Green Infrastructure in Portland's Stormwater Management Plan

An Overview

Environmental Planning

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Introduction

The rapid development of land in the modern world has increased stormwater runoff at an unsustainable rate. As the built environment replaces the natural, soil compaction, plant and vegetative removal, and the replacement of natural, spongy, infiltrative surfaces with hard, impervious surfaces has contributed to increased storm flows and larger flood volumes, as well as an increase in pollutant loads that wash into streams and rivers, decreasing the quality of the watershed (BES 2020). With an average rainfall of 49.9 inches (Climate Data, "Portland Climate") and a highly developed metro area, Portland, Oregon faces a particular need for water quality management via stormwater control. Additionally, climate change models of the region predict that "it will be warmer; there will be more precipitation during winter; the mountains will have more rain and less snow; and there will be fewer but stronger storms" (Oregon Metro, "Climate Change").

Thankfully, the City and people of Portland have long proven themselves willing to commit to environmental protection and improvement, often leading with programs that are innovative and exploratory. Enacted between 2002 and 2009, the Innovative Wet Weather Program "supports projects that effectively manage stormwater as close to its source as possible and use vegetation to slow, retain and filter stormwater" (City of Portland, "Innovative Wet Weather Program). This program uses Green Infrastructure (sometimes called Natural Infrastructure), or GI, which means putting nature to work within cities in the form of rain gardens, green roofs, stormwater swales, green streets, parks, natural corridors, and myriad others. This term is meant to contrast with that of Grey Infrastructure, which generally refers to more traditional means of stormwater management, including pipes, culverts, and concrete gutters. During the previous era of stormwater management, the so-called “good drainage” approach focused on utilizing gray infrastructure purely to move water out of an area. This approach minimized flooding on-site, but increased it downstream, in addition to greatly increasing pollution runoff (Randolph 2012, 250) In contrast, the green infrastructure method focuses on infiltrating water back into the soil, which slows water flows, decreases flooding, replenishes the water table, and improves water quality. One of the primary benefits of GI is its multifunctionality - in addition to all of these stormwater functions, increased vegetation also enhances the beauty of public spaces, sequesters carbon, provides shade and cover, benefits air quality, increases property values, and promotes wildlife and pollinator habitat. However, for simplicity, this paper will focus primarily on several main categories of Portland Stormwater’s green infrastructure projects, such as those in the Innovative Wet Weather Program, their applications, and their impacts on water quality.

Community Context

Historically, the city of Portland has faced serious issues with water quality. After the first sewer systems were constructed in the 1860s, the watershed experienced a serious decline in quality (Randolph 2012, 261), and all but one of Portland’s streams are listed as impaired (BES, “Environmental Assessment” 2004, 1-1). Portland’s size qualifies it as a Phase 1 community under the US EPA NPDES (National Pollutant Discharge Elimination System) Program, which requires the city to have a NPDES Stormwater Discharge Permit as well as a comprehensive stormwater management program under the authority of the Clean Water Act (Bureau of Environmental Services, “Environmental Assessment” 2004, 1-1). Some water is processed via water treatment plants, and some soaks into the ground, but most flows directly into waterways via dry wells, ditches, and stormwater sewers. Older parts of the city operate within a Combined Sewer System, where sewage and stormwater run through the same pipe and are treated before release, however, heavy rain events can and did cause frequent Combined Sewer Overflows (CSOs) directly into the Willamette River until the Big Pipe Project was completed in 2011 after 20 years of work (Figure 1). Green infrastructure was and remains a large part of this project, as the pipes' water treatment facilities' capacity is dependent upon as much stormwater being removed from the system as possible. This project decreased CSOs by 94-99 percent (Portland.gov, "Big Pipe Project"), however, CSOs still do occur and can have a dramatic effect on water quality and the health of the watershed, as pollutant concentrations are much higher than in separated stormwater systems (Table 1). According to the EPA, CSOs are a "priority water pollution concern for the approximately 700 municipalities across the U.S. that have combined sewer systems (US EPA, "Combined Sewer Overflows").

