Stormwater Master Plan

2013

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engineers | scientists | innovators

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EXECUTIVE SUMMARY

The University of Missouri (MU) is engaged in a planning effort to manage stormwater flow from the Main Campus. The MU Main Campus is located in Columbia, Missouri, with a campus community consisting of over 40,000 students, faculty, and staff. Urban land use and population in the Columbia area has nearly doubled since 1970. Increased stormwater runoff often accompanies urbanization due to build-out, paving and compaction of soils that may otherwise infiltrate precipitation. Stormwater runoff from urbanizing areas mobilizes pollutants during precipitation events. Pollutants often include heavy metals and organic compounds from roads and parking lots, sediment from construction sites, and nutrients from fertilizers. Diffuse pollution transported by runoff is a leading threat to waters in which we fish and swim. Growing recognition of this issue has prompted MU administrators to further develop stormwater management programs to protect water resources. To support Mizzou's ongoing commitment to environmental quality, MU developed this initial Stormwater Master Plan (SMP) to guide stormwater infrastructure planning.

It is important to emphasize that this initial SMP is an administrative and planning level document. The 2012 SMP is the first edition of an adaptive document that will develop and evolve as lessons are learned and incorporated. Information contained within the SMP should not be substituted for best engineering judgment based on unique knowledge of treatment systems, monitoring data, site constraints, or other relevant considerations.

Structural Best Management Practices

Structural Best Management Practices (BMPs) are engineered treatment systems designed to treat and capture stormwater runoff. To support effective implementation of BMPs on the main campus, the initial SMP includes three important engineering guidance items. The first is a BMP selection matrix that ranks common BMPs relative to treatment effectiveness for common pollutants. Second, engineering fact sheets for the following six common BMPs are included in the SMP to guide conceptual stormwater planning: (1) bioretention cells, (2) vegetated swales, (3) planter boxes, (4) cisterns, (5) permeable pavement, and (6) constructed wetlands.

Several BMP fact sheets are complimented by design nomographs generated from long-term (~40-year) rainfall-runoff simulations using the Stormwater Water Management model (SWMM, version 5). The advantage of using continuous simulation is the incorporation of real storm characteristics (e.g., magnitude, frequency, etc.) and antecedent moisture conditions in predicting long-term runoff.

The third guidance item is a case study analysis of a 150 acre East Campus subwatershed that demonstrates a BMP planning methodology using fact sheets and nomographs developed for the MU campus. The case study suggested that an optimal mixture of site-level and regional BMPs may best achieve preliminary stormwater sizing goals of 80% capture and 10% volume reduction. Opportunities for structural BMP implementation were also assessed within each of 10 campus subwatersheds.

Stormwater Management Opportunity Areas

Opportunities for distributed BMPs are available throughout the main campus. In many areas, impervious parking lots offer opportunities for linear bioretention cells and vegetative swales. Permeable pavements could also be used in parking lot areas where traffic volume is low and periodic. In areas of campus where the majority of impervious surfaces are comprised of roofs, incorporation of planter boxes and cisterns could be considered in combination with regional controls. Centralized detention opportunities (e.g., constructed wetlands, detention basins) are abundant in the eastern and southern campus boundaries near Hinkson Creek. Implementing BMPs at the time of new development and during infrastructure rehabilitation projects is a more cost-effective BMP implementation approach compared to retrofitting existing facilities.

Stormwater focus areas reported by campus personnel are evenly distributed throughout the campus and are primarily characterized as flooding caused by undersized or damaged conveyance infrastructure. Additional drainage analyses are needed to appropriately address site-level flooding issues. Sediment delivery from eroding areas was noted by campus staff. Slope stabilization practices that include bioretention terraces represent a complimentary erosion control and stormwater treatment approach.

Additional opportunities for water quality improvements include: (1) treatment of runoff from parking lots and roadways and (2) developing an adaptive monitoring program to identify source areas and assist in prioritizing BMP implementation. Developing a monitoring program would leverage and integrate education opportunities, a goal of the 2012 SMP.

Goals and Objectives

A clear vision is needed to organize and sustain effective management. The primary goal of the 2012 SMP is to provide an adaptable framework that enables the campus community to focus on stormwater quality, maintain regulatory compliance, and enhance water resource stewardship. This overall goal is energized by MU's research and innovation engine, a key asset in developing solutions to evolving stormwater challenges. To achieve this overall goal, four objectives are recommended:

- Identify an optimal suite of site-level stormwater controls for new development, redevelopment, and post-construction;
- Pursue a comprehensive, watershed-scale management approach to optimally select and place regional controls, assess contributions and evaluate water quality improvements;
- Provide an adaptive tool that assists MU in addressing evolving regulatory requirements that include NPDES (MS4) permit conditions and Total Maximum Daily Loads for adjacent waterways; and
- Integrate education, research, and outreach programs into SMP development and implementation.

SECTION 1. STORMWATER BASELINE INFORMATION

Situated in the lower Hinkson Creek watershed, the University of Missouri (MU) Main Campus covers 1,440 acres and intersects 10 smaller subwatersheds. These subwatersheds range from 22 to 292 acres in area with impervious cover encompassing 5% to 65% of land cover (i.e., percent impervious). Based on geospatial datasets provided by MU, the average percent impervious for the main campus is currently 32%. The 30-year annual mean precipitation measured in the Columbia area is approximately 40 inches. Soils in the area include a developed clay pan in upland areas, silt loams floodplains, and cherty clays in lower reaches of Hinkson Creek.

Geosyntec coordinated with Campus Facilities to assemble existing and relevant datasets to support SMP development. These datasets include: climate information, soil characteristics, topography, existing impervious areas, current and future building footprints, existing BMPs, stormwater conveyance infrastructure, subwatershed boundaries, stormwater improvement areas, flood zones, and local waterways. A project baseline map is provided as Appendix A that depicts several of these data items. Opportunities to enhance stormwater management information include: (1) ground-truth impervious area geospatial datasets, (2) prepare a more detailed stormwater conveyance dataset that includes invert elevations, geometry, and material descriptions, and (3) implement a monitoring program that evaluates runoff quantity and quality.

SECTION 2. STORMWATER MANAGEMENT GOALS AND OBJECTIVES

In coordination with the MU Stormwater Management Committee, Geosyntec identified the following goals and objectives to sustain and organize implementation activities. As the SMP is an adaptive document, we propose these objectives be iteratively revised along with the Campus Master Plan to incorporate emerging initiatives, policies, and development plans.

The primary goal of the 2012 SMP is to provide an adaptable framework that enables the campus community to improve stormwater quality, maintain regulatory compliance, and advance water resource stewardship. This overall goal is energized by MU's research and innovation engine, a key asset in developing solutions to evolving stormwater challenges.

The capacity for innovation is recognized as a valuable asset in the development and implementation of the SMP, and is essential to effectively address evolving regulations. Specific objectives of the SMP are outlined below.

Identify an optimal suite of on-site stormwater controls and guidelines for new development, redevelopment, and post-construction:

- Consider specific land uses, aesthetics, local climate, soils, and topography
- Complies with current and future regulatory requirements, including emerging Total Maximum Daily Loads
- Utilizes an optimal mix of structural and non-structural BMPs for new development
- Incorporates Climate Action Plan elements, energy modeling, carbon neutrality
- Encourages water use efficiency and environmental sustainability
- Provides education opportunities for students, employees, and faculty

Pursue a comprehensive, watershed-scale management approach to optimally select and place regional controls, assess contributions and evaluate water quality improvements

- Understand, manage, and evaluate MU stormwater contributions to local waterways in the context of build-out and Master Plan activities
- Assess appropriate contributions of on-site and regional solutions
- Identify types and locations of regional facilities by assessment of available opportunity areas, design constraints and scenario modeling
- Develop and utilize a framework to quantify runoff and water quality improvements gained through BMP implementation and compare with external or upstream sources
- Develop a framework to integrate Climate Action Plan elements on a broader scale

Provide a tool that assists MU in addressing evolving regulatory requirements that include NPDES (MS4) permit conditions and Total Maximum Daily Loads for adjacent waterways

- Clean water policies and regulations will change, and thus, the SMP will be revised accordingly
- A schedule will be developed for review and updating the SMP that coincides with Master Planning / build-out activities
- Feedback from monitoring and evaluations will result in an adaptive and more effective long-term stormwater management approach

Integrate education, research, and outreach programs into SMP development and implementation

- Successful development and implementation of the SMP will be aided by involvement and contributions from research faculty and students
- Contributions could include planning assistance, BMP maintenance and enhancement, data collection, performance evaluation or validation, and stakeholder education

SECTION 3. STRUCTURAL BEST MANAGEMENT PRACTICES

To support MU's on-going commitment to stormwater management, Geosyntec is providing the following three tools to enhance post-construction implementation of BMPs: (1) suggested additions to the University's Consultant Procedures & Design Guidelines (Green Book) to broadly integrate BMP fact sheets into new and redevelopment projects, (2) categorical performance and selection matrix for stormwater runoff BMPs, and (3) engineering design fact sheets for six common BMPs tailored to core campus hydroclimate, topography, and soils.

3.1 Suggestions

The following revisions are suggested under Section 3.3 Civil, 3.3.1 General, 3.3.1.4 Storm Drainage.

3.3.1.4 Storm Drainage

(proposed) q: Consultants shall evaluate the implementation of structural stormwater Best Management Practices (BMP) for all proposed new construction or redevelopment activities on campus. Stormwater management systems shall be designed for new developments that mimic pre-development runoff conditions to the maximum extent practicable at the site level. Redevelopment projects shall incorporate stormwater BMPs consistent with the pollutants of concern (e.g., nutrients, bacteria, volume, etc.). For common BMPs anticipated for implementation, consultants shall reference the "University of Missouri - BMP Fact Sheets." The fact sheets do not represent an exhaustive list of potential structural BMPs, but tailored guidance for the implementation of several BMPs within the University core campus.

3.2 Post-Construction Prioritization Matrix

To guide selection of structural BMPs, Geosyntec prepared a selection matrix that categorizes BMPs with respect to construction setting and relative treatment effectiveness. This BMP Prioritization Matrix is located on the following page.

Table 1. Structural Best Management Practice Selection Matrix

Project Type [1]	Recommended BMPs	Volume Mitigation	Treatment Effectiveness for Pollutants of Concern[2]					
			Trash	Nutrients	Bacteria	Metals[3]	Sediment	Organics[4]
Parking Lot Construction	Porous Asphalt, Concrete, and Pavers	High	Very Low	Moderate	High	High	Very High	High
	Bioretention	High	High	Very High	High	High	High	Very High
	Vegetated Swale Filter	Moderate	Moderate	Low	Very Low	Moderate	Moderate	Moderate
	Vegetated Filter Strips	Moderate	Moderate	Low	Very Low	Moderate	High	Moderate
	Sand Filters	Very Low	Very High	Moderate	High	High	Very High	High
Roadway Construction	Porous Asphalt, Concrete and Pavers	High	Very Low	Moderate	High	High	Very High	High
	Bioretention	High	High	Very High	High	High	High	Very High
	Vegetated Swale Filter	Moderate	Moderate	Low	Very Low	Moderate	Moderate	Moderate
	Vegetated Filter Strip	Moderate	Moderate	Low	Very Low	Moderate	High	Moderate
	Sand Filters	Very Low	Very High	Moderate	High	High	Very High	High
Building Construction	Cisterns	High	Building BMPS are generally intended for achieving volume reduction of roof drainage. Treatment effectiveness of building BMPs are not comparable to other BMPs in this table that treat runoff from a wide range of impervious surfaces that generally have higher pollutant concentrations.					
	Planter Boxes	Moderate						
	Green Roofs	Moderate						
Open Space Areas	Bioretention	High	High	Very High	High	High	High	Very High
	Vegetated Swale Filter	Moderate	Moderate	Low	Very Low	Moderate	Moderate	Moderate
	Vegetated Filter Strip	Moderate	Moderate	Low	Very Low	Moderate	High	Moderate
	Constructed Treatment Wetlands	High	High	Moderate	Low	Very High	High	Very High
	Wet Retention Basin	Low	Very High	High	Moderate	High	Very High	High
General Site Development	Bioretention	High	High	Very High	High	High	High	Very High
	Vegetated Swale Filter	Moderate	Moderate	Low	Very Low	Moderate	Moderate	Moderate
	Vegetated Filter Strip	Moderate	Moderate	Low	Very Low	Moderate	High	Moderate
	Constructed Treatment Wetlands	High	High	Moderate	Low	Very High	High	Very High
	Wet Retention Basin	Low	Very High	High	Moderate	High	Very High	High
	Sand Filters	Very Low	Very High	Moderate	High	High	Very High	High

Volume/Treatment Effectiveness: = Very High, = High, = Moderate, = Low, = Very Low

Notes:

1) Project types are intended to include both new and redevelopment projects.
2) Effectiveness may change based on design variations; standard BMP designs have been assumed.
3) Particulate and dissolved fractions.
4) Hydrocarbons, oil and grease.

3.3 Best Management Practice Factsheets

Engineering fact sheets for the following six common BMPs are included in the SMP to guide conceptual stormwater planning: (1) bioretention cells, (2) vegetated swales, (3) planter boxes, (4) cisterns, (5) permeable pavement, and (6) constructed treatment wetlands. Several BMP fact sheets are complimented by design nomographs generated from long-term (~40 year) rainfall-runoff simulations using the Stormwater Water Management model (SWMM, version 5). These factsheets are provided in Appendix B.

SECTION 4. STORMWATER MANAGEMENT IMPROVEMENT OPPORTUNITIES

Geosyntec conducted a stormwater focus area and opportunity assessment to assist MU in prioritizing improvements. The findings of the assessment, along with suggestions for BMP implementation strategies, are summarized in Section 4. Subwatershed planning fact sheets summarizing representative BMP opportunities is included as Appendices C. Stormwater improvement opportunities identified in Appendix C should not be interpreted as a comprehensive list for BMP placement on the MU campus. Other factors including, but not limited to environmental concerns and utility alignment, should be considered during site-level BMP design and implementation.

4.1 Focus Areas

Focus areas were identified through a survey questionnaire circulated to the University Stormwater Master Planning Team and other designated representatives. The survey questionnaire asked the participants to identify stormwater focus areas throughout the MU campus. The focus areas were characterized as flooding, poor water quality, visible erosion, poor vegetative growth due to water, or any other concern. Participants were asked to rank these areas on a scale from 1 to 10 based on occurrence and nuisance. Additionally, participants were asked to suggest a resolution or approach in solving the issue.

Results from the survey are summarized in Table 2. The survey responses yielded 14 focus areas throughout the campus. The majority of the focus areas identified were noted as the result of stormwater inlets overflowing during or after large storm events due to undersized or damaged stormwater infrastructure.

Suggestions provided in the survey consisted mainly of storm conveyance upgrades with the exception of a single visible erosion area where a detention basin was suggested.

For most of the focus areas, further investigation is required to identify cost-effective solutions. Where flooding was identified as the focus, performing detailed stormwater modeling will help to identify source areas or structural deficiencies (e.g., undersized storm conveyance). Modeling could also be used to further identify potential BMP locations and evaluate the expected performance of proposed BMPs. In areas where infrastructure repairs were identified, further field investigations are recommended to determine the extent of the repair, maintenance needs, and appropriate mitigation measures. Additional field investigations performed during storm events may also be beneficial in identifying the specific contributor and severity at the identified focus area.

Table 2. Summary of Focus Area Survey

Location	Focus	Severity[1] (1 - 10)
GSB (Stadium and Monk Dr.)	Flooding (Excessive Depth)	5
NANO (Research Park Dr.)	Visible Erosion	10
Botany Greenhouse	Flooding (Excessive Depth)	10
Animal Lab	Flooding (Excessive Depth)	8
McReynolds Hall	Water Inside Facility	8
Virginia Ave. and Hospital Dr.	Flooding (Excessive Depth)	10
Lafferre Hall	Broken Storm Conveyance	10
Conley Avenue Garage	Local Subsidence Area	10
Stanley Hall Play-yard	Flooding (Excessive Depth)	10
McKee Gym	Broken Gutter Drain	10
Professional Building	Broken Gutter Drain	10
Champions Dr. and Providence	Flooding (Excessive Depth)	TBD
Proposed ARC building site	Visible Erosion	10

[1] Severity scale is based on occurrence and nuisance

4.2 BMP Implementation Opportunity Areas

Representative BMP implementation opportunity areas were identified through a field assessment conducted by Geosyntec personnel. Opportunities for both centralized and distributed (i.e., site controls) BMPs were considered during the assessment.

Locations and pictures of each potential BMP opportunity area were recorded and depicted in subwatershed fact sheets for the MU campus (Appendix C). Photographs displayed on the fact sheets are not inclusive of all the identified potential BMP opportunities sited, but are representative of the variety of identified BMP opportunities.

Potential Constructed Wetland East of Campus

Representative centralized BMP opportunities were identified at the grass field east of campus near Hinkson Creek, south campus near the intersection of Champions Drive and Stadium Boulevard, and south of the Research Park Botany Greenhouse. These locations are recommended because they feature existing undeveloped open space areas and are located near the downstream portion of the respective subwatersheds. Constructed treatment wetlands could be implemented in these locations to provide stormwater management benefits (i.e., water quality treatment and rate control) for a significant portion of the respective subwatersheds. Implementation of regional BMPs within undeveloped areas should consider the consumptive water use and flood attenuation benefits of maintaining or expanding floodplain forests.

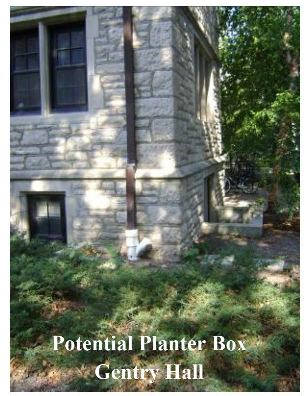
Potential Linear Bioretention Cell Parking Lot SG4

Opportunities for bioretention areas were identified for parking lot areas throughout the MU campus. The implementation of bioretention in many of the parking lot areas could be accomplished through the modification of existing parking lot islands or landscaped areas behind existing curbs. Under current conditions, stormwater runoff is generally routed via overland flow across parking lot areas to existing storm drain inlets. The general approach for implementing bioretention in these areas would consist of (1) construction of the bioretention cell in accordance with the BMP fact sheet, (2) connection of a under drain to the existing storm drain inlet structure, (3) creating a curb cut to allow runoff to enter the bioretention area, and (4) using the existing storm drain inlet as the overflow route for larger storm events. Implementation of bioretention areas following this approach is intended to provide water quality and volume reduction benefits without compromising the functionality of the existing storm conveyance during larger storm events. Site-specific constraints, such as utility conflicts, should be identified during the design phase for these opportunities.

Potential opportunities for vegetated swales were also identified throughout the MU campus. Many of these opportunities consisted of existing drainage channels that could be modified to provide water quality benefits and attenuate runoff flow velocities in the channel. For example, a potential opportunity for a vegetated swale exists in the western roadside ditch running parallel to Providence Road in the southern portion of the campus. Replacing the concrete conveyance channel with a vegetated swale and a series of check dams could provide stormwater benefits, but could also improve the aesthetics of the roadside area.


Potential Vegetated Swale
Providence and Research Park Dr.

Other potential BMP opportunities identified include planter boxes and cisterns. The representative locations identified for planter boxes and cisterns generally consist of areas where rain gutter downspouts were observed routing runoff directly into subsurface storm conveyance or onto impervious areas such as parking lots. Available space for the installation of these BMPs adjacent to the respective buildings was also used as a criterion in identifying potential opportunity areas for these BMPs. In the case of planter boxes, the generalized approach for implementation would involve (1) disconnection of the downspout from the storm conveyance or impervious area, (2) construction of the planter box in accordance with the BMP fact sheet, and (3) connection of the under drain and overflow to the existing storm conveyance. Cisterns are an alternative to planter boxes in locations where demand for stormwater reuse is available. Reuse opportunities identified on the campus included areas with lawn irrigation and greenhouses (e.g., Research Park Botany Greenhouse, Sears Plant Growth Facility, etc.).


