Water-related Ecosystem Services from Green Infrastructure

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Abstract

Green infrastructure is currently in common use to provide water-related ecosystem services. Common applications include: use include bio-retention basins, green roofs, constructed wetlands, permeable pavement, and sidewalk planter. These applications collectively can contribute to a city and region's alternative infrastructure. They help to improve the water quality of streams and drinking water supplies as well as manage and reduce the amount of storm water runoff.

While green infrastructure is increasingly applied, it is not consistently monitored to learn how it performs regarding specific ecosystem services. Ecosystem services are the benefits that people can get from nature ecosystem. In this paper we discuss specific methods and procedures to evaluate the effectiveness of specific ecosystem services related to water quality and quantity.

1. Introduction

The term green infrastructure is appearing more and more frequently in land conservation and land development discussions across the world, and many cities have introduced green infrastructure to manage stormwater, and improve water quality, among other ecosystem services. But there are not exactly answers about how effective green infrastructure is in practice to improve water quality and control water quantity. In this paper, we discuss specific methods and practices to measure how rain gardens, green roofs, bio-swales, bio-retention, constructed wetlands, and permeable pavement clean, infiltrate, evaporate, or reuse storm water on the site. Thus, what to measure and how to measure the success of green infrastructure dealing with water quality improvement and water quantity control become the top priorities of this study.

2. Ecosystem Services and Green Infrastructure

"Ecosystem services can be defined as the benefits we receive from nature: resource services, such as food, water, and energy; regulatory services, such as purification of water, carbon sequestration and climate regulation, waste decomposition and detoxification, crop pollination, and pest and disease control; support services, such as nutrient dispersal and cycling, and seed dispersal; and cultural services, including cultural, intellectual, and spiritual inspiration, recreational experiences, ecotourism, and scientific discovery." (Steiner, 2011) Ecosystem services are important portion of the total contribution of human welfare. Green Infrastructure support such functions and services, which include temperature regulation, energy conservation, water run-off management and flooding control, biodiversity, waste treatment, nutrient cycling, erosion control and sediment retention. The water-related ecosystem services that green infrastructure can provided are water quality improvement and water quantity control. Green infrastructure improves water quality by the processes of sediment removal, nitrogen removal, phosphorous removal, pollution control. And green infrastructure controls water quantity through the processes of stormwater runoff management, stormwater infiltration, and flooding control.

2.1 Water quality improvement

Green infrastructure improves water quality in particularly four ways: sediment removal, nitrogen removal, phosphorous removal, and organic pollution control.

2.1.1 Sediment removal

Sediment that comes from stormwater runoff strong affects the water quality. Green infrastructure remove the sediment by deposit it through the plants. Water turbidity is a good indicator to tell us the quality of water body. Scientists can easily measure turbidity of certain water sample in the laboratory. Alternatively, a handheld turbidity meter help scientist and landscape architects get to know water turbidity in the field. Another indicator related to the sediment removal is the Total Suspend Solids (TSS) of water. By installing sediment trap which is a small instrument bordered by a small beam that captures and collects sediment at the entrance to a bio-retention area, we can easily obtain the TSS of water. Thirdly, water turbidity is usually measured using Secchi disk test. A white and black disk is lowered into the water until the disk is no longer visible; this depth is regarded as the water turbidity depth. Typically, the deeper the disk is, the clearer the water is.

2.1.2 Nitrogen and Phosphorous removal

Stormwater from parking lots, driveways and building roofs usually contains high quantity of nitrogen and phosphorous which will cause significant water pollution problem. Even worse, high concentration of nitrogen and phosphorous lead to eutrophication which dirty water body and decrease dissolved oxygen. As a result, the absence of sufficient oxygen will kill large numbers of aquatic life. Plant roots and soils in the green infrastructure can ease pollution by absorbing nitrogen and phosphorous pollutants through chemical and biological reactions and then the stormwater is cleaned and filtered before infiltrating into the ground.

