Evaluating the Potential for Stormwater Collection, Treatment and Reuse by Green Infrastructure in NYC

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Abstract

Due to rapid population growth, human behavior and climate change, there is significant strain on the available water resources worldwide. In areas with inadequate water supplies, water reuse has attracted a lot of attention. Even wastewater which needs much more treatment process is considered as a source of water. The stormwater and precipitation have a higher quality and can be used for some purposes like lawn irrigation even without treatment. The rainwater harvesting system (RWHS) has great potential to improve surface and groundwater resources because reusing this source of water not only needs less treatment than wastewater but also in areas with high precipitation rate managing it is mandatory to protect infrastructure. So, the extra processes for treatment and reusing the harvested storm water seems reasonable. This study aims to examine the available and practical methods to collect stormwater and treatment processes and the feasibility of these methods for NYC.

Introduction

In addition to the benefits that urbanization has brought to us in terms of social and economic development, as a global trend it has drastically altered the environment and the hydrology of our living space. Urban areas have a rising percentage of impermeable surfaces, which causes more surface runoff and, as a result, a larger risk of flooding during rainy seasons, while due to climate change the frequency and severity of rainfall events throughout many regions has increased(Feng et al., 2022).

Stormwater runoff presents many risks to the environment and communities. As stormwater runoff passes over impermeable surfaces like highways and parking lots, it may collect contaminants like oil, fertilizers, pesticides, and germs. These contaminants may enter rivers, streams, and other bodies of water without effective management, lowering the quality of the water and endangering aquatic life (Müller et al., 2020). Reducing the demand for irrigation and other water-intensive activities by collecting and storing stormwater for later use is a wisely management idea. Reducing the risk of flooding in urban and suburban regions is possible with proper stormwater management and runoff control. Stormwater runoff can be captured and stored so that it can be released more gradually, lowering the volume of water entering rivers and other bodies of water and, ultimately, lowering the danger of floods. More important, it could be a good and reliable resource for water supply by implementing proper treatment processes(Prudencio & Null, 2018).

Effective stormwater management can contribute to enhancing the look of landscapes and aesthetics and property values while preventing erosion and flood risk. Stormwater can be handled in an aesthetically beautiful and environmentally responsible manner by including green infrastructure such as rain gardens, bioswales, and permeable pavement.

Alternative stormwater management practices have several terms, including best management practices, green infrastructure, low-impact development, managed aquifer recharge, and stormwater harvesting. Different studies investigated different methods for stormwater management and rainwater harvesting. The characteristics of the land area, rainfall patterns, the space available for the stormwater control measures, and regulatory criteria, goals, and crediting for stormwater management and treatment will all be important factors in the selection and design of control devices. Costs, safety, and aesthetics are some more considerations. Local geologic variables, such as high-water tables and karst underlying soils, may regulate the control method and device selection. Inlets, bypasses, pretreatment, and proprietary devices are part of the urban stormwater control measure toolbox (*Https://Www.Epa.Gov/.*, n.d.).

- The green roof is one of the methods made to collect and keep some rainwater for subsequent removal through evaporation and transpiration, as well as the gradual release of any overflows. Land is expensive and room is scarce in densely developed places like New York City. One of the few alternatives to limit the amount of stormwater produced is managing stormwater on rooftops. The possibility of converting the collected stormwater to a reliable source of potable water seems so tempting. This may offer benefits for stormwater management, but it may also offer a source of water that can lessen the need for potable water, perhaps providing a financial incentive. Normally, rooftops are used to collect water for harvesting, although other sources may be used based on demand. A rainwater collection system, a storage container, and a delivery/drainage system are necessities for rainwater harvesting as promising technology for future utilization. In some cases, the most beneficial use of stormwater may simply be to recharge natural surface or groundwater systems. Also, the harvested rainwater can be used for vehicle washing, irrigation, Indoor toilet flushing, laundry, drinking. Depending on the usage the appropriate treatment should be implemented.
- As the name implies, permeable pavement is a type of pavement including different layers that allows water to permeate rather than run off. Practically the same principles govern all varieties of permeable pavement. Flow typically has one dimension and raindrops traverse the

permeable pavement vertically. Five types of permeable pavements are commonly used, Permeable Asphalt (PA), Permeable Concrete (PC), Permeable Interlocking Concrete Pavers (PICP), Concrete Grid Pavers (CGP), and Plastic Grid Pavers (PG).

- Infiltration trenches and infiltration basins are two other stormwater control measures that are made with a porous bottom and sides to facilitate the infiltration of the stored water into the surrounding soils as surface or subsurface storage places. Successful infiltration will lead to groundwater recharge and reduction of surface runoff. The use of these systems for stormwater management is limited to areas where the local soil will allow some reasonable degree of infiltration. Sand filters have a similar mechanism to filter runoff to remove particulate matter, but the difference with infiltration trenches and basins is an impervious bottom that does not permit water percolation into surrounding soils. Therefore, hydrologic impacts from sand filters are minor, as no volume reduction will occur, except through evaporation from the media between storm events. Sand filters often remove particulate materials quite effectively. However, the removal of dissolved pollutants is typically poor.
- Another vegetative infiltration/filtration stormwater control method is called bioretention that when properly designed, constructed, and maintained, it will have a considerable impact on lowering peak volume and erosive flow rates, restoring evapotranspiration and recharge, and enhancing water quality. Bioretention is the process in which contaminants and sedimentation are removed from stormwater runoff. The main objective of the bioretention cell is to attenuate peak runoff as well as to remove stormwater runoff pollutants. The fundamental design of bioretention consists of a layer of vegetated media and a shallow bowl for runoff storage. A simple example of this method is a rain garden which is a small facility, usually at the scale that can be built by a homeowner on a residential lot (Jalali & Rabotyagov, 2020).
- Swales and filter strips are examples of planted stormwater control measures (SCMs) used for stormwater transport and treatment. Swales are linear systems with concentrated flow, and transportation plays a significant part in their application. Filter strips must handle sheet flow, which is frequent in parking lots and along roadways. In other applications, level spreaders—long, flat weirs intended to supply sheet flow to the filter strip—are used in conjunction with filter strips to deliver filtration. Due to their compatibility with linear infrastructure, swales and filter strips are both frequently used to treat runoff from highways (Ekka et al., 2021).
- The last stormwater control measures are stormwater wetlands which are available in a wide range of sizes and functional traits. They have several benefits, including excellent management

of both stormwater hydrology and water quality. However, they frequently have a big footprint and are required to keep a permanent shallow pool. Different types of stormwater wetlands are defined, including shallow wetlands, extended detention shallow wetlands, pond/wetland systems, submerged gravel wetlands (SGWs), and pocket wetlands.

As it can be seen there are a wide variety of stormwater control measures and the selection for a given application will depend on different elements and criteria (*Green Stormwater Infrastructure Fundamentals and Design*, n.d.). These include costs, site features, goals for stormwater control and land availability. Knowing that factors like goals, costs, and climate may change in the future, the ideal SCM will enable the highest advantages while minimizing present and future expenditures.