Potential Planter Box
Gentry Hall

Opportunities for permeable pavement were also observed throughout the MU campus. These areas consisted of parking lots and driveways, fire lanes and sidewalks. Traffic patterns and use data are needed to identify specific areas suitable for permeable pavement. It is recommended that MU personnel evaluate opportunities for the replacement of traditional low traffic impervious surfaces with permeable pavement during new development and infrastructure rehabilitation.

In addition to individual BMP opportunity areas, multiple BMPs were identified at select locations of the MU campus during the field assessment. These areas are noted as "Multiple Opportunity Areas." The commuter parking lot in the eastern portion of the campus is an example. The opportunities identified in this parking lot included (1) enhancements to the existing drainage channels along the lot perimeters, (2) bioretention areas at select locations within the parking lot, including in the areas between the existing curb stops, and (3) measures to address erosion on the northern edge of the parking lot.

In summary, existing main MU campus watershed conditions are largely comprised of impervious areas (e.g., large parking lots). These areas provide opportunities for distributed BMP implementation (e.g., bioretention, vegetated swales, planter boxes, etc.). Centralized detention opportunities (e.g., constructed wetlands, detention basins) are abundant in the eastern and southern campus boundaries where land cover is more pervious. Subwatersheds 4 and 6 have the highest expected build-out increase with the additions of the ARC building, Fire Station addition, and the Patient Care Tower (Campus Master Plan). Table 3 lists the predicted impervious cover change. Not all buildings in design or construction add to the overall imperviousness (i.e., Rehabilitation Projects).

Construction of BMPs at the time of new development and during infrastructure rehabilitation projects is a cost-effective way to implement BMPs. The nomographs provided in the BMP fact sheets for distributed and centralized BMPs can be used to determine footprints required for optimal performance. Stormwater modeling at the subwatershed scale could be used to identify a strategic combination of distributed and centralized BMPs to provide an optimized scenario for improving water quality, reducing runoff volumes, and preserving landscape appeal. Furthermore, a more detailed investigation of campus drainage will provide the most efficient and cost-effective stormwater management strategy on the MU campus.

Table 3. Summary of 2011 MU Main Campus Impervious Land Cover

Subwatershed (ID #)	Total Area[1] (acres)	Existing Impervious (acres)	Planned Impervious[2] (acres)	Current Impervious (% total acres)
1	91	59.0	59.0	65 %
2	22	6.9	6.9	31 %
3	135	71.3	71.3	52 %
4	150	61.3	62.0	41 %
5	122	34.9	34.9	29 %
6	228	128.0	130.8	56 %
7	41	19.0	19.0	47 %
8	186	9.9	9.9	5 %
9	292	41.0	41.0	14 %
10	173	25.0	25.0	15%

[1] Only areas inside the campus boundary are included.

[2] Planned Impervious is based on the In Design or Construction section of the Campus Master Plan.

4.3 Integrated Stormwater Monitoring Program

A monitoring program could be composed of several objectives to assess the effectiveness of the master plan. Monitoring results may supplement decisions made by the University. This could include implementing new or adjusting existing BMPs or prioritizing areas for future projects. The program could use the campus faculty and students to assist in the monitoring activities and analysis. A student program would provide educational opportunities and raise awareness of stormwater management opportunities. As part of the monitoring program, a comprehensive dataset of the stormwater infrastructure could be collected to analyze the stormwater drainage network. The monitoring program could target event-based water quality and flow characteristics at several locations throughout the campus. Combining these data with stormwater infrastructure information could support a detailed analysis of the stormwater drainage system.

SECTION 5. WATERSHED-BASED STORMWATER BMP PLANNING

The purpose of Section 5 is to provide guidance to size and evaluate stormwater BMPs on the main campus. Specific objectives include developing a procedure for (1) identifying BMP opportunities within a defined stormwater management area, (2) sizing BMPs based on estimated drainage areas and a targeted volume capture, and (3) evaluating the performance of the BMPs with respect to volume treatment, volume reduction, and regulatory flow rates. An example demonstration of this evaluation procedure using long-term model simulation is presented for a 150 acre East Campus subwatershed adjacent to Hinkson Creek. Section 5 concludes with recommendations to support conceptual and site-level planning.

Stormwater planning information provided in this section should not be interpreted as a formal design engineering procedure for BMPs on the MU Campus. Rather, the intent of this procedure is to demonstrate a planning-level approach that if implemented on a broader scale will: (1) support determination of watershed specific BMP performance goals for new construction, (2) provide a detailed tool for optimized BMP selection and placement, and (3) provide a cohesive quantitative approach (i.e., watershed monitoring and modeling) to track and record stormwater improvements. This procedure should not replace engineering best professional judgment based on site-specific monitoring data or unique knowledge of site constraints and conditions.

5.1 BMP Sizing and Design Evaluation Procedure

Structural BMPs may broadly be categorized as either distributed (i.e., site controls) or regional (i.e., centralized facilities). Site controls capture stormwater prior to, or shortly after, entering the storm drain system such that treatment and control occurs near locations yielding runoff. Examples of site controls include bioretention areas, vegetated swales, planter boxes, and permeable pavement.

Centralized controls capture stormwater that has been diverted to a downstream location within the storm drain conveyance system. Examples include dry extended detention basins, retention ponds, and constructed wetlands. Centralized BMP opportunities may be more desirable than site controls where significant existing development constrains implementation of site controls. Alternatively, site controls may be a more effective option for new development scenarios. As characterized in our example East Campus watershed analysis, an optimized mixture of site and regional controls is often necessary to achieve treatment, volume, and rate reduction targets.

Step 1: Identify Centralized BMP Opportunity Areas

Opportunity locations for centralized BMPs are typically open space areas in close proximity to the storm drain at the downstream end of a subwatershed. Site constraints could include the available surface area, underground utility conflicts, water table elevation, flood prone areas, natural wetlands, and inadequate relief between the inlet of the storm drain and the design water surface elevation of the BMP. In general, centralized BMPs require a footprint area that is at least 3% of the Effective Tributary Area (ETA). With upstream site control BMPs designed for volume reduction (e.g., bioretention with raised under drains), the footprint area may be reduced to approximately 2% of the ETA.

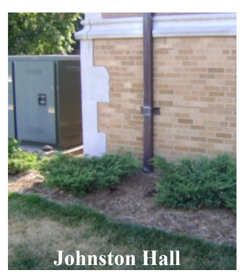
Step 2: Identify BMP Opportunity Areas and Constraints

Opportunity locations for site controls are often low-lying landscaped or natural open space areas adjacent to an impervious area. However, the removal of impervious surfaces to accommodate a surface or underground BMP should also be considered. Opportunities for routing system overflows and under drain flows back to the storm drain system should be assessed. While the use of thick media beds is recommended to increase volume reductions, there may be a maximum depth at which an under drain may be placed to allow gravity drainage back to the storm system. Sites constrained by soils, topography, groundwater hazards, bedrock, or utility infrastructure should be avoided.

When assessing areas for BMP opportunities, it is helpful to consider the various types of impervious and pervious surfaces at the site and how these surfaces are connected with the stormwater conveyance system. Impervious surfaces include rooftops, roadways, parking lots, driveways, sidewalks, and various other paved surfaces (e.g., courtyards, sports courts, stairs, etc.). Impervious surfaces contribute the majority of stormwater runoff and pollutant loads and therefore deserve the most attention when identifying BMP opportunities. It is also important to identify areas where impervious areas can be removed or modified (e.g., pavement, rock, brick).

Rooftops

When evaluating potential opportunities for treating rooftops, the location of the roof downspouts should be noted to determine whether they can drain to either pervious areas, cisterns, or locations where stormwater planter boxes could be added. Roof downspouts that are internal to the building and drain directly to the storm drain system cannot be easily accessed. Therefore, consideration for roof runoff treatment should be assessed early in the building plumbing design.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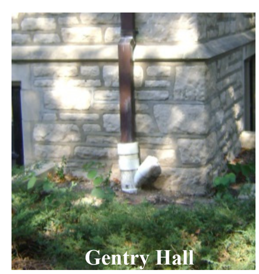

Gentry Hall

Roadways

Roadways are linear impervious features that are typically connected to the storm drain system. When evaluating methods to reduce runoff from roads, planners should consider traffic load, drainage infrastructure, and adjacent land uses. Roadways with extra right-of-way that is not being used for transportation or pedestrian uses may be converted to vegetated swales or linear bioretention areas. Low traffic roads could be paved with permeable pavement instead of conventional pavement. In some cases, bioretention cells may be placed within roadside parking areas by extending the curb out towards the travel way. In other instances, bioretention areas may be placed behind the curb where runoff enters through a slot in the curb (i.e., curb cut). Consequently, opportunities may include vegetated roadsides and medians, large sidewalks and lane widths, and under-utilized roadside parking.


Stewart Hall


Example

Parking Lots

When considering stormwater retrofit options for parking lots, occupancy characteristics are very important. For example, the ability to sacrifice parking spaces for stormwater management (e.g., swales, bioretention, etc.), primarily depends on whether the lot is space-limited or under capacity during the main hours of operation. In addition, the availability of underutilized medians or adjacent areas should be considered in evaluating parking lot BMP opportunities. Some parking lots are designed with landscaped medians and adjacent areas, but curbs prevent runoff from entering these areas. In this circumstance, curb-cuts may be a useful solution to reduce runoff. Permeable pavements may be a viable BMP approach in parking lots that are periodically space-limited, such as sport arenas. However, BMPs appropriate for periodically space-limited sites may vary drastically.


Parking Lot CG1

Other Paved Surfaces

In addition to rooftops, roadways, and parking lots, remaining impervious surfaces primarily include driveways, sidewalks, walkways, patios, courtyards, stairways, and other sports-related tracks and courts (e.g., tracks, basketball courts, tennis courts, etc.).

These areas may represent a small fraction of the watershed impervious area. Nonetheless, there are often simple solutions for incorporating site stormwater controls for these areas, such as placing a bioretention cell at the downgradient edge or utilizing permeable pavement. Trench drains can also be used to intercept sheet flow and route stormwater to adjacent landscaped areas or site controls.

Step 3: Delineate BMP Drainage Areas

The total drainage area to each potential BMP opportunity location should be estimated based on topography and existing or proposed conveyances. Proposed conveyances may include the addition of a diversion pipe that intercepts a storm drain upgradient of the potential BMP to support gravity flow to the BMP. The recommended accuracy of drainage area delineation depends on the scale of the analysis and whether the project is at the conceptual planning or detailed design stage.

Conceptual Planning Level Delineations

At the conceptual planning level, it is often not necessary or desirable to determine the drainage area of each individual site stormwater facility. Instead, a "level of commitment" approach may be adequate for each major drainage area. For example, if planter boxes are being considered for treating rooftop runoff from some of the buildings within a drainage area, then an estimate of the total drainage area to all planter boxes may be based on a commitment to treat some percentage (e.g., 50%) of the total rooftop areas. Similarly, a level of commitment to treat some portion of all parking lots with bioretention cells may be appropriate for conceptual analysis. With this type of approach, the precise location of the BMP may not be known, so site constraints are more uncertain. Consequently, the drainage areas of site BMPs of similar design characteristics may be lumped into a single hydrologic response unit (HRU), which is a conceptual drainage area with subareas that may not be physically connected. For example, all rooftops within a drainage area may be combined into a single drainage area that is treated by a single planter box (storage compartment) for the purposes of conceptual hydrologic analysis.

For centralized BMPs, more accurate delineations should be supported by topographic information and the known flow directions of existing storm drains. Storm drain invert elevations are often needed, but approximate elevations may be adequate for evaluating the feasibility of BMP implementation.

Offsite stormwater mitigation may also be considered during the planning stages. An offsite mitigation program would allow MU planners to make progress towards stormwater reduction goals (i.e., 80% capture) by supporting BMP implementation outside the main campus boundary. Typically, cooperative agreements between participating parties are developed to guide implementation. Participants in an offsite stormwater mitigation or 'banking' program could include the City of Columbia, Missouri, Boone County, Missouri and private development firms.

Detailed Design Stage Delineations

Before detailed BMP design can begin, accurate drainage area delineations are necessary for each BMP facility. For site controls, high resolution surface topography (e.g., 0.5 - 1 foot contours) is typically required because drainage areas are small and slopes are often mild. The storm drain system must also be well defined with regard to inlet locations, invert elevations, slopes, and pipe diameters. Site constraints must also be fully identified to determine whether the available space is adequate for the drainage area. BMPs placed in constrained locations may need to be sized below the recommended long-term goal (see Step 5) or alternative opportunity locations identified.

Step 4: Compute Effective Tributary Area to Each Distributed BMP

The ETA is the portion of the BMP drainage area that contributes direct runoff over an average annual basis and can be approximated by first computing a volumetric runoff coefficient based on Schueler (1987):

$$C = 0.05 + 0.9Imp$$

Where, C is the volumetric runoff coefficient and Imp is the impervious fraction of the watershed.

The ETA is the total tributary area multiplied by the volumetric runoff coefficient. By dividing the total tributary area into the pervious and impervious areas and combining terms, the ETA area can be estimated as:

$$ETA = 0.05A_{perv} + 0.95A_{imp}$$

Where, ETA is the effective tributary area, A_{perv} is the pervious area, and A_{imp} is the impervious area. Site-specific runoff coefficients for pervious areas may be developed based upon monitoring results or best professional judgment. The ETA can be used for BMP sizing as described below.

Step 5: Preliminary BMP Sizing

Size each BMP using the estimated ETA and the BMP nomographs provided within the corresponding BMP factsheet. Nomographs included in BMP factsheets are derived from long-term (1969 – 2010) rainfall-runoff simulations using the U.S. EPA Storm Water Management Model (SWMM5) based on climate data from the Columbia Regional Airport. These nomographs incorporate actual storm or precipitation characteristics (e.g., frequency, intensity, timing, etc.) and are provided as a more realistic alternative to approaches that rely on synthetic design storms.

The suggested long-term volumetric percent capture guideline for sizing BMPs associated with new construction is 80%. The volumetric percent capture is the long-term runoff volume captured by a BMP as a percentage of the runoff volume that would have occurred without the BMP. The volume captured includes both the volume lost due to infiltration and evapotranspiration as well as the volume treated and discharged to the storm drain system. In other words, percent capture is the fraction of the runoff volume that does not bypass or overflow the BMP. Typically, a goal of 80 - 90% capture is used for sizing stormwater BMPs for water quality due to the economics of diminishing returns. In many cases, the available footprint area for a BMP is smaller than is required to meet this target. If so, additional downstream controls may be necessary or alternative BMP locations should be considered. The recommended sizing method depends on the BMP type as described below.

Sizing Planter Boxes and Bioretention BMPs

To compute the required footprint for a planter box or a bioretention BMP given the ETA, identify the square footage per acre associated with the target percent capture on the relevant BMP nomograph. Multiply this value by the ETA to obtain the needed square footage for the BMP.

If this footprint is larger than what is available for a given BMP, choose an alternative design with larger storage components and/or reduce the target percent capture.

Sizing Vegetated Swales

To compute the required vegetated swale footprint for a given ETA, the overland flow time of concentration, t_o, for the drainage area must first be estimated. A commonly used formula for computing t_o is:

$$t_o = \frac{0.94L^{0.6}n^{0.6}}{i^{0.4}S^{0.3}}$$

Where, L is the length of overland flow (feet), n is Manning's roughness coefficient, i is the rainfall intensity (inches/hour), and S is the average slope of overland flow (foot/foot). Typical Manning's roughness coefficients are shown in Table 4. The recommended rainfall intensity to use for determining t_o is 0.4 inches/hour, which is approximately equal to twice the 80th percentile hourly rainfall intensity in Columbia, Missouri. For most drainage areas the time of concentration should be less than 30 minutes.

Table 4. Manning's Roughness Coefficients for Overland Flow

Surface	N
Smooth asphalt	0.011
Smooth concrete	0.012
Fallow soils (no residue)	0.05
Cultivated soils	
Residue cover < 20%	0.06
Residue cover > 20%	0.17
Range (natural)	0.13
Grass	
Short, prairie	0.15
Dense	0.24
Bermuda grass	0.41
Woods	
Light underbrush	0.40
Dense underbrush	0.80

Source: McCuen, R. et al. (1996), *Hydrology*, FHWA-SA-96-067, Federal Highway Administration, Washington, DC

With the estimated time of concentration, identify the cubic feet per second per acre (cfs/acre) associated with the target percent capture on the vegetated swale nomograph (see Vegetated Swale factsheet). Multiply this value by the ETA to obtain the total water quality design flow rate for the swale.

Compute the bottom width of the swale using the following simplified form of the Manning's equation (side slopes neglected):

$$W = \frac{nQ_{wq}}{1.49\ (D_{wq}^{1.67})S^{0.5}}$$

Recommended Manning's n for Grass Swales
Medium grass: n = 0.15
Dense grass: n = 0.25
Very dense Bermuda-type grass: n = 0.35

Where W is channel bottom width (feet), n is Manning's roughness coefficient, Q_{wq} is water quality design flow (cubic feet per second), D_{wq} is water quality flow depth (feet) (max of 0.33 feet), and S is the longitudinal slope (foot/foot). If bottom width is less than 2 feet, set W = 2 feet and recalculate the water quality design flow depth (D_{wq}). If bottom width is more than 10 feet, increase longitudinal slope, increase design flow depth (D_{wq}) to a maximum of 0.33 feet (4 inches), install flow divider and flow spreader, or relocate swale downstream of a detention facility.

Compute the water quality design velocity, v_{wq}, using the bottom width and neglecting side slopes:

$$v_{wq} = \frac{Q_{wq}}{WD_{wq}}$$

If v_{wq} is greater than 1 foot per second, go back and modify longitudinal slope, bottom width (need flow divider if > 10 feet), or increase depth.

Compute the minimum length of the swale:

$$L = tv_{wq}$$

Where *t* is the hydraulic residence time in the swale (seconds). A minimum *t* of 10 minutes or 600 seconds is suggested.

Sizing Centralized BMPs

When considering a single centralized BMP at the downstream end of a catchment, a unit volume sizing approach is recommended (as opposed to a unit area sizing or unit flow sizing used for bioretention and swales, respectively). Unit volume sizing is based on computing the volume of the BMP based on storm depth expressed in watershed inches. Dry extended detention basins provide runoff treatment and control by detaining and slowly releasing stormwater. The rate of release is often expressed as the brimful drawdown time. To provide adequate treatment for a given storm while also allowing for adequate regeneration of storage capacity for the next storm, the target drawdown time is typically between 24 and 72 hours.

Wet detention basins (i.e., wet ponds) provide treatment by retaining stormwater between storms. These BMPs ideally operate under plug flow conditions where the water contained in the permanent pool is replaced by incoming flows with minimal short-circuiting through the basin.

Sizing nomographs for extended detention basins and wet retention basins are provided in Figures 1 and 2. These nomographs include volumetric percent capture on the y-axis and the BMP storage volume expressed in watershed inches on the x-axis. The water quality design volume, V_{wq}, of the BMP is then computed by selecting the BMP storage volume associated with the target percent capture and then multiplying it by the ETA:

$$V_{wq} = ETA * P \left(\frac{3630\ cubic\ feet}{acre - inch}\right)$$

Where, P is water quality design volume in watershed inches (i.e., storm depth as inches) and ETA is the effective tributary area (acres). The footprint of the BMP can then be estimated by assuming an average design water quality depth for the basin (typically 3 - 6 feet). Additional area should be considered for the basin side slopes.

Step 6: Evaluate the Watershed with and without BMPs

After BMPs have been sized, watershed modeling is recommended to evaluate their performance with respect to the volume or flow captured, reduced, and controlled. Continuous simulation modeling is recommended to adequately characterize the long-term water balance and flow durations. Depending on the watershed model used, there are a number of ways BMPs may be conceptualized. The SWMM5 model currently includes a module for low impact development controls including bioretention cells, swales, and permeable pavement. SWMM5 and most other continuous simulation models (e.g., HSPF, HEC-HMS, etc.) also include categorical storage units that can be used to model practically any storage-based BMP by adjusting the storage-outflow relationship.