By measuring the total nitrogen and phosphorous that entering and exiting green infrastructure, the nitrogen and phosphorous removal rates of this system are evaluated. The quantity of aquatic plants like algae, plankton in are also good indicators of nitrogen and phosphorous concentration in Some types of green infrastructure like bio-retention, constructed wetlands, as the more nitrogen and phosphorous concentration, the larger number of those aquatic plants.

2.1.3 Organic Pollution control

Green infrastructure also improve water quality by controlling pollutants such as oil, asphalt pavement, and rubber tires that come from parking lots, roads, and automobiles. These kinds of pollutions will serious contaminate water, and then compact even kill some organisms that living in water. Plants and soils in green infrastructure play an important role in trapping and dissolving those pollutants, and then the stormwater is purified before entering river.

2.2 Water quantity control

Through stormwater management, which includes reduce stormwater runoff and increase stormwater infiltration, green infrastructure control water quantity, and then reduce flooding, and recharge groundwater. Green infrastructure reduces stormwater runoff by directing stormwater runoff to the green structure which contains soils and native plants. Stormwater infiltrates into the ground instead of flowing into the public drain pipe directly. In this way, the water that flow into river is greatly decreased and thus flooding risk is reduced spontaneously. On one hand, plants play an important role in recycling the water because they absorb and keep stormwater as resources for photosynthesis and evapotranspiration. On the other hand, stormwater infiltrates into the soil and recharge the groundwater. Inflow and outflow are two important parameters normally used to measure the change of water quantity in green infrastructure system. By measuring inflow and outflow of a green infrastructure system, we can calculate how much runoff has been reduced.

3. Monitoring of green infrastructure benefits

Monitoring is a process of routinely gathering information on all aspects of the project through the regular observation and recording of activities taking place in a project to check on how project is progressing. Monitoring of green infrastructure benefits can easily be done by installing some related monitors in the green infrastructures and then observation, recording and analyses the records to get the conclusions. Monitoring the ecosystem services benefits of green infrastructure as an opportunity to "learn-by-doing" will help us understand whether green infrastructure benefits or supports water-related ecosystem services (Ahern, 2011). While green infrastructure has been practiced successfully around the world for decades, its monitoring hasn't it been done more regularly. This due to the several reasons: 1) green infrastructure is a new idea and is in the developing process and people still in practice the green infrastructure, 2) monitoring costs time and money and is typically not budgeted into green infrastructure projects, 3) monitoring risks the possibility to disclose poor performance or even failure. If green infrastructure benefits the water-related services has an inherent potential to fail, these monitoring experiments can reduce the risk failure as "safe-to-fail".

4. Types of Green Infrastructure

4.1 Bio-retention basin

Bio-retention basins are open, shallow, constructed depressions planted with native plants and grasses. There are there kinds of bio-retention basins according to the size of bio-retention basins, which include rain gardens, bio-retention, and bio-swale. Water quality management and water quantity control are two basic benefits that bio-retention basins can provide to the ecosystem services. Retention basins are designed to receive runoff from impervious surfaces such as building roofs, sidewalk, driveway, and parking lots. The stormwater of parking lot, driveway, and building roofs contain sediments, oil, as well as chemical pollutants like nitrogen and phosphorous. Bio-retention basins capture this water before it flows into the storm sewer. Bio-retention basins slow down water from these imperious surfaces and hold the water in the shallow depression for a short period of time. They allow the water to slowly filter into the ground, rather than running off into the drain pipe directly and then flow into nearby streams and lakes. Sediments and pollutants settle out of the water and are absorbed by plant roots or treated through chemical processes in the soil.