Much of the basis for the implementation and funding of the Innovative Wet Weather Program was to help reduce the volume of stormwater in the sewer system, and thus the likelihood of CSO events, and the City of Portland submitted an Environmental Assessment to the EPA as a request for grant money that would help to keep them in compliance with their NPDES permit. This assessment references excerpts and language from the city's *Stormwater Management Manual*, which includes technical specifications that are foundational to the proposed new program. Within this manual, although not referred to by name, the city mandates a preference for the use of GI or other infiltrative methods, stating that "Vegetated and infiltration facilities must be used to the maximum extent practicable" (BES 2020, 2-28).

The City of Portland continually promotes watershed education in general, and specifically disseminated information about the CSO situation via media coverage, newsletters, meetings, classroom education, exhibits, and other means (BES, "Environmental Assessment" 2014). Public scoping has helped to identify community concerns, such as a need for improved water quality, and the public is kept informed during the implementation process. Green infrastructure has become a big part of Portland's livable environment, and to keep the community involved and aware, the city has even produced a *Stormwater Cycling Tour* Map and pamphlet, which guides visitors through 25 stormwater projects over 13 miles of cyclist-friendly streets.

Geographical Context

Portland, like many cities, faces a number of geographical challenges when planning and implementing green infrastructure and stormwater management plans. One of the biggest challenges is the city's location in the Pacific Northwest, which is known for its rainy climate. This means that there is a lot of stormwater runoff that needs to be managed, and it can be difficult to find space for green infrastructure projects in urban areas where space is at a premium. Another challenge is the city's topography. Portland is situated in a valley, which means that stormwater runoff can be particularly problematic. The city has a combined sewer system, which means that stormwater and sewage are carried in the same pipes. During heavy rain events, the system can become overwhelmed, leading to combined sewer overflows (CSOs) that discharge untreated sewage and stormwater into the Willamette River. This is a major environmental and public health concern, and one that the city has been working to address through its stormwater management plan.In addition to these challenges, Portland also faces issues related to urbanization and development. As the city has grown, more and more of its natural areas have been paved over, which means that there is less space for stormwater to infiltrate into the ground. This can lead to increased runoff and flooding, as well as water quality issues. Despite these challenges, Portland has been a leader in green infrastructure and stormwater management. The city's 'Big Pipe' project, which built two pipes to direct stormwater and sewage to wastewater treatment plants, was a major engineering feat that has helped to reduce the frequency of CSOs. The city has also implemented a number of green infrastructure projects, such as bioswales and downspout disconnection, to help manage stormwater at the source. These projects have not only helped to reduce the amount of stormwater in the combined sewer system, but they have also provided other benefits, such as improved water quality, increased biodiversity, and enhanced urban aesthetics. Overall, while Portland faces a number of geographical challenges when it comes to green infrastructure and stormwater management, the city has shown that it is possible to overcome these challenges through innovative engineering and policy solutions. By continuing to invest in green infrastructure and stormwater management, Portland can help to create a more sustainable and resilient city for future generations.

Background Research

Stormwater Green Infrastructure (SGI) can be applied in a wide variety of methods, depending on a site's hydrogeological capabilities, physical constraints, and needs. Some forms of SGI are more effective at delivering specific benefits than others. Practices that retain and slowly absorb water are most beneficial for water quality, such as bioretention ponds and rain gardens (Minnesota Pollution Control Agency, "Minnesota Stormwater Manual")(Table 2). GI acts as a sort of sponge, or filter within stormwater management - but it is not a perfect one. A 2020 report produced by the EPA suggests that the use of GI for infiltration may affect groundwater quality nearby (Beak et al 2020). However, changes to water quality and chemistry are much less when water is infiltrated than they would be should contaminated water flow directly into water bodies. The report states that "the groundwater wells near the outfall had concentrations less than the outfall and more than the upgradient groundwater" (Beak et al 2020, 178). Different chemicals also pose different levels of risk to groundwater. The current state of research on this subject is in flux, and is well summarized within Minnesota's Stormwater Manual. According to the manual, metals, usually minimal in urban stormwater, generally stay within the upper layers of the soil, which may benefit from periodic removal and replacement. Additionally, although not a cause for concern in terms of drinking water, areas with phosphorus-impaired waters may need to alter their management practices, since vegetation can leach more phosphorus into the water supply. The only chemical listed by the manual as a concern is chloride, which is not absorbed by GI. The primary source of chloride is chemical deicer. (Minnesota Pollution Control Agency, "Surface Water and Groundwater Quality Impacts"). Wide-scale use of deicer is not likely to pose an issue in Portland, but will in colder, more northern climates.