The primary goal of managing rainfall is frequently averting floods, and collected stormwater is not managed to reuse it or turn it into a useful water source. Although drought is anticipated to be a problem in many locations in future, reusing this water can be a promising approach. The mentioned methods have been studied in different locations and the quality of the collected water depending on the method and location is different. Although pathogen and bacteria examination seem reasonable according to the studies they are below the limitations and the parameters for stormwater quality assessment can be as below (Erickson et al., 2013; Goonetilleke & Lampard, 2018):

- Total suspended solids (TSS)
- Total P
- Dissolved phosphorus (DP)
- Particulate phosphorus (TP)
- Total N
- Total Kjeldahl nitrogen (TKN)
- Nitrate/Nitrite ($NO3^-$/$NO2^-$)
- Total zinc
- Total copper
- Dissolved copper (DC)
- Total lead
- Chloride
- Hydrocarbons
- Temperature

Although certain modifications to stormwater control measures can create multiple unit processes and enhance the pollutant removal, depending on the expected usage of harvested rainwater these mentioned method can be enough or need more advanced treatment processes. One of the most important strategies for reducing the shortage of water resources is the reuse of urban stormwater. With the growth in the population, which increases water stress, the demand for stormwater reuse has become more and more important (Goonetilleke & Lampard, 2018; Thomas et al., 2014). Rather than being absorbed naturally into the ground, much of New York City's stormwater eventually flows into storm drains or catch basins, and from there into the Sewer System. About 60% of New York City has a combined sewer system. In a combined sewer system, there is a single pipe that carries both stormwater runoff and sewage from buildings. This mix of stormwater and sewage is usually sent to a wastewater treatment plan. During the dry weather combined sewers system works well but during heavy rainstorms, it receives higher than normal flows. Treatment plants are unable to handle flows that are more than twice the design capacity. When this occurs, a mix of stormwater and untreated sewage discharges directly into the City's waterways. These events are called combined sewer overflows (CSOs). We are concerned about CSOs because of their effect on water quality and the recreational use of local water bodies. In recent years municipal separate storm sewer system (MS4) as a publicly owned conveyance or system of conveyances (including but not limited to streets, ditches, catch basins, curbs, gutters, and storm drains) is designed or used for collecting or conveying stormwater and discharges to surface waters of the State. Separate storm sewers carry stormwater runoff directly to local waterbodies. Although MS4 has a lot of benefits, there are comments like: "Stormwater picks up contaminants like oils, chemicals, germs, and sediments as it travels over streets and other impermeable surfaces. This pollution is transported by stormwater and dumped directly into nearby waterways in separate sewer districts. The water quality and recreational uses may suffer as a result." For addressing these issues and even more and more benefits the idea of treating the collected storm water and reusing it brings promising results (*Https://Www.Nyc.Gov/*, n.d.). By implementing sustainable stormwater management practices, we can reduce the strain on our municipal water supply, enhance local water resources, and improve overall water quality. Additionally, treating stormwater can create opportunities for alternative water use, such as irrigation, industrial processes, and even recreational activities. Overall, investing in stormwater treatment and reuse is a promising solution for promoting a more sustainable and resilient water system (Feng et al., 2022).

Rainwater usually contains chloride, nitrate, and sulfate anions, whereas phosphate and nitrite anions were less prevalent. Chloride concentrations correlate with proximity to oceans, which are rich in salt.

Levels are also dependent on geographic location, as well as altitude, the amount of rainfall, and distance from the source of the rain (usually an ocean).

the VWM concentration abundance order of major ions was Cl^- > Na^+ > SO_4^{2-} > Ca^{2+} > H^+ > NH_4^+ > NO_3^- > Mg^{2+} > HCO_3^- > K^+. The dominance of chloride and sodium was mainly observed near the coastline, suggesting the presence of sea salts in the rainwater, exhibiting maximum values in Channel Islands, California. , exhibiting maximum values in Channel Islands, California (153.67 μeq L^{-1}– Cl^-; 136.03 μeq L^{-1}-Na^+)and Nantucket, Massachusetts (155.93 μeq L^{-1}-Cl^-, ; 128.28 μeq L^{-1}-Na^+) The presence of Ca^{2+} and Mg^{2+} in precipitation shows the influence of terrestrial sources, such as the dissolution of dolomites and limestones but calcium can be originating from anthropogenic activities too, such as open quarries, cement factories, while magnesium can also be a attributed to marine sources. The highest VWM concentrations for Ca^{2+} and Mg^{2+} were found in Green River, Utah (66.09 μeq L^{-1}) (Keresztesi et al., 2020).

By focusing on a small sample area like Sheep Meadow in Central Park, we hope to develop strategies that can be applied more broadly throughout Manhattan to reduce runoff and the wastewater treatment plant’s load and improve sustainability. Same adaptations have been done in different states in the US like Cromwell Park in Shoreline, Washington, Herron Park Philadelphia, Pennsylvania, Historic Fourth Ward Park in Atlanta, Georgia, and an outstanding example of reuse practices is Sun Valley Park in Los Angeles County, California, was converted to a multi-use site that reduces flooding, treats stormwater, and conserves water while continuing to provide recreational benefits. The Sun Valley Park collects runoff from a 21-acre drainage area. The stormwater is piped into a treatment system to remove pollutants. Treated water then flows to infiltration basins located underground beneath the soccer and baseball fields to recharge the groundwater aquifer.

The aim of this study is to tackle the issue of stormwater runoff management in Manhattan by exploring the potential implementation of green infrastructure and rainwater harvesting facilities in Central Park. Previous practices have already converted various facilities, such as tennis courts and pavements, into green infrastructure. However, numerous studies confirm that bioretention practices have demonstrated satisfactory results in terms of both infiltration and evapotranspiration mechanisms, with increasing beneficial use (Ekka et al., 2021; Vijayaraghavan et al., 2021).

Rain gardens are also known as bioretention systems as they provide biological treatment of stormwater using plants and microorganisms. The diversity of vegetation plays an important role in both hydrologic and treatment performance of rain gardens. Stormwater treatment is also attributed to several other processes such as adsorption, ion exchange, and plant uptake. Stormwater tree pits are an alternative approach to the traditional practice of planting street trees, enabling stormwater treatment and infiltration. Like rain gardens, tree pits are also referred to as bioretention systems as stormwater management involves filtration, detention, and biological uptake. Therefore, the selection of trees is critical for the performance of tree pits and should consider soil type and other site-specific conditions. This approach can be incorporated in new constructions, re-developments, and for retrofitting. The treatment performance can be improved by connecting with other WSUD devices such as pervious pavements. Frequent maintenance of these devices is necessary for litter and sediment removal.