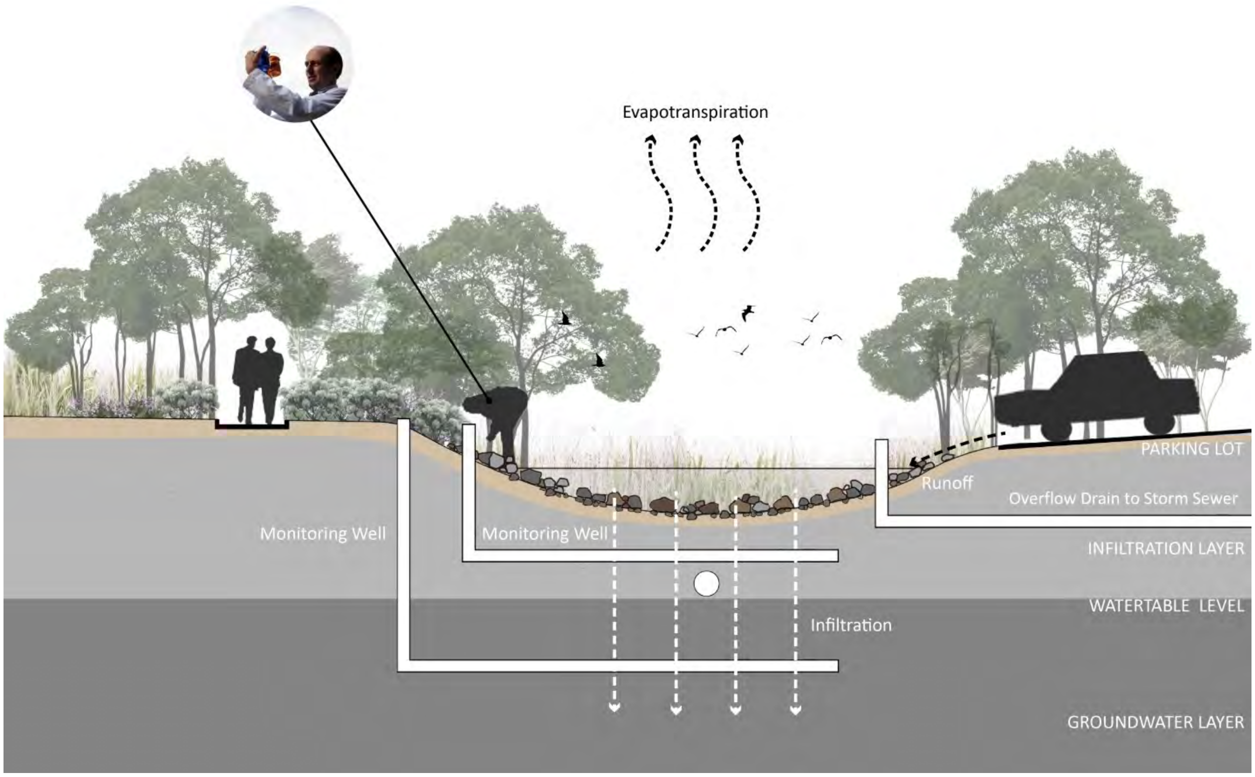

Figure 1. How to include monitoring devices in a typical rain garden

Multiple monitoring wells can be installed under the bio-retention basin: one is in the infiltration layer, the other in the groundwater layer (Figure 1). With these two sampling wells water samples can be collected to measure nutrient/pollutant levels before, and after treatment by subsoil. Samples can be analyzed for nitrogen, phosphorous, and other pollutants in the monitoring well. Water quality improvement can be analyzed by comparing the water quality of stormwater flow into bio-retention basin and the water quality of stormwater that is cleaned and filtered by this system collected in the monitoring well.

V-notch (Figure 2) and flow gauge (Figure3) are two basic tools to measure water quantity. A V-notch is integrated with a check dam/weir which contains scale to monitor the water quantity. In order to evaluate the success of bio-retention basin, this modified V-notch is putted at the outflow of bio-retention basin. Alternatively, the flow gauge can also be used to measure the outflow come from green infrastructure. By comparing the water quantity of stormwater that flow into the green infrastructure and the water quantity of stormwater that is processed by this system, the success of bio-retention is evaluated.

