DEVELOPMENT AND EVALUATION OF A SITE STORMWATER ANALYSIS CALCULATOR INTENDED FOR THE STATE OF MISSOURI UTILZING REGIONAL BEST MANAGEMENT PRACTICES

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By

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The undersigned, appointed by the dean of the Graduate School,

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DEVELOPMENT AND EVALUATION OF A SITE STORMWATER ANALYSIS CALCULATOR INTENDED FOR THE STATE OF MISSOURI UTILZING REGIONAL BEST MANAGEMENT PRACTICES

Presented by Brent Elliott

A candidate for the degree of

MASTER OF SCIENCE

And hereby certify that, in their opinion, it is worthy of acceptance.

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Dr. Allen Thompson

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List of Abbreviations

American Public Works Association (APWA)

Best Management Practices (BMPs)

Center for Neighborhood Technology (CNT)

Clean Water Act (CWA)

Council on Environmental Quality (CEQ)

Cubic Feet (ft^3)

Cubic Feet Per Second (cfs)

Curve Number (CN)

Environmental Protection Agency (EPA)

Escherichia coli (E. coli)

Feet (ft) / Feet/Feet (ft/ft)

Geographic Information System (GIS)

Green Stormwater Infrastructure (GSI)

Hinkson Creek Watershed (HCW)

Hydrologic Engineering Centre-Hydrologic Modelling System (HEC-HMS)

Hydrologic Soil Group (HSG)

Level of Service (LOS)

Long-Term Hydrologic Impact Assessment Model (L-THIA-LID)

Low Impact Developments (LIDs)

Mid-America Regional Council (MARC)

Minimum Control Measures (MCMs)

Model for Urban Stormwater Improvement Conceptualisation (MUSIC)

Municipal Separate Storm Sewer System (MS4)

National Oceanic and Atmospheric Administration (NOAA)

National Pollutant Discharge Elimination System (NPDES)

National Stormwater Calculator (NSC)

National Environmental Policy Act (NEPA)

Natural Resources Conservation Service (NRCS)

Precipitation Frequency Data Server (PFDS)

President of the United States (POTUS)

Publicly Owned Treatment Works (POTW)

Soil Conservation Service (SCS)

Soil Survey Geographic Database (SSURGO)

Square Feet (ft^2)

Stormwater Management Program (SWMP)

Storm Water Management Model (SWMM)

System for Urban Stormwater Treatment Analysis and IntegratioN (SUSTAIN)

Technical Release – 55 (TR-55)

Time of Concentration (T_C)

Total Maximum Daily Load (TMDL)

United States (U.S.)

United States Army Corps of Engineers (USACE)

United States Department of Agriculture (USDA)

United State Environmental Protection Agency (USEPA)

Water Environmental Research Foundation (WERF)

Abstract

The Site Stormwater with Best Management Practices (BMPs) Analysis Calculator was created to be utilized in the State of Missouri for developing or re-developing property. Simplistic and conservative stormwater evaluations utilizing regional stormwater treatment practices for development scenarios with minimal financial investment for stormwater professionals, developers, and municipality officials is not available.

In this study, an Excel based analysis calculator was built with practiced stormwater calculations to inform the user of development and redevelopment projects' impacts. Regional stormwater detention and water quality treatment practices are integrated into the calculator providing the user options and estimated costs for mitigating impacts for their proposed development and redevelopment scenarios. The calculator utilizes the precipitation data from all weather stations in the State of Missouri reporting data to National Oceanic and Atmospheric Administration (NOAA) Hydrometeorological Design Studies Center Precipitation Frequency Data Server (PFDS). The calculator is not intended to replace the need and requirement of stormwater engineering design. Instead, the calculator shall supplement the development and redevelopment discussion and aid in the understanding of potential stormwater impacts and treatment options for all Users regardless their educations and experiences.

Scenario results from the Site Stormwater with BMP Analysis Calculator are compared to the United States Environmental Protection Agency (USEPA) National Stormwater Calculator (NSC) and the L-THIA-LID model. Results dissect the calculator's benefits and shortcomings with potential future enhancements.

Chapter 1: Literature Review

1.1 Stormwater

Urbanization in the United States has led to increased volumes of stormwater runoff along with the degradation of water quality and habitat (J.G. Lee et al., 2012; Obropta and Kardos, 2007). Stormwater runoff is the rainfall that is not utilized by natural vegetation, does not infiltrate into the soil, is not detained in the landscape, and does not evaporate (Wiseman et. al., 2020). Urban areas with high amounts of impervious surfaces decrease the infiltration rate of stormwater resulting in mass volumes of water rapidly running into storm drains, sewer systems, and drainage ditches. Direct physical impacts of this are seen in downstream flooding, erosion of stream banks, habitat destruction, combined sewer overflows, and infrastructure damage among other things (USEPA, July 1, 2023). Furthermore, water quality impairment due to sediment, chemicals, debris, and other pollutants are growing stormwater management concerns. When these pollutants enter a water body, adverse effects on fish, animals, plants, and people occur. These consequences have led Federal, State, and local governments enacting regulations regarding stormwater treatment and development construction practices in addition to investing in maintenance and operation programs for public stormwater infrastructure.

1.2 Implementation of Stormwater Regulations

Current United States stormwater regulations are the culmination of over a hundred years of legal proceedings. In 1899, President William McKinley with Congress' support signed into law The Rivers and Harbors Act, the first federal water pollution law in the United State. The act made it unlawful to throw, discharge, or deposit waste of any kind into any navigable water or tributary of any navigable water of the United States (Rivers and Harbors Appropriation Act of 1899, 1899). Litigation has cited this act numerous times since its establishment. One of these cases was the United States, Petitioner, v. Republic Steel Corp. et al. argued in January of 1960. The U.S. Army Corps of Engineers (USACE) had determined for safe passage of vessels a water depth of 21 feet was required in the Calumet River. Discharges from the regional milling industry had decreased the available water depth to 12 to 17 feet (United States, Petitioner, v. Republic Steel Corp et al., 1960). The argument presented to the court detailed discharges of particulate solids entering the river in a suspended state, forming larger solid masses, and dropping to the river bottom instead of being captured in settling ponds constructed by the milling companies. The court ruled in favor of the United States stating that the obstruction was not permitted under the "Rivers and Harbors Act of 1899". The regional mills had to dredge the Calumet River while providing water quality improvements.

In 1912, the U.S. Public Health and Marine Hospital Service changed its name to the Public Health Service. Along with the name change, additional resources were allocated to investigate cases of disease, sanitation, water supplies, and sewage disposal (U.S. National Library of Medicine, 1995). Only twelve years later the USACE was granted policing responsibilities of coastal navigable waters of the United States. Any intentional discharge of oil and fuel from vessels was now considered illegal ("Federal Oil Pollution Act", 1924). The Public Health Service along with other federal, state, and local entities were authorized to prepare details programs for treating pollution in interstate waters and tributaries in 1948 under the "Federal Water Pollution Control Act". The Surgeon General of the Public Health Service ensured these programs contained improvement plans for public water supplies, aquatic life, recreational purposes, and agricultural and industrial uses of interstate waters and tributaries, and underground waters (Federal Water Pollution Control Act, 1948). Construction of treatment plants to prevent discharge of inadequately treated sewage into intrastate waters and tributaries were encouraged by the programs' improvement plans. To achieve this, an amendment to the act was introduced in 1956 providing states and municipalities with grants totaling $500 million for construction of wastewater treatment plants. Additionally, the Federal Government tasked the Secretary of the Department of Health, Education, and Welfare to authorize the development of research programs to determine pollutant effects and the best treatment methods.

The Water Quality Act of 1965 expanded the Federal Government's regulatory reach by calling on states to create and enforce water quality standards reviewal by the Federal Government. This law began to shift the focus of water quality from just drinking water and human health to also including the ecological health of waterways for fishing and swimming (USEPA, June 1, 2023). The following year saw an additional amendment to the Federal Water Pollution Control Act of 1948 known as the Clean Water Restoration Act of 1966. The amendment allowed the Secretary of the Department of Interior along with the Secretary of the Department of Agriculture and the Water Resources Council to perform studies on the effects of pollution, including sedimentation, on fish and wildlife in U.S. estuary zones (Federal Water Pollution

Control Act, 1948). Additionally, the Clean Water Restoration Act of 1966 applied fines to polluters who failed to submit water quality reports required by the polluter's state.

The "National Environmental Policy Act of 1969" ("NEPA",1969) authorized any federal agency to determine potential environmental effects of their proposed actions prior to executing those decisions. Proper execution of NEPA by the Federal Government meant plans, functions, programs, and resources needed to be implemented. Six (6) goals were established to outline the direction of all environmental decisions for developments both large and small and how people should view these decisions. The six (6) goals aim to

- Ensure environment success for all generations;
- Provide all Americans a safe and healthy environment;
- Attain without degradation the most beneficial use of the environment;
- Preserve significant historical, cultural, and natural aspects of the environment wherever possible;
- Balance population and resource use to raise the standards of living; and
- Improve the quality of renewable resources while maximizing their recycling process.

The NEPA goals defined the Federal Government's obligation toward the environment as well as the personal obligation each American citizen had to preserving and enhancing the environment. To maintain proper checks and balances, the formation of the Council on Environmental Quality ("CEQ", 1970) to oversee implementation of NEPA, ensure federal agencies meet all stated obligations, supervise federal agencies implementation of the environmental impact assessment process, and issue regulations regarding NEPA compliance. Additionally, the CEQ assists and advises the President of the United States (POTUS) on major natural, manmade, or altered environmental classes of the country in the annual Environmental Quality Report ("NEPA", 1969).

While legislation aimed to provide adequate oversite on pollution in the environment, the Federal Government and state agencies had overlapping jurisdications regarding water quality. To rectify the issue, the "Reorganization Plan No. 3 of 1970" was prepared and presented to Congress by POTUS ("Reorganization Plan No. 3 of 1970", 1970). In his speech to Congress, President Richard Nixon stated:

> *"Our national government today is not structured to make a coordinated attach on the pollutants which debase the aire we breathe, the water we drink, and the land that grows our food. Indeed, the present government structure for dealing with environmental pollution often defies effective and concerted action."* – POTUS Richard Nixon (USEPA, 2014)

This plan established the Environmental Protection Agency (EPA) bringing all environmental regulations, research efforts, monitoring, standard-setting, and supervision of activities under one roof. As a result, the EPA amended the Federal Water Pollution Control Act of 1948 with the "Clean Water Act" (CWA). The CWA established discharge regulations for pollutants in waters from point sources with additional focus on surface water quality standards (Federal Water Pollution Control Act, 1948). Established in the amendment was the National Pollutant Discharge Elimination System (NPDES) to handle discharge permit authorization. A subsection of the NPDES called the "Municipal and Industrial Stormwater Discharges" detailed conditions for issuing permits for industrial sites and municipalities including the requirement of establishing management practices, control techniques and systems, and design and engineering methods to reduce pollutants ("Municipal and Industrial Stormwater Discharges", 1994).

The EPA then introduced the Municipal Separate Storm Sewer System (MS4) permit program to guide municipalites in obtaining and maintaining NPDES permits for storwmater discharges. The EPA's goal for the MS4 permit program was to eliminate combined sewers and provide treatment to polluted stormwater not passing through a treatment plant, or publicly owned treatment works (POTW). Each MS4 permit program has an operator responsible for preventing harmful pollutants discharging into the publicly owned system of conveyances (USEPA, 2016). The MS4 permit holder(s) shall develop, implement, and enforce a stormwater management program (SWMP) for treating stormwater in the permitted area. Six (6) minimum control measures (MCMs) designed to guide and inform the public about pollution and means of prevention and reduction are required in the SWMP. The MCMs are the following:

- Public Education and Outreach
- Public Involvement and Participation
- Illicit Discharge Detection and Elimination
- Construction Site Runoff Control
- Post-Construction Runoff Control
- Pollution Prevention/Good Housekeeping

To achieve permit compliance, municipalities are required to implement pollutant reducing management practices.

1.3 Stormwater Management Practices

Conventional stormwater infrastructure moved water from one site to another through engineered networks consisting of pipes, channels, and basins. The conveyances did little to prevent stormwater from being polluted with chemicals, sediment, oil, and trash found on impervious surfaces like parking lots, roads, and driveways as well as delivered water too quickly downstream leading to severe flooding and channel erosion issues (National Research Council of the National Academies, 2009). Enlarging collection systems and hardening channels were cost effective preventative measures but did not mitigate the impacts to the aquatic ecosystem. The need to improve stormwater quality and detention practices was ushered in with the CWA.

The act led to the utilization of the term Best Management Practices (BMPs) to describe management practices or structured approaches to pollution prevention (Elliott & Trowsdale, 2007; Fletcher et al, 2015). In the last 30 years, much importance has been placed on characterizing and improving the quality of stormwater runoff (Beck et al., 2017; Pitt & Maestre, 2005). A wide range of research into stormwater treatment methods has been conducted with results leading to new regulations and ordinances for communities (Eckart et al., 2017). Common structural practices implemented for stormwater runoff treatment such as detention ponds, bioretention basins, rain gardens, vegetated swales, and permeable pavements are known as Best Management Practices (BMPs), Low Impact Development (LID) or Green Stormwater Infrastructure (GSI) (Fletcher et al., 2015; Zhang and Chui, 2017). Nonstructural practices and activities such as public outreach, flood mitigation, and groundwater recharge are also considered under the same naming convention of BMP, LID, and GSI. For this study, all discussed stormwater treatment methods will be referred to as BMPs and all are structural practices.

Designs of BMPs focus on returning developed sites to pre-developed hydrologic conditions while attempting to remove pollutants (Elliott and Trowsdale, 2007; Eckart et al., 2017). These engineered stormwater treatment structures which mimic pre-development landscape characteristics promote natural processes such as filtration, infiltration, evaporation, and groundwater recharge with the added benefit of pollutant removal vary in cost and required maintenance (Elliott and Trowsdale, 2007; Kaykhosravi et al., 2018). Other benefits include promotion of native flora and fauna, re-establishment of habitat, and improved aesthetics for community members (Ashley et al., 2011).

Typical installation of BMPs result from new development or redevelopment of property such as subdivisions, commercial businesses, and industrial facilities. Multiple types of BMPs have been designed and utilize across the United States to account for specific site characteristics, hydrological and ecological conditions, and constructions and maintenance costs constraints. Examples of these BMPs are Bioretention Cells, Infiltration Trenches, Vegetated Swales, Green Roofs, Rain Barrels or Cisterns, Permeable Pavement, Wet Detention Ponds, and Dry Detention Ponds. Common goals of BMPs include preventing erosion, limiting discharge of pollutants downstream, and minimizing peak flows leaving developing or redeveloping sites. To achieve these goals, BMPs utilize designs and structures promoting filtration and infiltration of water while detaining or retaining stormwater for specific durations. Through the rest of this subchapter different stormwater BMPs will be discussed.

1.3.1 Bioretention

Stormwater BMPs are compared to individual treatment plants for properties and when implemented over large development areas are found to produce positive stormwater benefits (Davis, 2008). One of these treatment plants is the bioretention cell developed by Prince George's County, Maryland, Department of Environmental Resources (USEPA, 1999a). A bioretention cell is an excavated soil bowl with a perforated drain in the bottom and filled with an engineered media mixture of sand, mulch, topsoil, and other organic matter (Figure 1.1). The bioretention media is planted with native woody and herbaceous plants to provide additional uptake of stormwater as well as removal of pollutants such as phosphorus and nitrogen (Novak et al., 2013). Bioretention treatment mechanisms include adsorption, biological treatment, filtration, and infiltration leading to stream base flow and groundwater recharge (Davis et al., 2009). The design of the bioretention cell accounts for drainage area and a target rainstorm (i.e., 1-year, 2-year, or 10-year) to function properly. Excess flow is released through a storm box or over a soil berm emergency spillway.

Bioretention and its treatment processes has been studied extensively in the last two decades. A study by Davis et al. (2006) analyzed phosphorus removal in laboratory box bioretention and field installed bioretention cells. The laboratory box bioretention recorded phosphorus removal rates of 70-85% while column grabs of field bioretention in Maryland resulted in 77-79% phosphorus removal. However, the same study analyzed field bioretention columns in North Carolina where the removal rate of phosphorus decreased to 65%. The variation is likely due differing levels of leaching of phosphorus from the parent bioretention material used in each test. The same study found a Total

Kjeldahl nitrogen removal in laboratory boxes of 55-65%. A later review of this study compared to field results from bioretention media in New Hampshire, North Carolina, and Pennsylvania showed a lower low end removal rate of 33%, but nearly matched the upper end of the laboratory nitrogen removal rate at 66% (Davis et al., 2009). Research conducted at the University of Missouri analyzed regional bioretention media effectiveness in removing phosphorus from stormwater. The study concluded bioretention media, comprised upwards of 80% sand, was too inert to remove phosphorus and even potentially leached phosphorus previously in the media (Novak et al., 2013). To address the issue, drinking water treatment residuals were introduced to sorb the phosphorus at highly effective levels. While research is still questioning the most effective design of bioretention, it is widely concluded that this BMP is effective in lowering peak flow rates, improving water quality including removal of large particulates and trash, and providing infiltration of stormwater into the landscape where the rain falls (Davis et al., 2006; Nazarpour et al., 2023).

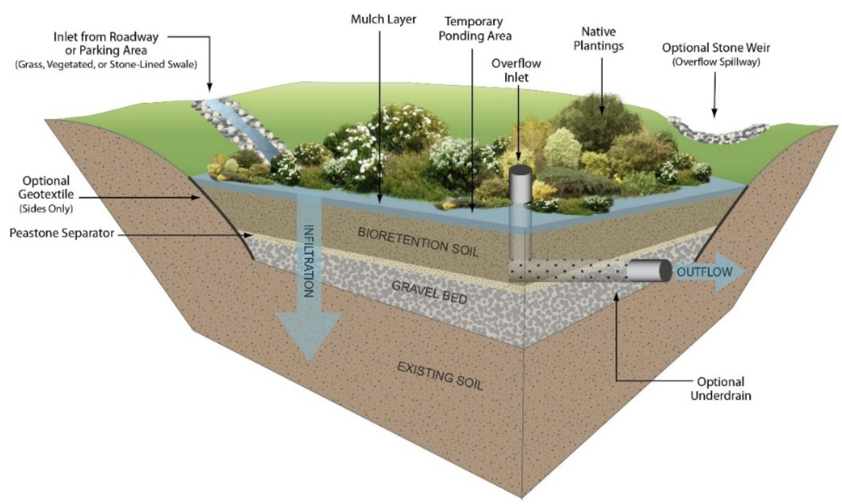

Figure 1.1: Typical Cross-Section of a Bioretention Cell

(Massachusetts Department of Environmental Protection, 2023)

1.3.2 Infiltration Trench

The infiltration trench is an effective BMP at capturing and treating the first flush runoff from storm events in urban settings (Dodson, 1999; Toran and Jedrzejczyk, 2017). Typical implementation of the BMP is near roads and parking lots and many infiltration trenches will have pipes directed to them (USEPA, 1999b). Due to limited storage, it is common to find the BMP in series with other stormwater control measures to handle larger volume flows. Additionally, routine maintenance is required to prevent surface clogging and buildup of captured pollutants such as heavy metals, sediment, trash, and other organics.

The construction of the BMP includes an excavated area with moderate side slopes containing a geotextile lining and clean rock. In areas with limited green space, this BMP is practical as it can be sized for the specific drainage area contributing stormwater runoff and needs only minimal surface area as shown in Figure 1.2. Native soil infiltration rates and the desired retention time measured in hours are other design parameters required for sizing and placement. Toran and Jedrzejczyk from the Temple University (2017) studied and monitored implemented infiltration trenches to determine if changes in design, maintenance, and construction practices resulted in treatment differences. A sand infiltration trench, a gravel infiltration trench, and a gravel infiltration trench with a leaf filter were analyzed over a 2.5-year period. The research noted that soil infiltration rates were likely impacted by "slicking" of the trench side walls and unbalanced water delivery resulted in differing peak flows captured. The gravel infiltration trench responded to rain events the best and did not experience clogging issues observed with the other two designs. Overall, the three trenches showed no significant reduction in exfiltration capacity over the course of the testing period. Recent research has indicated infiltration trenches with pretreatment such as plunge pools experience higher performance but note regular maintenance of the BMP is still required due to collection of fine particles (Mueller et al., 2022).

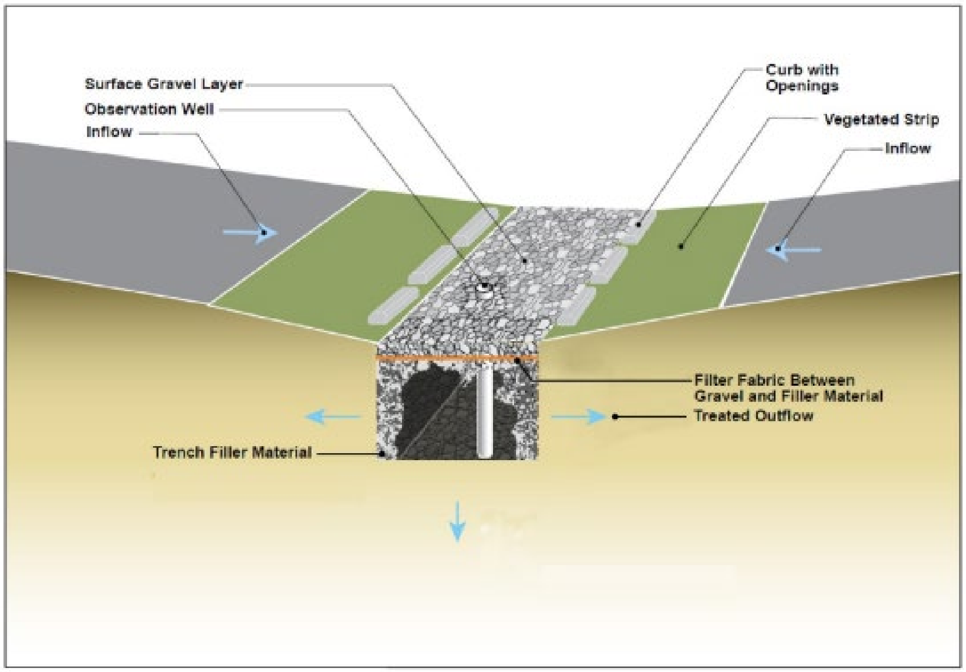

Figure 1.2: Typical Cross-Section of an Infiltration Trench (Caltrans, 2020)

1.3.3 Detention Pond

The Detention Pond BMP captures small to large drainage area's stormwater runoff and releases the water downstream over a specified amount of time. Also referred to as Extended Dry Detention, the BMP is effective at flood control and reducing peak runoff rates (Papa et al., 1999). Infiltration is not effective in detention ponds due to compaction during construction of the earthen basin and sedimentation is the most effective pollutant removal mechanism provided by the BMP (Wissler et al., 2019).

Stormwater flows into the BMP via surface flow and pipes and is slowly released through an outlet structure (concrete box, pipe, or other common construction materials) (Figure 1.3). Typically, the drawdown time for a detention pond is between 24 to 48 hours, and no more than 50% of the total storm volume should be released in the first 16 hours (San Francisco Public Utilities Commission, 2010). The drawdown time allows pollutants such as sediment, heavy metals, and other debris settle to the bottom of the pond as the water is trapped within the pond banks. Additionally, the collection of stormwater runoff prevents flooding and erosion of stream channels by reducing the peak flow rates in the drainage area of the pond. Detention Ponds require larger footprints than most BMPs and can be completely vegetated since there is no permanent pool of water.

Maintenance is relatively minimal with periodic mowing, trash collection following storm events, and correcting any erosion issues in and around the pond. Research at the University of North Carolina State conducted by Wissler et al. (2019) monitored two overgrown detention ponds near Raleigh, North Carolina having forgone routine maintenance for the previous decade. The researchers found that the two BMPs were highly effective at volume reduction through infiltration and evapotranspiration as well as pollutant concentration removals percentages ranging from 35% to 81%. The trees and shrubs were found to provide canopy interception of the stormwater, infiltration into the soil where roots were established, and the vegetation did not reduce the water storage volume in the basins.

Figure 1.3: Typical Detention Pond Design for Stormwater Runoff (Wikipedia, 2006a)

1.3.4 Retention Pond

Retention Ponds, also known as wet ponds or wet extended detention ponds, are constructed basins holding a permanent pool of water. Initially designed for flood prevention and capturing the first flush of a storm, this BMP has been found to provide moderate water quality treatment through extended retention time in the basin (Davis and McCuen, 2005). Stormwater runoff collected in the Retention Pond is subjected to multiple physical, biological, and chemical treatment processes resulting in the removal of heavy metals, nutrients, and organic matter pollutants. Construction of the BMP requires an earthen basin lined with either a thick layer of clay or an impermeable membrane liner. Release of water from the pond is directed through an outlet structure and if needed over an emergency spillway. Retention ponds are commonly designed with a normal pool elevation with the storage available to capture and slow release a specific water quality volume. This feature helps reduce peak flows experienced by waterbodies and waterways downstream of the BMP. Retention ponds create aquatic habitats but are also sinks for pest insects like mosquitos (Dodson, 1999).

A study in 2000 conducted by Comings et al. monitored the performance of two wet ponds receiving stormwater runoff from commercial and residential areas in Bellevue, Washington. One pond was designed to attenuate flow and treat water quality, while the second pond focused solely on water quality improvement. Both ponds positively impacted runoff pollutants concentrations, but the pond primarily designed for water quality treatment outperformed the other. This pond design accounted for extended detention time, additional pond volume, and minimal short circuiting. Other research has found that pollutant removal efficiencies are increased when retention ponds are combined or put in a treatment train with other BMPs such as sand filters, bioretention, or have forebays designed to slow the runoff flow rate entering the pond (Sønderup et al. 2016).

1.3.5 Permeable Pavement

A treatment method for impervious surface runoff on sites with limited developable space is the application of permeable surfaces such as porous asphalt and pervious concrete (Dodson, 1999; USEPA, 1999c; San Francisco Public Utilities Commission, 2010). Commonly referred to as permeable pavement, the BMP is designed to provide infiltration of stormwater in place of typical impervious surfaces such as parking lots, sidewalks, driveways, bike paths, walkways, and service roads (Figure 1.4). Asphalt and concrete construction remove void space preventing stormwater from filtering down to the subsurface and soil. As precipitation falls it collects and runoffs off the concrete and asphalt carrying pollutants like oil, sediment, trash, and other organics to the nearest waterbody or waterway. Permeable pavement utilizes structural mats, pavers, or engineered concrete and asphalt blends to create porous surfaces of handling light duty traffic. Underneath the pavement are highly permeable layers of gravel and crushed stone with a geotextile fabric to prevent further movement of fine sediment in the infiltrating runoff and an underdrain to remove excess water that has not entered the native soil. Installation of permeable pavement provides peak flow reduction, water quality treatment, is suitable for most cold climate applications, and can lessen the need of traditional stormwater infrastructure such as piping, storm boxes, and curbing (MARC/APWA, 2012). Permeable pavements are highly susceptible to clogging and should have periodic maintenance performed via vacuum trucks, street sweepers, and pressure washers (USEPA, 1999c).

Research in Ontario, Canada examined the water quality of effluent from three permeable pavement systems and a conventional asphalt surface during the spring, summer, and fall seasons between 2010 and 2012. The study found the three permeable pavements positively altered the quality of the water infiltrating by removing total suspended sediment, phosphorus, nitrogen, and metals like copper, iron, and zinc (Drake et. al., 2014). The asphalt surface effluent measured higher concentration of pollutants while not providing the peak runoff reduction of the permeable pavement systems. A study conducted by Selbig et al. of the U.S. Geological Survey Service (2019) founded similar results. The researchers tested three permeable pavements with different surface aggregates (permeable asphalt, permeable concrete, and permeable pavers) and internal impermeable membrane linings lowered the concentration of total suspended solids, total phosphorus, Escherichia coli (E. coli), and a wide array of metal pollutants from the concentration levels found upstream of the BMPs. Another conclusion of the study was the permeable pavers were determined to sustain a higher clogging rate than the permeable asphalt and permeable concrete following restorative maintenance.

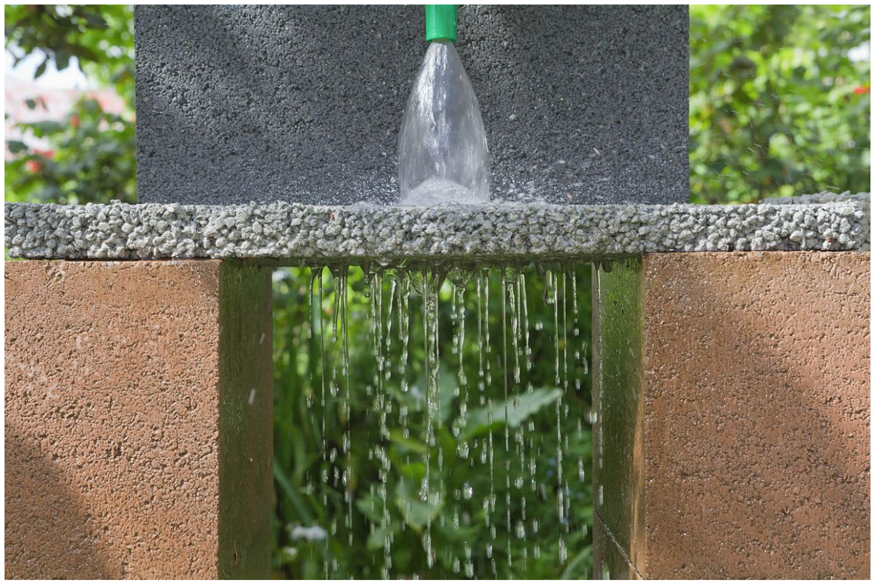

Figure 1.4: Permeable Pavement Example (Wikipedia, 2011)

1.3.6 Green Roofs

The Green Roof BMP installs a layer of soil and vegetation on conventional roofs (Figure 1.5). Capturing stormwater where it falls the BMP immediately helps lower stormwater runoff flows. Research by Buffam, Mitchell, and Durtsche (2016) analyzed a green roof in Cincinnati, Ohio and determined a positive correlation between higher temperatures and higher dissolved nutrient concentrations in the effluent discharged. Another study by Buffam and Mitchell (2015) noted Green Roofs provide runoff reductions benefits, but negatively impact water quality compared to scenarios without green roofs. Numerous Green Roof designs utilize different construction materials and installation methods (Carson et al., 2013). Green Roofs are classified as either extensive or intensive dependent upon the thickness of the soil substrate. Extensive Green Roofs are 6 inches or less and planted with drought resistant vegetation while intensive Green Roofs are designed with soil profiles deeper than 6 inches to accommodate deeper rooting vegetation. The BMP is more susceptible to extreme weather conditions compared to similar habitat on the ground (Butler et al., 2012). Green roofs require weeding, fertilizing, and irrigation maintenance to keep them viable options for stormwater management purposes.

Figure 1.5: Vegetated Roof System Cross-Section (Wikipedia, 2006b)

1.3.7 Vegetative Swale

A vegetated swale is a broad, shallow, trapezoidal, or parabolic earthen channel covered in dense vegetation that conveys water only during storm events (Davis and McCuen 2005; USEPA, 1999d). Also known as bioswales, this BMP is constructed in residential developments, highway medians, parking lots, and near other impervious areas (Lucke et al., 2014). Vegetative Swales provide attenuation of stormwater runoff, promote infiltration, and sedimentation of suspended solids. BMP length, width and slope, soil and vegetation type and stormwater pollutants contribute to the effectiveness of the BMPs' treatment processes (Hager et al., 2019). Dense growing, water and drought resistant vegetation is recommended to be planted in the swale (Figure 1.6). To minimize flow rates and promote infiltration in the swale due to higher bottom slope percentages check dams may be installed. Li et al. (2016) analyzed pollutant treatment in vegetative swales incorporated with sand, soil, humus, fly ash, and blast furnace slag. The study determined in low flow conditions, the blast furnace slag was the most effective in lowering nitrogen, phosphorus, and some heavy metal pollutant concentrations. Regular inspection of the channel bottom and sides is needed to prevent erosion problems and remove sediment and debris accumulation. Dependent upon the vegetation planted in the swale, regular mowing or trimming may be required.

Figure 1.6: Example of Vegetated Swale (Pennsylvania Department of Environmental Protection, 2007)

1.3.8 Rain Barrels and Cisterns

Rain Barrels and Cisterns are utilized for rainwater harvesting. Drainage from roofs and other impervious surfaces are directed into rain barrels and cisterns to store and use for purposes such as irrigation. Rain barrels range in a variety of sizes but are typically located above ground. Cisterns generally has a larger storage capacity than rain barrels and can be installed both above and below the ground. The BMP eases the burden on public storm infrastructure through quantity reduction and provides a non-potable water source for landowners looking to minimize water expenses (Hager et al., 2019). The downside to these BMPs is reliance upon local weather patterns, storage constraints, and questions regarding the quality of water collected (Ishaq et al., 2020; Liu et al., 2021). Rain barrel research in Cincinnati, Ohio analyzed six residential rain barrels utilized for watering indoor and outdoor plants. The harvested rainwater exhibited acidic conditions with total coliform and enterococci bacteria levels above acceptable secondary recreational contact water quality standards enforced by the USEPA (Shuster et al., 2013). The researchers determined utilizing the rainwater for plant watering was safe but cautioned against users having extended contact with the water due to potential microbial contaminants.

1.4 Stormwater Modeling

Communities have chosen to adopt stormwater BMPs due to their environmental, economic, social, and cultural benefits. This approach has led to the development and implementation of tools and models effective at applying BMP principles at a multitude of design scales (Elliott and Trowsdale, 2007). The diverse capabilities of BMPs and models has led to numerous comprehensive studies analyzing the computational ability to perform hydrologic and hydraulic analyses, accessibility and functionality of the models, resolution, scale, and intended model uses including research, public education, and conceptual and strategic planning.

Zoppou (2001) reviewed urban stormwater models capable of simulating stormwater quantity and quality and described the mathematical methods for flow routing and contaminant generation and transport in the models. Elliott and Trowsdale (2007) assessed ten stormwater models with BMP devices included or possessing the capability to simulate BMPs indirectly. Ahiablame et al. (2012a) complied a literature review of the benefits of stormwater BMPs as well as how BMPs are represented in hydrologic/water quality models. Models discussed in the study were the Long-Term Hydrologic Impact Assessment Model (L-THIA-LID), the EPA's System for Urban Stormwater Treatment Analysis and IntegratioN (SUSTAIN) model, and the EPA's Storm Water Management Model (SWMM). Research by Haris et al. (2016) compared ten models to the MSMA Design Aid and Database. The models were classified by ability to address stormwater management questions with built-in BMPs, ability to conduct economic analysis of their built-in BMPs, and if models could address both. Other studies compiled and discussed models based on BMP features and future BMP model needs (Rangari et al., 2015; Kaykhosravi et al., 2018).

The preceding reviews present valuable information on existing models utilizing BMPs. However, the continued adoption of BMPs for stormwater treatment yields a continuous improvement and/or creation of models and tools as research, design, and performance of in-field BMPs are evaluated (Kayhosravi et al., 2018). Table 1-1 summarizes existing models and tools with BMPs incorporated. Through the rest of this subchapter, models and tools will be discussed.

Table 1.1: Common Stormwater Models and Tools with BMPs Incorporated.

Model	Developed By	Accessibility	Comments
Green Values National Stormwater Management Calculator	Center for Neighborhood Technology	Publicly available for download	Tool calculates stormwater runoff and pollutant loading with cost estimates. Supports BMP design for Bioretention/Rain Gardens, Grass Swale, Open Wooded Space, Permeable Pavement, Rain Barrel/Cisterns, and Green Roof.
HEC-HMS	U.S. Army Corps of Engineers	Publicly available for download	Updated software version of HEC-1. Performs hydrological system analysis using simulated rainfall-runoff process (short- and long-term) on catchments.
Long-Term Hydrologic Impact Assessment Model (L-THIA-LID)	Bernie Engel and Jon Harbor (Purdue University)	Publicly available	Web Based Tool calculates stormwater runoff and pollutant loading scenarios utilizing BMPs such as Bioretention/Rain Gardens, Grass Swale, Open Wooded Space, Permeable Pavement, Rain Barrel/Cisterns, and Green Roofs.
National Stormwater Calculator	USEPA	Publicly available for download	Tool calculates annual rainwater totals and site runoff amount utilizing BMPs of Downspout Disconnection, Rainwater Harvesting, Rain Gardens, Green Roofs, Street Planters, Infiltration Basins, and Porous Pavement. Intended use by developers, urban planners, homeowners, and others interested in stormwater management.
Model for Urban Stormwater Improvement Conceptualisation (MUSIC)	Monarch University and the CRC for Catchment Hydrology, Australia	Commercially available	Model design concepts for urban drainage systems utilizing BMPs such as Bioretention, Infiltration and Media Filtration Systems, Gross Pollutant Traps, Buffer Strips, Vegetated Swales, Ponds, Sedimentation Basins, Rainwater Tanks, Wetlands, and Detention Basins. Model commonly used in Australia.
RECARGA	University of Wisconsin	Publicly available for download	Models and evaluates performance of stormwater BMPs (Bioretention, Rain Garden, and Infiltration Basins).

Table 1.1: Common Stormwater Models and Tools with BMPs Incorporated (Continued).

