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Piloting a Drain Gauge as a Method of Measuring Runoff from Ecoroofs in Portland

by

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Thesis Advisor:

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Abstract:

The following paper explores how we can measure ecoroof runoff, at the roof scale, for specific climate conditions in Portland. Portland, with a history of troubling stormwater management, has dedicated policies to implementing ecoroofs around the city. Since an ecoroof must reduce the annual volume of runoff by 50% to be considered efficient, it is important to understand how our ecoroofs are functioning and the drain gauge has the potential to inform managers of just that. The drain gauge is a less studied technique for measuring ecoroof runoff but holds high potential for developing better monitoring and management of ecoroofs within the city of Portland. What separates this stormwater runoff capturing device apart from other stormwater runoff calculation techniques is its adaptable design and simple installation. The drain gauge can be placed in any roof drain installed near an ecoroof simply by placing it into a roof drainage system. The drain gauge I constructed has been built and calibrated but needs to be implemented into an actual ecoroof setting to observe its full functionality. Overall, this paper highlights a pilot methodology of a drain gauge system I built to calculate stormwater runoff from ecoroofs in Portland, Oregon.

Introduction:

Given that this methodology study is focused and was performed in Portland, OR it is important to understand Portland's climate and stormwater background information. Portland is a dense city located in the Pacific Northwest with the coast to its west and the Cascade Mountains to its east. Given Portland’s topographical features, average annual rainfall can vary between 35 and 60 inches per year depending on the specific location in Portland. Furthermore, 90% of Portland precipitation events occur in mid-October and mid-May, which makes these events much more severe and intense compared to regions with year-round precipitation events (NOAA *Climate Summary)*. The city has a population of over 635,000 people and is covered in majority by impervious surfaces while being largely located in a previous flood plain. Given these conditions, intense storms have been problematic in Portland for previous stormwater infrastructures that have been put in place.

A historically large issue in Portland has been managing stormwater overflows and flooding. Portland used to have on average 50 combined sewage overflows into the Willamette River that consisted of stormwater runoff and untreated sewage waste. To combat this issue Portland constructed the Big Pipe project, which was completed partially in 2011, and has reduced 94% of CSO's into the Willamette (The City of Portland Oregon). The pipe can store more water before being sent to water treatment facilities, but the volume of stormwater being collected into the Big Pipe still had potential to be reduced. A solution Portland came up with for managing stormwater volumes are ecoroofs. The city of Portland has enacted an ecoroof mandate within their Portland Central City 2035 Plan (33.510 Central City Plan District). The plan was enacted in 2018 and mandates an ecoroof, or vegetated roofing, to be placed on any new buildings with a net area of 20,000 square feet or more. Roofs this large must have an ecoroof covering 100% of their roof with 20% vegetation being evergreen species (LPDD). The City of Portland states that "During heavy rains, when more rain falls than the ecoroof can absorb, the soil slows the flow of water into the pipes. Reducing the volume and speed of rain runoff in this way helps reduce the risk of flooding, sewer backups, and sewer overflows. (City of Portland)". With progressive policies increasing ecoroof implementation, it is important to understand how ecoroofs can be altered to maximize possible benefits. The main push for Portland's ecoroof plan was to minimize stormwater flows annually, and stated here by the

Bureau of Environmental Services the amount of water ecoroofs retain is important, “Although not all ecoroofs are equally effective at reducing stormwater, it is the intention of BES to develop ecoroofs with maximum stormwater benefit.” (*City of Portland Bureau of Environmental Services*). To maximize ecoroof water retention, we must have methods to capture and analyze stormwater runoff volumes. Furthermore, these methods must be able to catch a range of runoff volumes given Portland’s various seasons and precipitation loads.