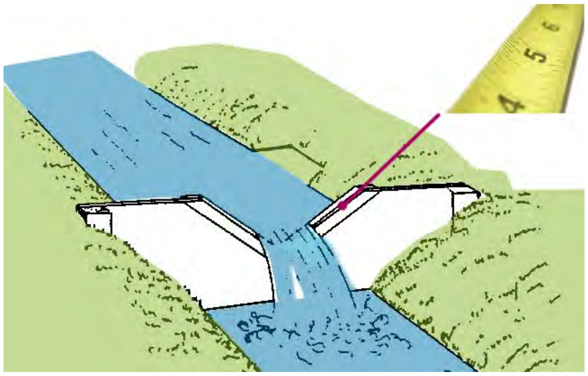

Figure 2. V-notch measure water quantity

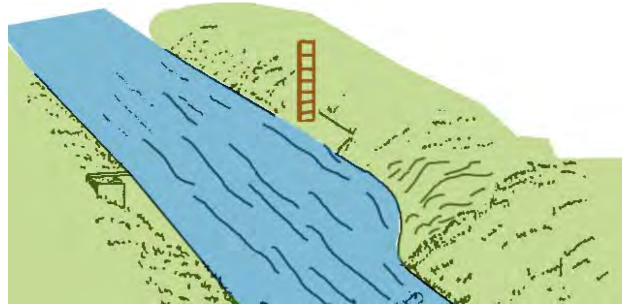

Figure 3. Flow Gauge measure water quantity

4.2 Green roof

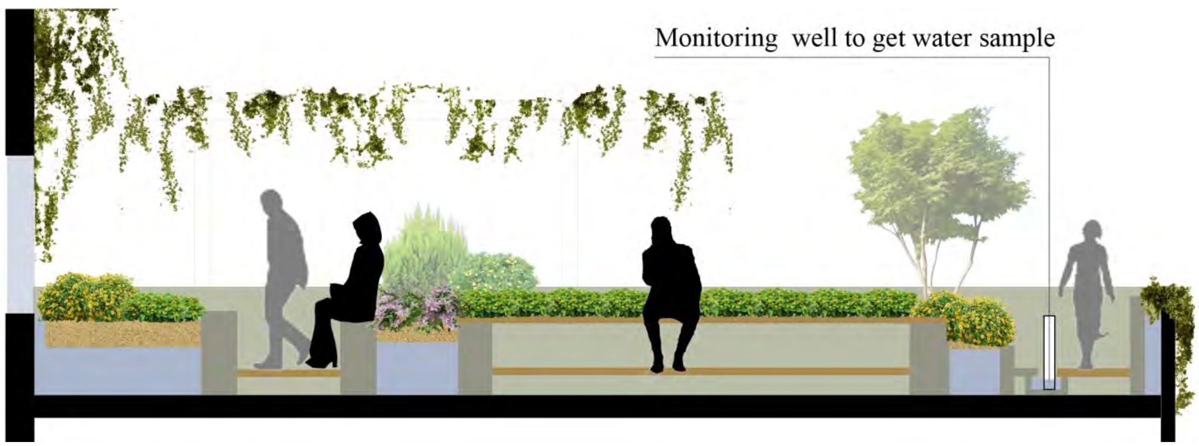

Figure 4. Structure of green roof

Green roofs (Figure 4) a permanent rooftop planting system containing living plants in a light-weight engineered soil medium. Through a variety of biological and chemical processes that filter pollutants, green roofs reduce the amount of pollution delivered to the local drainage system. These processes retain and filter the rainwater not only through the uptake zone of soils and plant roots, but also through foliage that collect dusts, transpire moisture and provide shades. Green roofs are easy to be incorporated into new constructions and can also be built on many existing buildings.

