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How Can Portland's Urban Landscape Better Utilize Stormwater?

Joni Frame

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by

Joni Frame

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Todd Ferry

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Research Question

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Introduction

It's proven that the way that spaces are designed impact people's day to day lives. Water quality and the way our water management systems are designed and developed contributes largely to people's wellbeing. Water management systems are used to store and treat stormwater (precipitation) that runs off impervious surfaces in our built environment. Stormwater is produced by rain and other forms of precipitation that runs off impervious surfaces such as streets, parking lots, and other sites. Climate changes are projected to include more frequent and more intensive storms which can lead to extreme flood hazards, increasing the stormwater runoff. (OCCRI, 2021). An increase in stormwater runoff can create new problems in pollution, which in return can overpower the capacity of water management systems in a city. This can lead to flooding, property damage, and a decrease in water quality. This thesis will explore ways that cities can better adapt their stormwater systems to help prevent flooding and reduce environmental impact. It will more specifically explore how the city of Portland, Oregon will experience climate change and the communities that will be most impacted by stormwater and flooding.

Climate Change and Water

This thesis will primarily be focusing on rainfall and the effects of stormwater runoff in Portland's urban setting; however, it is important to understand how climate change will affect Portland as a whole. According to the Fifth Oregon Climate Assessment, the state of Oregon's average temperature in 2050 is projected to increase by 5 degrees Fahrenheit and increase by over 6 degrees for summer seasons. (OCCRI, 2021). While temperatures are projected to go up year-round, precipitation is expected to surge during winter seasons. Conversely, the state of Oregon has had problems with drought that are expected to increase in the coming years. As reported by the Oregon Climate Change Research Institute, over a third of the state of Oregon experienced drought from the years 2000-2020. (OCCRI, 2021). While precipitation levels are increasing, most of the precipitation expected to fall is not snow due to rising temperatures. The lack of snowpack in Oregon's mountains will lead to water shortages. Oregon is expected to shift from rain-and-snow basins towards a more rain dominant basin by 2040. (Halofsky, 53), The decreasing snowpack will increase water drought and increased wildfire risk.

Portland's Current Water Management Infrastructure

Portland's current water management infrastructure at time lacks capacity to handle water, and without the ability to store it, we will significantly lack the resource when we really need it. A huge challenge that cities face is directing storm water along different paths proportional to how much water a system can hold. The urban environment is covered with impervious surfaces which causes stormwater to run across the streets, sidewalks, roofs, and parking lots rather than being able to infiltrate a natural surface. This causes run off that causes rivers to swell faster and fill with pollution. It is important to understand the impact of how water movement during storms both above and below the ground. Outside of the pollution caused by storm water management, managing storm water runoff is incredibly important as it can lead to flooding and property damage. According to research done by the Oregon Climate Change Research Institute, precipitation is projected to increase during winter seasons with heavier and longer rainfall. Summer precipitation levels are projected to decrease. (OCCRI, 2021). With heavier and faster rainfall expected, cities will need to adapt their stormwater management. In general, most cities organize their streets with a graded slope that causes water to flow away from buildings to prevent water damage. Standardized streets have gutters on the side with a crown in the center to keep the roads safe for vehicular paths of travel while still channeling the runoff. When too much runoff collects in the sewage system it can cause flooding in streets. In the past, water runoff in the streets were designed to run directly into the sewage system. Most cities, including Portland, heavily rely on grey water infrastructure. Grey infrastructure refers to pipelines and water and wastewater treatment plants that are man-made. In many areas, the capacity to manage large volumes of water runoff through grey infrastructure is decreasing with climate change and heavier and longer rainfall. In the city of Portland, water is managed in combined sewer systems, underground injection control (UIC) facilities, and separate storm sewer systems. According to the Portland plan, older neighborhoods in Portland use “combined sewer systems, which collects stormwater runoff from streets and sewage from buildings in the same pipes. Most of this mixture flows to the treatment plant. But when it rains, sewage overflows to the Willamette River.” (Portland, 3i).

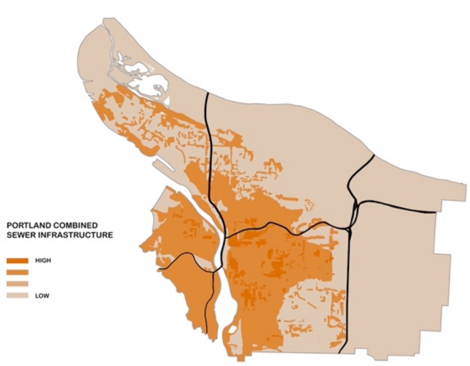

Fig. 1. Portland Stormwater Management (Figure by author, Adapted from The City of Portland, Portland Watershed Management Plan Potential Benefit of Green Infrastructure improvements, 1.

