GRACE ARSENAULT

REIMAGINING STORMWATER INFRASTRUCTURE ON CAMPUS

SENIOR PROJECT WRITE UP

COMMUNITY, ENVIRONMENT, & PLANNING 2019
UNIVERSITY OF WASHINGTON

ABSTRACT

With a campus of over seven hundred acres that borders two environmentally sensitive waterways, managing stormwater runoff is an important task for the University of Washington. Currently, the University meets the standards of stormwater management for new development dictated by local, state, and federal agencies, but incorporates very few of the latest and most environmentally sustainable methods of stormwater management. Moreover, the proposed Campus Master Plan, which emphasizes the creation of a more environmentally conscious campus, includes very little in the way of revising and retrofitting existing structures to better manage stormwater on campus. To begin addressing this gap, I have created a retrofit plan that incorporates modern methods of stormwater management based on an existing site on campus. My plan focuses on a single demonstration site, a redesign of the courtyard between Raitt Hall and Savery Hall adjacent to the central Quad. The proposal incorporates easily implemented infrastructure such as bioswales and permeable pavement to create a space that is both functional for its users and acts as a stormwater management site on campus. I chose this site to show how similar methods could be easily transferred to other parts of campus. By creating this design plan, I also demonstrate how the University of Washington could retrofit its existing structures so that they exceed local standards and become an example for other campuses looking to enhance their own stormwater management systems.

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INTRODUCTION

I have a background in environmental sciences, having been a student in the Program on the Environment with the intention of graduating with my BA in Environmental Studies program before I found my way to CEP. Similar to CEP, the Environmental Studies program is highly customizable, which allowed me to take a variety of environmental courses. This led me to take a different courses about water resource management from biological, infrastructure and human usage perspectives. One of the recurring subjects was Combined Sewer Overflows (CSO), a stormwater infrastructure problem that the City of Seattle has encountered in the last three decades. Two thirds of the city of Seattle was built on a stormwater infrastructure system that combines all wastewater (household waste as well as street runoff) into one system and sends it to a treatment facility. When properly functioning, this system takes care of stormwater runoff from the streets, that in separated systems would go directly into our watershed as it does in the other third of Seattle. But during heavy rains, the limited capacity of the storm system allows overflows directly into the region's waterways. These overflows include waste from our showers, sinks, and toilets. I first encountered this problem from the perspective of a biologist: the toxic pollution resulting from combined sewer overflows negatively affect the ecosystem in the sensitive areas around Seattle.

The subject later reappeared but this time it was framed as a public health issue: fecal matter is getting into our waterways and making them hazardous for people that use them. I later encountered this subject again when applying for a community engagement intern position for the RainWise program. This time it was framed as an issue of urban planning: through a three-pronged approach the City of Seattle and King County were trying to implement a system of wastewater diversions to reduce or completely eliminate the CSO problem all together.

As the Intern for the RainWise program I have learned about the extent of the CSO problem as well as other stormwater runoff problems afflicting Seattle, the Region, and many places across the country and world. My education in environmental studies taught me the hazards of runoff, but my education in urban planning has informed how I would propose a solution. My senior project is the culmination of my multidisciplinary education at the University of Washington, and the beginning of a career focused on urban planning as a tool for stormwater runoff intervention.

LITERATURE REVIEW

THE STORMWATER PROBLEM

My senior project is a proposal for how urban designers may use infrastructure and low-impact development to better adapt our built environment to suit the climate in which it exists. As a result of development, we have expanded areas covered by cement and asphalt, which has completely altered the natural hydrological functions of the areas we inhabit. Though restoring the ecosystem to its pre-development state may be impossible, there is room for improvement in the built environment to restore some of the functions of the natural environment. In Seattle, and on the campus of the University of Washington, we have the opportunity to reestablish the natural functions of the ecosystem, through green stormwater infrastructure interventions. The following literature review includes descriptions and analyses of conventional, and newer methods of stormwater management to address the problems affecting our environment.

To situate the problem in the global trends of climate change I've studied the specific impacts of climate change in our already damp climate of the Pacific Northwest. Trends in climate change show an increase in precipitation in the form of more severe storm events across the Pacific Northwest (Mauger 2018). For the highly developed City of Seattle this will result in more stress put on our combined sewer system. When water inundates the City and exceeds the capacity of the sewer system, the excess water is let out into neighboring waterways, this is called a Combined Sewer Overflow. Pollutants often washed out with CSOs are: solids, biodegradable organic matter, nutrients, faecal bacteria, and may also include chemicals and heavy metals (Jiri Marsalek 2008, 49). These chemicals and heavy metals may be harmful to the ecological systems in these bodies of water. CSOs may also have eutrophic effects on surrounding waters; the spilling of sewage increases the amount of nutrients in the water, creating a more productive environment for algae to grow. The later decomposition of algae uses up the oxygen in the water creating areas where fish and other aquatic species cannot live, also called dead zones (Khan 2014, 1).

POLICY CONTEXT

The City of Seattle, in collaboration with other governmental agencies, has proposed a goal to manage 400 million gallons of runoff using green stormwater infrastructure by the year 2020, and 700 million gallons by 2025 (Seattle Public Utilities 2015). The city has different incentive programs coupled with revised building codes to meet this goal, like stormwater codes requiring new structures to incorporate green infrastructure into site plans. The Alaskan Way project, for example, will implement roadside bioretention to filter and delay runoff before it is discharged into the Sound (Seattle Public Utilities 2015).

New developments have requirements to lower their impact on the stormwater problem, but retrofitting requirements are a bit more voluntary. The RainWise program is funded by the City and gives rebates to homeowners, and community members to manage the roof runoff on site using stormwater retrofits. Since the program's beginnings in 2011, RainWise has established coverage of 2.16 million square feet of roofs. This is equivalent to the amount of stormwater that can be managed by 50 acres of undeveloped land (Sullivan 2018). The success of the RainWise program shows the potential for other retrofit programs, potentially on publicly-owned (Jonathan L. Page 2015) buildings, like those found on the University of Washington Campus.

