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Current Stormwater Practices and Future Implementation at Portland State University with the Uncertainty of Climate Change

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Current Stormwater Practices and Future Implementation at Portland State University with the Uncertainty of Climate Change

by

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Report submitted in partial fulfillment of the
requirements for the degree of

Professional Science Masters
In
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Portland State University
2021

Executive Summary

Stormwater runoff is one of the most critical environmental issues in urban areas and is only expected to worsen as climate change persists (EPA, 2016). When precipitation events occur, stormwater travels across impervious surfaces collecting soils and pollutants which can negatively impact water quality in receiving waters. Additionally, stormwater has human health impacts, specifically through flooding and the contamination of drinking water. According to the Intergovernmental Panel on Climate Change (IPCC), it has been determined that climate change will increase the frequency, intensity, and/or number of precipitation events in some regions, including the Pacific Northwest, and decrease in others (IPCC, 2018).

One of the largest metropolitan areas in the Pacific Northwest is Portland, Oregon. Portland State University (PSU) is located in the heart of downtown Portland, where the percent of impervious surfaces are particularly high (81%). Consequently, precipitation events generate large amounts of stormwater that pollute the Willamette River. To combat stormwater runoff, PSU has made a concerted effort to increase the amount of stormwater green infrastructure (SGI), which work by mimicking natural processes of managing water, such as infiltration and retention, thus decreasing peak flows and flood risk by slowing and reducing stormwater discharges. Eighteen PSU buildings on campus have at least one type of SGI, and all these facilities treat 11% of the stormwater that falls on PSU impervious areas. The continued construction and maintenance of these systems is essential in creating a healthier urban environment.

In collaboration with PSU’s Campus Sustainability Office (CSO), we have created a comprehensive inventory of the SGI on campus and determined its effectiveness in reducing stormwater currently and in the future. To do this, we used the Environmental Protection Agency’s Stormwater Management Model (EPA SWMM) to model PSU’s buildings along with their various SGI facilities. We used current and future predicted precipitation data to estimate how stormwater runoff at the university will vary with climate change, and how the implementation of more SGI will help reduce this impact. PSU reduces 6.2% of stormwater runoff with its current number of SGI installations. Finally, we have proposed recommendations to the university based on these findings for the next 80 years.

Project Objectives

This research project is a collaboration with PSU Campus Sustainability Office through the Living Lab program and responds to the following three specific goals:

1. Define PSU's stormwater system by elaborating a complete inventory of the SGI on campus.
2. Develop a SWMM model to analyze the current effectiveness of the stormwater system and the expected impacts of climate change thereon and evaluate alternative scenarios with more SGI implemented.
3. Preparation of recommendations for PSU stormwater management planning by consolidating all the analyzed information and synthesizing insights from discussions with stakeholders.

Main findings

Type of surface

From our first goal, the SGI inventory, we were able to determine that 81% of the total study area was impermeable surface, and 19% was permeable. Of PSU-managed areas, 85% was impermeable, 15% was permeable. Additionally, SGI represented 2.4% of the total study area.

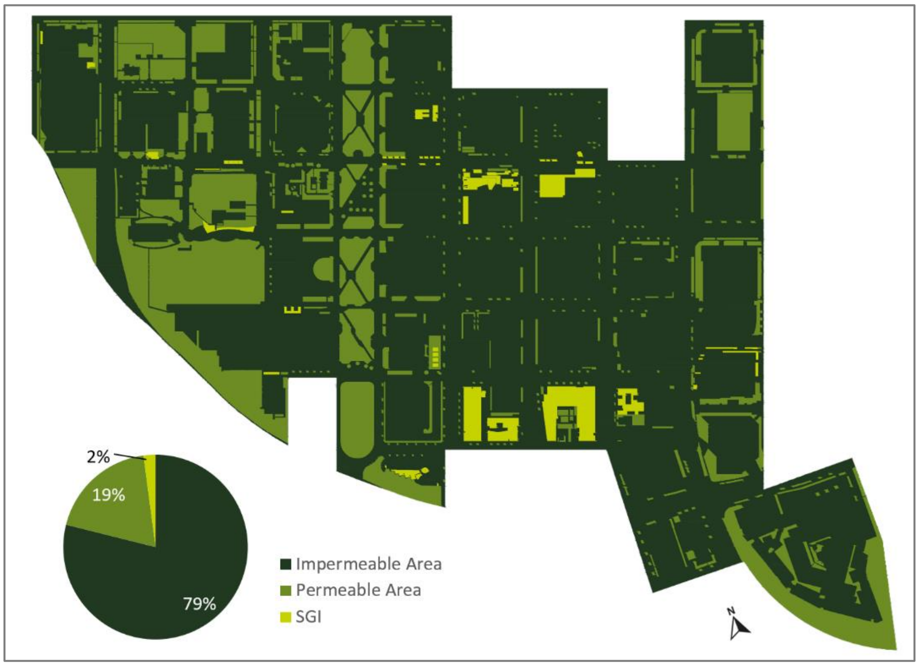

Figure A. Impermeable and permeable surfaces, and SGI within the study area.

ArcGIS inventory results

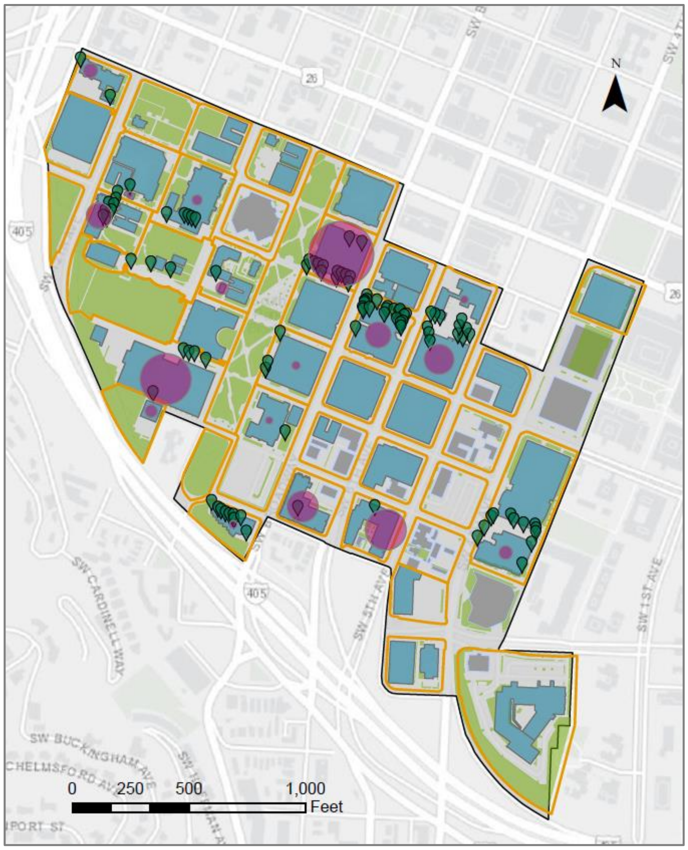

Figure B. Inventory results in ArcGIS.

For a visual representation of the data collected, most of the results from the SGI inventory were uploaded and converted into ArcGIS from the AutoCAD files to facilitate access and use for PSU students and faculty. The image on the right includes a preview of our inventory results in ArcGIS indicating different surfaces, buildings, SGI and stormwater runoff from impervious areas draining to SGI (represented with the magenta circles). This final map can be found in the following links:

- PSU Stormwater inventory map: https://arcg.is/1znG8n.
- Current Stormwater Practices and Future Implementation at Portland State University with the Uncertainty of Climate Change - Story map: https://storymaps.arcgis.com/stories/8db98f780df8434ca599c09fd91aa865

Single Rainfall Event – Simulation Results

When analyzing the effect that current SGI has in runoff reduction, using the 2-year storm scenario, the model reported a reduction of 8.5% less runoff in the simulations with SGI than the simulations without SGI. This reduction slightly decreases with the increment of the precipitation intensity, being 8.3% with 100-year storms. The figure below represents the runoff from both scenarios, without SGI (yellow column) and with current SGI (green column) for different types of storm intensities (blue area). The lines show the peak flow for each scenario (Figure C).

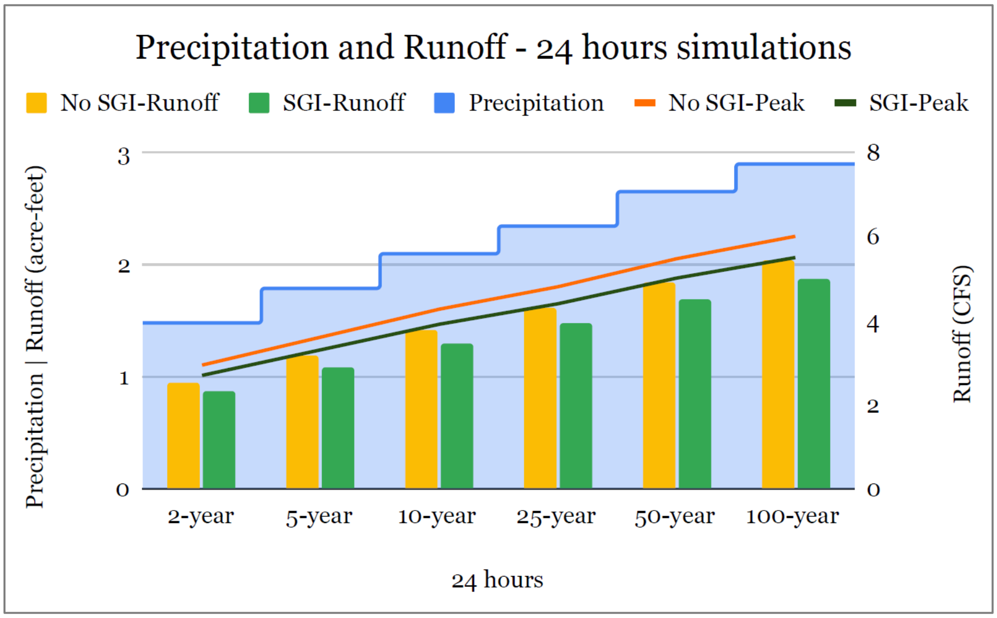

Figure C. Runoff and peak flow reduction with current SGI in single rainfall event simulations.

Long-Term Simulations – Simulation Results

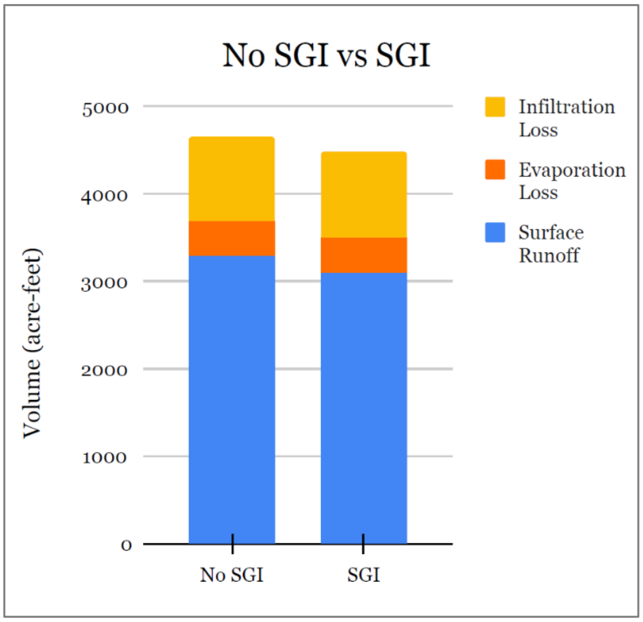

Figure D. Long-term simulations no SGI vs SGI.

Using precipitation and temperature data recorded from August 2000 to July 2020 in Portland, OR we ran two simulations one without SGI and the other one including current SGI on campus. The result showed that with the current SGI system PSU reduces 6.2% or 3,346,950 gallons of surface runoff annually, the equivalent of a little more than five Olympic swimming pools. In the second analysis, we compared the results of a model which included current SGI with current climate patterns and another with current SGI but projected future climate variation. In the future scenarios despite a significant increase in runoff loss through evaporation of 10.7%, the total runoff increased by 1.3% or 12,949,988 gallons

(Figure E). Finally, in the simulations where we added more potential SGI within the study area the reduction in surface runoff was 543,764,251 gallons or 50.5% (Figure F).

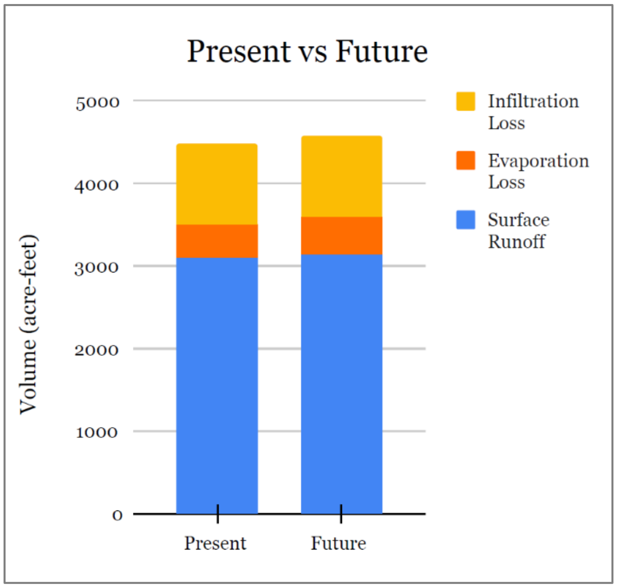

Figure E. Long-term simulations Climate Change.

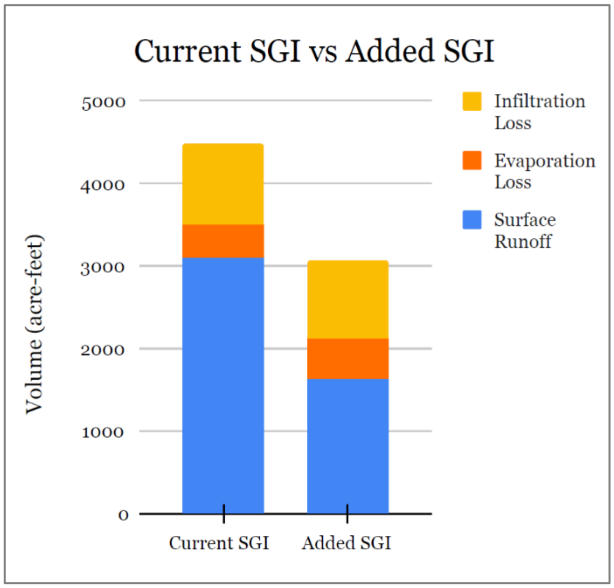

Figure F. Long-term simulations additional SGI.

Conclusions and recommendations

With the stormwater management system in place, PSU reduces 6.2% of the generated runoff, decreasing the related impacts as well. Currently, PSU impervious surfaces represent 62% of our total study area's impervious surfaces, or approximately 1,950,662 sq. ft. This large percentage of impervious surfaces represents an opportunity for PSU to implement more SGI. With PSU's limited resources, we would recommend that the university first focus on monitoring and maintaining current SGI before building more. We would recommend that PSU conduct a cost-benefit analysis to determine which infrastructure best compliments the university that is effective, yet not too expensive. As the climate continues to warm and precipitation events increase in severity and number, addressing the issue of runoff now will reduce its impacts, and ensure the health of our urban environments and waterways. Furthermore, due to the impervious nature of the city of Portland and PSU, stormwater runoff issues are expected to worsen. With the completion of this project, we have drawn attention to the need for the reduction of stormwater runoff and implementation of SGI.

For more information about stormwater management, contact the Campus Sustainability Office (greencampus@pdx.edu)

Acknowledgments

Land Acknowledgment and Portland's Native American History

"Portland State University is located in the heart of downtown Portland, Oregon in Multnomah County. We honor the Indigenous people whose traditional and ancestral homelands we stand on, the Multnomah, Kathlamet, Clackamas, Tumwater, Watlala bands of the Chinook, the Tualatin Kalapuya and many other indigenous nations of the Columbia River. It is important to acknowledge the ancestors of this place and to recognize that we are here because of the sacrifices forced upon them. In remembering these communities, we honor their legacy, their lives, and their descendants" (PSU, 2020).