The plan states that in a large portion of Portland stormwater flows into sumps in the ground which are known as the underground injection control (UIC) facilities. (Portland, 3i). Sumps are pipes that sit vertically with perforations that connect into sedimentation holes to expel pollutants. These facilities operate by collecting stormwater and allowing solids to settle to the bottom before the stormwater is treated. (3i) UIC stormwater management systems were implemented to help aid in reducing the amount of runoff that flows into combined sewer systems. These facilities were built in support of the Willamette River Combined Sewer Overflow Program. Common UIC facilities in Portland include sumps, drywells, and trench drains. UIC's discharge water below the ground, keeping runoff in the watershed out of sewers. In return these aid in reducing the amount of stormwater discharges to rivers and streams. By redirecting stormwater flows from combined sewer systems into UICs it reduces pollution and erosion in stream channels that are caused by stormwater discharges. Another form of water management that Portland utilizes are separate storm sewer systems. These operate as sanitary sewers that move sewage from buildings into water treatment facilities. Additionally, in 2011 Portland completed the Big Pipe project as a part of the Willamette River Combined Sewer Overflow (CSO) Program. Before this projects completion combined sewer overflows would occur regularly. The Big Pipes include projects developed in the Columbia Slough, West Side, and East Side. The first big pipe completed by the environmental services was a 3.5-mile-long tunnel along Columbia Boulevard that prevents approximately 300 million gallons of CSOs from overflowing every year. The West Sides big pipe project was completed in 2006 and uses a 14 foot-diameter pipe that extends 3.5 miles from SW Clay St to the Swan Island Pump station. The third big pump installed on the east side is the largest, with a 22 feet-diameter pipe that extends almost 6 miles. Portland's big pipe project redirects 96% of combined sewage and stormwater flows to treatment plants. In the flood risk overview for Portland, it shows that there are over 30,000 properties in Portland that have a 26% chance of flooding in the next 30 years. (Flood Factor, 1) Flooding can cause problems such as property damage, access to utilities and emergency services being cut off, transportation, and the economic situation in an area. (2). According to a study conducted by department of geography at PSU, the low-income areas in North and East Portland are more susceptible to flooding. This study used a "Topographic Wetness Index (TWI) and an Urban Heat Index (UHI) to model winter flood and summer heat hazard potential respectively, this research uses a geographic information system (GIS) to develop a combined index, and tests for relationships between sociodemographic variables and environmental hazard potential." (Fahy et all, 1). North and East Portland neighborhoods that have less green space and green infrastructure pose greater threats to flooding and heat island affects. As legislators work to address and prioritize resources for risk reduction, it is important to acknowledge the demographics of communities most at risk. It is proven that areas most susceptible to climate induced risks in Portland are marginalized low-income communities. The information provided from this study compares the winter flood and heat hazard protentional to a city's demographic. The study used a Topographic Wetness Index (TWI) to identify the location and size of such flow paths. By evaluating the TWI values in Portland, it is possible to study higher flood hazard potential areas based on the higher values. According to the Department of Geography, "Most low flood potential values are found in NW and SW Portland and near the NE-SE Portland transition along highway I-84… [the] analysis also shows clustering of high flood potential values (high-high) occurring in E Portland along the highway I-205, and low-low clustering occurring in the western hills and other central downtown areas of the city.” (Fahy et all, 5). Higher TWI values indicate higher flood hazard potential. The research done by the Department of Geography that shows the higher flood hazard zones can be compared to information available on city data that shows lower income neighborhoods here in Portland.