The pollutants in stormwater that run through roofs come from two major ways. One is inherited in the stormwater itself that stormwater formed in pollution air which contain with dust, sulfur, and carbonic oxide, another comes from the grey roofs that contain a lot of pollutant. Compared with the traditional grey roofs, green roofs do not contain so much pollutant, and the plants of the green roof can hold and absorb pollutants. Thus, to test whether the green roofs can improve the water quality or not, we need to compare the water quality that stormwater run through the small sampling green roofs and grey roofs (Figure 5). By evaluating the water quality run through the two different kinds of roofs, we can get the conclusion that whether green roof can improve the water quality or not.

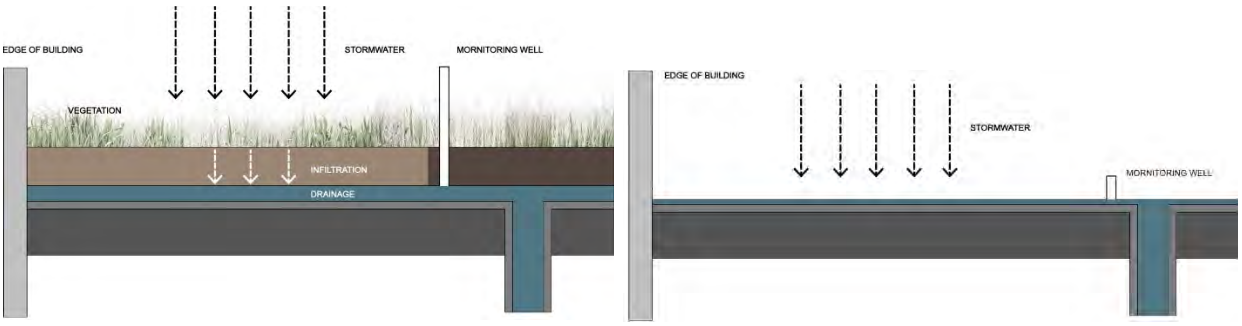

Figure 5. Location to get water sample on green roof and grey roof

To demonstrate that whether the green roofs can control the water quantity, we also need to do the control experiments. First, we need to compare the time that the same amount of water run through the two different kinds of roofs. If the water run through green roofs need more time than the water run through grey roofs, it proves that the green roof can hold the water for a certain time and thus may benefit to reducing the stormwater peak flow and control the water quantity. Secondly, we also need to collect and measure the water volume of water run through these two kinds of roofs. If the quantity of water that run through the green roof less than the stormwater run through the grey roof, we can conclude that green roof is beneficial to controlling stormwater quantity.

4.3 Constructed wetland

A constructed (Figure 6) wetland is an artificial wetland that performs many functions that benefit human and environment. Natural wetlands improve water quality by intercepting surface runoff and removing or retaining inorganic nutrients, processing organic wastes, and reducing suspended sediments before they reach open water, and constructed wetland can be designed to emulate these featured.