Model	Developed By	Accessibility	Comments
Storm Water Management Model (SWMM)	U.S. EPA	Publicly available for download	Complex model utilized for planning, analysis and design of stormwater runoff, combined sewer overflows, and drainage systems. BMPs available within the model are Bioretention, Infiltration Trenches, Porous Pavement, Rain Barrels, Vegetative Swales, Green Roofs, Street Planters, and Amended Soils.
System for Urban Stormwater Treatment Analysis and Integration (SUSTAIN)	U.S. EPA	Publicly available for download	Models detailed design and planning concepts utilizing BMPs such as Bioretention, Cisterns, Constructed Wetlands, Dry Ponds, Grassed Swales, Green Roofs, Infiltration Basins, Infiltration Trenches, Permeable Pavements, Rain Barrels, Sand Filters, Vegetated Filter Strips, and Wet Ponds. Model analyzes cost effectiveness of designs with regard to stormwater quality and quantity management goals.
WERF BMP and LID Whole Life Cycle Cost Modelling Tools	The Water Research Foundation	Publicly available for download	Spreadsheet tools designed to identify and cost estimate capital and maintenance costs for stormwater management. Tools designed for Green Roofs, Permeable Pavements, Rain Gardens, Retention Ponds, Swales, Cisterns, Bioretention, and Extended Detention Basins.

(References: Elliott and Trowsdale, 2007; Jayasooriya and Ng, 2014; Haris et al., 2016; Kaykhosravi et al., 2018)

1.4.1 Stormwater Models

The Center for Neighborhood Technology (CNT) created The Green Values National Stormwater Management Calculator to evaluate BMPs and associated costs to achieve specified stormwater volume capture goals (Jayasooriya and Ng, 2014). The tool is a web-based application that steps users through the needed inputs and is meant for site specific analysis. Inputted data are not required to be detailed as the program objective is estimation based on industry data (Kayhosravi et al., 2018). The Soil Conservation

Service (SCS) runoff curve number method is used to calculate the volume of runoff generated and each selected BMP factors into the values calculated for infiltration, evapotranspiration, and reuse of captured stormwater. Studies have utilized the Green Values National Stormwater Management Calculator to compare BMP costs, assess water quality impacts, runoff reductions and performance compared to conventional stormwater management practices (Liu et al., 2016; Thiagarajan et al., 2018).

The USACE designed the Hydrologic Engineering Centre-Hydrologic Modelling System (HEC-HMS) to simulate hydrological model systems with rainfall-runoff processes (Haris et al., 2016). Typically utilized by hydrologists and engineers, the program classifies hydrologic and hydraulic elements as basins meteorological, and time series components. Other capabilities of the program include continuous simulation for evapo-transpiration, snowmelt, and soil moisture analysis (Rangari et al., 2015). Research by Wiseman et al. (2020) developed a watershed model in HEC-HMS to determine inflow for use in a water balance of a Level Spreader BMP. As noted by Kaykhosravi (2018), the use of BMPs in HEC-HMS is possible by implicitly defining sub-catchments with BMP properties.

The Long-Term Hydrologic Impact Assessment of Low Impact Development (L-THIA-LID) is a user-friendly standalone model based on the spreadsheet version of the L-THIA-LID model developed by researchers at Purdue University (Liu et al., 2015; Kayhosravi et al., 2018). The model is based on SCS runoff curve number method, uses event mean concentration methods to simulate runoff, nonpoint source pollutant loads, land use, precipitation data, and soil properties for a collection of states in the middle of America (Ahiablame et al., 2012b). Model scenarios evaluate pre- and post-development scenarios without BMPs, and a post-development scenario with BMPs to understand the stormwater impacts of the inputted management plan. The model has been applied to lot and watershed scale research as demonstrated by Ahiablame et al. (2012b, 2013).

The National Stormwater Calculator (NSC) by the USEPA presents a simplified version of gauging BMP impacts on areas approximately 12 acres or less. The calculator is a web-based tool adopting computational processes from the USEPA Storm Water Management Model to calculate runoff flow reductions and annualized depths after inputs for land cover, topography, soils, and precipitation are selected (Schifman et al., 2018). Intended for non-technical professionals, the calculator utilizes Bing Maps, The United States Department of Agriculture (USDA) Soil Survey Geographic Database (SSURGO) and the National Weather Service Rain Gauge records as inputs based on selecting the scenario location (Rossman and Bernagros, 2018). The calculator can be applied for sites in the United States as well as Puerto Rico.

The RECARGA model, developed by the University of Wisconsin, evaluates the performance of Bioretention, Rain Garden, and Infiltration Basin BMPs for specific sites (Elliott and Trowsdale, 2007; Schifman et al., 2018). Simulating infiltration through 3 distinct soil layers using Wisconsin Department of Natural Resources standards and regional climate data, the model is typically applied to site or neighborhood scales (Jayasooriya and Ng, 2014). Model inputs include precipitation data, evapotranspiration records, drainage area details like curve numbers and soil properties, and specific design characteristics for the BMPs. A study by researchers in Romania developed RECARGA models for bioretention cells at four urban sites and determined soil hydraulic conductivity impacted performance of the BMPs the greatest (Boancă et al., 2018).

The EPA Storm Water Management Model (SWMM) was developed in 1970 with multiple improved versions released as recent as February 2023 (USEPA, 2023b). The model, while publicly available, is considered too complex for the general public and markets itself toward stormwater planners and engineers (Elliott and Trowsdale, 2007; Abi Aad et al., 2010). Typical applications of the model include hydraulic modeling such as routing runoff through drainage systems with pipes, channels, and storage units, accounting for hydrologic processes like snow accumulation and melting, evaporation and infiltration, and runoff reduction via BMPs, and estimating pollutant loading scenarios. Studies by Abi Aad et al. (2010) who modeled Rain Barrels and Rain Gardens in SWMM to assessed potential runoff reductions and Barco et al. (2008) who integrated geographic information system (GIS) input data with a calibrated SWMM large urban catchment in Southern California to estimate and optimize runoff parameters showcase SWMM's robust capabilities.

The EPA System for Urban Stormwater Treatment Analysis and IntegratioN (SUSTAIN) was developed for stormwater and watershed specialists to plan, evaluate, and optimize BMPs placement at various scales based on treatment effectiveness and costs (Jayasooriya and Ng, 2014; USEPA, 2023c). The program is an ArcGIS based decision support system and requires users to have extensive knowledge of stormwater management practices and GIS software (Lee et al., 2012). Input data for the model includes land use data, catchment data, and design details for BMPs. Research applications vary from site-specific BMP analysis to urban watershed BMP planning (Gao et al., 2015; Lai et al., 2007).

The Model for Urban Stormwater Improvement Conceptualisation (MUSIC) is a widely adopted BMP model in Australia. For this paper, the model will not be discussed in further detail. The Water Environment Research Foundation (WERF) BMP and LID Whole Cycle Cost Modelling Tool was disabled in February 2020 per the WERF website.

1.5 Motivation for Research

The management practice of implementing BMPs will continue as communities incorporate these treatment methods into stormwater regulations to accommodate expanding impervious footprints. Regulations put forth by communities require engineers and stormwater planners to utilize technical models and tools to design BMPs for flow reduction, storage, and water quality management. Models such as HEC-HMS, SWMM, SUSTAIN, MUSIC, and RECARGA require complicated algorithms, extensive data inputs, and a deep technical understanding to operate and output designs (Liu et al., 2015; Dell et al., 2021).

Screening level stormwater management analysis for development and redevelopment is needed for decision makers to assess viability of projects before designs are created (Liu et al., 2015; Schifman et al., 2018). The USEPA National Stormwater Calculator and the L-THIA-LID model are user-friendly, calculator-type, minimal data entry tools providing reliable representation of hydrologic processes. Research has noted these models fulfil the screening level need in stormwater management, but development improvements are necessary to keep with industry practice and recent design improvements (Liu et al., 2015, Dell et al. 2021).

The L-THIA-LID tool can simulate scenarios with a combination of green roof, rain barrel/cistern, permeable pavement, bioretention/raingarden, vegetated swale, and open wood space. The tool requires the user to provide the State and County of the scenario site, input land uses and respective areas, and select the hydrologic soil group (A, B, C, & D) for each land use. The pre-development, post-development (No BMP) and post-development (Including BMP) scenarios are computed and output composite CNs, average annual runoff volumes (acre-feet), average annual runoff depth (inches), and predicted amounts of Non-Point Source contaminants (nitrogen, phosphorus, suspended sediment, heavy metals, and biological indicators). The tool does not size or quantify the BMPs beyond treating a percentage of a given land use and does not include BMPs such as detention, retention, and infiltration trenches. Construction and maintenance costs are not included in the tool and BMPs are chosen by the user without consideration for the desired BMP treatment needs (i.e., water quality, flow reduction, storage, ground recharge via infiltration).

The USEPA National Stormwater Calculator can be accessed on a computer or mobile device. The model utilizes the USEPA SWMM computational engine to simulate long-term historical rainfall modelling coupled with stormwater BMPs. Scenario simulations can include a combination of disconnection, rain harvesting, rain gardens, green roofs, street planters, infiltration basins, and porous pavements. Multiple online national databases such as the USDA SSURGO and the National Weather Service Rain Gauge records are incorporated into the model limiting the required inputs. Users are prompted to input or select values regarding site location, soil drainage and type, site slope, rain gauge location, desired BMPs to model, and project suitability for development or redevelopment. Regional construction and annual maintenance cost data is compiled based on project location, selected stormwater BMPs, and the project suitability. The calculator provides percentages of the site treated by each selected BMP with basic sizing information. Similar to L-THIA-LID, the National Stormwater calculator does not include detention, retention, and vegetative swale BMP options. Suitability of the BMPs to the site's characteristics are not considered for the user and desired treatment needs (i.e., water quality, flow reduction, storage, ground recharge via infiltration) are not incorporated to guide BMP selections in simulations.

Incorporation of BMPs' suitability based on the site's physical characteristics, stormwater treatment needs, and other local, regional, and/or national constraints would provide the user a more informed platform from which they can determine the viability of property development or redevelopment. Providing additional BMPs to model like detention and retention ponds, infiltration trenches, and vegetative swales would expand treatment options for sites and match closer to the available BMPs detailed in many regional design manuals (Liu et al., 2015). Couple these improvements with construction and annual maintenance costs will provide a comprehensive baseline of stormwater management options for both technical and non-technical users.

Understanding the challenges and issues communities face regarding stormwater management reveals the need for technical information and tools that may be used all. Simplified and inexpensive tools providing stormwater management options, costs and effects on watershed health are needed to provide communities, city officials, developers, and engineers information regarding site development. The purpose of this study is to provide a tool that may be utilized by Missouri communities and citizens interested in stormwater management to help inform of potential treatment options using regionally adopted BMPs.

1.6 Objectives of Study

The objectives of the study are to develop and evaluate a Site Stormwater with BMPs Analysis Calculator for use in the State of Missouri capable of evaluating a site's stormwater changes due to development or redevelopment. The calculator, embedded with regional best management practices sizing calculations, will provide recommendations to the user on best suited stormwater management practices for the property in question. The calculator will be evaluated against the USEPA NSC and L-THIA-LID in a development scenario.

1.6.1 Stormwater Calculator

The first step is the development of the Site Stormwater with BMPs Analysis Calculator. The focus of the calculator is to minimize the required information the user must enter regarding stormwater and the site's physical characteristics. This goal allows the calculator to be utilized by professionals in the stormwater field as well as users with non-technical backgrounds. The calculator evaluates design storm peak flows for pre- and post-development scenarios and provides recommendations and cost information on the best suited regional BMPs. This tool does not eliminate the ultimate need for engineering analysis and designs for stormwater runoff from development and redevelopment situations. The calculator provides an initial analysis to inform Users of potential stormwater management options prior to significant financial investment.

1.6.2 Scenarios Evaluation

The second part of the study is to select three sites and model development and redevelopment scenarios in the Site Stormwater with BMPs Analysis Calculator to evaluate BMP strategies. The first scenario is a pad-ready commercial site requiring only water quality treatment as detention is assumed covered by a regional detention pond. The second scenario is a development of a residential subdivision consisting of 16 homes and driveways. This scenario requires detention and water quality treatment for the development. The third scenario is the retrofit of a drainage area that is experiencing erosion issues on the University of Missouri – Columbia campus. The goal for this scenario is to minimize peak flows contributing to erosion in the drainage area with the assumption there will be no additional development occurring. All scenarios are in the City of Columbia, Missouri. Outfalls from each scenario site drain to tributaries of the Hinkson Creek and ultimately flow into the Missouri River. These sites are representative of common stormwater and development scenarios for communities in Missouri and will showcase the simplicity of using the Site Stormwater with BMPs Analysis Calculator to inform the user of potential stormwater management options with no financial investment required. The commercial development scenario results from the Site Stormwater with BMPs Analysis Calculator will be compared to model results from the EPA NSC and L-THIA-LID to validate the effectiveness of the planning tool.

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Chapter 2: The Site Stormwater with BMPs Analysis Calculator

Abstract

Implementation of stringent stormwater regulations to improve water quality, minimize erosion, and reduce high flow rates due to land development has led to the utilization of best management practices (BMPs) Pitt & Maestre, 2005; Hathaway, 2012; Beck et al., 2017). Application of these BMPs requires an understanding of hydrology, stormwater models, and land development engineering limiting planning and design to technically trained individuals. However, non-technical people's expanding interest in stormwater has emphasized the need for simplistic, conservative models and/or tools utilizing regional treatment practices with minimal time and financial investment.

The following methodology and example scenarios introduce the Site Stormwater with Best Management Practices (BMPs) Analysis Calculator. The Excel based calculator analyzes individual scenarios and applies a suitability ranking to its eight BMPs to aid Users in planning any development or redevelopment projects. The calculator is embedded with NOAA PFDS storm data, estimated construction, operation, and maintenance costs, site-specific hydrologic calculations and required design criteria. The calculator, not intended to replace the need for stormwater engineering design, has been developed to educate Users of suitable stormwater treatment options with minimal information entry. Results of the calculator include Pre- and Post-Development hydrology for the scenario entered, costs for construction, maintenance, and operation of each potential BMP, and overall suitability ranking of each BMP to the site's physical characteristics and User preferred design variables.

2.1 Introduction

Regulations are being implemented in developing and redeveloping areas requiring stormwater BMPs capable of reducing runoff volumes and improving water quality (Pitt & Maestre, 2005; Hathaway, 2012; Beck et al., 2017). The means of achieving these stormwater regulations vary due to specific development scenario characteristics, design practices, development costs, and other jurisdiction expectations concerning urbanization. Proper design of BMPs requires a technical understanding of hydrological processes and the capability to operate and analyze a multitude of stormwater tools and models at all design scales (Elliott & Trowsdale, 2007). These tools and models range from simplistic, user friendly to highly technical for use by trained stormwater practitioners and engineers.

The development and redevelopment of land involves iterative planning, designs, and review processes with architects, engineers, community officials and public and private utilities. Consideration to topography, existing and proposed utilities, traffic movements in and out of the property in addition to stormwater infrastructure must fit within the envisioned development or redevelopment. The overall process from conception to finished construction product is intensive in time and costs. Experience, training, and education are necessary in understanding how to implement stormwater regulations, specifically BMPs. Interest in stormwater management is increasing by nontechnical decision makers creating the need for easy-to-use, screening level analysis tools and models to guide development and redevelopment (Liu et al., 2015; Schifman et al., 2018). Two existing models capable of evaluating BMPs are the L-THIA-LID model and he USEPA National Stormwater Calculator.

2.2 Best Management Practices Modeling Needs

Management of stormwater runoff can be addressed by a BMP defined as any action or practice aimed at reducing flow rates and pollution concentrations (City of Columbia, Missouri Public Works Department, 2013). Best Management Practices such as bioretention, infiltration trenches, permeable pavement, green roofs, vegetative swales, rain barrels and cisterns, vegetation management, disconnection, and street planters have been incorporated in industry accepted stormwater tools and models such as the L-THIA-LID model and the USEPA National Stormwater Calculator (Elliott & Trowsdale, 2007; Ahiablame et al., 2012; Rangari et al., 2015; Haris et al., 2016; Kaykhosravi et al., 2018). Robust programming allows these two models to provide scenario simulations informing users how development will alter stormwater with and without BMPs.

Limitations are still found with these screening level analysis tools and models (Liu et al., 2015; Dell et al. 2021). The L-THIA-LID model does not size or quantify the BMPs beyond treating a percentage of a given land use and does not include BMPs such as detention ponds, retention ponds, and infiltration trenches. Construction and maintenance costs are not included in the tool and BMPs are chosen by the user without consideration for the desired BMP treatment needs (i.e., water quality, flow reduction, storage, ground recharge via infiltration). The USEPA National Stormwater Calculator does not include detention ponds, retention ponds, and vegetative swale BMP options. Suitability of the BMPs to the site's characteristics are not considered for the user and desired treatment needs (i.e., water quality, flow reduction, storage, and ground recharge via infiltration) are not incorporated to guide BMP selections in simulations.

Expanding the current capacity of models and tools by implementing BMP suitability analysis based on the site's physical characteristics, stormwater treatment needs, and other local, regional, and/or national constraints, and adding BMPs such as detention ponds, retention ponds, infiltration trenches, and vegetative swales for simulations and estimating construction and annual maintenance costs would provide a comprehensive baseline of stormwater management options for both technical and non-technical users. The following sections describe the development and testing of a tool to be utilized by communities and citizens as well as stormwater practitioners and engineers. The Site Stormwater with BMPs Analysis Calculator is embedded with regional BMPs, construction and maintenance costs, site scale hydrologic calculations, and suitability criteria to guide users toward applying the best suited stormwater management practices for their development or redevelopment. The calculator is specifically for the State of Missouri but could be expanded if hydrological data for other states are incorporated. Additionally, the calculator focuses on minimizing the required information the user must enter regarding stormwater and the site's physical characteristics.

2.3 The Site Stormwater with BMPs Analysis Calculator

2.3.1 Calculator Overview and Objective

All development and redevelopment projects begin as conceptual schematics. The site layout regulations enforced by the local, state, and/or federal governments guide the decision-making process for developers. Analyzing stormwater requirements and determining the best method to meet water quality and quantity control measures can be an intimidating and exhaustive task due to the multitude of treatment options, range of treatment requirements, and other site constraints such as utilities, setbacks, and available area. The purpose of the Site Stormwater with BMPs Analysis Calculator is to provide an evaluation of how proposed development or redevelopment will hydrologically impact a site and what the best treatment options are for counteracting these impacts prior to investment of funds and time by design resources. Community officials and citizens, engineers, and developers will be able to determine site specific stormwater BMPs, approximate sizing of BMPs, and estimated stormwater construction costs and maintenance costs. Municipalities, developers, and designers will be able to plan environmentally sound developments with considerations for water quality, wildlife habitat, and community aesthetics by using the Calculator.

The Site Stormwater with BMPs Analysis Calculator, built in Microsoft Excel (Microsoft Corporation, 2021), utilizes industry accepted stormwater practices, equations, and regional data to assist in planning development or redevelopment of property located in the State of Missouri. The calculator is comprised off the following sections:

1. Instructions
2. User Questionnaire
3. Site Pre-Development
4. Site Post-Development
5. Site Hydrology
6. Cost Analysis
7. BMP Analysis
8. Summary

Additionally, design sheets for precipitation data and BMP suitability are utilized by the above sections of the Site Stormwater with BMP Analysis Calculator.

2.3.2 Instruction Sheet

The Instruction Sheet provides the User directions to utilize the Site Stormwater with BMP Analysis Calculator. Summaries of each sheet in the calculator are provided as well as color legend explaining default cell values, cell values not considered default, and cells needing the user to either select or input a value. The User is not expected to input or select any values on this sheet.

2.3.3 Questionnaire Sheet

The User Questionnaire worksheet is critical for the use of the entire Site Stormwater with BMP Analysis Calculator as multiple sections of the tool rely on answers selected on the questionnaire. To determine the BMPs which best fit the proposed project site, the User is asked to select answers for 26 questions. Questions and answers are developed from literature and stormwater manuals and are grouped into the following three categories: Site Considerations, BMP Treatment Considerations, and Investment and Maintenance Considerations. (USEPA, 1999b; USEPA, 1999c; USEPA, 1999d; USEPA, 1999f; USEPA,1999e; Maryland Department of the Environment, 2000; USEPA, 2004; The Minnesota Pollution Control Agency, 2005; Pennsylvania Department of Environmental Protection, 2006; USEPA, 2007; UDFCD, 2010; USGSA, 2011; MARC & APWA, 2012; City of Columbia, Missouri Public Works Department, 2013; City of San Francisco, California, 2016) Drop-down lists of answers are provided for each question presented. If uncertain on an answer, the user of the tool is presented with the default value for the selected drop-down list when hovering the mouse over the drop-down menu. Another helpful detail is the default value appears highlighted green while all other answer selections appear as yellow highlighted cells.

The following questions and answers can be found on the User Questionnaire of the Site Stormwater with BMP Analysis Calculator. Commercial

Site Considerations:

1) Classify site ownership.
    a. Public Property *(Default Answer)*
    b. Private Property
2) Classify type of construction.
    a. New Development
    b. Redevelopment *(Default Answer)*
3) Are there any active stormwater permits, or regulated outfalls located on the site?
    a. Yes
    b. No *(Default Answer)*
4) Is the site's stormwater management regulated under a MS4 permit?
    a. Yes
    b. No *(Default Answer)*
5) Does the site contain existing storm sewer infrastructure?
    a. Yes *(Default Answer)*
    b. No
    c. Unknown
6) Is there an existing pond or lake located on the site?
    a. Yes
    b. No *(Default Answer)*
7) Are utilities such as gas, water, electric, fiber, and sanitary sewer located on the site?
    a. Yes
    b. No *(Default Answer)*
    c. Unknown
8) Has the site had a history of flooding?
    a. Yes (Every Rain Event)
    b. Yes (occasional)
    c. No *(Default Answer)*
    d. Unknown
9) Does the site show evidence of soil erosion?
    a. Yes
    b. No *(Default Answer)*
    c. Unknown

10) Is there evidence of channel erosion or instability downstream of the site?
    a. Yes
    b. No *(Default Answer)*
    c. Unknown
11) Does the site drain to a waterbody classified on the 303(d) list as an "Impaired or Threatened Water?"
    a. Yes
    b. No *(Default Answer)*
12) Does the site have a history of theft, vandalism, odors, or excessive trash?
    a. Yes
    b. No *(Default Answer)*
    c. Unknown
13) Is there planned buildings or existing buildings on the site?
    a. Yes
    b. No (Default Answer)
    c. Unknown

BMP Treatment Considerations:

1) How effectively should the BMP treat nutrients in the stormwater?
    a. High *(Default Answer)*
    b. Moderate
    c. Low
2) How effectively should the BMP treat bacteria in the stormwater?
    a. High *(Default Answer)*
    b. Moderate
    c. Low
3) How effectively should the BMP treat heavy metals in the stormwater?
    a. High *(Default Answer)*
    b. Moderate
    c. Low
4) How effectively should the BMP treat suspended sediment in the stormwater?
    a. High *(Default Answer)*
    b. Moderate
    c. Low
5) How effectively should the BMP treat organics in the stormwater?
    a. High *(Default Answer)*
    b. Moderate
    c. Low
6) How effectively should the BMP treat oil/grease in the stormwater?
    a. High *(Default Answer)*
    b. Moderate
    c. Low

7) How effectively should the BMP provide peak flow reduction of site stormwater?
    a. High *(Default Answer)*
    b. Moderate
    c. Low
8) How effectively should the BMP provide channel protection from the site stormwater?
    a. High
    b. Moderate *(Default Answer)*
    c. Low
9) What quality habitat should the BMP provide?
    a. High
    b. Moderate
    c. Low *(Default Answer)*
10) How important are the visual aesthetics of the BMP?
    a. High
    b. Moderate *(Default Answer)*
    c. Low
11) How effectively should the BMP provide temperature reduction?
    a. High *(Default Answer)*
    b. Moderate
    c. Low

Investment and Maintenance Considerations:

1) What is the preferred cost range of implementing a BMP?
    a. High
    b. Medium
    c. Low *(Default Answer)*
2) What is the preferred cost range for yearly maintenance of a BMP?
    a. High
    b. Medium
    c. Low *(Default Answer)*
3) What is the preferred level of operation and maintenance required for a BMP?
    a. High
    b. Medium
    c. Low *(Default Answer)*

BMP treatment consideration answers of High, Moderate, and Low generalize treatment levels desired for each specific pollutant, aesthetic provided, and other outputs resulting applied management practices. Due to differences in research variables and study focuses specific ranges applied to each answer value (High, Moderate, and Low) were not assigned in this version of the calculator. This same idea was also applied to the Investment and Maintenance Considerations. While most new developments and re-developments are conscientious of costs, there may be scenarios where costs are not considered a major limiting factor. Consequently, the User has the option to select different answer values to see how the overall suitability ranking for their specific scenario adjusts. Clarifying calculator treatment answers with researched ranges for treatment levels in a future version of the calculator would provide the User more information when selecting answers.

2.3.4 BMP Suitability Sheet

The BMP Suitability sheet calculates scores for each BMP option in The Site Stormwater with BMPs Analysis Calculator from the selected answers in the User Questionnaire. A maximum score of 17 can be calculated for a BMP as all BMPs are weighted evenly in the suitability analysis. Consideration was made for weighting BMP treatment capabilities based on their ability to fit new development versus re-development better but was not applied for this version of the calculator. The table presented on this sheet details 17 design criteria with the selected User Questionnaire answer in the adjacent cell. The BMPs are organized by columns with auto-filled "Match" or "No Match" results for each criteria row. When a BMP result is a "Match" the cell is highlighted green while a result of "No Match" is highlighted yellow. Determination of "Match" or "No Match" is collated from regional and national stormwater treatment manuals as well as articles and fact sheets on each BMP. For a BMP to match the researched treatment capability, habitat, visual aesthetic, and cost constraints must match with the selected User answers on the Questionnaire sheet. The calculator accounts for whether the drainage area of the site can be adequately treated by multiple BMPs for the entered scenario. Some BMPs work within a range of slope percentages. Consequently, the calculator accounts for these ranges in determining whether User's selected answers match for each BMP.

The sheet provides a suitability ranking of BMPs to the site and desired treatment effectiveness. While most scenarios may lead to similar results, there are potential scenarios where less often selected BMPs such as permeable pavement and green roofs are considered viable options by the calculator. An example would be a re-development of business office with limited pervious space on the site. Removing parking lot to install permeable pavement with an underground conveyance system could adequately treat stormwater and roof space being converted to a green roof system would allow further treatment options. The calculator's suitability analysis accounts for these situations through the available questions and researched criteria answers.

The BMP Suitability sheet does not require the user to enter or edit cells. The following is a breakdown of each BMP in The Site and BMP Analysis Tool and its suitability answer to each User Questionnaire question.

Table 2.1: Bioretention Suitability Answers

Bioretention	
Treatment of Nutrients	High
Treatment of Bacteria	High
Treatment of Heavy Metals	High
Treatment of Suspended Sediment	High
Treatment of Organics	High
Treatment of Oil/Grease	High
Peak Flow Reduction	Moderate
Channel Protection	Moderate
Habitat Established	Medium
Visual Aesthetics	Medium
Temperature Reduction	High
Construction Cost	Medium
Maintenance Cost	Medium
Amount of maintenance required per year	Medium
Hydrologic Soil Classification	A/B/C/D
Drainage Area (Acres)	4
Calculated Slope % (Minimum)	0%
Calculated Slope % (Maximum)	5%

Table 2.2: Vegetative Swale Suitability Answers

Vegetative Swale	
Treatment of Nutrients	Low
Treatment of Bacteria	Low
Treatment of Heavy Metals	Moderate
Treatment of Suspended Sediment	Moderate
Treatment of Organics	Moderate
Treatment of Oil/Grease	Moderate
Peak Flow Reduction	Low
Channel Protection	Low
Habitat Established	Medium
Visual Aesthetics	High
Temperature Reduction	Low
Construction Cost	Low
Maintenance Cost	Low
Amount of maintenance required per year	Medium
Hydrologic Soil Classification	A/B/Engineered Media
Drainage Area (Acres)	5
Calculated Slope % (Minimum)	2%
Calculated Slope % (Maximum)	4%

Table 2.3: Infiltration Trench Suitability Answers

Infiltration Trench	
Treatment of Nutrients	High
Treatment of Bacteria	High
Treatment of Heavy Metals	High
Treatment of Suspended Sediment	Low
Treatment of Organics	High
Treatment of Oil/Grease	High
Peak Flow Reduction	High
Channel Protection	Moderate
Habitat Established	Low
Visual Aesthetics	High
Temperature Reduction	High
Construction Cost	High
Maintenance Cost	N/A
Amount of maintenance required per year	High
Hydrologic Soil Classification	A/B
Drainage Area (Acres)	5
Calculated Slope % (Minimum)	0%
Calculated Slope % (Maximum)	15%

Table 2.4: Green Roof Suitability Answers

Green Roof	
Treatment of Nutrients	Low
Treatment of Bacteria	Low
Treatment of Heavy Metals	Low
Treatment of Suspended Sediment	Low
Treatment of Organics	Low
Treatment of Oil/Grease	Low
Peak Flow Reduction	Moderate
Channel Protection	Moderate
Habitat Established	High
Visual Aesthetics	High
Temperature Reduction	High
Construction Cost	High
Maintenance Cost	High
Amount of maintenance required per year	Moderate
Hydrologic Soil Classification	Engineered Media
Drainage Area (Acres)	N/A
Calculated Slope % (Minimum)	N/A
Calculated Slope % (Maximum)	N/A

Table 2.5: Rain Barrel and Cisterns Suitability Answers

Rain Barrel and Cisterns	
Treatment of Nutrients	High
Treatment of Bacteria	High
Treatment of Heavy Metals	High
Treatment of Suspended Sediment	High
Treatment of Organics	High
Treatment of Oil/Grease	Low
Peak Flow Reduction	Low
Channel Protection	Moderate
Habitat Established	Low
Visual Aesthetics	Low
Temperature Reduction	Low
Construction Cost	Low
Maintenance Cost	Low
Amount of maintenance required per year	Low
Hydrologic Soil Classification	Engineered Media
Drainage Area (Acres)	N/A
Calculated Slope % (Minimum)	N/A
Calculated Slope % (Maximum)	N/A

Table 2.6: Permeable Pavement Suitability Answers

Permeable Pavement	
Treatment of Nutrients	Low
Treatment of Bacteria	Moderate
Treatment of Heavy Metals	Moderate
Treatment of Suspended Sediment	High
Treatment of Organics	Moderate
Treatment of Oil/Grease	Low
Peak Flow Reduction	Moderate
Channel Protection	Moderate
Habitat Established	Low
Visual Aesthetics	Medium
Temperature Reduction	High
Construction Cost	High
Maintenance Cost	High
Amount of maintenance required per year	High
Hydrologic Soil Classification	A/B/C
Drainage Area (Acres)	15
Calculated Slope % (Minimum)	1%
Calculated Slope % (Maximum)	5%

Table 2.7: Detention Pond Suitability Answers

Detention Pond	
Treatment of Nutrients	Low
Treatment of Bacteria	Moderate
Treatment of Heavy Metals	Moderate
Treatment of Suspended Sediment	Moderate
Treatment of Organics	Moderate
Treatment of Oil/Grease	Low
Peak Flow Reduction	High
Channel Protection	High
Habitat Established	Low
Visual Aesthetics	Medium
Temperature Reduction	Moderate
Construction Cost	Low
Maintenance Cost	Low
Amount of maintenance required per year	Low
Hydrologic Soil Classification	A/B/C/D
Drainage Area (Acres)	5
Calculated Slope % (Minimum)	1%
Calculated Slope % (Maximum)	25%

Table 2.8: Retention Pond Suitability Answers

Retention Pond	
Treatment of Nutrients	Moderate
Treatment of Bacteria	High
Treatment of Heavy Metals	High
Treatment of Suspended Sediment	High
Treatment of Organics	High
Treatment of Oil/Grease	High
Peak Flow Reduction	High
Channel Protection	High
Habitat Established	Medium
Visual Aesthetics	Medium
Temperature Reduction	Low
Construction Cost	Low
Maintenance Cost	Medium
Amount of maintenance required per year	Medium
Hydrologic Soil Classification	C/D
Drainage Area (Acres)	10
Calculated Slope % (Minimum)	1%
Calculated Slope % (Maximum)	25%

2.3.5 Site Pre- and Post-Development Sheets

The Site Pre- and Post-Development sheets calculate the CN and Time of Concentration (T_C) for the parcel of land being considered for development or redevelopment. These parameters are then utilized in development of the Pre- and Post-Development Dimensionless Hydrographs under the Site Hydrology sheet. The User must select the Hydrologic Soil Group (HSG) and the Land Use from drop down menus as well as input the area of the site in acres to calculate the CN. These cells are highlighted blue on the sheet. The soil group classifications are A (Sandy Clay, Loamy Sand, Sandy Loam), B (Silty Loam, Loam), C (Sandy Clay Loam), and D (Clay Loam, Sandy Clay, Silty Clay, Clay) (NRCS, 1986). The Land Use drop down menu offers cover descriptions from the CN tables found in Chapter 9 of Part 630 Hydrology of the National Engineering Handbook (Figure 2.3; NRCS, 2004) by the Natural Resources Conservation Service (NRCS). An example CN calculation is provided below Figure 2.1.

<u>*Curve Number:*</u>

HSG	Land use	CN	Area (Acres)	Percentage (%)	Product
D	Open Space (Good; Grass Cover > 75%)	80	2.5	71%	200
B	Woods (Good)	55	1	29%	55

Figure 2.1: Example of Pre- and Post-Development Sheet Entry Requirements (Highlighted Blue) for The Site Stormwater with BMPs Analysis Calculator

$$\boldsymbol{CN\ (Open\ Space - Good, Grass\ Cover > 75\%) = 80\ x\ 2.5\ acre = 200} \qquad \textbf{Eq'n 1}$$

$$\boldsymbol{CN\ (Woods - Good) = 55\ x\ 1.0\ acre = 55} \qquad \textbf{Eq'n 2}$$

$$\boldsymbol{CN\ Product\ Sum = 200 + 55 = 255} \qquad \textbf{Eq'n 3}$$

$$\textbf{\textit{Site CN}} = \frac{\textbf{\textit{CN Product Sum}}}{\textbf{\textit{Site Area}}} = \frac{\mathbf{255}}{\mathbf{3.5}} = \mathbf{72.9} \qquad \textbf{Eq'n 4}$$

The Tc consists of determining the longest flow path and calculating the Sheet Flow, Shallow Flow, and Channel Flow. Definitions of these terms and others are detailed in Table 2.9 below. The calculator has three (3) rows for Sheet Flow and Shallow Flow input information and two (2) rows for Channel Flow input. The Sheet Flow and Shallow Flow inputs required include Surface Cover (drop down menu), Flow Length in linear feet, and Slope in feet/feet (ft/ft). A corresponding Manning's 'n' value is automatically inputted based on the selected surface cover. Sheet Flow is computed by Equation 5 (NRCS, 2010) and the calculator inputted 'n' value.

Table 2.9: Hydrological Terms and Definitions (NRCS, 2010)

Term	Definition
Channel Flow	Flow assumed to begin where surveyed cross-section information has been obtained, where channels are visible on aerial photographs, or where bluelines (indicating streams) appear on U.S. Geological Survey (USGS) quadrangle sheets.
Flow Length	Length of flow (Sheet, Shallow, and Channel Flow) measured in feet.
Longest Flow Path	The hydraulically most distant point is the point with the longest travel time to the watershed outlet, and not necessarily the point with the longest flow distance to the outlet.
Shallow Flow	Concentrated flow collecting in swales, small rills, and gullies. Flow is assumed to not have a well-defined channel and has flow depths of 0.1 to 0.5 feet.
Sheet Flow	Flow over plane surfaces and usually occurs in the headwaters of a stream near the ridgelines that defines the watershed boundary. Typically, flow occurs for no more than 100 feet before transitioning to shallow concentrated flow.
Time of Concentration	The time required for runoff to travel from the hydraulically most distant point in the watershed to the outlet.

$$T_t = \frac{0.007(nl)^{0.8}}{[(P_2)^{0.5}S^{0.4}]}$$ **Eq'n 5**

T_t = Sheet Flow Travel Time (hours)
n = Manning's 'n' value
l = Length of Sheet Flow
P_2 = 2 year, 24-hour Precipitation
S = Slope (ft/ft)

The 2-year, 24- hour precipitation value for the Sheet Flow calculation is searched from the Precipitation Data sheet. Design storm values are pulled from the National Oceanic and Atmospheric Administration (NOAA) Hydrometeorological Design Studies Center Precipitation Frequency Data Server (PFDS) webpage (https://hdsc.nws.noaa.gov/pfds/) which utilizes the Atlas 14-point precipitation frequency estimates. For simplicity, counties with multiple weather stations on the PFDS were grouped together by averaging each design storm. If a Missouri county does not contain a weather station on the PFDS, the surrounding counties with verified weather stations are averaged together for each design storm to provide an approximate baseline for the county in question.

Shallow Flow calculations utilize the following equations in Figure 2.2 to calculate velocity (ft/s).

Table 15–3 Equations and assumptions developed from figure 15–4

Flow type	Depth (ft)	Manning's *n*	Velocity equation (ft/s)
Pavement and small upland gullies	0.2	0.025	$V = 20.328(s)^{0.5}$
Grassed waterways	0.4	0.050	$V = 16.135(s)^{0.5}$
Nearly bare and untilled (overland flow); and alluvial fans in western mountain regions	0.2	0.051	$V = 9.965(s)^{0.5}$
Cultivated straight row crops	0.2	0.058	$V = 8.762(s)^{0.5}$
Short-grass pasture	0.2	0.073	$V = 6.962(s)^{0.5}$
Minimum tillage cultivation, contour or strip-cropped, and woodlands	0.2	0.101	$V = 5.032(s)^{0.5}$
Forest with heavy ground litter and hay meadows	0.2	0.202	$V = 2.516(s)^{0.5}$

Figure 2.2: Surface Cover Velocity Equations and Assumptions to be Inputted into Shallow Flow Time Calculations - Chapter 15, Part 630 Hydrology of the National Engineering Handbook (NRCS, 2010)

The Calculator inputs the computed velocity into Equation 6 (NRCS, 2010).

$$T_t = \frac{l}{3{,}600V} \qquad \textbf{Eq'n 6}$$

T_t = Shallow Flow Travel Time (hours)
l = Length of Shallow Flow
V = Velocity (ft/s)

The final part to calculating the Pre-Development T_C is to determine the Channel Flow time. The user can select the best descriptor of the channel to assign a representative manning's 'n' as well as select the best fit channel geometry. Options provided are Triangular, Trapezoidal, and Rectangular. Additional inputs required to be entered are the Channel Length (ft), Slope (ft/ft), base channel width (ft), channel depth (ft), and side slope (ft/ft). If needed, the user can split the channel flow into two separate entries to best reflect changes in the channel as water moves downstream on the scenario site.