Even without modeling, the level of stormwater control achieved within a watershed by site control BMPs may be evaluated using a volumetric accounting approach. The basic approach is to compute the average annual runoff volume for each BMP drainage area using the average annual rainfall depth (40 inches per year) and the computed ETA.

The percent volume capture used to size the BMP is then used to estimate the total volume captured and treated. The sum of all of the captured volumes divided by the total runoff volume without BMPs is an estimate of the average annual stormwater capture volume for the entire watershed. Table 5 summarizes an example computation of the total capture volume for a watershed.

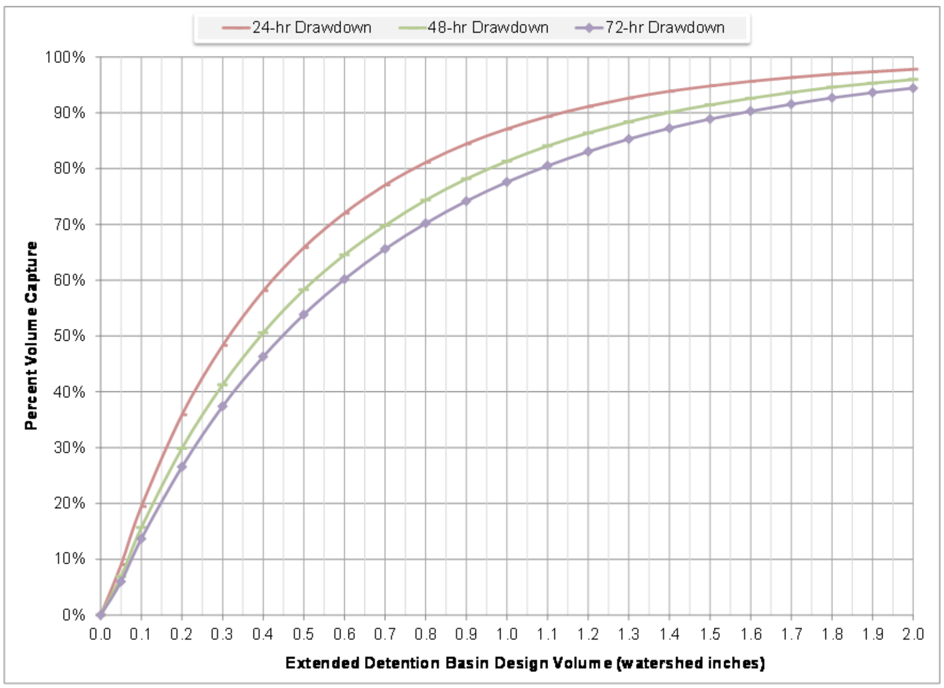


Figure 1. Design Nomograph for Extended Detention BMPs.

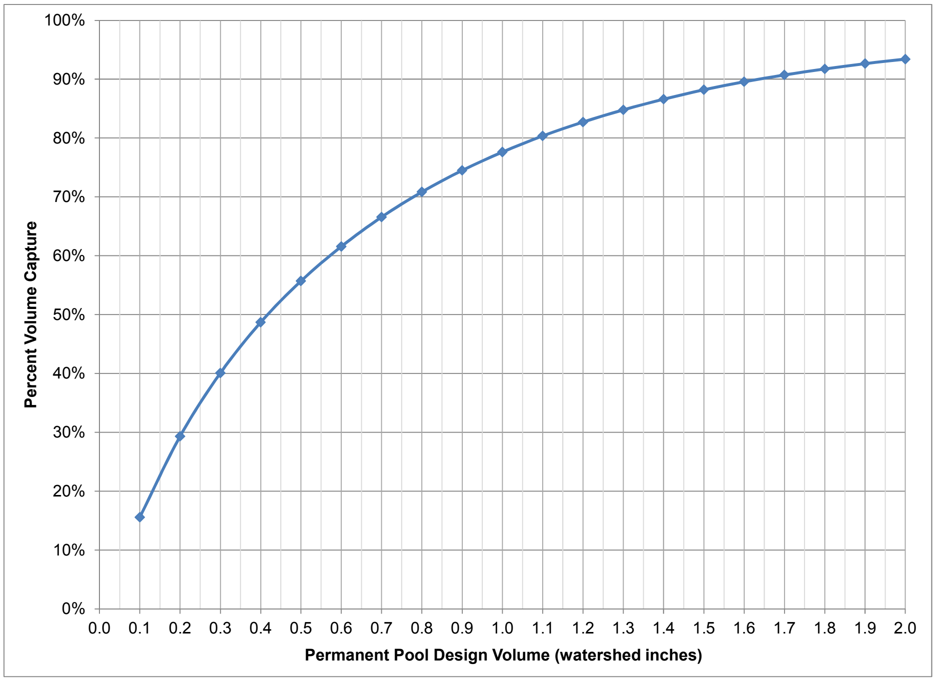


Figure 2. Design Nomograph for Wet Basins.

Table 5. Example Computation of Overall Average Annual Runoff Capture Volume

Ave. Annual Rainfall (in): 40

	Effective Tributary Area (acres)	Ave. Annual Runoff Vol. (cubic feet)	Average Annual Percent Capture	Average Annual Volume Captured (cubic feet)
Parking Lots Treated by Bioretention	11.4	1,655,280	80%	1,324,224
Roofs Treated by Planter Boxes	4.8	689,700	80%	551,760
Roads Treated by Swales	5.7	827,640	80%	662,112
Remaining Area	11.4	1,651,650	0%	0
Totals	33.3	4,824,270		2,538,096

Total Percent Captured: **52.6%**

Step 7: Evaluate Regulatory Flow Rates

To evaluate BMP performance in the context of the Hinkson Creek Total Maximum Daily Load (TMDL), continuous simulation modeling is required to develop a flow duration curve. Flow duration curves can be used to estimate the 3% and 5% flow duration exceedance values. For the Main Campus, flow rates referenced in the TMDL are based on the waste load allocations (WLAs) described in the TMDL, which have been derived by EPA to estimate the percent runoff contribution from the MS4 area. Table 6 summarizes the 3% and 5% exceedance values summarized for the TMDL including the runoff weighted values applicable to MU (shaded). These target values represent a 28.7% and 18.1% reduction in the duration of the 3% and 5% exceedance flow rates, respectively.

Table 6. Computed Unit Area Flow Duration Exceedance Values from Hinkson Creek Total Maximum Daily Load

TMDL Component	Area (square miles, sq.mi.)	Percent Runoff Contribution	TMDL Maximum Flow Duration Exceedance Values (cfs/sq. mi.)		TMDL Maximum Flow Duration Exceedance Values (cfs/acre)	
			3%	5%	3%	5%
Waste Load Allocation (MS4 WLA)	33.1	64%	17.9	12.7	0.028	0.020
Load Allocation (LA)	56.6	36%	5.9	4.2	0.009	0.007
TOTAL	89.7	100%	10.3	7.3	0.016	0.011

An alternative interpretation of the Hinkson Creek TMDL is to assume that the existing 3% and 5% flow duration exceedance values, as determined by continuous simulation modeling, should be reduced by 28.7% and 18.1%, respectively. A percentage-based interpretation assumes that all of the watersheds are equally contributing to flow rate concerns contended by the TMDL. Clearly, this is a poor assumption because some areas will produce larger runoff volumes and flow rates than others. For this reason, the former interpretation is recommended for comparing BMP performance to the TMDL. We note that MS4 areal flow rates included in the TMDL are not particularly well supported, or linked with the timing of actual flows in Hinkson Creek. In addition, Geosyntec understands that areal flows included in the TMDL may be considered interim and could be changed following TMDL adaptive management strategies. ***For these reasons, Geosyntec recommends that final BMP design decisions should not be controlled by TMDL wasteload allocations.***

Step 8: Revise BMP Opportunities or Sizes as Necessary

Estimation of potential volume captured and reduced by the proposed BMPs, as well as flow durations at the watershed outlet may change the approach. It may be necessary to identify additional BMP opportunities or increase design treatment capacities in order to meet stormwater control targets. For example, the footprint may be increased such that a 90% capture volume may be achieved at locations where ample space is available. If additional flow control is needed, then multistage outlet structures may be used to provide extended detention of low flows and peak attenuation of high flows. In many cases, an iterative design approach may be required to identify a suite of BMPs and associated design features that meet all of the hydrologic, hydraulic, and water quality design goals for the watershed.

5.2 BMP Sizing Case Study: East Campus

To provide an example of the sizing procedure, a drainage area located in the East Campus identified by MU was modeled. The selected watershed is located East of College Avenue and North of Ashland Road. Stormwater runoff from this area drains directly into Hinkson Creek. This area was chosen as per client selection due to upcoming new construction plans (i.e., Animal Resource Center Building). The methodology and results of the SWMM5 model are presented in this section.

Candidate BMP Areas

Several potential locations for regional and distributed BMPs were identified in the study area as described below and shown in Figure 3.

- <u>Regional Detention</u> – Proposed location for regional detention is the open field at the bottom of the watershed near the outfall;
- <u>Bioretention/Vegetative Swale</u> – Many locations throughout the model watershed provide optimal situations for bioretention or vegetative swale implementation. An example of linear bioretention is the drainage running along the north and south side of East Campus Dr.; and
- <u>Planter Box</u> – Any building with exterior gutter drains supplies potential sites for planter box implementation.

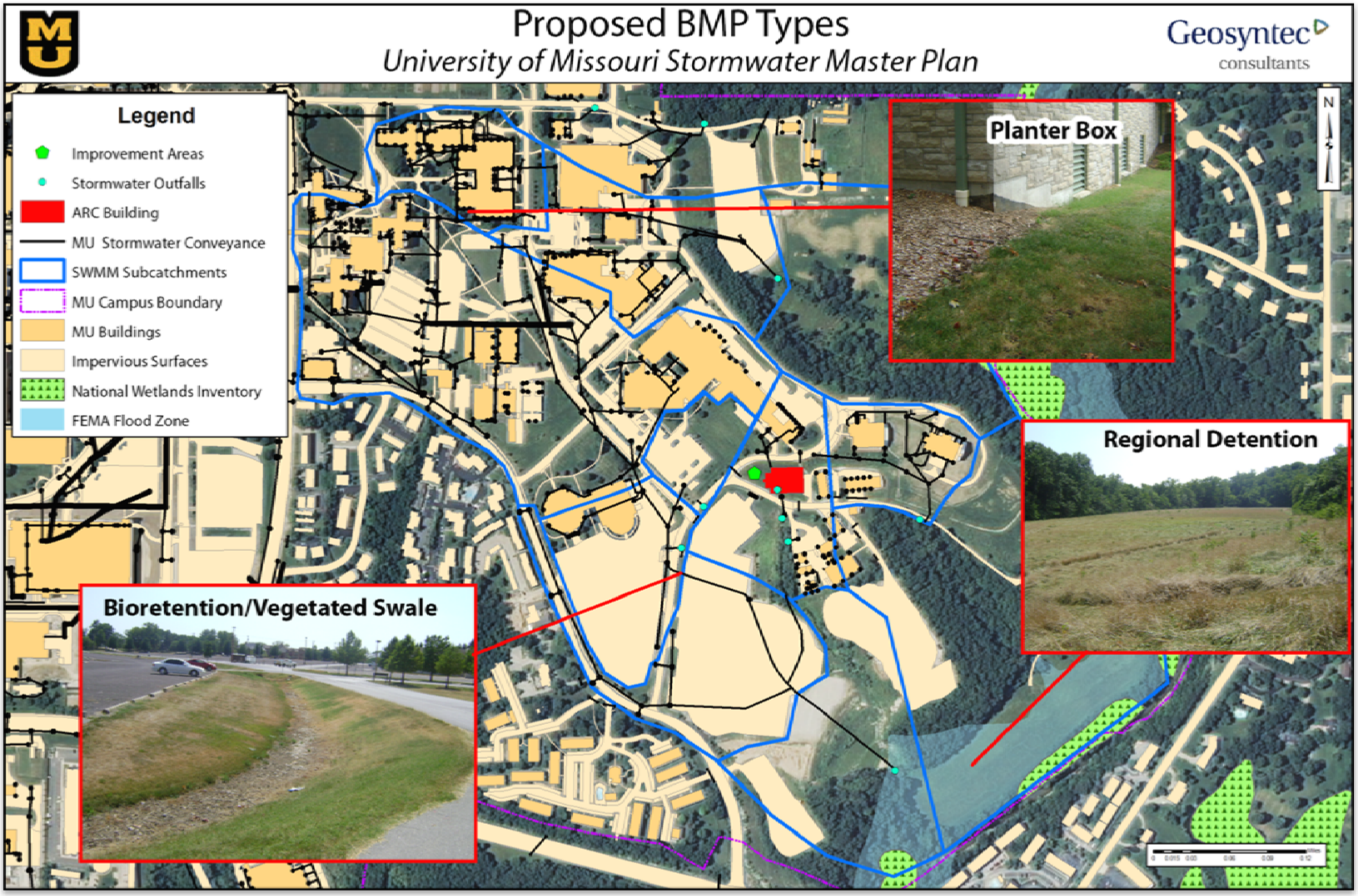


Figure 3. Example Candidate BMP Locations for Study Area. Note that MU Buildings are included as impervious area in calculations.

SWMM5 Model Set Up

The selected study area shown in Figure 5 was delineated and separated into 11 subcatchments according to overland flow paths and the existing stormwater conveyance system. A summary of the existing and post-construction land cover is displayed in Table 7. Average impervious cover over the existing model watershed is 40.8% with an average slope of approximately 9%. Soils throughout the watershed are a mix of Urban land complex (i.e., fill material) and Wrengart silt loam. Geosyntec ran a 40-year continuous simulation with SWMM5 based on local climate data. Additional data inputs include infiltration, evaporation, stormwater infrastructure, and land cover estimates included in available databases or geospatial (GIS) files provided by MU.

Table 7. Land Cover in East Campus Study Area

Urban Landuse	Area (acres)	
	Existing	Post - Construction
Parking	34.9	34.9
Building	13.85	14.22
Road	7.0	7.0
Sidewalks	5.3	5.3
Total Impervious Area	61.1	61.5
Total Area	149.7	149.7
Percent Impervious	*40.8%*	*41.1%*

The SWMM5 model was used to evaluate several BMP scenarios within the study area. A screen shot of the existing conditions SWMM5 model is shown in Figure 4. In addition to the existing condition and the post-development condition, three BMP scenarios for the study area were simulated. A summary of all of the model simulation scenarios is provided as follows:

- Existing Condition
- Post-Development Condition
- BMP 1: Distributed BMP Low (Constrained BMP Opportunity Scenario)
    - 20% of all parking lots treated with bioretention cells with a 6-inch ponding depth, 2-feet of media, and 1-foot gravel sump below the under drain.

  - 10% of all rooftops treated with planter boxes with a 6-inch ponding depth, 2-feet of media, and an under drain with no sump. Planter boxes are assumed to be lined.
- BMP 2: Distributed BMP High (Typical or Moderate BMP Opportunity Scenario)
  - 60% of all parking lots treated with bioretention cells with a 12-inch ponding depth, 3-feet of media, and 2 foot gravel sump below the under drain.
  - 20% of all rooftops treated with planter boxes with a 12-inch ponding depth, 2-feet of media, and an under drain with no sump. Planter boxes are assumed to be lined.
- BMP 3: Centralized BMP (Regional and Distributed BMP Mixture, Optimized Scenario)
  - Outfalls 2 and 3 in Figure 4 routed to a wetland system with extended detention designed with a 48-hour drawdown time and 3 foot depth. Underlying soils assumed to infiltrate at 0.1 inches per hour.
  - Upper outfall watershed same as BMP1 (Constrained Scenario)

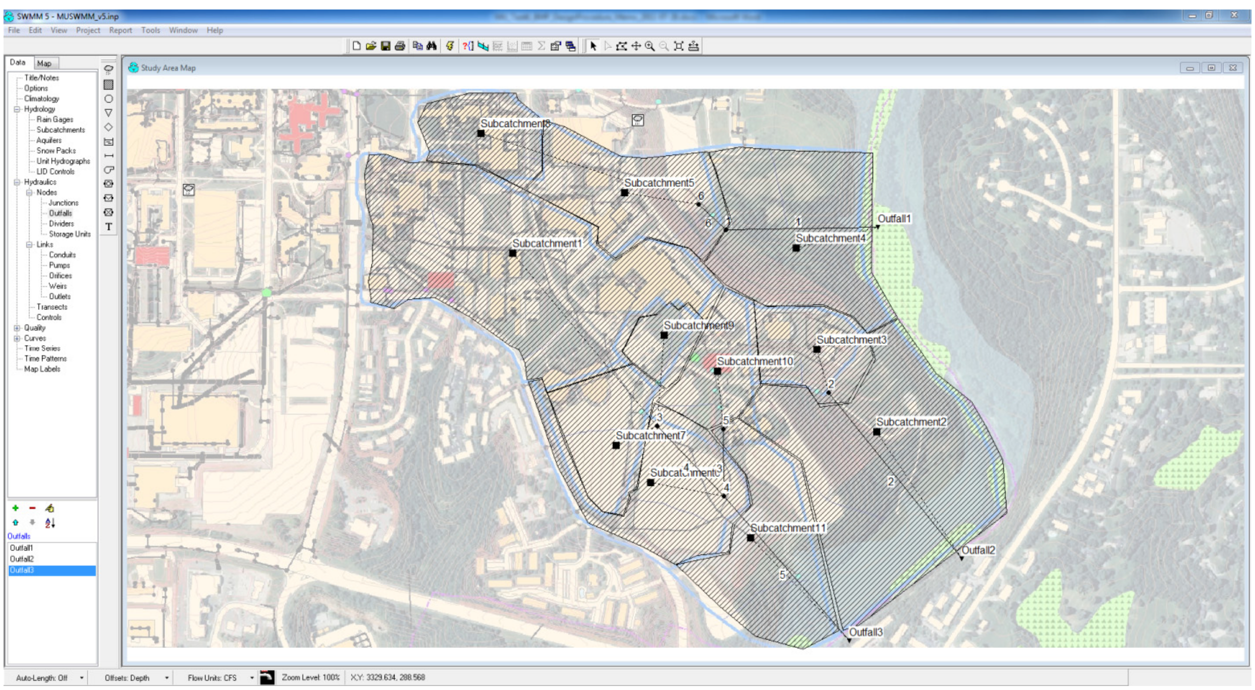


Figure 4. Existing Conditions SWMM5 Model for Study Area.

Modeling Results

A summary of the average annual runoff volumes with and without BMPs is provided in Table 8. The percent annual average volume captured and reduced by BMPs are also summarized. As shown in Table 8, the existing condition and post-development total discharge volumes are very similar because a slight increase (< 1%) in impervious area is expected to result from the proposed Animal Resources Center.

With limited implementation of distributed site control BMPs (BMP 1 = 20% of parking lots and 10% roof tops treated), the volume capture for the watershed is estimated to be about 10%, and 3% of this is associated with volume reductions. With a more aggressive implementation of site control BMPs (BMP 2 = 60% of parking lots and 20% roof tops treated), approximately 32% of the runoff volume from the watershed may be captured with a 12% volume reduction.

When a regional wetland system with extended detention (modeled as an extended detention basin) is considered (BMP 3), much higher capture volumes are possible. However, due to the deeper storage depths, the wetland system is not expected to provide the same relative level of volume reductions as bioretention BMPs that are specifically designed for that purpose (e.g., 2-foot gravel reservoir below the under drain). With additional implementation of bioretention within the watershed, greater volume reductions are possible.