Before the colonization of their land, numerous Native American tribes inhabited the area that is now PSU. The university is located on the traditional and ancestral homelands of the Multnomah, Kathlamet, Clackamas, Tumwater, Watlala bands of the Chinook, the Tualatin Kalapuya, and many other indigenous nations (PSU, 2020). Due to the location of these tribes, the Willamette and Columbia Rivers played a significant role in their way of life. The tribes believed their souls and spirits were inextricably tied to the natural world and those who inhabit it (CRITFC, 2015). Among the natural world's inhabitants, salmon was the most important, bringing sustenance and prosperity to the region's rivers and streams (CRITFC, 2015). Since the arrival of colonizers, the lives of native tribes have drastically changed, specifically through the appropriation of their lands and degradation of their once pristine environment. However, the Willamette and Columbia Rivers still serve as an extremely valuable resource of history, culture, and identity for native tribes and their people.

Considering our project takes place on PSU's campus, we want to recognize Indigenous people and their land as an expression of gratitude and appreciation for their territory on which the university resides. With this project, we hope to ensure the health of the Willamette, Columbia, and their connecting waterways so that current and future Native Americans can continue to use them as an influential spiritual entity.

Personal Acknowledgments

There are many people we have to thank for contributing to the success of this research project. We want to thank our research committee, especially Jen and Max for all their help and guidance over the last two years. The PSU Campus Sustainability Office, especially Jenny McNamara, Emily Quinton, and Amanda Wolf, for providing us the opportunity to work on a project that will better the university, the City of Portland, and its community. The PSU Campus Planning Office, City of Portland BES, Port of Portland, and Marc Leisenring for their respective roles in the success of this project. All of our lab mates for providing us with insightful feedback from the project's development to completion, and for being a trustworthy group we could count on for support. Our ESM peers for their assistance in the progress of this work. Our friends and family for their constant support and encouragement. Lastly, our partners (and AutoCAD consultants) for their help and patience.

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Glossary

- Academic Student & Recreation Center (ASRC)
- Bureau of Environmental Services (BES)
- Campus Sustainability Office (CSO)
- Clean River Rewards (CRR)
- Columbia Boulevard Wastewater Treatment Plant (CBWTP)
- Computer-Aided Design (AutoCAD)
- Department of Environmental Quality (DEQ)
- Environmental Protection Agency (EPA)
- Fariborz Maseeh Hall (FMH)
- Intergovernmental Panel on Climate Change (IPCC)
- Karl Miller Center (KMC)
- Leadership in Energy and Environmental Design (LEED)
- Low-Impact Development (LID)
- Municipal Separate Storm Sewer System (MS4) Discharge Permit
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- Science Building One (SB1)
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- Stormwater Management Model (SWMM)
- Stormwater Management Plan (SWMP)
- Synthetic Rainfall Distribution (SRD)
- United States Geological Survey (USGS)

Authors' Note

This project began in Fall 2019 in partnership with Portland State University's Campus Sustainability Office (PSU CSO). Originally, we developed four objectives to achieve an evaluation of PSUs current stormwater infrastructure and possible future implementation considering the uncertainty of climate change impacts. However, due to the nature of the COVID-19 pandemic, and the unpredictability surrounding the reopening of campus that would be safe for students, faculty, and staff, we prioritized remote work, deciding against visual monitoring of PSUs green infrastructure. This work focused on the elaboration of a complete and updated inventory of green infrastructure on campus, stormwater runoff analysis with the elaboration of a SWMM model, and recommendation for future campus stormwater management.

Introduction

Stormwater runoff is one of the most critical environmental issues in urban areas and is only expected to worsen as climate change persists (EPA, 2016). The high impervious surface cover in cities, such as buildings and paved roads, restricts stormwater infiltration, producing higher runoff that conveys urban pollutants to receiving waters. Effective stormwater management is thus a critical aspect of environmental planning in urban areas (EPA, 2016). Urban landscapes with 50–90% impervious cover can lose 40–83% of rainfall to surface runoff (Bonan, 2002). In contrast, forested landscapes lose about 13% of rainfall inputs to runoff from similar precipitation events (Bonan, 2002). Additionally, the magnitude of change in hydrologic behavior is larger in the Pacific Northwest than other regions in the contiguous U.S. because of its increased imperviousness. (Yeakley et al, 2014).

As climate change intensifies, there is substantial evidence that heavy precipitation events will increase in frequency, intensity and/or number (IPCC, 2018), potentially exacerbating problems in urban stormwater management. Precipitation is projected to increase during winters and to decrease during summers, resulting in increased winter time flooding (Yeakley et al, 2014). Models suggest most of the world will have a 16-24% increase in heavy precipitation intensity by 2100 (Hausfather, 2018).

In areas where stormwater runoff has already become a pressing issue, this prediction could potentially bring serious consequences for human and environmental health. Environmentally, stormwater runoff has serious implications for surrounding bodies of water, including the erosion of stream banks, growth of algae blooms, chemical contamination, and the accumulation of excess sediments (Chesapeake Bay Program, n.d.). Human impacts of stormwater runoff can include the flooding of public and private property, the contamination of drinking water, the impairment of recreational uses, and the decline of our waterways (BES, 2016). Thus, there is an urgent need to evaluate whether present-day urban stormwater management strategies can treat predicted increases in storms with climate change.

Historically, the city of Portland has dealt with notable issues surrounding stormwater runoff (information regarding Portland's historical stormwater management can be found in Appendix A). Likewise, Portland State University (PSU) located in the heart of downtown, has also wrestled with the implementation of effective stormwater management. In 2005, PSU tasked itself with achieving 100% on-site stormwater management within the next 50 to 100 years (PSU

SWMP, 2005). The university's most recent plan quantifying stormwater estimated that the university is responsible for approximately 39 million gallons of runoff each year (Bacon et al, 2013). Due to the impervious nature of PSU and the city of Portland, exceptional barriers exist to achieving 100% stormwater reduction.

To combat stormwater runoff in urbanized areas, including PSU and the city of Portland, environmental planners have made a conscious effort to increase stormwater green infrastructure (SGI), which use vegetation, soils, and other elements to mimic natural processes required to manage water. By retaining and treating rainfall from storms, SGI reduce stormwater discharges, peak flow, and pollutant loads (benefits of SGI beyond stormwater can be found in Appendix B). Since the origination of SGI a few decades ago, it is likely that existing systems were not constructed to accommodate the predicted increase in the frequency and intensity of precipitation events. Additionally, already-built systems could potentially cause environmental disservices if they are not regularly monitored and renovated as needed. For example, infiltration practices (e.g., pervious pavement, flow-through planters, etc.) have become an increasingly popular strategy for reducing stormwater volumes and pollutant loads in residential and light commercial developments, where pathogens in stormwater are a primary pollutant of concern (Taguchi et al., 2020). To maintain these systems, it is suggested that straining at the soil surface and sorption to solid particles can aid in removing pathogens (Taguchi et al., 2020). Unintended consequences, including groundwater contamination, have been documented at some sites without proper monitoring and maintenance (Taguchi et al., 2020). Therefore, taking advantage of opportunities to upgrade and implement new infrastructure during the replacement or renovation of buildings will be paramount to managing stormwater runoff on campus.

Since the creation of stormwater plans at PSU, the university has increased the amount of SGI on campus. However, the effectiveness of these systems has yet to be analyzed. In other words, how these systems perform in response to precipitation events is unknown. As PSU is expected to be responsible for treating increasing quantities of stormwater, it is critical to understand the efficiency of current systems and identify areas for infrastructure development and improvement at the university. Additionally, it is imperative that stormwater management emphasizes the ongoing monitoring, renovating of aging, and construction of new SGI.

In collaboration with PSU's Campus Sustainability Office (CSO), we have developed a comprehensive inventory of the SGI on campus and determined its effectiveness in reducing stormwater currently and in the future. To do this, we used the Environmental Protection Agency’s Stormwater Management Model (EPA SWMM) to model PSU’s buildings along with their respective facilities and other surfaces (e.g., non-PSU owned buildings) found on campus. We used historic precipitation data and Synthetic Rainfall Distributions (SRD) from the Natural Resources Conservation Service (NRCS) to estimate changes in stormwater runoff at the university with predicted increased intensity of rainfall and temperature. Finally, we have proposed recommendations to the university based on these findings for the next 80 years. With the completion of this project, we hope the resources we created, and our offered recommendations will help the university reach its goal of reducing its stormwater runoff for a healthier urban environment.

Project Objectives

Sustainability is a core principle of the identity and culture of PSU. Accordingly, the CSO aims to align policy, practice, and planning with PSU's sustainability, resilience, equity, and educational goals (PSU, 2021). The PSU CSO Living Lab program promotes collaborative research projects matching students and faculty with staff to advance campus sustainability goals. This research project aims to provide PSU with a comprehensive report on the SGI on campus to be considered for future stormwater strategies. Also, we have set the groundwork for further research. This project responds to three specific goals:

1. Define PSU's stormwater system by elaborating a complete inventory of the SGI on campus.
2. Develop a SWMM model to analyze the current effectiveness of the stormwater system and the expected impacts of climate change thereon and evaluate alternative scenarios with more SGI implemented.
3. Preparation of recommendations for PSU stormwater management planning by consolidating all the analyzed information and synthesizing insights from discussions with stakeholders.

1. Chapter 1: PSU’s Stormwater Green Infrastructure Inventory

This chapter will begin with a brief introduction about the city of Portland and PSU, SGI description and study area definition. Then we will discuss the methods we followed to achieve the SGI inventory on PSU campus, and present our results.

1.1. About the City of Portland and PSU

In this section, we will cover Portland's climate and other geographic characteristics, as well as PSU's current sustainability efforts and achievement on stormwater management.

1.1.1. Portland Climate

The City of Portland lies in the Pacific Northwest within the state of Oregon, at the confluence of the Columbia and Willamette Rivers. The temperate latitudes (45.5051° N, 122.6750° W), low altitude location, and proximity to the Pacific Ocean mainly influence its climate. The city is located at an average altitude of 15 meters above sea level within the Willamette Valley, and has mostly flat terrain (Weather Atlas, 2020).

Portland features a temperate, Mediterranean climate, where summers are warm and dry, and winters are mild and wet. On average, the city has a high temperature of 81.1°F in its warmest month (August), compared to its low average temperature of 35.2°F during its coldest month (December). The city experiences approximately 36.06 inches of precipitation a year, the large majority of which falls between November and February (U.S. Climate Data, 2020).

1.1.2. Sustainability at PSU & Stormwater Efforts

As a part of the university’s academic vision, PSU has dedicated itself to serve and sustain a vibrant urban region through collaborative learning, innovative research, sustainability, and community engagement (PSU, n.d.a). In terms of stormwater, PSU has made considerable strides, including by obtaining Leadership in Energy and Environmental Design (LEED) certifications for buildings and Salmon-Safe certification, and participating in Portland’s Clean River Rewards (CRR) program.

LEED is a green building certification program used worldwide that is committed to transforming the way buildings and communities are designed, built, and operated, to improve quality of life through a healthy, and prosperous environment (USGBC, n.d.). At PSU, there are currently 15 LEED certified buildings ranging from Platinum to Silver. These buildings have been recognized for their excellence in sustainability and achieved their certification in different ways, with some utilizing SGI. The Academic & Student Recreation Center (ASRC), a LEED Gold certified building, features eco-roofs and a rainwater harvesting system that repurposes precipitation for the purpose of flushing toilets. As the university is constantly creating new and renovating existing buildings, PSU has committed itself to meeting at least Gold certification. In the long run, this will create meaningful environmental change for stormwater, energy reduction, and much more.

Salmon-Safe is a certification and accreditation program that looks to protect water quality, maintain watershed health, and restore habitat for Pacific Salmon in Oregon, Washington, California, and British Columbia (Salmon-Safe, 2019). To receive this certification, urban developments, corporate & university campuses, and golf courses (amongst others) are subject to an independent assessment focused on stormwater management, pesticide reduction and water quality protection, water management, enhancement of native habitat, and if applicable, stream and wetlands area management (Salmon-Safe, 2019). PSU was the first university to be a part of this program in 2006.

CRR is Portland's stormwater utility discount program through Portland's Bureau of Environmental Services (BES), in which participants can save money by working to ensure the health of rivers and watersheds (BES, n.d.c). If stormwater is managed on-site, CRR can grant up to a 100% discount on stormwater charges for ratepayers' efforts to protect rivers, streams, and groundwater. PSU has been and continues to be an active participant in this program. During Summer 2020, we completed an internship with PSU CSO that tasked us with preparing the documentation necessary to demonstrate ongoing compliance with CRR requirements. More information concerning our procedure and takeaways can be found in Appendix C.

1.2. Introduction to Inventory and Common SGI Features

Portland State University has made a noteworthy contribution to reducing the university's environmental impact through the implementation of SGI as part of new and renovated buildings. SGI, including bioswales, rainwater harvesting systems, eco-roofs, flow-through planters, and permeable pavement, can be found across campus. Each of these SGI features are defined in detail below:

- **Bioswale**: Also known as vegetated swales, bioswales are gently sloping depressions planted with dense vegetation or grass that treat stormwater runoff from rooftops, streets, and parking lots. As the runoff flows along the length of the swale, the vegetation slows and filters it, promoting its infiltration into the ground. Bioswales are cost-effective and can provide wildlife habitat and visual enhancements (BES, 2006h).
- **Rainwater Harvesting Systems**: Rainwater harvesting is a system that uses a large cistern to capture and store roof runoff for landscape irrigation and some interior uses, such as toilets and washing machines. A roof washer or filter removes contaminants and debris before the runoff enters the cistern (BES, 2006a). Additionally, due to the infrastructure's ability to retain water within its soil and vegetation, eco-roofs delay peak flows and reduce stormwater volume through evapotranspiration.
- **Eco-Roofs**: An eco-roof is a lightweight vegetated roof system used in place of a conventional roof. Eco-roofs are typically made of a waterproof membrane, drainage material, a lightweight layer of soil, and a cover of plants (BES, 2006b).
- **Flow-Through Planters**: Flow-through planters are structures or containers with impervious bottoms or placed on impervious surfaces. They do not infiltrate into the ground. Flow-through planters are filled with gravel, soil, and vegetation and are typically waterproofed. They temporarily store stormwater runoff on top of the soil and filter sediment and pollutants as water slowly infiltrates down through the planter. Excess water collects in a perforated pipe at the bottom of the planter and drains to a destination point or conveyance system. (BES, 2006c)
- **Pervious Pavement**: Pervious pavement is made of pervious asphalt or concrete. It resembles conventional pavement but has more air spaces, which allow water to pass through the pavement into a reservoir base of crushed aggregate, then infiltrate into the ground (BES, 2006d). Another similar structure is turf block, which consists of interlocking concrete or plastic cells filled with soil and planted with turf grass or a low-maintenance ground cover. Water passes through the turf block into a reservoir base of crushed aggregate, then infiltrates into the subgrade (BES, 2006g).

1.2.1. Inventory Objectives

PSU has installed a significant number of SGI on campus; however, the university does not have an updated inventory of these features. To rectify this, we decided to determine the number and dimensions of SGI, as well as the percentage of impervious versus pervious surfaces on the study area. We also aimed to create an ArcGIS tool that would map this information across PSUs campus. Visual inspections, informational interviews, and computer software, including Computer-Aided Design (AutoCAD), Google Earth and ArcGIS were used to accomplish this.

1.3. Methods

1.3.1. Informational Interviews

One of our most significant sources of information was informational interviews conducted with representatives from PSU, City of Portland BES, the Port of Portland, and others that helped to advance our knowledge of stormwater runoff and SGI. This section will briefly describe those interviews and the valuable information that helped us complete this chapter.

Since the beginning of our project PSU CSO, our community partner, has provided us with general information concerning the expectations of this work as a living lab project, as well as all the related information they had previously gathered involving SGI and stormwater management on campus. Through consistent communication with CSO, we were able to better understand the university's sustainability goals and stormwater-related achievements. This allowed us to have a more precise idea for designing our project to meet the university's needs and serve as a basis for developing a stormwater master plan.

Another PSU entity that played a major role in our project was the Campus Planning Office. In addition to the beneficial interviews, they provided us with more extensive information on SGI, stormwater management on campus, and maps of the university that helped us define a study area. Before the project began, the planning office had begun creating a stormwater plan; their progress was significant for us. From Capital Projects & Construction, we received information about the specific building plans and study area. They gave us AutoCAD files of the university and its SGI and helped us fully understand the infrastructure on campus and its limits.

Outside of PSU, we conducted informational interviews with the Industrial Stormwater Program and Maintenance Inspection Program from BES. They gave us insight into Portland's stormwater management program, specified in their Stormwater Management Manual (BES, 2020), and the inspection program. Through these interviews, we learned about the findings and required actions from the inspection that took place on campus about two months before the interview. They also provided us with ArcGIS files containing information about PSU stormwater facilities, PSU properties, and SGI locations for all Portland, which complemented information in the AutoCAD files' information.