Currently, the University of Washington abides by federal requirement by the National Pollutant Discharge Elimination (NPDES), dictated by the EPA, as well as the Stormwater Management Program (SWMP), an extension of the NPDES (University of Washington 2016). The SWMP requires minimum measures of implementation that include public involvement and education, detection and elimination of point source pollutants, construction and post-construction runoff control, as well as everyday runoff maintenance. Additionally, the Seattle campus, as well as the Bothell and Tacoma campuses, are certified Salmon-Safe (Halberg 2016).The certification requires the University to rethink land management practices like reduction of fertilizer usage, and water use management. The Urban Standards for the Salmon-Safe program necessitate that the land owner minimize the amount and improve the quality of runoff before discharged (Herrera Environmental Consultants, Inc. 2018).

The final Environmental Impact Statement for the UW Campus Master Plan shows a 2% increase in the number of permeable surfaces with further campus development (University of Washington 2017). This minimal increase likely won't contribute to exceeding the capacity of current stormwater infrastructure. Additionally, any new development will be subject to the new stormwater code (Seattle Public Utilities 2015).

Because of these factors, improvements of the University's stormwater management will come, not from new gray infrastructure, but instead from retrofits to existing infrastructure and sites.

SOURCE REDUCTION AND CONTROL

Conventional methods of stormwater management often put into use water detention facilities with high capacity to collect runoff during large storm events, these are called are called structural management practices (National Research Council 2009). Often these are used to accommodate peak volumes and may also serve as filtration systems. After a large precipitation event, water is slowly released from the detention facility back into the storm system, to be processed (Pazwash 2016, 375). Whereas structural storm management systems delay and reduce the intensity of the inflow, new efforts are being made to divert runoff from the storm system completely through source reduction. Such practices aim to reduce the amount of water runoff from a surface by reducing the size of impermeable surfaces, or making surfaces more permeable (Pazwash 2016, 479).

According to Pazwash in the Second Edition of Urban Storm Water Management, compared to structural methods of stormwater management, source reduction had better results in the areas of effectiveness of filtration, cost, reduced need of water quality devices, and prevention of damage (2016, 481). Due to the nature of structural management infrastructure, water leaves the system without removal of pollutants including salt, phosphorus, and metals. Source reduction often has natural filtration built in, making the method a viable form of filtration. When used in combination with structural management, source control may reduce the costs of water detention because some of it may be diverted from the system completely by the source control method. For example, the employment of a green roof as source control may collect some of the water that falls on its surface and therefore reduce the amount of runoff that a detention pond, a structural stormwater management tool, must capture and process.

Alternatively, the use of a combination of source control methods may completely eliminate the need for water control devices. Lastly, the employment of source reduction methods of stormwater management makes systems more resilient to flooding and large storm events especially when a diverse system of management methods is employed to work in concert.

Currently, gray infrastructure- pipes, pumps, ditches, and detention ponds, are used to manage stormwater; new techniques of stormwater management are moving us away from gray infrastructure, toward green infrastructure. Green infrastructure incorporates a system of infrastructure improvements that promote natural functions like infiltration, and evaporation to manage stormwater (USGS n.d.). Due to the infeasibility of rebuilding our current gray infrastructure sewer system, the implementation of green infrastructure in Seattle is paramount to establishing a more sustainable stormwater system. When our combined system is overloaded during storm events, green infrastructure can take some of the stress off of the system through delay or total diversion from the conventional system (Foster 2011). Additionally, the use of green infrastructure techniques in the place of traditional methods provide major upfront cost savings, as well as long term financial and non-monetary benefits—like improved water quality and hydrologic system recharge (Foster 2011).

A proposed alternative to mitigate or reduce CSOs is the use of retention centers which temporarily store water during large storm events and delay entry into the sewer system. Many municipalities created such retention ponds initially intended for intermittent use only during large storm events. The Retention ponds function has turned into longer-term settling ponds that act as the first step of water purification. In Impediments and Solutions to Sustainable, Watershed-Scale Urban Stormwater Management the authors assess the use of retention ponds to be less effective than management of stormwater at the site using permeation into the ground (Allison H. Roy 2008).

Ideally, if a site were being built from the ground-up, the creation of interconnected green infrastructure would predate the creation of 'gray infrastructure'. Essentially, planners would ensure a web-like system of green infrastructure would be created, similar that of telecommunications or road systems. Since Seattle, and by extension UW is already highly developed, planners need to rethink the way that green space is incorporated into everyday street design. Benedict and McMahon advise incorporating hubs of biodiversity with connected pathways to enhance the wellbeing of each of the sites and increase their natural functions thus increase the overall effectiveness (Mark A. Benedict 2006). Such plans can be imagined in the form of bioswales along roadways and the incorporation of green roofs in place of impermeable roofs.

SITE APPROPRIATE INTERVENTION: POROUS PAVEMENTS

"A porous pavement is one with porosity and permeability high enough to significantly influence hydrology, rooting habitat, and other environmental effects," (Ferguson 2005, 1). Dense pavement is completely impervious, and acts as a collection pan for pollutants and toxins. When precipitation occurs, pollution is washed off the surface and is carried to the storm drain system, or to a holding tank. Porous pavements encourage precipitation to be absorbed- pulling pollutants through the filtering materials below the surface. This reduces the runoff from the area, which decreases the amount of pollutants carried downstream (Ferguson 2005). Variations in the materials used to create the porous surface may provide varying results. Porous pavements are also beneficial for supporting tree rooting, reducing the "heat island' effect, increased ecosystem connectivity, and increased safety-due to better drainage reducing the amount of standing water on a surface (Ferguson 2005, 20, 24).

SITE APPROPRIATE INTERVENTION:
TREES AS STORMWATER MANAGEMENT

The presence of a healthy urban forest is linked to reduced amounts of stormwater runoff in our cities because of natural qualities possessed by trees. There are at least three ways in which trees reduce runoff: canopy interception, transpiration, and improved infiltration (Adam Berlanda 2017).

Canopy interception is measured by the subtracting the amount of water that flows down the stem of the tree (stemflow) and water that bypasses the canopy (throughfall), from the gross precipitation falling on the tree. The tree species that composes the urban forest is a large determinant of the amount of canopy interception (Adam Berlanda 2017). A study performed in Davis California examined which trees have the highest canopy interception found that coniferous trees have the highest capacity to hold onto rainfall (Q. Xiao 2016). Second best was broadleaf evergreens, because the longer that a tree maintains its leaves, especially during rainy seasons, the more canopy interception would occur (J. C. Clapp 2014).