However, these results, though they may be diluted, are still cause for monitoring and vigilance when groundwater is used as a source of drinking water, as it is in Portland. Portland's aquifer is deep - 200 to 600 feet underground - but the city still manages groundwater pollution through a wellhead protection program, chemical management, and community outreach. Additionally, not all infiltration is good infiltration, and it should be avoided in locations where chemicals are heavily present, such as gas stations or chemical storage areas.

Analysis and Solutions

Portland’s sustainable stormwater strategy includes five main principles: managing runoff close to the source, mimicking natural hydrology, integrating runoff into the built environment, designing for multiple benefits, and acting early to avoid costly mitigation - all of which can be clearly seen in the following Green Infrastructure stormwater management methods.

An overview of several methods will be discussed below, however, the City of Portland has made available detailed schematics and reports for all of the projects mentioned.

Green Streets

Green streets integrate vegetation to infiltrate runoff as close to the source as possible - as soon as it flows off of streets and sidewalks. Multiple green street designs were tested during the early 2000’s, some as a part of the Innovative Wet Weather Program, and a Green Street Resolution was approved in 2007 to promote their use in both public and private development (The City of Portland, “Green Streets”).

Design

Although the design of each project must be customized by site, common features include curb cuts or sidewalk drains that divert water into recessed, vegetated planters, swales, or basins (Figure 3). Since many of these projects retrofit existing streets, this often takes the form of a curb extension from the existing sidewalk, which narrows the street and provides traffic-calming and pedestrian safety in addition to stormwater infiltration. Care must be taken to ensure that sidewalk safety and accessibility are not compromised. In order to direct water into a 90 degree curb cut, asphalt may either slope downwards, or a small asphalt berm can be installed to disrupt the downhill flow - however, high-intensity storms may still bypass the facility.

Vegetation will vary by locale, but must be tolerant to both drought and heavy watering, may ideally be evergreen, and should usually be short in stature where necessary to prevent safety and visibility concerns. Additionally, it is essential that soils are well-draining, and that water is directed in the event of an overflow. It is also important to ensure that debris and sediment is prevented from clogging the features - this can be achieved either through structurally designed means (bars, grates, etc.), or by strategic use of sturdy plants lining the entrance.

Budget and Maintenance

In most green streets projects, the majority of the budget is allocated to removal, excavation, and replacement of existing concrete infrastructure. Budget must also be allocated for design and project management, as well as smaller ancillary tasks. As the city undertakes more green streets and stormwater projects, these costs are expected to come down as the work becomes more routine.

Usually the city maintains project areas, sometimes with assistance from nearby residents. Since these facilities are meant to improve water quality, it is important to note that weeding must be done by hand and without the use of chemicals or pesticides. Other regular maintenance includes debris and sediment removal (four-six times per year in Portland), plant trimming, and occasional plant replacement. Vegetation will likely need to be hand-watered for a time as it becomes established.

Examples

The SW 12th Avenue Green Street Project incorporated four consecutive stormwater planters into the sidewalk, leaving accessible paved surface on either side (Figure 3, Figure 4). Stormwater runs down the existing street curb as usual, but instead of flowing into a storm drain, it is diverted under a sidewalk grate and into the infiltration planters. Cost of construction for the planters totaled about $34,000, or $4.65 per square foot, and each planter can hold and infiltrate seven inches of stormwater - once the first pond fills, water flows back out, and then into the second, and so on. Plant varieties were chosen for both their utilitarian and aesthetic characteristics. The design maintains on-street parking, does not affect traffic conditions, and adds considerable aesthetic value to the street, which has attracted interest and helped the program gain even more traction in the community and beyond. This design is focused on water quality improvement and meets the city's goal to integrate stormwater management into the built and urban environment.

