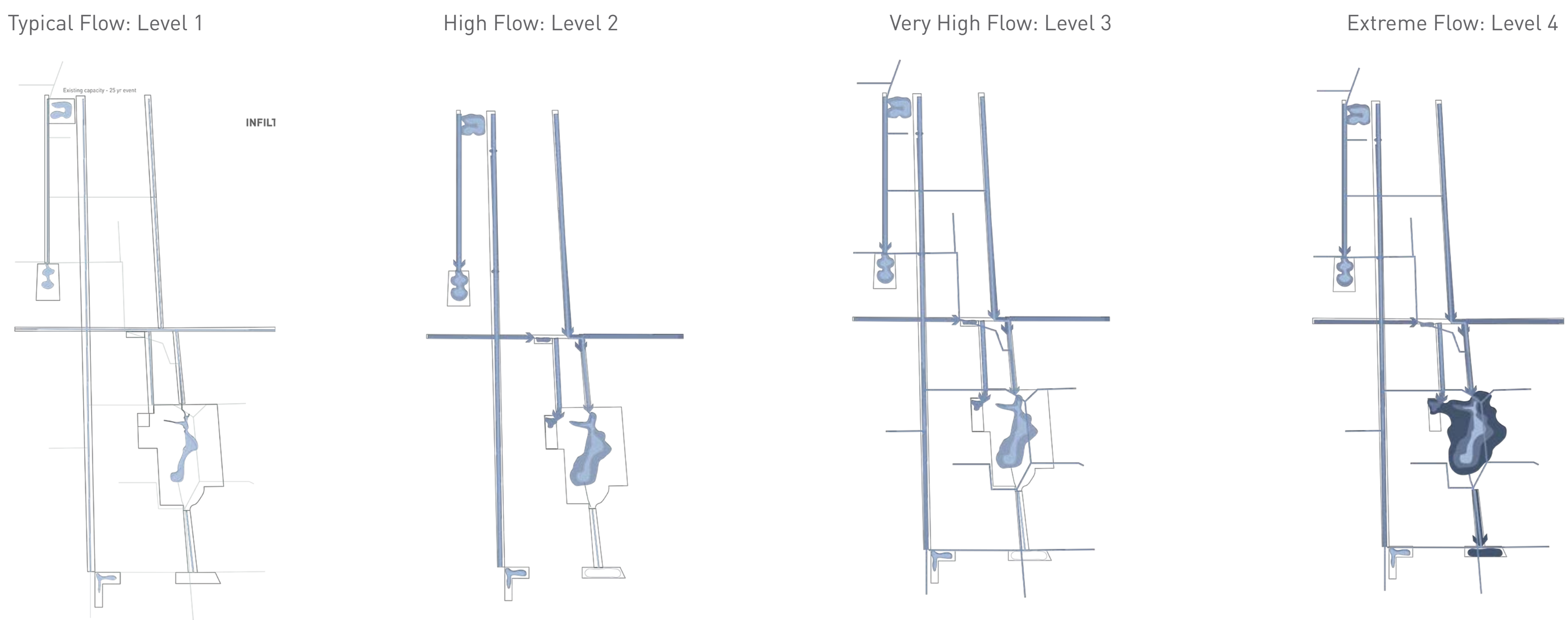

Typical Flow: Level 1
High Flow: Level 2
Very High Flow: Level 3
Extreme Flow: Level 4
Existing capacity - 25 yr event
INFILT