While an urban forest can be useful for the purposes of flood control, canopies tend to reach a saturation point during large storm event, making them less useful for reducing stormwater runoff in the event of heavy precipitation. Even so, lower volume rainstorms are responsible for most of the pollution runoff, so for this reason canopy interception can help more with water quality than with the reduction of flooding (Q. Xiao 2016).

Transpiration is the function in which water that is taken from the soil is evaporated from the leaves of the tree. Transpiration also includes the volume of water evaporated from other landscape surfaces and is an important part of the hydrologic cycle (USGS n.d.). Exact rates of transpiration are difficult to measure; meteorological conditions, soil moisture, albedo, spatial heterogeneity, and makeup of the vegetation, among other factors, have varying effects on transpiration rate. Generally, broadleaf trees are more effective at transpiration than conifers, but due to their varying peak transpiration seasons a combination of conifers, as well as broadleaf tree species allows for year-round water transpiration (Adam Berlanda 2017).

Filtration rates of an area are improved by the introduction of trees into a system. Additionally, the presence of trees increases the organic matter, and therefore biological activity in the soil. Tree roots may also provide physical macrostructures that smaller plants are unable to provide. While decreasing the amount of erosion caused by runoff, tree roots also facilitate infiltration by providing direct channels through which water may flow. All of these processes are best facilitated when trees are planted in a concave planter, so that water stays in the general area of the tree's base. Often trees are planted in mound structures which allow for water to flow away from the base of the tree (facilitating runoff) and eroding away the soil at its base. This contributes to unhealthy soils as well as tree root exposure.

Soils are often compacted so that they can support the structures built on them (Jonathan L. Page 2015). This compaction of soil reduces the success of tree growth in those areas because repeated compaction disrupts tree roots. Trees with reduced root capacity tend to grow slower and therefore have reduced transpiration, canopy interception, and infiltration capabilities (Adam Berlanda 2017). Creating a suspended pavement allows for healthy tree growth in our built environment (Jonathan L. Page 2015). One method to improve soil structure and reduce compaction is the use of a tree cell (commonly the SilvaCell), a modular structure composed of glass, plastic, and steel reinforcements that sits below ground.

In a study of the use of such structures performed in Wilmington, North Carolina, the SilvaCell unit allowed for water infiltration in an uncompacted soil engineered for the purposes of infiltration. In addition to the reduction of runoff, the root-soil matrix provided extra filtration of pollutants in the area. A conveyance pipe connected to the storm system was placed in the matrix as a diversion strategy to reduce the chance of flooding during large storm events. The use of the SilvaCell provided 80% capture of runoff in the specific areas where implemented. (Jonathan L. Page 2015)

METHODOLOGY

RESEARCH: GSI METHODS

I began my research with a certain level of understanding of green stormwater infrastructure, and various methods of implementation. My research focused more on how these techniques worked individually than in concert with one another. This involved gathering case studies of sites that seem to use GSI methods effectively to not only reduce the amount of stormwater runoff, but also to create inviting, and useful spaces for the public. The gaps in my knowledge tended to be the more technical side of GSI planning, focusing on civil engineering aspects. I cite different manuals on pervious pavements, and hydrology manuals in my literature revue as evidence of the technical work that goes into site planning for stormwater management.

PLACE CRITERIA

First, I developed criteria for choosing a site (1) it needed to be an outdoor space, (2) it needed to be covered by mostly impermeable surfaces, (3) it needed to be highly trafficked, and (4) it needed to be or have the potential to be a place where users wanted to dwell, and enjoy the space. The reasoning behind the first criteria, is obvious, I needed a space that was actually going to deal with precipitation, as long as the site is outdoors, this wouldn't be a problem.

My second criteria was based in the idea that I wanted to improve some aspect of the site, if were already covered in permeable surfaces then I wouldn't have much to fix. Next, I wanted to create a site for people to use, not only would this heighten recognition of the stormwater pollution problem if the plan was implemented, but I also wanted to create the design with the site's users in mind. In later stages I study exactly how people use the space, so high volumes are necessary to influence the design. Lastly, I wanted to create a space where people might actually want to sit down and enjoy the atmosphere. The University of Washington campus lacks outdoor areas where people are able to sit and hang out; I could create a space that addresses stormwater problem and create a space that is user friendly during dryer months. To satisfy the criteria, the chosen site will have a pleasant atmosphere- not too loud, with plenty of natural light, and be large enough to accommodate sitting areas as well as pathways.