Table 8. Volumetric Capture and Reduction Results for Modeled Scenarios

Model Scenario	Total Discharge (acre feet per year)	Annual Average Volume Capture (Percent)	Annual Average Volume Reduction (Percent)
Existing	188.4	0%	0%
Post-Development	189.3	0%	0%
BMP 1	183.7	10%	3%
BMP 2	168.9	35%	12%
BMP 3	169.5	68%	12%

Figure 5 shows a plot of daily average Flow Duration Curves (FDCs) for the five modeled scenarios, presented as cfs/acre. The FDCs demonstrate that implementation of BMPs cause the duration of low flow rates to increase while decreasing the duration of high flows. The plot also includes the 3% (0.028 cfs/acre) and 5% (0.02 cfs/acre) exceedance values derived from the TMDL. As indicated, all of the scenarios, including the existing condition, have cumulative daily flow durations that are below the 3% and 5% TMDL target flow rates derived by regulatory agencies. As mentioned earlier, flow durations calculated at the site-level in the TMDL are not particularly well supported and may be disconnected in time from flow durations actually occurring in Hinkson Creek. Therefore, runoff durations predicted for the East Campus subwatershed relative to actual flow in Hinkson Creek should be carefully considered.

The uncalibrated SWMM5 model prepared to support this evaluation is parameterized according to information contained in companion guidance documents, local soils data, local climate data, and experienced professional judgment. When and where possible, SWMM5 model inputs should be revised according to site-specific monitoring data and distinct site knowledge.

These findings presented from the East Campus subwatershed may differ from other campus watersheds as affected by the conveyance network, imperviousness characteristics, feasibility of regional controls, or site constraints.

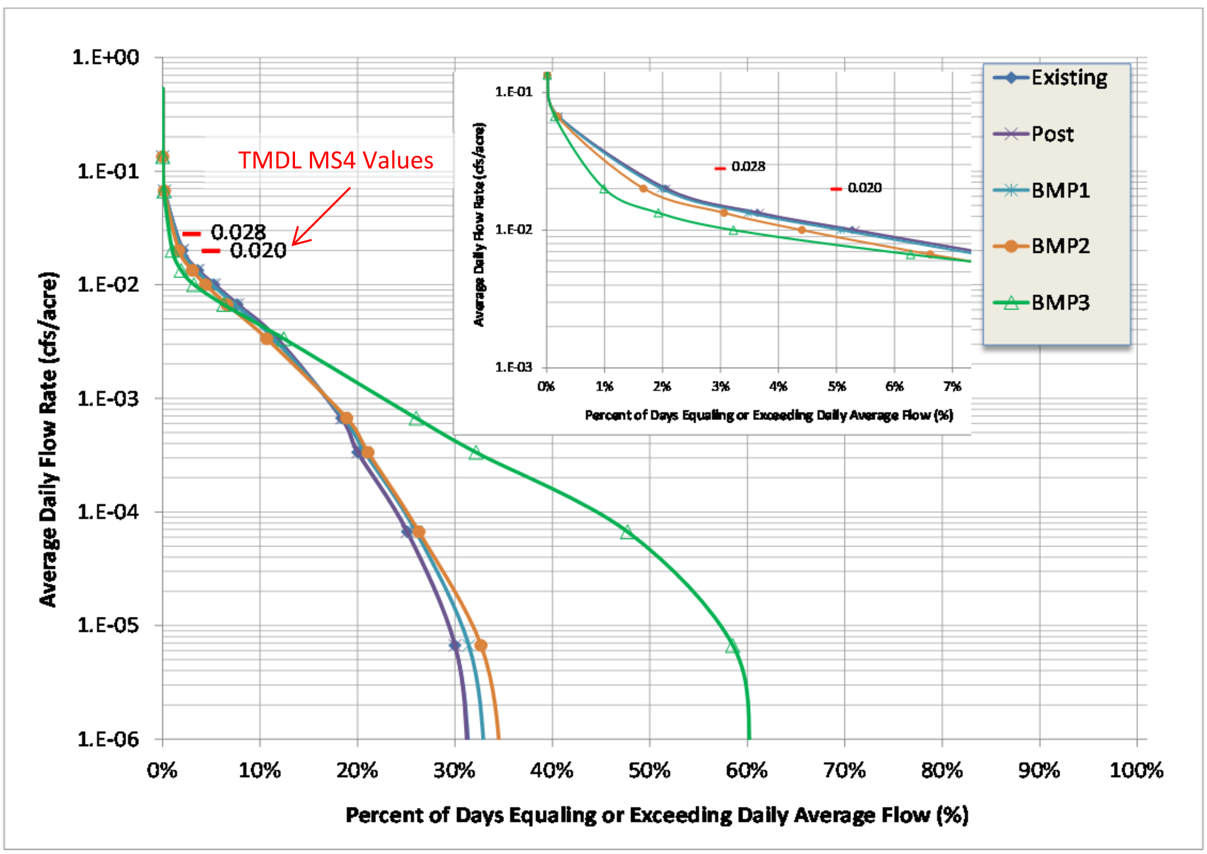


Figure 5. Comparison of Flow Duration Curves for Modeled Scenarios in Subcatchment 4.

5.3 Summary and Conclusions

Section 5 presents a method for identifying potential BMP locations within a watershed, sizing BMPs for those locations. This method also considers performance with respect to volume captured, volume reduced, and flow duration exceedance. The nomographs presented in the BMP fact sheets for distributed BMPs and presented below for regional BMPs can be used to quickly size BMPs to determine whether a candidate BMP site is space constrained and may or may not be able to capture and treat 80% of the runoff from the tributary area.

If a regional BMP site is slightly space constrained, then a deeper average design depth (up to about 6 feet) may be considered to reduce the footprint. Alternatively, distributed BMPs within the watershed that are specifically designed to maximize volume reductions can be evaluated to determine whether the design volume (and associated footprint) of the regional facility can be reduced while still meeting the volume capture goals. BMPs with gravel sumps below the under drain that allow for enhanced infiltration can be an effective method for reducing runoff volumes on-site.

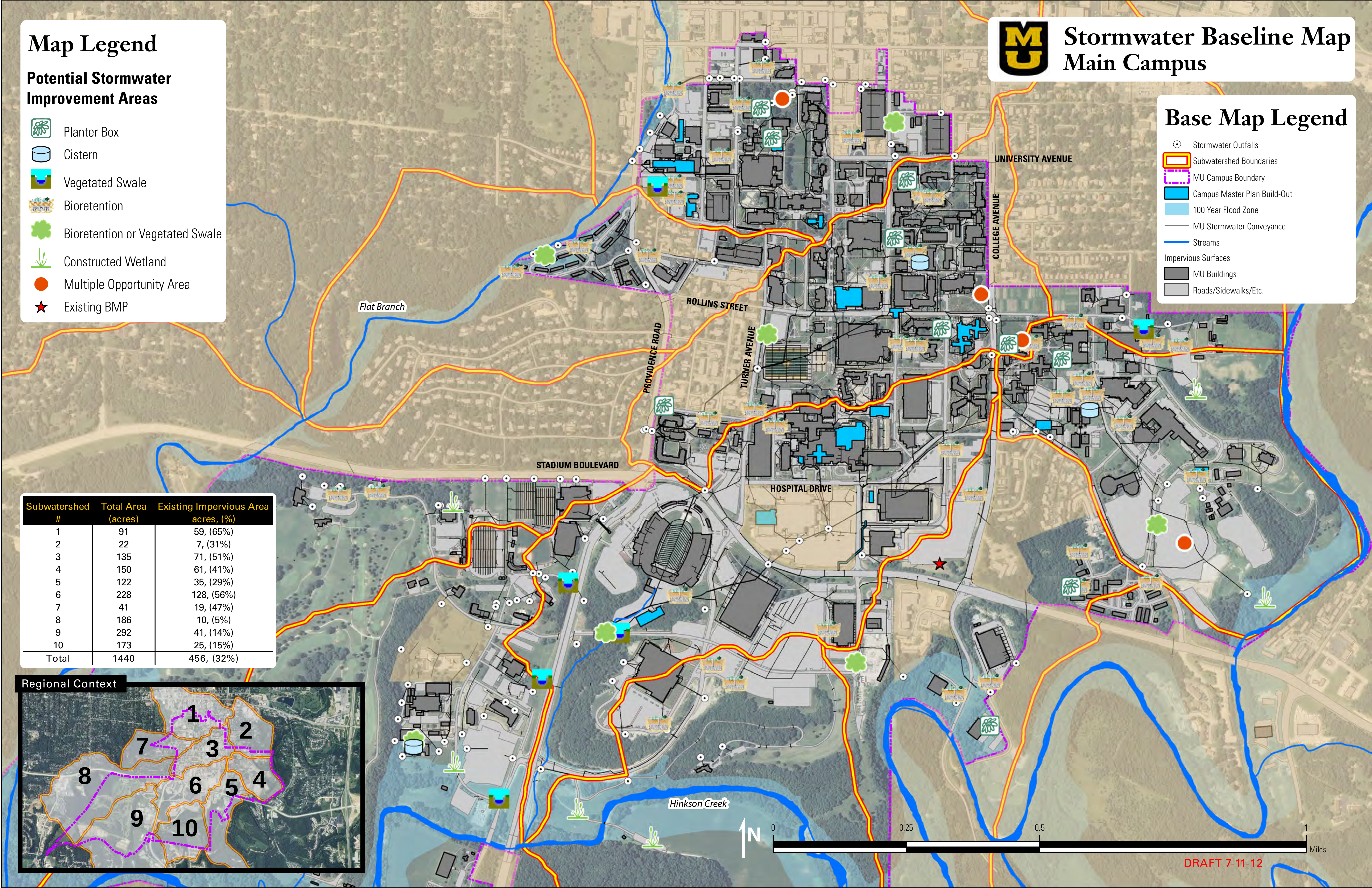
The example study area with the implementation of BMPs indicated that distributed BMPs may be as effective at reducing runoff volumes as a regional facility depending on the level of implementation and design attributes. Achieving 80% capture or above in the study area may require consideration of a regional facility. Flow durations calculated at the site-level for all modeled scenarios meet the MS4 targets presented in the Hinkson Creek TMDL.

SECTION 6. REFERENCES

Schueler, T. (1987). Controlling Urban Runoff - A Practical Manual for Planning and Designing Urban BMPs. Metropolitan Washington Council of Governments.

Appendix A

Stormwater Baseline Map



Subwatershed #	Total Area (acres)	Existing Impervious Area acres, (%)
1	91	59, (65%)
2	22	7, (31%)
3	135	71, (51%)
4	150	61, (41%)
5	122	35, (29%)
6	228	128, (56%)
7	41	19, (47%)
8	186	10, (5%)
9	292	41, (14%)
10	173	25, (15%)
Total	1440	456, (32%)

Appendix B

Structural Best Management Practice Fact Sheets

Stormwater Master Plan 2013

Geosyntec consultants

engineers | scientists | innovators

Vegetated Swale Filter

Application

- Parking lots, road shoulders and medians
- Open spaces, parks, golf courses
- Pretreatment for other BMPs

Advantages

- Combines stormwater treatment with runoff conveyance
- Often less cost than curb and gutter
- Volume and peak flow reduction
- Pollutant removal

Limitations

- Higher maintenance than curb and gutter
- Not applicable for steep slopes

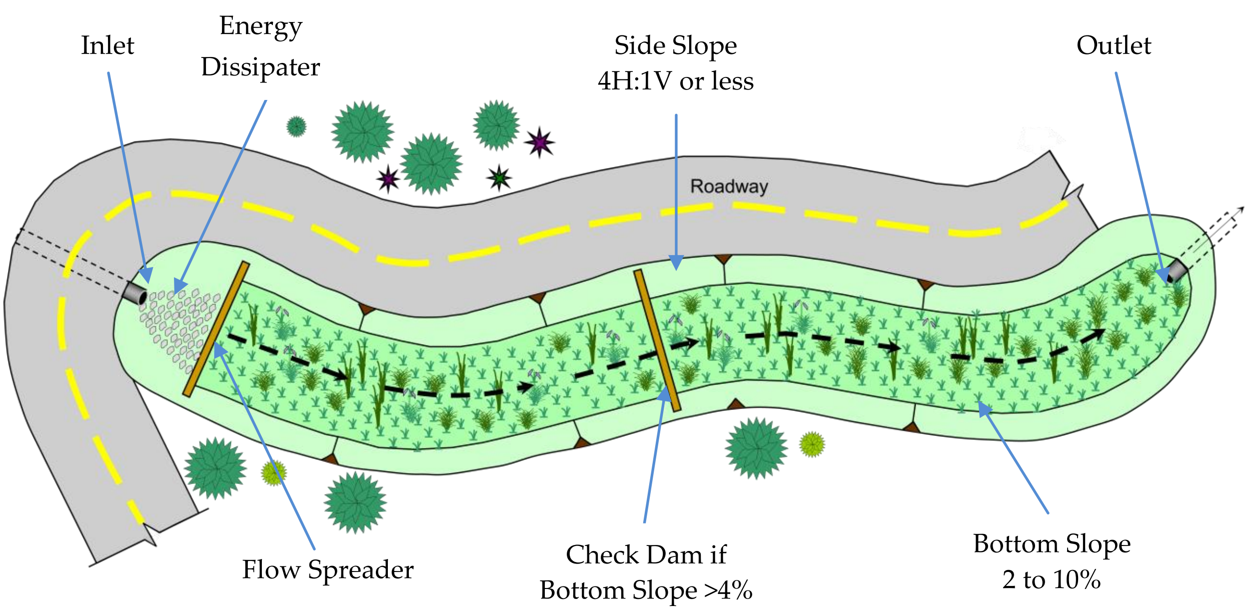
DESCRIPTION

Vegetated swale filters (vegetated swales) are shallow, open conveyances with low-lying vegetation covering the channel that collect and slowly convey runoff to downstream discharge points. Swales remove stormwater pollutants by filtering flows through vegetation (usually grasses) and by allowing suspended pollutants to settle due to the shallow flow depths and slow velocities in the swale. Additional pollutant removal mechanisms include volume reduction through infiltration and evapotranspiration. Biochemical processes provide treatment of dissolved constituents. An effective vegetated swale achieves uniform sheet flow through a densely vegetated area for a period at least 10 minutes. The vegetation in the swale can vary depending on its location within the University's campus. The designer can select vegetation to meet the desired aesthetics or to meet the functional criteria of maximizing water quality benefits. Use of native plant species are encouraged to maximize infiltration, pollutant removal, and vegetation survivability.

CONDITIONS WHERE PRACTICE APPLIES

Swales have a wide range of applications including parking lot perimeters, open space areas, and treatment adjacent to linear projects such as roadways. Swales should either be lined or avoided in areas where soils might be contaminated. A vegetated swale can be designed either on-line or off-line. On-line vegetated swales are used for conveying high flows as well as providing treatment at the water quality design flow rate. This system can replace curbs, gutters, and storm drain systems. On-line swales are designed to convey flow rates higher than the water quality design flow rate during intense storm events; however, these flows are not effectively treated. Off-line swales by-pass flows that exceed the water quality design flow rate. This approach requires two parallel flow paths and therefore more land area. Off-line swales are the preferred practice. However, in an ultra-urban environment such as the heart of the University's campus, off-line swales may not be feasible due to limited open space. Performance of on-line swales is enhanced by minimizing individual drainage areas and providing intermittent outlets along the length of the swale.

Given the limited infiltration capacity of underlying soils on the University's campus, underdrains (perforated pipes) are recommended if the longitudinal slope is less that 1.5%. Underdrains can improve the health of the vegetation and prevent the bottom of the vegetated swales from becoming soggy. Underdrains are recommended to mitigate vector (mosquito) concerns related to the formation of stagnant pools of water in poorly drained soils.



Site Suitability Considerations for Vegetated Swale Filters

Tributary Area	< 5 acres [1]
BMP Area Typically Required as Percentage of Tributary Area (%)	< 5 percent
Site Slope (%)	2 to 10 percent [2,3]
Hydrologic Soil Group	Any [3]

1) Tributary area is the area of the site draining to the vegetated swale filter. Tributary areas provided here should be used as a general guideline only. Tributary areas can be larger or smaller in some instances.

2) If the longitudinal slope of the swale exceeds 4%, check dams should be provided.

3) If the swale has a longitudinal slope less than 1.5% and is constructed within poorly drained soils (which are anticipated on campus), underdrains should be incorporated. If underdrains are provided, the site must have adequate relief between land surface and the underdrain to permit vertical percolation through the gravel drainage layer (open-graded base/sub-base) and underdrain to the stormwater conveyance system. The underdrain should have a minimum design slope of 0.5%.

Note: The water quality design flow rate is the maximum flow rate that the swale can effectively treat. The design flow rate within the swale should have a flow depth of less than 4 inches with a velocity of less than 1 ft/sec. The designer can vary the swale width, slope, and Manning's n to achieve the desired conditions. Flow rates in excess of the water quality design flow can be routed through the swale, as in an on-line swale; however, these flows are not effectively treated.

Stormwater Runoff BMP	Volume Mitigation (% of inflow)	Treatment Effectiveness for Pollutants of Concern[1]					
		Trash	Nutrients	Bacteria	Metals (particulate and dissolved fractions)	Sediment	Organics (hydro-carbons, oil, and grease)
Vegetated Swale Filter	○	○	◒	●	○	○	○
Volume/Treatment Effectiveness: ◉ *= Very High,* ◓ *= High,* ○ *= Moderate,* ◒ *= Low,* ● *= Very Low*							

[1] Effectiveness may change based on design variations; standard BMP designs have been assumed.

VARIATIONS AND ENHANCEMENTS

Enhancements that maximize contact time, aid in trapping and securing of pollutants, or assist with volume reduction are the main categories of enhancements for vegetated swales. Structural and operational enhancements that can increase performance in vegetative filtration facilities are presented below.

- Check dams are recommended where longitudinal slopes exceed 4% to reduce velocities and dissipate erosive forces. Check dams enhance sediment removal by causing stormwater to pond allowing coarse sediment to settle out.
- Amended soils provide sorption sites for the removal of dissolved and suspended pollutants and can also be used to increase or decrease infiltration and provide additional support for plant growth. Soil amendments also help to increase evapotranspiration and infiltration by increasing storage within the soils thereby allowing the underlying native soils time for deeper infiltration.
- Flow spreaders distribute flows evenly across the width of a vegetated filtration BMP. Vegetated filtration BMPs, such as vegetated swales, function best under conditions of even, shallow sheet flow. Flow spreaders should be placed where point discharges, such as the outlet of a storm sewer, enter the swale.
- Flow dividers are recommended for vegetated swales when the bottom width exceeds 10 feet. Flow dividers encourage sheet flow and limit channelization along the bottom of the swale.
- In areas where the infiltration capacity of the underlying soil is high, or the swale slope is greater than 1.5%, underdrains may not be required. Greater volume losses through infiltration and evapotranspiration can be achieved without an underdrain.

SIZING AND DESIGN CONSIDERATIONS

The following are recommended sizing and design considerations. Final vegetated swale designs should be based on site-specific considerations and limitations.

- The vegetated swale should be sized based on the target percent capture and estimated time of concentration using the sizing curves provided at the end of this fact sheet.
- The design flow velocity through the swale should not exceed 1ft/sec to keep the vegetation in the swale upright.
- The bottom width, longitudinal slope, and side slopes should be sized to handle the design flow rate such that flow depths in the swale do not exceed 4 inches or two-thirds of the height of the grass in the swale.
- The recommended minimum bottom width of the vegetated swale is 2 feet and maximum bottom width is 10 feet.
- The recommended swale length is the length required to achieve a minimum hydraulic residence time of 10 minutes. The recommended minimum swale length is 100 feet.
- The recommended side slope of the swale is flat with 4:1 slopes.

- The vegetated swale should be planted with wetland vegetation if the swale is designed to be persistently wet.
- If underdrains are provided, they should be made of slotted, polyvinyl chloride (PVC) pipe conforming to ASTM D 3034 or equivalent or corrugated high density polyethylene (HDPE) pipe conforming to AASHTO 252M or equivalent. *Intent: As compared to round-hole perforated pipe, slotted underdrains provide greater intake capacity, clog resistant drainage, and reduced entrance velocity into the pipe, thereby reducing the chances of solids migration.*

CONSTRUCTION CONSIDERATIONS

The following items should be considered for construction of vegetated swales.