Calculation of the T_C does not require selections and entries for Sheet Flow, Shallow Flow, and Channel Flow. Only Sheet Flow is required to be calculated for proper development of the Pre- and Post-Development Dimensionless Hydrographs on the Site Hydrology sheet. The calculated CN and T_C values for both the Site Pre- and Post-Development sheets are auto populated into multiple sheets for further use in the calculator.

Table 9–5 Runoff curve numbers for urban areas 1/

Cover description cover type and hydrologic condition	Average percent impervious area 2/	-- CN for hydrologic soil group -- A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.) 3/					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only) 4/		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation)		77	86	91	94

1/ Average runoff condition, and $I_a = 0.2S$.

2/ The average percent impervious area shown was used to develop the composite CNs. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition.

3/ CNs shown are equivalent to those of pasture. Composite CNs may be computed for other combinations of open space type.

4/ Composite CNs for natural desert landscaping should be computed using figures 9–3 or 9–4 based on the impervious area percentage (CN=98) and the pervious area CN. The pervious area CNs are assumed equivalent to desert shrub in poor hydrologic condition.

Figure 1.3: Runoff Curve Numbers for Urban Areas - Chapter 9, Part 630 Hydrology of the National Engineering Handbook (NRCS, 2004)

2.3.6 Site Hydrology Sheet

Auto populated by the results of the Site Pre-Development and Site Post-Development sheets, this page calculates the runoff depth and dimensionless hydrographs for both scenarios. The user shall select five (5) design storms from the highlighted blue drop down menus. A series of equations calculating the Maximum Potential Retention, Initial Abstraction, Runoff, Unit Peak Discharge, and Peak Discharge are prompted once selection of design storms is completed (See Equations 7-10; NRCS, 2004).

$$S = \frac{1000}{CN} - 10$$ **Eq'n 7**

S = Maximum Potential Retention (Inches)
CN = Curve Number

$$I_a = 0.2S$$ **Eq'n 8**

I_a = Initial Abstraction (Inches)
S = Maximum Potential Retention (Inches)

$$Q = \frac{(P-I_a)^2}{(P-I_a)+S}$$ **Eq'n 9**

Q = Depth of Runoff (Inches)
P = Depth of Rainfall (Inches)
I_a = Initial Abstraction (Inches)
S = Maximum Potential Retention (Inches)

$$q_p = Q(\frac{CN}{640})(q_u)$$ **Eq'n 10**

q_p = Peak Discharge (Cubic Feet Per Second "cfs")
Q = Depth of Runoff (Inches)
CN = Curve Number
q_u = Unit Peak Discharge (csm/in)

The calculator determines the ratio of Initial Abstraction and Precipitation and adjusts it if the value is less than 0.10. The Unit Peak Discharge chart (Figure 2.4) for an NRCS SCS Type II rainfall distribution is point by point entered into the calculator and then an Index calculation determines the corresponding Unit Peak Discharge value presented on the Site Hydrology sheet. This value is used to calculate the peak discharge for the given design storm selected by the User. Expansion of the calculator's hydrological data set to other states would require consideration of a NRCS SCS curve other than Type II.

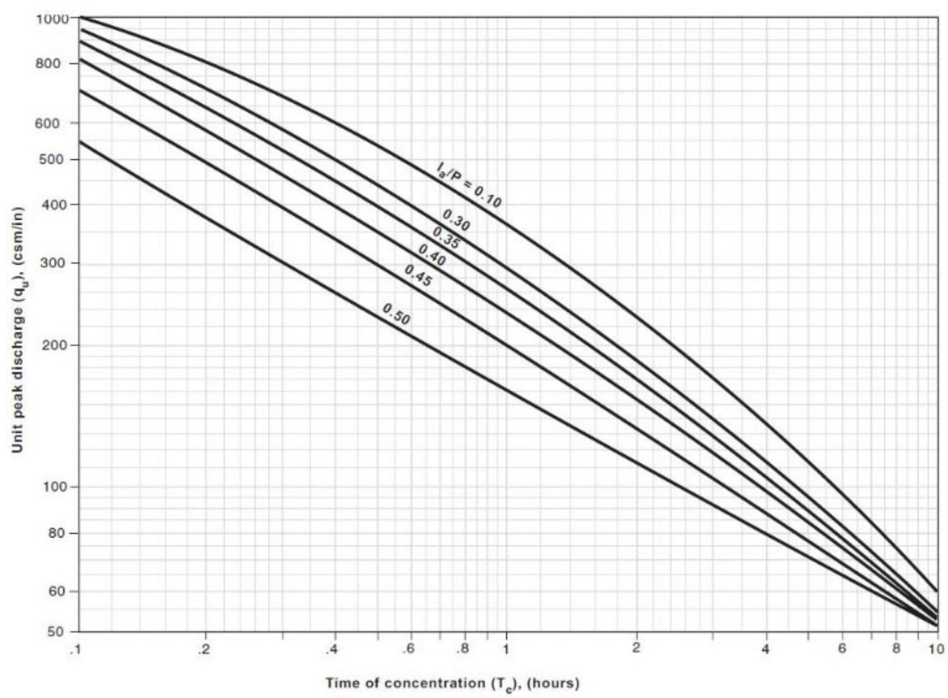


Figure 2.4: Unit Peak Discharge (q_u) Chart for NRCS SCS Type II Rainfall Distribution from Chapter 4 of TR-55 - Urban Hydrology for Small Watersheds (NRCS, 1986)

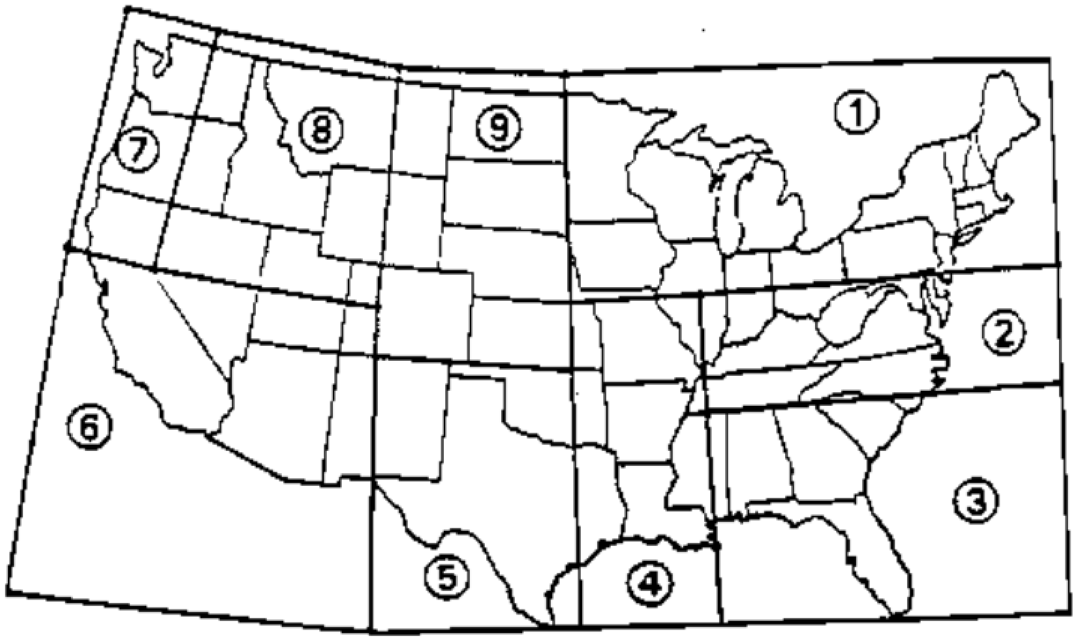
The calculations above contribute to the development of the unitless hydrograph. The calculator utilizes the ratios for the mass curve and dimensionless unit hydrograph found in Chapter 16 of the NRCS Part 630 Hydrology National Engineering Handbook

(2007) to plot the time and flow of each chosen design storm. The Urban Hydrology for Small Watersheds Technical Release -55 (TR-55) program was used to verify The Site Stormwater with BMPs Analysis Calculator correctly develops the peak discharges and hydrograph (NRCS, 1986). Results of this simulation can be found in Appendix A. Minor differences in peak flows can be attributed to rounding differences in the two programs. The standard design storm values vary slightly between TR-55 and the calculator. Another reason for peak discharge differences is TR-55 Shallow Flow Manning's "n" Values are either Paved (n = 0.025) or Unpaved (n=0.05). The Site Stormwater with BMPs Analysis Calculator provides multiple options of paved and unpaved surfaces and their respective Manning's "n" values. The TR-55 approach is conservative for Shallow Flow calculations and generally leads to smaller T_C and higher peak discharges.

The calculator details the pre- and post-development hydrographs based on land use changes but does not show the impact of the post-development hydrograph if a selected BMP is constructed on the scenario site. Implementation of a constructed BMP should increase the calculated T_C leading to decreased peak flow rates. However, the selected location of the BMP on the site would impact the total decrease in site runoff calculated for a given design storm.

2.3.7 Cost Analysis Sheet

The Cost Analysis sheet provides the Site Stormwater and BMPs Analysis Calculator user construction and maintenance costs for each potential treatment strategy. Cost values of each stormwater BMP throughout the U.S. were collected from published literature. Studies detailed costs calculations utilizing water quality volumes (Schueler, 1987; Brown and Schueler, 1997a; USEPA, 1999a), cost calculations utilizing BMP watershed area (Wossink & Hunt, 2003), and unit construction costs based on treatment volume, drainage area, or BMP footprint area. (Weiss et al., 2005; Joksimovic & Alam, 2014; USACE, 2014; Wright et al., 2016) All cost data were adjusted to 2018 pricing utilizing an annual average inflation rate of 3% and the USEPA's 'Regional Cost Adjustment Factors' (USEPA, 1999). Each rainfall zone shown in Figure 2.5 has an assigned cost adjustment factor (Table 2.10) which is divided into the researched cost value to account for regional cost biases. Table 2.11 details the ratio of construction costs to maintenance and operation costs. Construction and maintenance cost information analyzed does not include engineer design fees, permitting, and contingencies. (USEPA, 2015) Although the construction, operation, and maintenance costs are based on researched values and applied with regional cost adjustment factors and inflation percentages, all costs presented in The Site Stormwater with BMPs Analysis calculator are estimated and to be used as informative values for desired treatment practices.



Not shown: Alaska (Zone 7); Hawaii (Zone 7); Northern Mariana Islands (Zone 7); Guam (Zone 7); American Samoa (Zone 7); Trust Territory of the Pacific Islands (Zone 7); Puerto Rico (Zone 3) Virgin Islands (Zone 3).

Figure 2.5: USEPA Regional Rainfall Zones Utilized for Applying Regional Cost Bias Adjustment Factors to Calculate BMP Construction and Maintenance Costs. (USEPA, 1999a)

Table 2.10: Rainfall Zones and Corresponding Adjustment Factors (USEPA, 1999a)

Rainfall Zone	1	2	3	4	5	6	7	8	9
Adjustment Factor	1.12	0.90	0.67	0.92	0.67	1.24	1.04	1.04	0.76

Table 2.10: BMP Ratios of Construction to Maintenance and Operation Cost Averages

BMP	Ratio of Construction to Maintenance and Operation Cost Averages	Sources
Bioretention	20:1	Schueler, 1987; Brown & Schueler, 1997a; Brown & Schueler, 1997b; USEPA, 1999; Wossink & Hunt, 2003; Weiss et al., 2005; Schueler et al., 2007; MDESSA, 2011; MPCA, 2011; Joksimovic & Alam, 2014; USACE, 2014; USEPA, 2015; Wright et al., 2016; USEPA, 2017
Vegetative Swale	27:1	Brown & Schueler, 1997b; USEPA, 1999; Schueler et al., 2007; MDESSA, 2011; Joksimovic & Alam, 2014; USEPA, 2015; USEPA, 2017
Infiltration Trench	11:1	Brown & Schueler, 1997a; Brown & Schueler, 1997b; USEPA, 1999; Weiss et al., 2005; MDESSA, 2011; MPCA, 2011; Joksimovic & Alam, 2014; USEPA, 2017
Green Roof	11:1	Schueler et al., 2007; CNET, 2009; Joksimovic & Alam, 2014; USACE, 2014; USEPA, 2015; Wright et al., 2016
Rain Barrel/Cistern	20:1	Schueler et al., 2007; Joksimovic & Alam, 2014; USEPA, 2015; Wright et al., 2016
Continuous Permeable Pavement Systems	8:1	Schueler, 1987; Brown & Schueler, 1997a; Schueler et al., 2007; CNET, 2009; MDESSA, 2011; MPCA, 2011; Joksimovic & Alam, 2014; USACE, 2014; USEPA, 2015; Wright et al., 2016; USEPA, 2017
Detention Pond	38:1	Brown & Schueler, 1997a; Brown & Schueler, 1997b; USEPA, 1999; Weiss et al., 2005; Schueler et al., 2007; Olson et al., 2010; MDESSA, 2011; USEPA, 2017
Retention Pond	45:1	Brown & Schueler, 1997a; Brown & Schueler, 1997b; USEPA, 1999; Wossink & Hunt, 2003; Weiss et al., 2005; Schueler et al., 2007; Olson et al., 2010; MDESSA, 2011; MPCA, 2011; USEPA, 2017

2.3.8 BMP Analysis Sheet

The BMP Analysis Sheet contains the BMPs design parameters with calculations based on the contributing drainage area input in earlier calculator sheets. Design parameters filled blue may be changed by the user (See Figure 2.6). All other parameters are input values copied from other sheets or calculations embedded within the calculator researched from multiple national stormwater manuals. Each stormwater BMP utilizes a water quality rainfall event of 1.3 inches to calculate the water quality volume to be captured and treated. This rainfall amount equates to an event producing less than or equal to 90% stormwater runoff volume of all 24-hour storms on an annual basis. (City of Columbia Public Works Department, 2013) The 1.3 inches is a default value that can be changed by the user if desired or if local regulations utilize a different water quality design depth. The BMP Analysis Sheet inputs sizing information into the Summary sheet to calculate total construction and maintenance costs.

BMP Size and Treatment Analysis			
Project Name:	**Scenario 1 - Commercial Development Site**	**Date:**	**December 6, 2023**
		Location:	**Boone County**
Water Quality Storm (Event producing less than or equal to 90% stormwater runoff volume of all 24-hour storms on an annual basis)		1.3	**Inches**

Bioretention	
Tributary area to bioretention area - A_T (acres)	2.50
Water Quality Volume - WQ_v (ft^3)	8243.15
Planting bed soil depth - d_f (ft)	2.50
Coefficient of permeability for planting soil bed - k (ft/day)	1.00
Maximum ponding depth - h_{max} (ft)	1.00
Average height of water above bioretention bed - h_{avg} (ft)	0.50
Time required for WQ_v to filter through the planting soil bed - t_f (days)	2.00
Required filter bed surface area - A_f (ft^2)	3434.65
Approximate filter bed length - L_f (ft)	84.00
Approximate filter bed width - W_f (ft)	42.00
Required Ponding Area - A_p (sf)	8243.15

Figure 2.6: The BMP Analysis Sheet Showing the Bioretention BMP Sizing Variables (Blue Colored Cells Indicate Value can be Adjusted by the User).

2.3.9 Summary Sheet

The Summary Sheet summarizes the findings within the tool. The pre- and post-development inputs and calculations are presented along with the required water quality volume needing treated. The construction year and inflation rate are included along with construction and maintenance costs for each BMP quantity required to treat the water quality volume. The summary sheet also provides the ranking of each BMP based on the suitability analysis, cost, and BMP quantity needed. A composite score of the rankings is provided and the BMPs are ranked one (1) through eight (8) on their ability to provide the expected stormwater treatment and management needed for the specific site. The summary sheet also includes the pre- and post-development dimensionless hydrographs. If an overall rank is not assigned, this is due to the BMP not meeting a required minimum to construct. For example, if buildings are not planned or existing on a site, then the Green Roof BMP is not viable for treatment.

2.3.10 Precipitation Data Sheet

The Precipitation Data sheet has no User inputs or selections. The sheet allows the user to make selections on other sheets in the calculator. These selections look up values from the Precipitation Data sheet and enter those values into programed calculations regarding the scenario site's hydrology. Tabulated in the Precipitation Data Sheet are design storm values from the NOAA Hydrometeorological Design Studies Center (PFDS) webpage (https://hdsc.nws.noaa.gov/pfds/) which utilizes the Atlas 14-point precipitation frequency estimates for each county in Missouri (Perica et al., 2013). Figure 2.7 depicts all NOAA verified weather stations in the State of Missouri. Multiple counties contain one or more weather stations, while only four counties do not have a weather station available. For data simplicity, counties with multiple weather stations on the PFDS were grouped together by averaging each design storm. The four Missouri counties without a weather station on the PFDS have the surrounding counties' weather stations averaged together for each design storm to provide an estimated precipitation value. Design storm return years included on the precipitation sheet are 1-year, 2-year, 10-year, 25-year, and 100-year storms. Time values for each of the return periods are 1-hour, 2-hour, 6-hour, 12-hour, and 24-hour. The Use of Design storms is a widely adopted process for evaluating Low Impact Developments and Best Management Practices. (MARC & APWA, 2012; City of Columbia, Missouri Public Works Department, 2013)

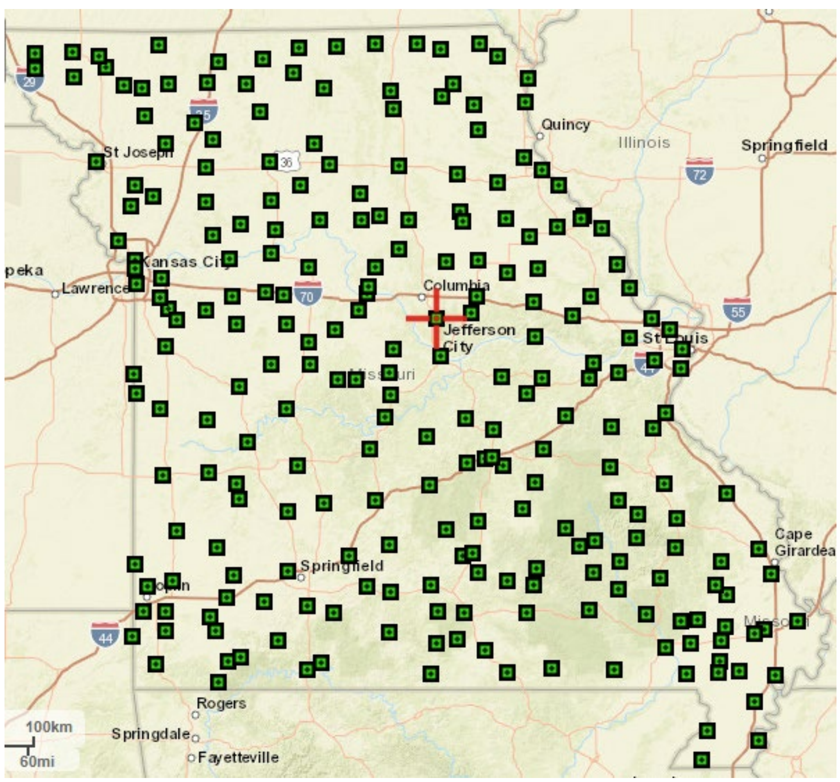


Figure 2.7: NOAA Precipitation Frequency Data Server Weather Stations in the State of Missouri (https://hdsc.nws.noaa.gov/pfds/pfds_map_cont.html?bkmrk=mo)

2.4 Methods

2.4.1 Site Location Overview

The focus area for the case studies is the City of Columbia in Boone County, Missouri. All development in the City of Columbia must comply with the city's stormwater ordinance and the Public Works Department's Stormwater Management and Water Quality Manual (2013). The case studies are in the Hinkson Creek Watershed (HCW) with each locations' outfall directed to the Hinkson Creek. The USEPA lists Hinkson Creek on the 303(d) list of impaired waters and established a Total Maximum Daily Load (TMDL) identifying bacteria within urban runoff as the impairment. (Flournoy, K. A., 2011) Other waterbodies located in the City of Columbia and Boone County, Missouri, have also been included on the 303(d) list for similar pollutant issues. (Show-Me Stormwater Management, 2022) The City of Columbia along with Boone County, Missouri and the University of Missouri campus were regulated to develop and maintain a municipal separate storm sewer system (MS4) stormwater management plan to inform and guide these jurisdictions about pollution. As a result of the MS4, the City of Columbia implemented a stormwater manual establishing protocols for selecting, sizing, and constructing BMPs for all development and re-development.

Other established requirements include treatment of a storm's water quality volume and detaining post-development flows onsite to a pre-development flow rate. The City's stormwater manual instructs stormwater collection system and detention calculations to utilize 24-hour rainfall depths. A collection system shall be able to adequately contain and convey a 10-year, 24-hour design storm while a 25-year, 24-hour design storm shall be released from BMPs at the same flow rate in the post-development design as the pre-development scenario allows. All higher intensity storms or more extreme weather situations have BMPs designed to fully contain and/or pass resulting flows from a 100-year, 24-hour design storm (without structural failure) through an emergency spillway. Consequently, any development scenario in the City of Columbia needs to consider the flows resulting from 1-year, 2-year, 10-year, 25-year, and 100-year 24-hour design storms. A final rule regarding development enforced by the city is a site can contain a maximum of 85% impervious surfaces. Therefore, if a proposed development is to occur on a 1-acre tract, only 0.85-acres can be impervious surfaces such as buildings, parking lot, sidewalks, etc. while the remaining 0.15-acres must be able to infiltrate stormwater.

2.4.2 Soil Overview

Classification of the hydrologic soil group is critical in determining the degree of stormwater runoff to be experienced on a particular site in the pre- and post-development scenarios. The upper portion of the HCW contains agricultural crop ground, pastures, and wooded areas while the lower half of the watershed is dominantly residential and urban as it is within the city limits of Columbia, Missouri as depicted in Figure 2.8. Hubbart (2009) described the HCW soils as a mix of loamy till with a well-developed clay pan, a thin cherty clay, and silty to sandy clay. Steep slopes in the watershed lead to highly erodible areas effecting water quality in Hinkson Creek. (Perkins, 1995) For modeling of soils in and around the City of Columbia, the clay-based soil results in utilizing HSG class C or D due to the soil's poor ability to infiltrate water. Additionally, if an area has experienced disturbance such as grading a site, the proper method is to assume HSG class D as the soil is no longer in its natural state or structure.

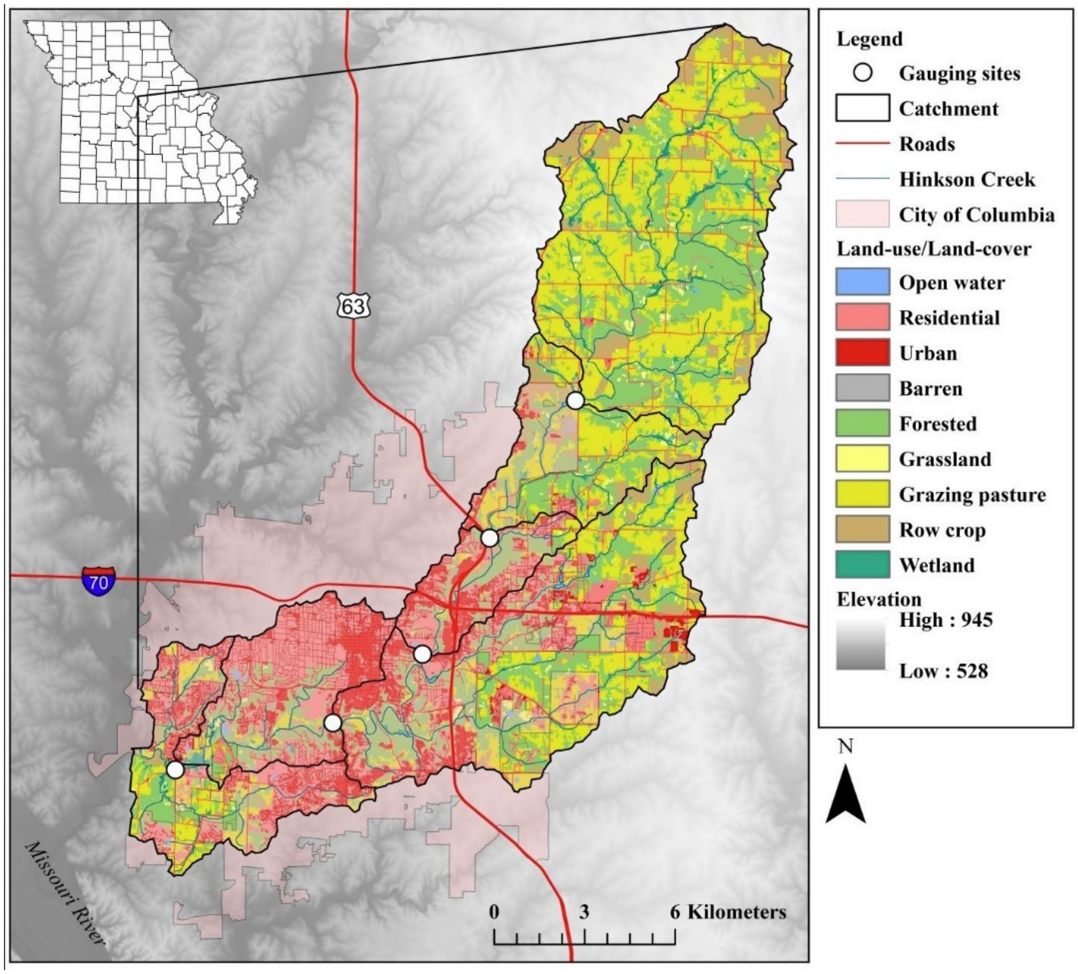


Figure 2.8: Land Cover Map of Hinkson Creek Watershed Overlaid on City of Columbia City Limit Layer. (Source: A Watershed Case Study – Hinkson Creek to the Gulf Website https://bigmuddyspeakers.org/2015/04/hinkson_roche-2015/)

2.4.3 Scenario 1

The first scenario is a 2.50-acre site (Figure 2.9) located near I-70 and the Highway 63 Interchange in the City of Columbia in Boone County, Missouri. The selected site is a build-ready pad zoned as mixed commercial (Figure 2.10). Topographic survey available on the Boone County Accessor's website (https://www.showmeboone.com/assessor/viewers.asp) details the site as having a 5% slope west to east and less than 1% south to north (Figure 2.11). A desktop review of the site noted existing easements and/or utility infrastructure is in place along the road facing portion of the site. Stormwater runoff from the site drains to a tributary of Hinkson Creek and regional detention for the development is included in the large detention basin southwest of the location as noted on Figure 2.9. A pre-development HSG class D soil is assumed as the site and surrounding land has been disturbed via grading. The total drainage area will be just the proposed site of 2.50 acres as the surrounding commercial developments will need to minimize offsite drainage to reach their prescribed treatment levels set forth by the City of Columbia stormwater regulations. Water quality volume treatment will need to be part of the BMP design for this scenario.

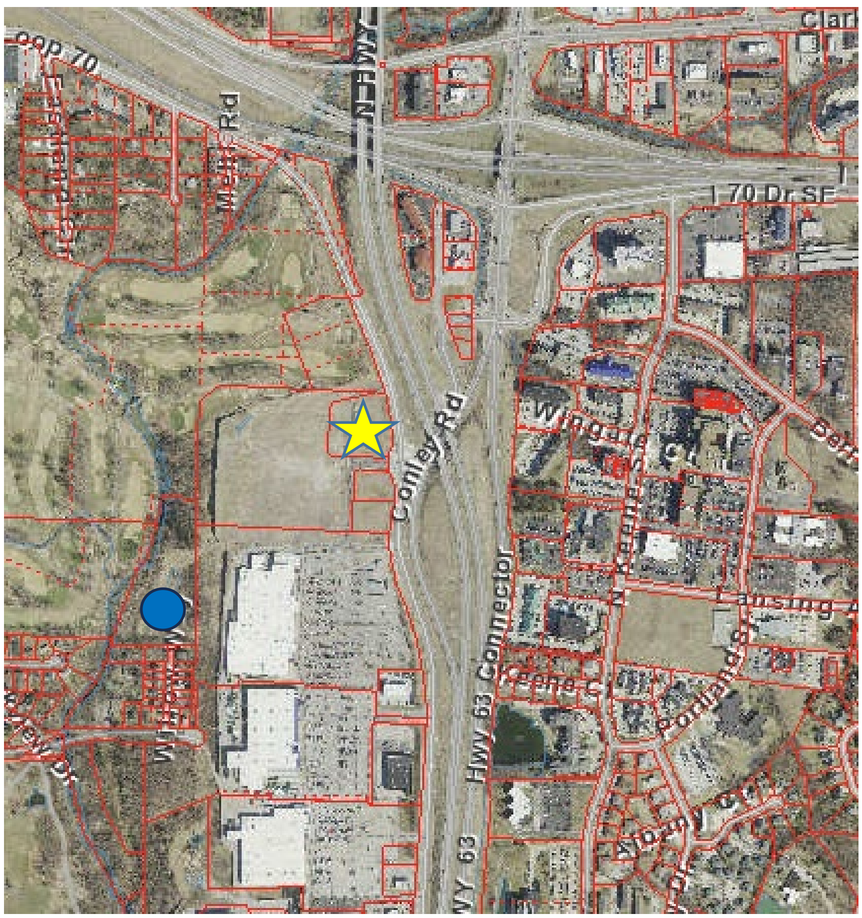


Figure 2.9: Satellite Imagery of Scenario 1 Site Indicated by Star and Area Detention Pond Indicated by Blue Dot. (Source: Boone County Parcel View, February 23, 2022)

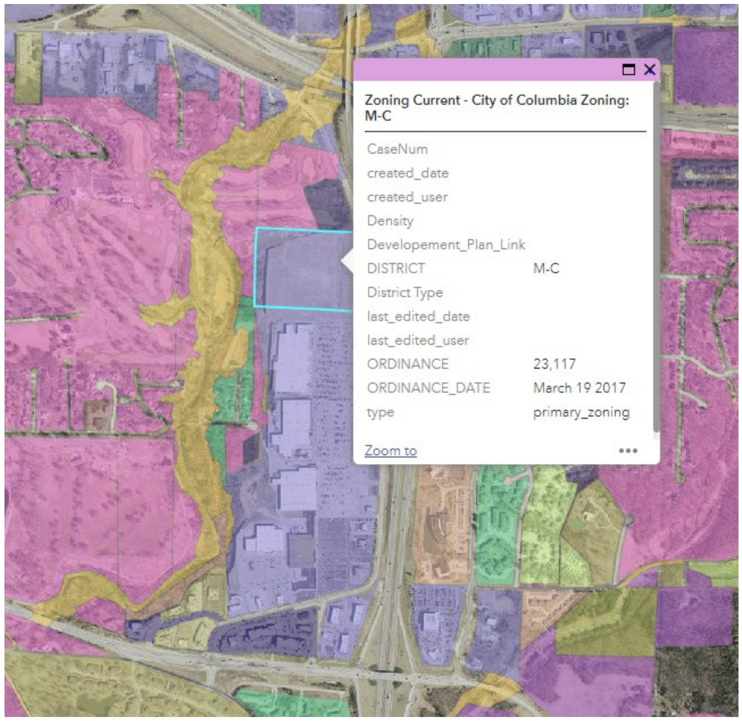


Figure 2.10: Zoning Map of Scenario 1 Site Indicating Mixed-Commercial (M-C)
(Source: City of Columbia City View Zoning Map, February 23, 2022)

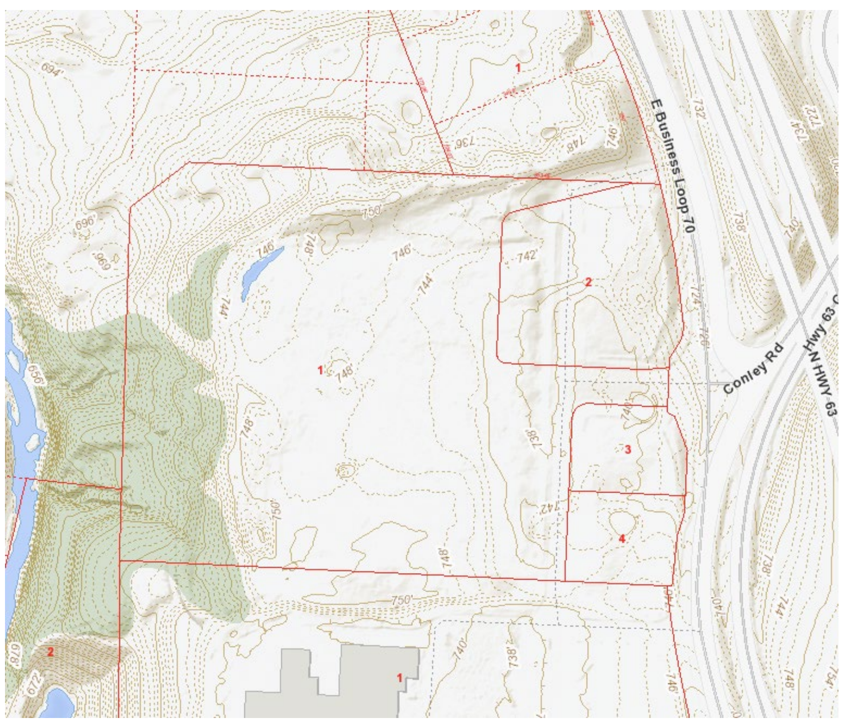


Figure 2.11: Publicly available Topographic Survey of Scenario Site 1 Showing Two (2) Foot Contours. (Source: Boone County Parcel View, February 23, 2022)

The development scenario will consist of a proposed commercial development including a parking lot. The site land use will be assumed to be urban commercial and business land with open space consisting of grass cover greater than 75%. This calculates to 1.80-acres of the site being considered impervious or approximately 72% which is below the maximum 85% impervious surface requirement set forth by the city. The commercial development will result in consistent vehicular traffic placing an emphasis on BMP treatment and reduction of heavy metals, nutrients, oil/grease, organics, suspended sediment, and temperature. As with any development or re-development, strong consideration shall be placed on minimizing construction, operation, and maintenance costs.

2.4.4 Scenario 2

The second scenario is a 7.0-acre site (Figure 2.12) along South Rolling Hills Road in the City of Columbia in Boone County, MO. The selected site is an undeveloped plat of an existing neighborhood and is zoned as residential (Figure 2.13). Topographic survey available on the Boone County Accessor's website details the site as having a 3% - 4% slope southeast to northwest across the site (Figure 2.14). Delineation of the survey contours determines a drainage area of 7.0 acres as the Columbia George Parkway and South Rolling Hills Road prevent offsite water from entering onto the scenario site. Satellite imagery and the topographic survey do not show existing waterways, waterbodies, or BMPs onsite. Soil information, publicly available on the University of Missouri Extension Map Room website (https://allthingsmissouri.org/missouri-map-room/), such as HSG (Dominant Condition) and the USDA-NRCS SSURGO soil boundaries are loadable into maps with state and county boundaries, delineated water and building boundaries, and roadways with names. Conventional subdivision development installs utility infrastructure prior to construction of streets. A review of the site shows no apparent evidence of existing utilities. This scenario will assume detention (peak flow reduction) and water quality treatment are important in selecting a suitable BMP.