An ecoroof, for general understanding, is a vegetation covered roof and has been found to overcome issues like reducing excess stormwater runoff, preventing flooding, increasing pollinator habitats, stabilizing temperatures, and providing access for residents to greenspaces *(Portland's Green Infrastructure*). Along with providing various ecosystem services, ecoroofs are a best management tactic for reducing peak flows and containing volumes of water from precipitation events (Schafique et al., 2018). As Portland expands, urban planning efforts are more frequently promoting the use of ecoroofs due to the plethora of ecosystem services they provide. However, it is vital that once they are installed, the ecoroofs are monitored for their success in producing these benefits to ensure they are performing as expected. According to the City of Portland, an efficient ecoroof is one that reduces annual runoff volume by 50% (LPDD). There are many ways to measure the effectiveness of an ecoroof, but specifically for stormwater runoff the main methods for calculating runoff is by using flumes, weirs, electromagnetic flowmeters, cisterns and tipping rain buckets while paired with local precipitation data (Skabelund et al., 2015).

Equipment for measuring effluent can be timely, expensive, inefficient, and variable in results because climate conditions and ecoroof design can be dramatically different across cities or regions. The methodology for calculating runoff from ecoroofs does exist, and is well studied, but each method comes with its own pros and cons. Known methods for measuring ecoroof runoff are flumes, weirs, and rain tipping buckets. Weirs are used to measure water flow. The water must flow over the top of the weir to understand the volume of water present (Energy Education). Therefore, we mostly see weirs in larger bodies of water. Since ecoroofs will generate less volumes of runoff than actual water bodies, weirs may be impractical for smaller ecoroof systems. Flumes also measure flow rates of water by knowing the dimensions of the flume and the level of water passing through the flume. Normally these are seen in open channels but have been used on buildings with ecoroofs (Intermountain Environmental Inc). Again, there’s a challenge for designs to be fitted to a small enough size to efficiently measure runoff from the roof scale of ecoroofs. Many times, the technology to monitor green roof discharge units have to be installed prior to the green roof design or must even be done during building construction. Consequently, volume monitoring devices and designs can be expensive and problematic for developers or other stakeholders within the building ownership and may be surpassed or avoided. Flumes and weirs are examples of methods that need to be engineered into the building of an ecoroof which can require extra time, money, and may not allow researchers to get ecoroof runoff volumes independent of all other water inputs coming into these designs. Rain tipping buckets are also a commonly used method and record rainfall but can be manipulated to measure runoff volumes (Segovia-Cardozo et al., 2023). This method is more small scale and does not give flow only volume. Therefore, there is room for improvement for implementing a design that can be placed in small or large scale ecoroofs and measure the volume and or flow of runoff. In response to these issues, below I describe how I designed and calibrated a drain gauge device to efficiently monitor ecoroof runoff at the roof scale in Portland, Oregon. The drain gauge design is a pilot method study in Oregon for ecoroof monitoring since it has only been utilized for irrigation best management practices on the US Botanical gardens near the East Coast (Partnerships - United States Botanic Garden, 2024).

Methods and Design:

The methods behind this design allow stakeholders or researchers to directly place the drain gauge into any existing storm drain at any time at the roof scale. The drain gauge design was modeled after Dr. John Lea-Cox's design that was presented in the "2022 Mid-Atlantic Green Roof Science and Technology Symposium", my replicated model can be seen below in Figure 1 (Lea-Cox, 2022). To construct the drain gauge's design, I used different sized pvc pipes, fittings, a CTD-10 sensor, a Recordall badger meter, and a Zentra data logger to establish a relationship of flow based on Portland's precipitation patterns. A 3-in wide pvc is drilled with holes in millimeters that increase in size as you rotate the cylinder upwards to output a certain amount of volume of water relative to Portland's maximum precipitation per hour in inches (PF Data Server 2023). Fittings are then glued to the 3-in pvc cylinder, creating a closed system. The smaller pvc pipe will have a fitting glued to it as well adjusting its width from 1 inch to 3 inches. The smaller pvc is then placed into the larger pvc and will stop where the width reaches 3 inches in the larger pipe (right below the fitting). The CTD-10 sensor is placed into the 3-in pvc and rests snuggly in the fitting at the bottom. To eliminate leaf blockage a leaf filter can be attached to the top of the 3 in pvc. Dead space must then be calculated to ensure the CTD-10 is recording the correct depths while resting at the bottom of the gauge.