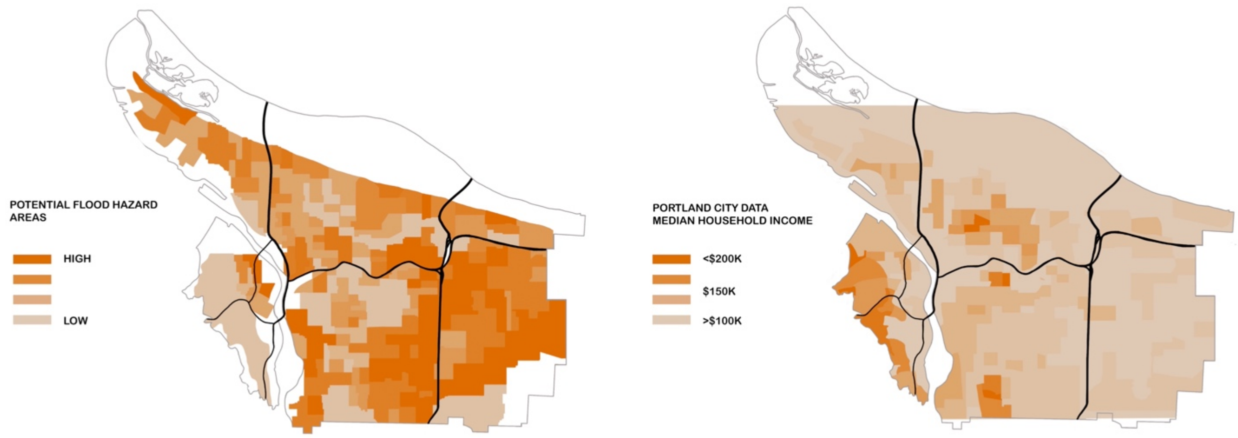

Fig. 2. (left) Flood Hazard Potential Areas. (Figure by author, Adapted from Fahy et all, Spatial analysis of urban flooding and extreme heat hazard potential in Portland, OR 5, fig. 3). (Right) Household Median Income Map.

Green Infrastructure

Stormwater run-off in urban areas is a major contributor to water pollution. According to Japans Landscape Ecological Engineering Consortium, “surface water can accumulate and not only flood nearby areas but carry nutrients and chemicals to nearby wetlands and water bodies…. during rainfall, the first couple of centimeters of water runoff contains a majority of anthropogenic pollutants” (Ishimatsu, 212). This means that the oils and pollutants from the surface runoff get washed into streams, wetlands, and ponds. Green Infrastructure (GI) is a response to water management and serves to restore the natural water cycle. It is an ecological system that utilize trees and wetlands to naturally clean, filter, and absorb water in comparison to building a new water treatment plant. These include both engineered systems and the natural environment to provide clean water and benefit people, wildlife, and conserve ecosystem functions by absorbing stormwater runoff and working to filter bacteria and pollutants. Types of GI Systems vary dependent on system goals but includes green roofs, rain gardens, bioswales, bioretention basins, permeable pavements, infiltration planters, and trees which can be implemented into the way we design our cities, streets, and buildings. Green Infrastructure also means the preservation of surrounding wetlands, forests, and floodplains. Traditional grey water infrastructure does not have the capacity to handle the projected influx of rainwater and other forms of precipitation that come with climate changes. Natural soil and other forms of vegetation has the ability to absorb and filter heavier precipitation where it falls than precipitation that lands on impermeable surfaces. Impervious surfaces in urban settings disrupts the natural hydrological process of the surface run off. (Saraswat et all, 4).