Figure: 4.15

TYPICAL FLOW: LEVEL 1

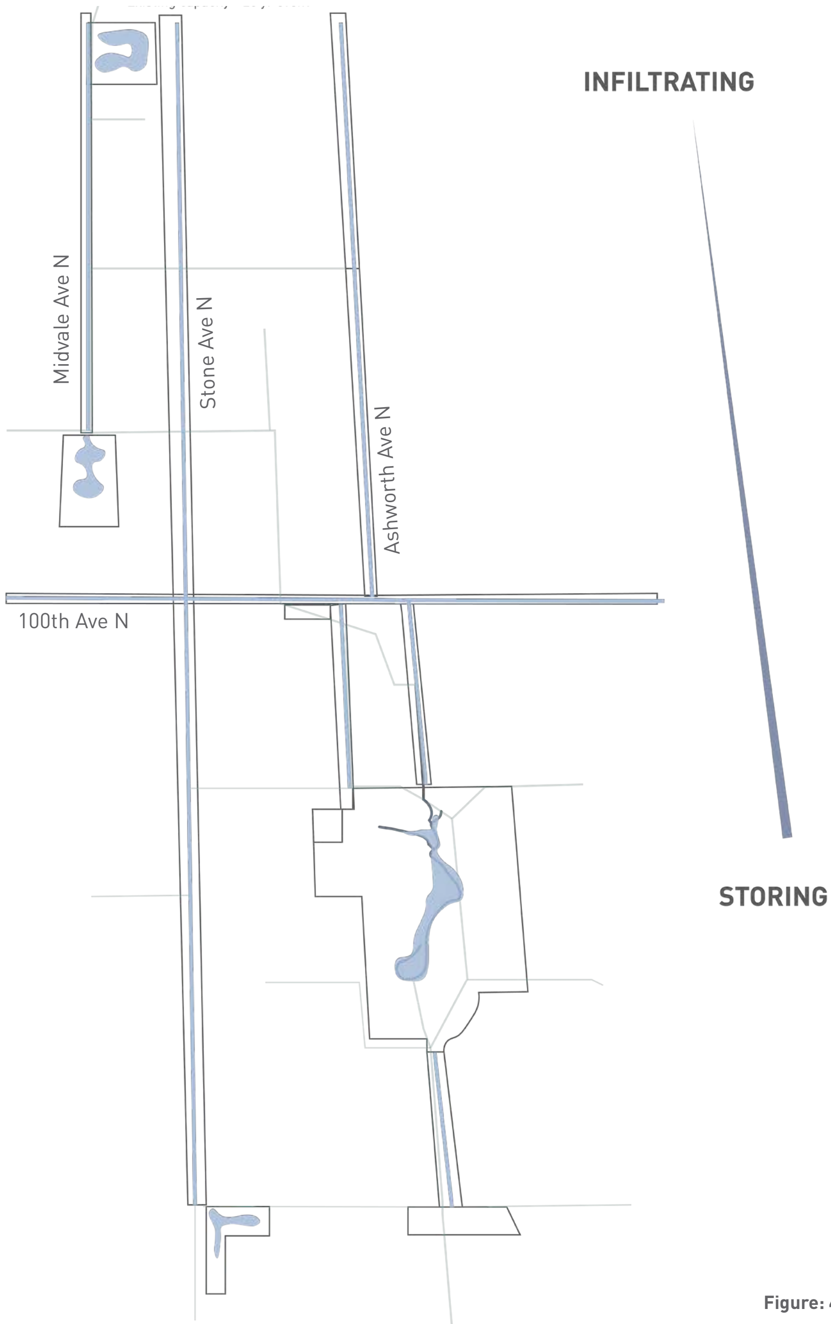


Figure: 4.16

In the typical, everyday stormwater flow scenario, all surface level interventions, including central and local detention areas, manage their own stormwater. Detention street interventions on Midvale Ave N, Stone Ave N, and Ashworth Ave N are sited in part for their high infiltration potential, and opportunities for this are limited elsewhere in this stormwater network due to the saturated nature of peat and wetland deposits. In these areas, water is stored and delayed.

HIGH FLOW: LEVEL 2

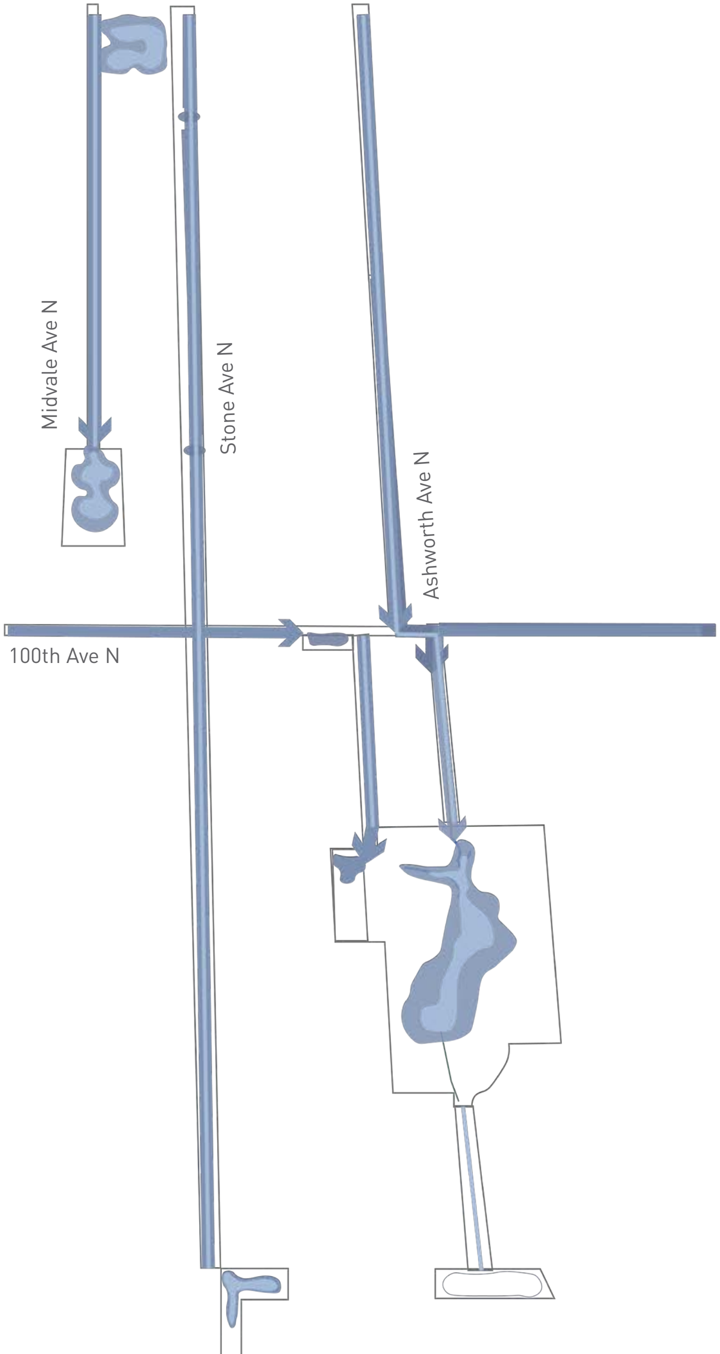


Figure: 4.17

In high flow scenarios, cloudburst pipes close to the surface act as connectors between the BGI system elements, in order so that those with lesser capacity, such as retention streets, may overflow to central retention areas, which have more capacity to hold the higher flows.