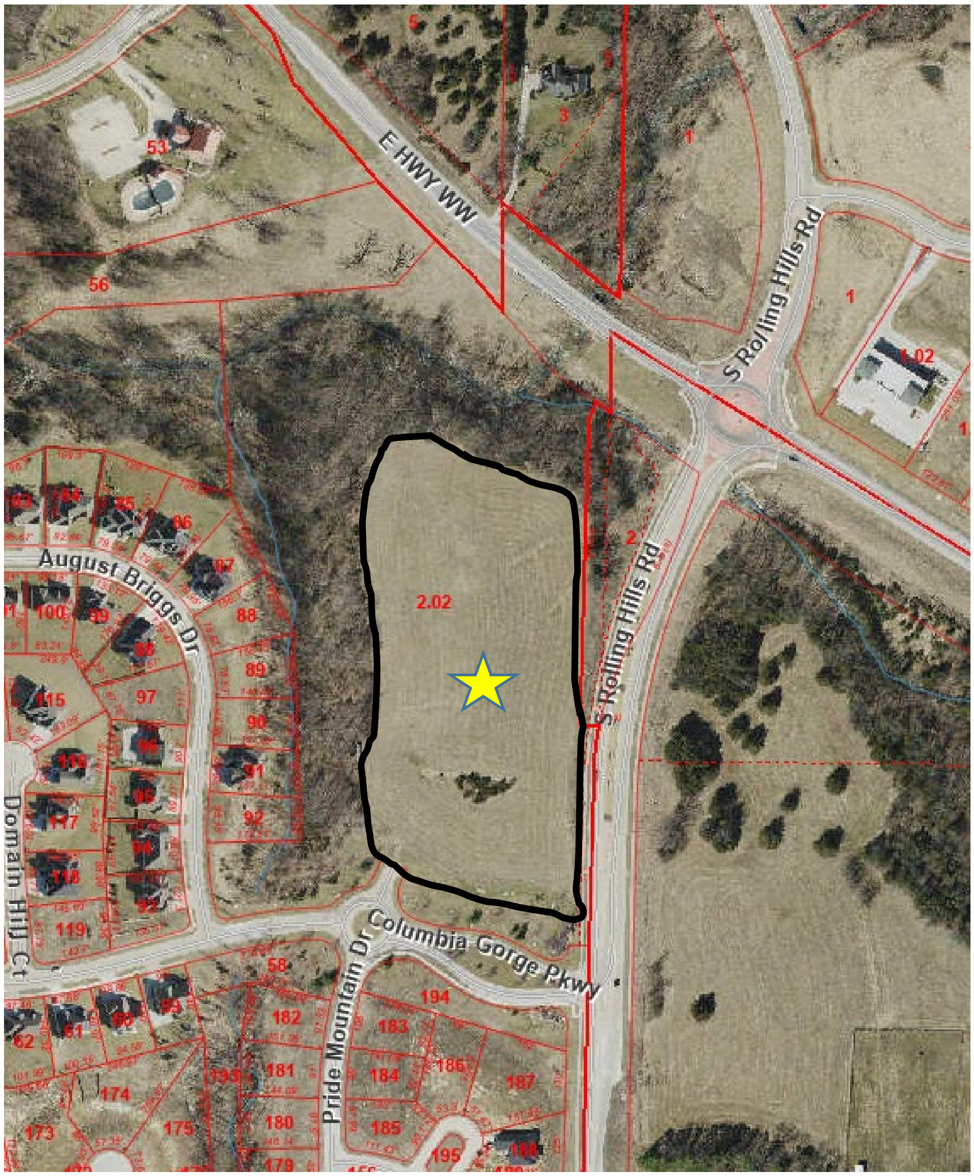


Figure 2.12: Satellite Imagery of Scenario 2 Site Indicated by Star. (Source: Boone County Parcel View, November 13, 2023)

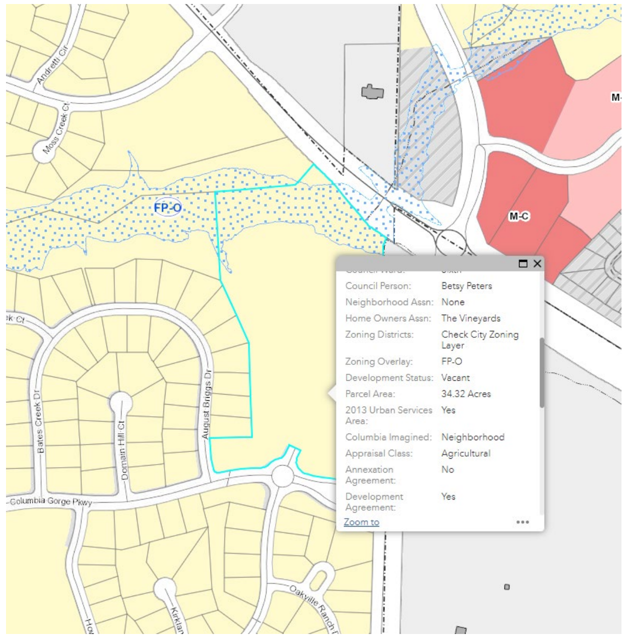


Figure 2.13: Zoning Map of Scenario 2 Site Indicating Residential (Source: City of Columbia City View Zoning Map, November 13, 2023)

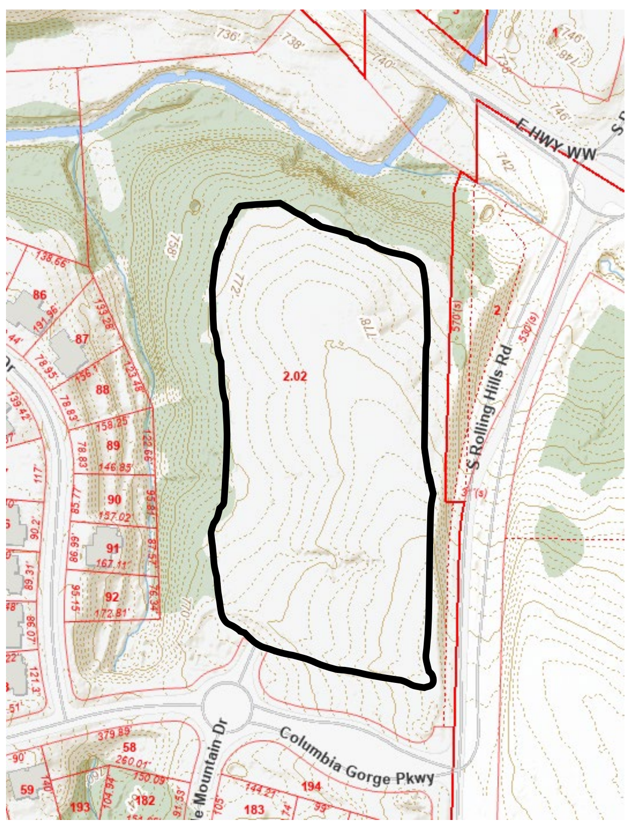


Figure 2.14: Publicly available Topographic Survey of Scenario Site 2 Showing Two (2) Foot Contours. (Source: Boone County Parcel View, November 13, 2022)

The development scenario will consist of sixteen (16) one-third (1/3) acre building lots for residential homes with an average impervious footprint of 2,250 square including driveways. When entering information into the Site Post-Development sheet the User shall select the Residential (1/3-acre lot) option in the dropdown. With 5.33 acres committed to homes, there is 1.67 acres of land available to be used by the development for BMP treatment area. The goals for this scenario are to reduce peak flow rates, provide water quality treatment and detention, and for the BMP to visually fit within the landscape of the subdivision. Maintenance and operation and associated costs will become the responsibility of the 16 lots once fully developed. Minimizing the amount of these costs is typically important to all future homeowners.

2.4.5 Scenario 3

The third scenario is the retrofit of a drainage way experiencing stormwater erosion located on the northwest side of the University of Missouri – Columbia campus. The site collects stormwater runoff in the northwest corner of the 1.80-acre drainage area where an existing storm box and pipe are located. The drainage area, delineated in Figure 2.15, includes a 1.16-acre asphalt parking lot with the remaining area being well-established grass and trees. Topographic survey available from the Boone County Accessor's website shows an average slope of 7.5% southeast to northwest in the drainage area (Figure 2.16). A review of satellite imagery indicates existing utilities evident by multiple manholes along Elm Street (Figure 2.15) where stormwater collects. Due to the existing parking lot, developed roads and buildings around the site the soil is assumed to have been previously disturbed and HSG class D. Minimizing soil erosion by lowering flow rates coming off the parking lot is the goal for this scenario with any added water quality benefits considered a bonus. This scenario has no planned additional impervious surface or change to the land use.

Figure 2.15: Satellite Imagery of Scenario 3 Site with Stormwater Collection Point Indicated by Star. (Source: Boone County Parcel View, November 19, 2023)

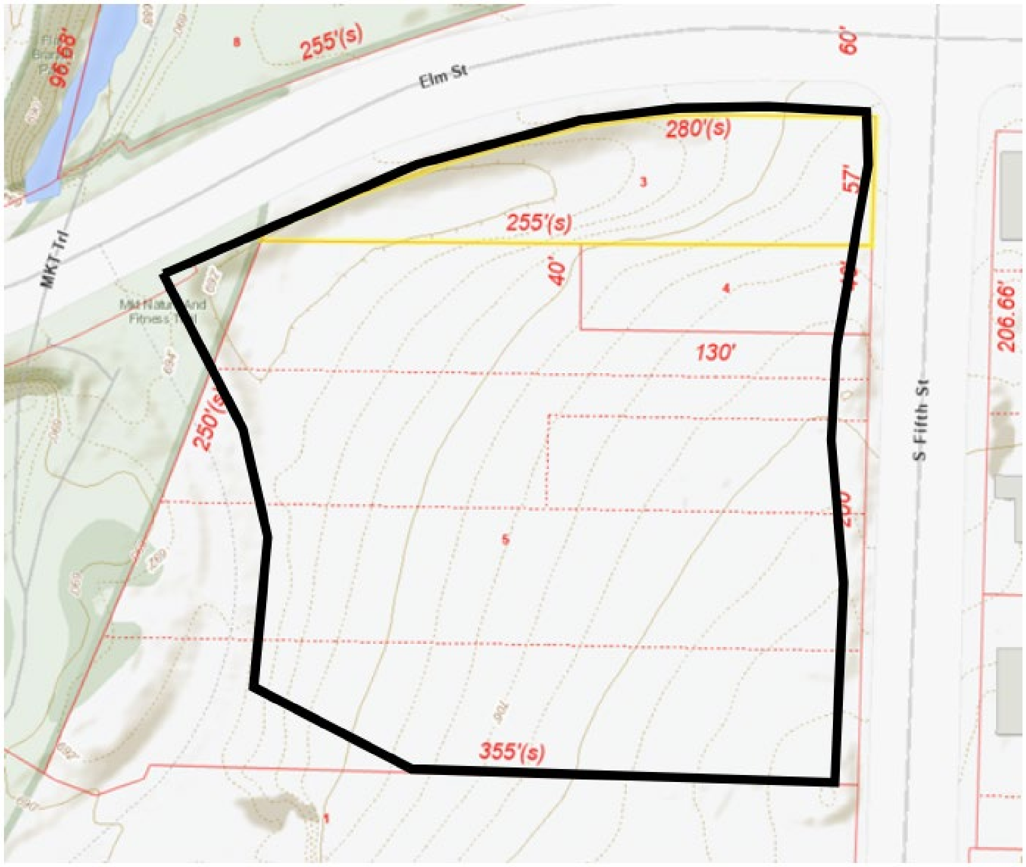


Figure 2.16: Publicly available Topographic Survey of Scenario Site 3 Showing Two (2) Foot Contours. Delineated Drainage Area Indicated by Black Line. (Source: Boone County Parcel View, November 19, 2022)

2.5 Results and Discussion

2.5.1 Scenario 1

The Site Stormwater with BMPs Analysis Calculator results for Scenario 1 can be reviewed in the printed format in Appendix B. The calculator ranked Detention Pond, Bioretention, Infiltration Trenches, and Vegetative Swale as the four best suited BMPs for this development scenario. The Retention Pond BMP was eliminated from consideration as the drainage area for this scenario is less than 10-acres which is the minimum drainage area needed to sustain this BMP. Of the four BMPs determined suitable by the calculator, Bioretention matched the best with the User Questionnaire selected values while the Infiltration Trenches and Detention Pond tied for second with 8 of 17 matches criteria. Vegetative Swale matched 5 of 17 criteria from based on the User Questionnaire Sheet. A water quality volume of 8,243 cubic feet was calculated for the site based on the proposed urban commercial and business land use. As a result, the BMP Analysis Sheet determined only one Detention Pond, Bioretention, or Infiltration Trench would be needed to adequately treat the site calculated water quality volume. The Vegetative Swale BMP would need two separate BMPs to handle the water quality volume. From this information the calculator estimated approximate construction, operation, and maintenance costs for the top four BMPs when constructed in 2023. The Vegetative Swale estimated total cost of $62,200 was the lowest followed by the Detention Pond ($64,700), the Infiltration Trench ($94,900) and the Bioretention cell at $152,400.

The Pre-Development peak flows range from 3.4 to 15.9 cfs. Prior to inputting a BMP into the post-development scenario to reduce peak flows, the calculator determined the post-development peak flows ranged from 8.2 cfs to 25.9 cfs. While the Post-Development peak flow rate does not account for a selected BMPs impact, it allows the User to see how a prescribed development impacts the stormwater runoff rate. These values can also be used by an engineer in the design process of a given BMP to adequately size the needed storage, outflow opening, and emergency spillway to reduce the post-development flow rate for a given design storm to its corresponding Pre-Development flow rate. Another advantage of the calculator is providing a Pre- and Post-Development CN value. Multiple municipalities across the Midwest adhere to the Mid-America Regional Council (MARC) and American Public Works Association (APWA)

Manual which calculates the Level of Service (LOS) based on the change of a development's CN. The calculated LOS must then be met by the matching or higher BMP Value Rating ensuring water quality, volume, temperature, and oils/floatables reduction are sufficiently addressed by the prescribed BMP(s) on the development site.

The BMP Analysis sheet provides basic sizing information for each BMP. The site has 0.70 acres available to incorporate one or more BMPs for stormwater treatment. The Bioretention cell needs a ponding area of 8,243.15 square feet (ft^2) (0.19-acres) and a filter bed area of 3,434.65 ft^2 (0.08-acres). The Infiltration Trench requires a bottom area of 17173.23 ft^2 (0.40-acres). While this area is less than the available open space around the development, a trench length of 2,862 feet is needed for a 6-foot-wide trench. The Infiltration Trench, as the only onsite BMP, is not suitable for treating the required water quality volume for the proposed development. The Detention Pond needs approximately 9,900 ft^3 for the water quality volume and sediment storage. The proposed depth of the Detention Pond and side slope ratio can be edited in the BMP Analysis sheet. Inputting a depth of 8 feet with 5:1 side slope resulted in a top surface area of approximately 9,930 ft^2 adequately containing the required pond volume and fitting within the allowable open space on the proposed site. The final BMP determined suitable for the proposed development is the Vegetative Swale. The BMP Analysis sheet calculates two (2) trapezoidal swales 200 feet in length with an approximate bottom width of 7 feet and a maximum water depth of 4 inches. Rock check dams are required for this preliminary design as the swale water velocity is higher than one (1) ft/s.

2.5.2 Scenario 2

The Site Stormwater with BMPs Analysis Calculator results for Scenario 2 are in printed format in Appendix B. The model scenario resulted in the calculator determining the best suited BMPs in order are Detention Pond, Vegetative Swale, Bioretention, and Rain Barrels or Cisterns. The Retention Pond BMP was eliminated from consideration as the drainage area for this scenario is less than 10-acres which is the minimum drainage area needed to sustain this BMP. Prioritizing peak flow reduction while still providing minimal water quality treatment led to the Detention Pond BMP matching 11 of 17 answers from the User Questionnaire. The Vegetative Swale BMP matched 7 of 17 answers, Bioretention matched 4 of 17 answers, and Rain Barrels or Cisterns matched 2 of 17 answers from the User Questionnaire. If the User in this scenario had placed a higher emphasis on treatment of bacteria, heavy metals, nutrients, organics, oil/grease, and suspended sediment in stormwater runoff, then the suitability ranking based on the User Questionnaire answers would have been Bioretention, Infiltration Trenches, Retention Pond, Detention Pond, Rain Barrels or Cisterns, followed by Vegetative Swale, Permeable Pavements, and Green Roofs.

A calculated Pre-Development CN of 80 combined with a time of concentration (T_C) of 0.39 hours (23.4 minutes) resulted in peak discharges ranging from 7.23 cfs to 34.23 cfs. The Post-Development land use of Residential (1/3-acre lot) and Open Space (Good; Grass Cover > 75%) resulted in a CN of 84.6 and a T_C of 0.18-hours (10.8 minutes). Due to the increased CN and decreased T_C, peak discharge ranges jumped to 13.10 cfs through 52.06 cfs. The full site water quality volume for the scenario drainage area was calculated to be 8,442.76 ft^3. Treatment of this water volume is dependent upon the drainage area that a single BMP can accommodate as well as the overall size of the BMP. For example, a vegetative swale has a maximum contributing drainage area of two (2) acres resulting in four (4) swales needed to capture and treat for this scenario. Each swale must be a minimum of 200 feet in length by eight (8) feet in width as detailed on the BMP Analysis sheet. The scenario would require two bioretention cells with a total media surface area of 0.11-acres, three 50-gallon rain barrels, and two (2) detention ponds with a minimum surface area of 0.13-acres each to accommodate the water quality volume in their respective drainage areas. Each suitable BMP would fit within the proposed site if selected by the User to construct.

The User selected construction to commence in 2023 kept the inflation rate at 3%. As a result, the most economical option is three (3) rain barrels or cisterns costing $63,000 for construction, operation, and maintenance combined. The four (4) Vegetative Swales are estimated to cost a total of $87,600 followed by the two (2) Detention Ponds at $131,400. Two (2) Bioretention cells are approximately $209,200 to construct and provide O&M. The higher-than-expected cost for the rain barrels or cistern BMPs is largely skewed by the higher costs associated with cistern setups. These researched values are adjusted by both regional factors and potential costs increases due to inflation. All costs are estimated approximations and should be treated as such in planning.

2.5.3 Scenario 3

The Site Stormwater with BMPs Analysis Calculator results for Scenario 3 are in printed format in Appendix B. The calculator modeled the scenario and determined the most suitable BMPs for the erosion issue is Detention Pond, Vegetative Swale, Infiltration Trench, and Bioretention. The Retention Pond BMP was eliminated from consideration as the drainage area for this scenario is less than 10-acres and the Green Roof BMP was not eligible due to no planned or existing buildings to construct the BMP atop. The User Questionnaire matched 10 of 17 criteria answers for the Detention Pond BMP. The Vegetative Swale BMP matched 6 of 17 answers, the Infiltration Trench matched 5 of 17 answers, and Bioretention was the least matched of all possible BMPs with 4 of 17 criteria answers. The focus on peak flow reduction over water quality treatment ultimately ranked these filtering BMPs lower.

The Pre- and Post-Development scenarios are entered into the calculator as the same even though there is no planned change to the land use. The CN for the scenario drainage area is 91.6 with a T_C of 0.10-hours. The calculated peak discharge flows range from 5.65 cfs to 18.26 cfs. The water quality volume calculated for the drainage area based on a 1.3-inch rainfall is 5,351 ft^3. Treatment of the water quality volume can be handled by one (1) of each of the four (4) BMPs deemed suitable for the retrofit project. Each BMP's footprint will fit within the open space in the drainage area as detailed on the BMP Analysis sheet. Construction is planned for 2023 and the estimated costs are adjusted with a 3% inflation. The Vegetative Swale is the most cost-effective BMP for constructing, maintaining, and operating at $28,000. The Detention Pond is estimated to cost $55,500 and the Infiltration Trench is approximately $71,200. The highest cost for retrofitting the site with a BMP to minimize erosion is the Bioretention cell at $108,800.

2.6 Conclusion

The Site Stormwater with BMPs Analysis Calculator is designed for planners, engineers, developers, community officials and citizens of the State of Missouri. This chapter details the fundamental stormwater equations, BMP capabilities, and input criteria required to operate the calculator. Users of the calculator answer questions about treatment needs, site status, and enter physical site characteristics for the pre- and post-development scenarios to receive a suitability ranked list of BMPs and associated cost data. Common development and re-development scenarios were evaluated within the calculator and each scenarios printed results can be viewed in Appendix B. The calculator requires no financial or major time investment and can be utilized by both technical and non-technical Users. The results of the calculator provide Users a guide to continue, adjust, or stop development plans based on stormwater treatment capabilities within a modeled location.

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Chapter 3: The Site Stormwater with BMPs Analysis Calculator Validation with EPA National Stormwater Calculator and L-THIA-LID Model.

Abstract

The development of the Site Stormwater with BMPs Analysis Calculator is intended to provide stormwater designers, planners, engineers, and citizens a user-friendly tool for determining land use change impacts on stormwater runoff. Additionally, the tool guides Users to understand which BMPs are best suited to be integrated into the scenario site. The calculator is embedded with NOAA PFDS storm data, estimated construction, maintenance, and operation costs, site-specific hydrologic calculations and required design criteria.

Planning tools like the USEPA NSC and the L-THIA-LID analyze site characteristics and hydrological data to create potential stormwater treatment plans similar to the Site Stormwater with BMPs Analysis Calculator. Comparing the hydrological results and BMP treatment options from these tools with the Missouri specific calculator will validate the new tool. A 2.5-acre commercial development scenario is entered into the three tools with results and discussion focusing on the benefits, constraints, and needed improvements of the Site Stormwater with BMPs Analysis Calculator.

3.1 Introduction

Planning level analysis of stormwater BMPs is critical for the assessment of a project's viability to move forward with design and construction (Liu et al., 2015; Schifman et al., 2018). Tools like the USEPA NSC and the L-THIA-LID model are user-friendly, calculator-type, minimal data entry tools providing reliable representation of hydrologic processes among other outputted results. However, research has noted development improvements are necessary to keep these and other similar tools up to date with design improvements and other industry accepted practices (Liu et al., 2015, Dell et al. 2021). Potential improvements include incorporating a BMPs' suitability based on a site's physical characteristics, stormwater treatment needs, and other local, regional, and/or national constraints provides the User an informative platform for planning a property development or redevelopment. Other possible updates include adding additional BMPs for modeling like detention and retention ponds, infiltration trenches, and vegetative swales, the ability to size BMPs based on contributing drainage areas and estimating costs for construction and annual maintenance and operation (Liu et al., 2015).

Due to these gaps identified in existing planning tools, the Site Stormwater with BMPs Analysis Calculator was developed and intended for use by technical and non-technical people interested in stormwater treatment options utilizing regional BMPs. The calculator is user-friendly with drop down answer menus and requires minimal inputted information by the User. The calculator is specifically for the State of Missouri but could be expanded if hydrological data for other states are incorporated. Construction and maintenance costs, site scale hydrologic calculations, and a suitability analysis of BMPs for the modeled site are outputs of the calculator to be utilized in planning a project.

3.2 Methods

The Site Stormwater with BMPs Analysis Calculator validation compares hydrological results to the outputs of the USEPA NSC and L-THIA-LID model. The commercial development scenario detailed in Chapter 2 is entered into each planning tool. Site specific information and assumptions needed to complete entry into each tool is detailed below along with results and analysis.

3.2.1 EPA National Stormwater Calculator

The NSC can be accessed at https://swcweb.epa.gov/stormwatercalculator/ where the User is requested to enter a Site Name, Location address or zip code and acreage of the site. Upon selecting the site, the User chooses the soil type. The map in the NSC incorporates the USDA's Web Soil Survey HSG polygons for areas considered undeveloped. The commercial scenario site is covered on the north portion of the property by the polygon for clay (high runoff) soil. As a result of selecting the clay soil, the corresponding soil drainage conductivity value of 0.01 inches/hour is entered into the calculator. The topography for this scenario is considered moderately flat (5% slope). The NSC requests the User to select a rain gage and weather station to source hour and daily precipitation and temperature data. The Columbia Regional Airport rain gage and weather station are selected as these are the closest options to the scenario site. The land cover portion of the NSC allows the user to set percentages for the proposed development scenario. The five (5) land cover options include: forest, meadow, lawn, desert, and impervious land cover. An impervious percentage of 85 and lawn percentage of 15 was entered for the commercial development scenario.

The NSC has the following BMP controls: disconnection, rain harvesting, rain gardens, green roofs, street planters, infiltration basins, permeable pavements. The User selects a percentage of the site's impervious area to drain to each BMP. Additionally, the User must input the design storm for sizing BMPs. Matching the Site Stormwater with BMPs Analysis Calculator, a design storm of 1.3 inches was entered. In the commercial development scenario, the Site Stormwater with BMPs Analysis Calculator determined detention pond, bioretention, infiltration trenches, vegetative swale, and permeable pavement were best suited for the site. Consequently, impervious area in the NSC is directed to these or similar BMPs. Due to sizing constraints, the NSC does not allow for all impervious area to be directed to just one BMP. As a result, 25% impervious area is directed to rain gardens, 25% to permeable pavement, and 50% infiltration basins. The NSC directs the User to define the type of project as new development or re-development and describe the suitability of the site as either poor, moderate, or excellent based on physical obstructions, utility conflicts, and other existing infrastructure which may drive costs up when installing stormwater treatment devices.

The final step in setting up a scenario in the NSC is to apply the period (in years) for which the scenario will be analyzed. Standard default by the calculator is 20 years. The User then selects the "Refresh Results" action to generate the NSC summary report. Report options include information regarding site description, summary results, rainfall/runoff events, rainfall/runoff exceedance frequency, rainfall retention frequency, runoff contribution by rainfall percentile, extreme event rainfall/runoff and cost summary. The User is also presented the option to treat an entered scenario in the NSC as a Baseline Scenario of which minor details can be modified and the results compared.

3.2.2 L-THIA-LID Model

The L-THIA-LID Model developed by the University of Purdue can be accessed at https://engineering.purdue.edu/~lthia/. The left side of the webpage has multiple options to select from of which the User clicks the L-THIA Low Impact Development Spreadsheet. At the bottom of the page, the User selects the "Next" button to move forward with creating a model. The model requires the state and county of the proposed scenario are selected from drop down menus. Modeling of the hydrological changes requires Land Use information for the pre- and post-development scenarios. The pre-development land use selected was 2.5-acres of grass/pasture with a HSG class D soil. The post-development land use entered is 2.12-acres of commercial and 0.38-acres of grass/pasture. Both land uses are considered HSG class D soils. The lot level BMP screening is selected for this model development.

The lot level BMPs available to be modeled by L-THIA-LID include the following categories: street/roads, buildings/roofs, sidewalks, parking/driveway, open space/lawn, and natural resource conservation. Best management practices can be selected within each category by the User. The User can define the impervious percentage of site contained within the street/roads, buildings/roofs, sidewalks, and parking/driveway categories or leave the default values provided by the model. The commercial development scenario left the default impervious percentage values for each BMP category. The selected BMPs for this model include the bioretention/raingarden, parking with porous pavement, and cisterns. Upon making the BMP selections, the runoff and nonpoint source pollutant results are computed and can be downloaded.

3.3 Results and Discussion

3.3.1 EPA National Stormwater Calculator

The results of the USEPA NSC commercial development scenario can be found in Appendix C. The BMPs for the scenario are rain garden, infiltration basin, and permeable pavement with impervious area contributions of 25%, 50%, and 25% respectfully to each BMP. The results summary of the NSC does not provide any information regarding the size or quantity of the BMPs needed to adequately treat area directed to them like the Site Stormwater with BMPs Analysis Calculator does. The NSC summary sheets detail the annual runoff, infiltration, and evaporation experienced on the site in multiple graphs and charts for the scenario. An extreme event rainfall/runoff depth chart details the design storms analyzed by the NSC. For example, a 25-year design storm is approximately 5.5-inches with less than 4-inches of runoff for the modeled scenario. This corresponds well with the Site Stormwater with BMPs Analysis Calculator where a 25-year design storm is 5.82-inches of rainfall with a pre-development runoff value of 3.61-inches and a post-development runoff value of 4.97-inches.

The NSC provides estimates of probable capital costs and maintenance cost in 2020 United States dollars. The rain garden is estimated to cost $7,154.35 to $14,063.78 to construct and has an estimated annual probable maintenance cost of $137.64 to $327.90. The infiltration basin construction cost ranges from $10,058.28 to $25,130.56 and the maintenance cost is estimated to be between $340.48 and $12,367.05. The permeable pavement is estimated to cost $29,430.67 to $39,645.45 to construct with yearly maintenance costs of $328.01 to $1,791.54. The Site Stormwater with BMPs Analysis Calculator estimated two (2) permeable pavement systems would be needed to treat the required water quality volume. The construction cost for two permeable pavement BMPs was estimated at $348,000 with an 8:1 ratio of average annual construction cost to maintenance cost. While the NSC cost values are presented in 2020-dollars, the Site Stormwater with BMPs Analysis Calculator adds an inflation percentage to 2018-dollar costs to adjust estimates to the current year or desired construction timelines.

3.3.2 L-THIA-LID Model

The results of the L-THIA-LID Model commercial development scenario can be found in Appendix D. Similar to the Site Stormwater with BMPs Analysis Calculator, the L-THIA-LID model calculates the composite CN for the pre- and post-development scenarios. Both programs determined a CN of 80 for the pre-development scenario and a CN of 93 for the post-development scenario. The L-THIA-LID model also calculated a post-development CN 82 factoring the effects of the proposed BMPs. Specifics to how this value is calculated is not available. The results summary provides a table break-down of runoff results including the average annual runoff volume in acre-feet and the average annual runoff depth in inches. These results are not directly comparable to the runoff results for specific design storms in The Site Stormwater with BMPs Analysis Calculator. The final portion of the summary results from the L-THIA-LID model is the nonpoint source pollutant results for the pre-, post-development, and post-development with BMP scenarios. Pollutants analyzed include nitrogen, phosphorous, suspended solids, lead, copper, zinc, cadmium, chromium, nickel, biological oxygen demand (BOD), chemical oxygen demand (COD), oil and grease, fecal coliform, and fecal strep.

Conclusion

The Site Stormwater with BMPs Analysis Calculator was validated against the USEPA NSC and the L-THIA-LID model. All three (3) of these planning tools are incorporated with stormwater BMPs to help facilitate potential design and construction options for areas undergoing development. The USEPA NSC does not include detention ponds, retention ponds, and vegetative swale BMP options found in the Site Stormwater with BMPs Analysis Calculator. The L-THIA-LID tool can simulate scenarios with a combination of green roof, rain barrel/cistern, permeable pavement, bioretention/raingarden, vegetated swale, and open wood space. Both the NSC and the L-THIA-LID model are designed to simulate scenarios in the United States while the Site Stormwater with BMPs Analysis Calculator is specifically designed for Missouri. Expanding the hydrological data inputs to other states would allow the calculator a wider user base to match the NSC and L-THIA-LID model.

The NSC analyzes periods of historical data and projects future climate simulations for the entered scenario. The NSC does not analyze specific design events that would be necessary in designing a BMP. Design storm specific runoff and peak flows are incorporated into the Site Stormwater with BMPs Analysis Calculator with the goal of informing engineers and designers of the impact changes due to the pre- and post-development land use changes. The L-THIA-LID model also provides hydrological values due to land use changes, but runoff values are annualized instead of being specific to a design storm.

The L-THIA-LID model does not size or quantify the number of BMPs needed to treat an area. The model only allows the User to enter a percent of impervious area conveyed to a specific BMP or series of BMPs. The NSC calculator has minimal BMP sizing criteria but does not provide enough sizing context to accurately understand the space a chosen BMP would need on a proposed development site like the Site Stormwater with BMPs Analysis Calculator does in the BMP Analysis sheet.

The L-THIA-LID model does not include estimated probable construction and maintenance and operation costs. Both the USEPA NSC and the Site Stormwater with BMPs Analysis Calculator provide estimated approximations to be considered by the User when planning projects. Cost data in both these calculators are subjective to the year of construction, price inflation, and regional cost factors and should be utilized as informative numbers for planning and not the final budget number for construction. Neither the NSC nor the L-THIA-LID model account for a User's desired treatment needs for a specific scenario. The Site Stormwater with BMPs Analysis Calculator provides Users the opportunity to rank treatment needs, financial needs, and answer site specific questions that help the calculator evaluate the best suited BMP versus requiring the User to select the BMP(s) for the scenario. This functionality increases the utilization of the calculator to an audience larger than just technically inclined designers and engineers.

The three (3) planning tools discussed in this chapter all provide value to Users looking to gain information regarding property development impacts to stormwater. Each tool is User-friendly and requires minimal information entry and technical understanding to create a simulation. The Site Stormwater with BMPs Analysis Calculator adds regional BMPs not incorporated in the USEPA NSC and the L-THIA-LID model. Additional improvements of this calculator compared to similar planning tools is the BMP suitability analysis method that guides Users to the best suited stormwater treatment devices coupled with estimated construction, maintenance and operation costs and design storm specific hydrological calculations.

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Chapter 4: Conclusion

The development of a planning level, user-friendly stormwater treatment tool for the state of Missouri known as the Site Stormwater with BMPs Analysis. Conclusions based on this calculator development are:

- The User Questionnaire regarding a scenario site's physical existing infrastructure, history, treatment needs, and cost considerations allows the calculator to perform an analysis of the best suited BMPs.
- Pre- and Post-Development scenario analysis coupled with design storm precipitation values for all Missouri Counties allows specific hydrological calculations informing Users of the impacts resulting from land use changes in a scenario.
- Hydrological and water quality volume values are incorporated into BMP sizing calculations to determine BMP quantities as well as approximate land area requirements to construct given BMPs on the proposed scenario property.
- Researched based values for construction, maintenance and operation costs are included in the calculator and factored into the overall ranking of best suited BMPs for the proposed scenario.
- Typical stormwater scenarios modeled in Chapter 2 of the study detail User required information, potential locations to gather needed data for entry into the calculator and how the operate the calculator.
- The regionally accepted BMPs incorporated in the calculator include: bioretention, vegetative swales, infiltration trenches, green roofs, rain barrels or

cisterns, continuous permeable pavement systems, detention pond and retention ponds.

The validation of the Site Stormwater with BMPs Analysis Calculator with the USEPA NSC and the L-THIA-LID model was performed utilizing the commercial development scenario analyzed in Chapter 2. Conclusions based on this validation process are:

- The L-THIA-LID and the Site Stormwater with BMPs Analysis Calculator match hydrological calculations but provide different values for stormwater runoff (specified design storm versus annualized depths). The USEPA NSC performs long-term precipitation simulations as well as graphs design storm rainfall depths and runoff depths. These values are similar to computed results in the Site Stormwater with BMPs Analysis Calculator.

Suggestions for Future Study

Based on the results obtained from this study, the recommendations for future work are:

- Clarify the User Questionnaire answer values of High, Moderate, Medium, and Low with researched value ranges to better guide Users.
- Weight BMP treatment criteria matched with answers from the User Questionnaire to factor into the overall BMP suitability ranking for sites undergoing new development versus re-development.
- Expand the hydrological data in the calculator to include other states allowing developments and re-developments to be analyzed outside the State of Missouri.
- Evaluate the peak flow impacts of incorporating BMPs into the scenarios to determine how post-development land use changes with BMPs compare to pre-development flow rates.

- Incorporate additional cost data to better estimate probable construction, maintenance, and operation costs and have the calculator prepare a life cycle analysis of each BMP to inform the User of when a retrofit or full replacement of scenario BMPs is required.