Bioretention basins are WSUD devices that primarily treat stormwater pollutants such as nutrients through the combined effect of a surface layer of vegetation and filter media. The main purpose of vegetation is to maintain the porosity and high permeability of the treatment matrix and provide a carbon source for denitrification reactions. The surface layer is used as a detention zone, where stormwater is detained, allowing infiltration into and percolation through the filter media. The layers underlying the vegetation typically consist of filter media (coarse sand/fine gravel), a transition layer, and a drainage layer surrounding a perforated underdrain pipe. In the case where fine gravel is used as filter media, a transition layer is introduced between filter media and drainage layer, preventing the migration of fine material into the bottom layers. Bioretention basins also have the potential to control stormwater runoff quantity. This depends on the porosity, the soil moisture characteristics (available water capacity), and the pre-storm moisture content of the filter media. This latter value is influenced by the length of the antecedent dry period and transpiration potential of the vegetation. Longer dry periods and plant species suitable for dry weather conditions reduce the moisture content, increase the soil water deficit, and consequently, the filtration and detention/retention time.

Once installed, the filter media needs to be kept permeable to maintain satisfactory performance. Therefore, timely replacement of the filter media is necessary. This will prevent clogging due to sediment and flushing and leaching of native materials (filter media) and previously accumulated pollutants.

Swales are constructed as a pretreatment device for downstream structures of a treatment train, primarily focusing on improving stormwater quality with limited flow control through detention. The vegetated top layer of a swale initially removes the coarser fraction of particulate solids in stormwater runoff. As the runoff enters the bioretention component, which is a layered filter media of soil, sand,

and gravel layers, several treatment mechanisms such as filtration, infiltration, adsorption, and biological uptake are involved. The treatment capacity of vegetated/bioretention swales depends on the longitudinal slope (controls the flow velocity and avoids erosion of swale surface); species type and height of the vegetation; filter media; and cross-sectional area of the swale (controls the detention time). In biofilters/bioretention basins, rain gardens and tree pits target pollutants are Litter and sediments, Toxicants, Nutrients, and Microorganisms (Goonetilleke & Lampard, 2018).

Bioretention is a versatile solution for designers, as it can be customized to meet the specific needs of clients. This section outlines key design considerations for constructing bioretention systems and explores the potential for combining them with other stormwater control measures, such as permeable pavements. Before embarking on the design of a bioretention system, practical questions must be addressed, including site requirements, the characteristics of the runoff to be treated, and the expected water quality and quantity outcomes. Additionally, it's important to determine whether the bioretention system will be used alone or in conjunction with other stormwater control measures. To effectively collect runoff from impervious surfaces, the bioretention basin should be strategically positioned. Ideally, it should be located in a slightly depressed area where the seasonal high-water table is within 1.22 meters of the media bottom. If such a depression is unavailable, the flat site must be engineered accordingly. For soils with high permeability, it's best to create a downstream depression in a flat area to capture runoff from the impermeable surface. However, for soils with low permeability, excavation of the area beneath the bioretention basin (to a depth of 0.61-1.22 meters) may be necessary, with a good permeable mixture filling the excavated area and an underdrain system installed.

According to previous studies a depth of 0.229-0.305 meters is capable of capturing runoff up to 15.2 centimeters from an impervious area. Assuming 2.54 centimeters of rainfall on an impervious area with a runoff curve number of 98 results in 2 centimeters of runoff, the excavated bioretention basin with a 15.2-centimeter storage depth is expected to store 7.6 times more runoff from a similar impermeable area. Thus, a 1619 square meter bioretention cell can receive runoff from 3 impermeable areas. Additionally, the impermeable area can be adjusted by changing the storage depth of the bioretention area to handle the first flush ratio. In case of rainfall exceeding 2.54 centimeters, excess runoff beyond the first flush is either diverted or allowed to percolate through the bioretention system. Excess water can leave the bioretention cell from different areas, including the back end of the system. It's important to designate an overflow area for this runoff. Small-scale bioretention cells can use turf reinforcement mats or rocks for the runoff to overflow into designated areas. Alternatively, commercial bioretention cells can have an overflow riser pipe installed, generally set at the preferred maximum water depth of 15.2 centimeters, to enable exit of additional runoff. When designing and implementing a bioretention system, it is crucial to consider the type and characteristics of the runoff that will enter the system. If the runoff is expected to have high levels of suspended sediment, it is recommended to incorporate vegetated buffer strips, such as grass, to enable force sheet flow. This will allow some sediment to be trapped and retained by the vegetation, resulting in cleaner runoff entering the bioretention cell. In situations where the runoff is flowing from a pipe or ditch, it is not advisable to allow concentrated flow directly into the bioretention cell. Instead, it is necessary to use a level spreader to evenly distribute the flow and dissipate the energy before entering the bioretention system. This will help to optimize the performance of the bioretention system by reducing pollutant levels and managing the volume of runoff (Vijayaraghavan et al., 2021).

As with all stormwater treatment practices, bioretention practices require regular maintenance if they are to remain effective. The required frequency of inspection and maintenance is dependent on the watershed land use (e.g., urban, rural, and farm, among others), construction in the watershed, and rainfall amounts and intensity. Visual inspection and any associated maintenance should be performed at least once per year. Additional recommended maintenance includes annual inspection for sediment accumulation and removal, if necessary. If any level of assessment reveals that a bioretention practice is not adequately infiltrating runoff, the following steps should be taken: 1. Replacement of mulch, if present, and the top layer of material. 2. If the previous step does not correct the situation, the entire practice may need to be replaced (Erickson et al., 2013).

Method

In this study, we have chosen to investigate the implementation of this system in the Sheep Meadow area of Central Park to determine its effectiveness. Using the National Stormwater Calculator by the EPA, we can evaluate the outcomes of different treatment systems that can bring the stormwater back to the water cycle instead of being discharged into water bodies through the Municipal Separate Storm Sewer System (MS4) or sent to the wastewater treatment plant. By collecting data on runoff, climate change, soil characteristics, and future climate of NYC, we went through the steps and have calculated the following data.

The National Stormwater Calculator is a user-friendly tool that can be utilized to calculate small site hydrology for any location in the United States. It estimates the quantity of stormwater runoff produced by a site under varying development and control circumstances during a long-term period of historical rainfall. The analysis considers factors such as local soil conditions, slope, land cover, and meteorology. To help collect and preserve rainfall on-site, various types of low impact development (LID) practices, also known as green infrastructure, can be applied. Furthermore, internationally recognized climate change projections can be considered to evaluate future climate change scenarios. The calculator provides rough estimates of the capital and maintenance costs of LID controls, allowing planners and managers to evaluate and compare their effectiveness and expenses. The calculator uses the EPA Storm Water Management Model (SWMM) as its computational engine SWMM is a well-established, EPA developed model that has seen continuous use and periodic updates for 40 years.

The various pages of the calculator are used as follows:

1. The location page is the first step, allowing users to establish the site's location and pin it on a map. Users can enter the location manually if the exact longitude and latitude are not available. The selected location in this study is Sheep Meadow with a 10 acers area.