VERY HIGH FLOW: LEVEL 3

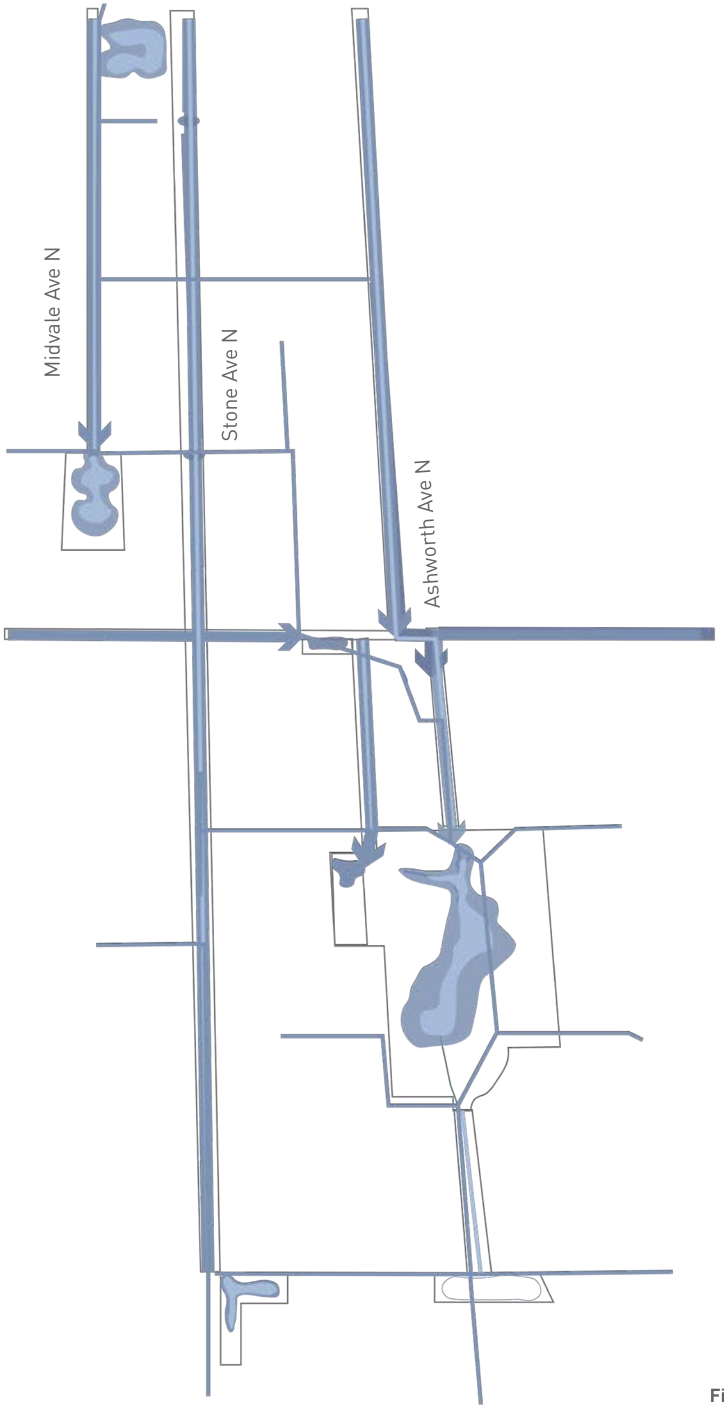
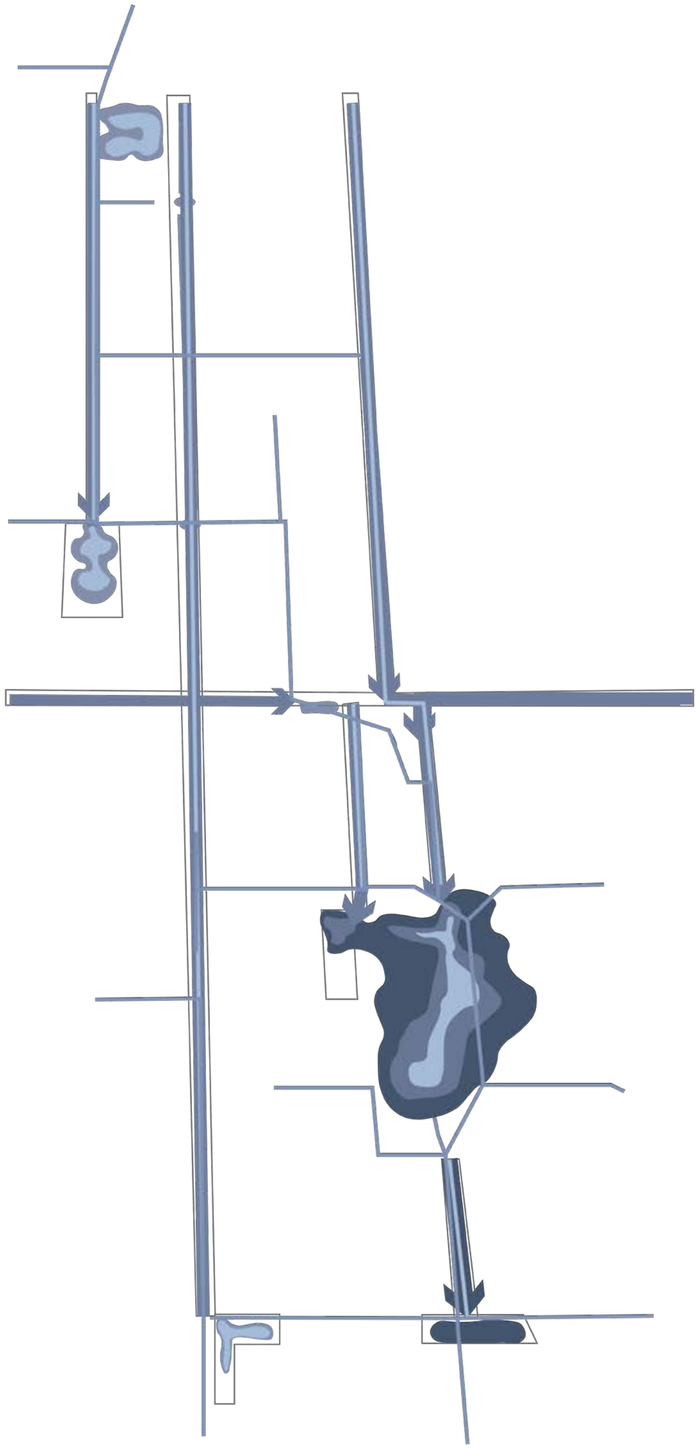


Figure: 4.18

In situations of very high flows, the overwhelmed BGI systems discharge into the original, underground pipe system as a backup. In this scenario, because it is a more extreme (and hopefully rare) event, priority shifts from the typical goals of infiltration and improved water quality to avoiding flooding of the right-of-way, residential and commerical properties. However, due to the age and limited capacity of the existing pipe system, as part of the BGI installation process, these pipes should be replaced or upgraded to ensure that this layer of flood prevention performs adequately.