Appendix A – TR-55 Verification of the Site Stormwater with BMPs Analysis Calculator Site Hydrology and Hydrographs Scenarios Printouts

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The Site Stormwater with
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Pre-Development Watershed Information

Project Name: TR-55 Example

Date: November 17, 2023

Location: Boone County

Curve Number:

HSG	Land use	CN	Area (Acres)	Percentage (%)	Product
D	Open Space (Good; Grass Cover > 75%)	80	10	100%	800
			10	100%	

Pre-Development Curve Number	**80.0**

Time of Concentration:

Flow Type	Surface Cover	Length (ft)	Slope (ft/ft)	Manning's n Value	Time (hrs)
Sheet Flow	Grass (Short-grass prairie)	100	0.03	0.150	0.14
Sheet Flow					
Sheet Flow					
Shallow Flow	Short-grass pasture	900	0.04	-	0.18
Shallow Flow				-	
Shallow Flow				-	

Flow Type	Type of Channel	Length (ft)	Slope (ft/ft)	Manning's n Value	Time (hrs)
Channel Flow	Natural Stream: Clean stream, straight	2500	0.025	0.03	0.04
	Channel Geometry	**Base (ft)**	**Depth (ft)**	**Side Slope (ft/ft)**	
	Trapezoidal	10	5	4	
	Type of Channel	**Length (ft)**	**Slope (ft/ft)**	**Manning's n Value**	**Time (hrs)**
Channel Flow					0.00
	Channel Geometry	**Base (ft)**	**Depth (ft)**	**Side Slope (ft/ft)**	

Time of Concentration (hrs)	**0.36**

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Site Hydrology

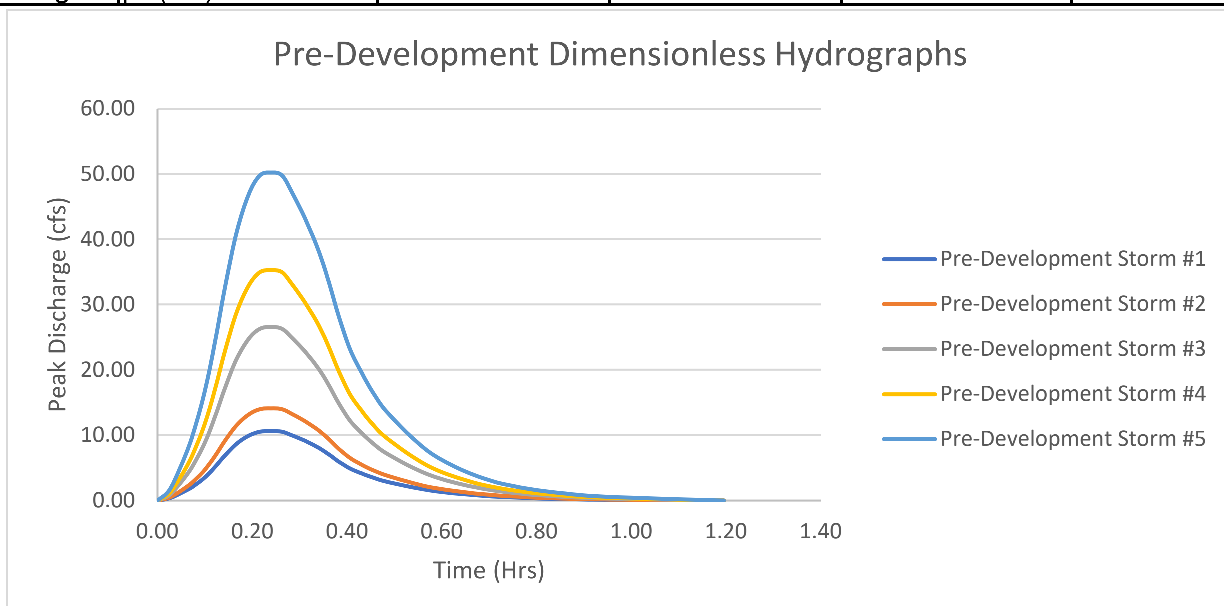
Project Name: **TR-55 Example**

Date: **November 17, 2023**

Location: **Boone County**

Pre-Development Hydrology:

	Storm #1	*Storm #2*	*Storm #3*	*Storm #4*	*Storm #5*
Precipitation Event	1 YR 24 HR	2 YR 24 HR	10 YR 24 HR	25 YR 24 HR	100 YR 24 HR
Precipitation Amount (Inches)	2.88	3.34	4.81	5.82	7.49
Pre-Development Curve Number	80.0				
Time of Concentration (Hrs)	0.36				
Maximum Potential Retention "S" (Inches)	2.50				
Initial abstraction "Ia" (Inches)	0.50				
Ratio: Initial abstraction/Precipitation	0.17	0.15	0.10	0.09	0.07
Adjusted Ratio: Initial abstraction/Precipitation	0.17	0.15	0.10	0.10	0.10
Runoff "Q" (Inches)	1.16	1.51	2.73	3.61	5.15
Unit Peak Discharge "qu" (csm/in)	587.78	599.78	622.77	624.74	624.74
Peak Discharge "qp" (cfs)	10.63	14.12	26.54	35.29	50.26



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Sub-Area Time of Concentration Details

Sub-Area Identifier/	Flow Length (ft)	Slope (ft/ft)	Mannings's n	End Area (sq ft)	Wetted Perimeter (ft)	Velocity (ft/sec)	Travel Time (hr)
Sub-1							
SHEET	100	0.0200	0.150				0.156
SHALLOW	900	0.0400	0.050				0.077
CHANNEL	2500	0.0250	0.030	150.00	51.23	16.150	0.043
						Time of Concentration	.276

Sub-Area Summary Table

Sub-Area Identifier	Drainage Area (ac)	Time of Concentration (hr)	Curve Number	Receiving Reach	Sub-Area Description
Sub-1	10.00	0.276	80	Outlet	

Total Area: 10 (ac)

Hydrograph Peak/Peak Time Table

Sub-Area or Reach Identifier	Peak Flow and Peak Time (hr) by Rainfall Return Period 2-Yr (cfs) (hr)	10-Yr (cfs) (hr)	25-Yr (cfs) (hr)	100-Yr (cfs) (hr)	1-Yr (cfs) (hr)
SUBAREAS					
Sub-1	19.53	36.63	43.86	58.61	14.85
	12.06	12.05	12.05	12.05	12.07
REACHES					
OUTLET	19.53	36.63	43.86	58.61	14.85

Project: Elliott Thesis

Subarea: (Sub-1) Storms: 2-Yr, 10-Yr, 25-Yr, 100-Yr, 1-Yr

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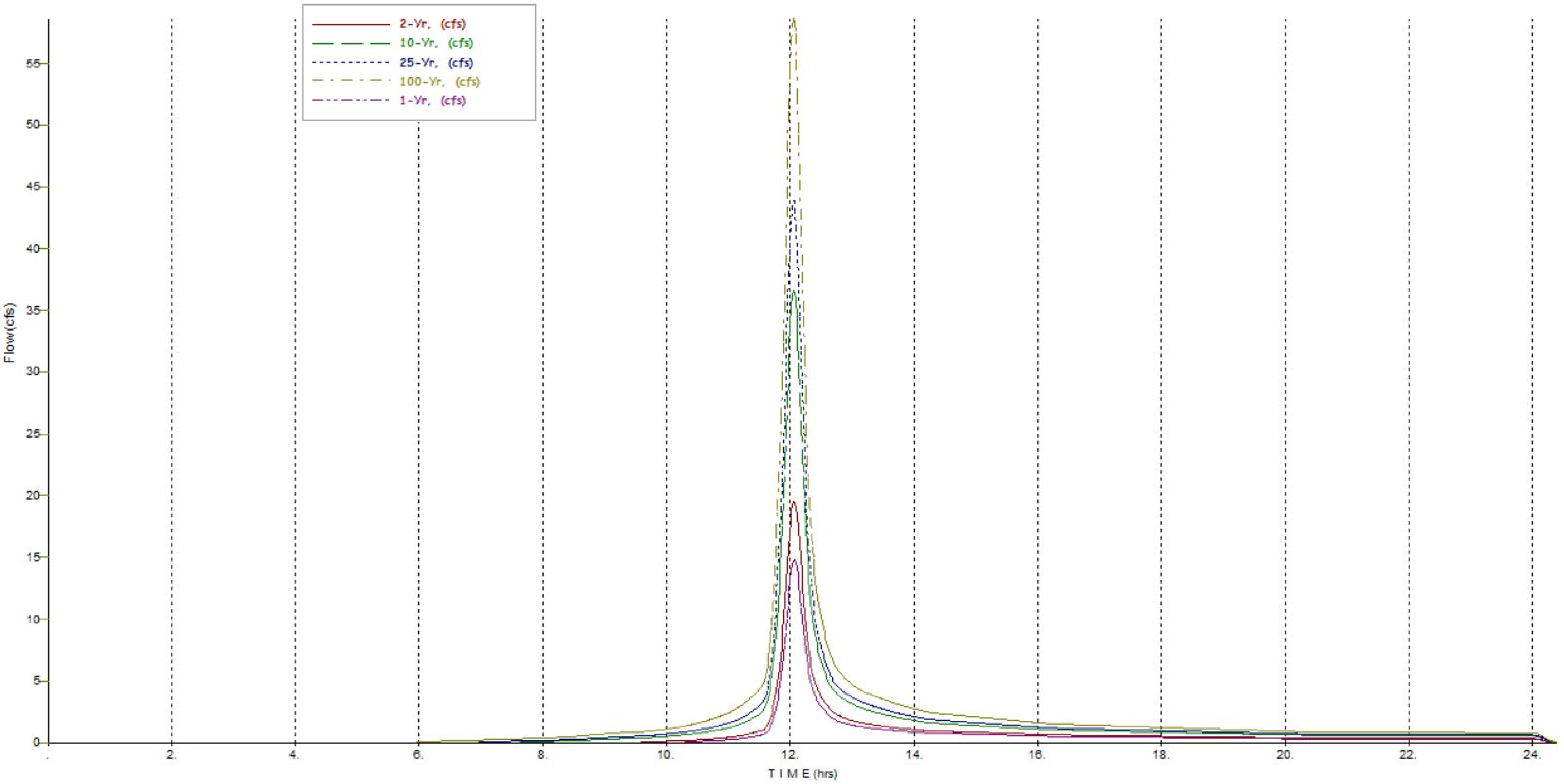

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Pre-Development Watershed Information

Project Name:	TR-55 Example (No Shallow Flow)	Date:	November 17, 2023
		Location:	Boone County

Curve Number:

HSG	Land use	CN	Area (Acres)	Percentage (%)	Product
D	Open Space (Good; Grass Cover > 75%)	80	10	100%	800
			10	100%	

Pre-Development Curve Number	80.0

Time of Concentration:

Flow Type	Surface Cover	Length (ft)	Slope (ft/ft)	Manning's n Value	Time (hrs)
Sheet Flow	Grass (Short-grass prairie)	100	0.03	0.150	0.14
Sheet Flow					
Sheet Flow					
Shallow Flow				-	
Shallow Flow				-	
Shallow Flow				-	

Flow Type	Type of Channel	Length (ft)	Slope (ft/ft)	Manning's n Value	Time (hrs)
Channel Flow	Natural Stream: Clean stream, straight	2500	0.025	0.03	0.04
	Channel Geometry	**Base (ft)**	**Depth (ft)**	**Side Slope (ft/ft)**	
	Trapezoidal	10	5	4	

Flow Type	Type of Channel	Length (ft)	Slope (ft/ft)	Manning's n Value	Time (hrs)
Channel Flow					0.00
	Channel Geometry	**Base (ft)**	**Depth (ft)**	**Side Slope (ft/ft)**	

Time of Concentration (hrs)	0.18

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Site Hydrology

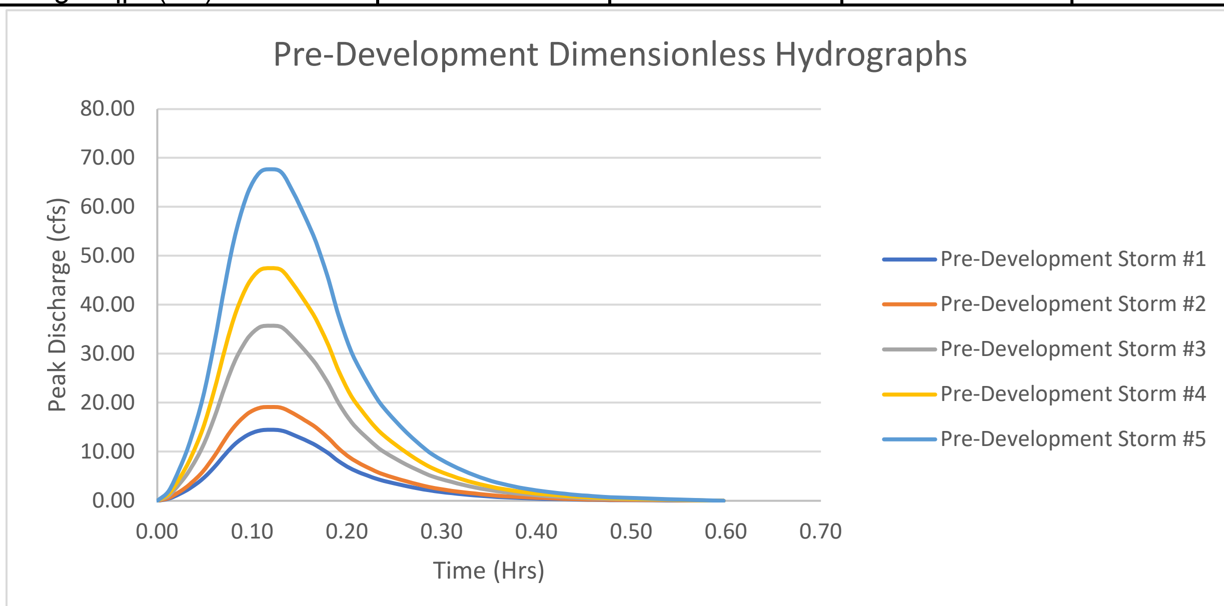
Project Name: **TR-55 Example (No Shallow Flow)**

Date: **November 17, 2023**

Location: **Boone County**

Pre-Development Hydrology:

	Storm #1	*Storm #2*	*Storm #3*	*Storm #4*	*Storm #5*
Precipitation Event	1 YR 24 HR	2 YR 24 HR	10 YR 24 HR	25 YR 24 HR	100 YR 24 HR
Precipitation Amount (Inches)	2.88	3.34	4.81	5.82	7.49
Pre-Development Curve Number	80.0				
Time of Concentration (Hrs)	0.18				
Maximum Potential Retention "S" (Inches)	2.50				
Initial abstraction "Ia" (Inches)	0.50				
Ratio: Initial abstraction/Precipitation	0.17	0.15	0.10	0.09	0.07
Adjusted Ratio: Initial abstraction/Precipitation	0.17	0.15	0.10	0.10	0.10
Runoff "Q" (Inches)	1.16	1.51	2.73	3.61	5.15
Unit Peak Discharge "qu" (csm/in)	800.81	813.91	839.01	841.17	841.17
Peak Discharge "qp" (cfs)	14.48	19.16	35.76	47.51	67.67



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Boone County, Missouri

Sub-Area Time of Concentration Details

Sub-Area Identifier/	Flow Length (ft)	Slope (ft/ft)	Mannings's n	End Area (sq ft)	Wetted Perimeter (ft)	Velocity (ft/sec)	Travel Time (hr)
Sub-1							
SHEET	100	0.0300	0.150				0.133
CHANNEL	2500	0.0250	0.030	150.00	51.23	16.150	0.043
						Time of Concentration	.176
							========

Sub-Area Summary Table

Sub-Area Identifier	Drainage Area (ac)	Time of Concentration (hr)	Curve Number	Receiving Reach	Sub-Area Description
Sub-1	10.00	0.176	80	Outlet	

Total Area: 10 (ac)

B. Elliott Elliott Thesis - V2

Boone County, Missouri

Hydrograph Peak/Peak Time Table

Sub-Area or Reach Identifier	Peak Flow and Peak Time (hr) by Rainfall Return Period 2-Yr (cfs) (hr)	10-Yr (cfs) (hr)	25-Yr (cfs) (hr)	100-Yr (cfs) (hr)	1-Yr (cfs) (hr)
SUBAREAS					
Sub-1	22.44	41.89	50.14	66.92	17.07
	12.00	11.99	12.00	11.98	12.01
REACHES					
OUTLET	22.44	41.89	50.14	66.92	17.07

WinTR-55 Output Hydrograph

Project: Elliott Thesis - V2

Subarea: (Sub-1) Storms: 2-Yr, 10-Yr, 25-Yr, 100-Yr, 1-Yr

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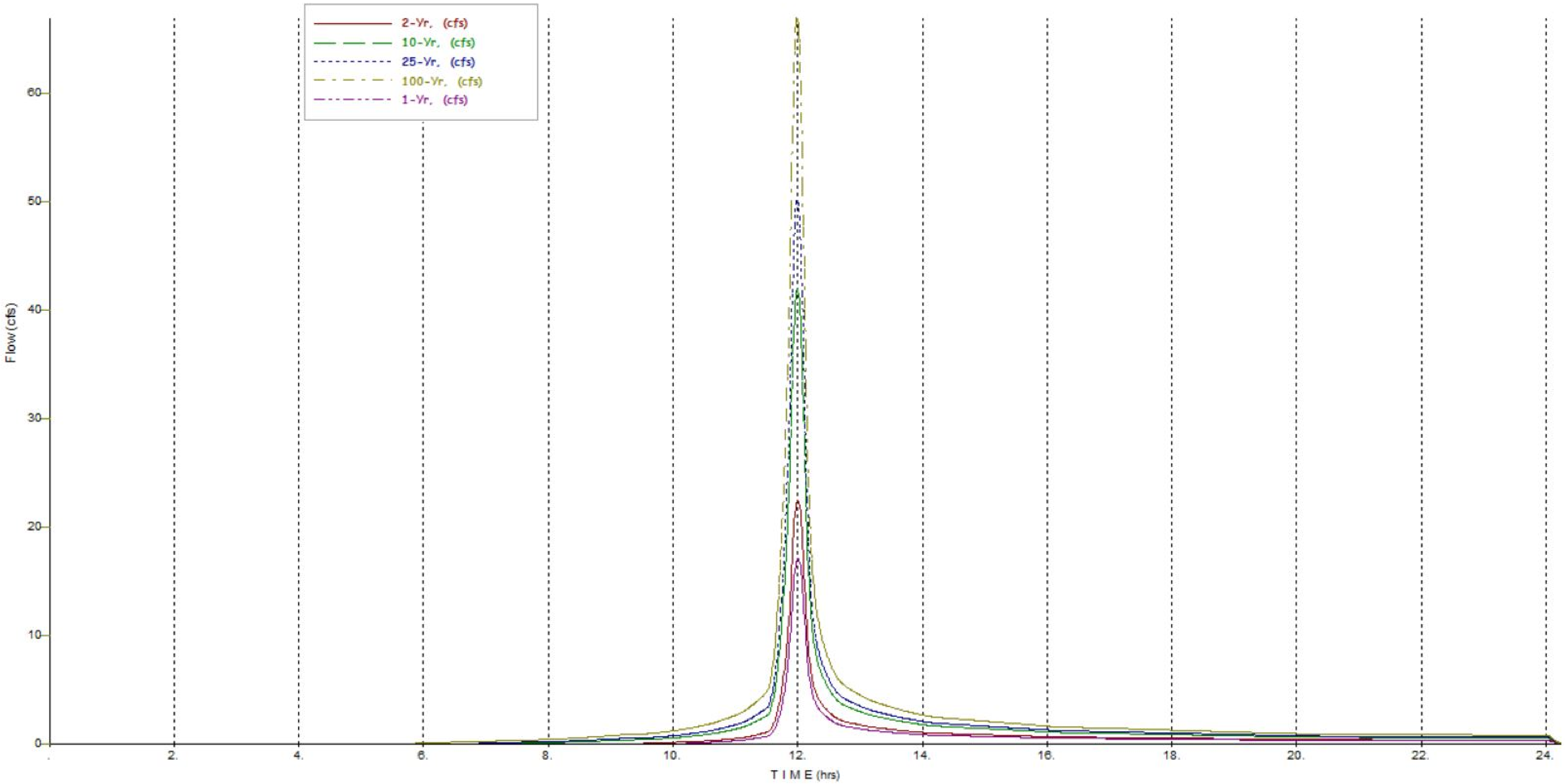

Appendix B: The Site Stormwater with BMPs Analysis Calculator Printouts

Scenario 1

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The Site Stormwater with BMPs Analysis Calculator

Site and BMP Analysis Calculator Instructions

- This worksheet provides instructions on how to use the Site and BMP Analysis Calculator.
- The Site and BMP Analysis Calculator was developed to assist Missouri residents, developers, engineers, and community officials understand stormwater impacts incurred during development and the treatment options available to minimize impacts.
- The calculator utilizes regional and national stormwater manuals, practices, and cost information to determine BMP sizing, BMP costs, and overall treatment effectiveness for specific site conditions in the State of Missouri.
- The Site and BMP Analysis Calculator does not replace the expertise and necessary consultation of engineers when developing or redeveloping property.
- The calculator is intended for sites (new development or redevelopment) between 1 and 1,000 acres. Multiple Site and BMP Analysis Calculators may be used for site containing multiple discharge locations up to 1,000 acres.

CALCULATION PROCESS

The Site and BMP Analysis Calculator utilizes the Soil Conservation Service (SCS) Curve Number (CN) method to determine runoff with considerations to hydrologic soil group (HSG), land cover type, hydrologic condition, and the antecedent moisture condition. The Curve Number (CN) method originally developed for agricultural analysis was applied to urban watersheds in the Technical Release 55 (TR-55, 1986) by calculating mass runoff and converting this quantity into a hydrograph by using unit hydrograph theory.

General Information: Project Name, Address, Project Site Area

- Enter the general specifications for this project at the top of the User Questionnaire worksheet. The date autopopulates when the BMP Tool is opened. Select the Missouri County that the proposed development or re-development site occurs in.

SUMMARY OF WORKSHEETS

User Questionnaire: The worksheet presents the user with questions regarding implementation of BMPs, treatment capabilities, and cost and maintenance. Each question has a drop-down menu of answers for the user to chose from. The default values are green, and all other answers are blue. The user selected answers are utilized in recommending the most suitable BMPs for the proposed site. Answers are autopopulated into the BMP Suitability worksheet.

Site Pre-Development: Worksheet determines existing or pre-development hydrologic conditions of the proposed site. The worksheet calculates Pre-Development Curve Number (CN) and the time of concentration (hours).

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The Site Stormwater with BMPs Analysis Calculator

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Site Post-Development: The worksheet determines proposed hydrologic conditions of the proposed development or re-development. The worksheet calculates Post-Development Curve Number (CN) and the time of concentration (hours).

Site Hydrology: Autopopulated by the results of the Site Pre-Develoopment and Site Post-Development worksheet, this worksheet calculates runoff depth and dimensionless hydrographs for both the site's pre-development and post-development scenarios.

Cost Analysis: The worksheet calculates construction costs and maintenance and operation (O&M) costs for each BMP. Cost Information published in the United States was compiled from research publications and converted to 2018 prices by utilizing APWA Rainfall Zone Adjustment Factors and an average inflation rate of 3%. Users may change the "Projected Inflation Year" to calculate the cost of installation and O&M for the year the project is proposed to be built.

BMP Site and Treatment Analysis: The worksheet calculates the basic design parameters for each BMP in the tool. All values are considered standard design parameters recommended by multiple stormwater design manuals utilized across the United States. Value cells highlighted in blue can be adjusted by the user if different design characteristics are required.

Summary: The worksheet combines all relevant information from the BMP Tool's worksheets and presents the user with a summary of the best suited BMPs for the proposed development or re-development. The summary includes pre-development and post-development site characteristics, site hydrology, hydrographs, construction cost and O&M costs, and BMP sizing information.

LEGEND

(light blue)	User must select option from dropdown menu or enter value
(green)	Default Value if User chooses not to revise
(yellow)	Option selected by User that is not considered Default

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The Site Stormwater with BMPs Analysis Calculator

User BMP Questionnaire

Project Name:	**Scenario 1 - Commercial Development Site**	**Date:**	**November 20, 2023**
		Location:	**Boone County**

Site Considerations

1)	Classify site ownership.	Private Property
2)	Classify type of construction.	New Development
3)	Are there any active stormwater permits or regulated outfalls located on the site?	No
4)	Is the site's stormwater management regulated under a MS4 permit?	Yes
5)	Does the site contain existing storm sewer infrastructure?	Yes
6)	Is there an existing pond or lake located on the site?	No
7)	Are utilities such as gas, water, electric, fiber, and sanitary sewer located on the site?	Yes
8)	Has the site had a history of flooding?	No
9)	Does the site shows evidence of soil erosion?	No
10)	Is there evidence of channel erosion or instability downstream of the site?	No
11)	Does the site drain to a waterbody classified on the 303(d) list as an "Impaired or Threatened Water?"	Yes
12)	Does the site have a history of theft, vandalism, odors, or excessive trash?	No
13)	Is there planned buildings or existing buildings on the site?	Yes

BMP Treatment Considerations

1)	How effectively should the BMP treat nutrients in the stormwater?	High
2)	How effectively should the BMP treat bacteria in the stormwater?	Moderate
3)	How effectively should the BMP treat metals in the stormwater?	High
4)	How effectively should the BMP treat suspended sediment in the stormwater?	High
5)	How effectively should the BMP treat organics in the stormwater?	High
6)	How effectively should the BMP treat oil/grease in the stormwater?	High
7)	How effectively should the BMP provide peak flow reduction of site stormwater?	Moderate
8)	How effectively should the BMP provide channel protection from the site stormwater?	Low
9)	What quality of habitat should the BMP provide?	Low
10)	How important are the visual aesthetics of the BMP?	Moderate
11)	How effectively should the BMP provide temperature reduction?	High

Investment and Maintenance Considerations

1)	What is the preferred cost range of implementing a BMP?	Low
2)	What is the preferred cost range for yearly maintenance of a BMP?	Low
3)	What is the preferred level of operation and maintenance required for a BMP?	Low

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The Site Stormwater with BMPs Analysis Calculator

BMP Suitability with User Questionnaire

Project Name: **enario 1 - Commercial Development S**

Date: **November 20, 2023**
Location: **Boone County**

Comparison Table:

	Questionnaire Result	Bioretention	Vegetative Swale	Infiltration Trenches	Green Roofs	Rain Barrels or Cisterns	Continuous Permeable Pavement Systems	Detention Pond	Retention Pond
Treatment of Nutrients	High	Match	No Match	Match	No Match	Match	No Match	No Match	No Match
Treatment of Bacteria	Moderate	No Match	No Match	No Match	No Match	No Match	Match	Match	No Match
Treatment of Metal	High	Match	No Match	Match	No Match	Match	No Match	No Match	Match
Treatment of Suspended Sediment	High	Match	No Match	No Match	No Match	Match	Match	No Match	Match
Treatment of Organics	High	Match	No Match	Match	No Match	Match	No Match	No Match	Match
Treatment of Oil/Grease	High	Match	No Match	Match	No Match	No Match	No Match	No Match	Match
Peak Flow Reduction	Moderate	Match	No Match	No Match	Match	No Match	Match	No Match	No Match
Channel Protection	Low	No Match	Match	No Match	No Match	No Match	No Match	No Match	No Match
Habitat Established	Low	No Match	No Match	Match	No Match	Match	Match	Match	No Match
Visual Aesthetics	Moderate	Match	No Match	No Match	No Match	No Match	Match	No Match	No Match
Temperatue Reduction	High	Match	No Match	Match	Match	No Match	Match	No Match	No Match
Construction Cost	Low	No Match	Match	No Match	No Match	No Match	No Match	Match	Match
Maintenance Cost	Low	No Match	Match	No Match	No Match	No Match	No Match	Match	No Match
Amount of maintenance required per year	Low	No Match	No Match	No Match	No Match	Match	No Match	Match	No Match
Hydrologic Soil Classification	D	Match	No Match	No Match	No Match	No Match	No Match	Match	Match
Drainage Area (Acres)	2.5	Match	Match	Match	No Match	No Match	Match	Match	No Match
Calculated Slope	2.50	Match	Match	Match	No Match	No Match	Match	Match	Match

Criteria Matched:	11	5	8	2	6	8	8	7
Suitability Ranking:	**1**	**7**	**2**	**8**	**6**	**2**	**2**	**5**

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Pre-Development Watershed Information

Project Name:	**Scenario 1 - Commercial Development Site**	**Date:**	**November 20, 2023**
		Location:	**Boone County**

Curve Number:

HSG	Land use	CN	Area (Acres)	Percentage (%)	Product
D	Open Space (Good; Grass Cover > 75%)	80	2.5	100%	200
			2.5	100%	

Pre-Development Curve Number	**80.0**

Time of Concentration:

Flow Type	Surface Cover	Length (ft)	Slope (ft/ft)	Manning's n Value	Time (hrs)
Sheet Flow	Grass (Short-grass prairie)	100	0.02	0.150	0.16
Sheet Flow					
Sheet Flow					
Shallow Flow	Short-grass pasture	280	0.06	-	0.05
Shallow Flow				-	
Shallow Flow				-	

Flow Type	Type of Channel	Length (ft)	Slope (ft/ft)	Manning's n Value	Time (hrs)
Channel Flow					0.00
	Channel Geometry	**Base (ft)**	**Depth (ft)**	**Side Slope (ft/ft)**	

Flow Type	Type of Channel	Length (ft)	Slope (ft/ft)	Manning's n Value	Time (hrs)
Channel Flow					0.00
	Channel Geometry	**Base (ft)**	**Depth (ft)**	**Side Slope (ft/ft)**	

Time of Concentration (hrs)	**0.21**

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Post-Development Information

Project Name:	Scenario 1 - Commercial Development Site	Date:	November 20, 2023
		Location:	Boone County

Curve Number:

HSG	Land use	CN	Area (Acres)	Percentage (%)	Product
D	Urban Commercial and Business	95	2.12	85%	201.4
D	Open Space (Good; Grass Cover > 75%)	80	0.38	15%	30.4
			2.5	100%	

Post-Development Curve Number	92.7

Time of Concentration:

Flow Type	Surface Cover	Length (ft)	Slope (ft/ft)	Manning's n Value	Time (hrs)
Sheet Flow	Smooth surface (Concrete, asphalt, gravel or bare soil)	100	0.025	0.011	0.02
Sheet Flow					
Sheet Flow					
Shallow Flow	Pavement and small upland gullies	100	0.025	-	0.01
Shallow Flow				-	
Shallow Flow				-	

Flow Type	Type of Channel	Length (ft)	Slope (ft/ft)	Manning's n Value	Time (hrs)
Channel Flow					0.00
	Channel Geometry	Base (ft)	Depth (ft)	Side Slope (ft/ft)	
	Type of Channel	Length (ft)	Slope (ft/ft)	Manning's n Value	Time (hrs)
Channel Flow			0		0.00
	Channel Geometry	Base (ft)	Depth (ft)	Side Slope (ft/ft)	

Time of Concentration (hrs)	0.10

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The Site Stormwater with BMPs Analysis Calculator

Site Hydrology

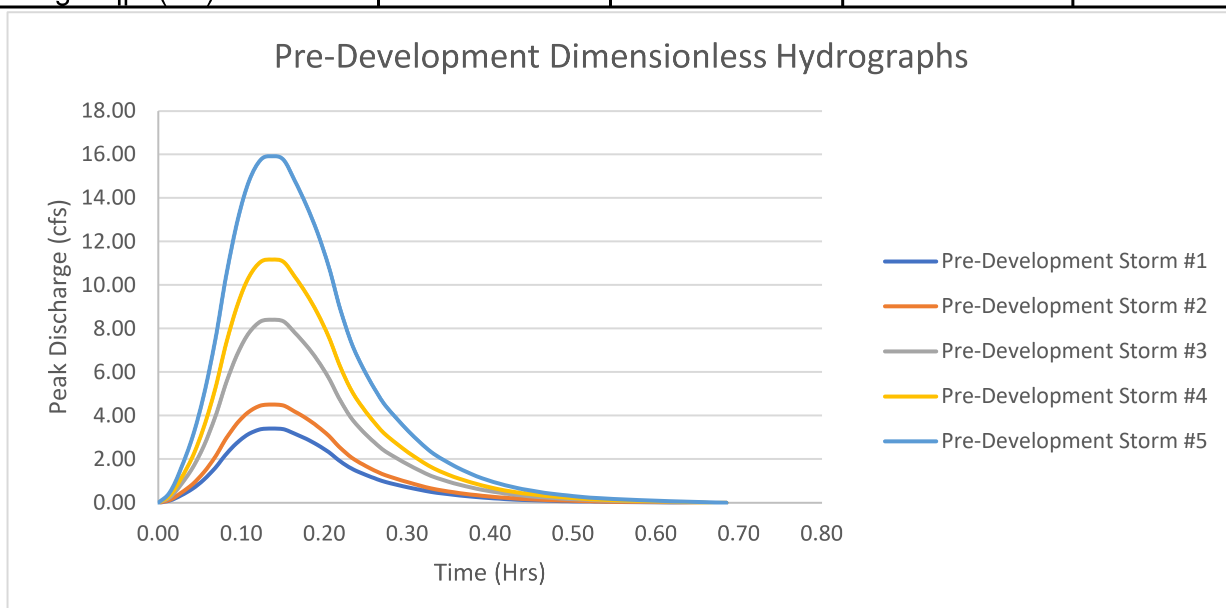
Project Name: Scenario 1 - Commercial Development Site

Date: November 20, 2023

Location: Boone County

Pre-Development Hydrology:

	Storm #1	Storm #2	Storm #3	Storm #4	Storm #5
Precipitation Event	1 YR 24 HR	2 YR 24 HR	10 YR 24 HR	25 YR 24 HR	100 YR 24 HR
Precipitation Amount (Inches)	2.88	3.34	4.81	5.82	7.49
Pre-Development Curve Number	80.0				
Time of Concentration (Hrs)	0.21				
Maximum Potential Retention "S" (Inches)	2.50				
Initial abstraction "Ia" (Inches)	0.50				
Ratio: Initial abstraction/Precipitation	0.17	0.15	0.10	0.09	0.07
Adjusted Ratio: Initial abstraction/Precipitation	0.17	0.15	0.10	0.10	0.10
Runoff "Q" (Inches)	1.16	1.51	2.73	3.61	5.15
Unit Peak Discharge "qu" (csm/in)	754.69	766.68	789.67	791.65	791.65
Peak Discharge "qp" (cfs)	3.41	4.51	8.41	11.18	15.92



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Site Hydrology

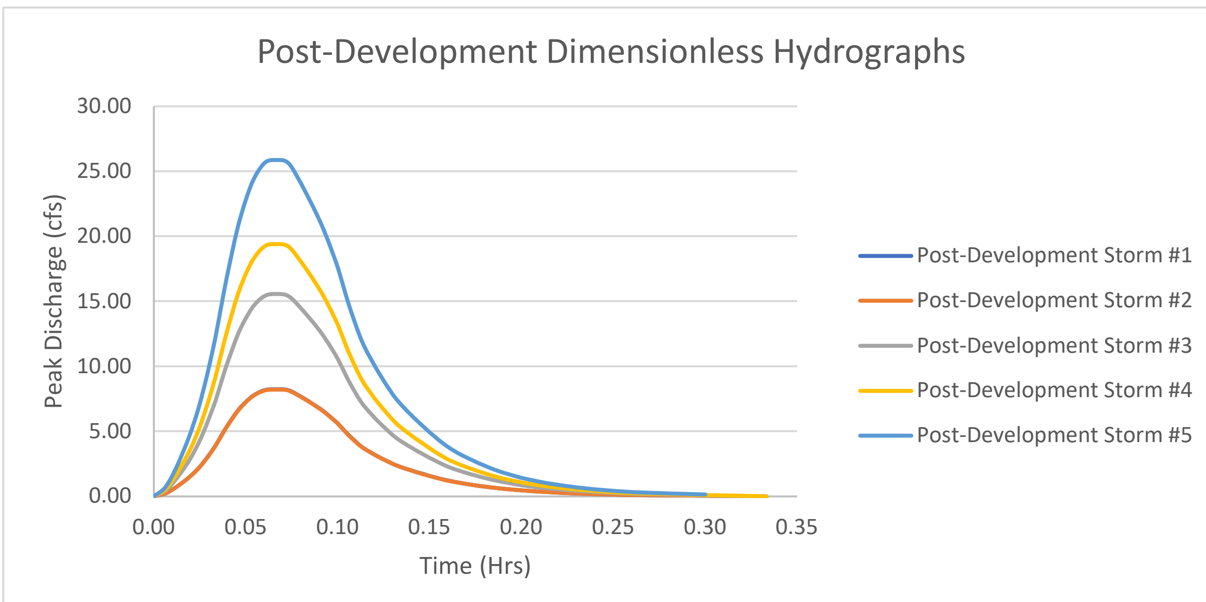
Project Name: Scenario 1 - Commercial Development Site

Date: November 20, 2023

Location: Boone County

Post-Development Hydrology:

	Storm #1	Storm #2	Storm #3	Storm #4	Storm #5
Precipitation Event	1 YR 24 HR	2 YR 12 HR	10 YR 24 HR	25 YR 24 HR	100 YR 24 HR
Precipitation Amount (Inches)	2.88	2.87	4.81	5.82	7.49
Post-Development Curve Number	92.7				
Time of Concentration (Hrs)	0.10				
Maximum Potential Retention "S" (Inches)	0.79				
Initial abstraction "Ia" (Inches)	0.16				
Ratio: Initial abstraction/Precipitation	0.05	0.05	0.03	0.03	0.02
Adjusted Ratio: Initial abstraction/Precipitation	0.10	0.10	0.10	0.10	0.10
Runoff "Q" (Inches)	2.11	2.10	3.98	4.97	6.62
Unit Peak Discharge "qu" (csm/in)	1000.00	1000.00	1000.00	1000.00	1000.00
Peak Discharge "qp" (cfs)	8.24	8.22	15.55	19.41	25.87



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The Site Stormwater with BMPs Analysis Calculator

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BMP Size and Treatment Analysis

Project Name:	**Scenario 1 - Commercial Development Site**	**Date:**	**December 6, 2023**
		Location:	**Boone County**
Water Quality Storm (Event producing less than or equal to 90% stormwater runoff volume of all 24-hour storms on an annual basis)		1.3	**Inches**

Bioretention

Tributary area to bioretention area - A_T (acres)	2.50
Water Quality Volume - WQ_v (ft^3)	8243.15
Planting bed soil depth - d_f (ft)	2.50
Coefficient of permeability for planting soil bed - k (ft/day)	1.00
Maximum ponding depth - h_{max} (ft)	1.00
Average height of water above bioretention bed - h_{avg} (ft)	0.50
Time required for WQ_v to filter through the planting soil bed - t_f (days)	2.00
Required filter bed surface area - A_f (ft^2)	3434.65
Approximate filter bed length - L_f (ft)	84.00
Approximate filter bed width - W_f (ft)	42.00
Required Ponding Area - A_p (sf)	8243.15

Continous Permeable Pavement Systems

Tributary area to Continous Permeable Pavement Systems - A_T (acres)	1.67
Water Quality Volume - WQ_v (ft^3)	5498.18
Porosity of Aggregate - n	0.36
Minimum depth of gravel - D_g (in)	2.52
Minimum surface area (acres)	0.10
Soil Permeability (in/day)	0.50
Drawdown Time (days)	2.60

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Vegetative Swale

Tributary drainage area - A_T (acres)	2.00
Water Quality Volume - WQ_v (ft^3)	6594.52
2 Year, 24 Hour Storm Maximum Design Velocity	1.38
10 Year, 24 Hour Storm Maximum Design Velocity	2.58
Swale Geometry	Trapezoidal
Maximum Bottom Width - B_m (ft)	8
Side Slopes (ft/ft)	5
Longitudinal Slope (ft/ft)	0.01
Manning's n value	0.03
Depth - D (ft)	0.33
Length - L (ft)	200
Velocity (ft/s)	2.13
Runoff Flow Rate (ft^3/s)	6.77
Area (ft^2)	3.18
Hydraulic Radius (ft)	0.28
Calculated Bottom Width - B (ft)	7.03
Velocity Check	Check Dam(s) required

Infiltration Trench

Tributary drainage area - A_T (acres)	2.50
Runoff Volume - V (ft^3)	8243.15
Percolation Rate - P (in/hr)	0.20
Void space fraction in storage media	0.40
Retention Time - t (hrs)	72.00
Bottom Area of Trench - A_B (ft^2)	17173.23
Percolation Rate of surrounding existing soil - P (in/hr)	0.20
Void space fraction in storage media	0.40
Retention Time - t (hrs)	72.00
Trench Depth - D (ft)	3.00
Trench Width - W (ft)	6.00
Trench Length - L (ft)	2862

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Green Roof

Building Roof Area - A_B (acres)	0.90
Water Quality Volume - WQ_v (ft^3)	2970.83
Average Soil Depth (inches)	4.00
Soil Porosity (% Pore Space)	40.00
Water Retention (in^3)	0.90
Moisture Mat (in^3)	0.15
Drainage Board (in^3)	0.20
Total Water Retention (in^3)	1.25
Water Retention Check	Effective Design

Rain Barrel

Building Roof Area - A_B (acres)	0.90
Rain Barrel Volume - V_B (gallons)	50
Water Quality Volume - WQ_v (ft^3)	2970.83
Number of Rain Barrels needed to treat WQ_v	8.0

Detention Pond

Tributary drainage area - A_T (acres)	2.5
Water Quality Volume - WQ_v (ft^3)	8243.15
20% Deposition of Silt and Sediment in Basin (ft^3)	9891.78
Water Quality Outlet Type	V-notch Weir
Water Quality Depth at Outlet, Z_{WQ} (ft)	1.00
Water Quality Outlet Single Orifice Diameter, D_O (in)	1.67
Perforated Riser: Design circular perforation diameter, D_{perf} (in)	1.35
Perforated Riser: Number of Columns, n_c	1.00
Perforated Riser: Number of Row, n_r	3.00
Weir: Average head of water quality pool volume over invert of v-notch, H_{WQ} (ft)	0.50