- Provide energy dissipation and a flow spreader at each concentrated inlet point. Sheet flow inputs along the length of the swale do not require energy dissipation.
- If infiltration is considered desirable do not operate heavy machinery along the bottom of the swale. If compaction occurs, till the bottom of the swale, re-grade and vegetate.
- If site soils are highly impermeable, amend the soils at the bottom of the swale to facilitate infiltration and promote plant growth.
- Avoid using treated wood or galvanized metal anywhere within the vegetated swale.

INSPECTION AND MAINTENANCE

Routine Maintenance

Routine maintenance activities in vegetative swales should include the tasks listed below.

- Maintain vegetation to preserve aesthetics of swales located in prominent areas.
- Remove trash and debris and visible floatables such as oil and grease.
- Remove minor sediment accumulations near inlet and outlet structures.
- Stabilize and repair eroded banks.
- Perform minor structural repairs to inlet and outlet structures.
- Eliminate conditions that promote vectors (e.g. mosquitoes).

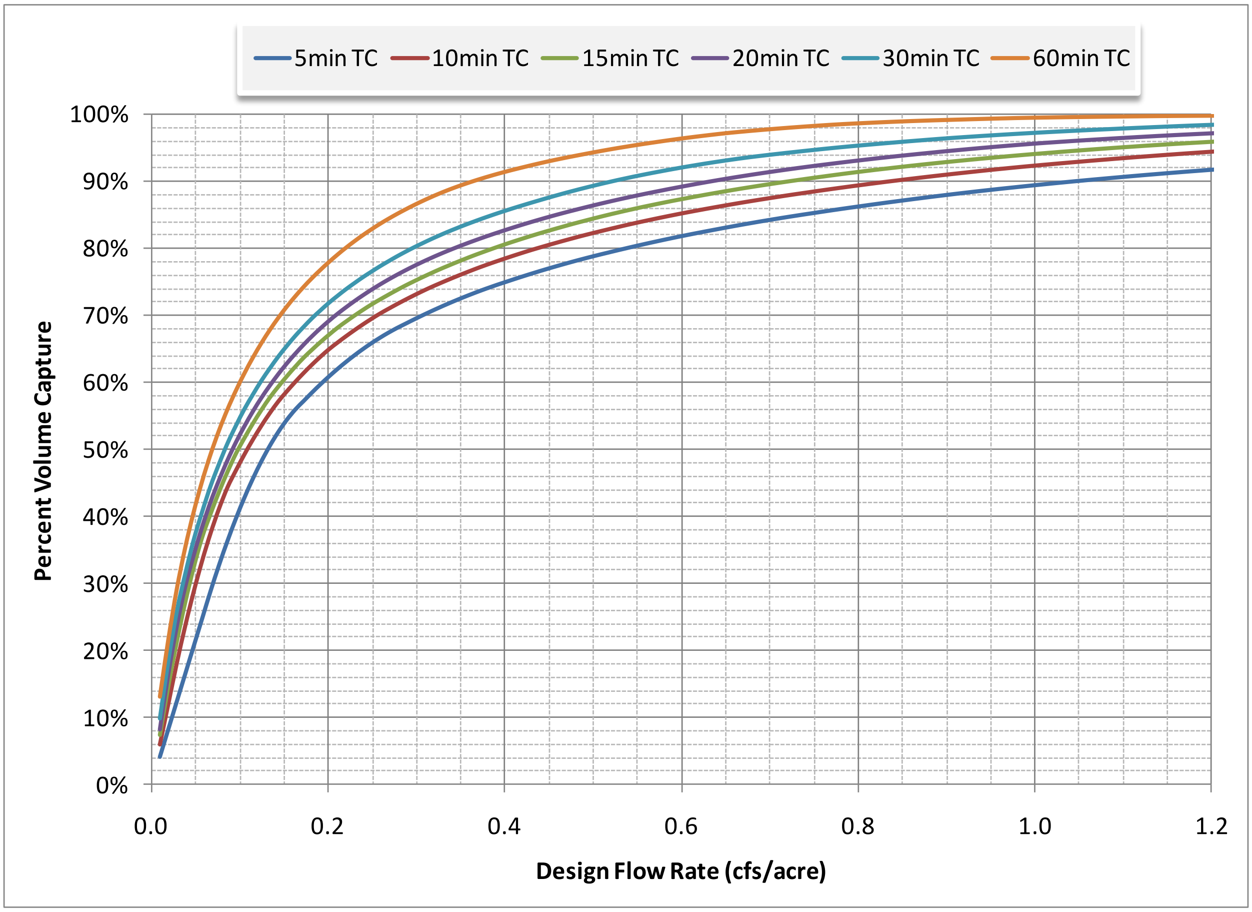
Major Maintenance

Major maintenance activities in bioretention areas should include the tasks listed below.

- Re-construct and repair side slopes and berms when needed.
- Re-grade swale bottom to restore design longitudinal slope.
- Aerate or scarify compacted areas to restore infiltration capacity.

DESIGN NOMOGRAPHS

Volumetric Percent Capture for Various Times of Concentration



Volumetric Percent Capture

The total volumetric percent capture is the long-term runoff volume captured by a BMP as a percent of the runoff volume that would have occurred without the BMP. The volume captured includes both the volume lost due to infiltration and evapotranspiration as well as the volume treated and discharged to the storm drain system. Typically, a goal of 80-90% capture is used for sizing stormwater BMPs for water quality due to the economics of diminishing returns.

Estimating Effective Tributary Area

Volumetric percent capture plots have been developed to assist with BMP sizing and evaluating expected performance. Nomographs are based on continuous hydrologic simulations of various BMP sizes and a unit tributary area with 100% impervious cover, or the effective tributary area. The effective tributary area is the portion of the drainage area that contributes to runoff over an average annual time period and can be approximated using a simple volumetric runoff coefficient equation based on Schueler (1987):

$$C = 0.05 + (0.9*Imp)$$

Where, C is the volumetric runoff coefficient and Imp is the impervious fraction of the watershed. The effective tributary area is the volumetric runoff coefficient times the total tributary area. By dividing the total tributary area into the pervious and impervious areas and combining terms, the effective tributary area can be estimated as:

$$A\_eff = 0.05A\_perv + (0.95*A\_imp)$$

Where, A_eff is the effective tributary area, A_perv is the pervious area, and A_imp is the impervious area. Site-specific runoff coefficients for pervious areas may be developed based on monitoring results or best professional judgement.

Schueler, T. (1987). Controlling Urban Runoff - A Practical Manual for Planning and Designing Urban BMPs. Metropolitan Washington Council of Governments.

Planter Boxes

Application

- Building downspouts
- Sidewalks and walkways
- Roadway runoff

Advantages

- Volume and peak flow reduction
- Pollutant removal
- Does not require a setback from building foundation

Limitations

- May require additional support on steep slopes
- Must be constructed with underdrain system to convey excess water to stormwater conveyance system

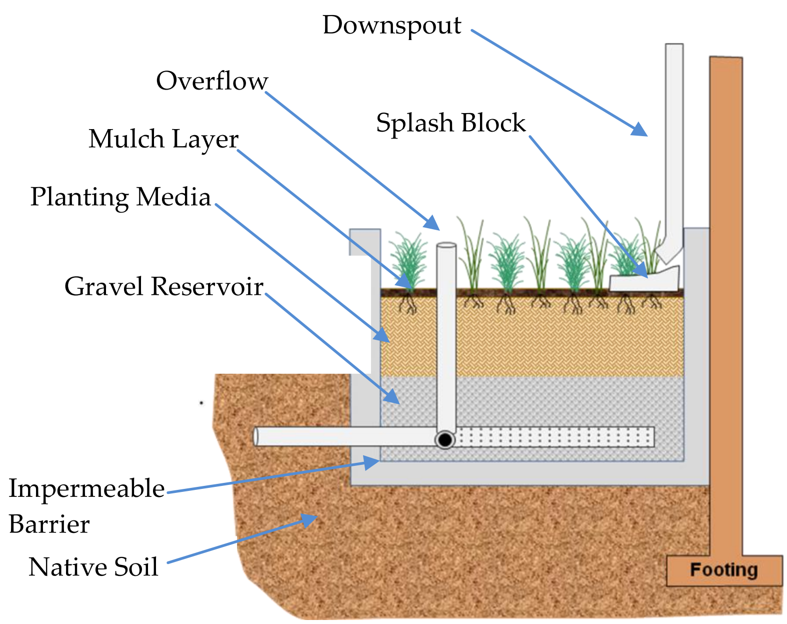
DESCRIPTION

Planter boxes, either elevated or at ground level, are designed to capture and temporarily store stormwater runoff. Planter boxes are comprised of a variety of materials (usually chosen to be the same material as the adjacent building or sidewalk). The boxes are filled with gravel on the bottom (to house the underdrain system), planting soil media, and vegetation. Planter boxes may also require splash blocks for flow energy dissipation and geotextile filter fabric or choking stone between the media bed and the gravel layer to reduce clogging of the underdrain system. The stormwater infiltrates into the soil where it is used by the plants, stored and filtered. If the runoff volume is large the stormwater may even pond on the surface for a limited period of time. Planter boxes are intended to be placed next to buildings and installed with underdrains and an impervious liner. Once the soil becomes saturated, the excess water collects in the underdrain system where it may be routed to a stormwater conveyance system or another stormwater runoff BMP, such as a vegetated swale filter. Planter boxes are similar in design to bioretention areas, which are also comprised of media layers that provide filtration and adsorption of pollutants. The primary function of lanter boxes is to provide pollutant removal therefore serving as a biofiltration device.

Planter boxes are designed to limit or prohibit the infiltration of water into underlying soils, depending on site conditions. Runoff volume reduction is achieved through evapotranspiration. Planter boxes are more appropriate to bioretention when adjacent to structures or for steep slope applications where the planter boxes can be terraced as a cascading storage and conveyance system.

CONDITIONS WHERE PRACTICE APPLIES

Planter boxes may be placed adjacent to or near buildings, other structures, or sidewalks. Planter boxes can be used directly adjacent to buildings beneath downspouts as long as the boxes are properly lined on the building side and the overflow outlet discharges away from the building. They can also be placed further away from buildings by conveying roof runoff in shallow engineered open conveyances, shallow pipes, or other innovative drainage structures. Planter boxes are uniquely suited for redevelopment in urban or dense campus areas. In addition, planter boxes are suitable for sites where infiltration practices are impractical or discouraged. Planter boxes should not be located in areas with excessive shade to avoid poor vegetative growth. Shade tolerant plants should be used where abundant sunlight is not available.



Site Suitability Considerations for Planter Boxes

Tributary Area	< 0.35 acres [1]
BMP Area Typically Required as Percentage of Tributary Area (%)	5 to 15 percent
Site Slope	Site must have adequate relief between land surface and the stormwater conveyance system to permit vertical percolation through the planting media and underdrain to the stormwater conveyance system. The final box must be level or designed as a cascading series of level boxes.
Hydrologic Soil Group	Any

1) Tributary area is the area of the site draining to the planter box. Tributary areas provided here should be used as a general guideline only. Tributary areas can be larger or smaller in some instances.

VARIATIONS AND ENHANCEMENTS

Planter boxes may be designed in a variety of configurations to be seamlessly incorporated into building landscaping. The gravel reservoir may be increased to provide better peak flow attenuation. Amendments may be added to the planting media to provide additional support for plant growth and increase water holding capacity and evapotranspiration. In some instances, infiltration into the underlying native soils may be possible if they are well-drained and adequate barriers are installed near building foundations. French drains may be incorporated into the outlet structure to divert and infiltrate runoff away from buildings.

SIZING AND DESIGN CONSIDERATIONS

The following are recommended sizing and design considerations. Final planter box designs should be based on site-specific considerations and limitations.

- Drawdown time of surface ponding should be less than 12 hours.
- The recommended maximum ponding depth is 12 inches above the planter box mulch layer.
- The recommended minimum soil media depth is 2 feet with 3 feet preferred. *Intent: The planting soil depth should provide a beneficial root zone for the chosen plant palette and adequate water storage for the water quality design volume.*
- The soil media composition is recommended to be 60 to 70% sand, 15 to 25% compost, and 10 to 20% clean topsoil; organic content 8 to 12%; and pH 5.5 to 7.5.
- Overflow devices are required.

- Underdrains should be made of slotted, polyvinyl chloride (PVC) pipe conforming to ASTM D 3034 or equivalent or corrugated high density polyethylene (HDPE) pipe conforming to AASHTO 252M or equivalent. *Intent: As compared to round-hole perforated pipe, slotted underdrains provide greater intake capacity, clog resistant drainage, and reduced entrance velocity into the pipe, thereby reducing the chances of solids migration.*
- The underdrain should be placed within a bed of aggregate with a minimum thickness of 6 inches around the top, bottom, and sides of the slotted pipe.
- A 30 mil geomembrane liner or equivalent liner is recommended to avoid infiltration near building foundations.

CONSTRUCTION CONSIDERATIONS

The following items should be considered for the construction of planter boxes:

- Provide energy dissipation (i.e., splash block) at each concentrated inlet point to the planter box.
- The use of treated wood or galvanized metal anywhere within the planter box should be avoided.
- Material of planter boxes should be selected carefully to blend in and enhance aesthetics of adjacent structures (buildings and sidewalks).
- Plants should be selected carefully to minimize maintenance and function properly. Native plant species and/or hardy cultivars that are not invasive are preferred.

INSPECTION AND MAINTENANCE

Routine Maintenance

Routine maintenance activities in planter boxes should include:

- Repair of small eroded areas and ruts by filling with gravel,
- Reseed bare areas to reestablish vegetation,
- Removal of trash and debris and raking surface soils to mitigate ponding,
- Removal of accumulated fine sediments, dead leaves and trash to restore surface permeability,
- Removal of any evidence of visual contamination from floatables such as oil and grease,
- Eradication of weeds and pruning back excess plant growth that interferes with facility operation,
- Removal of non-native vegetation and replace with native species,
- Remove sediment and debris accumulation near inlet and outlet structures to alleviate clogging,
- Cleaning and resetting flow spreaders (if present) as needed to restore original function,

- Periodic observation of planter box function under wet weather conditions, and
- Periodic placement of well-aged mulch or compost on the surface to maintain media thickness.

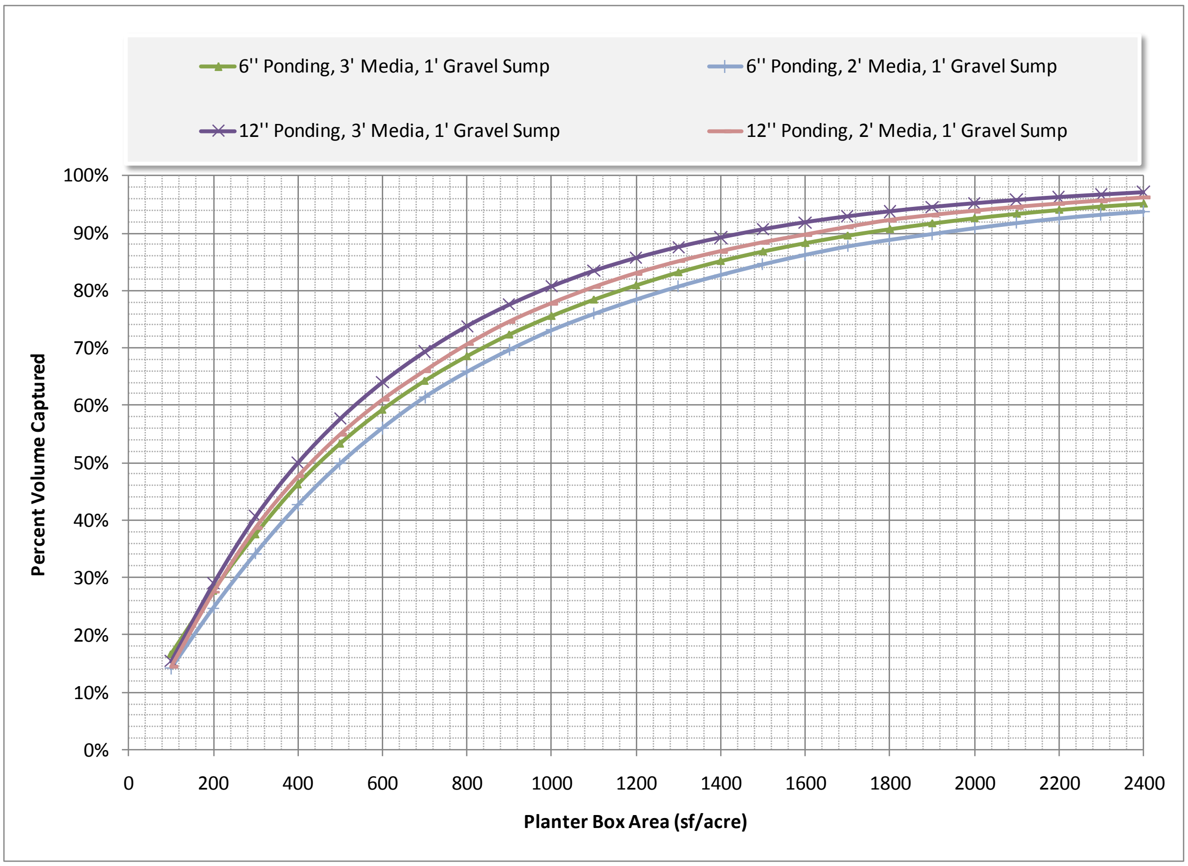
Major Maintenance

Major maintenance activities for planter boxes should include:

- Repair of structural damage to flow control structures including inlet, outlet, and overflow structures,
- Clean out of underdrain to alleviate ponding,
- Replacement of soil media (if ponding or loss of infiltrative capacity persists) and revegetation, and
- Revegetation to repair damage from severe erosion.

DESIGN NOMOGRAPH

Assumes 2 in/hr media filtration rate and minor (0.1-3.2%) evapotranspiration losses.



Volumetric Percent Capture

The total volumetric percent capture is the long-term runoff volume captured by a BMP as a percent of the runoff volume that would have occurred without the BMP.

The volume captured includes both the volume lost due to infiltration and evapotranspiration as well as the volume treated and discharged to the storm drain system. Typically, a goal of 80-90% capture is used for sizing stormwater BMPs for water quality due to the economics of diminishing returns.

Estimating Effective Tributary Area

Volumetric percent capture plots have been developed to assist with BMP sizing and evaluating expected performance. Nomographs are based on continuous hydrologic simulations of various BMP sizes and a unit tributary area with 100% impervious cover, or the effective tributary area. The effective tributary area is the portion of the drainage area that contributes to runoff over an average annual time period and can be approximated using a simple volumetric runoff coefficient equation based on Schueler (1987):

$$C = 0.05 + (0.9*Imp)$$

Where, C is the volumetric runoff coefficient and Imp is the impervious fraction of the watershed. The effective tributary area is the volumetric runoff coefficient times the total tributary area. By dividing the total tributary area into the pervious and impervious areas and combining terms, the effective tributary area can be estimated as:

$$A\_eff = 0.05A\_perv + (0.95*A\_imp)$$

Where, A_eff is the effective tributary area, A_perv is the pervious area, and A_imp is the impervious area. Site-specific runoff coefficient for pervious areas may be developed based on monitoring results or best professional judgement.

Schueler, T. (1987). Controlling Urban Runoff - A Practical Manual for Planning and Designing Urban BMPs. Metropolitan Washington Council of Governments.

Permeable Pavement and Pavers

Application

- Parking lots and driveways
- Low speed roads
- Fire lanes
- Sidewalks

Advantages

- Allows runoff to infiltrate, reducing site imperviousness
- Easily integrated into existing infrastructure
- Filtration of pavement runoff

Limitations

- Higher maintenance than standard pavement/asphalt
- Sediment-laden runoff can clog pervious pavement
- Not appropriate for high speed traffic areas

DESCRIPTION

Permeable pavements are alternatives to conventional impervious asphalts and concretes that allow water to pass through them into a subsurface gravel layer that doubles as a storage/infiltration area and a structural base layer. Where site conditions allow, the subsurface gravel layer (open-graded base/sub-base) is configured to allow water to infiltrate into the surrounding subsoil. If site conditions do not allow for infiltration, the water is detained in the gravel storage layer and then routed to a storm water conveyance system. In either case, the initial infiltration through the surface layers increases the time of concentration, T_c, provides some filtering of pollutants, and decreases peak flows. Only when the water is allowed to infiltrate does it significantly decrease the runoff volume. There are several styles of permeable pavement available, including those that are poured in place (i.e., porous concrete and porous asphalt), and modular paving systems (i.e., interlocking concrete, grass and gravel pavers).