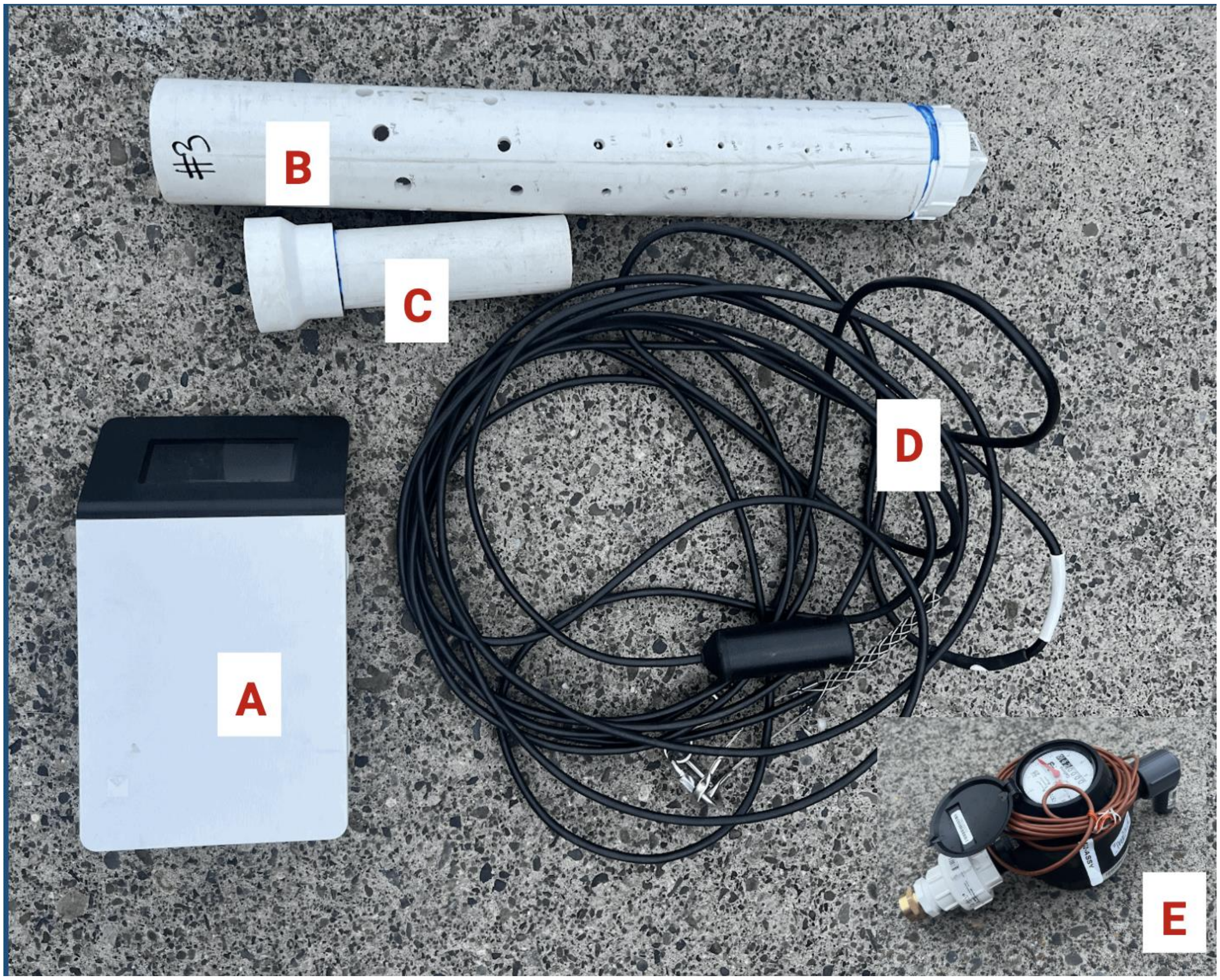

Figure 1: The figure above shows the drain gauge and the needed components to calibrate it. The visible pieces of the system are labeled A-E. A is illustrating the Zentra data logger which is reading the depth measurements from the CTD-10 sensor. B is labeling the drain gauge device. C is labeling the inner body of the drain gauge that will be set inside the gauge and attached to a leaf filter to reduce blockage. D is labeling the CTD-10 sensor which gives depth measurements in mm. Lastly, E is labeling the badger meter which is only needed for calibration; it reads the flow rate of water entering the drain gauge.

Calibration:

The most vital step in this design is calibrating the drain gauge. My personal calibration set up can be seen in Figure 2. The calibration process allows users to understand the relationship of flow input into the gauge in response to different amounts of stormwater runoff. Similar to a study done in Auckland using an orifice restrictive device (ORD), the pressure inside the device is taken at known flow rates (Voyde et al., 2010). Given different volumes of water entering the drain gauge, the drain will release various volumes from the drilled in holes and the pressure inside the gauge will fluctuate. To calibrate the drain gauge, the badger meter is used to measure the volume of water coming from a hose spicket into the drain gauge system. It is crucial that the calibrator is recording the gallons per minute so that the volume of water is under a time denominator and can be paired with the depth readings further on. Within the drain gauge the CTD-10 is recording depth of water in the gauge in millimeters. The CTD-10 sensor is also connected to a Zentra utility data logger, giving in time readings of the depth that can be accessed by laptop. The recorded depth data can then be graphed with the timed water volume data to get a flow equation that represents the flow relationship between the height of the drain gauge and the volume of water entering. Once fully assembled and calibrated, the drain gauge can be placed directly into the storm drain on a rooftop. The data logger stays connected to the drain gauge through the CTD-10 sensor to deliver the readings to whichever device it's synced to, providing real time data. Since the relationship of flow has been calibrated, the Zentra logger is set on rechargeable batteries, and the leaf filter reduces clogging, the drain gauge can be left in the drain and won’t require regular maintenance or monitoring once it’s installed.

Figure 2: The image above shows my personal experience of calibrating the drain gauge device I constructed. As shown, a hose is attached to the Recordall badger meter which is recording the rate of water entering the drain gauge (GPM). The drain gauge is being held up by a variety of random objects creatively placed to keep the gauge upright. Not shown in this image is the CTD-10 sensor which is inside the drain gauge and the Zentra data logger giving me in time readings from the sensor.