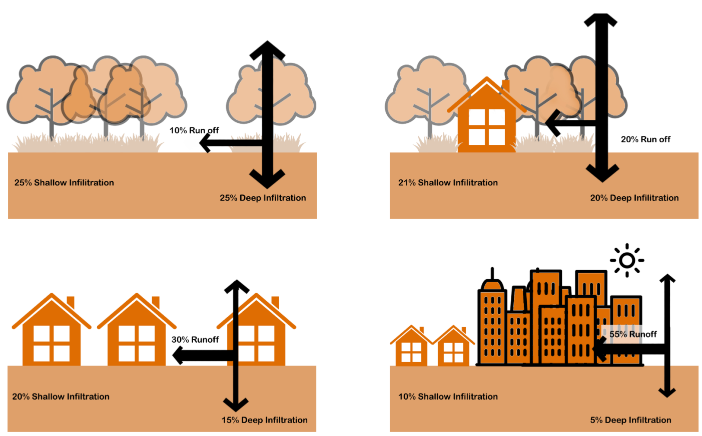

Fig. 3. Impervious Surfaces vs Pervious Surfaces

Green Infrastructure also helps reduce the heat island effect, which is important to consider with temperature rises that come with climate change. Studies show that “green infrastructure throughout the city, and street trees in particular, are of utmost importance in terms of their influence on thermal comfort… Vegetated roofs and/or walls are also considered to be constituents of UGI, providing additional cooling through evapotranspiration.” (Saaroni et all, 94). Green roofs are a form of green infrastructure that proves to be valuable contributors to both reducing run off pollutants and providing a cooling impact and reducing building energy consumption. Green roofs are often referred to as *living roofs* to describe the growing vegetation on that sits on the roof as water sensitive design device. According to Landcare Research NZ Ltd, “Rooftops are a significant proportion of the total impervious area in urban settings. Downpipes are often connected directly to piped stormwater networks and surface waters. Management of rooftop runoff can therefore make a large contribution to comprehensive stormwater control” (Simcock, 1). Living roofs consist of several layers including waterproofing membranes, root barriers, drainage, substrate, and vegetation. Roof structures with impervious materials increase stormwater runoff, and in large storms can heavily contribute to flooding and sewer overflows. As rain hits the living roof it begins to percolate in the growing substrate which then holds a net volume of runoff. When the field capacity of the runoff is reached, subsequent quantities of the water will then drain from the roof. It effectively manages peak flows and reduce pressures of combined sewage systems as it temporarily detains the water as the water must absorb through the growing substrate and flow through the drainage layers before reaching the water outlets. Living roof performance is dependent on the climate and construction detailing of the design. On the ground, Bioswales are another alternative to storm sewers. They are vegetated depressions in the land that help capture and treat storm water runoff as water flows downstream. They operate by slowing down stormwater. Rain gardens are like bioswales and are also shallow depressions in the land that help treat stormwater runoff, but unlike bioswales, they are designed to store and infiltrate stormwater. Both are designed to manage rainwater but utilize water management in different ways. Bioswales, planter boxes, and trees are popular forms of green infrastructure that can easily be incorporated into street and alley design. Green Infrastructure is an effective way to naturally manage and treat stormwater runoff while also contributing to the well-being of people that use those spaces.

Global Precedents

Japan's use of raingardens are valuable precedent studies for low maintenance ways to introduce more green infrastructure in urban environments. Japan's International Consortium of Landscape and Ecological Engineering did a study in 2016 on the use of rain gardens from storm water management. According to their studies "increased surface area of impermeable surfaces is the alteration of hydrological regimes and, in particular, changes to local stream discharge" (Ishimatsu, 214), which means that with the greater percentage of impervious surfaces comes with the smaller the percentage of shallow and deep infiltration from water. This leads to a higher runoff percentage (212). Rain gardens are considered a type of LID system, or a low-impact development system, and is a recommended GI stormwater treatment option. Low-impact development systems offer an alternative to the traditional grey infrastructure used to manage stormwater and is a strategy that is ecologically sensitive. "Rain gardens are shallow depressions in the landscape that are planted with trees and/or shrubs and covered with a layer of bark mulch or ground cover”. (Dietz and Clausen, 5). Rain gardens are commonly drained from below and have an overflow to allow large storm passes allowing the soil to absorb the stormwater. The soil then stores rainwater for dry seasons, allowing plants to maintain fruition and continue to grow. Rain gardens require minimal to no irrigation, depending on the climate and plants chosen, but are generally self-watering and self-fertilizing gardens. In Portland’s climate, rain gardens are an optimal choice for incorporating low maintenance green infrastructure. Alternatively, according to the Department of Landscape at the University of Sheffield, domestic gardens offer another solution for managing storm water runoff. They state, “Gardens provide storm attenuation ‘services’ to the urban matrix. Vegetation, trees especially, intercept intense precipitation, hold water temporarily within their canopy thus reducing peak flow and easing demand on urban drains…vegetation mitigates flood risk by increasing infiltration into the soil reducing surface flow” (Cameron, W.F Ross et all, 4). Green Infrastructure improves wellbeing by regulating water quality, protecting biodiversity, and improving air quality. Research in this study shows how domestic gardens in urban spaces not only help in reducing surface flow of water but have health benefits for the people in the community using these spaces. Thus, outside of environmental benefits of green infrastructure, it is an important aspect in the health and wellbeing of people. According to Maria Beatrice Andreucci, a Doctor Europaeus in Environmental Technological Design, “the mismatch between what human beings need and what urban built environments often fail to provide—exposure to nature—has proven detrimental to mental health. Conversely, other studies have reported that human exposure to UGBI [Urban Green Blue Infrastructure] increase physical, improve mental health, and decrease crime, violence, and aggression, as well as morbidity in multiple disease categories" (35). Studies show that exposure to natural elements such as therapeutic or healing gardens can positively impact the wellbeing of people suffering from illness. Urban walks don't offer the same benefit as nature walks towards people diagnosed with a mental disorder (4). In Southeast Asia, hydraulic performance is especially important. In Singapore more water storage capacity is crucial as the intensity of a 1-hour length storm that occurs every 2 years is the equivalent on a storm that occurs every 100 years in New York (Hamel, 2). To help reduce runoff and control flood hazard, green roofs and bio retention systems were implemented. Green roofs showed significant reduction in reducing runoff and reducing issues in relation to stormwater quality (8). In a study from Manila, it was found that stormwater management systems were positively correlated with reducing heat island effect, reducing social, vulnerability, and improving air quality (10). In China, they have implemented a practice for constructing a "Sponge City" to increase the area of urban land that can absorb surface water and be able to retain or reuse stormwater. In a guideline for sponge city construction, it shows that permeable pavements have low maintenance costs and prove to be a cost-effective way of reducing stormwater pollutants. Green roofs, artificial ponds, wetlands, rain gardens, and bioswales were also used in the sponge city pilot projects to enhance the ecological function of the space. In Europe, constructed wetlands are commonly used as green infrastructure stormwater management systems and are relatively new in North America. A recent study was conducted in Sweden that analyzed the performance of a constructed wetland that operated for 19 years with no maintenance other than sediment removal from the forebay. Results from the study show that despite the lack of maintenance the CW was able to efficiently remove pollutants and reduce peak flow. (Al-Rubaei, 1). Another study analyzing the cost of constructed wetlands as CSO systems show that CWs minimize the use of additional mechanisms that are found in traditional grey water infrastructure. Aside from maintenance and other operational costs, CWs are relatively less expensive to construct. The unit cost of a wetland treatment system developed in Washington was estimated at $2.28/m3 in comparison to a $4.63/m3 sewer separation and chemical treatment system. (Tao et all, 4).