Lastly, an informational interview with the Water Quality Manager at the Port of Portland was conducted. In that meeting, we received information concerning available data maps from the city and the stormwater system and more references to interview for the second part of this project (see chapter 2.2.2).

1.3.2. Study Area Definition

To determine the boundary of our project, we used the Campus Planning Office’s definition of central campus. This represents an 88.5-acre study area that encapsulates most PSU buildings and their respective SGI (Figure 1). The study area is bordered by Market Street to the north, Third Avenue to the east, including the University Place Hotel, and Interstate 405 Highway to the southwest. The study area includes buildings owned and managed by the university, as well as other public and private buildings. This inventory does not include three PSU buildings that are outside of our study area: Crown Plaza, Robertson Life Science Building, and the Corbett Building.

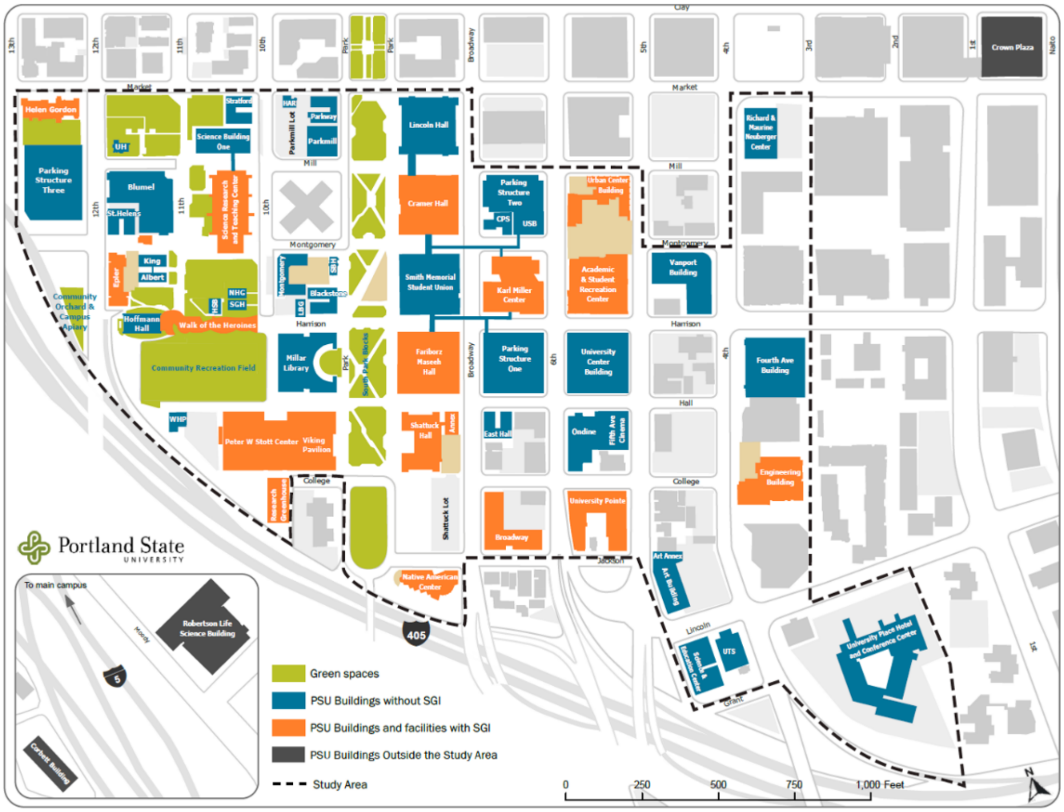

Figure 1. Study areas with PSU owned spaces, classified by color as buildings without SGI, green spaces, buildings with SGI, and buildings outside the study area.

1.3.3. Visual Inspection and Measurements

As an initial stage of the inventory development process, visual inspections of all accessible SGI on campus to identify them, understand them, and characterize their status were conducted. For these inspections, criteria from the City of Portland's Bureau of Environmental Services Manual (BES, 2016) were used that evaluated the three following elements:

- Structure components must be operated and maintained in accordance with the design specifications.
- Vegetation must cover at least 90% of the facility at maturity.
- The growing medium must sustain healthy plant cover and infiltrate within 48 hours.

Additionally, we reviewed the BES's most recent inspection report for the twelve PSU properties registered in the City's Maintenance Inspection Program. Later, we conducted additional inspections to get information concerning the SGI measurements, take notes on the facilities, and photograph them. Due to the COVID-19 pandemic, we were unable to continue with this aspect of our project. The closing of campus and uncertainty surrounding its reopening, made it difficult to inspect these SGI regularly.

For some infrastructure, there was no available information concerning the square footage of the facilities and/or their treated areas. So, we measured this infrastructure, calculated their areas, and took pictures to gather this information. We performed these actions for the bioswale at Millar Library Bicycle Garage (Bicycle Garage) and the pervious pavement at Shattuck Hall. Also, we measured some other facilities, such as the flow-through planters at ASRC, Helen Gordon Child Development Center (Helen Gordon), and Cramer Hall, to corroborate the AutoCAD information.

1.3.4. Visualization and measurements using Google Earth

To learn more about the infrastructures and verify some characteristics and dimensions, we needed to perform visual inspections and measurements. However, with COVID-19 restrictions, Google Earth and Google Maps became a key set of tools for surveying SGI features. Both are computer programs that map the Earth by superimposing satellite images, aerial photography, and GIS data onto a 3D globe. They include coordinates to identify specific locations and tools for measuring distance tools (Google, n.d.).

Google Maps allowed us to do preliminary measurements, such as distances, areas, elevations, and slopes. Using coordinates, we were able to identify some important locations, like the highest and lowest points on campus, which we later used to georeferenced the CAD files. Google Earth was used to calculate the dimensions of the two research eco-roofs on campus, Cramer Hall and SRTC, which were not included in the CAD files, as well as the eco-roofs on Crown Plaza, Robertson Life Sciences Building, and University Pointe, which PSU does not administer. Additionally, Google Earth was used to identify other buildings and facilities not owned by PSU within the study area and calculate their eco-roofs' approximate dimensions to be included in the calculations of SGI surfaces within the study area.

1.3.5. Calculations and Analysis using AutoCAD

To measure, draw, and analyze the dimensions of buildings and other facilities on campus, we used AutoCAD Map 3D 2021 software. This program can be used to draft, annotate, and create precise 2D and 3D drawings (AutoDesk, n.d.). We carried out this task mainly by reviewing and updating the AutoCAD file "Im-Permeable.dwg" provided by PSUs Capital Projects & Construction Department during our internship with CSO (see Appendix C). In cases where data was unavailable, we measured SGI in the field or used reference dimensions from satellite tools to complete the inventory.

In the final AutoCAD file "PSU_SWMP (Figure 2), we worked with 18 different layers, some given to us by Capital Project & Constructions, and some created for our analysis. Most of the layers did not require modifications, but others needed to be adjusted to match their respective buildings' plans or missing information. We created some layers by copying or drawing each type of SGI, and another layer by separating one the study area into 44 groups (excluding the streets not administered by the university), which were then used as subcatchments for the SWMM model (chapter 2). Information concerning each AutoCAD's layer details can be found in Appendix D.

1.3.6. ArcGIS Map Elaboration

As a final stage for our elaboration of campus inventory, we used ArcGIS to create a visual representation of the information collected. ArcGIS Pro version 2.7.0 is a software application that uses a Geographic Information System to visualize, analyze, and develop geographic data. We also used ArcGIS Online to make our map available to PSU students and faculty. ArcGIS Online is a cloud-based version of the software (Esri, n.d.).

The information we included in this map consisted of study area, impervious and pervious surfaces, PSU and non-PSU buildings and other facilities within the study area, trees from the most recent inventory, and SGI, including their type, size, location, and stormwater treated (i.e., impervious area drainage flowing to facility).

1.4. Results: The Inventory

Our inventory included 53 of the 56 total buildings listed on the university campus website; their construction dates span the last 120 years. The oldest building on campus is the University Honors building, constructed in either 1893 or 1898 by the early Portland pioneer banker-realtor Robert Howard, in the Queen Ann style. The newest building on campus is the Vanport Building, which opened for use in 2021. It is a seven-story condominium partnership between Portland State University, the City of Portland, Portland Community College, and Oregon Health & Science University, with retail tenants on the ground floor (PSU, n.d.b). About 75% (40/53) of PSU buildings were constructed before the first municipal stormwater permit for the City of Portland was issued by the Oregon Department of Environmental Quality (DEQ) in 1995. Therefore, it is possible to infer that adequate stormwater management systems were not considered during the original construction of these buildings (Figure 2). In addition to the buildings mentioned above, PSU includes other landscaping and recreation infrastructure.

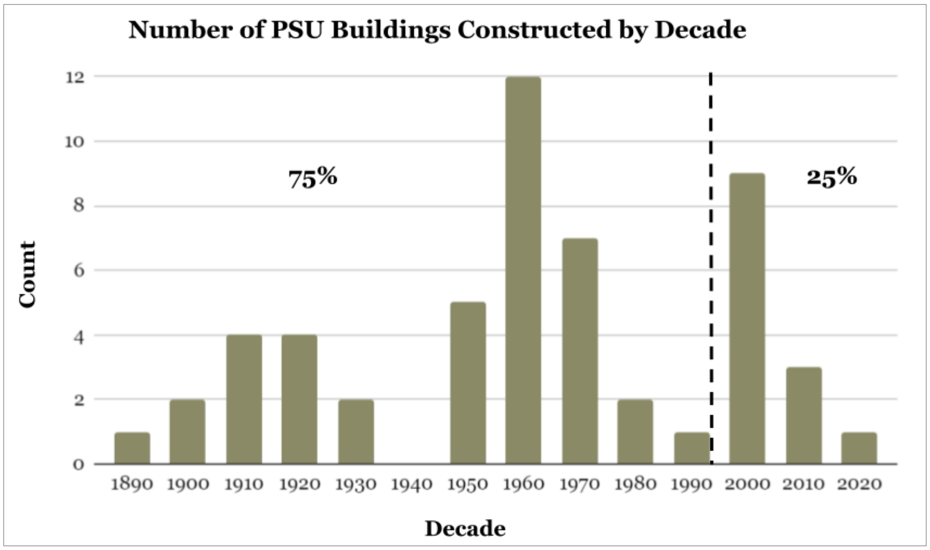

Figure 2: Number of PSU campus buildings constructed by decade. 75% were built before the first municipal stormwater permit for the City of Portland was issued by DEQ in 1995 (BES, n.d.b)

1.4.1. Study Area Inventory

The first analysis was conducted identifying and measuring the different types of surfaces within the study area. Table 1 summarizes the results of the SGI inventory and the different types of surfaces, including all PSU and non-PSU buildings and SGI within the limits of our study area. The information was presented in two main categories, including: surface type (impermeable or permeable) and owner (PSU or non-PSU), so that it would be easier to interpret the data and distinguish between PSU and non-PSU managed areas. Our total study area was calculated to be 3,857,102 sq. ft.

Table 1. Study area coverage by owner, surface type, area (sq.ft), and percent area that it covers.

Surface	Owner	Surface type	Area (Sq. ft.)	%
Study Area	Total	Total	3,857,102	100%
PSU Impermeable Area	PSU	Impermeable	1,950,662	51%
PSU Permeable Area	PSU	Permeable	349,195	9%
Non-PSU Impermeable Area	Non-PSU	Impermeable	1,171,667	30%
Non - PSU Permeable Area	Non-PSU	Permeable	385,578	10%

From this inventory, we were able to determine that 81% of the total study area was impermeable, and 19% was permeable. Of PSU-managed areas, 85% was impermeable, 15% was permeable. Additionally, SGI represented 2.4% of the total study area (Figure 3).

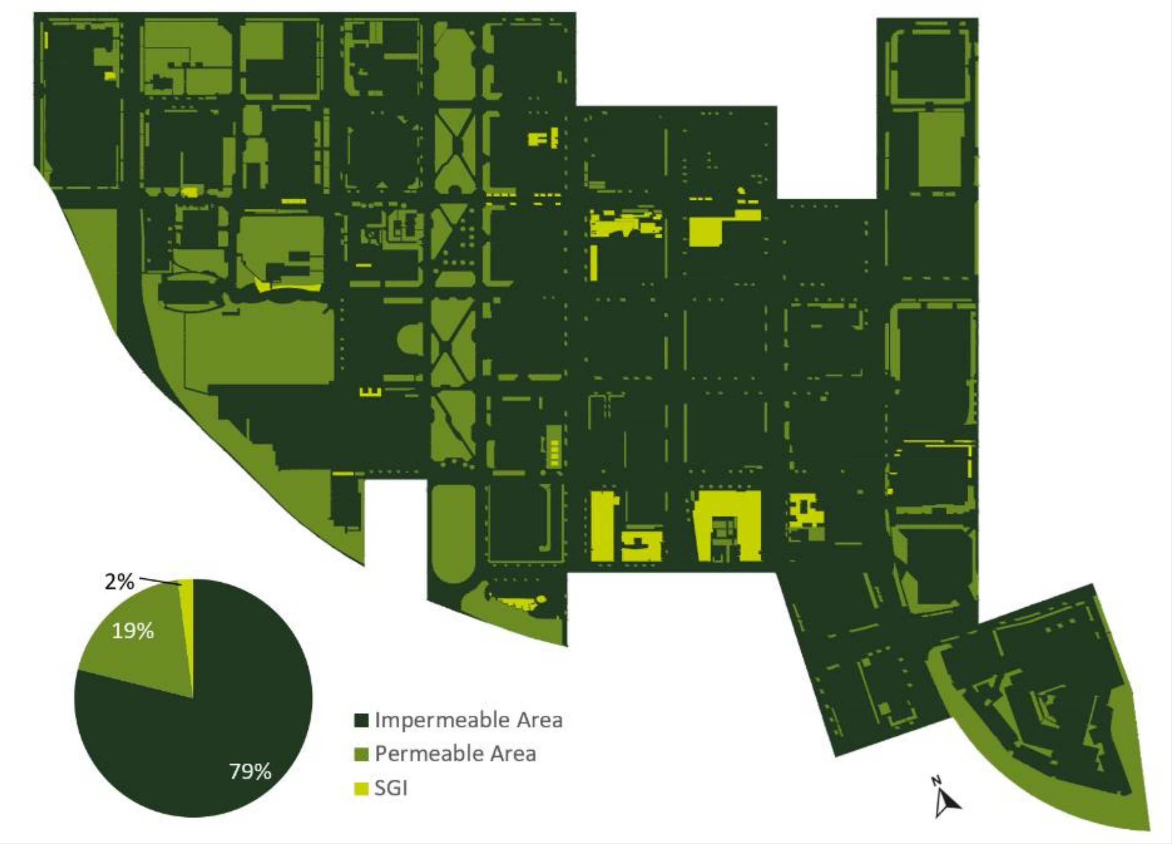

Figure 3: Impermeable and permeable surfaces, and SGI within the study area.

1.4.2. SGI Inventory

PSU has five types of SGI, including: bioswales, eco-roofs, flow-through planters, pervious pavement, and rainwater harvesting systems, on 18 of their properties on campus which receive 12% of all stormwater generated on PSU impervious surfaces. Table 2 shows the number of each type of SGI, the number of buildings on campus with each type of infrastructure, their total area, and the area that drains into these facilities. The most abundant infrastructure type is flow-through planters (Figure 4), which manage 58% (137,945 sq. ft.) of PSU-responsible impervious surfaces, almost 17 times more than the area they occupy (Table 2). Twelve buildings feature constructed flow-through planters, including: Cramer Hall, Engineering Building, Epler Hall, ASRC, Fariborz Maseeh Hall (FMH), Helen Gordon, Karl Miller Center (KMC), Peter Stott & Viking Pavilion (Peter Stott), Research Greenhouse, Science Research & Teaching Center (SRTC), Urban Center Building (Urban Building), and the Walk of the Heroines.

Figure 4. Flow-Through Planters on Campus. A: FMH, B: Peter Stott, C: KMC, D: Cramer Hall, and E: Helen Gordon (2020-2021).