Monitoring of the site reports that the ponds consistently retain about 74% of storm flows, despite draining a larger area than was initially planned for (upstream areas frequently clog and overflow). Despite identical design, some bays performed better than others - this cause of this discrepancy is unknown, but may have to do with underlying soil conditions. Water sometimes misses the 90 degree gutter entry, especially at high volume.

Green Roofs

Green roofs, also known as ecoroofs, have become increasingly popular in Portland due to their numerous benefits. These roofs are designed to be self-sustaining and consist of vegetation and a few inches of soil. They help reduce stormwater runoff, improve water quality, and provide insulation for buildings. The city of Portland has been encouraging the construction of ecoroofs through building and zoning codes, grants, and stormwater fee discounts. In this section, we will explore the design, budget, maintenance, and examples of ecoroofs in Portland.

Design

Ecoroofs in Portland are designed to be lightweight and self-sustaining. They consist of vegetation and 2-6 inches of soil, which can support a variety of plant species. The roofs are designed to be accessible to the public, providing a unique green space in the city. Environmental Services staff provide technical assistance, tours, presentations, and online resources for interested citizens and people installing ecoroofs. The city also monitors and evaluates ecoroofs in Portland to gather data on how effective they are in reducing stormwater runoff and improving water quality.

Budget and Maintenance

City grants have funded ecoroofs ranging from high-rise apartment complexes and office buildings to small park shelters and community-based projects. Development in the nine square miles of central Portland is eligible for Floor Area Ratio bonuses for installing an ecoroof. Through Clean River Rewards, stormwater fee discounts are available to properties that reduce impervious area with ecoroofs. The maintenance of ecoroofs is relatively low, as they are designed to be self-sustaining. However, occasional weeding and pruning may be necessary.

Examples

One example of an ecoroof in Portland is a reroof completed in 2005, with a square footage of 7100 and a soil depth of 3 inches. This ecoroof is accessible to the public and provides a unique green space in the city. Another example is the Hamilton Apartments ecoroofs, which were completed in 2001 and are being monitored for their effectiveness in reducing stormwater runoff. Over 25 ecoroofs have been built in the city, ranging from residential to commercial buildings.

Ecoroofs have become an important part of Portland's landscape and culture. They provide numerous benefits, including reducing stormwater runoff, improving water quality, and providing insulation for buildings. The city of Portland has been encouraging the construction of ecoroofs through building and zoning codes, grants, and stormwater fee discounts. The maintenance of ecoroofs is relatively low, and they are designed to be self-sustaining. With over 25 ecoroofs built in the city, Portland is leading the way in sustainable building practices.

Applicability to Other Locations

Although Portland is known for its rainy climate, the benefits of stormwater green infrastructure aren't limited only to similar locations. Although Missoula, Montana averages less than a third of Portland's yearly rainfall, employees within the stormwater department see Portland's program as a goal to reach towards, with methods that are highly transferable (Butterfield 2023), even to a drier climate. Indeed, even arid cities can benefit from green infrastructure - when rain does fall, more hot, impervious surfaces, such as asphalt, mean more evaporation. Without vegetation to capture and infiltrate the minimal water available, this precious resource is lost, where it could have helped to recharge groundwater supplies.

The basic design and implementation of both green streets and green roofs is highly customizable and would likely benefit any city. Primary alterations are climate-related: the design, depth, and frequency of retention basins or planters should be determined based on average precipitation, as should the plant varieties selected to fill them. A city without experience designing and implementing these types of projects should expect a higher initial cost per project, decreasing as experience increases. The many supplementary benefits of green infrastructure - shade, urban heat island mitigation, air quality improvement, and others - makes it an even more attractive solution for a whole range of climates.