2. Soil Type page identifies the site's soil type. Soil type is represented by its Hydrologic Soil Group (HSG). This is a classification used by soil scientists to characterize the physical nature and runoff potential of a soil. The calculator uses a site's soil group to infer its infiltration properties. Below the list of the definitions of the different soil groups is available:

- Group A: Low runoff potential. Soils have high infiltration rates even when thoroughly wetted and consisting chiefly of deep, well to excessively drained sands or gravels. (Saturated Hydraulic Conductivity (in/hr) ≥ 0.45)
- Group B: Moderate low. Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to well-drained soils with moderately fine to moderately coarse textures. E.g., shallow loess, sandy loam. (Saturated Hydraulic Conductivity (in/hr)= 0.30-0.15)
- Group C: Moderate high. Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine textures. E.g., clay loams, shallow sandy loam. (Saturated Hydraulic Conductivity (in/hr)= 0.15-0.05)

- Group D: High runoff potential. Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high-water table, soils with a clay-pan or clay layer at or near the surface, and shallow soils over nearly impervious material. (Saturated Hydraulic Conductivity (in/hr) = 0.05-0.00)

By retrieving a soil map overlay from the U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS) SSURGO database the examined location in this study belongs to group C (*Http://Soils.Usda.Gov/Survey/Geography/Ssurgo/*, n.d.)

3. Soil Drainage page that specifies how quickly the site's soil drains. This rate, known as the "saturated hydraulic conductivity," is arguably the most significant parameter in determining how much rainfall can be infiltrated. According to the location software suggested 0.4 inches/hour and due to lack of available scientific study in this location and field measurements we rely on this given data.

4. Topography page characterizes the site's surface topography. Site topography, as measured by surface slope (feet of drop per 100 feet of length), affects how fast excess stormwater runs off a site. Flatter slopes result in slower runoff rates and provide more time for rainfall to infiltrate into the soil. Runoff rates are less sensitive to moderate variations in slope. Therefore, the calculator uses only four categories of slope.

- Flat (2% Slope)
- Moderately flat (5% Slope)
- Moderately steep (10% Slope)
- Steep (above 15% Slope)

As with soil type and drainage rate, any available SSURGO slope data will be displayed on the map if the View Soil Survey checkbox is selected the resulting display as a guide can be used. Using local knowledge and observation site's topography is flat and belongs to the first category, confirming the result shown by software.

5. Precipitation page by providing nearby rain gage to supply hourly rainfall data gives a good estimation of the location's data. Rainfall is the principal driving force that produces runoff. To ensure that the calculator can replicate the full range of possible storm events, it uses a long-term, continuous hourly rainfall record. Furthermore, the calculator identifies a series of 24-hour extreme event storms linked to

each rain gage location. The calculator will automatically locate the five nearest gages to the site and list their location, period of record and average annual rainfall amount. Fortunately, Central Park is listed as a station with 49.36 inches average annual precipitation recorded from 1970 to 2006.

6. Evaporation page selects a nearby weather station to supply evaporation rates. Evaporation determines how quickly the moisture retention capacity of surfaces and depression storage consumed during one storm event will be restored before the next event. The calculator will automatically locate the five nearest stations to the site and list their location, period of record and average daily evaporation rate (the average of the twelve-monthly rates). Again, Central Park is listed as a station with 0.2 inches/day average evaporation rate recorded from 1970 to 2006.

7. Climate Change page selects a climate change scenario to apply. Each choice of climate change scenario and projection year produces a different percent change in monthly average rainfall, monthly average temperature, and annual maximum day precipitation for each rain gage location and weather station in the calculator's database. The precipitation changes for the current choice of rain gage are shown in the right-hand panel of the Climate Change page which is shown in Figure*. These changes are used to adjust the historical meteorological records for the site as follows:

- The changes in monthly average rainfall are applied as a multiplier to each historical hourly rainfall reading that occurred in the particular month for each year of record.
- The changes in monthly average temperatures are applied in similar fashion to the historical daily temperature records used to calculate an average daily evaporation rate for each month of the year.
- Climate change influenced extreme event rainfalls are used in place of the historical ones.

The hot/dry, median, and warm/wet scenarios can be used to better understand the uncertainty associated with future climate projections. According to the report from Columbia University NYC will experience stronger and more intense precipitations and hotter summers. So, we choose warm/wet option as the projected scenario for our location and apply it for a short-term period (2020-2049) (*Https://News.Climate.Columbia.Edu/2019/04/26/New-York-City-Preparing-Climate-Change/*, n.d.).

8. Land Cover page specifies the site's land cover for the scenario being analyzed. It is used to describe the different types of pervious land cover on the site. Rainwater can only penetrate the ground through surfaces that allow water to pass through. The quantity of rainwater that is collected varies depending on the type of permeable surface, such as vegetation or natural indentations, and the level of surface

roughness. Surfaces with a rougher texture tend to decelerate the flow of runoff water, giving it more time to seep into the ground. The percentage of

- Forest – stands of trees with adequate brush and forested litter cover.
- Meadow – non-forested natural areas, scrub, and shrub rural vegetation
- Lawn – sod lawn, grass, and landscaped vegetation
- Desert – undeveloped land in arid regions with saltbush, mesquite, and cactus vegetation
- Impervious – artificial structures such as pavements (roads, sidewalks, driveways, and parking lots, …) that are covered by water-resistant materials like asphalt, brick, concrete, stone, …

As it is named Sheep Meadow it is 100% meadow.

9. LID Controls page selects a set of LID control options, along with their design features, to deploy within the site and specifies site and project considerations for cost estimation purposes. There are seven different types of green infrastructure (GI) LID controls available that can be elected to apply any mix of these LID controls by simply telling the calculator what percentage of the impervious area is treated by each type of control. Each control has been assigned a reasonable set of design parameters, but these can be modified by clicking on the name of the control. You have the option to specify a 24-hour design storm to assist you with sizing the selected LID controls. For the purposes of cost estimation, the calculator factors in the cost implications of construction feasibility and site suitability and adjusts the cost of the LID Controls based on regional cost differences associated with a site's location. As in previous pages we chose 100% meadow and no impervious area, in this page we should skip the first part. By indicating whether the project is new- or re-development and selecting from poor, moderate, or excellent for site suitability for placing LID controls along with other user input information, the calculator computes and applies the appropriate cost curve for the project. The project is a new development and by the figurative definition that software provides the site suitability is excellent. Regional cost multipliers for each Region are selected as the default multiplier for areas within a 100-mile radius of the regional center. Areas that are not within a 100-mile radius of any regional center are assigned a default National value of 1. I override the default selection by selecting the first option of the closest regions to my location from the Cost Region drop down menu which was New York with a 4-mile distance. Regional cost multipliers that are greater than 1 increase costs, while multipliers that are less than 1 decrease costs compared to the National average.

10. Results page runs a long-term hydrologic analysis and displays the results including estimates of capital and maintenance costs. The input controls on this page are grouped together in three sections: Options, Actions, and Reports.