Where Should Portland be Heading?

According to the Environmental Services in the city of Portland, there are currently 62 current stormwater and sewer improvement projects. Several of these projects are sewer repair projects aimed to prevent backups and sewage overflows into the city. Many of these pipe repairs will prevent basement flooding and sewage releases onto the streets. Out of the 61 projects, only 5 are in North Portland, and 19 projects are in Southeast neighborhoods. These are lower income communities in Portland that have a median household income below $50k - $75k. In North Portland the only stormwater project that incorporates green infrastructure is the Irving Park Stormwater Project. In the Southeast area, only 4 projects utilize green infrastructure in their street design and are not focused on the high flood neighborhoods that are more vulnerable and susceptible to water management issues. Water management, water quality, and natural elements are important to promote physical and mental health of people living in those communities. Incorporating more urban green infrastructure in neighborhoods that are more susceptible to flood and heat hazard is necessary to protect the individuals residing in those areas. Environmental hazards from climate change deepen the effects of racial and economic disparities that disproportionately affect low-income and marginalized communities and should be addressed by future stormwater management projects from the city's Environmental Services Department. Precedents offer solutions for reducing annual run off control rates that the city of Portland could utilize in their future stormwater management plans. The pilot city projects China has implemented in Beijing, Shanghai, and Xinjiang showed that runoff rates were reduced by 85%. Their use of permeable pavements reduced runoff an average of 50-93% and LID rain gardens helped reduce 40-97% of run off. (Mohurd, 1). In Singapore, it was found that "the combination of green roof and bioretention systems can return peak runoff to preurbanisation levels… up to 75% could be retained in bioretention cells. Peak flow was also reduced by 63%." (Andreucci et all, 9), which is another practice Portland could incorporate in future development projects. In the prior analysis of Portland's current water management, there is a noticeable gap in infrastructure in low-income neighborhoods. CSO treatment wetlands are found to be less costly to construct than traditional grey infrastructure and may be found as a productive solution that the Environmental Services Department of the city could further explore.

Conclusion

Stormwater management practices have evolved globally to incorporate low impact developments. This study analyzed the context of climate change in the city of Portland, OR, to understand how climate changes will affect water management on a local scale. Cities have found value in incorporating Green Infrastructure and nature-based techniques that are now common practices around the world. This thesis explored Portland's current stormwater management system to focus in on areas of opportunity and current gaps in their water management system. To understand potential solutions in Portland, global precedents were explored to see how other cities have addressed the need for more efficient water management practices. Portland has greatly expanded their water management systems in the past through projects like the Big Pipes Project, however, have gaps in their water management Infrastructure. Findings showed that rising heat temperatures, wildfires, heavy precipitation will disproportionally affect low-income communities in North and Southeast Portland along the 84 and 205 that will be the most impacted by climate change and heavy rainfall. Portland can better utilize their water management practices by incorporating the use of more permeable pavements, rain gardens, bio-retention basins, and green roofs. Utilizing more LID and GI systems in the city's urban fabric will help reduce flood hazards and help filter, treat, and retain water from heavy storms to prevent flooding and toxic pollutants from water runoff.