Conclusion

It is clear that stormwater runoff is a significant issue in modern urban environments, and Portland, Oregon is no exception. With an average rainfall of nearly 50 inches and a highly developed metro area, the city faces a particular need for effective stormwater management strategies. Fortunately, the City of Portland Bureau of Environmental Services has developed a comprehensive Stormwater Management Manual that provides guidance on a range of strategies which can help to mitigate the negative impacts of stormwater runoff.

Green streets are an innovative approach to stormwater management that involve retrofitting existing streets with features that promote infiltration and reduce runoff. These features can include curb extensions, which narrow the street and provide traffic-calming and pedestrian safety benefits, as well as vegetation and well-draining soils that help to absorb and filter stormwater. While green streets can be effective at reducing the negative impacts of stormwater runoff, care must be taken to ensure that they do not compromise sidewalk safety and accessibility, and that they are designed to prevent debris and sediment from clogging the features. Green roofs consist of vegetation and a few inches of soil, and are designed to be self-sustaining. They help reduce stormwater runoff, improve water quality, and provide insulation for buildings. The city of Portland has been encouraging the construction of ecoroofs through building and zoning codes, grants, and stormwater fee discounts.

Overall, the City of Portland's Stormwater Management Manual provides a valuable resource for communities looking to address the issue of stormwater runoff. By implementing strategies like green streets and green roofs, cities can help to reduce the negative impacts of stormwater runoff on water quality and the environment. However, it is important to recognize that stormwater management is an ongoing challenge, particularly in the face of climate change and the increasing frequency of extreme weather events. As such, it is essential that communities continue to invest in innovative and effective stormwater management strategies in order to protect the health and well-being of their citizens and the environment.