EXTREME FLOW: LEVEL 4

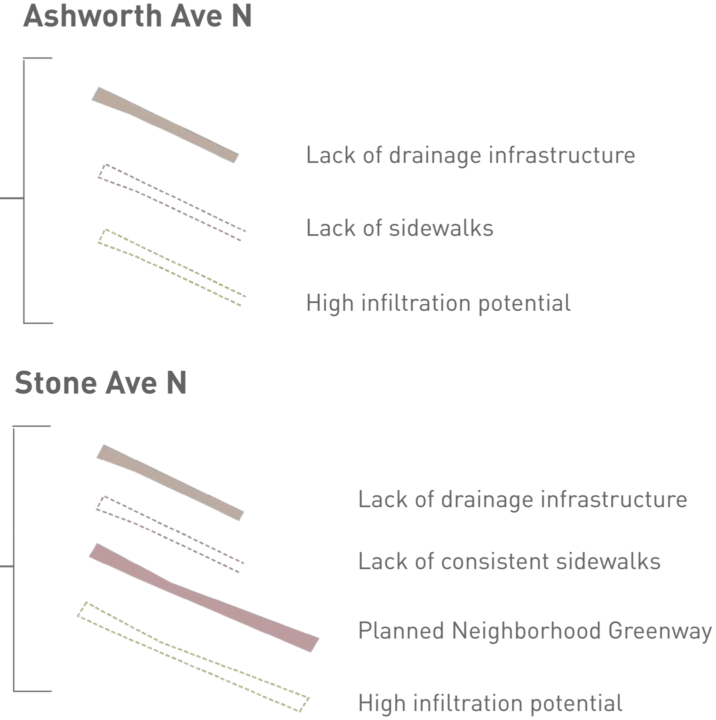


In extreme storms, it is possible that the prior three lines of defense against flooding will be insufficient. In these scenarios, in which the BGI elements and underground pipe system are overwhelmed and at capacity, pipes will discharge into designated blue streets and emergency overflow areas. For example, if Licton Springs' storage capacity were to be reached, water would spill over onto Woodlawn Ave N, a designated blue street. Flows would be conveyed to the emergency overflow area at the Wilson-Pacific School. The idea is for this fourth line of defense to be a last resort, perhaps for a storm on the scale of an 100 or 150-year flood.

Figure: 4.19

AREAS OF POTENTIAL: Ashworth Ave N & Stone Ave N

Figure: 4.20



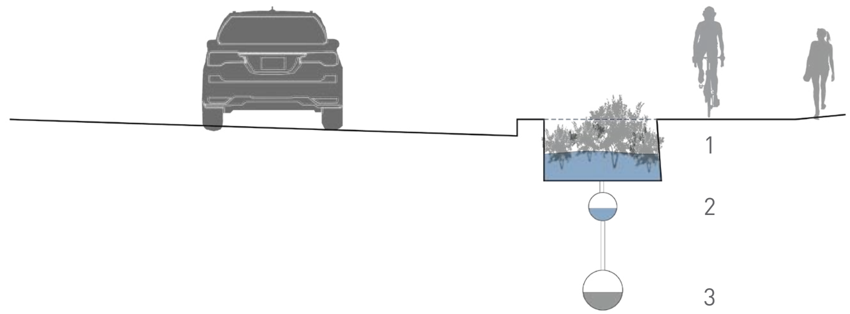
Both Stone Ave N and Ashworth Ave N show promise for a floodable intervention in the right-of-way by virtue of their adjacency and connection to other identified areas of potential (as shown within the map on page 86) and their proximity to the drainage mainline.

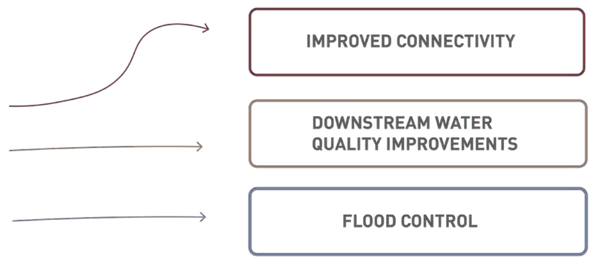
Both streets lack drainage infrastructure north of N 100th St, and thus, stormwater runs off these sloped streets to the capacity-constrained drainage mainline, which runs east to west beneath N 105th St. Stone Ave N lacks consistent sidewalks, while Ashworth Ave N lacks sidewalks completely. Due to their underlying geology, both streets have high infiltration potential.

SDOT also plans to designate Stone Ave N a Neighborhood Greenway. Neighborhood greenways are safer, calmer streets in residential areas that encourage walking and biking, discourage vehicular use, and "get people where they want to go, like parks, schools, shops and restaurants"[5].

Figure: 4.21

Retention Streets





These overlapping factors suggest that Stone Ave N and Ashworth Ave N stand to benefit from an intervention in the right-of-way. I propose that these streets be established as retention streets that at once reduce flooding, improve water quality, replenish groundwater, and increase safety and connectivity for pedestrians and cyclists by formalizing the right-of-way in a way that accommodates flexible, flood-resilient blue-green infrastructure.