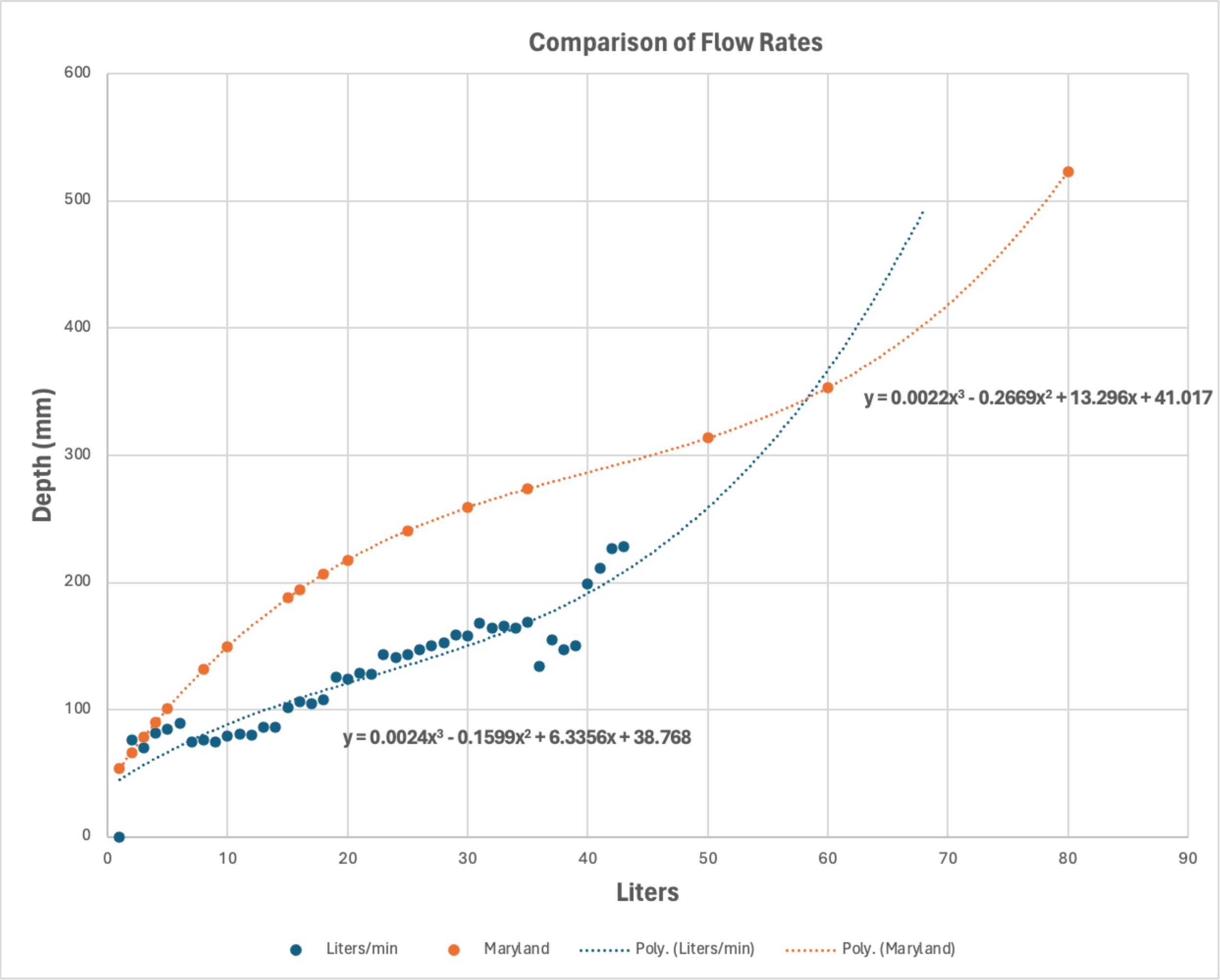

Figure 3: The flow equation, in orange, modeled for the drain gauge made for the US Botanical Gardens (Lea-Cox, 2022) versus the flow equation modeled for the drain gauge I constructed, in blue. On the x-axis is the water volume coming into the system from the hose, through the badger meter, and into the drain gauge (liters). On the y-axis are the recorded depths from the CTD-10 sensor (mm).

Comparing the modeled equations above in Figure 3, my drain gauge model has a smaller rate of flow than the one designed for Maryland. Although my drain gauge was modeled after the Maryland gauge, the relationship of flow is most likely different due to the different pvc fittings used for the bottom of the gauge. The dead spaces between the bottom of the CTD-10 sensor and the fitting could be different lengths, giving my readings a smaller flow rate than the Maryland model. Also, it is unknown what type of depth sensor was used for the Maryland model and how the calibration process occurred. The method I used to calibrate was done using a home hose spicket that could not reach above 45 liters per minute, and reading of the volume from the badger meter was done through personal observations. If the water source I had access to was able to reach up to 80 liters, as the Maryland model did, then the flow equation could look differently. This further demonstrates why each drain gauge needs to be calibrated because the flow equation for the drain gauge can differ depending on how it was designed, built, and tested.