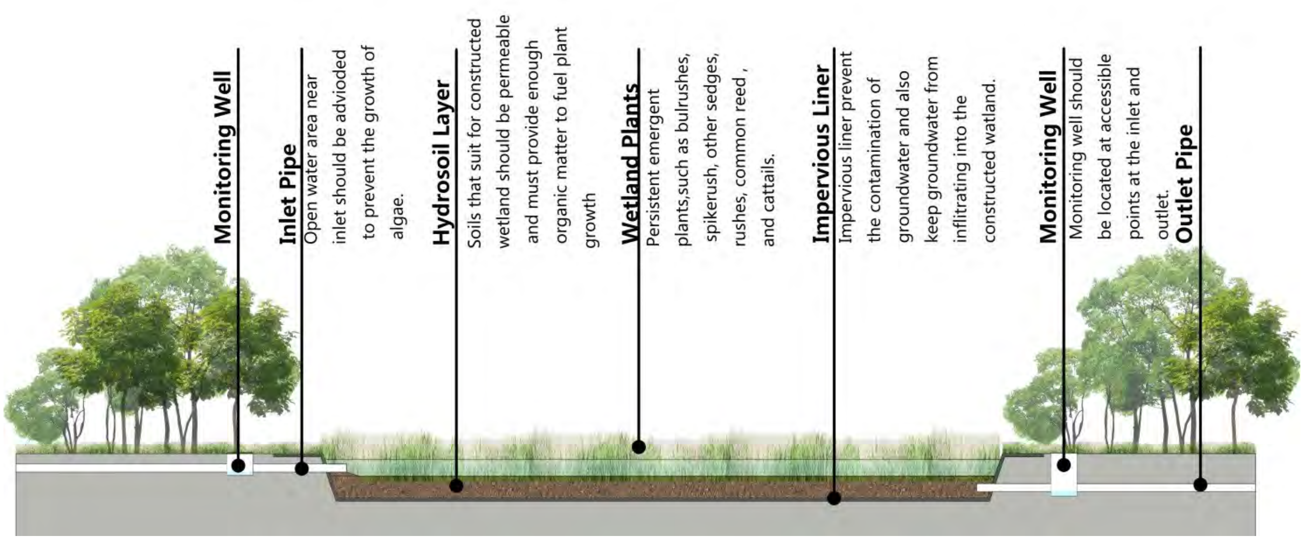

Figure 6. Structure of constructed wetland

Constructed wetland performances are estimated by inflow and outflow rates, and water quality changes between inflow and outflow. The effectiveness of contaminant removal can be determined by the difference between influent loads (inflow volume x contaminant concentration) and effluent loads (discharge volume x contaminant concentration). Monitoring wells are located at the points that near outlet and inlet. Weir boxes are installed to measure the inflow and outflow volumes. (Figure 7) Water samples should be monitored periodically to check the water quality.

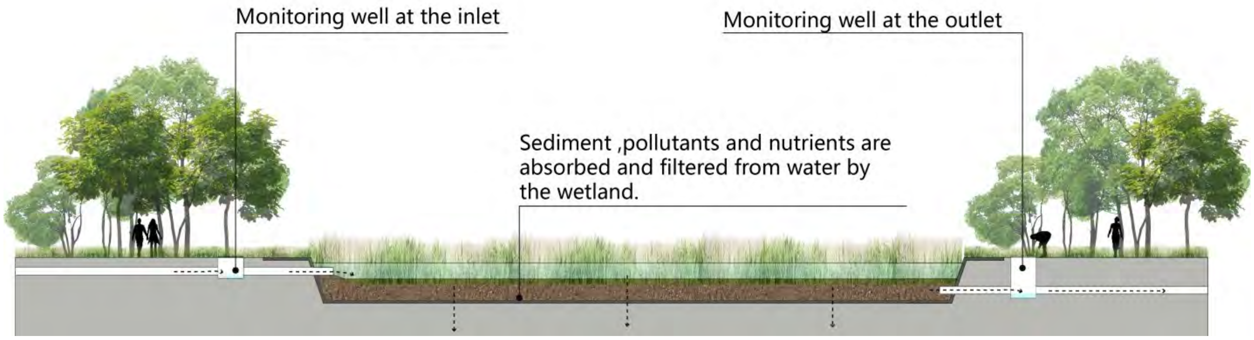

Figure 7. Methods of measuring the effectiveness of constructed wetland

4.4 Permeable pavement

Permeable pavement (Figure 8) is one of the widely used green infrastructure practices, especially in parking lots and driveway. Parking lots are typically sized to accommodate peak traffic usage, which occurs only occasionally, leaving most of the area unused during a majority of the time (Brattebo and Booth, 2003). Permeable pavement systems are commonly made up of a matrix of concrete blocks or a plastic web-type structure with voids filled with sand, gravel, or soil (Booth and Leavitt, 1999). The stormwater is infiltrated through these voids into underlying soil, which can significantly reduce stormwater runoff. In addition to control stormwater runoff, permeable pavement can capture and absorb pollutants.