Pour in Place Permeable Pavements

Pour in place permeable pavements are poured where they will ultimately be used and allowed to cure in place. Typically, the pore spaces in the pavement make up about 10% of the total surface area. Porous asphalt and porous concrete are similar to each other in that the porosity is created by removing the small aggregate or fine particles from the conventional recipe, which leaves stable air pockets (gaps through the material) for water to drain to the subsurface.

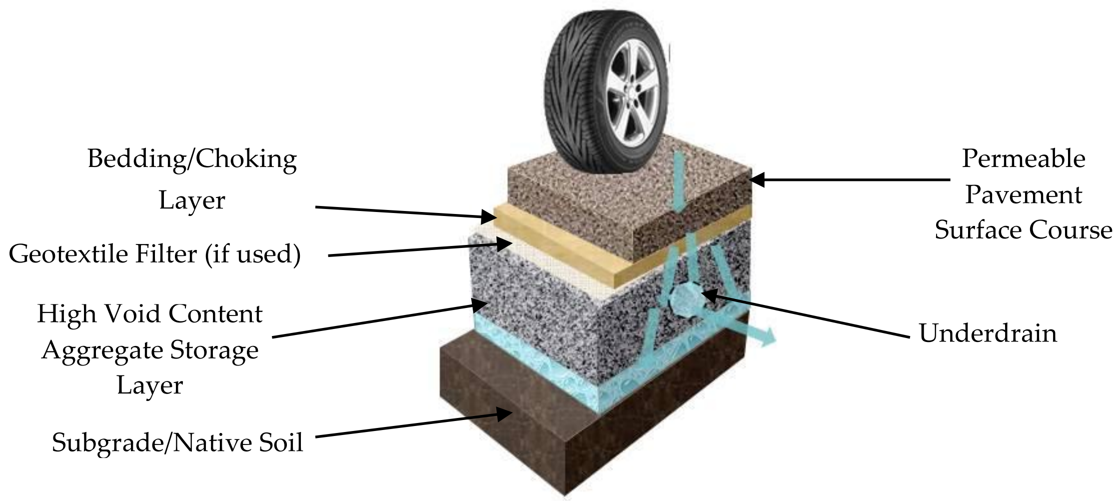
Porous concrete is rougher than its conventional counterpart, and unlike oil-based asphalt will not release harmful chemicals into the environment. These types of permeable pavements should only be used in areas of slow and low traffic (e.g., parking lots, low traffic streets, pedestrian areas, etc.).

Modular Paving Systems

There are several varieties of pavers that promote infiltration, including (but not limited to) interlocking concrete pavers, grass pavers, and gravel pavers. Interlocking concrete pavers are not porous themselves, rather the mechanism that allows them to interlock creates voids and gaps between the pavers that are filled with a pervious material. Grass and gravel pavers are nearly identical to each other in structure (rigid grid of concrete or durable plastic) but differ in their load bearing support capacities. The grids are embedded in the soil to support the loads that are applied, thereby preventing compaction, reducing rutting and erosion. Grass pavers are generally filled with a mix of sand, gravel, and soil to support vegetation growth (e.g., grass, low-growing groundcovers, etc.), which provides a matrix for microbial growth, which aides in pollutant removal. Grass pavers are good for low-traffic areas, while gravel pavers are good for high-frequency, low speed traffic areas. Gravel pavers differ from grass pavers in that they are filled with an open-graded gravel with no fines and are often underlain with a geotextile fabric to prevent the migration of the gravel into the subbase. Gravel systems typically support greater loads and higher traffic volumes than grass pavers.

CONDITIONS WHERE PRACTICE APPLIES

Permeable pavement can be applied as an alternative to traditional impermeable surfaces such as sidewalks, low traffic roads, fire lanes, and parking lots. Given the limited infiltration capacity of the underlying soils on the University campus, underdrains, in the form of perforated pipes, are recommended for all permeable pavement applications. Underdrains are recommended to prevent excessive saturation of underlying soils, thus reducing load bearing capacity, and surface ponding. Where underlying soils provide some infiltration capacity, the perforated pipe is placed above the bottom of the gravel drainage. This creates a sump storage area to achieve runoff volume losses through infiltration. Permeable pavement should be either lined or avoided in areas where soils might be contaminated to prevent the migration of contaminants.



Site Suitability Considerations for Permeable Pavement

Tributary Area	< 3 times the area of the permeable pavement surface [1]
Site Slope (%)	< 2 percent
Depth to Seasonally High Groundwater Table	< 2 ft then pavement not recommended
Hydrologic Soil Group	Any [2]

1) Tributary area is the area of the site draining to the porous pavement area. Tributary areas provided here should be used as a general guideline only. Tributary areas can be larger or smaller in some instances.

2) Underdrains may not be required in areas where the infiltration capacity of the underlying soils in not limited (hydrologic soil groups "A" or "B"). If the permeable pavement is located within 10 feet from a building or has a longitudinal slope less than 1.5%, underdrains should be incorporated. If underdrains are provided, the site must have adequate relief between land surface and the stormwater conveyance system to permit vertical percolation through the gravel drainage layer (open-graded base/sub-base) and underdrain to the stormwater conveyance system.

Storm Water Runoff BMP	**Volume Mitigation (% of inflow)**	**Treatment Effectiveness for Pollutants of Concern[1]**					
		Trash	**Nutrients**	**Bacteria**	**Metals (particulate and dissolved fractions)**	**Sediment**	**Organics (hydro-carbons, oil, and grease)**
Permeable Pavement	◓	●	○	◓	◓	◉	◓

Volume/Treatment Effectiveness: ◉ *= Very High,* ◓ *= High,* ○ *= Moderate,* ◒ *= Low,* ● *= Very Low*

[1] Effectiveness may change based on design variations; standard BMP designs have been assumed.

VARIATIONS AND ENHANCEMENTS

There are several variations to the standard permeable pavement design that can be used to increase storage capacity or pass larger flows, including use of a deeper gravel layer, amending native subgrade, and installing perforated riser underdrains. In many cases, roof downspouts may be routed to permeable pavement to reduce runoff rates and increase volume losses.

SIZING AND DESIGN CONSIDERATIONS

The following are recommended sizing and design considerations. Final permeable pavement designs should be based on site-specific considerations and limitations.

- Depending on how and where permeable pavement will be used, pretreatment of the runoff entering the pavement may be necessary—(e.g., vegetated filter strips, etc.).
- Depth of each layer should be determined by a licensed civil engineer based on analyses of not only the hydrology and hydraulics, but also the structural requirements of the site.
- The thickness of the permeable pavement surface course, consisting of either poured in place materials (i.e., porous concrete and porous asphalt) or modular paving materials (i.e., interlocking concrete, grass and gravel pavers), will vary depending on structural and functional design. The surface course for a concrete paver system consists of the concrete block, underlying angular sand used as a leveling/bedding layer, and angular joint material to fill the void between the pavement blocks.
- The bedding material should consist of small sized aggregate (e.g., No. 8) placed below the permeable pavement surface course. This layer provides a level surface for porous concrete and asphalt and servers and a barrier to prevent the migration of the leveling sand used in porous concrete blocks into the reservoir layer. This layer is typically about 1.5” to 3” inches thick and may be underlain by a geotextile fabric.
- The gravel storage layer must be designed to function as a support layer as well as a reservoir layer (i.e., consideration must be given to the soil conditions as well as the expected loads). The reservoir layer is typically washed, open-graded No. 57 aggregate without fines.

Recommended drawdown time of sub-surface storage layer is less than 72 hours. *Intent: Soils must be allowed to dry out periodically in order to restore hydraulic capacity to receive flows from subsequent storms, maintain infiltration rates, maintain adequate sub soil oxygen levels for healthy soil biota, provide proper soil conditions for biodegradation and retention of pollutants, and maintain structural integrity of underlying soil.*

If underdrains are provided, they should be made of slotted, polyvinyl chloride (PVC) pipe conforming to ASTM D 3034 or equivalent or corrugated high density polyethylene (HDPE) pipe conforming to AASHTO 252M or equivalent. *Intent: As compared to round-hole perforated pipe, slotted underdrains provide greater intake capacity, clog resistant drainage, and reduced entrance velocity into the pipe, thereby reducing the chances of solids migration.*

CONSTRUCTION CONSIDERATIONS

The following items should be considered for the construction of a permeable pavement system:

- Pavement surfaces should not be used to store site materials, unless the surface is well protected from accidental spillage or other contamination.
- To prevent/minimize soil compaction in the area of the permeable pavement installation, use light equipment with tracks or oversized tires.
- Divert stormwater from the area as needed (before and during installation).
- The pavement should be the last installation done at a development site. Landscaping should be completed and adjacent areas stabilized before pavement installation to minimize risk of tracking mud onto pavement and causing premature clogging.
- Vehicular traffic should be prohibited for at least 2 days after installation.

INSPECTION AND MAINTENANCE

Permeable pavement mainly requires vacuuming and the management of adjacent areas to limit soils migration and prevent clogging by fine sediment particles; therefore, little special training is needed for maintenance crews. Trash tends to accumulate in paved areas, particularly in parking lots and along roadways. The need for litter removal should be determined through periodic inspection.

Routine Maintenance

Routine maintenance activities of the permeable pavement system should include:

- Regular (e.g., monthly for a few months after initial installation, then quarterly) inspection of pavement for pools of standing water after rain events, this could indicate surface clogging;
- Vacuum sweep permeable asphalt, concrete, and concrete block systems annually to remove fine sediments that can result in the clogging of the permeable pavement system.
- Inspection for vegetation growth on pavement and removal via power washing when present; power washing should occur after vacuuming to minimize the introduction of particles into the deeper pores of the pavement.

- Replacement of missing gravel in void spaces between pavers; and
- Repair ruts or depressions that form near high traffic areas, such as entrance locations or turn around points. Maintain landscaped areas that may flow onto pavement to prevent clogging (reseed bare areas).
- Prevention of vehicle loads on gravel or grass pavements system that exceed bearing capacity.

Major Maintenance

Major maintenance activities for permeable pavement systems should include:

- Use of high powered vacuum trucks to remove excessive surface clogging of porous asphalt, porous concrete, and concrete block systems. These trucks can be used to remove the joint gravel material between interlocking concrete block systems.
- Repair ruts or depressions that form due to excessive traffic or loads.

Constructed Treatment Wetland

Application

- Regional detention and treatment for:
    - Roads, parking lots, and buildings
    - Parks, open spaces, and golf courses

Advantages

- Volume and peak flow reduction
- Suspended solids and particulate-bound pollutant removal
- Treatment of large tributary areas
- Creates wildlife habitat

Limitations

- Large footprint
- Public perception of vector concerns
- Significant capital cost

DESCRIPTION

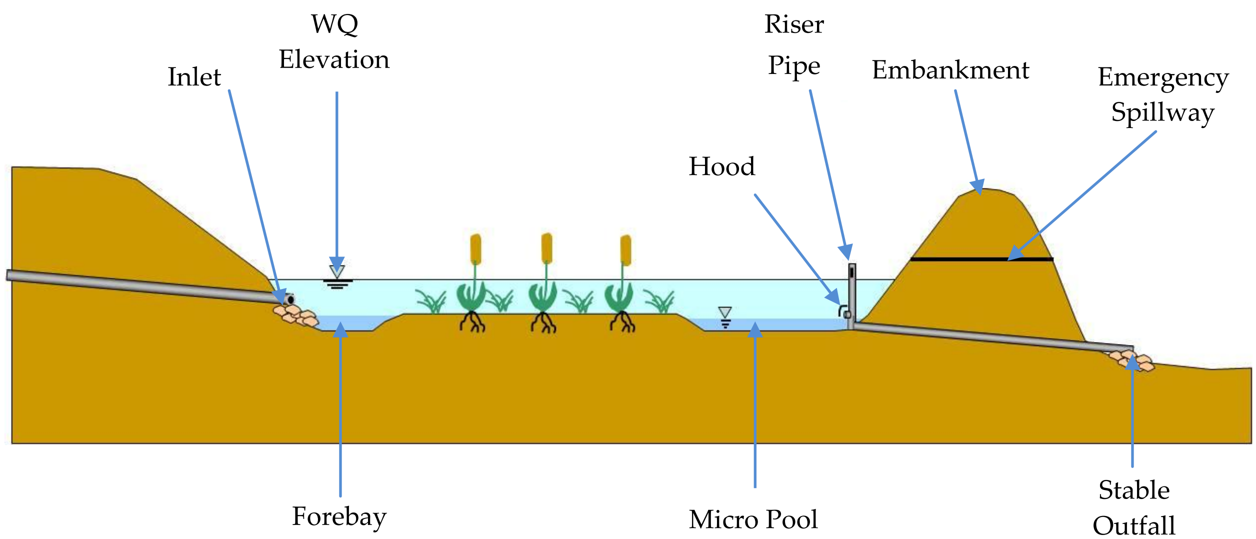
A constructed treatment wetland is a system consisting of a sediment forebay and one or more permanent micro-pools with aquatic vegetation covering a significant portion of the basin. Constructed treatment wetlands typically include components such as an inlet with energy dissipation, a sediment forebay for settling out coarse solids and to facilitate maintenance, a base with shallow sections planted with emergent vegetation, deeper areas or micro pools, and a water quality outlet structure. The interactions between the incoming storm water runoff, aquatic vegetation, wetland soils, and the associated physical, chemical, and biological unit processes are a fundamental part of constructed treatment wetlands. Therefore, it is critical that dry weather base flows or cumulative wet weather flows exceed evaporation and infiltration losses to prevent loss of aquatic vegetation and to avoid stagnation and vector problems. The size and configuration of the treatment wetland must be commensurate to the tributary area, anticipated runoff volume, historic rainfall, and treatment objectives. In addition to water quality treatment, constructed wetlands can be designed for flow control by including extended detention above the permanent pool elevation.

Constructed treatment wetlands are generally designed as plug flow systems where the water already present in the permanent pool is displaced by incoming flows with minimal mixing and no short circuiting. Plug flow describes the hypothetical condition of storm water moving through the wetland in such a way that older “slugs” of water (meaning water that’s been in the wetland for longer) are displaced by incoming slugs of water with little or no mixing in the direction of flow. Short circuiting occurs when quiescent areas or “dead zones” develop in the wetland where pockets of water remain stagnant, causing other volumes to bypass using shorter paths through the basin (e.g., incoming storm water slugs bypass these zones). Water quality benefits are also improved when the permanent wet pool volume is significantly greater than the water quality volume, resulting in longer residence times. If flow control using extended detention is desired for meeting peak discharge requirements, the wetland will first displace water present in the permanent pool with incoming flows (usually equal to or greater than the water quality treatment volume) and will then fill the wetland above the permanent pool elevation and allow the water level to drop back to the permanent pool elevation allowing higher flows to discharge from the wetland at rates required for meeting the peak runoff discharge requirements.

CONDITIONS WHERE PRACTICE APPLIES

Constructed treatment wetlands can be applied anywhere sufficient space and runoff volumes are available. The wetland must be designed and sized commensurate with the tributary area. It is important to note the difference between constructed treatment wetlands and mitigation wetlands that are constructed as part of regulatory requirements. Constructed mitigation wetlands are intended to provide fully functional habitat similar to the habitat they replace. Constructed treatment wetlands are intended for water quality treatment and, when applicable, flow control. They should be designed to capture and treat pollutants to protect receiving waters, including natural wetlands and other ecologically significant habitat.

Factors that favor the selection of stormwater treatment wetlands over other kinds of BMPs include enhanced treatment capability (including dry-weather flow treatment if a base flow is present), aesthetics, habitat, and the ability to treat large tributary areas. Factors that may limit the use of stormwater treatment wetlands include large footprint to tributary area ratios (up to 14% percent of tributary area, dependant on overall imperviousness of the tributary area), public perception with regard to the potential for vector infestation, and high initial capital cost of implementation.



Site Suitability Considerations for Constructed Treatment Wetlands

Tributary Area	< 100 acres [1]
BMP Area Typically Required as Percentage of Tributary Area (%)	6 to 14 percent
Site Slope (%)	< 15 percent
Hydrologic Soil Group	Any [2]

1) Tributary area is the area of the site draining to the BMP. Tributary areas provided here should be used as a general guideline only. Tributary areas can be larger or smaller in some instances. Smaller "pocket" wetlands can be feasible in areas where space is restricted.

2) An impermeable liner may be required if soils have high infiltrative capacity (e.g., A or B type soils, which are not significantly present on the University campus except for perhaps imported fill).

Storm Water Runoff BMP	Volume Mitigation (% of inflow)	Treatment Effectiveness for Pollutants of Concern[1]					
		Trash	Nutrients	Bacteria	Metals (particulate and dissolved fractions)	Sediment	Organics (hydro-carbons, oil, and grease)
Constructed Treatment Wetland	◒	◉	◓	○	◓	◉	◓
Volume/Treatment Effectiveness: ◉ *= Very High,* ◓ *= High,* ○ *= Moderate,* ◒ *= Low,* ● *= Very Low*							

[1] Effectiveness may change based on design variations; standard BMP designs have been assumed.

VARIATIONS AND ENHANCEMENTS

Enhancements that maximize contact time, aid in trapping and securing of pollutants or assist with volume reduction are the main categories of enhancements available for constructed treatment wetlands. Water quality benefits can be improved with a larger permanent pool, shallower depths, and denser vegetation. Wetland vegetation selected by a landscape architect with known pollutant uptake potential may also enhance wetland performance. Outlet controls may be used to seasonally change wet pool depths and flow rates through the system to increase residence time. Extended detention flow control may also be integrated into the design to improve peak flow reductions.

SIZING AND DESIGN CONSIDERATIONS

Constructed treatment wetlands typically include components such as an inlet with energy dissipation, a sediment forebay for settling out coarse solids and to facilitate maintenance, a base with shallow sections (1 to 2 feet deep) planted with emergent vegetation, deeper areas or micro pools (3 to 5 feet deep), and a water quality outlet structure. Gentle side slopes are desirable, particularly at the normal water line in wetlands used for extended detention. The shallow slopes provide an appropriate environment for vegetation to acclimate to fluctuating water levels throughout the season. Ideally, side slopes should be 10:1 (horizontal to vertical) for one foot above and one foot below the normal water level. Side slopes should not exceed 3:1, with a target of 4:1 or flatter. Gentle side slopes are particularly important in the proper functioning of extended detention wetlands. Local, native vegetation provides the best variety and resilience to be used within the various zones of the constructed wetland. Native vegetation has evolved to thrive within the local climate and conditions. The general vegetation zones include emergent, wet-mesic, and upland vegetation.

Water balance calculations should demonstrate that adequate water supply will be present to maintain a permanent pool of water during a drought year when precipitation is 50% of average for the site. Water balance calculations should include evapotranspiration, infiltration, precipitation, spillway discharge, and dry weather flow (where appropriate). Where water balance indicates that losses will exceed inputs, the wetland surface area to tributary area should be re-evaluated. A possible alternative is to use an alternate source of water to maintain a minimum water surface elevation during excessive drought periods. The water supply should be of sufficient quantity and quality to not have an adverse impact on the wetland water quality.

The following are general sizing and design considerations. Final constructed treatment wetland design should be based on site-specific considerations and limitations.