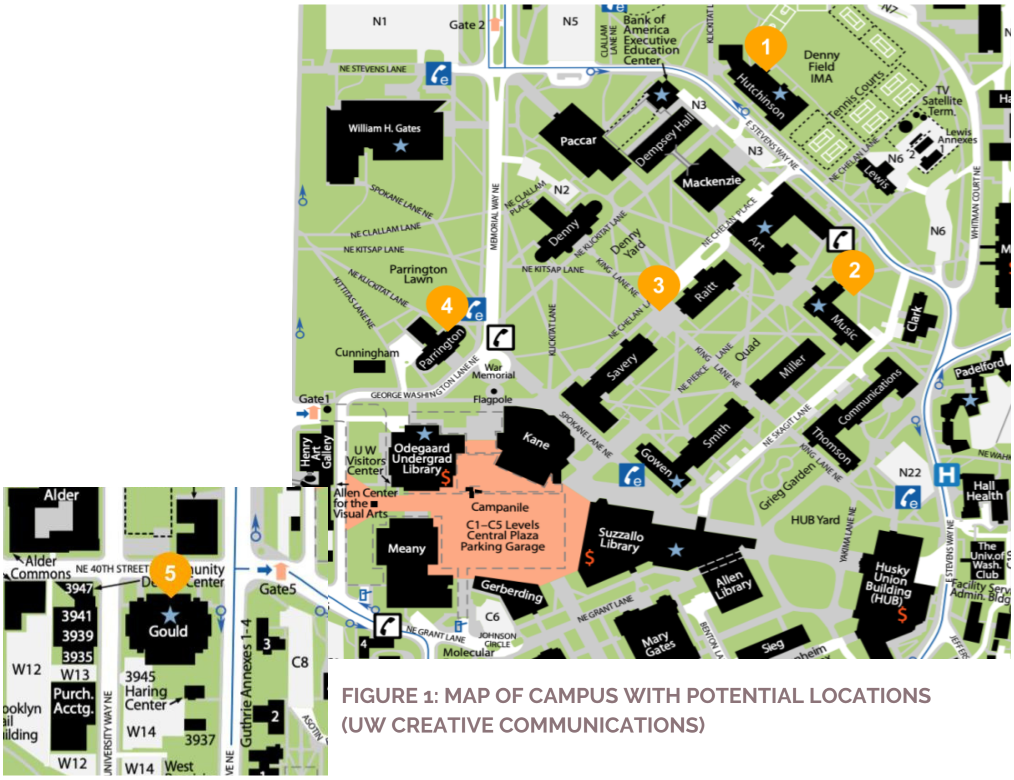


FIGURE 1: MAP OF CAMPUS WITH POTENTIAL LOCATIONS (UW CREATIVE COMMUNICATIONS)

EXPLORING CAMPUS

After developing the criteria, I went on a campus tour- though I've attended classes on all sides of the campus in my time here, I walked around campus with a new perspective. Some of the sites that were interesting to me and satisfied some of the criteria are labelled in figure 1: Hutchinson Hall (1), the lawn on the back side of the music department (2), the courtyard between Savery and Raitt Hall on the quad (3), Parrington Hall (4), as well as the 'moat' outside of Gould hall (5). I finally decided on the courtyard between Savery and Raitt hall because it, more than any of the other locations, satisfied all of the criteria. (figure 2)

FIGURE 2: MAP OF SITE (KING COUNTY GIS)

OBSERVATIONS

Next, I moved into an observation portion of my project. This phase of my project involved studying movement in the space: both human and hydrological. I visited the space on a few different days to do so; the first time was an informal visit on an overcast afternoon. I took photos of the space and who was using it, as well as studied how they travelled throughout the space. Two women stood and spoke for the entirety of my visit in the central path of the courtyard. Others just strolled through the courtyard, with direction but at a moderate speed. My observations began just after 2:30, when most people in the area were in class.

My next visit was in the late morning of a rainy day; though it was not raining when I got there, water was still sitting on top of the brick paving. During this observation time, people were sparse, and never lingered. This is also when I noticed that most of the people who used the courtyard were passing through the space, and not coming out of the neighboring two buildings, Raitt Hall or Savery Hall.The third visit was a sunny morning; it was this time that I sat down and counted the amount of people that passed through the courtyard and the path that they took. In the time between 10:55-11:00 AM I counted 41 people passing through the courtyard, and two people who sat down on the benches.

One person left Raitt Hall and passed through the courtyard, and two people entered the building through the courtyard. Most people moved along the path between Denny Yard and the Quad, or between the corner path that leads closer to Paccar Hall and the Quad. During this observation period I noticed that passersby tended to take awkward paths between the benches, and the tree plantings. Additionally, I believe that due to the amount of people coming from, or heading towards, Paccar Hall on the northeastern side of the courtyard, the eastern side of the courtyard was used much more heavily than the west side.

INSPIRATION ON CAMPUS

The intent of exploring campus was to find a space that I could reinvent using green stormwater design techniques but along the way I actually found some places on campus that were already using such techniques. Municipal Storm Code in Seattle requires any new building have some variety of stormwater management on site; following those requirements, green infrastructure can be seen in a lot of the newer buildings on campus. These sites have inspired early designs of my space.

TERRACED BIOSWALE STAIRWAY

Between Maple and Terry Hall, on west campus, there is a courtyard with chairs and tables, and benches. This courtyard acts as a transition between street levels on the north and south sides of the building (the north side being about a floor higher than south). This transition is connected by a set of stairs, which is the source of my inspiration: along with their most basic purposes, these stairs also act as a terraced bioswale (figure 3). On either side of the steps there are large terrace-style planter boxes that have the ability to capture rain. I took this idea of terraced bioswales incorporated into steps and have expanded upon it and integrated it into my own design.

WATER RETENTION BASINS

Alongside the new Burke Museum and the neighboring School of Law, there are two sets of planted water detention terraces Figure 4. They are similar to the Maple/Terry terraced bioswale stairs example in concept but function quite differently: these installations are much wider and could perceivably hold much more water. Made up of five holding sections, water fills up the top basin, and what does not get infiltrated spills over into the next basin, and so on. Water from the roofs of neighboring buildings is pumped into the top basin to begin the process of infiltration.

FIGURE 4: WATER RETENTION BASINS

FIGURE 3: TERRACED BIOSWALE STAIRWAY

DESIGN PROCESS

I began imagining how all of my research- visual research of other stormwater conscious design, observations on campus, observations of my chosen space, as well as GSI methods, would begin to come together as a functional system in my own designs. Narrowing down three GSI interventions: tree cells, bioswales, and permeable pavers, allowed me to begin experimenting with the integration of each system. Though eventually I would translate these designs into a graphic program- SketchUp and Illustrator, I began my design process with a pencil and paper. Beginning with the most fundamental drafting allowed for quick development of ideas in any place. Having a background in drawing urban forms, I was able to take my sketchbook and ruler out to my site and get a feel for what my redesign would feel like if implemented.

I began by drawing small thumbnail sketches of ideas including stairway sections, bioswale plantings, and tree placement (figure 5). As I developed the basic structure of the perspective drawing (figure 6), I began implementing the details that I had developed in my thumbnail designs. I focused a lot of my time on developing the perspective drawings- what it would look like if someone stood at the bottom of the lower level stairs, looking up to the courtyard, versus sitting on a bench in the southeast corner of the courtyard. It was while developing these perspectives that I was able to think about placemaking in my redesign. Was it a comfortable place to sit- did the seating arrangement make sense with the line of site that the seating provided? Was it useable for walking- did the tree placement obstruct obvious walking patterns? While contemplating these matters I referenced my previous observations taken earlier in my process. I recalled that I saw little to no use of one of the current walking paths, I translated this to my design by removing the walking path altogether and replacing it with a bioswale and seating area. In my drawing process I also developed an aerial view and overlaid my walking path observations- reflecting on current use of the space, and how my redesign could impact future use.