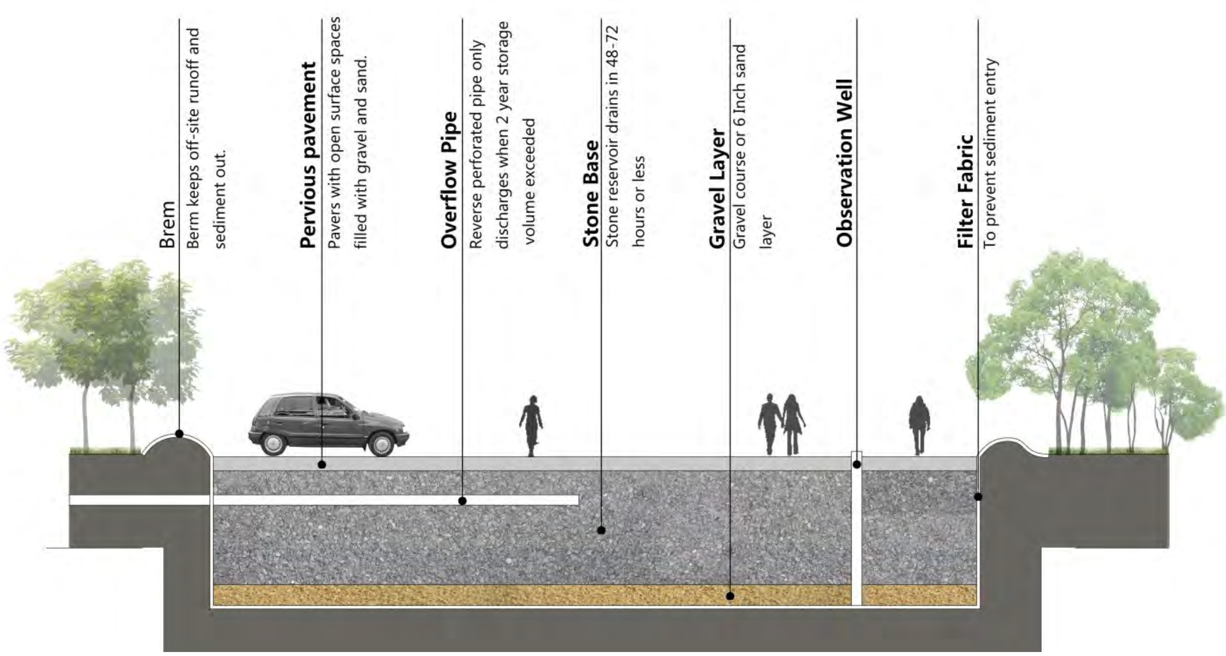

Figure 8. Structure of permeable pavement

Permeable pavement has the filtering capability to keep sediments in place, underlying soils and it also can filter pollutants from water. Turbidity and the total amount of suspended sediment (TTS) are two effective indicators of water quality. By measuring these two indicators can help to estimate the efficiency of water quality improvement provided by the pervious pavement. At first, we install wells (Figure 9) in permeable pavement and impervious pavement, and then we get the water samples from these wells to test the water quality.