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Appendix

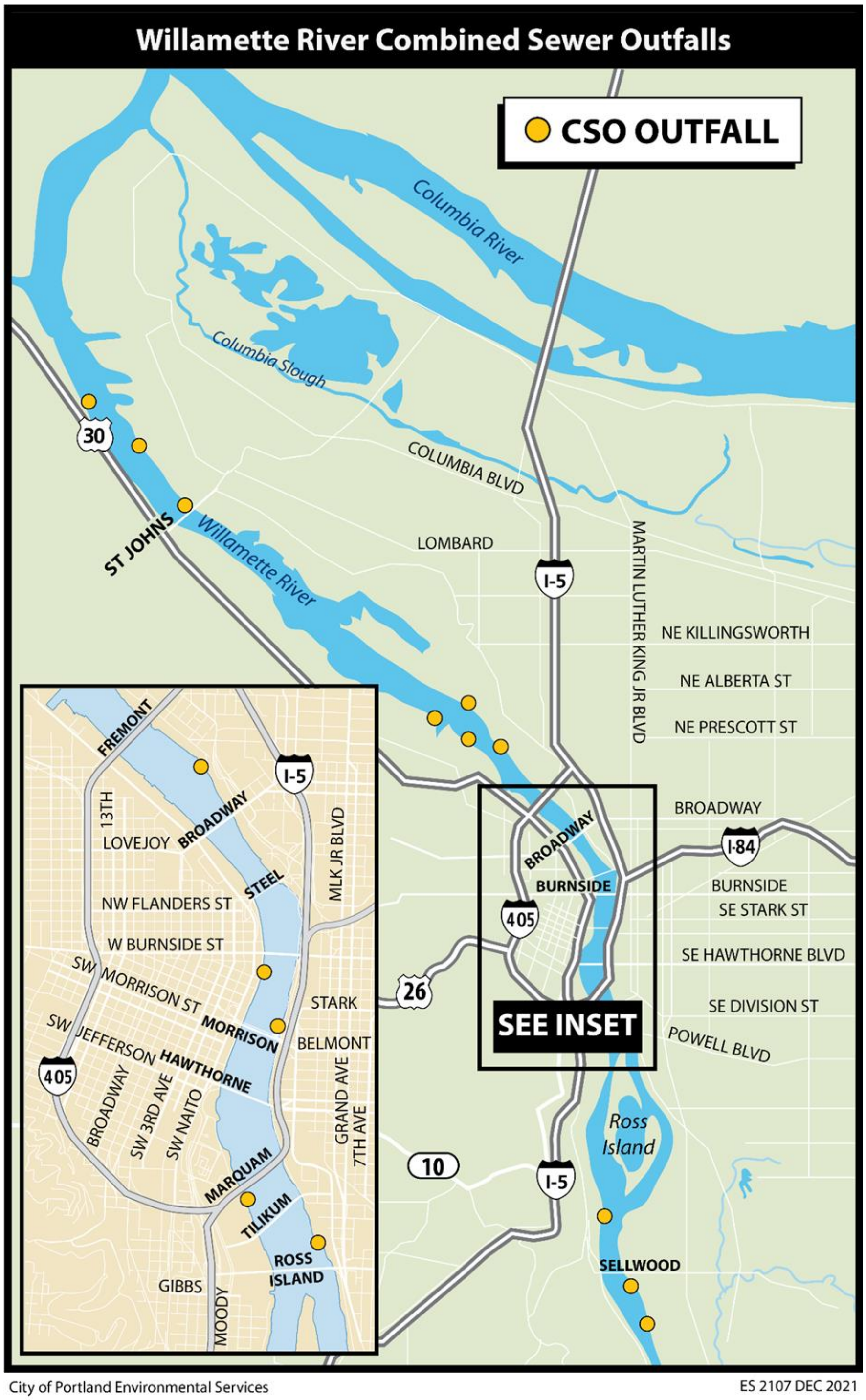

Figure 1: CSO Outfall Locations

AVERAGE POLLUTANT CONCENTRATIONS FOR SEWAGE, CSOs, AND STORMWATER			
Pollutant	**Domestic Sewage**	**CSO**	**Stormwater**
TSS, mg/L	265	120	59
BOD_5, mg/L	260	28	10
TKN, mg/L	68	7.8	1.2
Copper, mg/L	0.068	0.020	0.014
Lead, mg/L	0.015	0.016	0.021
Zinc, mg/L	0.158	0.090	0.083
E. coli bacteria, CFU	1-10 million	10-100 thousand	1000

TSS = total suspended solids.
BOD_5 = 5-day biochemical oxygen demand.
TKN = total kjeldahl nitrogen.
CFU = Colony Forming Units.
Source: City of Portland, December 2003.

Table 1: Pollutant Concentrations for Sewage, CSOs, and Stormwater

Practice	Water quality benefit	Notes
Bioretention	●	Infiltration is most effective; potential phosphorus leaching in filtration practices
Tree trench and tree box	●	Infiltration is most effective; potential phosphorus leaching in filtration practices
Green roof	◔	Potential phosphorus leaching
Vegetated swale	◔	Infiltration is most effective; less effective for dissolved pollutants
Vegetated filter strip	◔	Removes solids; less effective for dissolved pollutants
Permeable pavement	◕	Infiltration is most effective
Constructed wetland	◑	Removes solids; less effective for dissolved pollutants
Rainwater harvesting	◕	Can be used on low permeability soils
Level of benefit: ○ - none; ◔; - small; ◑ - moderate; ◕ - large; ● - very high		

Table 2: Water Quality Benefits of SGI Practices - Minnesota Pollution Control Agency

***Figure 5-4*: Green Street Planters at SE Reedway & 89th (left) and SW 12th & Montgomery (right)**

***Figure 5-5*: Green Street Swale at N Willamette & Denver, before (May 2007) and after construction (September 2007)**

***Figure 5-6*: Green Street Basins at N Albina & Prescott (left) and SW 30th & Dolph (right)**

Figure 2: Green Street Types (City of Portland, Oregon, BES)

SW 12th & Montgomery Green Street

Summary Information		
Evaluation Period:	**4 years** (Jul 2005 – Jun 2009)	**A series of four planters designed to fit into the urban environment of downtown Portland. Metered parking is accommodated with a step-out area between the street curb and the facility.**
Constructed:	**June 2005**	
Facility Type:	**Street Planter**	
Drainage Area:	**7,000 ft²**	
Facility Area:	**272 ft²**	
Sizing Factor:	**4%**	