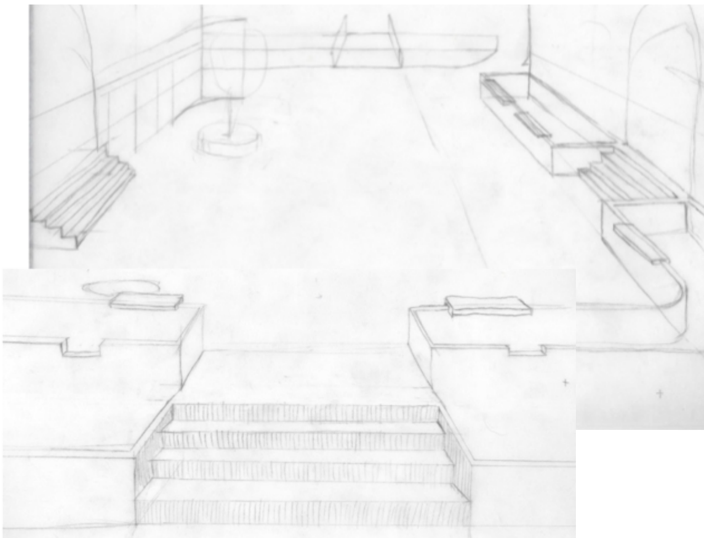


FIGURE 6: LARGE PERSPECTIVE SKETCH

Using trace paper, I was able to develop different aspects of the design separate from one another. On the base layer I laid out the dimensions of the courtyard itself- where the buildings were placed, and the current parameters. On the first layer of trace paper I sketched out the hardscape design- the bioswale placement, stairs, benches, etc. On another layer I placed the trees, grasses, plants. Another layer, the hydrology of the site- how rainwater might flow outward toward the proposed bioswales, and trees. The final layer added the human users back into the space- looking at viewsheds, walking paths, and seating area. By using various overlays, I was able to manipulate one aspect at a time, without disturbing others. This technique mimics what I would later do in Adobe Illustrator using different layers for various design elements.