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Weir: Average water quality pool outflow rate, C_{WQ} (cfs)	0.06
Weir: V-notch weir angle, θ (deg)	20.00
Weir: Top width of V-notch weir, W_v (ft)	1.30
Total Outlet Area - A_{ot} (in^2)	686.61
Single Orifice Outlet Trash Rack Open Area - A_t (in^2)	2746.42
Length to width ratio (should be at least 3:1 (L:W))	3.00
Low Flow Channel side lining	Soil / Riprap
Top stage floor drainage slope (toward low flow channel), S_{ts} (%)	2.00
Top stage depth, D_{ts} (ft)	1.5
Bottom stage volume, V_{bs} (ft^3)	1236.47
Forebay Volume - Minimum of 10% WQ_v (ft^3)	824.31
Forebay depth, Z_{FB} (ft)	1.50
Forebay surface area, A_{FB} (ft^2)	549.54
Paved/hard bottom and sides?	Yes
Basin side slopes: Minimum of 4:1 (H:V)	5.00
Dam Embankment: Minimum of 3:1 (H:V)	3.00
Basin Bottom Width (ft)	35.16
Basin Bottom Length (ft)	35.16
Proposed Depth of Detention Pond (ft)	8.00
Basin Top Width (ft)	75.16
Basin Top Length (ft)	75.16
Total Pond Volume (ft^3)	9929.04

Retention Pond

Tributary drainage area - A_T (acres)	2.5
Water Quality Volume - WQ_v (ft^3)	8243.15
Rational runoff coefficient - C	0.73
14-day Wet Season Rainfall -R_{14} (inches)	2.2
Permanent Pool Volume (Method 1), VP1 (ft^3)	14623.96
TSS Removal Efficiency (%)	90.0

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Mean storm depth, S_d (in)	0.60
Impervious tributary area, A_I (ac)	1.80
Permanent Pool Volume (Method 2), V_{P2} (ft^3)	15699.02
Design Permanent Pool Volume, V_P (ft^3)	18838.83
Average Permanent Pool Depth, Z_P (ft)	10.00
Permanent Pool Surface Area, A_P (ft^2)	1883.88
Water Quality Outlet Type	V-notch Weir
Water Quality Depth at Outlet, Z_{WQ} (ft)	1.00
Water Quality Outlet Single Orifice Diameter, D_O (in)	1.67
Perforated Riser: Design circular perforation diameter, D_{perf} (in)	1.35
Perforated Riser: Number of Columns, n_c	1.00
Perforated Riser: Number of Row, n_r	3.00
Weir: Average head of water quality pool volume over invert of v-notch, H_{WQ} (ft)	0.50
Weir: Average water quality pool outflow rate, C_{WQ} (cfs)	0.06
Weir: V-notch weir angle, θ (deg)	20.00
Weir: Top width of V-notch weir, W_v (ft)	1.30
Total Outlet Area - A_{ot} (in^2)	686.61
Single Orifice Outlet Trash Rack Open Area - A_t (in^2)	2746.42
Forebay Volume - Minimum of 10% WQ_v (ft^3)	824.31
Forebay depth, Z_{FB} (ft)	1.50
Forebay surface area, A_{FB} (ft^2)	549.54
Paved/hard bottom and sides?	Yes
Basin side slopes: Minimum of 4:1 (H:V)	4.00
Dam Embankment: Minimum of 3:1 (H:V)	3.00
Littoral Bench Surface Area (ft^2)	470.97
Bench Width, W_{LB} (ft)	20.00
Bench Depth, Z_{LB} (ft)	1.00

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Basin Bottom Width (ft)	43.40
Basin Bottom Length (ft)	43.40
Basin side slopes: Minimum of 4:1 (H:V)	7.00
Basin Top Width (ft)	113.40
Basin Top Length (ft)	113.40
Total Pond Volume (ft^3)	20891.43

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BMP Cost Analysis

Project Name:	**Scenario 1 - Commercial Development Site**	**Date:**	**December 6, 2023**
		Location:	**Boone County**

BMP Type	Construction Costs (2018)	Maintenance Costs (2018)	Total Cost (2018)	Projected Construction Year	Construction Cost Inflation	Maintenance Costs Inflation	Total Cost
Bioretention	$ 125,000	$ 6,380	$ 131,380	2023	$ 145,000	$ 7,400	$ 152,400
Vegetative Swales	$ 26,000	$ 960	$ 26,960		$ 30,000	$ 1,100	$ 31,100
Infiltration Trenches	$ 75,000	$ 6,840	$ 81,840		$ 87,000	$ 7,900	$ 94,900
Green Roofs	$ 676,000	$ 60,100	$ 736,100		$ 784,000	$ 69,700	$ 853,700
Rain barrels or Cisterns	$ 49,000	$ 2,450	$ 51,450		$ 57,000	$ 2,800	$ 59,800
Continuous Permeable Pavement Systems	$ 150,000	$ 18,470	$ 168,470		$ 174,000	$ 21,400	$ 195,400
Detention Pond	$ 54,000	$ 1,430	$ 55,430		$ 63,000	$ 1,700	$ 64,700
Retention Pond	$ 294,000	$ 6,600	$ 300,600		$ 341,000	$ 7,700	$ 348,700

Inflation Rate (%)	3.0

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Summary

Project Name:	Scenario 1 - Commercial Development Site	Date:	December 6, 2023
		Location:	Boone County

Pre-Development		Post-Development	
Site Area (Acres)	2.50	Site Area (Acres)	2.50
Pervious Area (Acres)	2.50	Pervious Area (Acres)	1.80
Impervious Area (Acres)	0.00	Impervious Area (Acres)	0.70
Pre-Development CN	80.0	Post-Development CN	92.7
Pre-Development Time of Concentration (hrs)	0.22	Post-Development Time of Concentration (hrs)	0.10

Best fit BMPs

Construction Year	2023	***Inflation Rate (%)***	3.0	***Water Qaulity Vol. (WQ_v) ft^3***	8,243.00

	Cost per Installed BMP	Maintenance Cost per Installed BMP	Number of BMPs to Treat WQ_v	Total Cost
Bioretention	$ 145,000	$ 7,400	1.00	$ 152,400
Vegetative Swales	$ 30,000	$ 1,100	2.00	$ 62,200
Infiltration Trenches	$ 87,000	$ 7,900	1.00	$ 94,900
Green Roofs	$ 784,000	$ 69,700	1.00	$ 853,700
Rain barrels or Cisterns	$ 57,000	$ 2,800	8.00	$ 478,400
Continuous Permeable Pavement Systems	$ 174,000	$ 21,400	2.00	$ 390,800
Detention Pond	$ 63,000	$ 1,700	1.00	$ 64,700
Retention Pond	$ 341,000	$ 7,700	1.00	$ 348,700

	BMP Quantity Needed Rank	BMP Cost Rank	BMP Suitability Ranking	Composite Score	Overall Rank
Bioretention	1	4	1	6	2
Vegetative Swales	6	1	7	14	4
Infiltration Trenches	1	3	2	6	2
Green Roofs	1	8	8	17	6
Rain barrels or Cisterns	8	7	6	21	7
Continuous Permeable Pavement Systems	6	6	2	14	4
Detention Pond	1	2	2	5	1
Retention Pond	1	5	-	-	-

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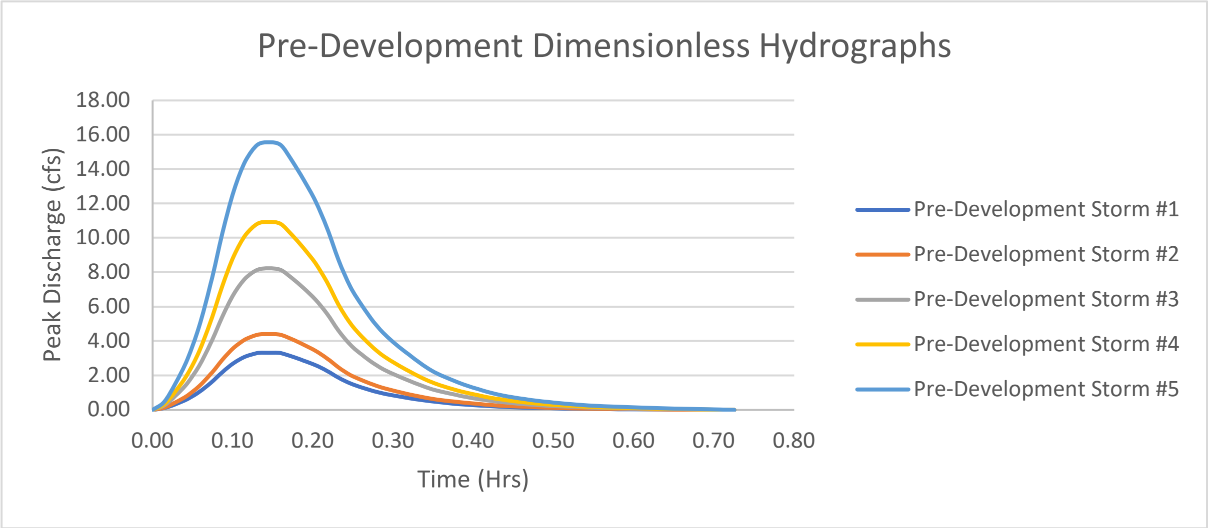

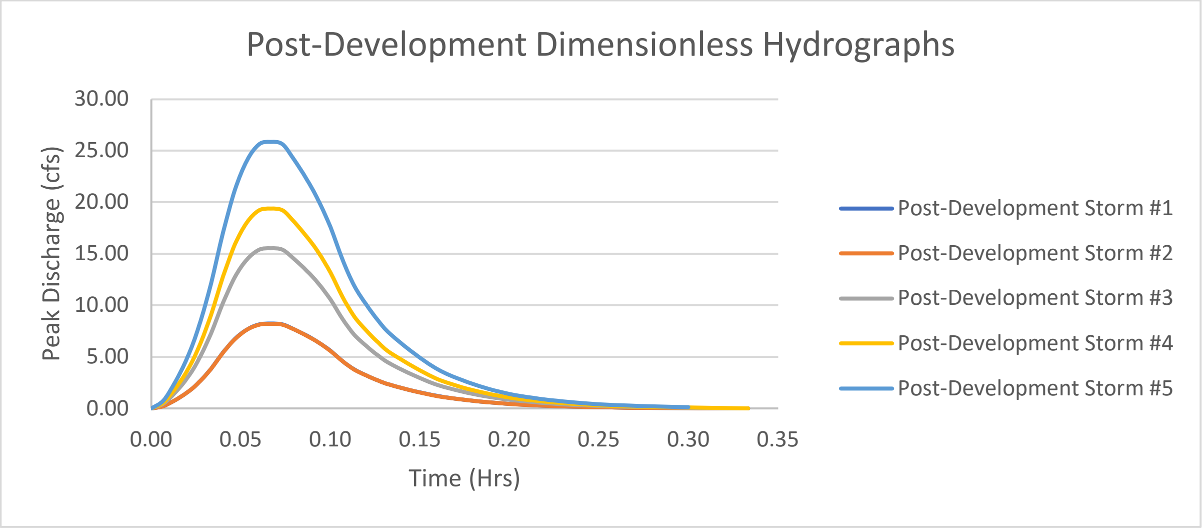

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Scenario 2

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The Site Stormwater with BMPs Analysis Calculator

Site and BMP Analysis Calculator Instructions

- This worksheet provides instructions on how to use the Site and BMP Analysis Calculator.
- The Site and BMP Analysis Calculator was developed to assist Missouri residents, developers, engineers, and community officials understand stormwater impacts incurred during development and the treatment options available to minimize impacts.
- The calculator utilizes regional and national stormwater manuals, practices, and cost information to determine BMP sizing, BMP costs, and overall treatment effectiveness for specific site conditions in the State of Missouri.
- The Site and BMP Analysis Calculator does not replace the expertise and necessary consultation of engineers when developing or redeveloping property.
- The calculator is intended for sites (new development or redevelopment) between 1 and 1,000 acres. Multiple Site and BMP Analysis Calculators may be used for site containing multiple discharge locations up to 1,000 acres.

CALCULATION PROCESS

The Site and BMP Analysis Calculator utilizes the Soil Conservation Service (SCS) Curve Number (CN) method to determine runoff with considerations to hydrologic soil group (HSG), land cover type, hydrologic condition, and the antecedent moisture condition. The Curve Number (CN) method originally developed for agricultural analysis was applied to urban watersheds in the Technical Release 55 (TR-55, 1986) by calculating mass runoff and converting this quantity into a hydrograph by using unit hydrograph theory.

General Information: Project Name, Address, Project Site Area

- Enter the general specifications for this project at the top of the User Questionnaire worksheet. The date autopopulates when the BMP Tool is opened. Select the Missouri County that the proposed development or re-development site occurs in.

SUMMARY OF WORKSHEETS

User Questionnaire: The worksheet presents the user with questions regarding implementation of BMPs, treatment capabilities, and cost and maintenance. Each question has a drop-down menu of answers for the user to chose from. The default values are green, and all other answers are blue. The user selected answers are utilized in recommending the most suitable BMPs for the proposed site. Answers are autopopulated into the BMP Suitability worksheet.

Site Pre-Development: Worksheet determines existing or pre-development hydrologic conditions of the proposed site. The worksheet calculates Pre-Development Curve Number (CN) and the time of concentration (hours).

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Site Post-Development: The worksheet determines proposed hydrologic conditions of the proposed development or re-development. The worksheet calculates Post-Development Curve Number (CN) and the time of concentration (hours).

Site Hydrology: Autopopulated by the results of the Site Pre-Develoopment and Site Post-Development worksheet, this worksheet calculates runoff depth and dimensionless hydrographs for both the site's pre-development and post-development scenarios.

Cost Analysis: The worksheet calculates construction costs and maintenance and operation (O&M) costs for each BMP. Cost Information published in the United States was compiled from research publications and converted to 2018 prices by utilizing APWA Rainfall Zone Adjustment Factors and an average inflation rate of 3%. Users may change the "Projected Inflation Year" to calculate the cost of installation and O&M for the year the project is proposed to be built.

BMP Site and Treatment Analysis: The worksheet calculates the basic design parameters for each BMP in the tool. All values are considered standard design parameters recommended by multiple stormwater design manuals utilized across the United States. Value cells highlighted in blue can be adjusted by the user if different design characteristics are required.

Summary: The worksheet combines all relevant information from the BMP Tool's worksheets and presents the user with a summary of the best suited BMPs for the proposed development or re-development. The summary includes pre-development and post-development site characteristics, site hydrology, hydrographs, construction cost and O&M costs, and BMP sizing information.

LEGEND

(light blue)	User must select option from dropdown menu or enter value
(green)	Default Value if User chooses not to revise
(yellow)	Option selected by User that is not considered Default

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User BMP Questionnaire

Project Name:	**Scenario 2 - Residential Development**	**Date:**	**November 20, 2023**
		Location:	**Boone County**

Site Considerations

1)	Classify site ownership.	Private Property
2)	Classify type of construction.	New Development
3)	Are there any active stormwater permits or regulated outfalls located on the site?	No
4)	Is the site's stormwater management regulated under a MS4 permit?	Yes
5)	Does the site contain existing storm sewer infrastructure?	No
6)	Is there an existing pond or lake located on the site?	No
7)	Are utilities such as gas, water, electric, fiber, and sanitary sewer located on the site?	No
8)	Has the site had a history of flooding?	No
9)	Does the site shows evidence of soil erosion?	No
10)	Is there evidence of channel erosion or instability downstream of the site?	No
11)	Does the site drain to a waterbody classified on the 303(d) list as an "Impaired or Threatened Water?"	Yes
12)	Does the site have a history of theft, vandalism, odors, or excessive trash?	No
13)	Is there planned buildings or existing buildings on the site?	Yes

BMP Treatment Considerations

1)	How effectively should the BMP treat nutrients in the stormwater?	Moderate
2)	How effectively should the BMP treat bacteria in the stormwater?	Moderate
3)	How effectively should the BMP treat metals in the stormwater?	Moderate
4)	How effectively should the BMP treat suspended sediment in the stormwater?	Moderate
5)	How effectively should the BMP treat organics in the stormwater?	Moderate
6)	How effectively should the BMP treat oil/grease in the stormwater?	Moderate
7)	How effectively should the BMP provide peak flow reduction of site stormwater?	High
8)	How effectively should the BMP provide channel protection from the site stormwater?	Moderate
9)	What quality of habitat should the BMP provide?	Moderate
10)	How important are the visual aesthetics of the BMP?	Moderate
11)	How effectively should the BMP provide temperature reduction?	Moderate

Investment and Maintenance Considerations

1)	What is the preferred cost range of implementing a BMP?	Low
2)	What is the preferred cost range for yearly maintenance of a BMP?	Low
3)	What is the preferred level of operation and maintenance required for a BMP?	Low

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BMP Suitability with User Questionnaire

Project Name: **Scenario 2 - Residential Developmen** **Date:** **November 20, 2023**
Location: **Boone County**

Comparison Table:

	Questionnaire Result	Bioretention	Vegetative Swale	Infiltration Trenches	Green Roofs	Rain Barrels or Cisterns	Continuous Permeable Pavement Systems	Detention Pond	Retention Pond
Treatment of Nutrients	Moderate	No Match	No Match	No Match	No Match	No Match	No Match	No Match	Match
Treatment of Bacteria	Moderate	No Match	No Match	No Match	No Match	No Match	Match	Match	No Match
Treatment of Metal	Moderate	No Match	Match	No Match	No Match	No Match	Match	Match	No Match
Treatment of Suspended Sediment	Moderate	No Match	Match	No Match	No Match	No Match	No Match	Match	No Match
Treatment of Organics	Moderate	No Match	Match	No Match	No Match	No Match	Match	Match	No Match
Treatment of Oil/Grease	Moderate	No Match	Match	No Match	No Match	No Match	No Match	No Match	No Match
Peak Flow Reduction	High	No Match	No Match	Match	No Match	No Match	No Match	Match	Match
Channel Protection	Moderate	Match	No Match	Match	Match	Match	Match	No Match	No Match
Habitat Established	Moderate	No Match	No Match	No Match	No Match	No Match	No Match	No Match	No Match
Visual Aesthetics	Moderate	Match	No Match	No Match	No Match	No Match	Match	No Match	No Match
Temperatue Reduction	Moderate	No Match	No Match	No Match	No Match	No Match	No Match	Match	No Match
Construction Cost	Low	No Match	Match	No Match	No Match	No Match	No Match	Match	Match
Maintenance Cost	Low	No Match	Match	No Match	No Match	No Match	No Match	Match	No Match
Amount of maintenance required per year	Low	No Match	No Match	No Match	No Match	Match	No Match	Match	No Match
Hydrologic Soil Classification	D	Match	No Match	No Match	No Match	No Match	No Match	Match	Match
Drainage Area (Acres)	7	No Match	No Match	No Match	No Match	No Match	Match	No Match	No Match
Calculated Slope	3.12	Match	Match	Match	No Match	No Match	Match	Match	Match

Criteria Matched:	4	7	3	1	2	7	11	5
Suitability Ranking:	**5**	**2**	**6**	**8**	**7**	**2**	**1**	**4**

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Pre-Development Watershed Information

Project Name:	Scenario 2 - Residential Development	Date:	November 20, 2023
		Location:	Boone County

Curve Number:

HSG	Land use	CN	Area (Acres)	Percentage (%)	Product
D	Open Space (Good; Grass Cover > 75%)	80	7	100%	560
			7	100%	

Pre-Development Curve Number	80.0

Time of Concentration:

Flow Type	Surface Cover	Length (ft)	Slope (ft/ft)	Manning's n Value	Time (hrs)
Sheet Flow	Grass (Short-grass prairie)	100	0.01	0.150	0.21
Sheet Flow					
Sheet Flow					
Shallow Flow	Short-grass pasture	800	0.033	-	0.18
Shallow Flow				-	
Shallow Flow				-	

Flow Type	Type of Channel	Length (ft)	Slope (ft/ft)	Manning's n Value	Time (hrs)
Channel Flow					0.00
	Channel Geometry	Base (ft)	Depth (ft)	Side Slope (ft/ft)	
	Type of Channel	Length (ft)	Slope (ft/ft)	Manning's n Value	Time (hrs)
Channel Flow					0.00
	Channel Geometry	Base (ft)	Depth (ft)	Side Slope (ft/ft)	

Time of Concentration (hrs)	0.39

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Post-Development Information

Project Name: Scenario 2 - Residential Development
Date: November 20, 2023
Location: Boone County

Curve Number:

HSG	Land use	CN	Area (Acres)	Percentage (%)	Product
D	Residential (1/3 acre lot)	86	5.33	76%	458.38
D	Open Space (Good; Grass Cover > 75%)	80	1.67	24%	133.6
			7	100%	

Post-Development Curve Number	**84.6**

Time of Concentration:

Flow Type	Surface Cover	Length (ft)	Slope (ft/ft)	Manning's n Value	Time (hrs)
Sheet Flow	Smooth surface (Concrete, asphalt, gravel or bare soil)	100	0.025	0.011	0.02
Sheet Flow					
Sheet Flow					
Shallow Flow	Pavement and small upland gullies	100	0.025	-	0.01
Shallow Flow	Short-grass pasture	700	0.033	-	0.15
Shallow Flow				-	

Flow Type	Type of Channel	Length (ft)	Slope (ft/ft)	Manning's n Value	Time (hrs)
Channel Flow					0.00
	Channel Geometry	**Base (ft)**	**Depth (ft)**	**Side Slope (ft/ft)**	

Flow Type	Type of Channel	Length (ft)	Slope (ft/ft)	Manning's n Value	Time (hrs)
Channel Flow			0		0.00
	Channel Geometry	**Base (ft)**	**Depth (ft)**	**Side Slope (ft/ft)**	

Time of Concentration (hrs)	**0.18**

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Site Hydrology

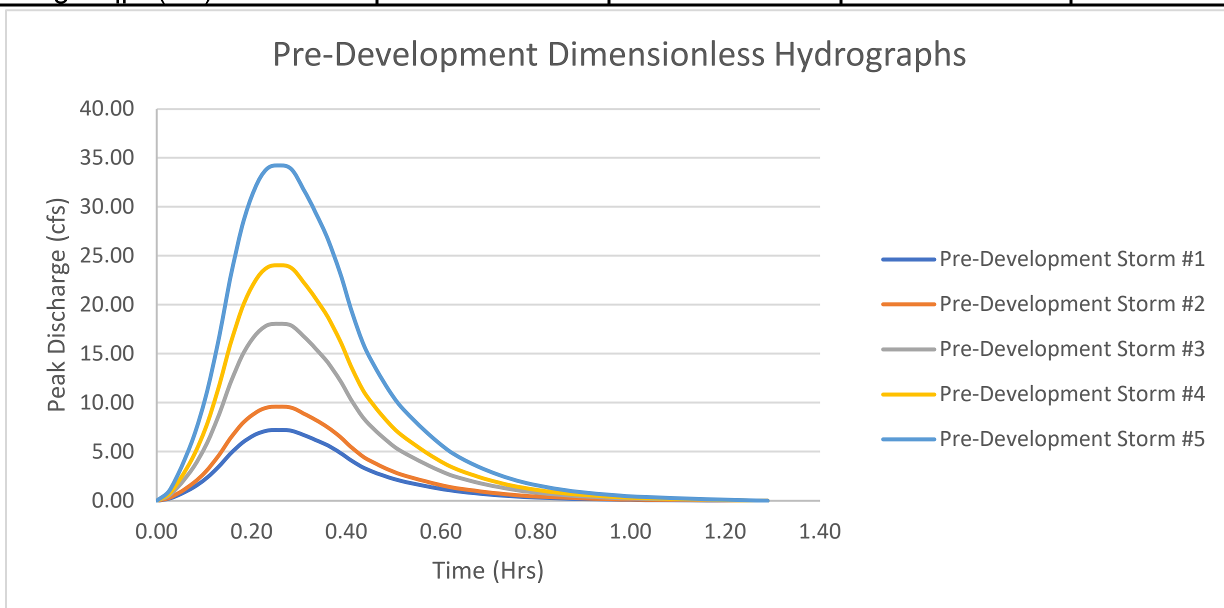
Project Name: **Scenario 2 - Residential Development**

Date: **November 20, 2023**

Location: **Boone County**

Pre-Development Hydrology:

	Storm #1	*Storm #2*	*Storm #3*	*Storm #4*	*Storm #5*
Precipitation Event	1 YR 24 HR	2 YR 24 HR	10 YR 24 HR	25 YR 24 HR	100 YR 24 HR
Precipitation Amount (Inches)	2.88	3.34	4.81	5.82	7.49
Pre-Development Curve Number	80.0				
Time of Concentration (Hrs)	0.39				
Maximum Potential Retention "S" (Inches)	2.50				
Initial abstraction "Ia" (Inches)	0.50				
Ratio: Initial abstraction/Precipitation	0.17	0.15	0.10	0.09	0.07
Adjusted Ratio: Initial abstraction/Precipitation	0.17	0.15	0.10	0.10	0.10
Runoff "Q" (Inches)	1.16	1.51	2.73	3.61	5.15
Unit Peak Discharge "qu" (csm/in)	570.98	582.97	605.96	607.93	607.93
Peak Discharge "qp" (cfs)	7.23	9.61	18.08	24.04	34.23



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Site Hydrology

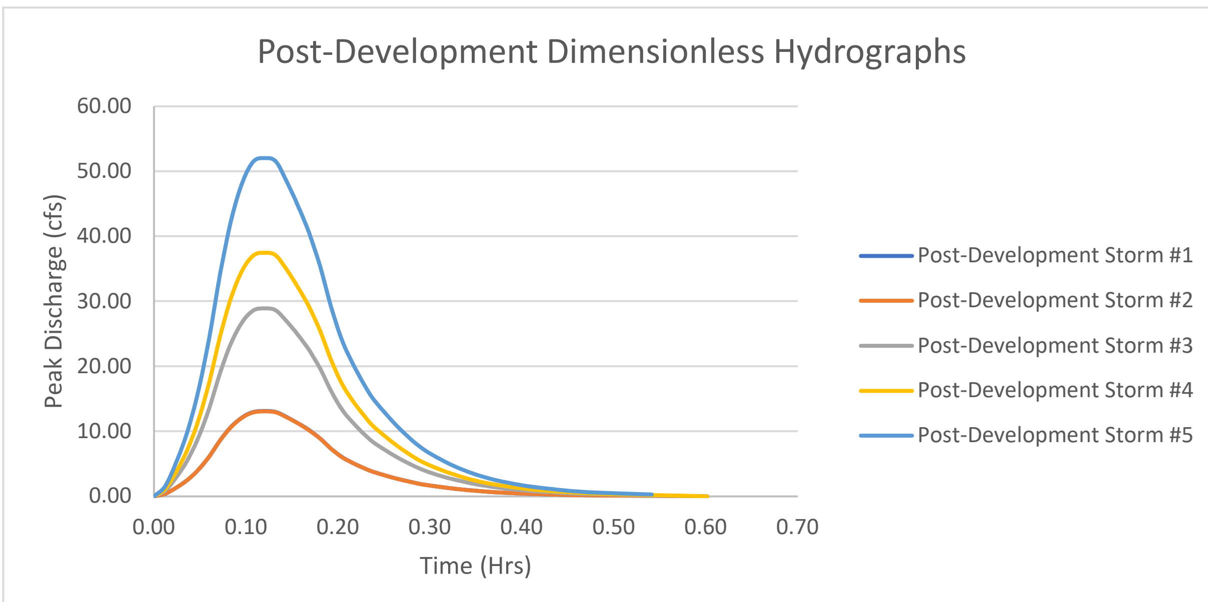
Project Name: Scenario 2 - Residential Development

Date: November 20, 2023

Location: Boone County

Post-Development Hydrology:

	Storm #1	Storm #2	Storm #3	Storm #4	Storm #5
Precipitation Event	1 YR 24 HR	2 YR 12 HR	10 YR 24 HR	25 YR 24 HR	100 YR 24 HR
Precipitation Amount (Inches)	2.88	2.87	4.81	5.82	7.49
Post-Development Curve Number	84.6				
Time of Concentration (Hrs)	0.18				
Maximum Potential Retention "S" (Inches)	1.82				
Initial abstraction "Ia" (Inches)	0.36				
Ratio: Initial abstraction/Precipitation	0.13	0.13	0.08	0.06	0.05
Adjusted Ratio: Initial abstraction/Precipitation	0.13	0.13	0.10	0.10	0.10
Runoff "Q" (Inches)	1.45	1.45	3.15	4.08	5.67
Unit Peak Discharge "qu" (csm/in)	824.26	824.13	839.04	839.04	839.04
Peak Discharge "qp" (cfs)	13.10	13.06	28.92	37.47	52.06



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BMP Size and Treatment Analysis

Project Name:	**Scenario 2 - Residential Development**	**Date:**	**December 6, 2023**
		Location:	**Boone County**

Water Quality Storm (Event producing less than or equal to 90% stormwater runoff volume of all 24-hour storms on an annual basis) 1.3 **Inches**

Bioretention

Tributary area to bioretention area - A_T (acres)	4.00
Water Quality Volume - WQ_v (ft^3)	4824.44
Planting bed soil depth - d_f (ft)	2.50
Coefficient of permeability for planting soil bed - k (ft/day)	1.00
Maximum ponding depth - h_{max} (ft)	1.00
Average height of water above bioretention bed - h_{avg} (ft)	0.50
Time required for WQ_v to filter through the planting soil bed - t_f (days)	2.00
Required filter bed surface area - A_f (ft^2)	2010.18
Approximate filter bed length - L_f (ft)	70.00
Approximate filter bed width - W_f (ft)	35.00
Required Ponding Area - A_p (sf)	4824.44

Continous Permeable Pavement Systems

Tributary area to Continous Permeable Pavement Systems - A_T (acres)	4.67
Water Quality Volume - WQ_v (ft^3)	5631.32
Porosity of Aggregate - n	0.36
Minimum depth of gravel - D_g (in)	0.92
Minimum surface area (acres)	0.30
Soil Permeability (in/day)	0.50
Drawdown Time (days)	2.60

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Vegetative Swale

Tributary drainage area - A_T (acres)	2.00
Water Quality Volume - WQ_v (ft^3)	2412.22
2 Year, 24 Hour Storm Maximum Design Velocity	
10 Year, 24 Hour Storm Maximum Design Velocity	
Swale Geometry	Trapezoidal
Maximum Bottom Width - B_m (ft)	8
Side Slopes (ft/ft)	5
Longitudinal Slope (ft/ft)	0.005
Manning's n value	0.03
Depth - D (ft)	0.33
Length - L (ft)	200
Velocity (ft/s)	1.50
Runoff Flow Rate (ft^3/s)	4.79
Area (ft^2)	3.18
Hydraulic Radius (ft)	0.28
Calculated Bottom Width - B (ft)	7.03
Velocity Check	Check Dam(s) required

Infiltration Trench

Tributary drainage area - A_T (acres)	5.00
Runoff Volume - V (ft^3)	6030.54
Percolation Rate - P (in/hr)	0.20
Void space fraction in storage media	0.40
Retention Time - t (hrs)	72.00
Bottom Area of Trench - A_B (ft^2)	12563.64
Percolation Rate of surrounding existing soil - P (in/hr)	0.20
Void space fraction in storage media	0.40
Retention Time - t (hrs)	72.00
Trench Depth - D (ft)	3.00
Trench Width - W (ft)	6.00
Trench Length - L (ft)	2094

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Green Roof

Building Roof Area - A_B (acres)	0.80
Water Quality Volume - WQ_v (ft^3)	964.28
Average Soil Depth (inches)	4.00
Soil Porosity (% Pore Space)	40.00
Water Retention (in^3)	0.90
Moisture Mat (in^3)	0.15
Drainage Board (in^3)	0.20
Total Water Retention (in^3)	1.25
Water Retention Check	Effective Design

Rain Barrel

Building Roof Area - A_B (acres)	0.80
Rain Barrel Volume - V_B (gallons)	50
Water Quality Volume - WQ_v (ft^3)	964.28
Number of Rain Barrels needed to treat WQ_v	3.0

Detention Pond

Tributary drainage area - A_T (acres)	7
Water Quality Volume - WQ_v (ft^3)	8442.76
20% Deposition of Silt and Sediment in Basin (ft^3)	10131.32
Water Quality Outlet Type	V-notch Weir
Water Quality Depth at Outlet, Z_{WQ} (ft)	1.00
Water Quality Outlet Single Orifice Diameter, D_O (in)	1.69
Perforated Riser: Design circular perforation diameter, D_{perf} (in)	1.36
Perforated Riser: Number of Columns, n_c	1.00
Perforated Riser: Number of Row, n_r	3.00
Weir: Average head of water quality pool volume over invert of v-notch, H_{WQ} (ft)	0.50

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Weir: Average water quality pool outflow rate, C_{WQ} (cfs)	0.06
Weir: V-notch weir angle, θ (deg)	20.00
Weir: Top width of V-notch weir, W_v (ft)	1.30
Total Outlet Area - A_{ot} (in^2)	686.61
Single Orifice Outlet Trash Rack Open Area - A_t (in^2)	2746.42
Length to width ratio (should be at least 3:1 (L:W))	3.00
Low Flow Channel side lining	Soil / Riprap
Top stage floor drainage slope (toward low flow channel), S_{ts} (%)	2.00
Top stage depth, D_{ts} (ft)	1.5
Bottom stage volume, V_{bs} (ft^3)	1266.41
Forebay Volume - Minimum of 10% WQ_v (ft^3)	844.28
Forebay depth, Z_{FB} (ft)	1.50
Forebay surface area, A_{FB} (ft^2)	562.85
Paved/hard bottom and sides?	Yes
Basin side slopes: Minimum of 4:1 (H:V)	5.00
Dam Embankment: Minimum of 3:1 (H:V)	3.00
Basin Bottom Width (ft)	35.59
Basin Bottom Length (ft)	35.59
Proposed Depth of Detention Pond (ft)	8.00
Basin Top Width (ft)	75.59
Basin Top Length (ft)	75.59
Total Pond Volume (ft^3)	10069.65

Retention Pond

Tributary drainage area - A_T (acres)	7
Water Quality Volume - WQ_v (ft^3)	8442.76
Rational runoff coefficient - C	0.44
14-day Wet Season Rainfall -R_{14} (inches)	2.2
Permanent Pool Volume (Method 1), VP1 (ft^3)	24432.37
TSS Removal Efficiency (%)	90.0

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Mean storm depth, S_d (in)	0.60
Impervious tributary area, A_I (ac)	1.60
Permanent Pool Volume (Method 2), V_{P2} (ft^3)	13930.49
Design Permanent Pool Volume, V_P (ft^3)	29318.84
Average Permanent Pool Depth, Z_P (ft)	10.00
Permanent Pool Surface Area, A_P (ft^2)	2931.88
Water Quality Outlet Type	V-notch Weir
Water Quality Depth at Outlet, Z_{WQ} (ft)	1.00
Water Quality Outlet Single Orifice Diameter, D_O (in)	1.69
Perforated Riser: Design circular perforation diameter, D_{perf} (in)	1.36
Perforated Riser: Number of Columns, n_c	1.00
Perforated Riser: Number of Row, n_r	3.00
Weir: Average head of water quality pool volume over invert of v-notch, H_{WQ} (ft)	0.50
Weir: Average water quality pool outflow rate, C_{WQ} (cfs)	0.06
Weir: V-notch weir angle, θ (deg)	20.00
Weir: Top width of V-notch weir, W_v (ft)	1.30
Total Outlet Area - A_{ot} (in^2)	686.61
Single Orifice Outlet Trash Rack Open Area - A_t (in^2)	2746.42
Forebay Volume - Minimum of 10% WQ_v (ft^3)	844.28
Forebay depth, Z_{FB} (ft)	1.50
Forebay surface area, A_{FB} (ft^2)	562.85
Paved/hard bottom and sides?	Yes
Basin side slopes: Minimum of 4:1 (H:V)	4.00
Dam Embankment: Minimum of 3:1 (H:V)	3.00
Littoral Bench Surface Area (ft^2)	732.97
Bench Width, W_{LB} (ft)	20.00
Bench Depth, Z_{LB} (ft)	1.00

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Basin Bottom Width (ft)	54.15
Basin Bottom Length (ft)	54.15
Basin side slopes: Minimum of 4:1 (H:V)	7.00
Basin Top Width (ft)	124.15
Basin Top Length (ft)	124.15
Total Pond Volume (ft^3)	26291.50

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BMP Cost Analysis

Project Name: Scenario 2 - Residential Development

Date: December 6, 2023

Location: Boone County

BMP Type	Construction Costs (2018)	Maintenance Costs (2018)	Total Cost (2018)	Projected Construction Year	Construction Cost Inflation	Maintenance Costs Inflation	Total Cost
Bioretention	$ 85,000	$ 4,850	$ 89,850	2023	$ 99,000	$ 5,600	$ 104,600
Vegetative Swales	$ 18,000	$ 750	$ 18,750		$ 21,000	$ 900	$ 21,900
Infiltration Trenches	$ 60,000	$ 5,690	$ 65,690		$ 70,000	$ 6,600	$ 76,600
Green Roofs	$ 600,000	$ 53,330	$ 653,330		$ 696,000	$ 61,800	$ 757,800
Rain barrels or Cisterns	$ 17,000	$ 850	$ 17,850		$ 20,000	$ 1,000	$ 21,000
Continuous Permeable Pavement Systems	$ 261,000	$ 23,850	$ 284,850		$ 303,000	$ 27,600	$ 330,600
Detention Pond	$ 55,000	$ 1,440	$ 56,440		$ 64,000	$ 1,700	$ 65,700
Retention Pond	$ 440,000	$ 7,700	$ 447,700		$ 510,000	$ 8,900	$ 518,900