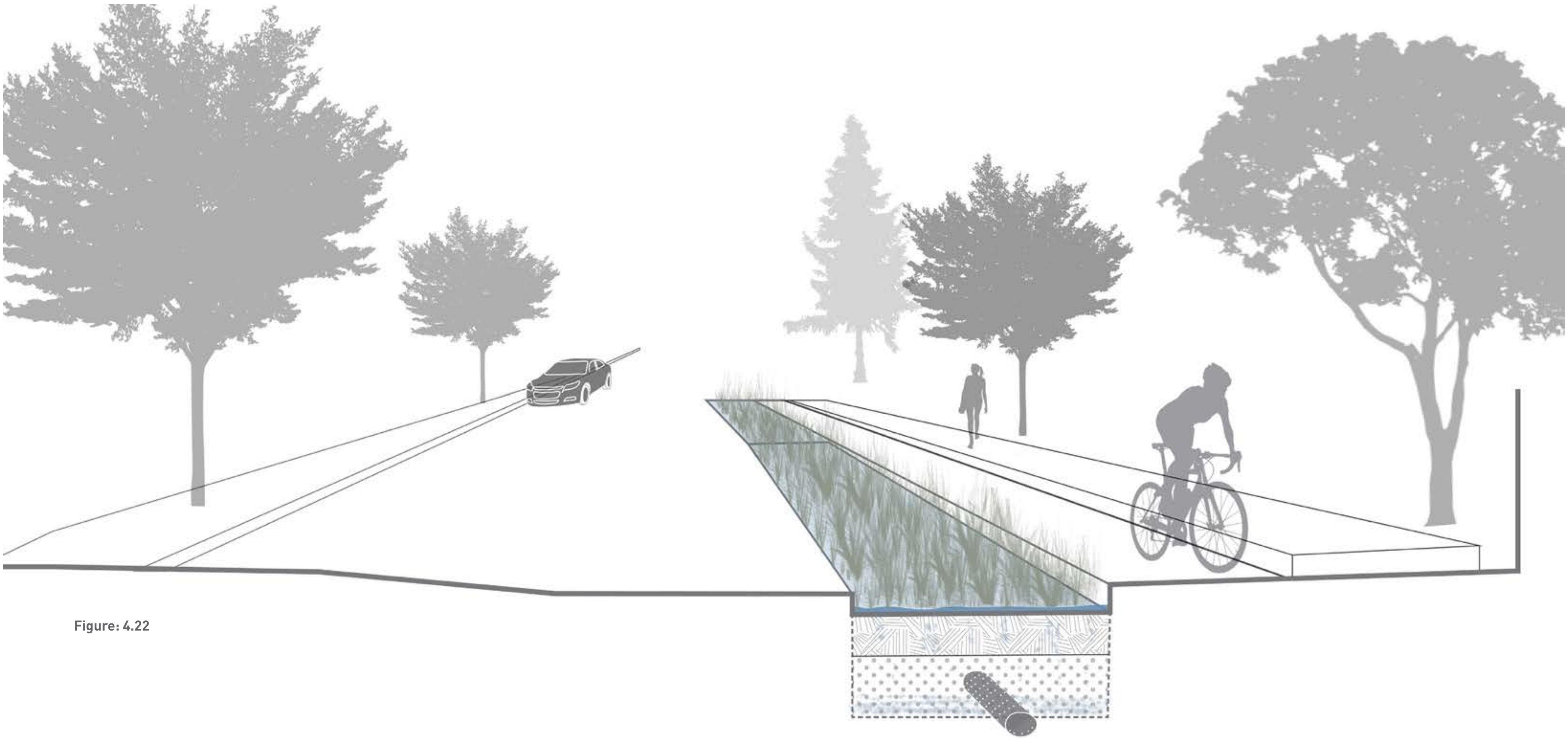


Figure: 4.22

NORMAL CONDITIONS (Level 1)

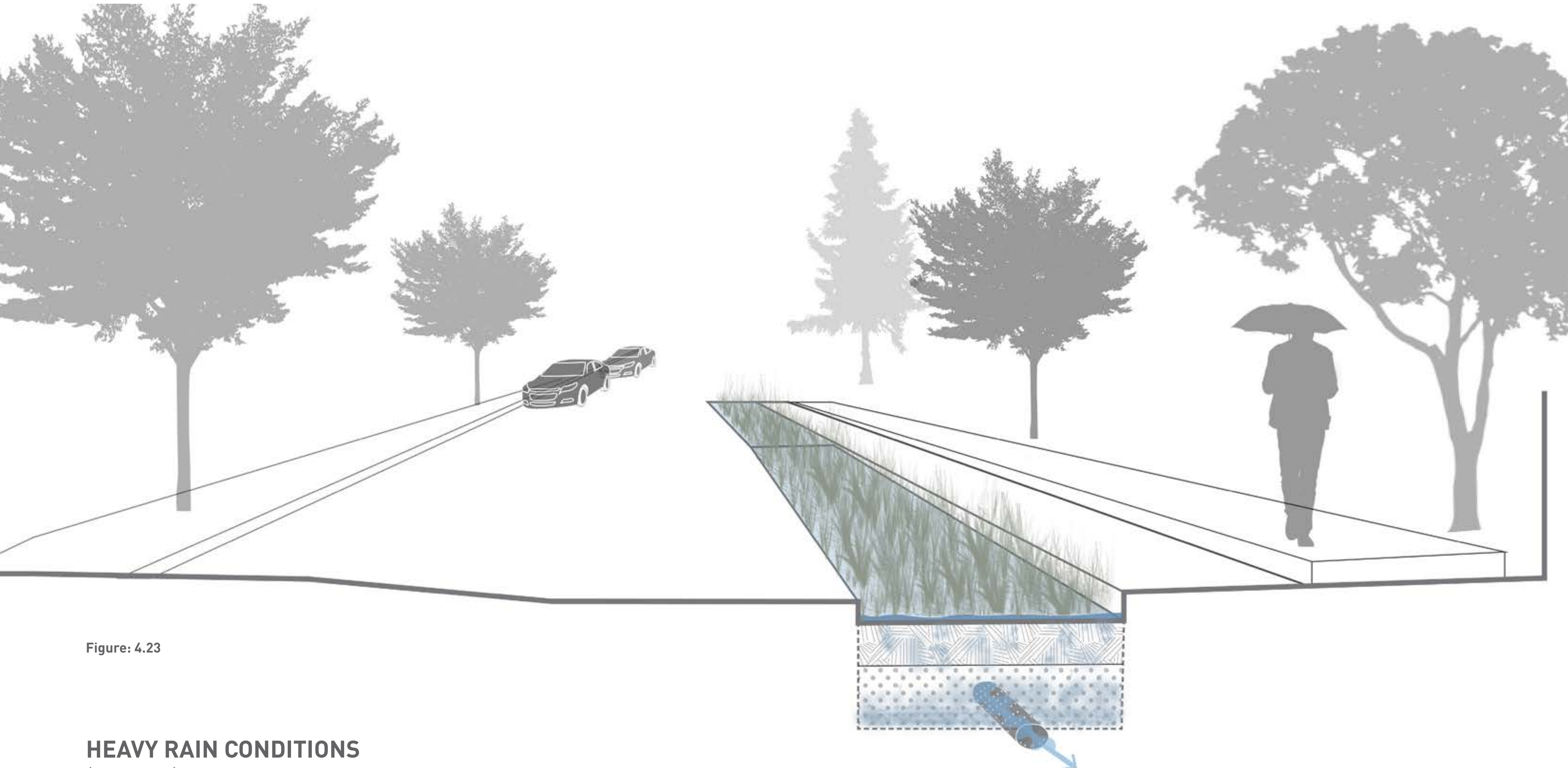


Figure: 4.23

HEAVY RAIN CONDITIONS (Level 2)

Licton Springs Park is a site of great historical significance that has become degraded in the wake of the area's urbanization. Long recognized as a sacred site and resource for Duwamish and other Coast Salish tribes, people gathered here to harvest the red-ochre paint produced by the iron oxide spring for generations. This was a place of ceremony and spritual renewal, and it represents one of the last remaining signifcant places of the Duwamish and other Coast Salish people, on whose land the City of Seattle was founded[6].

The sunken interior of the park remains a wetland, but its edges are choked by invasive species such as reed canarygrass and blackberry[7]. Licton Springs suffers troubles of both water quality and quantity: because the creek and spring waters receive toxic stormwater runoff from upstream, the wetland environment of the park is no longer considered valuable habitat by the Washington Department of Fish & Wildlife[8].

Formerly part of an interconnected system of groundwater-fed wetlands and creeks[3], the waters of Licton Springs are now diverted to the drainage system, the piped components of which are undersized and aging, and as a result, chronic, occasionally severe flooding has plagued the park and the surrounding area[8]. Present day Licton Springs Park and its degradation exemplifies the negative impacts of urbanization to hydrological and ecological systems.