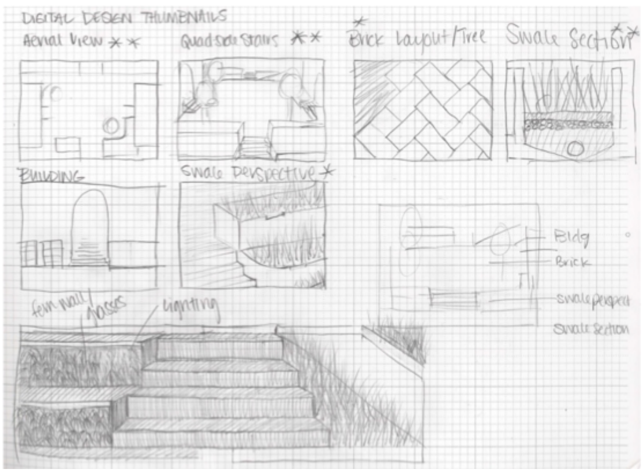


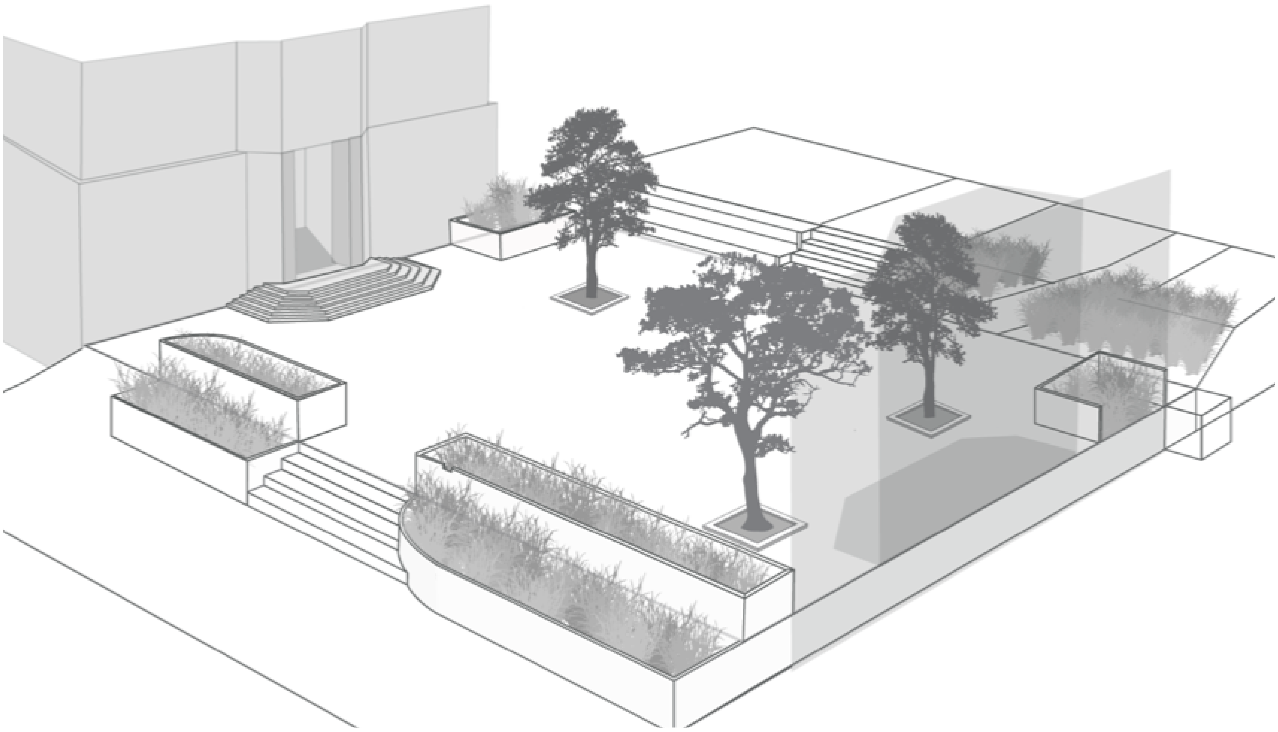
FIGURE 5: THUMBNAIL SKETCHES

Next, I translated my drafts into a three-dimensional CAD program, SketchUp. I was able to recreate the parameters of the space- the proportions of the buildings with the width and length of the courtyard by importing aerial images from King County Parcel viewer. This would be the basis of my graphic work- it was imperative that I set up an accurate depiction of the current site. I used the extruding function of SketchUp that allows the user to create the three-dimensional models. This provided the elevation differences that give this courtyard varying planes to expand my designs. After creating these different planes, I worked to extrude the stairs and slopes that would connect each of the elevations. From there, I further developed the hardscape- like the bioswales, and tree planters. Due to the broad use of SketchUp in various design communities, there are often premade, open-source models in the Adobe Illustrator 3D Warehouse. I was able to locate a realistic model of Raitt and Savery Halls, which I scaled to fit my model. This was helpful when attempting to make my model feel more realistic. I decided to take some extra time to develop the exact measurements in SketchUp because after my model was complete, I was able to create accurate perspective views using a two-dimensional design software- Adobe Illustrator. SketchUp, though sometimes finicky in the design stage, provides the viewer with total freedom a 360-degree view of the design, once the model is complete. Once I found the best view to display my model, I used a camera tool to capture the exact perspective- I later uploaded it to Illustrator.

With the capture of the perspective view from SketchUp as my base, I began adding in the different elements of my designs, all organized by layers. This was a similar process to using the tracing paper in my drafting process- isolating categories of elements. While working on the overall perspective design, the process of establishing the bioswales, stairs, tree planter placement, and seating, required the most amount of time. This was due to two factors: my desire to be exact in my angles and measurements, as well as my everchanging desires for the outcome of the space. Once I was comfortable with the hardscape of the design, I moved onto finding and creating plant vectors for my bioswales, and trees for my tree planters. For this process I found an open source tree vector image, and manipulated the size and shape, as well as made it all one shade- eliminating any distracting details. Then I created some dimension by layering the grasses on one another and varying each layer’s shade of gray.

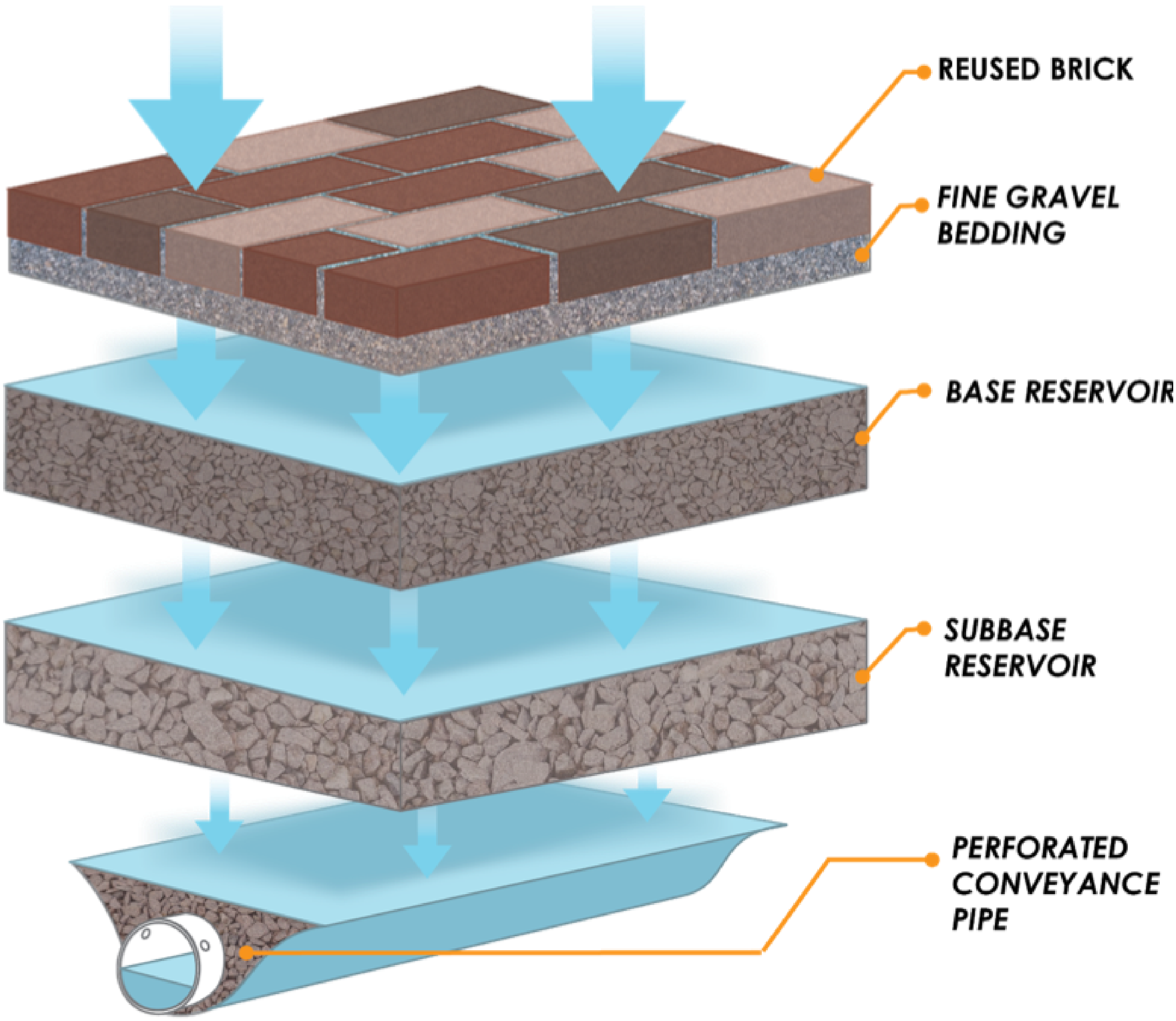
As for creating the separate elements of infrastructure, the bioswale, permeable pavers, and tree cells, I relied heavily on my research and previous experience. To fully demonstrate the layering method used in the permeable paver system I decided to visibly separate each layer. As for the bioswale graphic I thought it would be useful to demonstrate the bioswale in action by creating a ‘section’ of it. Using this method allowed me to show how the conveyance pipes would feed the bioswale; I could also show how the biofiltration soil gives water and nutrients to the grasses while the infiltration mix percolates the water down into the ground. The tree cell graphic took a bit more effort to create than the other two, due to the angle that I wanted to present it at. I wanted to show an underground view of how the cell actually performs while also showing off the three-dimensional depth of the apparatus. I also wanted to depict the roots of the trees in concert with the tree cell, as well as how a conveyance pipe might be incorporated. Though these three graphics were created separately, I wanted them to have the same theme throughout. To accomplish this, I created a color palette, as well as made sure that all three of the designs used the dame line weight and color. Lastly, I labelled each graphic in the same style to increase cohesion and understanding between each.