Eco-roofs represent the second most abundant SGI type (Figure 5), managing 25% (59,089 sq. ft.) of the treated impervious surfaces (Table 2). In the case of eco-roofs, the area draining to the facility is the area of the SGI itself, as it only treats water that falls upon it. Eight buildings have this type of facility: ASRC, Blumel Bike Garage, Broadway, KMC, and Native American Student & Community Center (NASCC) have either extensive (i.e., facilities with shallower soil depths), intensive (i.e., facilities with deeper soil depths, typically 1.5-2m or more) or both types of eco-roof specifically designed for stormwater management and connected to the stormwater system pipes. Cramer Hall and SRTC have research eco-roofs that are disconnected from the stormwater system, but nevertheless retain precipitation and reduce stormwater runoff. University Pointe, Crown Plaza, and Robertson Life Sciences Building contain eco-roofs that are not managed by PSU. The eco-roofs on Crown Plaza and Robertson Life Sciences Building were not considered in this inventory because they are located outside of our defined study area.

Figure 5. Eco-roofs on Campus. A: KMC, B: NASCC, C: ASRC (2020-2021).

There are three pervious pavement installations on campus that, similar to eco-roofs, manage only the water that falls upon them. These SGI are located at ASRC, Shattuck Hall, and Walk of the Heroines, and manage 3% of the treated impervious surfaces (Figure 6). There is also one bioswale in the study area, a 231 sq. ft. facility located near the Library Bike Garage, which treats stormwater from its surrounding areas (Figure 7).

Figure 6. Pervious Pavement on Campus. A: Shattuck Hall, B: Walk of the Heroines, C: ASRC (2020-2021).

Figure 7. Bioswale on Library Bicycle Garage (2021).

Additionally, the university has implemented rainwater harvesting systems in three buildings: ASRC, Engineering Building and Epler Hall, where rainwater is harvested through some of the SGI already described and used to power plumbing and fire protection systems as well as in hydraulics labs and toilets (PSU, n.d.c). Although rainwater harvesting systems are an important strategy to reduce stormwater runoff, these features were not included in our SWMM analysis because the type of modeling required is different from that of other SGI and considered outside the scope of this project. As a result, we also did not include the rainwater harvesting systems in our inventory results. Finally, there are four buildings that in addition to their SGI have storm-filter catch basins, a device comprised of media-filled cartridges that trap particulates and adsorb pollutants from stormwater runoff such as total suspended solids, hydrocarbons, nutrients, metals, and other common pollutants (Contech Engineering Solutions, n.d.). The buildings with these devices are: ASRC, FMH, NASCC, and Peter Stott. Additionally, we did not include storm-filter catch basins within our inventory results since they are commonly associated with stormwater water quality and our project is primarily focused on stormwater quantity.

The implementation of SGI, specifically eco-roofs and flow-through planters was included in the construction of the Vanport Building in 2021. Although we mention the recently opened building within this report, we do not have the necessary information concerning its infrastructure and therefore it will not be included in the analysis.

Table 2: Stormwater Green Infrastructure and other stormwater facilities on campus, number of buildings with each type of facility, total area of the and total area treated by each facility.

Type of Facility	SW Facilities	N° of Buildings w/ facilities	Total area (sq ft)	Area treated by facility (sq ft)
Stormwater Green Infrastructure	Bioswale	1	231	4,961
	Eco-roof	8	59,089	59,089
	Flow-Through Planters	12	8,199	137,945
	Pervious Pavement	3	8,286	8,286
Total	**4**	**18**	**75,805**	**210,281**

1.4.3. ArcGIS Inventory

For a visual representation of the data collected for the inventory, we transformed and uploaded the results from our inventory into an ArcGIS map, and created a Story Map of our project, to facilitate access and use for PSU students and faculty.

- PSU Stormwater inventory map: https://arcg.is/1znG8n.
- Current Stormwater Practices and Future Implementation at Portland State University with the Uncertainty of Climate Change - Story map: https://storymaps.arcgis.com/stories/8db98f780df8434ca599c09fd91aa865.

1.4.4. Discussion

With this inventory, it was estimated that impervious surfaces account for 81% of our total study area. Additionally, PSU-managed areas accounted for approximately 62% of the total impervious surfaces within our defined site. Currently, 18 PSU-owned buildings and facilities overall have implemented SGI, but permeable surfaces for which PSU is responsible plus the SGI surfaces account for only 10% of our study area. Furthermore, when dividing the total surface area that drains into all PSU SGI facilities (210,281 sq. ft.) by the total surface area (3,857,102 sq. ft), we discovered that PSU SGI treats only 5.5% of our total study area. Additionally, we divided the area that drains into all PSU SGI facilities by the total PSU impermeable area (1,950,662 sq. ft.) and discovered that PSU SGI treats only 10.8% of the university’s impermeable surfaces. We want to reiterate that this does not include rainwater harvesting systems, which would have likely increased this percentage. Nevertheless, this untreated 89% of the university impermeable surfaces represents an opportunity to increase PSU’s SGI footprint to more fully capture the stormwater runoff generated on campus.

PSU’s campus has more than 100,000 square feet of larger sections of continuous green space (29% of the total permeable areas). This segment includes the Oak Savanna, PSU Park, Community Orchard, Mini Golf area, and the park next to the Stratford Building. Large green spaces represent an opportunity to implement other types of rainwater reduction strategies, such as afforestation and rain gardens.

PSU impervious area is prevalent compared to permeable area and SGI. The data show that if the university wants to reach 100% stormwater reduction in the next 50 to 100 years, the construction of new SGI and permeable spaces across campus will be necessary. In chapter three, we present recommendations that will increase SGI and thereby hopefully reduce stormwater runoff from PSU’s premises.

2. Chapter 2: SWMM Model & Climate Change Considerations

This chapter will begin with a brief introduction about the SWMM model and climate change. Then we will discuss the methods we followed for the elaboration of PSU campus SWMM model including input parameters, scenarios ran and model considerations. Finally, we will present and interpret our results.

2.1. Introduction: SWMM Model and Climate Change

As previously established, it is not known exactly how effective the already implemented SGI are at reducing the stormwater runoff that PSU is responsible for managing. With climate change expected to increase the severity and/or frequency of precipitation events, it is crucial to understand the efficiency of these infrastructure currently, so that PSU stormwater managers can create precise plans surrounding maintenance, renovation, and future application of SGI.

To achieve this understanding, we used the EPA's Stormwater Management Model (SWMM), a program that is utilized to plan, analyze, and design facilities related to stormwater runoff, combined and sanitary sewers, and other drainage systems (EPA, 2020). The program was created to help local, state, and national stormwater managers in reducing runoff through infiltration and retention, and to help reduce discharges that result in the impairment of water bodies (EPA, 2020). Using SWMM, we created a model that represented our study area at PSU with each building's respective SGI. Simulations of water runoff quantity were done to estimate how climate change will alter precipitation patterns and temperature currently and in the future.

2.2. Methods

2.2.1. Informational Interview

In order to create a representative SWMM model, informational interviews were conducted. Similar to chapter one, PSU faculty and both private and public sector professionals provided valuable information concerning SGI, Portland's stormwater system, and use of SWMM. Our interviews with PSU faculty provided specifications and design information concerning two research eco-roofs on campus. With these parameters, we developed a PSU-specific SWMM model. Additionally, informational interviews with BES staff from the

Maintenance Engineering Department were conducted for the development of our model. We received information about the sewer and stormwater systems in Portland and their main features through this interview, which we used to accurately model our study site. To learn more about SWMM, we were referred to an engineer from Geosyntec Consultants, a firm that works with environmental and civil infrastructure solutions. We received essential tools needed to develop an accurate and representative model, including general subcatchment properties and the type of infiltration model used. Additionally, he served as an advisor to ensure that our model was usable and representative of PSU.

2.2.2. Data Collection

We used the data gathered from our inventory (chapter one) consisting of building areas, SGI locations, and the percentage of impervious surfaces, and hydrologic and hydraulic data described in this chapter to build our SWMM model.

2.2.2.1. Climate Data

Our first source of raw precipitation data was from the United States Geological Survey (USGS) City of Portland HYDRA Rainfall Network page (USGS, 2018). We used data from the closest gauge to campus, Station 164, which is located in SW 12th and Clay, 1500 feet away from the center of the study area. For the historical precipitation simulation, we used 20 years of hourly rainfall data from August 1st, 2000, to July 31st, 2020. For the projected simulations, we assumed a scenario of a global warming of 2 degrees Celsius (3.6 °F) and considered an estimated increase of 6% average precipitation for the Winter period (Fischer et al, 2014), December 21 through March 20 (Timeanddate.com, n.d). Since precipitation intensity is projected to decrease in summer months (Yeakley et al., 2014), we assumed a 6% reduction from June 20 to September 22 (Timeanddate.com, n.d). We did not change precipitation patterns for Spring or Fall. Model projections of precipitation have large uncertainties. With a model agreement of 80%, Fisher et al. illustrated that in the Pacific Northwest, change in heavy precipitation is projected to increase 4 to 6 % per degree of global warming, and change in annual mean precipitation about 2 to 4% (Fisher et al, 2014).

The model also included daily temperatures to analyze how temperature variability throughout the year affects stormwater runoff reduction through evaporation, and how this will increase due to climate change. For the historical record scenarios, we used the daily average high and low temperature from the weather station at Portland International Airport (NOAA, 2021). For 24-hours simulations we selected the daily average high and low of January and August for being the coldest and the warmest month in Portland, Oregon (Weather Atlas, n.d.). For the simulations with future climate change considerations, we used the monthly high and low 2060-2090 average RCP 8.5 weighted mean projections temperatures from the Climate Explorer for Portland, OR in Multnomah County. RCP 8.5 (Representative Concentration Pathway) is a hypothetical future described by the amount of radiative forcing in the atmosphere. This pathway indicates an increase in the atmosphere's greenhouse capacity, in watts per square meter, in 2100 relative to 1750. In this scenario, the atmosphere's ability to trap heat (a measure called radiative forcing) reaches 8.5 Watts per square meter in the year 2100. The RCP 8.5 pathway is considered a Higher Emissions scenario (Climate Explorer. n.d.).

To analyze the effect of different storm intensities, we used Synthetic Rainfall Distribution (SRD) developed by the NRCS. The intensity of rainfall varies considerably during a storm as well as in geographic regions. To represent various regions of the United States, NRCS developed four SRD (I, IA, II, and III). Type IA is the least intense and represents the Pacific Northwest maritime climate with wet winters and dry summers (USDA, 1986). We used type IA to develop a SRD for our model, with total rainfall depth for a 24-hour storm in 6 minutes intervals from the National Weather Service station located at the Portland International Airport, as stated in the Sewer and Drainage Facilities Design Manual (BES, 2020).

2.2.2.2. Study Area and Model Definition

To determine the amount of runoff water generated in a given storm event on campus, only buildings and other infrastructure within the limits of the study area described in Chapter 1 were considered (Figure 1). Of the 56 buildings owned by PSU, three are outside this zone and were not included in the model: Crown Plaza, Robertson Life Sciences Building, and Corbett Building. Besides buildings, the study area included other PSU properties such as landscaping and recreation infrastructure. Additionally, 28% of this area corresponds to non-PSU facilities, including the city sidewalks, roads, central campus South Park Blocks, and buildings not owned by PSU. Our model includes all these facilities except city roads. We decided to exclude this surface because of the different elements that affect street runoff compared to other structures, including increased pollution and litter from humans and motor vehicles.

The study area has a shallow 4% west-east slope, determined by the elevation of the Tualatin Mountains to the west and the Willamette River channel to the south. The highest point of the study area is the west corner of the Peter W. Stott Community Field (45°30'42" N, 122°41'17" W), with 176 feet elevation. The lowest point is the intersection of Market Street and 3rd Avenue (45°30'43" N, 122°40'43"W), with 79 feet elevation (Google Earth, n.d.).

The runoff component of SWMM operates on a collection of subcatchment areas that receive precipitation and generate runoff and pollutant loads (Rossman, 2015). For our model, we divided the study area described above into 44 subcatchments, comprising 83% (almost 74 acres) of the total study area (Table 3). The criteria used when determining the majority of the subcatchments were street blocks, limited by the boundary between sidewalks and streets. We used the "003-Street-Blockouts" layer from the AutoCAD files to determine most of the subcatchment limits. In the same file, we created a new layer called "001-Reference Subcatchments", where we drew each section to calculate the area and the percentage of impervious surface to later input in SWMM. Within the study area, from SW Twelfth Avenue to SW Broadway, transit is closed to the general public and is used primarily by pedestrians. These are the only streets included in the subcatchments of that zone (Figure 8).

Figure 8: Study Area divided in 44 subcatchments for SWMM.

To determine the percentage of impervious surface, we identified the permeable area of each subcatchment, including PSU and non-PSU layers, and the layer with impervious areas data. The results are shown in Table 3. See Appendix D for more detail on the AutoCAD layers used.

Table 3. Study Area 44 subcatchments with name of buildings and other facilities for each.

Subcatchment	Buildings and other facilities	Subcatchment area (ac)	% Impervious
S01	Helen Gordon	0.91	81%
S02	Parking Structure Three	1.61	95%
S03	Community Orchard & Campus Apiary	0.74	20%
S04	University Honors	1.42	30%
S05	Blumel Bike Garage, Blumel Residence Hall, and Saint Helens Residence Hall	1.73	87%
S06	King Albert Residence Hall and Stephen Epler Residence Hall	1.21	75%
S07	Science Building One and Stratford Hall	1.31	69%
S08	Science Research and Teaching Center	1.84	81%
S09	George Hoffmann Hall, Harrison Street Building, North Greenhouse, Oak Savanna, South Greenhouse and Walk of the Heroines	2.16	57%
S10	Peter W. Stott Community Field	2.66	4%
S11	Harder House, Parkmill, and Parkway Residence Hall	1.16	82%
S12	Vue Apartments	1.16	96%
S13	Blackstone Residence Hall, Millar Library Bicycle Garage, Montgomery Residence Hall, and Simon Benson House	1.37	79%
S14	Millar Library	1.40	87%
S15	Peter W. Stott Center and Viking Pavilion and West Heating Plant	3.65	85%
S16	Research Greenhouse	1.10	36%
S17	Park blocks	4.03	46%
S18	Park block south	0.71	0%
S19	Lincoln Hall	1.36	91%
S20	Cramer Hall	1.47	92%
S21	Smith Memorial Student Center	1.45	92%
S22	Fariborz Maseeh Hall	1.51	94%

S23	Shattuck Hall & Annex	2.66	89%
S24	Native American Student and Community Center	0.95	56%
S25	Campus Public Safety, Parking Structure Two, and University Service Building	1.18	96%
S26	Karl Miller Center	1.20	97%
S27	Parking Structure One	1.18	98%
S28	East Hall	1.18	97%
S29	Broadway Residence Hall	1.18	97%
S30	Academic and Student Recreation Center and Urban Center Building	2.69	100%
S31	University Center Building	1.18	98%
S32	Ondine Residence Hall and Fifth Avenue Cinema	1.18	97%
S33	University Pointe	1.14	93%
S34	Vanport Building	1.18	99%
S35	Not PSU 1	1.18	95%
S36	Not PSU 2	1.18	98%
S37	Not PSU 3	1.11	95%
S38	Art Building and Art Annex	1.14	97%
S39	Science and Education Center, University Technology Services	1.24	94%
S40	Richard and Maurine Neuberger Center	1.32	81%
S41	Not PSU 4	2.89	75%
S42	Engineering Building and Fourth Avenue Building	3.64	89%
S43	Not PSU 5	1.40	79%
S44	University Place Hotel	5.93	67%

2.2.3. SWMM Model Elaboration

SWMM is a model that conceptualizes a drainage system as a series of water and material flows between several major environmental compartments (Rossman, 2016). Not all compartments need to appear in a particular model. The following are the compartments and their SWMM objects included in our model:

- Atmosphere: Rain gage represents rainfall inputs to the system

- Land Surface: Subcatchments receive precipitation from the rain gage and send outflows as infiltration and surface runoff to the transport compartment
- Transport: A network of pipes and manholes transport water to outfalls

The hydrological processes included in SWMM are depicted in the following diagram. The items with dark grey are the processes excluded from our model (figure 9).