Discussion:

This thesis paper explores a pilot methodology of a drain gauge system I built to calculate stormwater runoff from ecoroofs. What separates this stormwater runoff capturing device apart from other stormwater runoff calculation techniques is its simplistic and inexpensive design, along with the ability to be specialized for any storm drain system in various regions. The methodology used here is based on Portland’s precipitation data and is useful for monitoring the efficiency of ecoroofs in and around Portland but can be applied to any roof system to calculate runoff volumes. Along with allowing stakeholders, developers, engineers, and or researchers to model runoff from ecoroofs, this methodology also supports further research work on ecoroofs. By providing real time data for low impact green designs, this piloting drain gauge also provides an opportunity to connect citizens to science. Lastly, understanding how an ecoroof is functioning is critical to improving stormwater management efforts within densely populated cities. By piloting this device, I hope to increase implementation of ecoroof monitoring devices in Portland, especially since managing stormwater runoff is a complex issue here. In conclusion, this paper introduces a pilot undergraduate research drain gauge device that can be used to effectively monitor ecoroof runoff in Portland, Oregon.

Sources:

33.510 Central City Plan District | Portland.gov. (2024, March 1). https://www.portland.gov/code/33/500s/510

About Combined Sewer Overflows | Portland.gov. (n.d.). Retrieved May 26, 2024, from https://www.portland.gov/bes/about-csos

About the Big Pipe Project | Portland.gov. (n.d.). Retrieved June 7, 2024, from https://www.portland.gov/bes/about-big-pipe

Hodges, C. (2021). Comparing Instruments for Measuring Runoff from Experimental Ecoroof Platforms: A Case Study on Test Plots at Portland State University [Bachelor of Science in Environmental Engineering and University Honors, Portland State University]. https://doi.org/10.15760/honors.1170

Ecoroofs | Portland.gov. (n.d.). Retrieved June 7, 2024, from https://www.portland.gov/bes/stormwater/managing-rain-your-property/ecoroofs

Evolution of Portland Wastewater Treatment | Columbia Boulevard Wastewater Treatment Plant | The City of Portland, Oregon. (n.d.). Retrieved June 7, 2024, from https://www.portlandoregon.gov/bes/article/41962

Guidance on CC2035 Ecoroof Requirements and the Stormwater Management Manual | Portland.gov. (n.d.). Retrieved November 12, 2023, from https://www.portland.gov/bes/stormwater/cc2035-and-swmm

Lea-Cox, J. (2022). Measuring Green Roof Performance of Stormwater Management in Two Different Plant Systems at the US Botanical Garden. *Mid-Atlantic Green Roof Science and Technology Symposium*.

Partnerships | *United States Botanic Garden*. (n.d.). Retrieved June 10, 2024, from https://www.usbg.gov/science-conservation/partnerships

PF Data Server-PFDS/HDSC/OWP. (n.d.). Retrieved September 25, 2023, from https://hdsc.nws.noaa.gov/pfds/

Portland's EcoRoof Requirements. (n.d.). LPDD. Retrieved November 12, 2023, from https://lpdd.org/resources/portlands-ecoroof-requirements/

Portland's Green Infrastructure: Quantifying the Health, Energy and Community Livability Benefits. (n.d.).

Segovia-Cardozo, D. A., Bernal-Basurco, C., & Rodríguez-Sinobas, L. (2023). Tipping Bucket Rain Gauges in Hydrological Research: Summary on Measurement Uncertainties, Calibration, and Error Reduction Strategies. *Sensors (Basel, Switzerland), 23(12), 5385.* https://doi.org/10.3390/s23125385

Shafique, M., Kim, R., & Rafiq, M. (2018). Green roof benefits, opportunities and challenges – A review. *Renewable and Sustainable Energy Reviews, 90, 757–773.* https://doi.org/10.1016/j.rser.2018.04.006

Voyde, E., Fassman, E., & Simcock, R. (2010). Hydrology of an extensive living roof under sub-tropical climate conditions in Auckland, New Zealand. *Journal of Hydrology*, *394*(3), 384–395. https://doi.org/10.1016/j.jhydrol.2010.09.013

Weir—Energy Education. (n.d.). Retrieved June 4, 2024, from https://energyeducation.ca/encyclopedia/Weir