FINAL PRODUCT



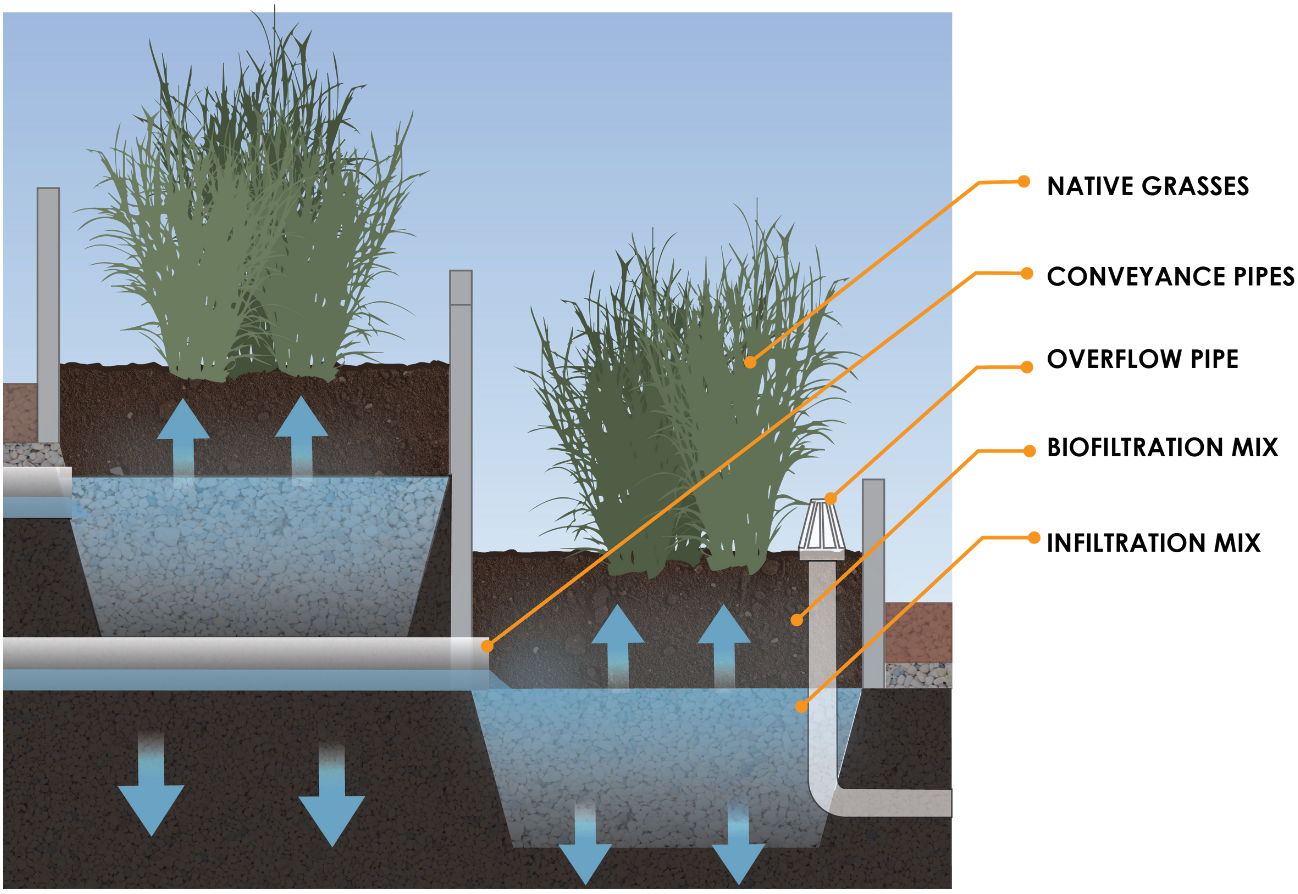
My final product is a set of designs that depict the reimagined courtyard. This includes a perspective view, alongside three graphics that show the functioning parts of the stormwater management plan: the bioswale, tree cell, and permeable paver system.

The redesign is just one example of how the University of Washington can redesign its existing spaces to incorporate more stormwater friendly design in the built environment. While new development is required to incorporate Green Stormwater Infrastructure on site, there is very little being done to revisit the stormwater management of sites that already exist on campus the goals motivating my decisions is to maintain the character of the space, while drastically improving the space's hydrology. The two buildings on either side of this courtyard are Raitt hall to the east, and Savery to the west; both were built in the 1910s in the Collegiate Gothic architecture style. Rather than replacing the bricks with a pervious paver (often used in other permeable designs), I designed the permeable surfaces to reuse the existing bricks in the space. Additionally, the courtyard sits next to the quad, an open space that is known for its brick pathways and cherry blossoms. Reusing the bricks in the courtyard creates continuity between the quad and neighboring courtyard.