- The sediment forebay should be 4-8 feet deep and contain 10-20% of the total wetland volume.
- Emergent wetland vegetation should account for 50-70% of the permanent pool surface area.
- A range of depths intermixed throughout the wetland basin to a maximum of 5 feet is recommended with at least 50% less than 1 foot deep.
- The flow path length-to-width ratio should be a minimum of 3:1, but preferably at least 4:1 or greater. *Intent: a high flow path length-to-width ratio will maximize fine sediment removal*.
- Residence time should be a maximum of 7 days during dry weather

CONSTRUCTION CONSIDERATIONS

The following items should be considered for construction of constructed treatment wetlands.

- Base flows should be temporarily diverted around the facility during construction.
- Avoid using treated wood or galvanized metal anywhere within the vegetated swale.
- Plant plugs, if used, should be protected from geese and other waterfowl until established.
- Use an adjustable outlet weir to manage water levels to promote establishment of vegetation at various zones along the side slopes.

INSPECTION AND MAINTENANCE

Routine Maintenance

Routine maintenance activities in constructed treatment wetlands should include the tasks listed below.

- Remove trash and debris and visible floatables such as oil and grease.
- Remove minor sediment accumulations near inlet and outlet structures.
- Remove algae mats as needed to prevent coverage of more than 20% of wetland surface.
- Stabilize and repair eroded embankments.
- Mow or conduct controlled burns to suppress upland vegetation or weeds. Control invasive weeds if native vegetation is established within wetland.

Major Maintenance

Major maintenance activities in constructed treatment wetlands should include the tasks listed below.

- Remove dead, diseased, or dying trees and woody vegetation that interfere with facility maintenance.
- Correct problems associated with berm settlement.
- Repair berm/dike breaches and stabilize eroded parts of the berm.
- Repair and rebuild spillway as needed to reverse the effects of severe erosion.
- Remove sediment build up in forebay and main wetland area to restore original sediment holding capacity.
- Re-grade main wetland bottom to restore bottom slope and eliminate the incidence of standing pools.
- Aerate compacted areas to promote infiltration if volume reductions are desired.
- Repair or replace gates, fences, flow control structures, and inlet/outlet structures as needed.

Cisterns

Application

- Any type of land use, provided adequate end use of water
- Collect rooftop runoff
- Collect pavement runoff

Advantages

- Volume and peak flow reduction
- Collects stormwater for alternative on-site uses
- Reduction in use of potable water
- Flexible site application

Limitations

- Must be monitored periodically to ensure that there is adequate storage capacity
- Regulatory obstacles may limit reuse opportunities

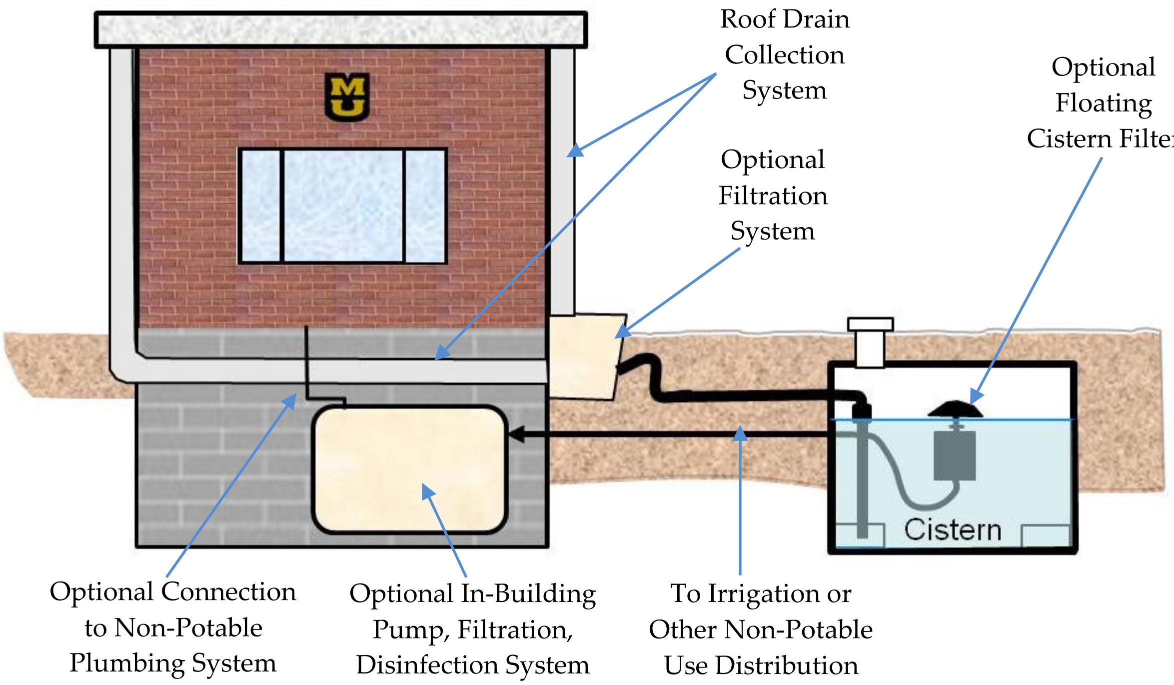
DESCRIPTION

Cisterns are essentially large rain barrels. While rain barrels are typically less than 100 gallons, cisterns approach 10,000 gallons in capacity. Cisterns collect and temporarily store runoff from rooftops (and possibly other low pollutant generating impervious areas) for later use as irrigation and/or other non-potable uses. Cistern function can be modified by the installation of active outlet controls. Active outlet controls can be programmed to allow for the release of stored stormwater in advance of predicted storm events, thus enhancing the detention function of the cistern. Cisterns come in a variety of materials, which is chosen based on its location (aboveground or underground) and sizing needs.

CONDITIONS WHERE PRACTICE APPLIES

Cisterns may be installed wherever a demand for non-potable water and space for the cisterns exist. Irrigation demand is typically low immediately after a storm event, so large storage volumes may be needed for this practice to significantly reduce runoff. Supplemental non-potable indoor water uses can improve the effectiveness of this practice. However, plumbing and health codes may require parallel piping and onsite disinfection before indoor uses are permitted. Cisterns may be placed above or below ground. Pumps are often necessary to distribute rainwater harvested from rooftops or pavement to the point of use.

Rooftop runoff is typically captured as additional pretreatment is required prior to storing pavement runoff. However, with the growing availability of high flow capacity, surface water treatment devices on the market, the capture of pavement runoff is evolving as a conventional practice.



Site Suitability Considerations for Cisterns

Tributary Area	Varies. The tank is sized to correspond to tributary area and demand. If a rooftop has multiple downspouts that discharge to different locations, then multiple cisterns may be needed to service the entire roof.
Site Slope (%)	Any. Customary to install cistern to accept gravity flow from tributary area, however pumps can be used to divert water into cistern. Cistern must be installed on a level base and secured in place
Depth to Seasonally High Groundwater Table	> 2 ft below tank bottom
Hydrologic Soil Group	Any

Cisterns are generally intended for achieving volume reduction of roof drainage. Treatment effectiveness of cisterns is not comparable to other BMPs that treat runoff from a wide range of impervious surfaces that generally have higher pollutant concentrations.

VARIATIONS AND ENHANCEMENTS

Integrated real-time irrigation controls may be employed to effectively manage water retained in cisterns for application between rain events. Active outlet controls that drain the cistern prior to a storm event may be employed to improve the capture efficiency and peak attenuation capacity of the cistern. Even if there is no demand for the captured water at the time the tank needs to be emptied, these controls are effective at reducing flood flows because captured water is released between storms when the storm drain system has ample capacity.

Cisterns can be used to capture stormwater from impervious areas such as parking lots provided appropriate pretreatment practices are installed upstream of the cisterns. These pretreatment practices, such as bioretention areas, oil/water separators, or media filters, are intended to remove trash and debris, suspended solids, and other pollutants commonly present in stormwater runoff from impervious areas.

SIZING AND DESIGN CONSIDERATIONS

The following components are required for installing and utilizing a cistern: (1) pipes that divert runoff to the cistern, (2) an overflow for when the cistern if full, (3) a pump to deliver water to point of use, and (4) a distribution system to get the water to where it is intended to be used. Additional components are needed if treatment prior to storage is required (e.g., downspout filter for roofs with overhanging trees, oil/water separator if capturing parking lot runoff). If indoor non-potable water uses such as toilet flushing are desired, then a disinfection system must also be installed.

The effectiveness of a rainwater harvesting system is a function of tributary area, storage volume, demand patterns, magnitudes, and whether active outlet controls are employed. If either of the factors are complex, simple design criteria metrics are not possible. Due to the intricacies involved in considering a variable storage capacity, actively controlled cisterns are best sized using a continuous simulation model with a long-term precipitation record and known water demand cycle.

CONSTRUCTION CONSIDERATIONS

The following items should be considered for the construction of the cisterns:

- The foundation for the cistern must be adequate to support the weight of the cistern and the water it will store.
- Above ground cisterns must be secured in place.
- The use of treated wood or galvanized metal should be avoided.
- The locations of the infrastructure must be clearly identified during the design phase for cistern installations in existing developed portions of the University campus.
- Covers and screens should be used to prevent mosquitoes from entering the tanks.

INSPECTION AND MAINTENANCE

Routine Maintenance

Routine maintenance activities of cistern system should include:

- Inspection of cisterns, associated pipes, and valve connections for leaks;
- Cleaning of gutters and downspout filters when roof runoff is captured;
- Cleaning surface media filter when pavement runoff is captured;
- Removal of accumulated sediment, as needed; and
- Minor structural repair of inlet/outlet structures.

Major Maintenance

Major maintenance activities for cisterns should include:

- Replacement of broken screens, spigots, valves, level sensors, etc.;
- Replacement of media filter when pavement runoff is captured;
- Structural repair of cistern; and
- Pump and electrical overhaul.

Bioretention

Application

- Parking lot islands, traffic circles
- Road shoulders and medians
- Building downspouts

Advantages

- Provides high pollutant removal and volume reduction
- Can be integrated into landscape areas
- Relatively low maintenance

Limitations

- Not recommended for steep slopes
- Requires adequate soils for infiltration
- Adequate depth to groundwater required for infiltration

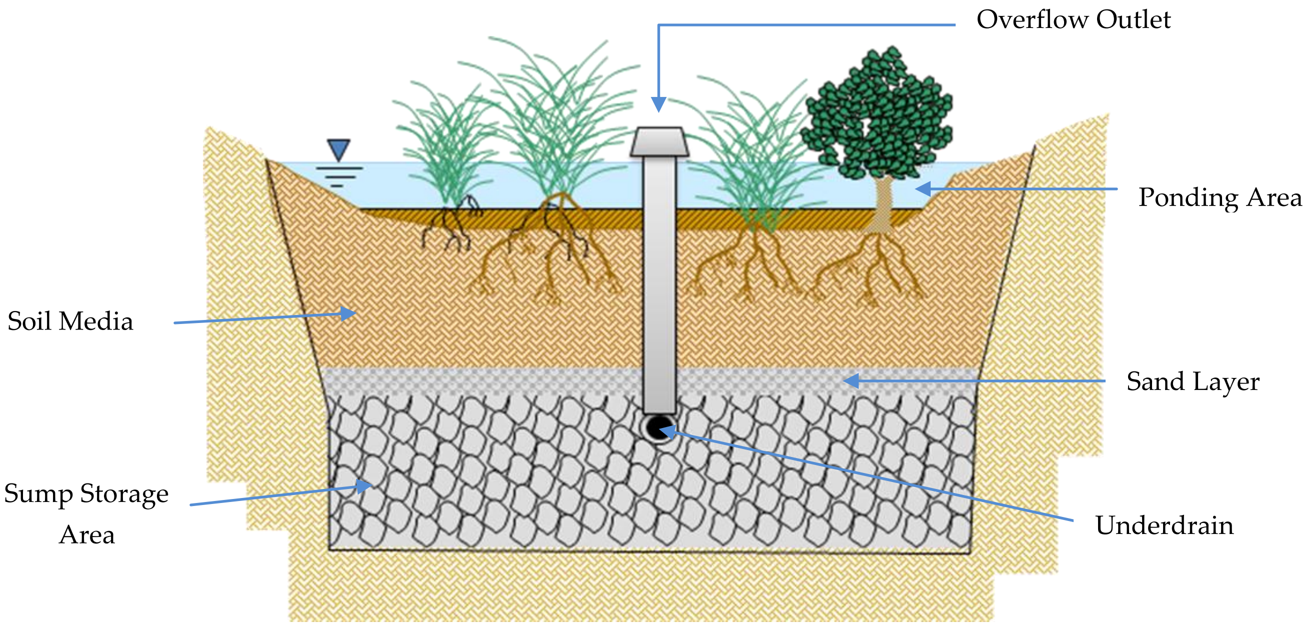
DESCRIPTION

Bioretention areas are vegetated and mulched (i.e., landscaped) shallow depressions that capture and temporarily store stormwater runoff. These facilities normally consist of a ponding area, mulch layer, planting soils, and plantings. For areas where native soils have low permeability or steep slopes, bioretention areas can be designed with amended soils and an underdrain system to route treated runoff to storm drain networks. Bioretention areas function as a soil and plant-based filtration device that removes pollutants through a variety of physical and biochemical treatment processes. As stormwater passes down through the planting soil, pollutants are filtered, adsorbed, and biodegraded by the soil and plants.

CONDITIONS WHERE PRACTICE APPLIES

Bioretention areas have a wide range of applications and can be easily incorporated into area of existing development. These facilities are very versatile and can be easily integrated into landscaped areas and within roadway right-of-ways. Runoff from the site is typically conveyed in shallow engineered open conveyances, shallow pipes, curb cuts, or other innovative drainage structures. Perforated pipe underdrains are recommended for bioretention BMPs due to the limited infiltration capacity of soils underlying the University core campus. Underdrains can improve vegetation health and prevent the bottom of bioretention areas from becoming soggy.

Underdrains are recommended to mitigate vector concerns related to the formation of stagnant pools of water in poorly drained soils. Additional volume losses can be realized if the perforated pipe is placed above the bottom of the gravel drainage layer creating a sump storage area.



Site Suitability Considerations for Bioretention Areas

Tributary Area	< 5 acres [1]
BMP Area Typically Required as Percentage of Tributary Area (%)	5 to 15 percent
Hydrologic Soil Group	Any [2]

1) Tributary area is the area of the site draining to the bioretention area. Tributary areas provided here should be used as a general guideline only. Tributary areas can be larger or smaller in some instances.

2) Underdrains may not be required in areas where the infiltration capacity of the underlying soils is not limited (hydrologic soil groups "A" or "B"). If the bioretention area is located within 10 feet from a building or has a longitudinal slope less than 1.5%, underdrains should be incorporated. If underdrains are provided, the site must have adequate relief between land surface and the stormwater conveyance system to permit vertical percolation through the gravel drainage layer (open-graded base/sub-base) and underdrain to the stormwater conveyance system.

Stormwater Runoff BMP	Volume Mitigation (% of inflow)	Treatment Effectiveness for Pollutants of Concern[1]					
		Trash	Nutrients	Bacteria	Metals (particulate and dissolved fractions)	Sediment	Organics (hydro-carbons, oil, and grease)
Bioretention	◓	◓	◉	◓	◓	◓	◉
Volume/Treatment Effectiveness: ◉ *= Very High,* ◓ *= High,* ○ *= Moderate,* ◒ *= Low,* ● *= Very Low*							

[1] Effectiveness may change based on design variations; standard BMP designs have been assumed.

VARIATIONS AND ENHANCEMENTS

Enhancements that maximize contact time, aid in trapping and securing of pollutants or assist with volume reduction are the main categories of enhancements for rain gardens. Structural and operational enhancements that can increase performance in bioretention area facilities are presented below.

- Check dams or drop structures are recommended where slopes exceed 6%. Shallower slopes enhance sediment removal by causing stormwater to pond allowing coarse sediment to settle out.
- Amended soils provide sorption sites for the removal of dissolved and suspended pollutants, can be used to increase or decrease infiltration, and provide additional support for plant growth. Soil amendments can increase evapotranspiration and infiltration losses by increasing retention storage and hydraulic conductivity.
- In areas where the infiltration capacity of the underlying soils in not limited (hydrologic soil groups "A" or "B"), underdrains may not be required. Additional volume losses can be provided through omission of the underdrain.
- Placing the underdrain at 2 feet above the bottom of the gravel sump area is recommended to provide additional storage and volume losses.

SIZING AND DESIGN CONSIDERATIONS

The following are recommended sizing and design considerations. Final bioretention designs should be based on site-specific considerations and limitations.

- The bioretention area should be sized based on the target percent capture using the sizing curves provided at the end of this fact sheet.
- Drawdown time of soil media should be less than a few hours.
- The recommended maximum ponding depth is 12 inches.
- The recommended minimum soil media depth of 2 feet with 3 feet preferred.
- The soil media composition is recommended to be 60 to 70% sand, 15 to 25% compost, and 10 to 20% clean topsoil; organic content 8 to 12%; and pH 5.5 to 7.5.
- The recommended minimum gravel sump storage area depth is 2 feet.
- Overflow devices are required.
- If underdrains are provided, they should be made of slotted, polyvinyl chloride (PVC) pipe conforming to ASTM D 3034 or equivalent or corrugated high density polyethylene (HDPE) pipe conforming to AASHTO 252M or equivalent. *Intent: As compared to round-hole perforated pipe, slotted underdrains provide greater intake capacity, clog resistant drainage, and reduced entrance velocity into the pipe, thereby reducing the chances of solids migration.*

CONSTRUCTION CONSIDERATIONS

The following items should be considered for the construction of the bioretention areas:

- Provide energy dissipation and a flow spreader at each concentrated inlet point to the bioretention area. Sheet flow inputs into the bioretention area do not require energy dissipation.
- If infiltration is considered desirable do not operate heavy machinery along the bottom of the bioretention area. If compaction occurs, till the bottom of the bioretention area, re-grade and vegetate.
- If site soils are impermeable, amend the bioretention area soils to facilitate infiltration and promote plant growth.
- The use of treated wood or galvanized metal anywhere inside a bioretention area should be avoided.

INSPECTION AND MAINTENANCE

Routine Maintenance

Routine maintenance activities in bioretention areas should include:

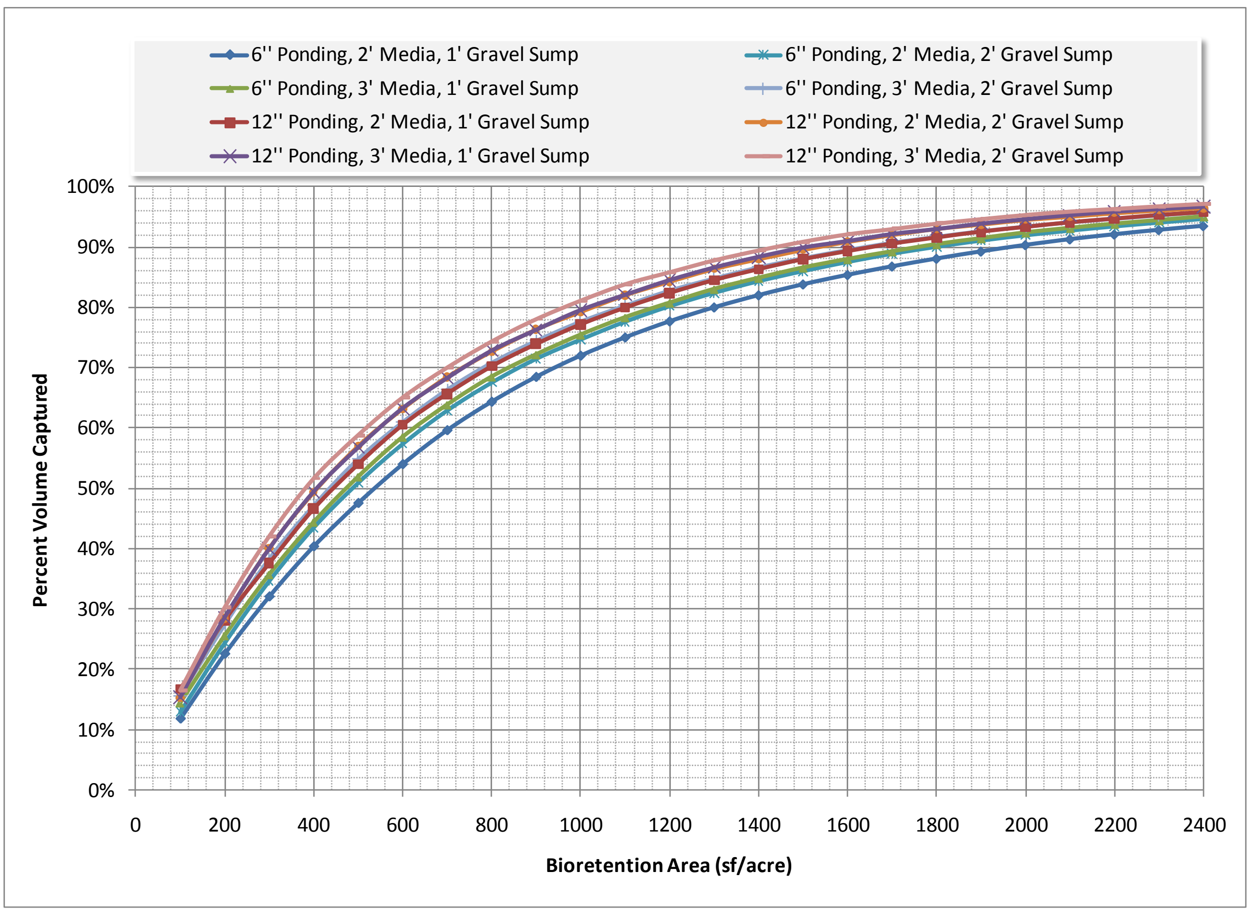
- Maintenance of vegetation as needed to preserve aesthetics in urban areas;
- Removal of trash and debris and visible floatables such as oil and grease;
- Removal of minor sediment accumulations near inlet/outlet structures;
- Stabilization and repair of eroded areas;
- Performing minor structural repairs to inlet/outlet structures; and
- Eliminate vectors and conditions that promote vectors.