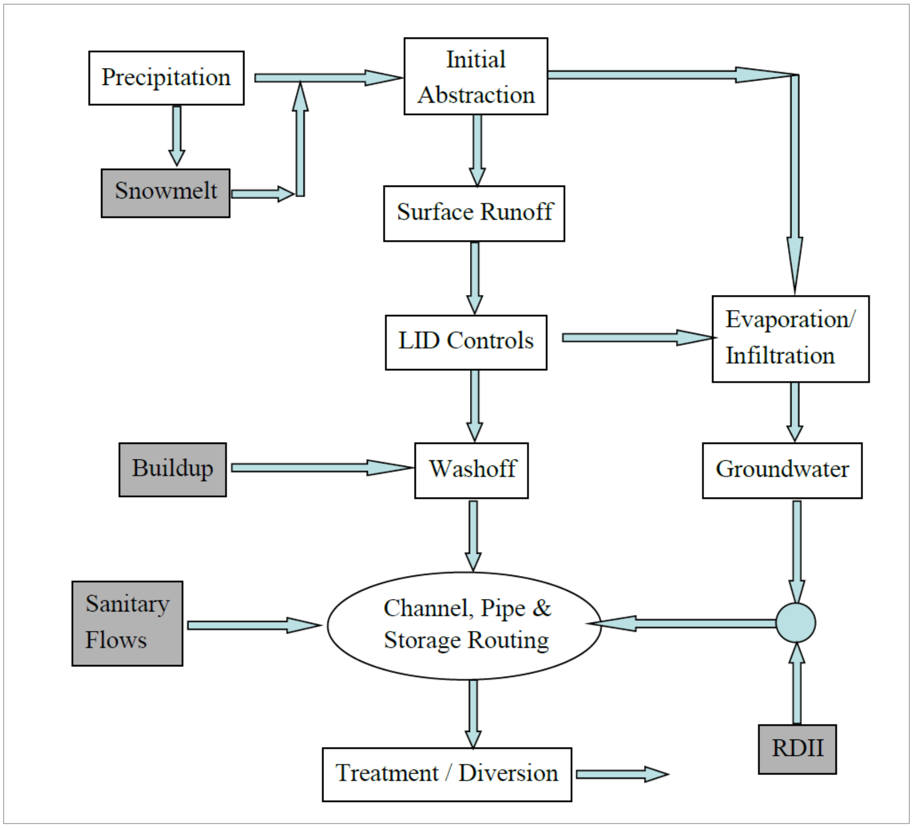

Figure 9. SWMM diagram of the hydrological processes included in the model.

From the diagram shown above, our model had only one input of water to the system: precipitation, and three different outlets: evaporation from of standing surface water and LID (Evaporation Loss), infiltration of rainfall into unsaturated soil layers in according to the subcatchments' permeability and from LID (Infiltration Loss), and the final outlet in the waterbody (Rossman, 2016).

SWMM has two types of objects, the visual objects that can be displayed in a map of which we use: subcatchments, nodes, conduits, outlets, and rain gage; and non-visual data objects that describe additional characteristics and processes within a study area. For our model, we include temperature to compute evaporation rates and Low Impact Development (LID) controls. We used the CAD plans as a backdrop image reference for creating the subcatchments and our calculated data for setting the model's parameters, such as area and percentage of permeability (Figure 10).

Runoff flow from the subcatchment is routed to two identified stormwater pipe outlets and ultimately to the Willamette River. To the North, near the Hawthorne bridge is the outfall ABU832 (122°40'24" W, 45°30'43" N), and to the South by Marquam bridge ANW165 (122°40'14" W, 45°30'23" N) (Portland Maps, n.d.b). To describe rainfall's infiltration from the pervious fraction of the subcatchments into the unsaturated upper soil layer, we used the Modified Green-Ampt infiltration model. The Green and Ampt equation is a half-empirical and half-theoretical model describing the soil water infiltration process (Li et al., 2018). This method assumes that a sharp wetting front exists in the soil column, separating soil with some initial moisture content below from saturated soil above. The Modified Green-Ampt method modifies the original by not depleting the moisture deficit in the top surface soil layer during initial periods of low rainfall. This change can produce more realistic infiltration behavior for storms with long initial periods where the rainfall intensity is below the soil's saturated hydraulic conductivity. The input parameters required are the soil's initial moisture deficit, the soil's hydraulic conductivity, and the suction head at the wetting front (Rossman, 2015). We used the default input values on SWMM.

One attribute required when creating subcatchments is slope. We calculated a 4 percent slope for the whole study area; however, the leveling of ground necessary for the construction of buildings had to be considered. We decided to use a 1 percent slope for all subcatchments, being the minimum needed for swales and drainage ways to prevent standing water and muddy conditions (USGSA, 2019).

Subcatchment width of the overland flow path was estimated by dividing the subcatchment area by the average maximum overland flow length. The maximum overland flow length is the length of the flow path from the outlet to the furthest drainage point of the subcatchment. Maximum lengths from several different possible flow paths were averaged. Adjustments were made to the width parameter to produce good fits to measured runoff hydrographs. (Rossman, 2015). Thus, considering that the width parameter is used to adjust the hydrograph and is not a physical measurement, we estimated it by calculating the square root of each subcatchment area. We compared those results with the dimensions of other subcatchments to verify we had representative values. A typical value for overland flow length in urban areas is around 300-500 feet.

Another required parameter is Manning's roughness coefficient (n). This is the most frequently used index for the classification of different surfaces' textures and implies flow delay, which depends on the surfaces' roughness (McCuen, 1998). Rougher surfaces like underbrush have higher coefficient values than smoother surfaces like glass. For the pervious surfaces, we used a Manning's value of 0.1 and for impervious 0.01 (McCuen, 1998).

Figure 10. SWMM diagram that conceptualizes a drainage system in the study area.

2.2.3.1. Stormwater Pipes - conduits

SWMM transports stormwater runoff from the subcatchments through a system of pipes, channels, storage/treatment devices, pumps, and regulators. SWMM tracks the quantity and quality of runoff generated within each subcatchment, including the flow rate, flow depth, and quality of water in each pipe and channel during a simulation period (EPA SWMM Manual, 2015). For the development of this routing system, we used existing stormwater pipe characteristics from the City of Portland, BES (Portland Maps, n.d.a). From this map, we identified principal input parameters for the conduits, such as the elevation above the inlet and outlet node inverts, slope, their material, length, and shape (Rossman, 2015). In the creation of this section, we discovered that some street blocks contained more than one stormwater pipe, and these pipes were often connected to one another. To simplify our model, we drew one pipe and input a length adding all individual length. The cross-section geometry for all pipes was circular, but the building materials varied, resulting in the need to utilized different Manning's coefficients. The six pipe materials and their respective coefficients are as follows: Corrugated steel (0.024), CIPP (0.009), HDPE (0.009), PVC (0.009), Reinforced Concrete (0.013), and Vitrified clay (0.015) (McCuen, 1998).

2.2.3.2. Low Impact Development Controls (LID)

LID controls are low impact development practices designed to capture surface runoff and provide some combination of detention, infiltration, and evapotranspiration (Rossman, 2015). In order to use consistent terminology with the SWMM model, the term LID is used to capture a broader array of practices and features than the term SGI suggests. Both terms had been used interchangeably for this report. SWMM can explicitly model eight different types of LID controls, for our model we used the following four types:

- Bio-Retention Cells (Flow-Through Planters): planters that contain vegetation grown in engineered soil mixture placed above a gravel drainage bed. They provide storage, infiltration, and evaporation of direct rainfall and runoff captured from surrounding areas (Figure 11) (Rossman, 2015).

- Green Roofs (Eco-Roofs): contain a soil layer that is on top of a special drainage mat material that coveys excess percolated rainfall off the roof (Figure 12) (Rossman, 2015).
- Permeable Pavement - Block Pavement: impervious pavement blocks placed on a gravel bed with a gravel storage layer below. Rainfall is captured in the open spaces between the blocks and conveyed to the storage zone and native soil below or directed to an outlet (Figure 13) (Rossman, 2015).
- Vegetated Swales (Bioswale): channels or depressed areas with sloping sides covered with vegetation. They slow down the conveyance of collected runoff and allow it more time to infiltrate into the native soils beneath it (Rossman, 2015).

For the model, we designed six LIDs using specifications from PSU plans or our own measurements, and reference SWMM default values for the remaining parameters. The types of LID controls used were bio-retention cells, permeable pavement, and bioswales. Average dimension values were used primarily for the bio-retention cells, due to their prevalence on campus. For the eco-roof, the following three LID controls were created depending on the type of vegetation or function: extensive, intensive and research. To design the LID controls, we first selected the input parameters, which are divided into different groups. We will mention some of the parameters used for the LID controls in our model, and the remaining can be found in Appendix E. One parameter is surface, where the exterior of the SGI, including the berm height (which limits the maximum depth to which water can pond above the surface of the unit before overflow occurs), vegetation fraction, volume occupied by stems and leaves, slope, and Manning's roughness coefficient are described. We used coefficient values of 0.2 for the eco-roofs, 0.15 for the bio-retention cells, and 0.1 for the bioswales, using as reference grass values from the SWMM manual. For the pervious pavement we used a Manning's coefficient of 0.024 similar to the coefficient for cement rubble surface (Rossman, 2015). Additionally, soil information, including thickness, porosity, and field capacity was collected from plans and information interviews and entered in our model. Information concerning draining and storage properties were found via literature review and using default values from SWMM. Finally, for the pavement properties group, we used values from a similar study (Zhang & Guo, 2014).

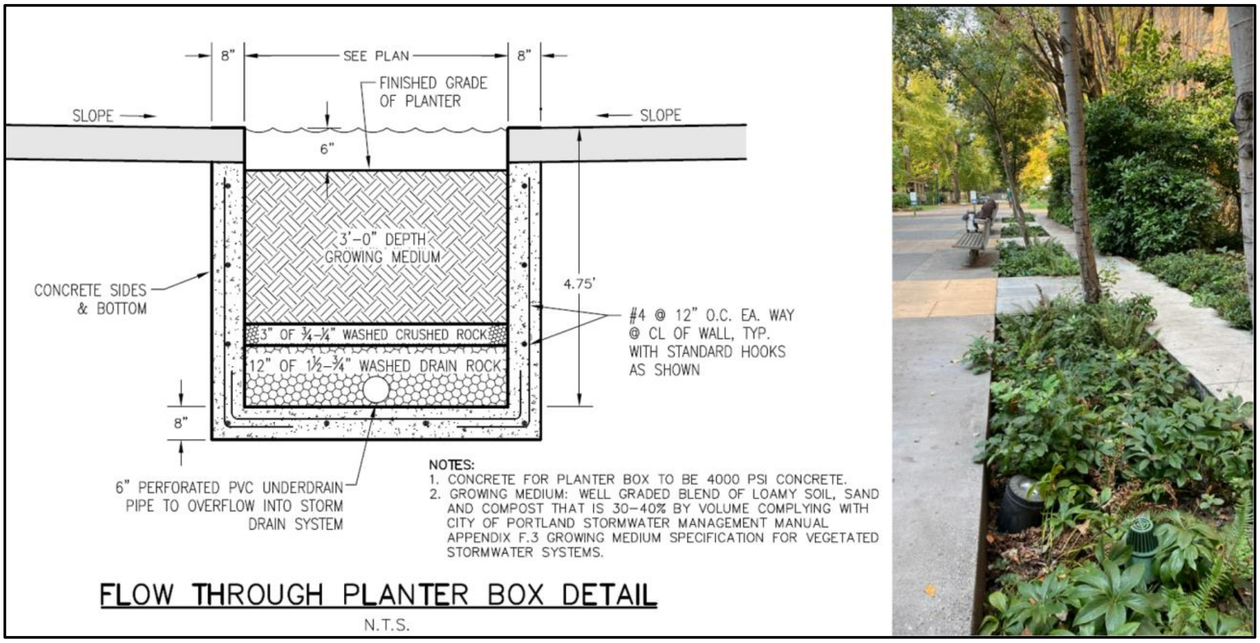

Figure 11. Flow-Through Planters details. PSU Cramer Hall (North Plaza Plan Street Cross Sections C2 6/5/2009.)

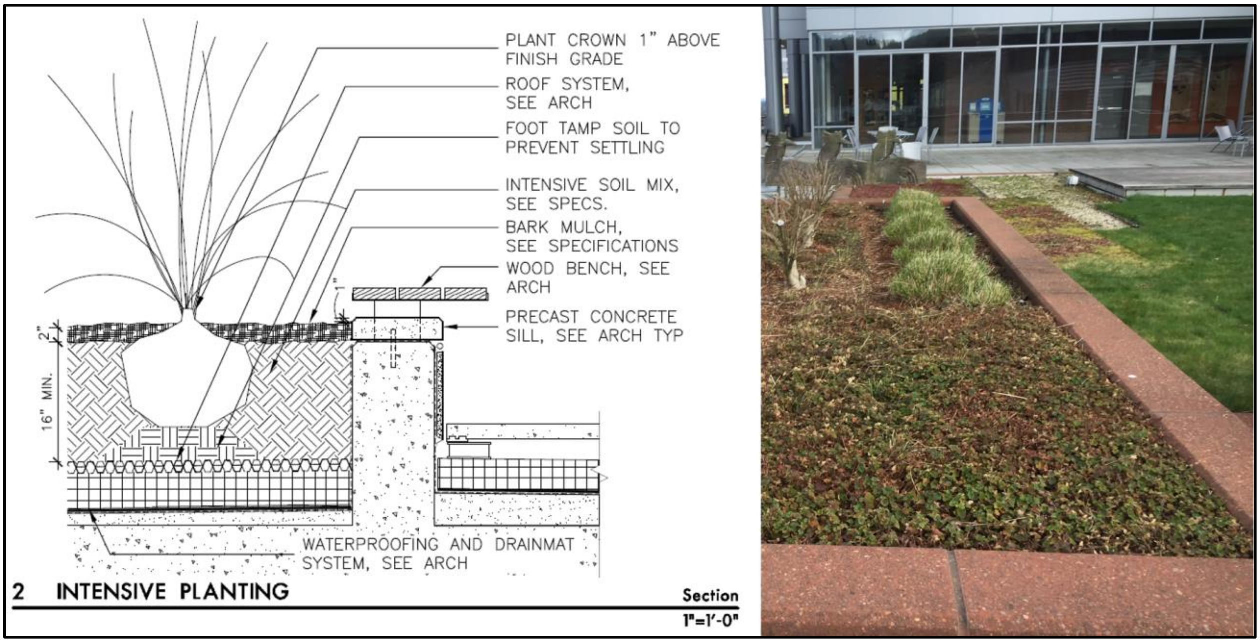

Figure 12. Intensive Eco-roof details. PSU ASRC (Details L5.07 2/29/2008.)

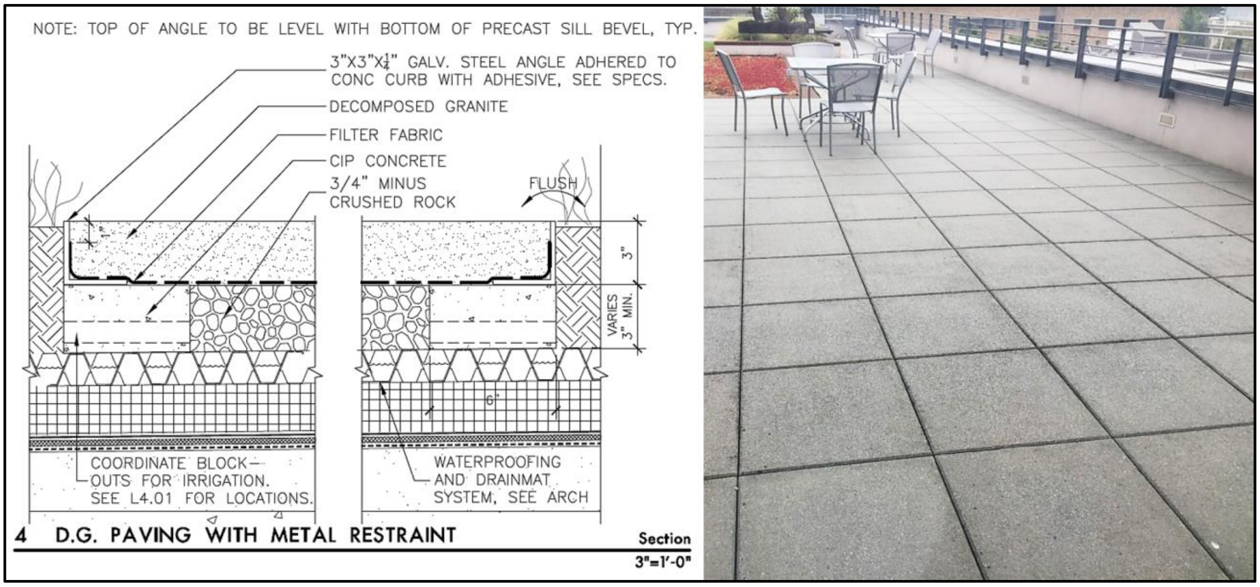

Figure 13. Pervious Pavement details. PSU ASRC (Details L5.07 2/29/2008.)