The Options section allows you to control how the rainfall record is analyzed via the following settings:

- The number of years of rainfall record to use which we chose 20 years (moving back from the most recent year on record).
- The event threshold, which is the minimum amount of rainfall (or runoff) that must occur over a day for that day to be counted as having rainfall (or runoff). Rainfall (or runoff) above this threshold is referred to as "observable" or "measurable". The limitation we applied is 0.1 inches.
- The choice to ignore consecutive wet days when compiling runoff statistics (i.e., a day with measurable rainfall must be preceded by at least two days with no rainfall for it to be counted). We checked this box to make the calculations more accurate.

The Actions section of the page contains commands that perform the following actions:

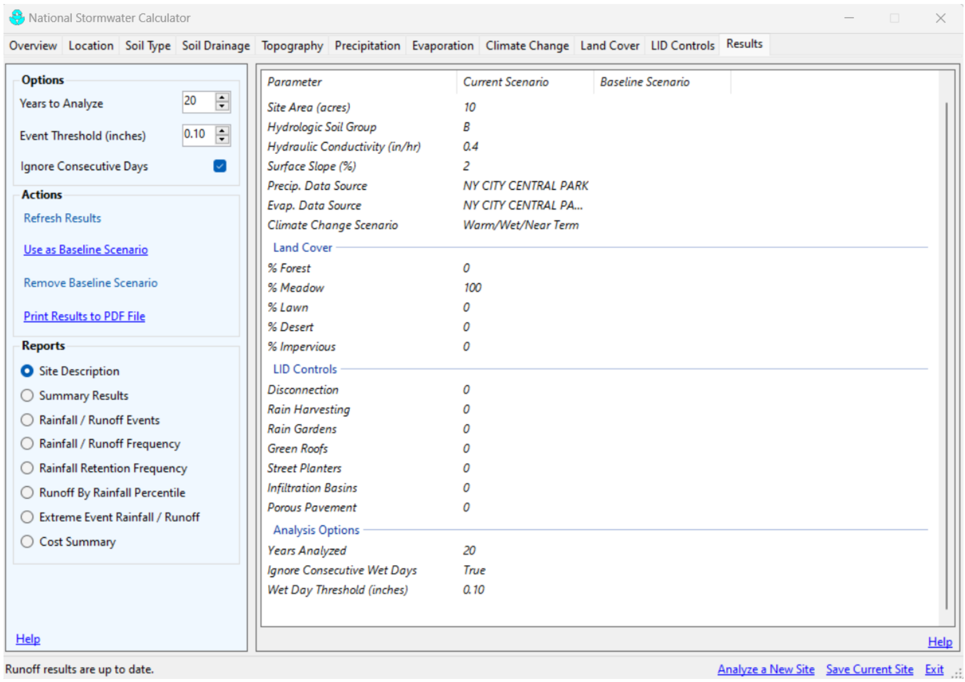
- Refresh Results
- Use as Baseline Scenario
- Remove Baseline Scenario
- Print Results to PDF File

The option we used is the first one to see the results.

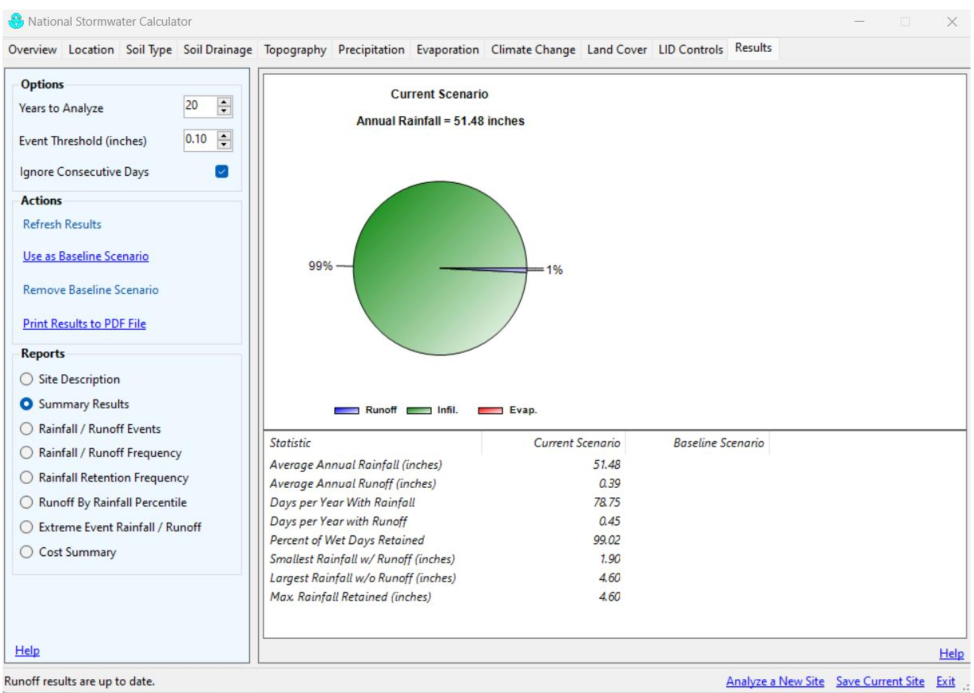
Results

The Reports section of the page allows to choose how the rainfall / runoff results for the site should be displayed. There are eight options which the extracted data for each can be seen below:

- Site Description



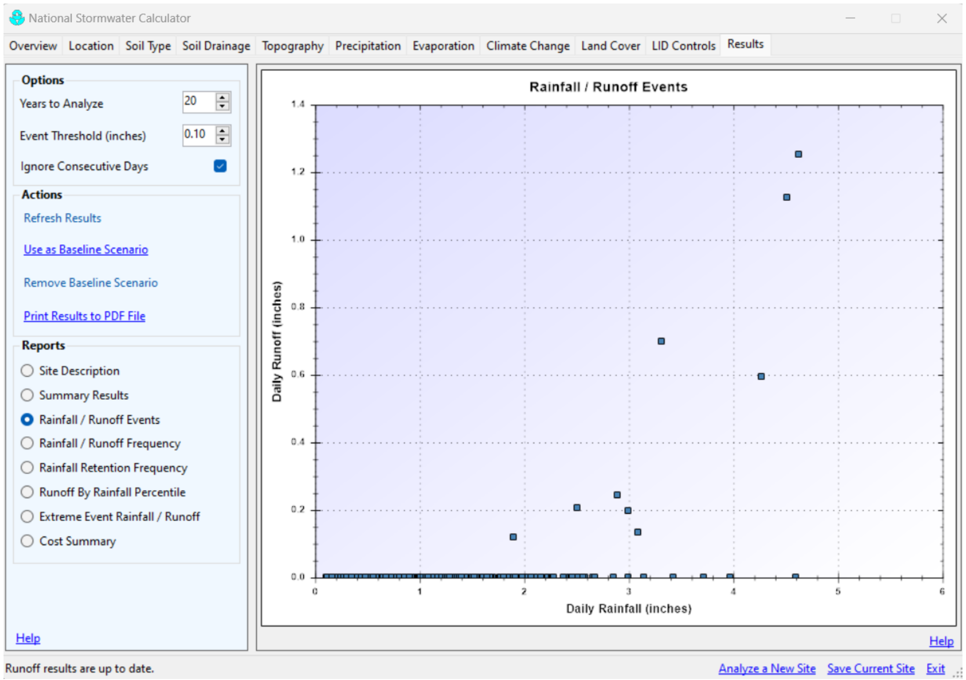
- Summary Results



  - A pie chart showing the percentage of total rainfall that infiltrates, evaporates, and becomes runoff. Note that because the calculator does not explicitly account for the loss of soil moisture to vegetative transpiration, the latter quantity shows up as infiltration in this chart.