Licton Springs Park exhibits many of the characteristics that I considered relevant to floodable space suitability and prioritization, such as harboring an enclosed depression, having significant flooding problems, and being a city-owned park space. However, through my secondary, more thorough analysis of this area, beyond the original set of citywide parameters I initially examined, I discovered additional information of significance that help make the case for how a floodable intervention in this area might manifest.

As aforementioned, given its long history as a wetland environment[2], Licton Springs Park and adjacent residential properties are underlain by peat, and are therefore prone to peat settlement. This risk is in addition to flood risk - some of these properties have had to install their own drainage lines to counteract flooding[3]. Furthermore, several of those properties are considered to have redevelopment potential according to the spatial dataset of the same name created by OPCD.

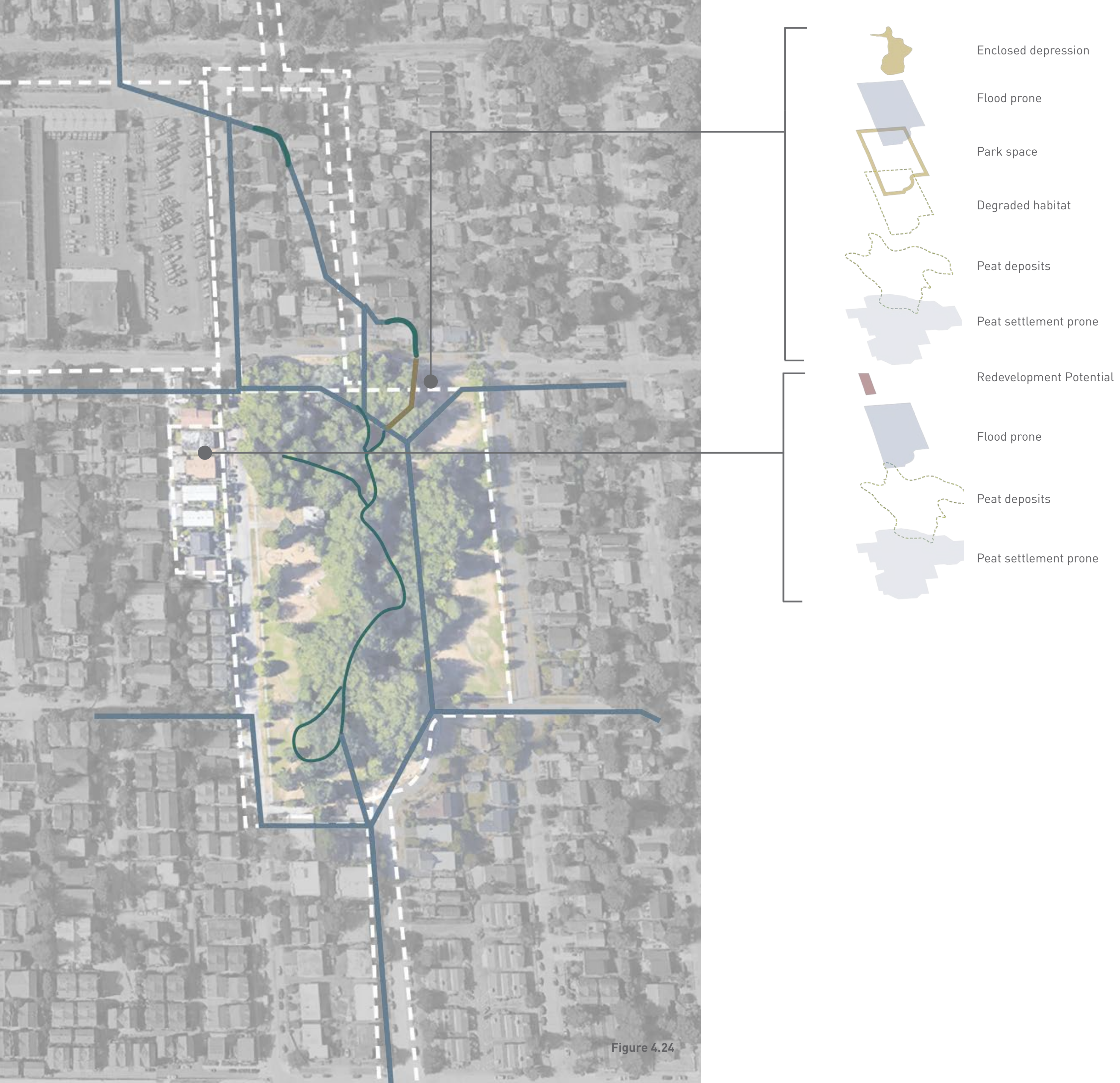

Enclosed depression
Flood prone
Park space
Degraded habitat
Peat deposits
Peat settlement prone
Redevelopment Potential
Flood prone
Peat deposits
Peat settlement prone

Figure 4.24

INTERVENTION: Licton Springs Expansion & Restoration: Central Retention

Licton Springs Park and the residential lots adjacent to it represent an excellent opportunity to achieve multiple benefits with a single intervention as a site for central retention.

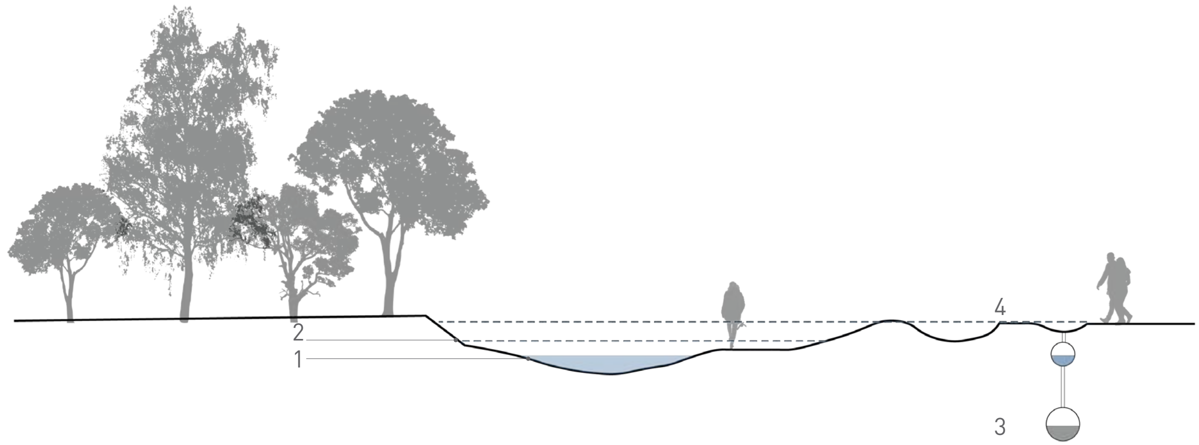
A regrading and expansion of the park, potentially involving acquisition of the adjacent at-risk properties and a topographical exaggeration to deepen depressions and raise pathways, would increase capacity to accommodate variable amounts of water in order to address both existing and projected future flood risk. This would have the additional benefit of expanding park space in a densifying neighborhood, and making the dynamism of surface water more visible in the public realm with the potential for educational as well as aesthetic benefits to the neighborhood and its residents.