2.2.3.3. Model Considerations and Assumptions

This preliminary model of the PSU SGI stormwater management system was designed including all the available information that we were able to obtain during the project development time. Therefore, it has some considerations and assumptions as listed below:

- As mentioned previously we did not include the runoff water from the city roads within the study area.
- When choosing the outlet for each subcatchment we selected one of the closest nodes.
- According to the information from portlandmaps.com, there were two PSU facilities not directly connected to the stormwater pipes. We directed their runoff to the nearest node, even if that required going through another building.
- Peter Stott Recreation Field contains artificial turf constructed from recycled tires. Information provided from PSUs Capital Projects and Construction allowed us to assume it was permeable. We did not have information on the percentage of permeability for this type of facility, so we assumed a 100% permeability similar to the green spaces within the study area.

- Our model did not include stormwater harvesting systems. As noted above, PSU has three buildings with rainwater harvesting systems, which is a significant way to reduce runoff water. The modeling of rainwater harvesting systems in SWMM is a different analysis than the other types of SGI. To represent the reduction of stormwater, in addition to considering the SGI as a subcatchment outlet, other variables must be involved to simulate the demand and consumption of that water. This type of modeling was outside the scope of our project.
- As already described, we used Google Earth to calculate the dimensions of some eco-roofs. For our model, we only considered buildings owned or used by the university. As a result, the eco-roof facilities on the MW8 Apartments and Cyan PDX Apartments buildings were not included in the SWMM model.
- For some SGI without available information about their dimensions, design, or area draining toward the facility, it was necessary to make additional assumptions. For example, the area draining from the roofs of Helen Gordon to the Flow-Through Planters was estimated to be 50% of the building surface, and the area draining from the Urban Plaza to the Flow-Through Planters was estimated to be 1859.91 sq. ft.

2.2.4. Scenarios and Analysis

Once the model was completed with the aforementioned information, two types of simulations were designed. Single 24-hour rainfall event to simulate long-duration high-volume storms of varying intensity (Kasey & Dulcy, 2016). We also modeled long-term scenarios, to simulate the intensity and duration of typical precipitation patterns in Portland, Oregon (Rossman, 2016). We used both models to analyze SGI's role in reducing runoff, seasonal temperature changes and climate change, and the potential effect if implementing more SGI in the study area.

2.2.4.1. Single Rainfall Event

For the elaboration of the single rainfall simulation, we used the Synthetic Rainfall Distribution described in section 2.2.2.1. Climate Data. This method is best for analyzing the hydraulics of the system (e.g., pipes capacity) and not the hydrology. However, the small amount of data makes it a simpler model, and it takes a couple of sections to perform the simulations. For precipitation patterns we used the following six different storm intensities in 6 minutes intervals:

- 2-year storm: Channel Shaping Storm: Streams adjust to additional water by readjusting their shape. The frequency of this storm may vary from 18 months to 2.5 years.
- 5-year storm: Similar to 2-year storm but would cause erosion.
- 10-year storm: The size of this storm dictates conveyance design of pipes, swales, ditches, etc.
- 25-year atoms: Similar to 10-year storm agencies use this storm to design systems.
- 50-year storm: Conveyance or Flood Storm: The size of this storm dictates conveyance design of pipes and bridges for primary roads.
- 100-year storm: Similar to 50-year storm, this storm dictates conveyance design depending on the importance of using the road/highway during major flood events. (OSU, 2019)

To consider temperature variability within a year and future projection due to climate change, we used the following four temperature high and low daily averages:

- Current average temperature in winter (January) - high: 46 F°, low: 35 F°
- Current average temperature in summer (August) - high: 82 F°, low: 55 F°
- Projected average temperature in winter (January) - high: 49 F°, low: 38 F°
- Projected average temperature in summer (August) - high: 87 F°, low: 60 F°

Finally, to evaluate the effectiveness of current SGI on campus we run simulations without SGI and simulation with current SGI: 18 PSU buildings with Flow-Through Planters, 8 PSU buildings with Eco-Roof, 3 PSU buildings with Pervious Pavement, and 1 PSU buildings with a Bioswale.

- Study area without SGI
- Study area with current SGI

All these variables gave us a total of 48 simulations. This type of simulation assumes a 24-hour constant precipitation; therefore, since we predefined our model to consider evaporation only during dry periods, the annual temperature changes or climate change, was not reflected in any of these models.

Additionally. To determine the effectiveness of individual SGI types, we created four scenarios, erasing most of the LID controls and leaving only one design. We first analyzed 2-year and 100-year storms with current winter average temperatures. Under these scenarios, we wanted to analyze the SGI response to conditions where temperature does not have a significant effect on evaporation loss.

2.2.4.2. Long-Term Simulations

A long-term simulation utilizes recorded precipitation and temperature data from a more extended period; accordingly, this continuous simulation offers an excellent method for obtaining the frequency of events. However, it has the disadvantages of a higher run time and the need for a continuous rainfall record. This has led to using a simplified method with the "design storm" in a single event simulation instead, like those described in the previous section (Rossman, 2016).

With this method, we designed twenty years simulations (August 2000 to July 2020), using historical precipitation data in 60-minute intervals and daily average minimum and maximum temperatures specific to Portland, Oregon. We ran the model with and without the current SGI in the study area to analyze the current effects of SGI in reducing runoff. Then we repeated the simulation using the average temperature projections and the future precipitation time series we designed, considering a 6% precipitation increase in Winter and a 6% decrease in Summer. We used this scenario to analyze how the PSU stormwater management system will be affected by climate change. Finally, to analyze the effect of implementing more SGI on campus, we add one flow-through planter on each PSU building with a treatment capacity equal to the total area of the buildings within each subcatchment and with a surface area equivalent to 6% of the building being treated (Clean Water Services, 2016). Considering the recommendation to design Flow-Through Planters with 6% of the total impervious area to be treated, we obtained some rather extensive SGI requirements for the largest buildings. The most extensive planter area needed was 4,455 sq. ft. for Peter Stott & Viking Pavilion. This SGI area does not need to be in one single planter; it could be divided into smaller ones distributed in the building's surroundings. We also add Eco-roof on the 8 buildings that fulfill the following selected criteria: less than 50 years since construction, on buildings with hard roofs with at least 4,000 square feet. available space. Lastly, we added 10 Vegetated Curb Extensions[1], first only on the PSU pedestrian zone, one per street, with a size of 200 square feet for a treatment capacity of an impervious area of approximately 4000 square feet, then we added 27 more of these facilities on the other streets within the study area. With all this larger quantity of SGI, we estimated an additional 124,951 square feet of impervious surfaces draining and being treated by SGI, increasing the runoff management from the current 10.8% to 17.2%. We ran this final model only with historical climate data to evaluate runoff reduction with current precipitation and temperature pattern. In total, we created the following four scenarios:

- Historical climate data - without SGI
- Historical climate data - with current SGI
- Future climate data - with SGI
- Historical climate data - with current and additional SGI

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[1] Vegetated Curb Extensions perform similarly to Flow-Through Planters but are mainly used for street runoff management. In general, this type of facility is less expensive when used in place of underground storm sewer piping. The surface area is generally between four and seven percent of the tributary area (BES, 2016).

2.3. Results: SWMM Model

To analyze the reduction of stormwater runoff in the study area, the two analysis methodologies described in the previous section were used: 24-hour rain event simulations using SDR and a continuous simulation based on the historical data of the last 20 years.

2.3.1. Single Rainfall Event - Results

Since we designed our model to consider evaporation only during dry periods, the temperature changes were not reflected in these simulations. Consequently, we only produce twelve different runoff results (Figure 14). When analyzing the effect that current SGI has in runoff reduction, using the 2-year storm scenario, the model reported a reduction of 8.5% less runoff in the simulations with SGI than the simulations without SGI. This reduction slightly decreases with the increment of the precipitation intensity, being 8.3% with 100-year storms. The runoff reduction of 8.5% in a 2-year storm represents 26,394 gallons of water, and the runoff reduction of 8.3% in a 100-year storm represents 55,069 gallons of water (Table 4). Additionally, the models with the current SGI showed a peak flow reduction of approximately 8.4% for all six storm intensities scenarios (Table 4).

Table 4. Single Rainfall Event simulation results - Runoff and Peak Flow Reduction with Current SGI

Storm Intensity	2-year	5-year	10-year	25-year	50-year	100-year
Runoff Difference (gal)	26,394	32,911	39,428	44,642	50,833	55,069
Peak Difference (gal/sec)	1.83	2.26	2.69	3.03	3.45	3.79

To analyze the effect of each type of SGI, we created four different models, only keeping one type of current SGI (Only the Flow-Through Planters, only Eco-roofs, only pervious pavement, or just the bioswale). For this analysis, we used only 2-year and 100-year storm scenarios. In the 2-year scenario, we can see that previous pavers receive about 4% of the draining stormwater, but they are responsible for reducing more than 7% (Table 5). Contrastingly, the bioswale that receives 2.34% of the stormwater from impervious surfaces reduces only 1.2% in the 2-year storm scenario and less in the more intense scenario (Table 6).

Table 5. 2-year storm - SGI efficiency

2-year Storm Scenarios	Area draining to facility		Runoff Reduction		Efficiency
	sq. ft.	%	Gal	%	Gal/sq. ft. drained
Flow-Through Planters	137,945	65.60%	17,922	66.27%	0.13
Eco-roof	59,089	28.10%	6,843	25.30%	0.12
Pavers	8,286	3.94%	1,955	7.23%	0.24
Bioswale	4,961	2.36%	326	1.20%	0.07
Total	210,281	100%	27,046	100%	0.55

Table 6. 100-year storm - SGI efficiency

100-year Storm Scenarios	Area draining to facility		Runoff Reduction		Efficiency
	sq. ft.	%	Gal	%	Gal/sq. ft. drained
Flow-Through Planters	137,945	65.60%	36,821	65.70%	0.27
Eco-roof	59,089	28.10%	14,663	26.16%	0.25
Pavers	8,286	3.94%	4,236	7.56%	0.51
Bioswale	4,961	2.36%	326	0.58%	0.07
Total	210,281	100%	56,046	100%	1.09

2.3.2. Long-term simulations - Results

To simulate the intensity and duration of typical precipitation in the last 20 years, historical precipitation data in 60 minutes increments were used. For our first simulations, we used precipitation and temperature data recorded from August 2000 to July 2020 in Portland, OR. One simulation was run including the four types of SGI, to reflect the current condition, and another one without SGI, to examine the existing runoff reduction of this type of infrastructure. With the current SGI system PSU reduces 3,346,950 gallons of surface runoff annually, the equivalent of a little more than five Olympic swimming pools (see Table 7). This means that current SGI are responsible for a runoff reduction of 6.2% (see Table 8).

Table 7. SWMM simulations results for a 20-year analysis

Scenario	Climate Data	Evaporation Loss (gal)	Infiltration Loss (gal)	Surface Runoff (gal)
Without SGI	Recorded (2000-2020)	125,472,678	317,305,326	1,076,848,722
With SGI	Recorded (2000-2020)	134,803,434	315,006,445	1,009,909,714
With SGI	Projected (2060-2090)	149,253,642	319,603,231	1,022,859,701
Additional SGI	Recorded (2000-2020)	158,381,718	309,475,768	533,084,470

In the second analysis, we compared the results of a model which included current SGI with current climate patterns and another with current SGI but projected future climate variation. In the future scenarios despite a significant increase in runoff loss through evaporation of 10.7%, the total runoff increased by 1.3%. Finally, in the simulations where we added more SGI the reduction in surface runoff was 50.5% (Table 8).

Table 8. Comparison of Long-Term simulations

Scenario	Surface Runoff variation (%)	Surface Runoff variation (gal)
With SGI compared to without SGI	-6.2%	66,939,008
Future compared to present	1.3%	12,949,988
Additional SGI compared to no SGI (recorded climate data)	-50.5%	-543,764,251

2.4. Discussion

SGI is a sustainable, cost-effective, and efficient method for reducing stormwater on PSU campus. Currently, they reduce between 6.2% and 8.5% of the surface runoff, depending on the type of analysis performed. This reduction is equivalent to avoiding draining the amount of water of about five Olympic swimming pools of contaminated stormwater to the Willamette River every year. The SGI on campus currently occupies 2% of the total study area and treats 10.8% of the precipitation that falls in PSU impervious surface. To achieve a 100% reduction in stormwater runoff, PSU will need to implement more than one strategy. As we described in previous chapters, PSU has rainwater harvesting systems in three buildings, and this data has not been considered in our model.

24-hour simulations were not a representative model to analyze climate change, however they are a simpler model for preliminary analysis. For a more precise analysis it is recommended to design long-term simulations, with extensive data.

Climate change could represent an overall increase of 1.3% in runoff, a relevant impact that needs to be considered when developing stormwater management plans. Expected increases in temperature due to climate change will have a significant effect in reducing the amount of runoff water, however, it is expected that humidity will increase as well (Raymond et al., 2020). According to the Clausius-Clapeyron equation, the air can generally hold around 7% more moisture for every 1 degree Celsius of temperature rise. As such, a world that is around 4 degrees Celsius warmer than the pre-industrial era would have around 28% more water vapor in the atmosphere (Hausfather, 2018). In a more humid atmosphere, rates of evaporation are reduced (Skilling, 2019). Wind speed is an important factor that affects the rate at which the water evaporates. High-speed winds remove water particles in the atmosphere; this reduction of humidity increases the evaporation rate (Davarzani et al., 2014). It should be noted that our analysis did not include wind properties.

According to our results, pervious pavement is the most efficient SGI on campus, and the least efficient is the bioswale. However, the cost of implementation and maintenance has not been considered in this analysis, and it is critical to determine which SGI should PSU build. The implementation of more SGI within the study area could have a significant impact in reducing runoff water in the future and with the projected increase in storm intensity cause by climate change.

Within the study area, city roads open to vehicle transit, represent 15.8% of surface area, however, they were not included in the analysis. We considered this to be outside the scope of our project because they are owned by the City of Portland, not PSU. Additionally, creating a model of just SGI would allow us to better understand how the infrastructure works and their efficiency without a complex variable such as roads.

Buildings on PSU's campus represent 62% (1,950,662 sq. ft.) of the total impervious surfaces. This should be considered in planning for more SGI because the water from the roofs can be more easily directed to an SGI, such a flow-through planter, than runoff from the ground level. Only by implementing flow-through planters to treat the runoff from each PSU building, PSU could manage about 70% of the stormwater from PSU own impervious surfaces, reducing runoff by 40%.

Additionally, we have to note that only 60% of the study is PSU owned or managed, so only in these sectors, PSU can make stormwater management decisions. Finally, these models did not include rainfall harvesting systems. To achieve 100% on-site treatment rain harvesting system have to be considered

3. Chapter 3: Recommendations

The management of stormwater runoff has long been an issue of significance in highly urbanized areas. Through the recent implementation and construction of green spaces and SGI, the City of Portland and PSU have attempted to reduce the impacts of stormwater on human and environmental health. However, as the effects of climate change become more pronounced, it is expected that stormwater runoff will increase due to the increase in the frequency, intensity, and/or number of precipitation events. In anticipation of these increasing challenges, the City of Portland adopted the Portland Central City 2035 Plan in 2018, requiring new buildings to construct an eco-roof that covers 100% of the roof area, with up to a 40% exemption for rooftop mechanical equipment (Morris, 2018). Additionally, PSU committed to achieving 100% stormwater reduction in the next 50 to 100 years. This chapter looks to help the university accomplish this goal, and provide recommendations concerning stormwater reduction currently and in the future.

3.1. Climate Change Considerations

With an expected increase in temperature and dry periods between storms (specifically during the summer months) due to climate change, it will become difficult to maintain the vegetation within SGI. As a result, the possible expansion of an irrigation system plan, and an evaluation of the resiliency of SGI vegetation taxa in both drought and flood conditions is needed. Additionally, during the Winter months, we expect to see an increase in the intensity of precipitation events. Therefore, the creation of SGI that is efficient and can withstand larger storm events than we have previously seen, is imperative to achieving stormwater reduction. Rainwater harvesting systems could be effective in these types of conditions as the water can be reused for various purposes (e.g., irrigation, building use such as toilet flushing, etc.).

3.2. General Recommendations

To ensure the effectiveness of SGI, the proper maintenance and monitoring of these systems are essential. Maintenance and monitoring will ensure the optimum efficiency of this infrastructure while avoiding unintended disservices. The necessary procedures will vary for each type of infrastructure but establishing these practices within stormwater management plans will help to diminish runoff impacts and ensure the health of urban environments.