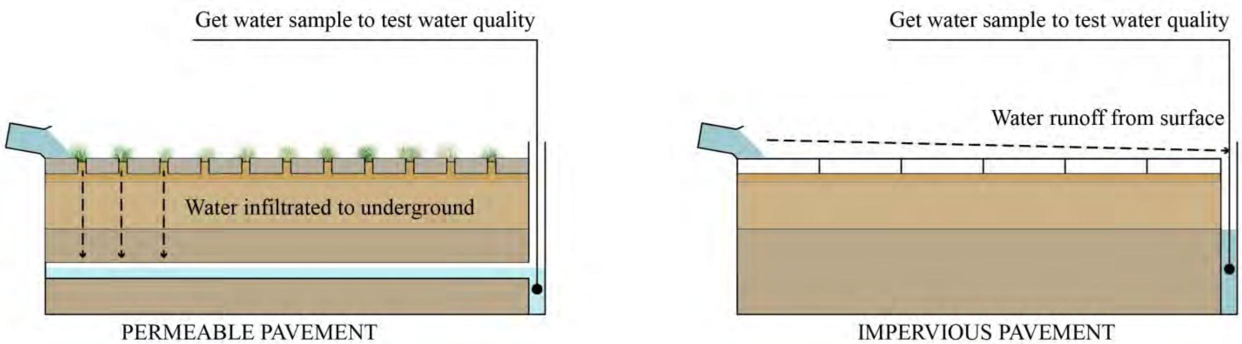

Figure 9. Get water sample to test water quality that runs through permeable pavement and impervious pavement

Permeable pavement allows stormwater to infiltrate into the underlying soils and minimize runoff volumes. By measuring the volume of water runoff in permeable pavement and impervious pavement, we can conclude that whether permeable pavement can help us reduce stromwater runoff. To test this, we also need to install wells in permeable pavement and impervious pavement (Figure 10). Then we measure the volume of water in these two wells that stormwater runoff and get the conclusion that whether permeable can help us reduce stormwater runoff.

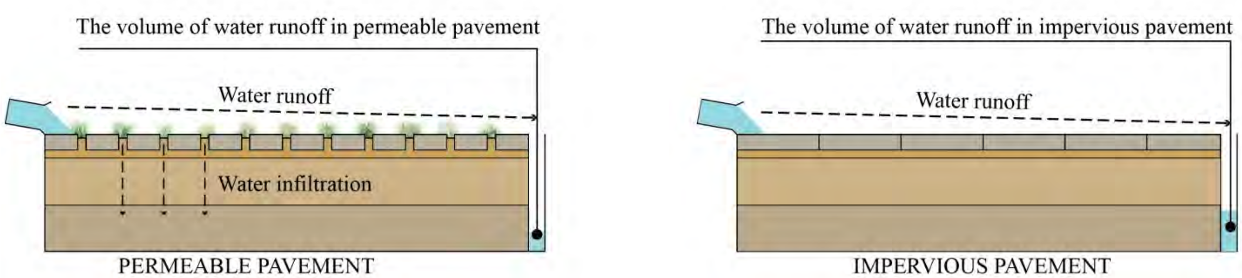

Figure 10. Get water sample to test stormwater runoff in permeable pavement and impervious pavement

5. Conclusion

Green infrastructure is a great opportunity in urban city and is smart conservation that addresses the ecology and the fragmentation of open land (Mark A. Benedict and Edward T. McMahon). The hydrology in urban area often fails with respect to other landscape or ecological functions stable stream flow, flood protection, groundwater recharge and infiltration. Thus, we need to use the green infrastructure to turn the problems that brought to us into opportunities and do it from right now (Nelson, A.C, 2004). This strategy is not only important to the developed cities that need innovation, but also relevant to the unprecedented period of economic growth and urban development area.

The value of water-related ecosystem services that green infrastructure provided will solve many serious problems that urbanization has brought. Of cause, whether green infrastructure will improve water quality and water quantity needs to be tested by designing multiple monitoring devices in green infrastructure system, monitor the changes of water quality and quantity in this system. Scientific methods and devices will be used to test the sampling water and the results will tell us whether green infrastructure system works or not. Through the process of leaning-by-doing, we will reduce the risk of failure, that is, safe to fail. Thus, to understand how green infrastructure works to improve water quality and quantity is quite profound for sustainable development.

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