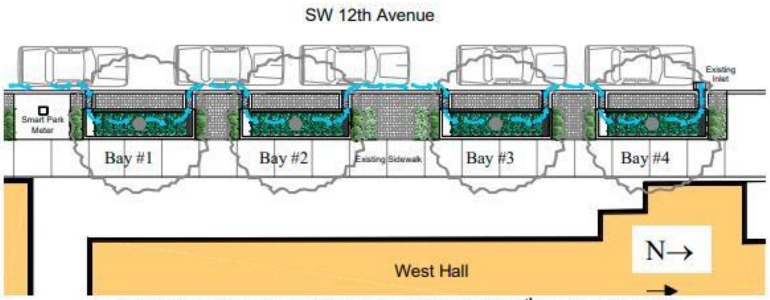

***Figure SW-1*: Plan view of the planters at SW 12th & Montgomery**

***Figure SW-2*: First two bays looking south (left) and the first three bays from above (right) looking east**

Figure 3: SW 12th Avenue Green Street Project (City of Portland, Oregon BES)

Figure 4: SW 12th Avenue Green Street during a rain event - *Urbanraindesign.com*

Interview with Carver Butterfield of Missoula Stormwater - 4/19/2023 (Answers are paraphrased)

Is green infrastructure officially a part of Missoula's stormwater plan? What about in other departments? If so, how is this collaborated on across departments, since GI is a multipurpose tool? If it isn't, is it on the horizon? Why or why not?

Yes, it is an official part of the plan. Multiple city plans reference GI and promote its installation, (such as the Downtown Master Plan), however, the problem is that there is no official enforcement - it's just "words on paper." There *has* been somewhat of a shift recently to include green infrastructure, which is more likely to occur on city-led projects.

It can be cheaper or more expensive, depending on the situation. A recent replacement of a failed dry well up Rattlesnake Creek with a curb cut into a vegetated area was cheaper, for example, because the vegetation already existed.

Unknowns surrounding maintenance and upkeep cause a lot of resistance to implementing more green infrastructure.

What are the priorities for stormwater management in Missoula?

The main priorities can be summarized by the six Minimum Control Measures designated by the MS4 program. Public outreach, discharge detection and elimination, construction site management, and overseeing stormwater pollution prevention within municipal operations (such as fire, police, parks and recreation, and community facilities) are among the top priorities. Understanding the infrastructure that's already in place and creating a database of that infrastructure are both a challenge and a priority. It's also important to regularly assess what's working and what's not, through testing and monitoring.

What are some of the main difficulties?

Public perception is a huge hurdle. Many citizens still don't understand that stormwater isn't treated after it goes down the drain, and there is a sentiment in Missoula, and Montana, that our environment is so pristine that we can't do anything to negatively affect it.

Data collection and monitoring is also difficult - sampling a rain event is really hard! Events are quick, pollution concentrations can vary widely across the length of them. Non-point source pollution in general is really difficult to track and measure.

Are you familiar with the stormwater management methods used in Portland? They obviously have a very different climate from ours, and different concerns. Does anything translate for you? What might need to be changed to make it applicable?

Yes, it translates, and Portland's solutions would be great in Missoula - of course Portland has a much bigger budget. People from Portland have actually come to stormwater conferences in Missoula and discussed their methods with Missoula staff. Overall, Missoula Stormwater wants to move in a similar direction as Portland, integrating more green infrastructure. The department is slowly growing, and conversations are being had with other cities.

Part of the issue is that dry wells are *really* easy to install, and very effective in Missoula. Missoula's soils infiltrate really well.

Since Missoula's aquifer is so close to the surface, does infiltrating by means of green infrastructure pose any risks to water quality? Are there specific pollutants that are an issue? What about chloride?

Yes - groundwater is really easy to contaminate in Missoula, and many wells have been temporarily shut down in the past due to pollution events. Since dry wells are drilled about eight feet straight down towards the aquifer, they bypass a lot of infiltration potential.

Missoula is actually one of the few cities that allows people to put their leaves in the right-of-way in the fall. Most cities don’t do this because leaves are known to leach phosphorus and nitrogen into stormwater, which can cause eutrophication in downstream water bodies.