Inflation Rate (%)	3.0

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Summary

Project Name: Scenario 2 - Residential Development **Date:** December 6, 2023 **Location:** Boone County

Pre-Development		Post-Development	
Site Area (Acres)	7.00	Site Area (Acres)	7.00
Pervious Area (Acres)	7.00	Pervious Area (Acres)	1.60
Impervious Area (Acres)	0.00	Impervious Area (Acres)	5.40
Pre-Development CN	80.0	Post-Development CN	84.6
Pre-Development Time of Concentration (hrs)	0.39	Post-Development Time of Concentration (hrs)	0.18

Best fit BMPs

Construction Year	2023	***Inflation Rate (%)***	3.0	***Water Qaulity Vol. (WQ_v) ft^3***	8,443.00

	Cost per Installed BMP	Maintenance Cost per Installed BMP	Number of BMPs to Treat WQ_v	Total Cost
Bioretention	$ 99,000	$ 5,600	2.00	$ 209,200
Vegetative Swales	$ 21,000	$ 900	4.00	$ 87,600
Infiltration Trenches	$ 70,000	$ 6,600	3.00	$ 229,800
Green Roofs	$ 696,000	$ 61,800	1.00	$ 757,800
Rain barrels or Cisterns	$ 20,000	$ 1,000	3.00	$ 63,000
Continuous Permeable Pavement Systems	$ 303,000	$ 27,600	5.00	$ 1,653,000
Detention Pond	$ 64,000	$ 1,700	2.00	$ 131,400
Retention Pond	$ 510,000	$ 8,900	1.00	$ 518,900

	BMP Quantity Needed Rank	BMP Cost Rank	BMP Suitability Ranking	Composite Score	Overall Rank
Bioretention	3	4	5	12	3
Vegetative Swales	7	2	2	11	2
Infiltration Trenches	5	5	6	16	5
Green Roofs	1	7	8	16	5
Rain barrels or Cisterns	5	1	7	13	4
Continuous Permeable Pavement Systems	8	8	2	18	7
Detention Pond	3	3	1	7	1
Retention Pond	1	6	-	-	-

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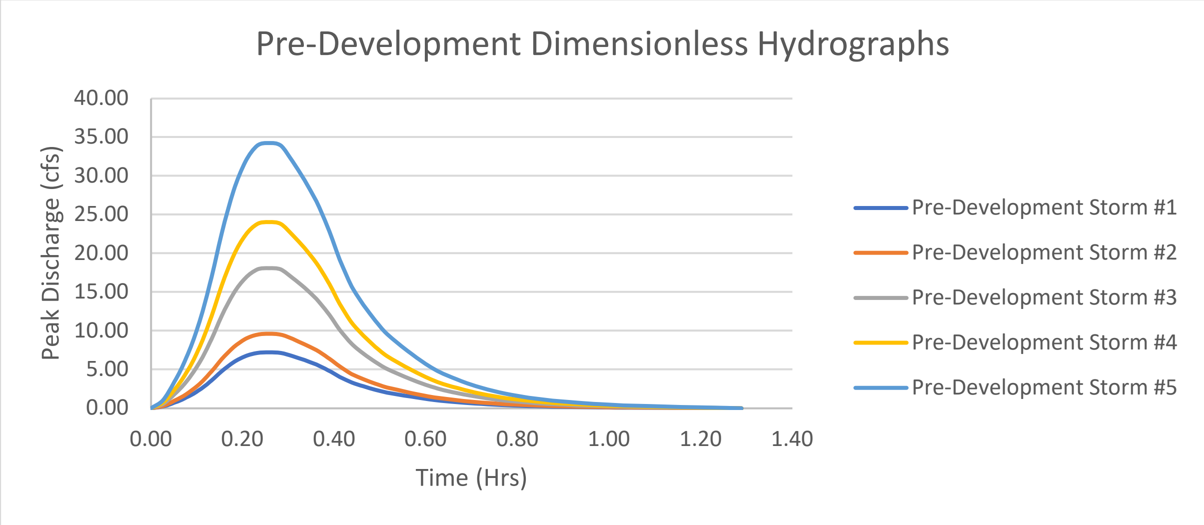

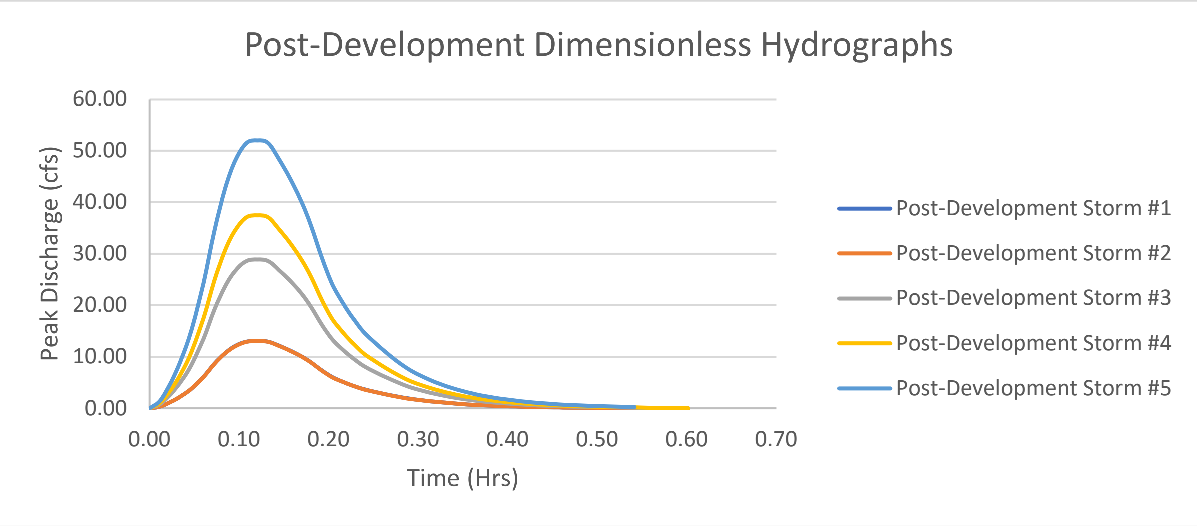

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Scenario 3

The Site Stormwater with BMPs Analysis Calculator

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Site and BMP Analysis Calculator Instructions

- This worksheet provides instructions on how to use the Site and BMP Analysis Calculator.
- The Site and BMP Analysis Calculator was developed to assist Missouri residents, developers, engineers, and community officials understand stormwater impacts incurred during development and the treatment options available to minimize impacts.
- The calculator utilizes regional and national stormwater manuals, practices, and cost information to determine BMP sizing, BMP costs, and overall treatment effectiveness for specific site conditions in the State of Missouri.
- The Site and BMP Analysis Calculator does not replace the expertise and necessary consultation of engineers when developing or redeveloping property.
- The calculator is intended for sites (new development or redevelopment) between 1 and 1,000 acres. Multiple Site and BMP Analysis Calculators may be used for site containing multiple discharge locations up to 1,000 acres.

CALCULATION PROCESS

The Site and BMP Analysis Calculator utilizes the Soil Conservation Service (SCS) Curve Number (CN) method to determine runoff with considerations to hydrologic soil group (HSG), land cover type, hydrologic condition, and the antecedent moisture condition. The Curve Number (CN) method originally developed for agricultural analysis was applied to urban watersheds in the Technical Release 55 (TR-55, 1986) by calculating mass runoff and converting this quantity into a hydrograph by using unit hydrograph theory.

General Information: Project Name, Address, Project Site Area

- Enter the general specifications for this project at the top of the User Questionnaire worksheet. The date autopopulates when the BMP Tool is opened. Select the Missouri County that the proposed development or re-development site occurs in.

SUMMARY OF WORKSHEETS

User Questionnaire: The worksheet presents the user with questions regarding implementation of BMPs, treatment capabilities, and cost and maintenance. Each question has a drop-down menu of answers for the user to chose from. The default values are green, and all other answers are blue. The user selected answers are utilized in recommending the most suitable BMPs for the proposed site. Answers are autopopulated into the BMP Suitability worksheet.

Site Pre-Development: Worksheet determines existing or pre-development hydrologic conditions of the proposed site. The worksheet calculates Pre-Development Curve Number (CN) and the time of concentration (hours).

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Site Post-Development: The worksheet determines proposed hydrologic conditions of the proposed development or re-development. The worksheet calculates Post-Development Curve Number (CN) and the time of concentration (hours).

Site Hydrology: Autopopulated by the results of the Site Pre-Develoopment and Site Post-Development worksheet, this worksheet calculates runoff depth and dimensionless hydrographs for both the site's pre-development and post-development scenarios.

Cost Analysis: The worksheet calculates construction costs and maintenance and operation (O&M) costs for each BMP. Cost Information published in the United States was compiled from research publications and converted to 2018 prices by utilizing APWA Rainfall Zone Adjustment Factors and an average inflation rate of 3%. Users may change the "Projected Inflation Year" to calculate the cost of installation and O&M for the year the project is proposed to be built.

BMP Site and Treatment Analysis: The worksheet calculates the basic design parameters for each BMP in the tool. All values are considered standard design parameters recommended by multiple stormwater design manuals utilized across the United States. Value cells highlighted in blue can be adjusted by the user if different design characteristics are required.

Summary: The worksheet combines all relevant information from the BMP Tool's worksheets and presents the user with a summary of the best suited BMPs for the proposed development or re-development. The summary includes pre-development and post-development site characteristics, site hydrology, hydrographs, construction cost and O&M costs, and BMP sizing information.

LEGEND

(light blue)	User must select option from dropdown menu or enter value
(green)	Default Value if User chooses not to revise
(yellow)	Option selected by User that is not considered Default

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The Site Stormwater with BMPs Analysis Calculator

User BMP Questionnaire

Project Name:	**Case Study No. 3 - Retrofit Site**	**Date:**	**November 20, 2023**
		Location:	**Boone County**

Site Considerations

1)	Classify site ownership.	Private Property
2)	Classify type of construction.	Redevelopment
3)	Are there any active stormwater permits or regulated outfalls located on the site?	No
4)	Is the site's stormwater management regulated under a MS4 permit?	Yes
5)	Does the site contain existing storm sewer infrastructure?	Yes
6)	Is there an existing pond or lake located on the site?	No
7)	Are utilities such as gas, water, electric, fiber, and sanitary sewer located on the site?	Yes
8)	Has the site had a history of flooding?	No
9)	Does the site shows evidence of soil erosion?	Yes
10)	Is there evidence of channel erosion or instability downstream of the site?	No
11)	Does the site drain to a waterbody classified on the 303(d) list as an "Impaired or Threatened Water?"	Yes
12)	Does the site have a history of theft, vandalism, odors, or excessive trash?	No
13)	Is there planned buildings or existing buildings on the site?	No

BMP Treatment Considerations

1)	How effectively should the BMP treat nutrients in the stormwater?	Low
2)	How effectively should the BMP treat bacteria in the stormwater?	Low
3)	How effectively should the BMP treat metals in the stormwater?	Low
4)	How effectively should the BMP treat suspended sediment in the stormwater?	High
5)	How effectively should the BMP treat organics in the stormwater?	Low
6)	How effectively should the BMP treat oil/grease in the stormwater?	Low
7)	How effectively should the BMP provide peak flow reduction of site stormwater?	High
8)	How effectively should the BMP provide channel protection from the site stormwater?	Moderate
9)	What quality of habitat should the BMP provide?	Low
10)	How important are the visual aesthetics of the BMP?	Low
11)	How effectively should the BMP provide temperature reduction?	Low

Investment and Maintenance Considerations

1)	What is the preferred cost range of implementing a BMP?	Low
2)	What is the preferred cost range for yearly maintenance of a BMP?	Low
3)	What is the preferred level of operation and maintenance required for a BMP?	Low

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BMP Suitability with User Questionnaire

Project Name: **Case Study No. 3 - Retrofit Site**
Date: **November 20, 2023**
Location: **Boone County**

Comparison Table:

	Questionnaire Result	Bioretention	Vegetative Swale	Infiltration Trenches	Green Roofs	Rain Barrels or Cisterns	Continuous Permeable Pavement Systems	Detention Pond	Retention Pond
Treatment of Nutrients	Low	No Match	Match	No Match	Match	No Match	Match	Match	No Match
Treatment of Bacteria	Low	No Match	Match	No Match	Match	No Match	No Match	No Match	No Match
Treatment of Metal	Low	No Match	No Match	No Match	Match	No Match	No Match	No Match	No Match
Treatment of Suspended Sediment	High	Match	No Match	No Match	No Match	Match	Match	No Match	Match
Treatment of Organics	Low	No Match	No Match	No Match	Match	No Match	No Match	No Match	No Match
Treatment of Oil/Grease	Low	No Match	No Match	No Match	Match	No Match	Match	Match	No Match
Peak Flow Reduction	High	No Match	No Match	Match	No Match	No Match	No Match	Match	Match
Channel Protection	Moderate	Match	No Match	Match	Match	Match	Match	No Match	No Match
Habitat Established	Low	No Match	No Match	Match	No Match	Match	Match	Match	No Match
Visual Aesthetics	Low	No Match	No Match	No Match	No Match	Match	No Match	No Match	No Match
Temperatue Reduction	Low	No Match	Match	No Match	No Match	No Match	No Match	No Match	Match
Construction Cost	Low	No Match	Match	No Match	No Match	No Match	No Match	Match	Match
Maintenance Cost	Low	No Match	Match	No Match	No Match	No Match	No Match	Match	No Match
Amount of maintenance required per year	Low	No Match	No Match	No Match	No Match	Match	No Match	Match	No Match
Hydrologic Soil Classification	D	Match	No Match	No Match	No Match	No Match	No Match	Match	Match
Drainage Area (Acres)	1.8	Match	Match	Match	No Match	No Match	Match	Match	No Match
Calculated Slope	7.54	No Match	No Match	Match	No Match	No Match	No Match	Match	Match

Criteria Matched:	4	6	5	6	5	6	10	6
Suitability Ranking:	**8**	**2**	**6**	**2**	**6**	**2**	**1**	**2**

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Pre-Development Watershed Information

Project Name:	Case Study No. 3 - Retrofit Site	Date:	November 20, 2023
		Location:	Boone County

Curve Number:

HSG	Land use	CN	Area (Acres)	Percentage (%)	Product
D	Impervious (Pavement, Paved Streets/Roads, Roof, etc.)	98	1.16	64%	113.68
D	Open Space (Good; Grass Cover > 75%)	80	0.64	36%	51.2
			1.8	100%	

Pre-Development Curve Number	91.6

Time of Concentration:

Flow Type	Surface Cover	Length (ft)	Slope (ft/ft)	Manning's n Value	Time (hrs)
Sheet Flow	Smooth surface (Concrete, asphalt, gravel or bare soil)	100	0.08	0.011	0.01
Sheet Flow					
Sheet Flow					
Shallow Flow	Pavement and small upland gullies	165	0.085	-	0.01
Shallow Flow	Short-grass pasture	80	0.05	-	0.01
Shallow Flow				-	

Flow Type	Type of Channel	Length (ft)	Slope (ft/ft)	Manning's n Value	Time (hrs)
Channel Flow					0.00
	Channel Geometry	Base (ft)	Depth (ft)	Side Slope (ft/ft)	

	Type of Channel	Length (ft)	Slope (ft/ft)	Manning's n Value	Time (hrs)
Channel Flow					0.00
	Channel Geometry	Base (ft)	Depth (ft)	Side Slope (ft/ft)	

Time of Concentration (hrs)	0.10

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Post-Development Information

Project Name:	**Case Study No. 3 - Retrofit Site**	**Date:**	**November 20, 2023**
		Location:	**Boone County**

Curve Number:

HSG	Land use	CN	Area (Acres)	Percentage (%)	Product
D	Impervious (Pavement, Paved Streets/Roads, Roof, etc.)	98	1.16	64%	113.68
D	Open Space (Good; Grass Cover > 75%)	80	0.64	36%	51.2
			1.8	100%	
	Post-Development Curve Number	**91.6**			

Time of Concentration:

Flow Type	Surface Cover	Length (ft)	Slope (ft/ft)	Manning's n Value	Time (hrs)
Sheet Flow	Smooth surface (Concrete, asphalt, gravel or bare soil)	100	0.08	0.011	0.01
Sheet Flow					
Sheet Flow					
Shallow Flow	Pavement and small upland gullies	165	0.085	-	0.01
Shallow Flow	Short-grass pasture	80	0.05	-	0.01
Shallow Flow				-	

Flow Type	Type of Channel	Length (ft)	Slope (ft/ft)	Manning's n Value	Time (hrs)
Channel Flow					0.00
	Channel Geometry	**Base (ft)**	**Depth (ft)**	**Side Slope (ft/ft)**	
	Type of Channel	**Length (ft)**	**Slope (ft/ft)**	**Manning's n Value**	**Time (hrs)**
Channel Flow			0		0.00
	Channel Geometry	**Base (ft)**	**Depth (ft)**	**Side Slope (ft/ft)**	

Time of Concentration (hrs)	**0.10**

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Site Hydrology

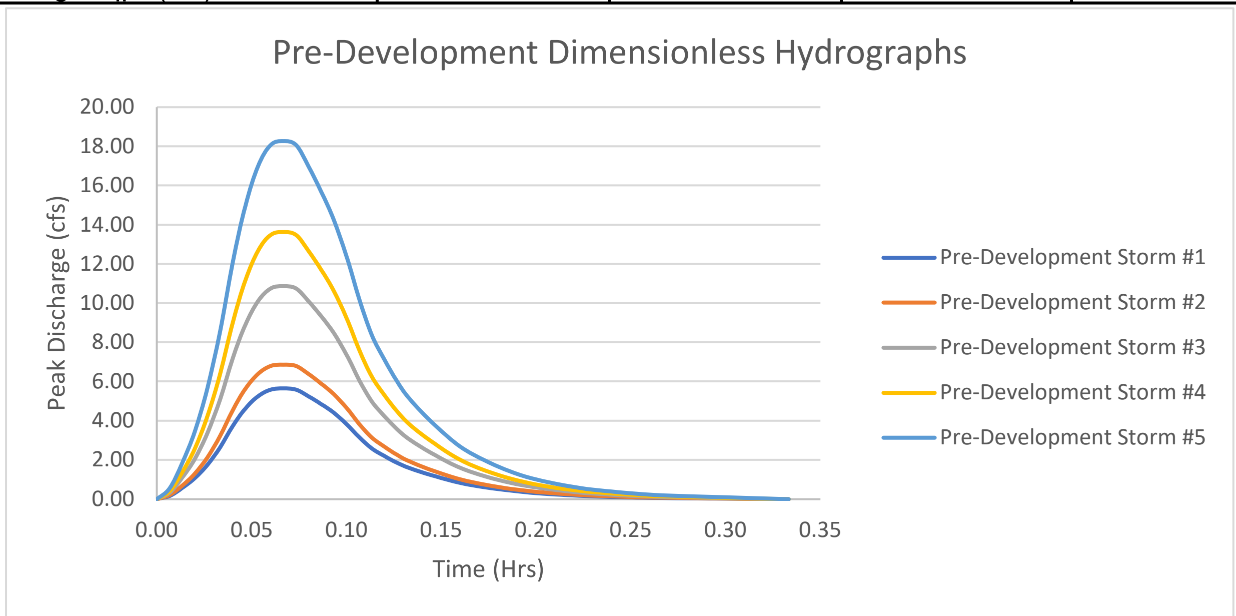
Project Name: **Case Study No. 3 - Retrofit Site**

Date: **November 20, 2023**

Location: **Boone County**

Pre-Development Hydrology:

	Storm #1	Storm #2	Storm #3	Storm #4	Storm #5
Precipitation Event	1 YR 24 HR	2 YR 24 HR	10 YR 24 HR	25 YR 24 HR	100 YR 24 HR
Precipitation Amount (Inches)	2.88	3.34	4.81	5.82	7.49
Pre-Development Curve Number	91.6				
Time of Concentration (Hrs)	0.10				
Maximum Potential Retention "S" (Inches)	0.92				
Initial abstraction "Ia" (Inches)	0.18				
Ratio: Initial abstraction/Precipitation	0.06	0.05	0.04	0.03	0.02
Adjusted Ratio: Initial abstraction/Precipitation	0.10	0.10	0.10	0.10	0.10
Runoff "Q" (Inches)	2.01	2.44	3.86	4.84	6.49
Unit Peak Discharge "qu" (csm/in)	1000.00	1000.00	1000.00	1000.00	1000.00
Peak Discharge "qp" (cfs)	5.65	6.87	10.86	13.62	18.26



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Site Hydrology

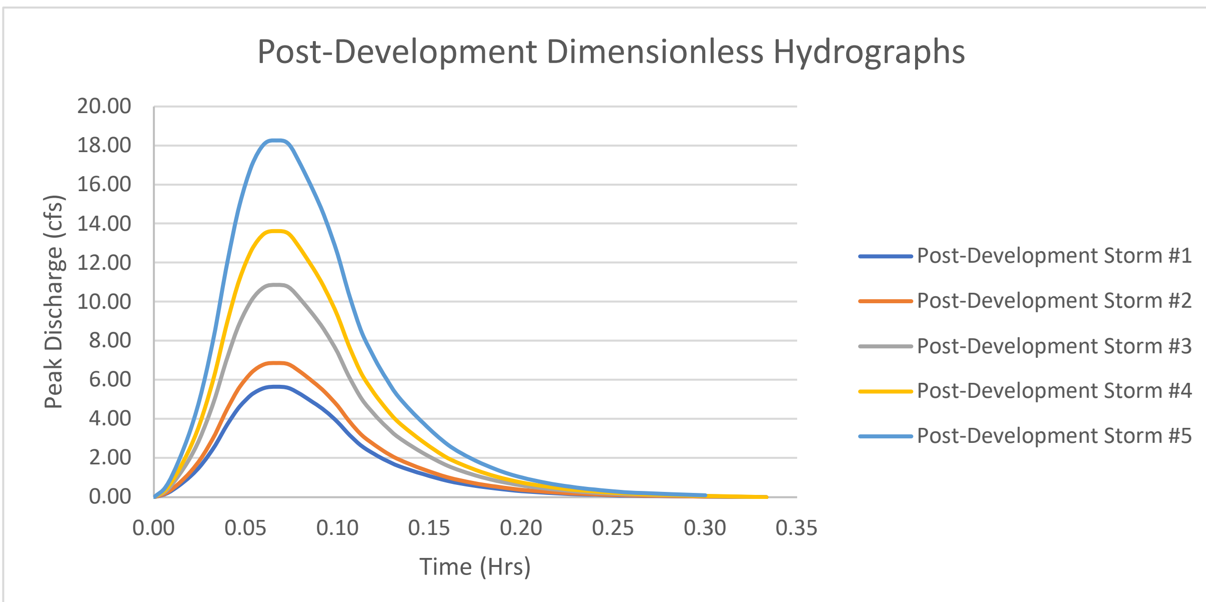
Project Name: **Case Study No. 3 - Retrofit Site**

Date: **November 20, 2023**

Location: **Boone County**

Post-Development Hydrology:

	Storm #1	***Storm #2***	***Storm #3***	***Storm #4***	***Storm #5***
Precipitation Event	1 YR 24 HR	2 YR 24 HR	10 YR 24 HR	25 YR 24 HR	100 YR 24 HR
Precipitation Amount (Inches)	2.88	3.34	4.81	5.82	7.49
Post-Development Curve Number	91.6				
Time of Concentration (Hrs)	0.10				
Maximum Potential Retention "S" (Inches)	0.92				
Initial abstraction "Ia" (Inches)	0.18				
Ratio: Initial abstraction/Precipitation	0.06	0.05	0.04	0.03	0.02
Adjusted Ratio: Initial abstraction/Precipitation	0.10	0.10	0.10	0.10	0.10
Runoff "Q" (Inches)	2.01	2.44	3.86	4.84	6.49
Unit Peak Discharge "qu" (csm/in)	1000.00	1000.00	1000.00	1000.00	1000.00
Peak Discharge "qp" (cfs)	5.65	6.87	10.86	13.62	18.26



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The Site Stormwater with BMPs Analysis Calculator

Department of Bioengineering
254 Agricultural Engineering
Columbia, Missouri 65211

BMP Size and Treatment Analysis

Project Name:	**Case Study No. 3 - Retrofit Site**	**Date:**	**December 6, 2023**
		Location:	**Boone County**
Water Quality Storm (Event producing less than or equal to 90% stormwater runoff volume of all 24-hour storms on an annual basis)		1.3	**Inches**

Bioretention

Tributary area to bioretention area - A_T (acres)	1.80
Water Quality Volume - WQ_v (ft^3)	5351.35
Planting bed soil depth - d_f (ft)	2.50
Coefficient of permeability for planting soil bed - k (ft/day)	1.00
Maximum ponding depth - h_{max} (ft)	1.00
Average height of water above bioretention bed - h_{avg} (ft)	0.50
Time required for WQ_v to filter through the planting soil bed - t_f (days)	2.00
Required filter bed surface area - A_f (ft^2)	2229.73
Approximate filter bed length - L_f (ft)	73.00
Approximate filter bed width - W_f (ft)	37.00
Required Ponding Area - A_p (sf)	5351.35

Continous Permeable Pavement Systems

Tributary area to Continous Permeable Pavement Systems - A_T (acres)	1.20
Water Quality Volume - WQ_v (ft^3)	3569.35
Porosity of Aggregate - n	0.36
Minimum depth of gravel - D_g (in)	2.28
Minimum surface area (acres)	0.05
Soil Permeability (in/day)	0.50
Drawdown Time (days)	2.60

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Vegetative Swale

Tributary drainage area - A_T (acres)	1.80
Water Quality Volume - WQ_v (ft^3)	5351.35
2 Year, 24 Hour Storm Maximum Design Velocity	
10 Year, 24 Hour Storm Maximum Design Velocity	
Swale Geometry	Trapezoidal
Maximum Bottom Width - B_m (ft)	8
Side Slopes (ft/ft)	5
Longitudinal Slope (ft/ft)	0.005
Manning's n value	0.03
Depth - D (ft)	0.33
Length - L (ft)	200
Velocity (ft/s)	1.50
Runoff Flow Rate (ft^3/s)	4.79
Area (ft^2)	3.18
Hydraulic Radius (ft)	0.28
Calculated Bottom Width - B (ft)	7.03
Velocity Check	Check Dam(s) required

Infiltration Trench

Tributary drainage area - A_T (acres)	1.80
Runoff Volume - V (ft^3)	5351.35
Percolation Rate - P (in/hr)	0.20
Void space fraction in storage media	0.40
Retention Time - t (hrs)	72.00
Bottom Area of Trench - A_B (ft^2)	11148.64
Percolation Rate of surrounding existing soil - P (in/hr)	0.20
Void space fraction in storage media	0.40
Retention Time - t (hrs)	72.00
Trench Depth - D (ft)	3.00
Trench Width - W (ft)	6.00
Trench Length - L (ft)	1858

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Green Roof

Building Roof Area - A_B (acres)	1.00
Water Quality Volume - WQ_v (ft^3)	2972.97
Average Soil Depth (inches)	4.00
Soil Porosity (% Pore Space)	40.00
Water Retention (in^3)	0.90
Moisture Mat (in^3)	0.15
Drainage Board (in^3)	0.20
Total Water Retention (in^3)	1.25
Water Retention Check	Effective Design

Rain Barrel

Building Roof Area - A_B (acres)	0.58
Rain Barrel Volume - V_B (gallons)	50
Water Quality Volume - WQ_v (ft^3)	1724.32
Number of Rain Barrels needed to treat WQ_v	5.0

Detention Pond

Tributary drainage area - A_T (acres)	1.8
Water Quality Volume - WQ_v (ft^3)	5351.35
20% Deposition of Silt and Sediment in Basin (ft^3)	6421.62
Water Quality Outlet Type	V-notch Weir
Water Quality Depth at Outlet, Z_{WQ} (ft)	1.00
Water Quality Outlet Single Orifice Diameter, D_O (in)	1.35
Perforated Riser: Design circular perforation diameter, D_{perf} (in)	1.08
Perforated Riser: Number of Columns, n_c	1.00
Perforated Riser: Number of Row, n_r	3.00
Weir: Average head of water quality pool volume over invert of v-notch, H_{WQ} (ft)	0.50

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Weir: Average water quality pool outflow rate, C_{WQ} (cfs)	0.04
Weir: V-notch weir angle, θ (deg)	20.00
Weir: Top width of V-notch weir, W_v (ft)	1.30
Total Outlet Area - A_{ot} (in^2)	686.61
Single Orifice Outlet Trash Rack Open Area - A_t (in^2)	2746.42
Length to width ratio (should be at least 3:1 (L:W))	3.00
Low Flow Channel side lining	Soil / Riprap
Top stage floor drainage slope (toward low flow channel), S_{ts} (%)	2.00
Top stage depth, D_{ts} (ft)	1.5
Bottom stage volume, V_{bs} (ft^3)	802.70
Forebay Volume - Minimum of 10% WQ_v (ft^3)	535.13
Forebay depth, Z_{FB} (ft)	1.50
Forebay surface area, A_{FB} (ft^2)	356.76
Paved/hard bottom and sides?	Yes
Basin side slopes: Minimum of 4:1 (H:V)	5.00
Dam Embankment: Minimum of 3:1 (H:V)	3.00
Basin Bottom Width (ft)	28.33
Basin Bottom Length (ft)	28.33
Proposed Depth of Detention Pond (ft)	8.00
Basin Top Width (ft)	68.33
Basin Top Length (ft)	68.33
Total Pond Volume (ft^3)	7807.95

Retention Pond

Tributary drainage area - A_T (acres)	1.8
Water Quality Volume - WQ_v (ft^3)	5351.35
Rational runoff coefficient - C	0.69
14-day Wet Season Rainfall -R_{14} (inches)	2.2
Permanent Pool Volume (Method 1), VP1 (ft^3)	9870.70
TSS Removal Efficiency (%)	90.0

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Mean storm depth, S_d (in)	0.60
Impervious tributary area, A_I (ac)	1.16
Permanent Pool Volume (Method 2), V_{P2} (ft^3)	10105.92
Design Permanent Pool Volume, V_P (ft^3)	12127.10
Average Permanent Pool Depth, Z_P (ft)	10.00
Permanent Pool Surface Area, A_P (ft^2)	1212.71
Water Quality Outlet Type	V-notch Weir
Water Quality Depth at Outlet, Z_{WQ} (ft)	1.00
Water Quality Outlet Single Orifice Diameter, D_O (in)	1.35
Perforated Riser: Design circular perforation diameter, D_{perf} (in)	1.08
Perforated Riser: Number of Columns, n_c	1.00
Perforated Riser: Number of Row, n_r	3.00
Weir: Average head of water quality pool volume over invert of v-notch, H_{WQ} (ft)	0.50
Weir: Average water quality pool outflow rate, C_{WQ} (cfs)	0.04
Weir: V-notch weir angle, θ (deg)	20.00
Weir: Top width of V-notch weir, W_v (ft)	1.30
Total Outlet Area - A_{ot} (in^2)	686.61
Single Orifice Outlet Trash Rack Open Area - A_t (in^2)	2746.42
Forebay Volume - Minimum of 10% WQ_v (ft^3)	535.13
Forebay depth, Z_{FB} (ft)	1.50
Forebay surface area, A_{FB} (ft^2)	356.76
Paved/hard bottom and sides?	Yes
Basin side slopes: Minimum of 4:1 (H:V)	4.00
Dam Embankment: Minimum of 3:1 (H:V)	3.00
Littoral Bench Surface Area (ft^2)	303.18
Bench Width, W_{LB} (ft)	20.00
Bench Depth, Z_{LB} (ft)	1.00

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Basin Bottom Width (ft)	34.82
Basin Bottom Length (ft)	34.82
Basin side slopes: Minimum of 4:1 (H:V)	7.00
Basin Top Width (ft)	104.82
Basin Top Length (ft)	104.82
Total Pond Volume (ft^3)	17076.17

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BMP Cost Analysis

Project Name: Case Study No. 3 - Retrofit Site

Date: December 6, 2023

Location: Boone County

BMP Type	Construction Costs (2018)	Maintenance Costs (2018)	Total Cost (2018)	Projected Construction Year	Construction Cost Inflation	Maintenance Costs Inflation	Total Cost
Bioretention	$ 89,000	$ 5,040	$ 94,040	2023	$ 103,000	$ 5,800	$ 108,800
Vegetative Swales	$ 23,000	$ 900	$ 23,900		$ 27,000	$ 1,000	$ 28,000
Infiltration Trenches	$ 56,000	$ 5,340	$ 61,340		$ 65,000	$ 6,200	$ 71,200
Green Roofs	$ 750,000	$ 66,710	$ 816,710		$ 869,000	$ 77,300	$ 946,300
Rain barrels or Cisterns	$ 29,000	$ 1,450	$ 30,450		$ 34,000	$ 1,700	$ 35,700
Continuous Permeable Pavement Systems	$ 118,000	$ 17,640	$ 135,640		$ 137,000	$ 20,400	$ 157,400
Detention Pond	$ 47,000	$ 1,310	$ 48,310		$ 54,000	$ 1,500	$ 55,500
Retention Pond	$ 202,000	$ 6,100	$ 208,100		$ 234,000	$ 7,100	$ 241,100

Inflation Rate (%)	3.0

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Summary

Project Name: Case Study No. 3 - Retrofit Site **Date:** December 6, 2023 **Location:** Boone County

Pre-Development		Post-Development	
Site Area (Acres)	1.80	Site Area (Acres)	1.80
Pervious Area (Acres)	0.64	Pervious Area (Acres)	1.16
Impervious Area (Acres)	1.16	Impervious Area (Acres)	0.64
Pre-Development CN	91.6	Post-Development CN	91.6
Pre-Development Time of Concentration (hrs)	0.10	Post-Development Time of Concentration (hrs)	0.10

Best fit BMPs

Construction Year	2023	***Inflation Rate (%)***	3.0	***Water Qaulity Vol. (WQ_v) ft^3***	5,351.00

	Cost per Installed BMP	Maintenance Cost per Installed BMP	Number of BMPs to Treat WQ_v	Total Cost
Bioretention	$ 103,000	$ 5,800	1.00	$ 108,800
Vegetative Swales	$ 27,000	$ 1,000	1.00	$ 28,000
Infiltration Trenches	$ 65,000	$ 6,200	1.00	$ 71,200
Green Roofs	$ 869,000	$ 77,300	1.00	$ 946,300
Rain barrels or Cisterns	$ 34,000	$ 1,700	5.00	$ 178,500
Continuous Permeable Pavement Systems	$ 137,000	$ 20,400	2.00	$ 314,800
Detention Pond	$ 54,000	$ 1,500	1.00	$ 55,500
Retention Pond	$ 234,000	$ 7,100	1.00	$ 241,100

	BMP Quantity Needed Rank	BMP Cost Rank	BMP Suitability Ranking	Composite Score	Overall Rank
Bioretention	1	4	8	13	4
Vegetative Swales	1	1	2	4	1
Infiltration Trenches	1	3	6	10	3
Green Roofs	1	8	-	-	-
Rain barrels or Cisterns	8	5	6	19	6
Continuous Permeable Pavement Systems	7	7	2	16	5
Detention Pond	1	2	1	4	1
Retention Pond	1	6	-	-	-

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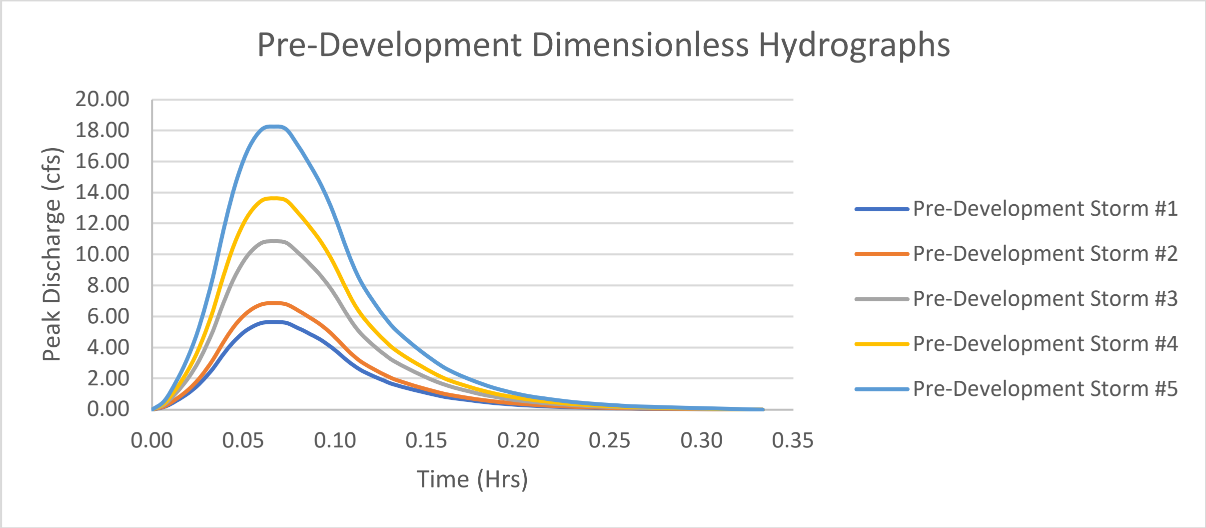
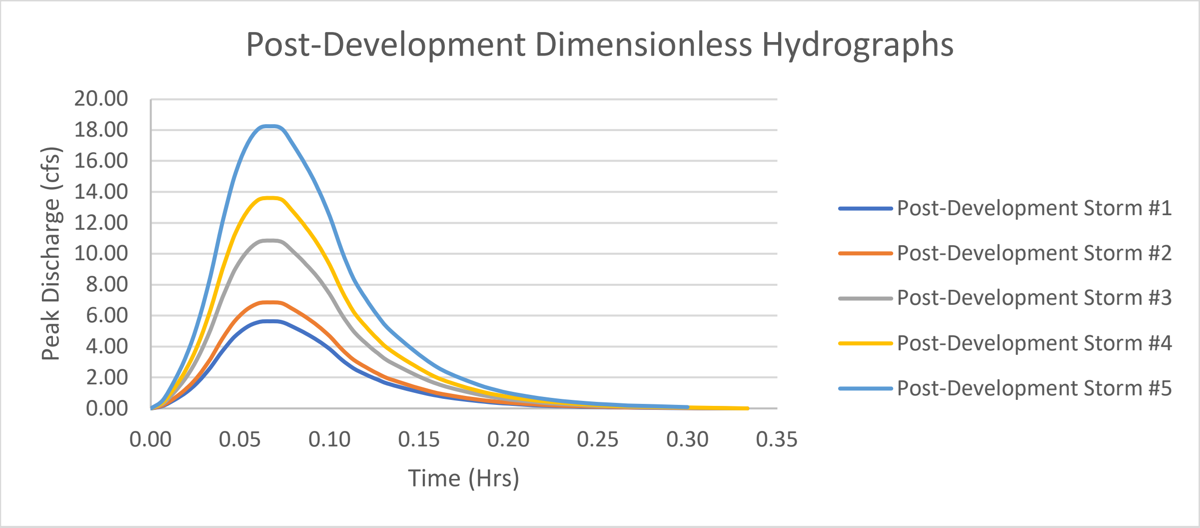




Appendix C: USEPA National Stormwater Calculator Scenario 1 Printouts

National Stormwater Calculator Report

Results

Site Description

Scenario 1 - Commercial Development

Parameter	Current Scenario
Site Characteristics	
Site Area (acres)	2.5
Hydrologic Soil Group	D
Hydraulic Conductivity (in/hr)	0.01
Surface Slope (%)	5
Precip. Data Source	COLUMBIA REGIONAL AIRPORT
Evap. Data Source	COLUMBIA REGIONAL AIRPORT
Climate Change Scenario	None
Extreme Storm Scenario	None
Land Cover	
% Forest	0
% Meadow	0
% Lawn	15
% Desert	0
% Impervious	85
LID Controls	
% Disconnection	0
% Rain Harvesting	0
% Rain Gardens	25 / 7
% Green Roofs	0
% Street Planters	0
% Infiltration Basins	50 / 12
% Permeable Pavement	25 / 20
Analysis Options	
Years Analyzed	20
Ignore Consecutive Wet Days	False
Wet Day Threshold (inches)	0.1

National Stormwater Calculator Report

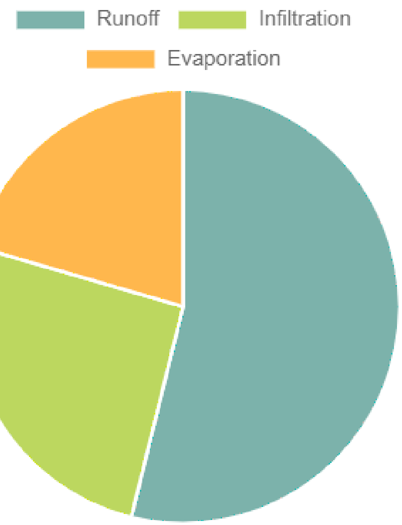
Results

Site Summary

Scenario 1 - Commercial Development

Current Scenario

Annual Rainfall: 40.01 in.