Restoration of Licton Springs Park in order to clean as well as retain a larger volume of water might also incorporate ecological restoration to return the site as closely as possible to its pre-urbanized state with native wetland plants. Such restoration work would create additional wildlife habitat in an increasingly dense cityscape, and as a functioning wetland capable of removing pollutants from surface water, could benefit wildlife downstream as well.

Furthermore, representatives of the Duwamish tribe are working on the designation of Licton Springs as a City of Seattle landmark, which they've stated would incorporate the restoration of the site using indigenous plants and uncapping or daylighting all Licton Springs[6]. As SPU works towards its goal of becoming a community-centered utility concerned with equity, environmental protection, and resilience, restoration of Licton Springs to acheive multiple benefits may also represent an opportunity to partner with the Duwamish tribe on an area of interest and honor indigenous knowledge.

Amplifying the functionality of this pre-existing natural drainage infrastructure in this way would yield benefits for both humans and wildlife alike while simultaneously making the neighborhood more resilient to the impacts of climate change, improving quality of life, and connecting urban dwellers more directly with our most precious life resource: water.

INTERVENTION: Licton Springs Expansion & Restoration



- EXPANDED PARK SPACE in DENSIFYING DISTRICT
- WATER QUALITY IMPROVEMENTS
- FLOOD CONTROL
- HABITAT IMPROVEMENTS
- TRANSITIONING VULNERABLE LAND USES to more RESILIENT ONES

Figure: 4.25

NORMAL CONDITIONS (Level 1)

Figure: 4.26

Figure: 4.27

HEAVY RAIN CONDITIONS (Level 2)

AREAS OF POTENTIAL: AMC Oak Tree 6 & Parking Lot

Figure: 4.28

AMC Oak Tree 6 theatre, IHOP and CorePower Yoga occupy a large area in the center of the Aurora-Licton urban village. The vast majority of this lot is dedicated to parking space and is thus almost entirely impervious. It faces commercial arterial Aurora Ave N on its eastern side, and to the west are residential properties, the Seattle City Light property, and Licton Springs Park.

Due to the low density of its existing land use, this parcel is marked as redevelopable by the Office of Planning and Community Development's "Redevelopment Potential" GIS layer. This may represent an opportunity for SPU, given the parcel's adjacency to the drainage system. It also may indicate an opportunity for Seattle Parks and Recreation: this site is located in a park gap. Furthermore, both N 100th St and Stone Ave N, which pass by the parcel, are planned bike routes. As aforementioned, this proposal calls for the planned neighborhood greenway on Stone Ave N to become a retention street, which has the potential to be connected to other flexible urban surface water solutions.

INTERVENTION: Redeveloped Mixed Use Building

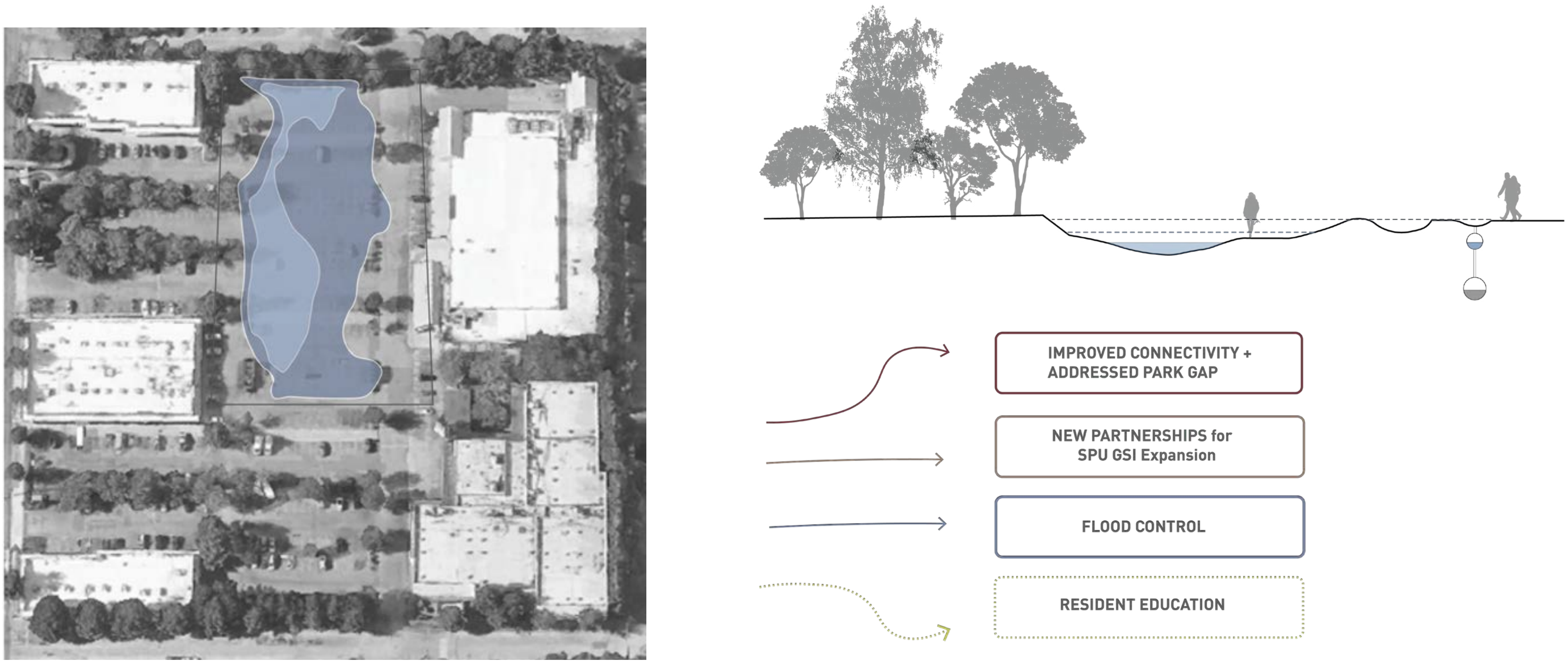


Figure: 4.29

I envision two possible scenarios for this parcel, assuming its redevelopment at some point in the near future.