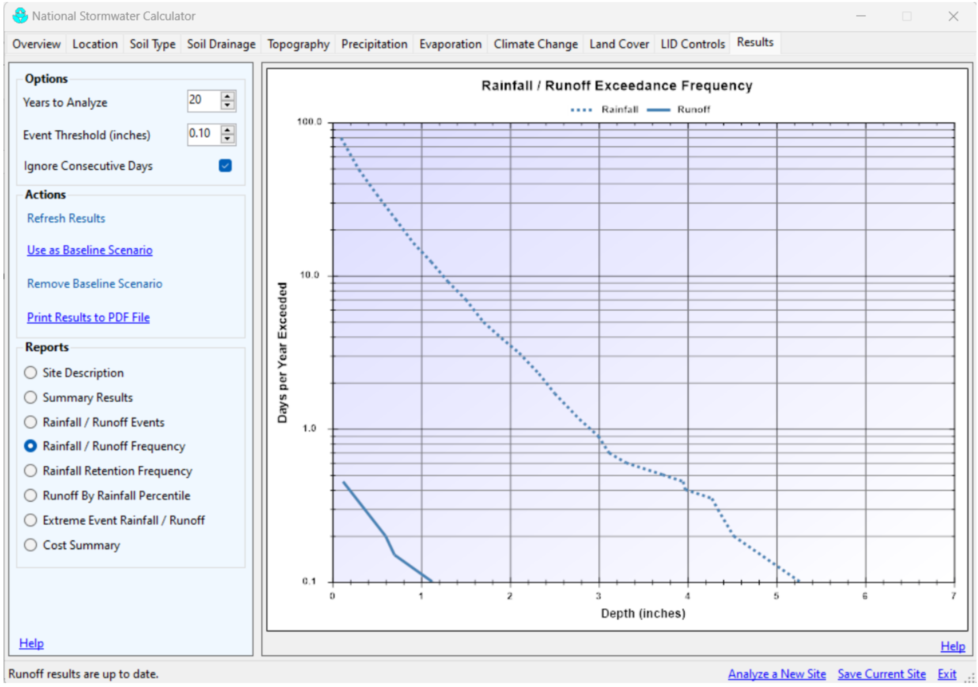
- Average Annual Rainfall: Total rainfall (51.48 inches) that falls on the site divided by the number of years simulated. It includes all precipitation amounts recorded by the station assigned to the site, even those that fall below the Event Threshold.
- Average Annual Runoff: Total runoff (0.39 inches) produced by the site divided by the number of years simulated. It includes all runoff amounts, even those that fall below the Event Threshold.
- Days per Year with Rainfall: The number of days with measurable rainfall divided by the number of years simulated, i.e., the average number of days per year with rainfall above the Event Threshold which equals 78.75.
- Days per Year with Runoff: The number of days with measurable runoff divided by the number of years simulated, i.e., the average number of days per year with runoff above the Event Threshold which equals 0.45.
- Percent of Wet Days Retained: The percentage of days with measurable rainfall that do not have any measurable runoff generated. It is computed by first counting the number of days that have rainfall above the Event Threshold but runoff below it. This number is then divided by the total number of rainfall days above the threshold and multiplied by 100. The result is 99.02%.
- Smallest Rainfall w/ Runoff: The smallest daily rainfall that produces measurable runoff in our case is 1.9 inches. All days with rainfall less than this amount have runoff below the threshold.
- Largest Rainfall w/o Runoff: The largest daily rainfall that produces no runoff is 4.6 inches. All days with more rainfall than this will have measurable runoff. Of the wet days that lie between this depth and the smallest rainfall with runoff, some will have runoff and others will not.
- Max. Retention Volume: The largest daily rainfall amount retained on site over the period of record. This includes days that produce runoff from storms that are only partly captured. The result is 4.6 inches.

- Rainfall/ Runoff Events



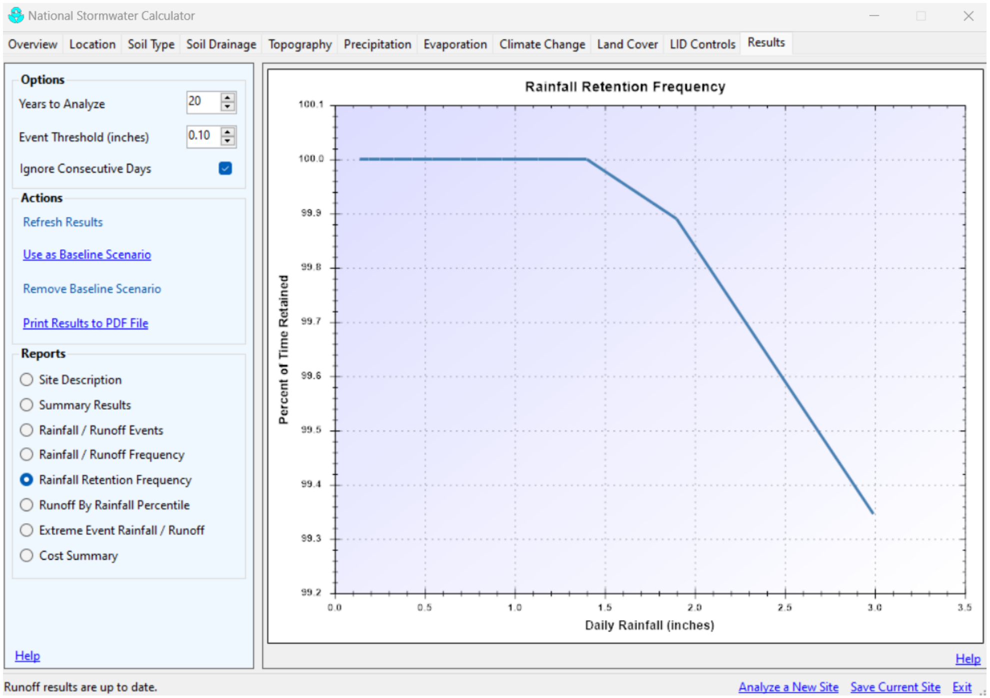
The calculator’s Rainfall/Runoff report contains a scatter plot of the daily runoff depth associated with each daily rainfall event over 20 years of record analyzed. Only days with rainfall above the event threshold are plotted. Events that are completely captured on site (i.e., have runoff below the event threshold) show up as points that lie along the horizontal axis. There is not always a consistent relationship between rainfall and runoff. Days with similar rainfall amounts can produce different amounts of runoff depending on how that rainfall was distributed over the day and on how much rain occurred in prior days.