The planting of trees is an important mechanism for reducing stormwater runoff. Trees slow runoff flow and can decrease stormwater volume by 35% or more for small storms through infiltration (BES, 2006f). A single mature tree with a 30-foot canopy can intercept over 700 gallons of rainfall annually (BES, 2006f). Evergreen trees will capture more rainwater in the winter months than deciduous trees (BES, 2006f). Street trees can be 16 times more cost-effective than eco-roofs (Plumb, 2007) (see Appendix B). According to the most recent PSU tree inventory from 2019, there are approximately 1220 trees on campus, and about 500 are PSU property. Therefore, wherever planting is possible, the implementation of trees could be extremely cost-effective and beneficial to achieving successful stormwater management.

Science and engineering are not enough to achieve effective stormwater management. Public outreach and educational programs surrounding stormwater and SGI will generate greater support and understanding of this infrastructure. Through these programs, greater compliance will be achieved as the public understands their personal responsibilities in reducing stormwater runoff (EPA, 2005). For example, the accumulation of trash and stepping on SGI by humans can impact its efficacy. Trash could prevent water from infiltrating into the system, and the weight of humans could cause compaction, leading to decreased aeration within soils and thereby decreasing water infiltration rates. Additionally, individuals can take it upon themselves to protect and improve runoff within their communities.

Lastly, before the implementation of any SGI recommendations discussed below, we suggest that the university carry out an analysis of the effectiveness of different infrastructure on campus, including their installation and maintenance costs. It is unlikely that all the recommendations we make will be implemented due to a multitude of reasons (i.e., economic, social, etc.). Therefore, this further emphasizes the importance of a comparative analysis of the comparative effectiveness and efficiency. As climate change persists, this analysis will make evident what does and does not work for the university, which can potentially serve as a framework for future SGI construction and advance PSUs stormwater reduction goals.

3.3. New SGI Implementation

3.3.1. Eco-Roof

Eco-roofs are an efficient SGI, partly due to its high evaporation rate and larger areas compared to other systems. However, from our literature review, we know that eco-roofs are not the most cost-effective alternative. Additionally, eco-roofs require a stronger infrastructure to support the weight of the roof. The issue becomes more complicated considering PSU has buildings that were constructed over 100 years ago. Therefore, the adaptation of roofs to support eco-roofs may be a difficult solution to implement for many campus buildings. The implementation of eco-roofs could be less expensive if it is considered part of the construction or renovation of buildings. The relative affordability of eco-roofs during the construction and renovation of PSU buildings serves as an opportunity for the university to increase its infrastructure and decrease its runoff.

In Fall Quarter 2020, we took a course called Environmental Data Analysis. For our final assignment, along with two other peers, we completed a project using EPA SWMM to determine if there were significant differences in campus runoff due to increasing precipitation, increasing temperature, and a combination of both increased temperature and precipitation when increasing green infrastructure. In this scenario, we created a build-out where all buildings that could potentially be suitable for eco-roofs and did not currently have any, were retrofitted with them. The model used for this analysis was preliminary. Properties within this model were not the same as our finalized version. Ultimately, we discovered that each building eco-roof contributed a 2.32% reduction and 2.26% reduction in total runoff under low-intensity storms and high-intensity storms, respectively. Additionally, if all the selected locations chosen in our build-out scenario implemented eco-roofs, we found a 67.32% reduction and 65.64% reduction in total runoff across all buildings during low-intensity storms and high-intensity storms, respectively. More information concerning the methods of our analysis can be found in Appendix G.

Eco-roofs are a unique type of SGI. Beyond stormwater, eco-roofs serve other benefits, including climate (reduction of urban heat island effect and improved air quality), infrastructure (roof longevity), creation of habitat for pollinators and other animals, and the physical and mental benefits on human health (BES, 2008). As we previously mentioned, we recommend that PSU undergo a cost-benefit analysis of SGI implementation including the incorporation of these ancillary benefits of eco-roofs. Therefore, the university needs to determine whether the additional advantages are worth the cost.

3.3.2. Flow-Through Planters

According to our inventory results, flow-through planters were the most prevalent SGI on campus, while also treating the largest area. Flow-through planters are located at the street level, which allows them to treat the many impervious surfaces surrounding them. Additionally, they can receive rainwater that falls on roofs that is then routed through pipes into a planter. This is a common design for flow-through planters at PSU.

One of the most notable benefits of this infrastructure is its ability to be constructed at compact sites while still treating large amounts of runoff. The implementation is approximately $8/sq.ft., which initially seems like a steep cost (NACTO, 2008). Additionally, the need to consider and purchase the necessary vegetation that will thrive in these features can be both time and cost intensive. However, the system does not need to be large to be effective. Assuming that there is space to accommodate the implementation of planters, this could potentially be an area of interest for the university, as they do not take up much space but treat large areas, and are a cost-effective solution compared to other SGI.

3.3.3. Pervious Pavement

After analyzing the runoff reduction with different types of LID controls in the SWMM model, we learned that pervious pavement is the most efficient alternative. Although we did not include roads within our analysis, the implementation of pervious pavements has great potential for reducing stormwater runoff. Considering the nature of the city of Portland and PSU, the upheaval and replacement of PSU-responsible sidewalks, roads, and open parking lots (i.e., Shattuck Lot) would substantially diminish the percentage of impervious surfaces. PSU can use similar designs from the pervious pavement located at Shattuck Hall, which purifies and recharges groundwater through the capture of stormwater runoff (PSU, n.d.c.).

Cost is always a matter of concern in SGI implementation. Construction costs vary for different materials used, such as porous concrete ($2 to $7/sq. ft), porous asphalt ($0.50 to $1/sq. ft), and interlocking pavement ($5 to $10/sq.ft) (Uni-Group U.S.A, 2012). Especially in large areas, these costs can accumulate quickly, and this does not account for ongoing maintenance needs or the excavation of the preexisting impervious surfaces. However, across large areas of pervious pavement, infiltration rates are generally hundreds of inches per hour (Uni-Group U.S.A, 2012). Additionally, the infrastructure does an excellent job of removing pollutants for all systems, including total suspended solids (85% to 95%), total phosphorus (65% to 85%), total nitrogen (80% to 85%), nitrate (30%), and metals (98%) (Uni-Group U.S.A, 2012).

3.3.4. Bioswale on Montgomery Street

In 2019, Southwest Montgomery Street, located in the middle of PSUs campus was closed to vehicular traffic and turned into a pedestrian-only plaza. The block between KMC and the Campus Public Safety and University Services building now serves as an open public space that occasionally hosts various events (Swordfisk, 2019). Along the KMC sidewalk side of Montgomery Street are two planters that receive rainwater from the skybridge located above it.

In Fall 2020, we took part in the EPAs Campus Rainworks Challenge. We teamed up with PSU civil and environmental engineering students and others to design a bioswale on campus to showcase the environmental, economic, and social benefits of green infrastructure practices. The 2009 Montgomery Green Street Plan advocated for green infrastructure and walkability along the corridor (BES, 2009). This served as the inspiration for the design of a bioswale along Southwest Montgomery Street. For this project, we created a SWMM model to determine exactly how effective the implementation of a bioswale in this location would be in reducing stormwater. Ultimately, the model determined a 6% to 8% reduction in stormwater under current precipitation events. More information concerning the challenge, design, and analysis can be found in Appendix F.

3.4. Open Green Spaces

PSU Park located across from Science Building One (SB1) and the Oak Savanna located near the Walk of the Heroines are two of the open spaces we identified that could play an important role in the reduction of stormwater runoff on PSU premises. PSU Park currently serves as a trailer spot for mobile offices and workspaces as other buildings on campus undergo major renovations. The area consists primarily of gravel and concrete. At the conclusion of these renovations, we recommend that the university remove the concrete and create an open green space that can naturally infiltrate stormwater from surrounding impervious surfaces. The implementation of native vegetation and trees would help to beautify the campus, while also allowing for the natural treatment of stormwater through infiltration.

On the other hand, the Oak Savanna looks to stitch together adjacent student housing, classroom buildings, Peter Stott Community Recreation Field, and future bike barn and food cart pod (2.ink Studio, 2017). In its current state, the Oak Savanna contains vegetation and a few trees which consequently treat stormwater from surrounding impervious surfaces. We recommend that the university plant more trees in this area. As we mentioned at the beginning of this chapter, trees are a cheaper alternative than SGI and can potentially infiltrate hundreds of gallons of water annually that would otherwise become stormwater. These two recommendations would certainly contribute to the university's goal of 100% on-site stormwater management.

3.5. Future Work

There are many opportunities for future work concerning stormwater research at PSU. First, our study was focused primarily on stormwater quantity, potentially creating an opportunity for further analysis focused on stormwater quality management and the impacts of the pollutants in runoff. Second, we created the most PSU-specific SWMM model possible with the information accessible to us. However, a fair amount of the data we used was drawn from the literature review or default model values embedded in SWMM or from its manual. Therefore, more PSU-specific information concerning SGI properties for which we used default values (i.e., hydraulic conductivity) could facilitate a more accurate representation of the university's stormwater infrastructure. Third, we did not include rainwater harvesting systems in this SWMM model because they require a different type of analysis than the other SGI features, we modeled. To represent the reduction of stormwater, in addition to considering the SGI as a subcatchment outlet, other variables must be involved to simulate the infiltration and use of that stormwater. This type of modeling was outside the scope of our project. The addition of rainwater harvesting infrastructure to the SWMM model would result in a more accurate representation of PSUs stormwater systems and runoff.

Fourth, we used hourly precipitation data from the last 20 years to represent our historical precipitation simulation. To get a more comprehensive understanding of historical precipitation, it would be beneficial to analyze the data for a longer period of time. Lastly, the idea of visually monitoring PSUs SGI during precipitation events using the BES's inspection criteria was in our original project plan. However, due to the nature of COVID-19 and the uncertainty surrounding the opening of campus, we removed it from our project scope. There is not much information concerning how effective PSU's SGI infrastructure is during precipitation events. Therefore, visual monitoring at least, if not empirical measurements of water inputs and outputs, will give the university a better understanding of infrastructure that needs to be better maintained or renovated to better treat stormwater.

3.6. Conclusions

Currently, PSU impervious surfaces represent 62% of our total study area's impervious surfaces, or approximately 1,950,662 sq. ft. This large percentage of impervious surfaces represents an opportunity for PSU to implement more SGI. As the number of SGI increases, the amount of stormwater runoff produced by the university is expected to decrease, creating a healthier and safer environment for faculty, staff, and students. This will also help the university get closer to achieving its goal of 100% on-site stormwater management.

A new stormwater master plan is being developed by the university. Given the basis of our project, we hope that our analysis can serve as a foundation for future stormwater runoff initiatives. In our recommendations, we included a few alternatives, including the construction of new SGI and creation of new green spaces. With PSU's limited resources, we would recommend that the university first better understand the systems already constructed before creating new ones. If already built systems on campus are failing, it would be more beneficial for the university to use those resources in the upkeep and regular monitoring and maintenance of these infrastructure. Additionally, as a first step, we would recommend that PSU conduct a cost-benefit analysis to determine which infrastructure best compliments the university that is effective, yet not too expensive. Especially as climate change alters historical weather observations, these analyses will help set the university on the correct path to efficient and effective future implementation.

Stormwater runoff is an urbanized issue that impacts all those who inhabit cities and beyond. As the climate continues to warm and precipitation events increase in severity and number, addressing the issue of runoff now will reduce its impacts, and ensure the health of our urban environments and waterways. Furthermore, due to the impervious nature of the city of Portland and PSU, stormwater runoff issues are expected to worsen. With the completion of this project, we have drawn attention to the need for the reduction of stormwater runoff and implementation of SGI. Additionally, the importance in considering climate change and increased runoff within stormwater analysis. We hope that the issue will continue to be discussed, as it should be considered of utmost importance in future PSU sustainability initiatives.

For more information about stormwater management, contact the Campus Sustainability Office (greencampus@pdx.edu).

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Appendices

Appendix A: History of Stormwater Management in the City of Portland

Dating back to the late 19th and early 20th century, the city of Portland had utilized a combined sewer system, which carried sewage and stormwater runoff in the same pipes. These pipes would discharge the combined sewage and runoff directly into the Willamette River and Columbia Slough. With the creation of the Columbia Boulevard Wastewater Treatment Plant (CBWTP) in 1952, the city began an effort to improve its water quality (BES, 2018). However, even after the creation of the CBWTP, when precipitation events were large enough to inundate the system, it would cause a combined sewer overflow event. This would trigger the straight discharge of these combined sewer pipes into the Willamette and Columbia Rivers. On average, it was approximated that six billion gallons were discharged into the Willamette and Columbia every year (Vimeo, 2014).

In 1991, the Oregon Department of Environmental Quality (DEQ) and the City of Portland reached an agreement to significantly reduce overflow events by 2011. In order to accommodate this agreement, the City of Portland began the Big Pipe Project. The purpose was to create one pipe in the Columbia Slough watershed and two pipes in the Willamette River that would intercept combined sewage and direct it to the treatment plant (BES, n.d.a). With the completion of this project, the city of Portland saw drastic improvements in their stormwater reduction. Before the project, there was an average of 50 combined sewer overflow events in the Willamette River every year, which has now been decreased to an average of four every winter and one every third summer (BES, n.d.a). This translates to a 94% reduction in overflow events in the Willamette River and a 99% reduction in the Columbia Slough (BES, n.d.a).

Since 1995, the City of Portland and its co-permittee, the Port of Portland, have implemented stormwater management programs under an Oregon DEQ permit issued under the federal Clean Water Act (BES, n.d.b). The permit is formally called the Phase I National Pollutant Discharge Elimination System (NPDES) Municipal Separate Storm Sewer System (MS4) Discharge Permit. It is referred to as the NPDES permit, MS4 permit, or municipal stormwater permit. The permit requires each co-permittee to develop and implement a Stormwater Management Plan (SWMP) that describes measures the co-permittee will implement throughout the permit term to control pollutant discharges to the storm sewer system. The permit has since been renewed for a second term in 2004 (with modifications in 2005) and a final third term on January 31, 2011 (BES, 2011). However, the final permit expired on January 30, 2016, but continues to be administratively extended by the DEQ (BES, 2011).

Appendix B: Benefits of SGI Beyond Stormwater

Beyond stormwater, SGI provide a multitude of other environmental, social, and economic benefits. Environmentally, trees, bushes, and other greenery have the ability to absorb air pollutants and trap airborne particulates on their leaves, create shading and increase evapotranspiration which reduce surface and air temperatures, and act as a physical barrier in reducing noise pollution (EPA, Healthy Benefits).

Socially, green infrastructure has been found to have positive impacts on health and social capital (EPA, Healthy Benefits). The creation of natural systems in urbanized areas can create recreation opportunities for humans, while also providing habitat for wildlife. Accessible and attractive green spaces have been linked to a reduction in stress and improvements in mental health and overall well-being (EPA, Healthy Benefits). This is largely due to nature's ability to improve community identity, improve aesthetics, and provide a place of congregation and social interaction.

Economically, green infrastructure creates sustainable, stable jobs, while costing less than conventional gray infrastructure (EPA, Healthy Benefits). In a case study of Lancaster, Pennsylvania, the EPA analyzed the city’s comprehensive green infrastructure plan. Lancaster, similar to Portland, has a combined sewer system which carries sewage and stormwater to their respective wastewater treatment facilities. Overall, at the end of Lancaster’s 25-year implementation period, it was found that the implementation of SGI would result in annual benefits of $2 million from energy, $1 million from air quality, $786,000 from climate change, and $661,000 from reduced pumping and treatment costs (EPA, 2014). Additionally, the city would avoid nearly $120 million in gray infrastructure capital costs (EPA, Economic Benefits).

In New York City, Plumb and Seggos investigated the effectiveness of comparing conventional CSO controls with storage tanks and LID controls based on gallons of stormwater managed per $1,000 invested. Except for eco-roofs, LID options reduce more runoff than conventional systems (Plumb, 2007).

Stormwater control	Gallons per $1,000 Invested
Conventional Storage Tanks	2,400
Greenstreets	14,800
Street Trees	13,170
Greenroof	810
Rain Barrel	9,000

Source: Plumb and Seggos 2007.

An investigation by Leimgruber et al., revealed that there is not one specific optimal LID strategy when considering runoff reduction efficiency and cost. The selection of a reasonable LID strategy requires a holistic approach and the specific objective expected. It is especially valuable combining a cost-saving LID that accounts for evapotranspiration and a downstream LID that accounts for infiltration and results in no further demand for land (Leimgruber et al., 2019). In general, the cost of flow-through planter boxes varies depending on size and materials, but for new development and redevelopment, they are often less expensive than conventional stormwater management facilities (BES, 2006h).