1) Due to the site's location within a park gap along with its adjacency to the capacity-constrained drainage system, SPU and SPR could together acquire the parcel to construct a floodable park space here. This could simultaneously serve as usable recreational space for the community, serving an identified need, as well as a retention area that could function as overflow for extreme storm events in which the drainage system is overwhelmed. However, given the ever-increasing cost of land in Seattle, especially considering the size of this particular parcel, this scenario is the less realistic of the two.

2) In the event that the site is purchased for the construction of a higher density land use, such as a multi-story mixed use residential/commercial building, SPU could incentivize the new property owner to manage stormwater beyond their code requirements to manage right-of-way runoff in addition to the property's own runoff in times of high flow. Such a policy is currently under consideration by SPU as part of a ramped up GSI expansion effort. This arrangement could manifest in the form of a floodable park space in a central courtyard for year-round use by residents, retail shoppers, or even the general public, creating opportunities for exposure to the fluctuations of the area's hydrology throughout the year with adjacent walkable, bikable connections to other park areas such as Licton Springs.

Figure: 4.30

NORMAL CONDITIONS
(Level 1)

Figure: 4.31

HEAVY RAIN CONDITIONS
(Level 2)

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3. Personal communication with Joe Starstead, SPU, April 2019.

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5. Seattle Department of Transportation. Neighborhood Greenways Program Overview. Accessed from http://www.seattle.gov/transportation/projects-and-programs/programs/greenways-program

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7. Personal observation, April 2019.

8. Personal communication with Holly Scarlett, SPU, Feburary 2019.

Figures

Conclusion

In this thesis, I proposed an integrated blue-green infrastructural network for the Lower Densmore Subbasin/Aurora-Licton neighborhood. Thie proposal aimed to demonstrate how the spatially extensive, interconnected nature of a healthy, resilient stormwater system can also form the backbone for an interconnected network of public spaces that do more together than apart, catalyzing a multitude of additional benefits while mitigating urban impacts of climate change.

However, my proposal for Lower Densmore Subbasin/Aurora-Licton neighborhood area only represents half of this thesis: I began with a citywide analysis that sought to identify priority locations for floodable spaces in Seattle. The Lower Densmore Subbasin and the Aurora-Licton urban village with which it overlaps were selected from the priority locations identified through the citywide analysis. Zooming in on one of those identified locations and developing a vision for how floodable spaces might work to yield multiple benefits in that particular context provided the opportunity to test how the parameters and structure of the citywide analysis did or did not lend themselves to their intended purpose.

Based on the synergies revealed and leveraged for multifunctional floodable interventions, I believe that the overall approach to the citywide analysis in terms of its structure and components proved to fulfill my goals for it. However, conducting a deeper analysis at the neighborhood scale that engaged additional parameters allowed me to see potential synergies that were not captured by the citywide analysis, but perhaps should have been. For example, as I began to zero in on the Aurora-Licton neighborhood and learned about the history of Licton Springs, it became clear that considerations such as opportunities for habitat improvements and tribal interests and initiatives should be incorporated into the citywide analysis, and considered as potential co-benefits.

Another such example is infrastructure age: a priority risk area with aging infrastructure that will soon require replacement, and therefore investment, would provide additional incentive for a green infrastructural and potentially floodable intervention in that location.

Geological risks should also be included as part of a citywide prioritization process, such as liquefaction and peat settlement. My neighborhood analysis revealed that the incorporation of geological risk was an important addition that helped to strengthen the argument for one aspect Licton Springs proposal specifically: property acquisition for park expansion and risk mitigation. These represent just a few examples amongst a list of many factors that I only came to realize were relevant at the city scale once I'd zoomed in to the neighborhood scale.

Citywide analyses to identify priority locations for floodable spaces could be continually refined and improved upon through the establishment of an iterative relationship between city-scale and neighborhood-scale analyses and concept development. In this way, one continuously informs the other, and each is improved by advancements or new insights made at each scale.

Had this thesis been more extensive in scope, there are number of next steps I would have liked to take. The iterative relationship between the city and neighborhood scale I've described could have been tested, either by feeding the insights gained from neighborhood-scale analyses back into the city analyses, or by going through the process with another area of the city and comparing the two outcomes.

Another area of for further elaboration is community involvement. Engagement with local residents could have enriched both the citywide analysis process as well as neighborhood-scale explorations and concept development by supplementing geospatial data with neighborhood knowledge to better identify areas of challenge, opportunity, and community desires. Fortunately, any such planning processes carried out by SPU will involve community engagement from the outset.

On a separate note, SPU DWW System Planning is currently conducting a Drainage Systems Analysis as part of the Integrated System Plan, which includes analyses to identify areas of the city that will be impacted by a large storm event. With the results of this analysis in hand, perhaps with an updated capacity constraint in terms of storage volume for the Lower Densmore Subbasin identified, another next step might entail a prioritization process within the opportunity areas identified: which elements of my proposal should be planned, designed, and implemented first? Another question for further exploration would be, how might lessons learned through this neighborhood application be transferred to other Seattle neighborhoods with similar conditions?

While the unprecedented scale and scope of the challenges climate change presents can be overwhelming to the point of paralysis, our species' survival on this planet requires rapid adaptation to shifting baselines. A part of that adaptation must be a more integrated approach to urban water management. I see a great irony in the fact that water systems in the United States, as elsewhere, have largely been made invisible in the built environment, yet water is our most precious life resource. Howeverm it is also a source of great potential destruction in both quality and quantity. Through the design and planning of our built environments, we can choose what type of relationship we have with this most powerful and life-sustaining resource - one of risk, fear, and periodic destruction, or one of great synergy and benefit.

By making more room for water in our human settlements, re-designing them in a way that reflects its essential (and beneficial) role in the lives of both human and non-human beings, we have the opportunity to re-construct our relationship with our water resources to one that is healthier and mutually beneficial for all.

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