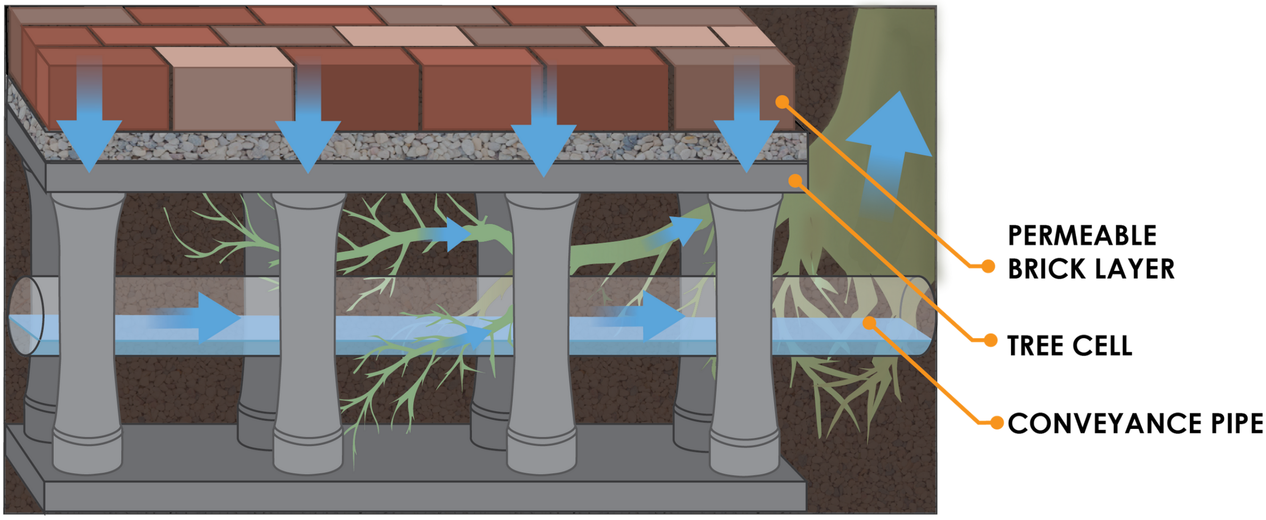
PERMEABLE PAVERS

Permeable pavements are typically constructed with pervious blocks as pavers, which allow water to pass through various grated reservoirs into the ground. The permeable paver system that I have developed, instead reuses impermeable bricks but replaces the grouting medium with a permeable fine-grained gravel bedding. This will allow water to pass between the bricks and then down through the layers of gravel to be infiltrated into the ground. In addition, my design includes a conveyance pipe that will allow water to move away from the site during heavy rains. These conveyance pipes will feed into the constructed bioswales where water may be further infiltrated or evaporated by the plantings. The gravel reservoirs, in addition to their rapid drainage, also provide physical filtration capabilities. The use of the permeable surfaces in my design will eliminate the need for drains in the courtyard. The permeable surfaces will also reduce, if not completely get rid of the puddle problem currently affecting the courtyard. Reducing the amount of standing water during precipitation events will make the space more user friendly and therefore more inviting.



BIOSWALES

The bioswale that I've designed sits on either side of the stairway leading to the quad. In the case of flooding, there are two chambers which will allow water to spill over into the lower level. This is modeled from the terraced bioswales seen on other parts of campus. The bioswales are fed by the conveyance pipe during heavy rains and will otherwise be watered directly by lighter rains. The bioswales contain a biofiltration mix that promote healthy soil organisms to filter any pollutants from the runoff. They also contain an infiltration mix with a higher sand and gravel content, which promoted the infiltration of the runoff. Planted in the bioswales are native grasses, like switchgrass and Indian grass. Both species do well in occasionally saturated soils, as well as in the dryer months. While some watering and light maintenance may be necessary for the survival of these plants in their first year, the species chosen are hardy and acclimated to our climate. Planting a variety of grasses in the bioswale will allow for more biodiversity, and therefore create healthier soils. Additionally, included in my bioswale design is an overflow pipe. Typical in most bioswales and rain gardens, an overflow pipe allows for quick conveyance of water in the case of unusually heavy rains. The overflow pipe directs the water to the nearest storm system.



TREE CELLS

The tree cell is the most discreet part of my GSI plan. Under the brick upper surface and gravel bedding mediums are the structures that allow healthy root growth. These structures are made of an especially strong plastic, glass composite material and are reinforced steel tubes. They are perforated along the top surface to provide channels for water to further infiltrate down the vertical structures. These tree cells protect tree roots as they grow and help maintain an even brick layer that is more accessible to users. The tree cell also protects the conveyance pipes that are placed below ground for the permeable paver system.

REFLECTION

THE STORMWATER PROBLEM

When I started my project, I was focused on the Combined Sewer Overflow problem that afflicts about two-thirds of Seattle homes. My experience with the stormwater problem, especially in my internship, is centered around combined sewers. After doing my research and building a strong case toward working on stormwater infrastructure in combined sewer areas, I was looking into picking a redesign site. In my research I had also looked into the University of Washington's Campus Master Plan, which showed a lack of measurable effort toward reinstating a natural ecosystem's hydrologic functions. But when I found that the University of Washington is not on a combined sewer system and was in fact included in the one-third of the city on a separated system I had to redirect my project. This led me to research further into the importance of proper runoff mitigation in urban design as a tool for creating more environmentally resilient communities.

GRAPHIC DESIGN PROGRAMS CAN BE DAUNTING

I found that a large part of my design process focused on making the graphics that represent my designs. After two quarters of processing different decisions regarding my design, I hesitated to start on my graphics; it was much easier to redo drafts and change elements of my design on paper. When I translated my design to SketchUp and later Illustrator, I had to commit to a specific design. Though any line or shape created in the design programs could be manipulated, (everything was arguably less permanent than when sketched out) the amount of time spent developing a design made it much more difficult to abandon and go down a different path. But of course, as I worked with the programs more, I became more acclimated to their functions, making adjustments much easier to make.

GREEN STORMWATER INFRASTRUCTURE IS EVERYWHERE

Once I really began researching green infrastructure methods, I began to notice it everywhere in the built environment. Conversely, I also couldn't help noticing when spaces desperately needed more green infrastructure. This changed my perspective a bit on how I wanted to approach my own project. When I began this project, I was convinced that the development of stormwater friendly open spaces required a major overhaul of whatever inadequate structures were already there. This had me thinking about major changes to my chosen space. But when I began to quite literally noticing that the ground beneath my feet had been engineered for excellent permeability, despite its unassuming appearance, I saw my own space in a new light. I didn't necessarily have to install high-tech green infrastructure methods to make my space more stormwater-friendly, I could instead just reimagine what was already there, beginning with the bricks. This realization informed my decision to re-use the bricks currently in the space, and replacing the infill that separates each brick to increase its permeability.

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