Bibliography:

Al-Rubaei, Ahmed Mohammed, Malin Engström, Maria Viklander, and Godecke-Tobias Blecken. "Long-Term Hydraulic and Treatment Performance of a 19-Year Old Constructed Stormwater Wetland—Finally Maturated or in Need of Maintenance?" *Ecological Engineering* 95 (2016): 73–82. https://doi.org/10.1016/j.ecoleng.2016.06.031.

Andreucci, Maria Beatrice, Alessio Russo, and Agnieszka Olszewska-Guizzo. "Designing Urban Green Blue Infrastructure for Mental Health and Elderly Wellbeing." Sustainability (Basel, Switzerland) 11, no. 22 (2019): 6425.

Cameron, Ross W.F, Tijana Blanuša, Jane E Taylor, Andrew Salisbury, Andrew J Halstead, Béatrice Henricot, and Ken Thompson. "The Domestic Garden – Its Contribution to Urban Green Infrastructure." Urban Forestry & Urban Greening 11, no. 2 (2012): 129-37.

Chan, Faith Ka Shun, James A Griffiths, David Higgitt, Shuyang Xu, Fangfang Zhu, Yu-Ting Tang, Yuyao Xu, and Colin R Thorne. "“Sponge City” in China—A Breakthrough of Planning and Flood Risk Management in the Urban Context." Land Use Policy 76 (2018): 772-78.

Dietz, Michael E, and John C Clausen. "Stormwater Runoff and Export Changes with Development in a Traditional and Low Impact Subdivision." Journal of Environmental Management 87, no. 4 (2008): 560-66.

Fahy, Benjamin, Emma Brenneman, Heejun Chang, and Vivek Shandas. "Spatial Analysis of Urban Flooding and Extreme Heat Hazard Potential in Portland, OR." International Journal of Disaster Risk Reduction 39 (2019): 101117.

Hamel, Perrine, and Leanne Tan. "Blue–Green Infrastructure for Flood and Water Quality Management in Southeast Asia: Evidence and Knowledge Gaps." Environmental Management (New York) 69, no. 4 (2021): 699-718.

Halofsky, Jessica E., and David L Peterson, eds. Rep. Climate Change Vulnerability and Adaptation in the Blue Mountains Region. United States Department of Agriculture, 2017.

Ishimatsu, K., K. Ito, Y. Mitani, Y. Tanaka, T. Sugahara, and Y. Naka. "Use of Rain Gardens for Stormwater Management in Urban Design and Planning." Landscape and Ecological Engineering 13, no. 1 (2017): 205-12.

Mohurd. “The Construction Guideline of Sponge City in China − Low Impact Development of Stormwater System ,” 2014. Ministry of Housing and Urban-Rural Development of the Peoples Republic of China .

Oregon Climate Change Research Institute. “Fifth Oregon Climate Assessment,” January 2021.

Saaroni, H., J.H Amorim, J.A Hiemstra, and D. Pearlmutter. "Urban Green Infrastructure as a Tool for Urban Heat Mitigation: Survey of Research Methodologies and Findings across Different Climatic Regions." Urban Climate 24 (2018): 94-110.

Saraswat, Chitresh, Pankaj Kumar, and Binaya Kumar Mishra. “Assessment of Stormwater Runoff Management Practices and Governance under Climate Change and Urbanization: An Analysis of Bangkok, Hanoi and Tokyo.” *Environmental Science & Policy* 64 (2016): 101–17. https://doi.org/10.1016/j.envsci.2016.06.018.

Simcock, R, E Fassman-Beck, and J Ansen. Rep. *APPLICATION OF LIVING (GREEN) ROOF DESIGN RECOMMENDATIONS FOR STORMWATER MANAGEMENT*. University of Auckland, n.d.

The City of Portland. “Portland Watershed Management Plan Potential Benefit of Green Infrastructure” 2011.

“Portland, Oregon.” Flood Factor. Accessed May 12, 2022. https://floodfactor.com/city/portland-oregon/4159000_fsid.