- Rainfall/ Runoff Frequency



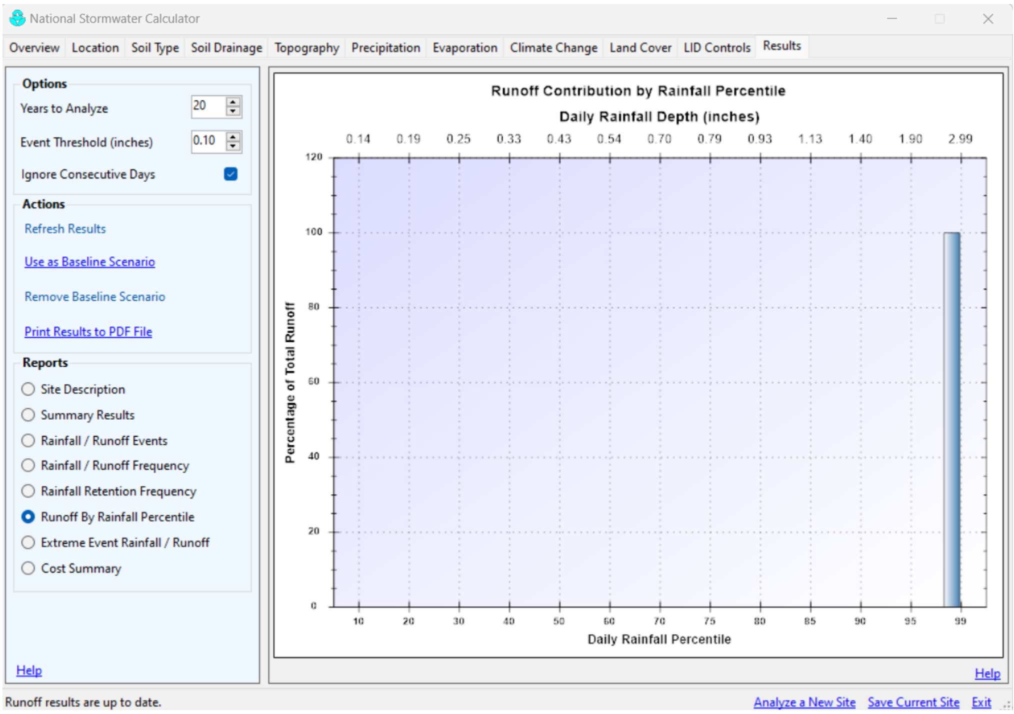
It shows how many times per year, on average, a given daily rainfall depth or runoff depth will be exceeded. As an example, from Figure * we see that there are four days per year where it rains more than two inches, but there is no day per year where there is more than this amount of runoff and all over the year runoff is less than one inch. Events with more than four inches of rain occur only once every two years. The rainfall frequency curve is generated by simply ordering the measurable daily rainfall results from the long-term simulation from lowest to highest and then counting how many days have rainfall higher than a given value. The same procedure is used to generate the daily runoff frequency curve. Curves like these are useful in comparing the complete range of rainfall / runoff results between different development, control and climate change scenarios. Examples might include determining how close a post-development condition comes to meeting pre-development hydrology or seeing what effect future changes in precipitation due to climate change might have on LID control effectiveness.

- Rainfall Retention Frequency



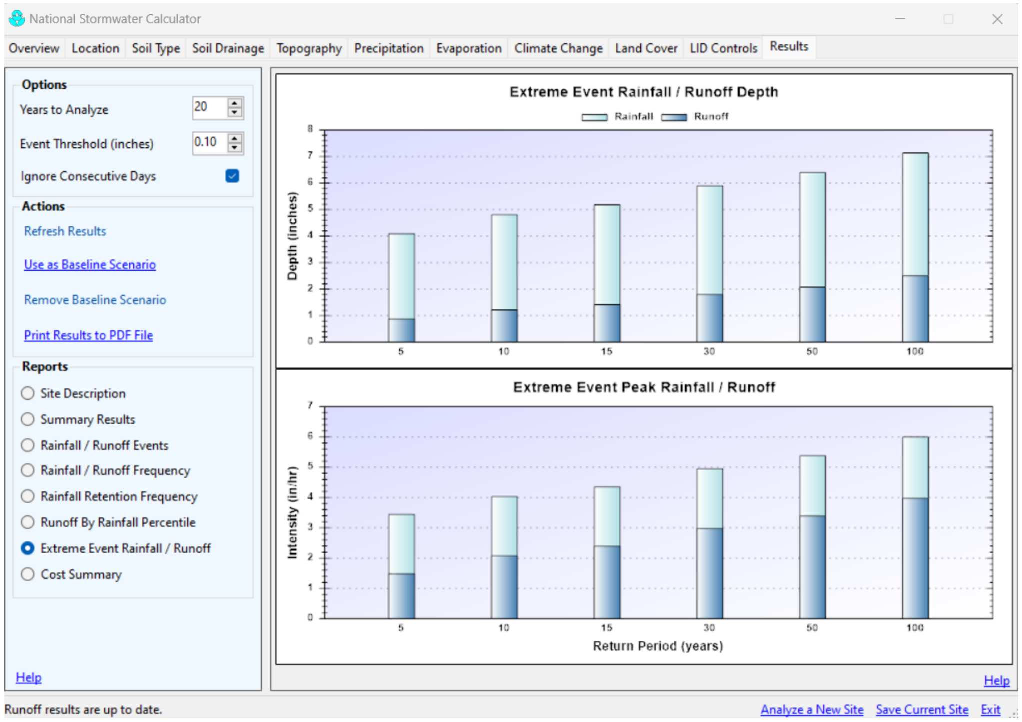
Another type of report generated by the calculator is the Rainfall Retention Frequency plot as shown in Figure *. It graphs the frequency with which a given depth of rainfall will be retained on site for the scenario being simulated. For a given daily rainfall depth for example 2 inches the corresponding percent of time (99.84%) it is retained represents the fraction of storms below this depth that are completely captured plus the fraction of storms above it where at least 2 inches are captured. A rainfall event is considered to be completely captured if its corresponding runoff is below the user stipulated Event Threshold which is 0.1 inches. The Rainfall Retention Frequency report is useful for determining how reliably a site can meet a required stormwater retention standard.