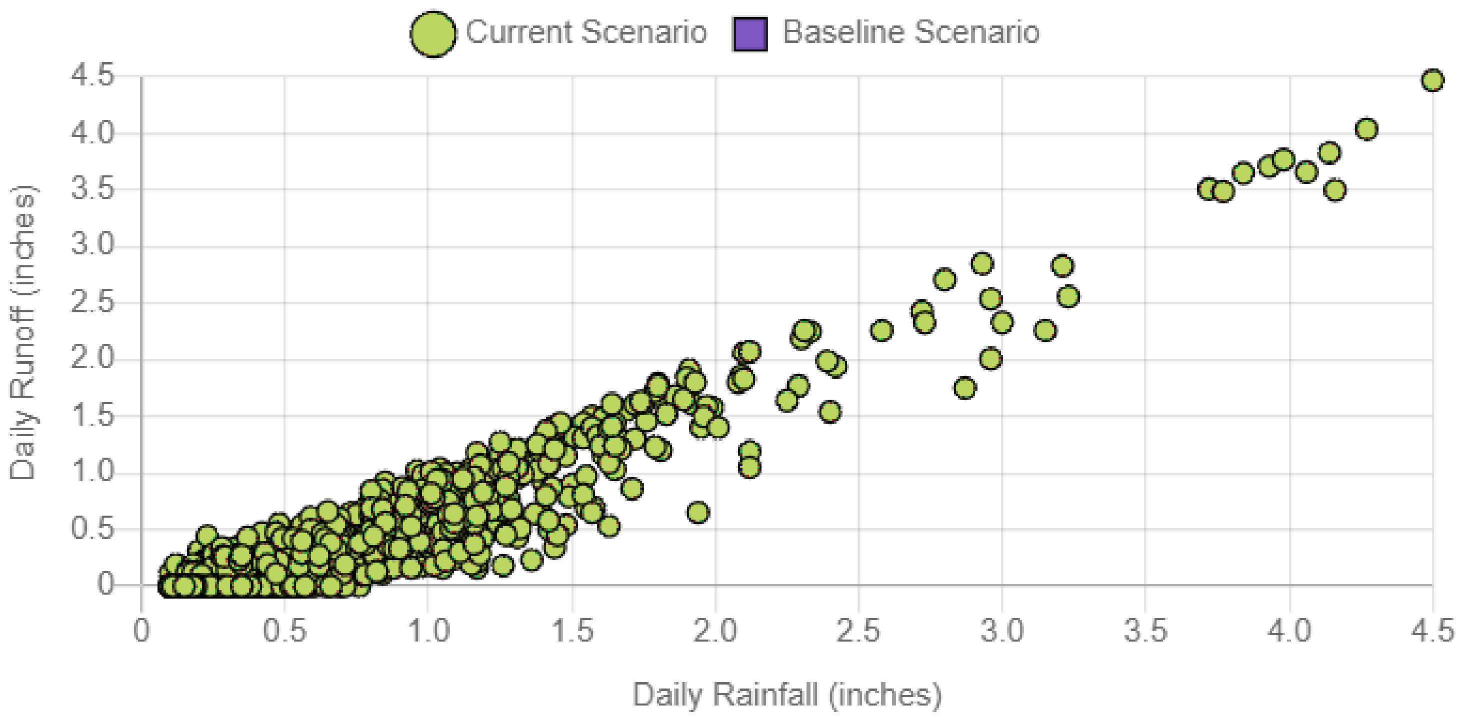
Statisic	Current Scenario
Average Annual Rainfall (inches)	40.01
Average Annual Runoff (inches)	21.69
Days per Year with Rainfall	64.71
Days per Year with Runoff	32.78
Percent of Wet Days Retained	49.34
Smallest Rainfall w/ Runoff (inches)	0.10
Largest Rainfall w/o Runoff (inches)	0.76
Max Rainfall Retained (inches)	1.29

National Stormwater Calculator Report

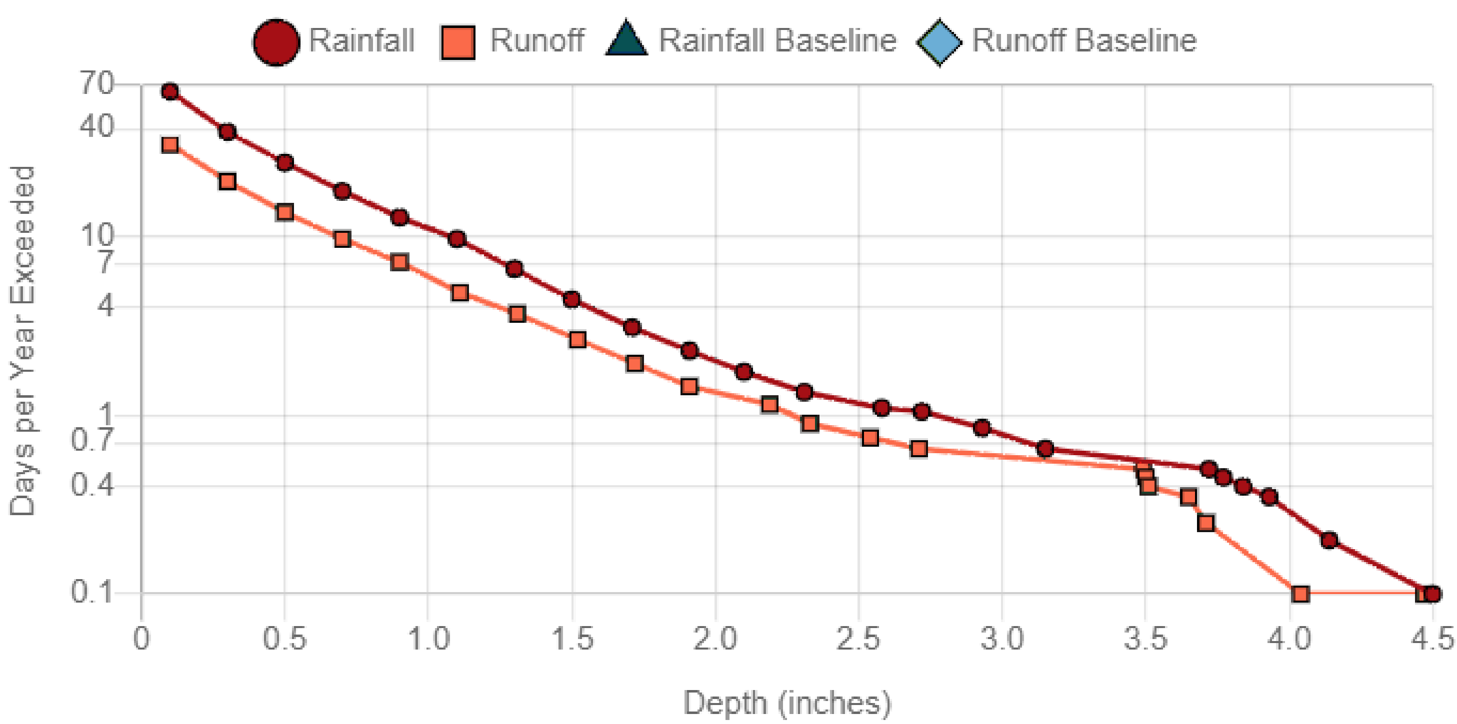
Results

Scenario 1 - Commercial Development

Rainfall / Runoff Events



Rainfall / Runoff Exceedance Frequency

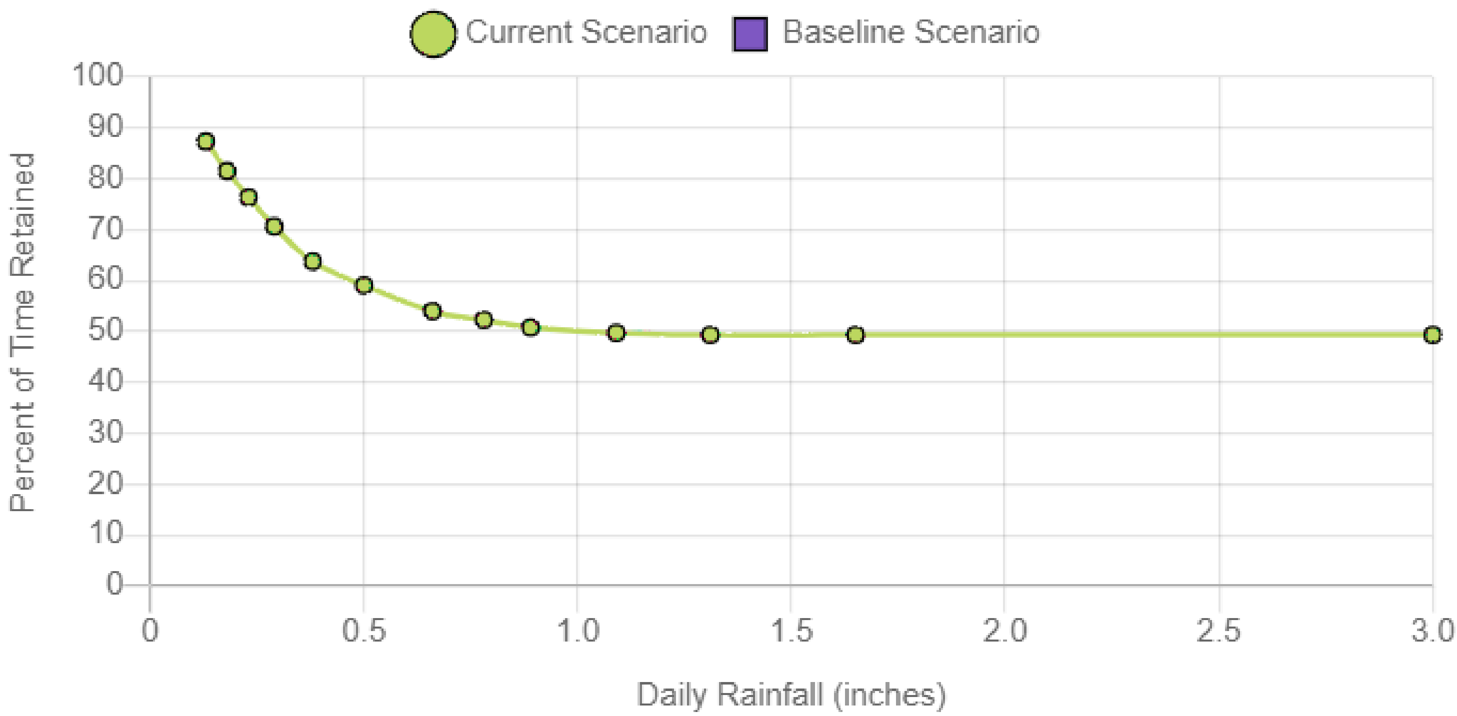


National Stormwater Calculator Report

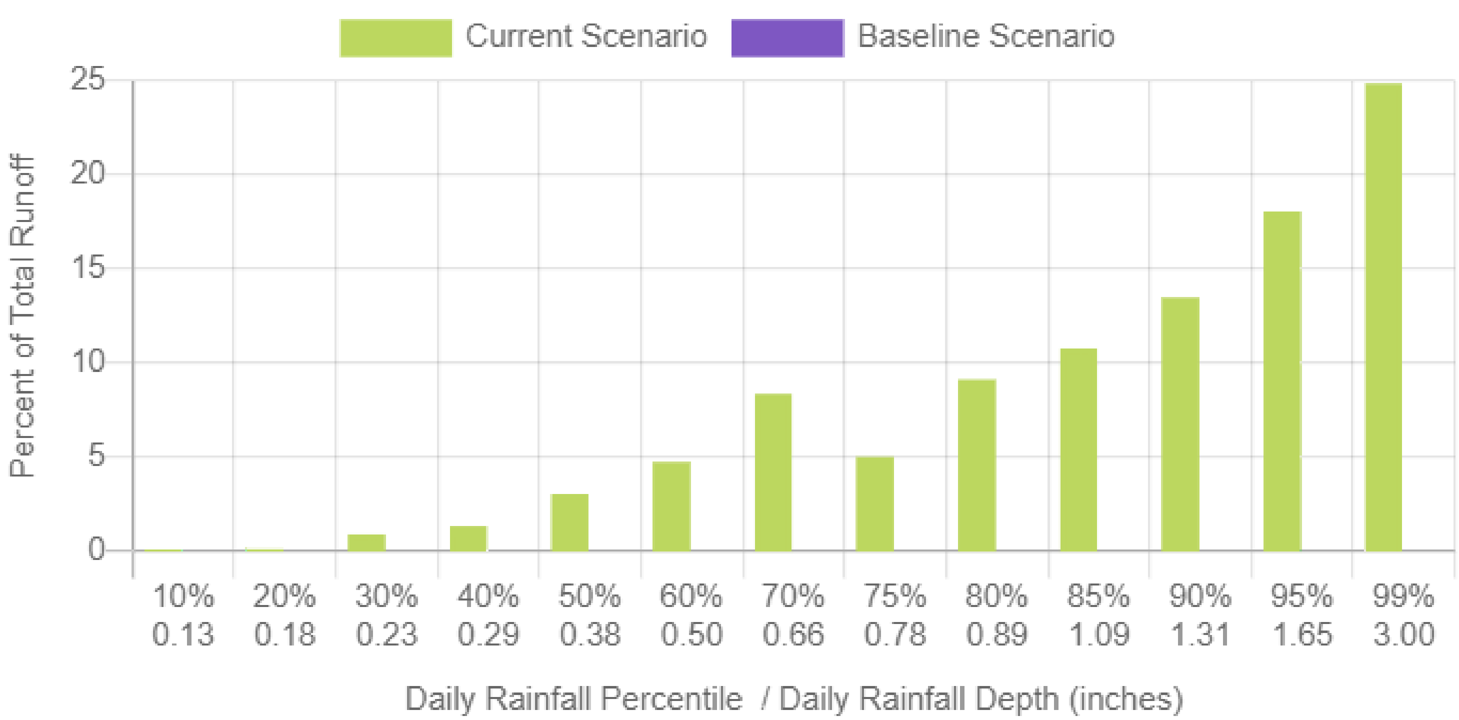
Results

Scenario 1 - Commercial Development

Rainfall Retention Frequency



Runoff Contribution by Rainfall Percentile



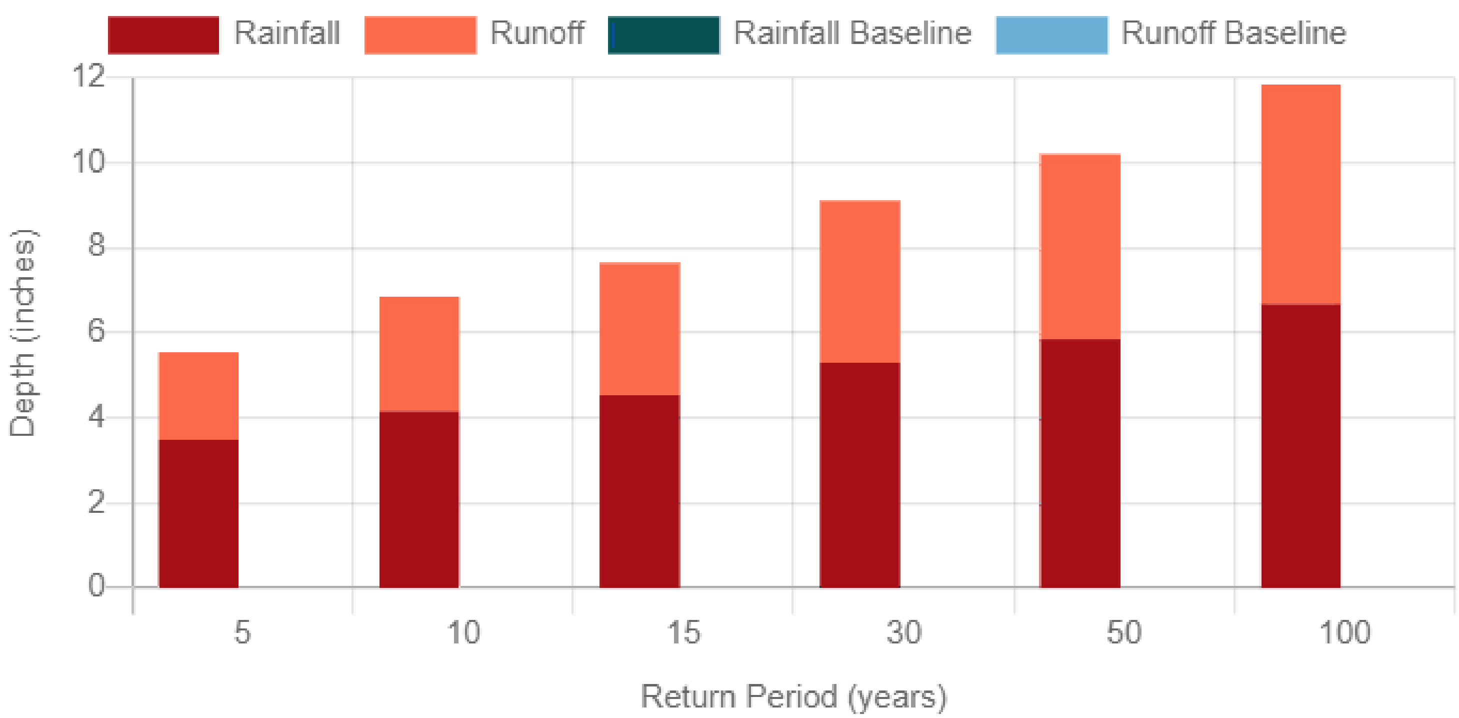
National Stormwater Calculator Report

Results

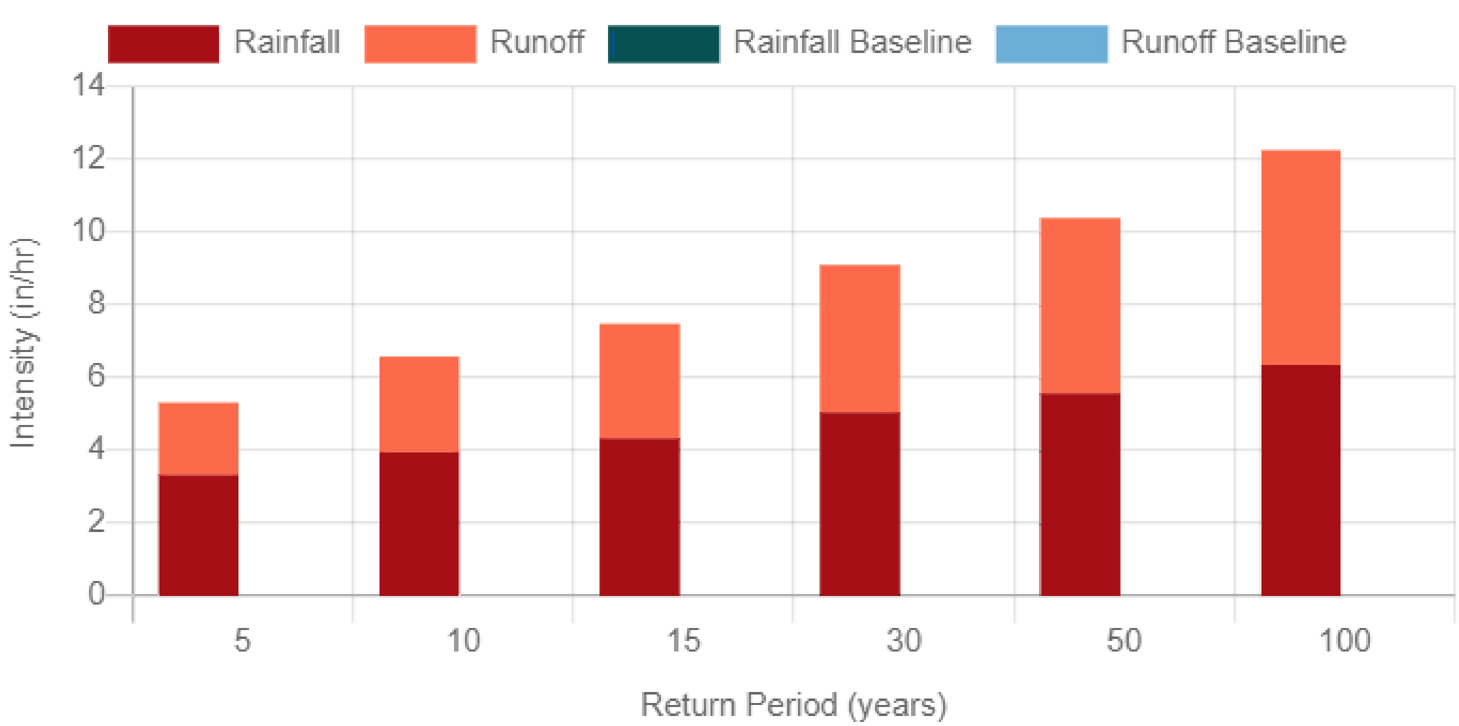
Scenario 1 - Commercial Development

Extreme Event Rainfall / Runoff

Extreme Event Rainfall / Runoff Depth



Extreme Event Peak Rainfall / Runoff



National Stormwater Calculator Report

Results

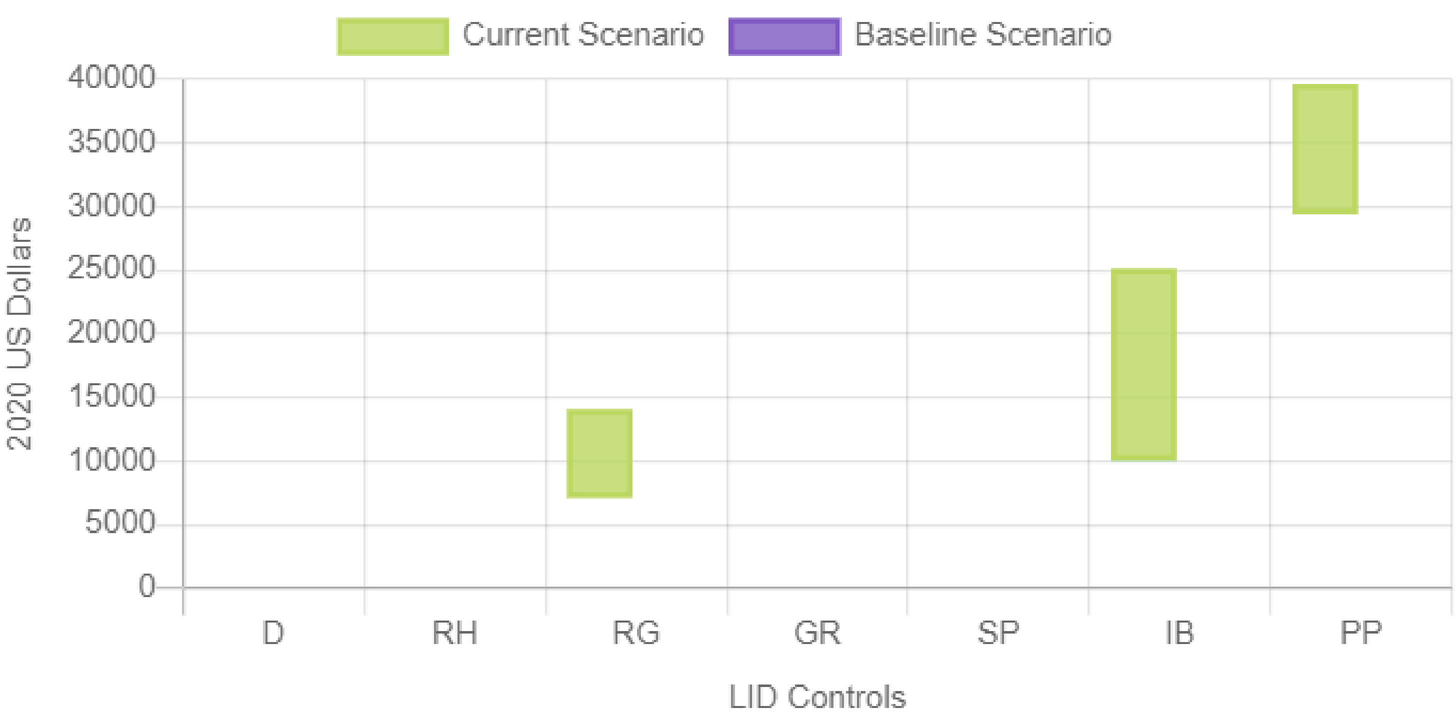
Scenario 1 - Commercial Development

Cost Summary

Estimate of Probable Capital Costs (estimates in 2020 US.$)

	Drainage Area %	Has Pre-Treatment?	Area Treated (C)	Area Treated (B)	Difference (C-B)
D	0 (C)	NA	$0.00 - $0.00	NA / NA	
RH	0 (C)	NA	$0.00 - $0.00	NA / NA	
RG	25 (C)	NA	$7154.35 - $14063.78	NA / NA	
GR	0 (C)	NA	$0.00 - $0.00	NA / NA	
SP	0 (C)	NA	$0.00 - $0.00	NA / NA	
IB	50 (C)	NA	$10058.28 - $25130.56	NA / NA	
PP	25 (C)	NA	$29430.67 - $39645.45	NA / NA	

Key	LID Control
D	Disconnection
RH	Rain Harvesting
RG	Rain Gardens
GR	Green Roofs
SP	Street Planters
IB	Infiltration Basins
PP	Permeable Pavement



National Stormwater Calculator Report

Results

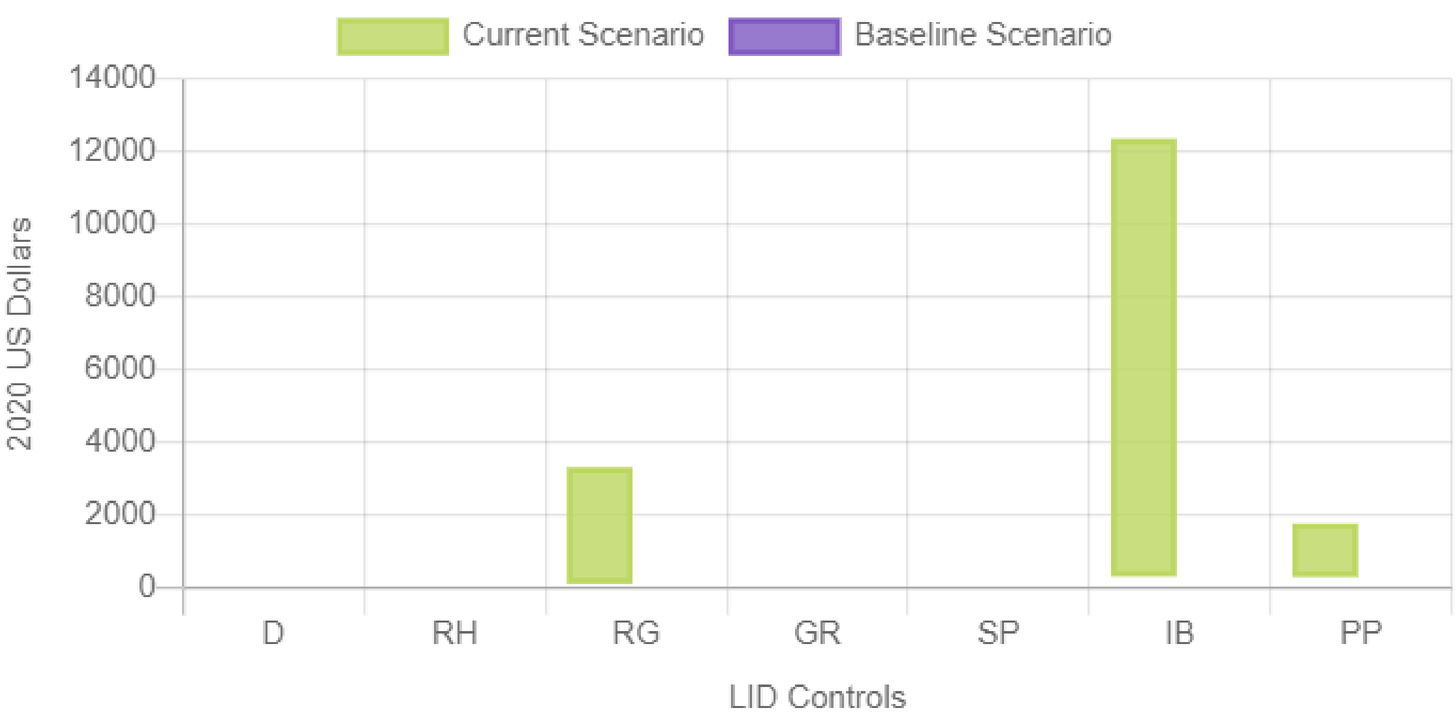
Scenario 1 - Commercial Development

Cost Summary

Estimate of Annual Probable Maintenance Costs

	Drainage Area %	Has Pre-Treatment?	Area Treated (C)	Area Treated (B)	Difference (C-B)
D	0 (C)	NA	$0.00 - $0.00	NA / NA	
RH	0 (C)	NA	$0.00 - $0.00	NA / NA	
RG	25 (C)	NA	$137.64 - $3327.90	NA / NA	
GR	0 (C)	NA	$0.00 - $0.00	NA / NA	
SP	0 (C)	NA	$0.00 - $0.00	NA / NA	
IB	50 (C)	NA	$340.48 - $12367.05	NA / NA	
PP	25 (C)	NA	$328.01 - $1791.54	NA / NA	

Key	LID Control
D	Disconnection
RH	Rain Harvesting
RG	Rain Gardens
GR	Green Roofs
SP	Street Planters
IB	Infiltration Basins
PP	Permeable Pavement



Appendix D: L-THIA-LID Model Scenario 1 Printouts

SUMMARY OF SCENARIOS
State: Alabama
County: Autauga

Land Use	Hydrologic Soil Group	Pre-Developed	acres Post-Developed W/o LID	Post-Developed With LID As Proposed
Grass/Pasture	D	2.5	0.38	-
Commercial	D	-	2.12	2.12

COMPOSITE CURVE NUMBER

Current	Post-Developed W/o LID	Post-Developed With LID As Proposed
80	93	82

Curve Number
View as:

Land Use	Hydrologic Soil group	Current	Post-Developed W/o LID	Post-Developed With LID As Proposed
Grass/Pasture	D	80	80	-
Commercial	D	-	95	82

RUNOFF RESULTS
Avg. Annual Runoff Volume (acre-ft)

Land Use	Current	Post-Developed W/o LID	Post-Developed With LID As Proposed
Grass/Pasture	2.58	0.39	0.39
Commercial	-	5.94	2.48
Total Annual Volume (acre-ft)	2.58	6.33	2.87

Also view Annual Variation and Probability of Exceedence

Avg. Annual Runoff Depth (in)
View as: Select

Current	Post-Developed W/o LID	Post-Developed With LID As Proposed
12.43	30.42	13.81

Avg. Runoff Depth by Landuse

Land Use	Hydrologic Soil group	Current	Post-Developed W/o LID	Post-Developed With LID As Proposed
Grass/Pasture	D	12.48	12.48	12.48
Commercial	D	-	33.79	14.12
Average Annual Rainfall Depth (in)				57.47

NONPOINT SOURCE POLLUTANT RESULTS

Nitrogen (lbs)

Land Use	Pre-Developed	Post-Developed W/o LID	Post-Developed With LID As Proposed
Grass/Pasture	4	0.750	0.750
Commercial	-	21	9
Total	4	21.75	9.75

Phosphorous (lbs)

Land Use	Pre-Developed	Post-Developed W/o LID	Post-Developed With LID As Proposed
Grass/Pasture	0.070	0.010	0.010
Commercial	-	5	2
Total	0.07	5.01	2.01

Suspended Solids (lbs)

Land Use	Pre-Developed	Post-Developed W/o LID	Post-Developed With LID As Proposed
Grass/Pasture	7	1	1
Commercial	-	899	375
Total	7	900	376

Lead (lbs)

Land Use	Pre-Developed	Post-Developed W/o LID	Post-Developed With LID As Proposed

Grass/Pasture	0.035	0.005	0.005
Commercial	-	0.210	0.088
Total	0.035	0.215	0.093

Copper (lbs)			
Land Use	Pre-Developed	Post-Developed W/o LID	Post-Developed With LID As Proposed
Grass/Pasture	0.070	0.010	0.010
Commercial	-	0.234	0.098
Total	0.07	0.244	0.108

Zinc (lbs)			
Land Use	Pre-Developed	Post-Developed W/o LID	Post-Developed With LID As Proposed
Grass/Pasture	0.042	0.006	0.006
Commercial	-	2	1
Total	0.042	2.006	1.006

Cadmium (lbs)			
Land Use	Pre-Developed	Post-Developed W/o LID	Post-Developed With LID As Proposed
Grass/Pasture	0.007	0.001	0.001
Commercial	-	0.015	0.006
Total	0.007	0.016	0.007

Chromium (lbs)			
Land Use	Pre-Developed	Post-Developed W/o LID	Post-Developed With LID As Proposed
Grass/Pasture	0.052	0.008	0.008
Commercial	-	0.161	0.067
Total	0.052	0.169	0.075

Nickel (lbs)			
Land Use	Pre-Developed	Post-Developed W/o LID	Post-Developed With LID As Proposed
Grass/Pasture	-	-	-
Commercial	-	0.191	0.079
Total	0	0.191	0.079

BOD (lbs)			
Land Use	Pre-Developed	Post-Developed W/o LID	Post-Developed With LID As Proposed
Grass/Pasture	3	0.536	0.536
Commercial	-	372	155
Total	3	372.536	155.536

COD (lbs)			
Land Use	Pre-Developed	Post-Developed W/o LID	Post-Developed With LID As Proposed
Grass/Pasture	-	-	-
Commercial	-	1879	785
Total	0	1879	785

Oil & Grease (lbs)			
Land Use	Pre-Developed	Post-Developed W/o LID	Post-Developed With LID As Proposed
Grass/Pasture	-	-	-
Commercial	-	145	60
Total	0	145	60

Fecal Coliform (millions of coliform)	

Land Use	Pre-Developed	Post-Developed W/o LID	Post-Developed With LID As Proposed
Grass/Pasture	6	0.974	0.974
Commercial	-	508	212
Total	6	508.974	212.974

Fecal Strep (millions of coliform)			
Land Use	Pre-Developed	Post-Developed W/o LID	Post-Developed With LID As Proposed
Grass/Pasture	-	-	-
Commercial	-	1325	553
Total	0	1325	553

These results were generated by the L-THIA (Long-Term Hydrologic Impact Assessment) model at "http://www.ecn.purdue.edu/runoff/lthianew"