Appendix C: Summer Internship

As a graduation requirement for the Professional Science Master's Degree, we completed an internship with PSU CSO in Summer 2020. In this internship, we were tasked to complete PSU's Clean River Rewards form, which is Portland's stormwater utility discount program. Therefore, if the property manages stormwater on site, Portland ratepayers can save money while also working for clean rivers and healthy watersheds (BES, n.d.c). This form required us to determine the type of green infrastructure on campus, including the size of the facility (in sq. ft), the impervious area drainage flowing to the facility (if applicable), and the number of trees that exceed 15 feet on property. Since PSU is a large campus, there were 14 different accounts that needed to be completed.

We spent months analyzing AutoCAD and ArcGIS files given to us by PSU faculty and Google Earth engine to find the necessary information. Additionally, we spent a day measuring infrastructure with a tape measure for facilities that we were unable to find on AutoCAD. Through this internship, we were able to create an elaborate inventory of PSU's stormwater infrastructure, including the exact number of facilities and their areas. However, possibly the most important information we found was the impervious area drainage flowing to each SGI, which we collected using information from past forms and AutoCAD files. Additionally, we found the percentage of permeable, impermeable, and SGI area within our study area (Figure 3). This information helped in identifying areas on campus that lack SGI and possible facility recommendations that would aid in reducing the university's stormwater runoff.

Appendix D: AutoCAD Information by Layer

001-Study Area: Delimits the 88.5-acre study area. This information was not modified.

002-PSU Tax Lot Lines: Delimits the lots that belong to the university. This information was not modified.

003-Street-Blockouts: Delimits the borders between the sidewalks and the streets owned by the city, excludes the roads managed by the university, and pedestrian use. We modify this layer slightly, especially at the limits of the study area, in order to create closed areas and allow us to determine the total surface of the tracks.

003.1-Other Street: This layer was created to draw asphalt areas not run by the university, such as parking lots, gas stations, and vehicular access entryways.

010-PSU Building Area: Delimits buildings owned by the university, those that are shared, and those used by the university but do not belong to it. In this layer, we made some slight modifications according to each building's specific plans, and some non-drawn buildings were added, such as the University Center Building.

011-PSU Impermeable Area: Delimits PSU's impervious surfaces, such as Walk of the Heroines and the Epler Hall Plaza. This information did not have any significant changes.

011.1-PSU Impermeable Area: We created this layer to draw a surface on Helen Gordon that was not registered.

012-PSU Permeable Area: Delimits the permeable surfaces of the university, such as the Peter Stott Field, the Oak Savanna, and planters. Some of the green areas identified in this layer were SGI, and we moved them to layer "032-PSU SGI-Planters-bioswale-filters".

012.1-PSU Permeable Area: We created this layer to draw permeable areas not identified in Helen Gordon and Shattuck Hall.

013.1-PSU Impermeable in Eco-Roof: In this layer, we draw the impervious areas in the eco-roof on Broadway Hall and then discount them to calculate the total green roof area.

020-Non-PSU Buildings: Delimits the buildings that do not belong to the university. Some constructions, such as the University Technology Center, were moved to layer "010-PSU Building Area" for being university-managed buildings.

022-Non-PSU Permeable Area: Delimits permeable surfaces that do not belong to the university, such as Park Blocks, planters, and tree planters. This information was not modified. If some of the planters in this layer are rain green infrastructure, we did not identify them separately.

031-PSU SGI-Eco-Roof: We created this layer to import the green roofs from each building's plans with this type of infrastructure. The research green roofs: Science Research & Teaching Center (SRTC) and Cramer drew them taking satellite images as a reference and corroborating the area with reference documents from the university.

032-PSU SGI-Planters-Bioswale-Filters: We created this layer to import the planters from the plans of each building with this type of infrastructure. We draw some flow-Through planters not identified in the plan with the measurements taken in situ, as in Cramer Hall and Urban Plaza. We also outlined the Bioswale on the central Food carts area, and we identified the Stormwater Catch Basin Filters. We use reference points for the location of the filters we did not find on the AutoCAD plans.

033-PSU SGI-Pervious Pavement: In this layer, we only include the permeable floors of Shattuck Hall that we drew with the measurements taken in the field and the roof of ASRC that we subtract the eco-roofs from the total roof area.

041-Non-PSU SGI-Eco-Roof: We created this layer to draw the two unidentified green roofs in buildings not owned or used by the university, Cyan PDX Apartments, and the MW8 apartment building.

Non-study area Eco-Roof: We created this layer to draw the green roofs in the university buildings that are not within the study area.

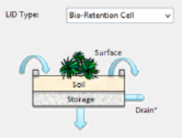
Non-study area Buildings: We create this layer to draw the three buildings of the university that are not within the study area, Crown Plaza, Robertson Life Science Building, Corbett Building.

Appendix E: SWMM LID controls parameters

***Default (D)**: values from EPA SWMM Model*
***PSU**: values used in our model*
***Source**: source of values selected (D for default. - not default, not zero. See complete reference list at the bottom of this tab.*

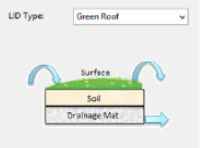
Bio-Retention Cell: Used for Flow-Through Planters

Surface	Default	PSU	Source	Soil	Default	PSU	Source	Storage	Default	PSU	Source	Drain	Default	PSU	Source
Berm Height (in)	0	6	2	Thickness (in)	-	30	4	Thinckness (in)	-	15	2	Flow Coefficient	0	2.5	8
Vegetation Volume Fraction	0	0.1	1	Porosity (volume fraction)	0.5	0.47	5	Void Ratio (Voids/Solids)	0.75	0.75	D	Flow Exponent	0.5	0.5	1
Surface Roughness (Manning's n)	0.1	0.15	3	Field Capacity (volume fraction)	0.2	0.25	5	Seepage Rate (in/hr)	0.5	0	1	Offset (in)	6	0	7
Surface Slope (percent)	1	0	1	Wilting Point (volume fraction)	0.1	0.09	5	Clogging Factor	0	0	1	Open Level (in)	0	0	D
				Conductivity (in/hr)	0.5	0.5	D					Closed Level (in)	0	0	D
				Conductivity Slope	10	10	D					Control Curve			
				Suction Head (in)	3.5	3.5	D					**Check drain advisor if needed*			



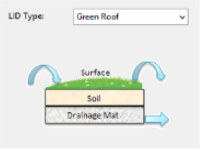
Green Roof - Extensive: Blumel garage, KMC, ASRC & Broadway

Surface	Default	PSU	Source	Soil	Default	PSU	Source	Drainage Mat	Default	PSU	Source
Berm Height (in)	-	1.5	6	Thickness (in)	-	5.5	6	Thickness (in)	3.00	0.50	6
Vegetation Volume Fraction	0	0.10	1	Porosity (volume fraction)	0.5	0.5	D	Void Ratio (Voids/Solids)	0.5	0.5	D
Surface Roughness (Mannings n)	0.1	0.2 [1]	3	Field Capacity (volume fraction)	0.2	0.3	9	Roughness (Mannings n)	0.1	0.009	3
Surface Slope (percent)	1	1	D	Wilting Point (volume fraction)	0.1	0.06	9				
				Conductivity (in/hr)	0.50	0.50	D				
				Conductivity Slope	10	10	D				
				Suction Head (in)	3.50	3.50	D				



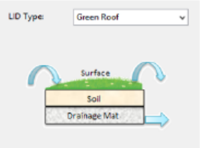
Green Roof - Intensive: NASCC, ASRC

Surface	Default	PSU	Source	Soil	Default	PSU	Source	Drainage Mat	Default	PSU	Source
Berm Height (in)	-	2	11	Thickness (in)	-	16.0	11	Thickness (in)	3.00	0.50	6
Vegetation Volume Fraction	0	0.15	1	Porosity (volume fraction)	0.5	0.5	D	Void Ratio (Voids/Solids)	0.5	0.5	D
Surface Roughness (Mannings n)	0.1	0.2 [2]	3	Field Capacity (volume fraction)	0.2	0.3	9	Roughness (Mannings n)	0.1	0.009	3
Surface Slope (percent)	1	1	D	Wilting Point (volume fraction)	0.1	0.06	9				
				Conductivity (in/hr)	0.50	0.50	D				
				Conductivity Slope	10	10	D				
				Suction Head (in)	3.50	3.50	D				



Green Roof - Research: SRTC & Cramer Hall

Surface	Default	PSU	Source	Soil	Default	PSU	Source	Drainage Mat	Default	PSU	Source
Berm Height (in)	-	2.4	10	Thickness (in)	-	6.3	10	Thickness (in)	3.00	2.4	10
Vegetation Volume Fraction	0	0.10	1	Porosity (volume fraction)	0.5	0.5	D	Void Ratio (Voids/Solids)	0.5	0.5	D
Surface Roughness (Mannings n)	0.1	0.2 [3]	D	Field Capacity (volume fraction)	0.2	0.3	9	Roughness (Mannings n)	0.1	0.009	3
Surface Slope (percent)	1	1	D	Wilting Point (volume fraction)	0.1	0.06	9				
				Conductivity (in/hr)	0.50	0.50	D				
				Conductivity Slope	10	10	D				
				Suction Head (in)	3.50	3.50	D				

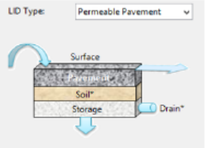


References:

1	EPA SWMM Manual
2	Cramer Hall - C2_Sections_MPX9C001.pdf
3	McCuen, 1998
4	PSU Detail CAD files average
5	Soil properties
6	KMC - L129_Terrace-Details.pdf (2 Pedestral Paver Ecoroof 4th and 5th)
7	EPA SWMM Help
8	Wang et al. (2019)
9	Dr. Starry Email (2/1/21)
10	Thompson 2020 Thesis
11	ARSC - L5.07_Details_ARC7C001.pdf
12	Zhang, S., & Guo, Y. (2014)
13	Xie et al., 2017
14	Own calculations

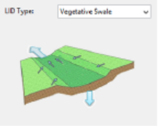
Permeable Pavement: ASRC

Soil	Default	PSU	Source	Storage	Default	PSU	Source	Drain	Default	PSU	Source	Surface	Default	PSU	Source	Pavement	Default	PSU	Source
Thickness (in)	0.00	0	11	Thickness (in)	-	3.00	11	Flow Coefficient	0	1000	12	Berm Height (in)	-	0	11	Thickness (in)	-	3	11
Porosity (volume fraction)	0.5	-	-	Void Ratio (Voids/Solids)	0.75	0.75	D	Flow Exponent	0.5	0.5	1	Vegetation Volume Fraction	0	0	D	Void Ratio (Voids/Solids)	0.15	0.16	12
Field Capacity (volume fraction)	0.2	-	-	Seepage Rate (in/hr) (Filtration Rate)	0.5	0	1	Offset (in)	6	0	7	Surface Roughness (Mannings	0.1	0.024 [4]	1	Impervious Surface Faction	0	0	12
Wilting Point (volume fraction)	0.1	-	-	Clogging Factor	0	0	1	Open Level (in)	0	0	D	Surface Slope (percent)	1	1	D	Permeability (in/hr)	100	9.6	12
Conductivity (in/hr)	0.5	-	-					Closed Level (in)	0	0	D					Clogging Factor	0	0	12
Conductivity Slope	10	-	-					Control Curve								Regeneration Interval (days)	0	0	D
Suction Head (in)	3.5	-	-					**Check drain advisor if needed*								Regeneration Fraction	0	0	D



Vegetative Swale: Bioswale in central food carts

Surface	Default	PSU	Source
Berm Height (in)	-	5.91	14
Vegetation Volume Fraction	0	0.05 [5]	1
Surface Roughness (Mannings n)	0.1	0.3	13
Surface Slope (percent)	1	0.5	13
Swale Slide Slope (run/rise)	5	5.78	14



Appendix F: EPA Rainworks Challenge

During the Fall 2020 quarter, we had the opportunity to work alongside a group of Portland State University civil and environmental engineers in the EPA Campus RainWorks Challenge. This was a green infrastructure design competition for American colleges and universities with the goal of creating engagement with future environmental professionals, fostering dialogue surrounding innovative stormwater management, and displaying the environmental, economic, and social benefits of green infrastructure (EPA, 2021). The 2009 Montgomery Green Street Plan advocated for green infrastructure and walkability along the Montgomery Street corridor and served as the inspiration for this design. Our group looked to add three green walls (on skybridge pillars connecting KMC and University Services Building) and a bioswale, incorporating native vegetation that can tolerate both wet and dry soil conditions. This design would help to greatly reduce the amount of stormwater runoff the university produces and reconnects the geography of the sites with its natural water cycle; the rain from the hills of downtown Portland draining into the Willamette River basin.

For this project, we were tasked with creating an EPA SWMM model to analyze the impact our designed bioswale would have in reducing stormwater runoff. We tested the model under 24 different scenarios, using current temperatures and predicted future temperatures as climate change persists. Additionally, we created a Portland 2-year, 10-year, and 100-year 24-hour storm event. From this analysis, we found that the implementation of our designed bioswale would reduce the amount of stormwater runoff produced by 6% to 8% under current climate conditions. If future climate model predictions of a 10°F increase are accurate, we can expect evaporation from the bioswale to increase by approximately 10%.

Appendix G: Environmental Data Analysis Project

In this project, our group wanted to determine if there were significant differences in runoff from campus due to increasing precipitation, increasing temperature, and a combination of increased temperature and precipitation when increasing green infrastructure (based on climate predictions over the next 80 years). To achieve this, we used standard 24-hour rainfall distributions from the Natural Resources Conservation Service, where low-intensity storms were considered 5-year and high intensity storms were considered 50-year. Using the nearest National Oceanic and Atmospheric Administration (NOAA) weather station to the university, we chose temperature data from January 8th, 2020. This date was chosen because January has the highest amount of recorded precipitation in the last twenty years, and January 8th has a daily minimum of 37 °F and a maximum of 46 °F, which is in the average range for that month. According to the IPCC, we are currently on track for a global temperature rise of between 6.3° and 13.3°F by 2100. For our future scenarios studied, we selected an increase of 10 °F from the minimum and maximum current temperature values. With this climate data, we created the following 24-hours scenarios for Portland:

1. Current temperature with low storm intensity (5-year storm) - Control ©
2. Current temperature with high storm intensity (50-year storm) - Precipitation increase (P)
3. Future temperature with low storm intensity (5-year storm) - Temperature increase (T)
4. Future implementation with high storm intensity (50-year storm) - T+P

Using EPA SWMM, we created a model that incorporated all PSU buildings, and the city park blocks that created a total subcatchment area of 31.8 acres. Runoff from the street was not considered, but the model included existing stormwater pipe dimensions and sub-catchment areas. For the four scenarios, we ran the model 30 times, changing the amount of green eco-roof in the area. The first analysis assumed PSU did not have low-impact developments (LIDs), where the runoff would only infiltrate in open green spaces. The second analysis included the eco-roofs of the seven PSU buildings that currently have an LID and their areas. The third analysis involved adding eco-roofs measuring the total surface of a building and kept adding LIDs until we had 30 different scenarios, a significant sample size for statistical analyses. By the end, most of the buildings with available roof-top space for LIDs were covered, reaching an impervious area reduction of 75%.

At the end of our analysis, we were able to determine that there were no significant differences in runoff from PSU with increasing green space between the control and the treatment when only temperature was increased. Additionally, there were not significant differences in runoff from the PSU campus with increasing green infrastructure between the increased rainfall intensity scenario and the increased temperature and rainfall intensity scenario. Temperature did not play a significant role in reducing runoff as it is likely the difference was not great enough to influence evaporation before it reaches storm drains.

In contrast, there were significant differences in runoff with increasing green space for climate scenarios with increased rainfall intensity. On average, each building's worth of green space resulted in 0.111 acre-feet reduction in runoff under low-intensity storms and 0.173 reduction in runoff under high-intensity storms (a 2.32% reduction and 2.26% reduction in total runoff, respectively). If all selected locations on campus were converted to green infrastructure, there would be a 3.224 acre-feet reduction in campus runoff in a low-intensity storm and 5.021 acre-feet reduction in a high-intensity storm (67.32% reduction and 65.64% reduction in runoff, respectively), according to the model. These findings indicate that even moderate additions in green infrastructure to the campus would result in significant reductions in runoff, potentially reducing flooding, stormwater system overflow, and the runoff of contaminants into the nearby Willamette River and other water bodies.