- Runoff By Rainfall Percentile



The Runoff by Rainfall Percentile report produced by the calculator is displayed in Figure *. It shows what percentage of total measurable runoff is attributable to different size rainfall events. The bottom axis is divided into intervals of daily rainfall event percentiles. The top axis shows the rainfall depth corresponding to each end-of-interval percentile. The bars indicate what percentage of total measurable runoff is generated by the rainfall within each size interval. This provides a convenient way of determining what rainfall depth corresponds to a given percentile (percentiles are listed along the bottom of the horizontal axis while their corresponding depths are listed across the top of the axis). Looking at the bar in Figure* associated with the 95th to 99th percentile storm interval (daily rainfalls between 1.9 and 2.99 inches). Storms of this magnitude make up 100 % of the total runoff (for this site and its land cover).

- Extreme Event Rainfall/Runoff



The Extreme Event Rainfall/Runoff report shows the rainfall and resulting runoff for a series of extreme event (high intensity) storms that occur at different return periods. Each stacked bar displays the annual max day rainfall that occurs with a given return period and the runoff that results from it for the current set of site conditions. The max day rainfalls correspond to those shown on the Climate Change page for the scenario we selected. Note that the max day rainfalls at different return periods are a different statistic than the daily rainfall percentiles that are shown in the Runoff by Rainfall Percentile report. The latter represents the frequency with which any daily rainfall amount is exceeded while the former estimates how often the largest daily rainfall in a year will be exceeded (hence its designation as an extreme storm event). Most stormwater retention standards are stated with respect to rainfall percentiles while extreme event rainfalls are commonly used to define design storms that are used to size stormwater control measures.

Bioretention Cell Static Storage and Hydrologic Performance

The hydrologic performance of a bioretention system is significantly influenced by its footprint in relation to the drainage area it serves. Bigger facilities have higher capacity for storing and infiltrating runoff, as well as providing greater surface area for evapotranspiration.

When designing a bioretention system, the storage capacity of the facility can be estimated based on its size, media properties, and drainage configuration. This estimation can be made from a static design standpoint.

Area= 10 acres= 435600 sq ft

Depth= 4 ft

Average precipitation= 0.125 inches

According to the characteristic of the considered area and the results of several studies that confirm bioretention as the best practice, we will examine the features of the under drained bioretention cell for sheep meadow. For an under drained bioretention cell, underdrain flow generally occurs before

bowl storage. Also, full media depth is utilized. The BAV in this case is given by:

BAV = RZMS * (SAT- WP) + LMS (SAT- FC) = 435600*(0.45- 0.081) +1306800*(0.45-0.179) =$1.54*10^{11}$ ft^3

While RZMS is the root zone media storage, equal to the total bulk volume of the media from the surface through a defined root zone depth. SAT and WP represent the saturated fraction and wilting point, respectively, for the type of media used in the cell which the media in our location is classified as sandy loam. The values of SAT and WP and FC as the field capacity of the media are presented for various soil textures and SAT, FC, and WP for a sandy loam soil are estimated at 0.45, 0.179, and 0.081, respectively. Without additional information, the depth of the root zone as a default is assumed as 0.3 m (1 ft). The LMS is the lower media storage, equal to the media volume below the root zone.

Once the storage capacity of the bioretention facility is exceeded, the cell will begin to discharge through the underdrain, or excess water will overflow if an underdrain is not provided. The relationship between volume in and out of the bioretention cell will depend on the exfiltration characteristics of the water from the bioretention media into the surrounding soils. If the surrounding soils are tight, most of the water that enters beyond the BAV will subsequently exist. If the surrounding soils have a moderate-to-high infiltration rate, the infiltration will reduce the volume of water leaving the facility.

Bioretention Cell Evapotranspiration Rate

Evapotranspiration is a significant process for eliminating accumulated water from bioretention and similar facilities. During the time between rain events, evapotranspiration (ET) as well as infiltration/percolation are responsible for removing stored water from the facility. These mechanisms are essential to recover the available storage volume before the arrival of the next rainfall event. According to previous studies and as expected, average ET values were highest in the summer and lowest in the winter. The system that had internal water storage showed the highest evapotranspiration (ET) rate. While The use of crop coefficients in the ET models improved the model predictive capabilities crop coefficients for internal water storage (IWS) vegetation are higher, at 0.95 to 1.71 for all stages.

According to precipitation data in Central Park (updated in January) the heaviest rainfall event happened in September, 23rd of 1882 which was 8.28 inches and the max and min temperatures in the same date were 66 °F and 55 °F, respectively. The depth of water is found from the media depth (4 ft= 48 in) and difference in media moisture contents:

D = 48 in (0.179 - 0.081) = = 4.704 in= 119.4816 mm

Sheep Meadow latitude and longitude: 40°46’19”N 73°58’30”W

The Hargreaves equation is used to find the ET. From reference the September

extraterrestrial radiation (Ra) measured in terms of evaporation rate is 12.5 mm/day at 40°.

The average temperature on the same date is almost 16°C. the ET is calculated as below:

ET_0=0.0023 R_a (TC+17.8)(T_{max}-T_{min})$^{0.5}$= 0.0023(12.5 mm/day)(16+17.8)(18.3-12.8)$^{0.5}$=2.28 mm/day

So the time to evapotranspiration of 119.4816 mm water will be:

119.4816 mm÷2.28 mm/day=52.4 days

According to the stormwater quality and the type of the media particulate matter removal occurs via sedimentation and filtration. As water infiltrates into and through the media, filtration of suspended solids will occur. The mechanism of filtration depends on media size, the size of the particulate being captured, and the contact time with the media, or media depth. Due to the presence of heavy metals such as copper (Cu), lead (Pb), and zinc (Zn) in runoff, both in the form of particles and dissolved substances, various methods are employed in bioretention to eliminate them. The elimination of particulate metals occurs simultaneously with the removal of particulate matter. Also, hydrocarbons in water will sorb to organic matter in bioretention media. Effective removal of various hydrocarbons, such as toluene, naphthalene, and motor oil onto a leaf compost bioretention surface media has been noted in laboratory studies. Nitrogen and Phosphorous removal are other processes need to be considered in bioretention process.

Conclusion

This study summarized different green infrastructures that can be used for stormwater management. Due to urbanization and increasing impervious surfaces, especially in cities like New York City with high precipitation rate, there is a high risk of flood and damage to the urban structures. In recent years using green infrastructure to manage rainfall and stormwater attracted a lot of attention but it still needs more and more research and development including novel ideas for not only preventing floods but also reusing this source of water. Although sheep meadow is a small sample of implementing green infrastructure it can show the significance and effectiveness of such programs even for semipervious areas. This will completely justify the application of green infrastructure for impervious areas. There were limitations in the software like being applicable for areas less than 500 acres. So even for Central Park, with an 840 acres area, the software is not applicable. Also, another limitation is lack of considering different surfaces which have different permeability rate in calculations. This is the reason that this project limited the area to a uniform area like Sheep Meadow with similar soil and slope. According to the review done in this project bioretention cell is one of the best options especially for locations like parks because in addition to collecting stormwater can provide green space which had austenitic effects on the location.

Dissemination

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