Major Maintenance

Major maintenance activities in bioretention areas should include:

- Re-grading of bioretention area to restore design longitudinal bottom slope and
- Aeration of compacted areas to restore infiltration capacity.

DESIGN NOMOGRAPHS



Volumetric Percent Capture

The total volumetric percent capture is the long-term runoff volume captured by a BMP as a percent of the runoff volume that would have occurred without the BMP. The volume captured includes both the volume lost due to infiltration and evapotranspiration as well as the volume treated and discharged to the storm drain system. Typically, a goal of 80-90% capture is used for sizing stormwater BMPs for water quality due to the economics of diminishing returns.

Estimating Effective Tributary Area

Volumetric percent capture plots have been developed to assist with BMP sizing and evaluating expected performance. Nomographs are based on continuous hydrologic simulations of various BMP sizes and a unit tributary area with 100% impervious cover, or the effective tributary area. The effective tributary area is the portion of the drainage area that contributes to runoff over an average annual time period and can be approximated using a simple volumetric runoff coefficient equation based on Schueler (1987):

$$C = 0.05 + (0.9*Imp)$$

Where, C is the volumetric runoff coefficient and Imp is the impervious fraction of the watershed. The effective tributary area is the volumetric runoff coefficient times the total tributary area. By dividing the total tributary area into the pervious and impervious areas and combining terms, the effective tributary area can be estimated as:

$$A\_eff = 0.05A\_perv + (0.95*A\_imp)$$

Where, A_eff is the effective tributary area, A_perv is the pervious area, and A_imp is the impervious area. Site-specific runoff coefficients for pervious areas may be developed based on monitoring results or best professional judgement.

Schueler, T. (1987). Controlling Urban Runoff - A Practical Manual for Planning and Designing Urban BMPs. Metropolitan Washington Council of Governments.

Appendix C

Subwatershed Fact Sheets and Opportunity Areas

Stormwater Master Plan 2013

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Structural BMP Opportunities in Subwatershed 1

University of Missouri Stormwater Master Plan

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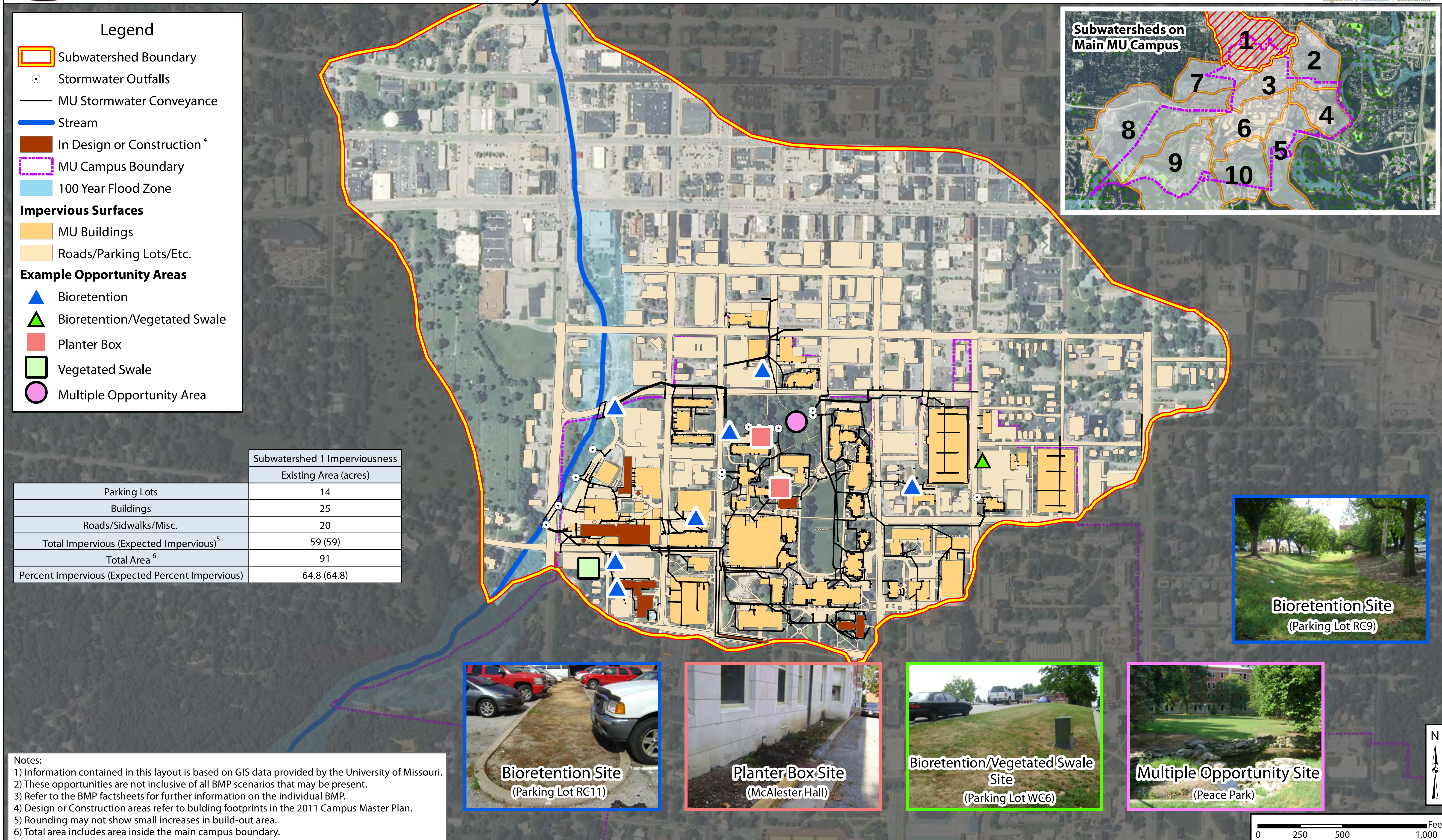

Legend

- Subwatershed Boundary
- Stormwater Outfalls
- MU Stormwater Conveyance
- Stream
- In Design or Construction [4]
- MU Campus Boundary
- 100 Year Flood Zone

Impervious Surfaces

- MU Buildings
- Roads/Parking Lots/Etc.

Example Opportunity Areas

- Bioretention
- Bioretention/Vegetated Swale
- Planter Box
- Vegetated Swale
- Multiple Opportunity Area

	Subwatershed 1 Imperviousness
	Existing Area (acres)
Parking Lots	14
Buildings	25
Roads/Sidwalks/Misc.	20
Total Impervious (Expected Impervious) [5]	59 (59)
Total Area [6]	91
Percent Impervious (Expected Percent Impervious)	64.8 (64.8)

Bioretention Site
(Parking Lot RC9)

Bioretention Site
(Parking Lot RC11)

Planter Box Site
(McAlester Hall)

Bioretention/Vegetated Swale Site
(Parking Lot WC6)

Multiple Opportunity Site
(Peace Park)

Notes:
1) Information contained in this layout is based on GIS data provided by the University of Missouri.
2) These opportunities are not inclusive of all BMP scenarios that may be present.
3) Refer to the BMP factsheets for further information on the individual BMP.
4) Design or Construction areas refer to bulding footprints in the 2011 Campus Master Plan.
5) Rounding may not show small increases in build-out area.
6) Total area includes area inside the main campus boundary.

Structural BMP Opportunities in Subwatershed 2

University of Missouri Stormwater Master Plan

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	Subwatershed 2 Imperviousness
	Existing Area (acres)
Parking Lots	3
Buildings	2
Roads/Sidewalks/Misc.	2
Total Impervious (Expected Impervious) 5	7 (7)
Total Area 6	22
Percent Impervious (Expected Percent Impervious)	31.3% (31.3%)

Notes:
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Structural BMP Opportunities in Subwatershed 3

University of Missouri Stormwater Master Plan

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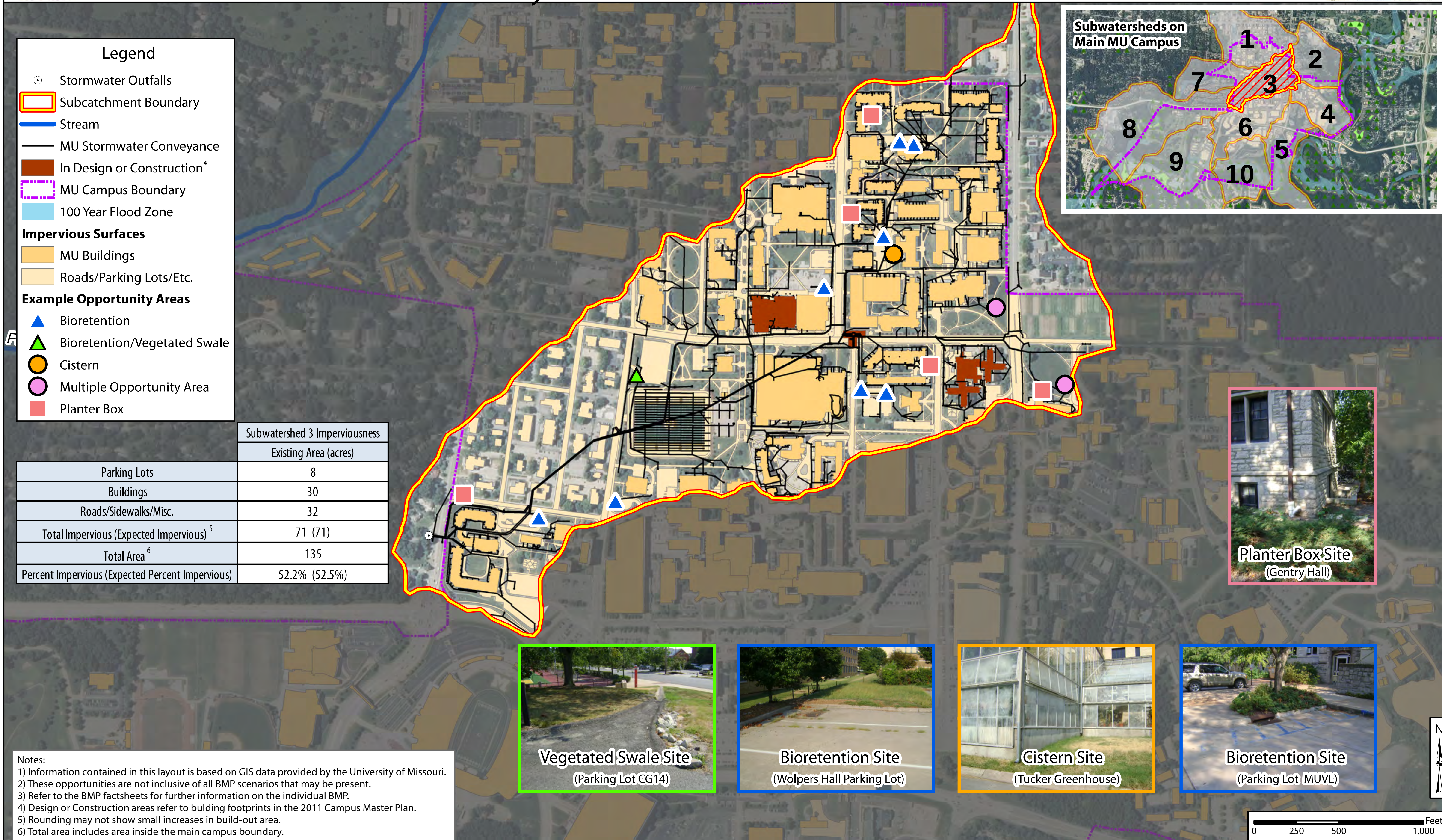

Legend

- Stormwater Outfalls
- Subcatchment Boundary
- Stream
- MU Stormwater Conveyance
- In Design or Construction[4]
- MU Campus Boundary
- 100 Year Flood Zone

Impervious Surfaces

- MU Buildings
- Roads/Parking Lots/Etc.

Example Opportunity Areas

- Bioretention
- Bioretention/Vegetated Swale
- Cistern
- Multiple Opportunity Area
- Planter Box

	Subwatershed 3 Imperviousness
	Existing Area (acres)
Parking Lots	8
Buildings	30
Roads/Sidewalks/Misc.	32
Total Impervious (Expected Impervious)[5]	71 (71)
Total Area[6]	135
Percent Impervious (Expected Percent Impervious)	52.2% (52.5%)

Planter Box Site
(Gentry Hall)

Vegetated Swale Site
(Parking Lot CG14)

Bioretention Site
(Wolpers Hall Parking Lot)

Cistern Site
(Tucker Greenhouse)

Bioretention Site
(Parking Lot MUVL)

N

Feet
0 250 500 1,000

Notes:
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3) Refer to the BMP factsheets for further information on the individual BMP.
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5) Rounding may not show small increases in build-out area.
6) Total area includes area inside the main campus boundary.

Structural BMP Opportunities in Subwatershed 4

University of Missouri Stormwater Master Plan

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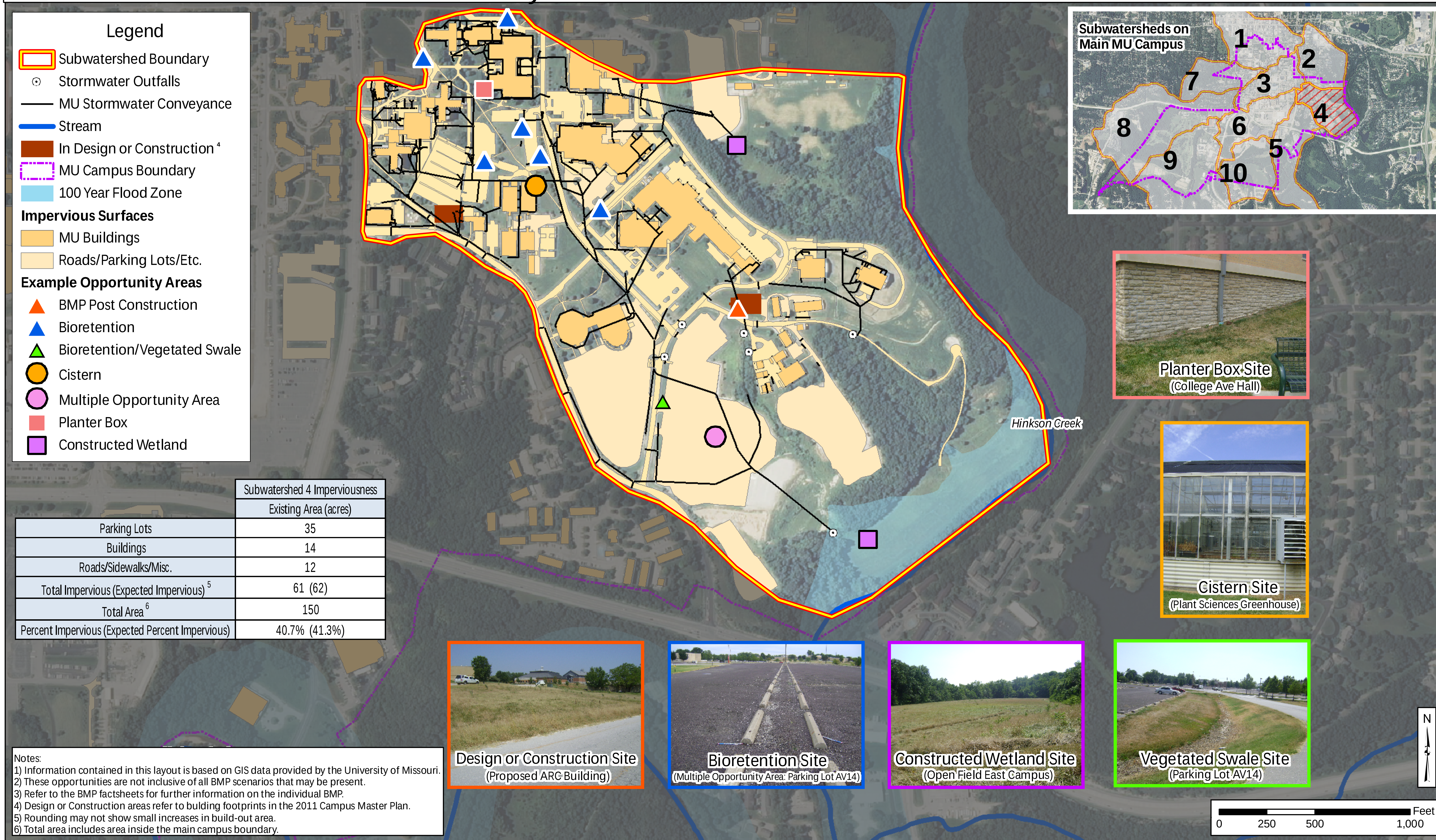

Legend

- Subwatershed Boundary
- Stormwater Outfalls
- MU Stormwater Conveyance
- Stream
- In Design or Construction [4]
- MU Campus Boundary
- 100 Year Flood Zone

Impervious Surfaces

- MU Buildings
- Roads/Parking Lots/Etc.

Example Opportunity Areas

- BMP Post Construction
- Bioretention
- Bioretention/Vegetated Swale
- Cistern
- Multiple Opportunity Area
- Planter Box
- Constructed Wetland

	Subwatershed 4 Imperviousness
	Existing Area (acres)
Parking Lots	35
Buildings	14
Roads/Sidewalks/Misc.	12
Total Impervious (Expected Impervious) [5]	61 (62)
Total Area [6]	150
Percent Impervious (Expected Percent Impervious)	40.7% (41.3%)

Planter Box Site
(College Ave Hall)

Cistern Site
(Plant Sciences Greenhouse)

Design or Construction Site
(Proposed ARC Building)

Bioretention Site
(Multiple Opportunity Area: Parking Lot AV14)

Constructed Wetland Site
(Open Field East Campus)

Vegetated Swale Site
(Parking Lot AV14)

N

0 250 500 1,000 Feet

Notes:
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3) Refer to the BMP factsheets for further information on the individual BMP.
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5) Rounding may not show small increases in build-out area.
6) Total area includes area inside the main campus boundary.

Structural BMP Opportunities in Subwatershed 5

University of Missouri Stormwater Master Plan

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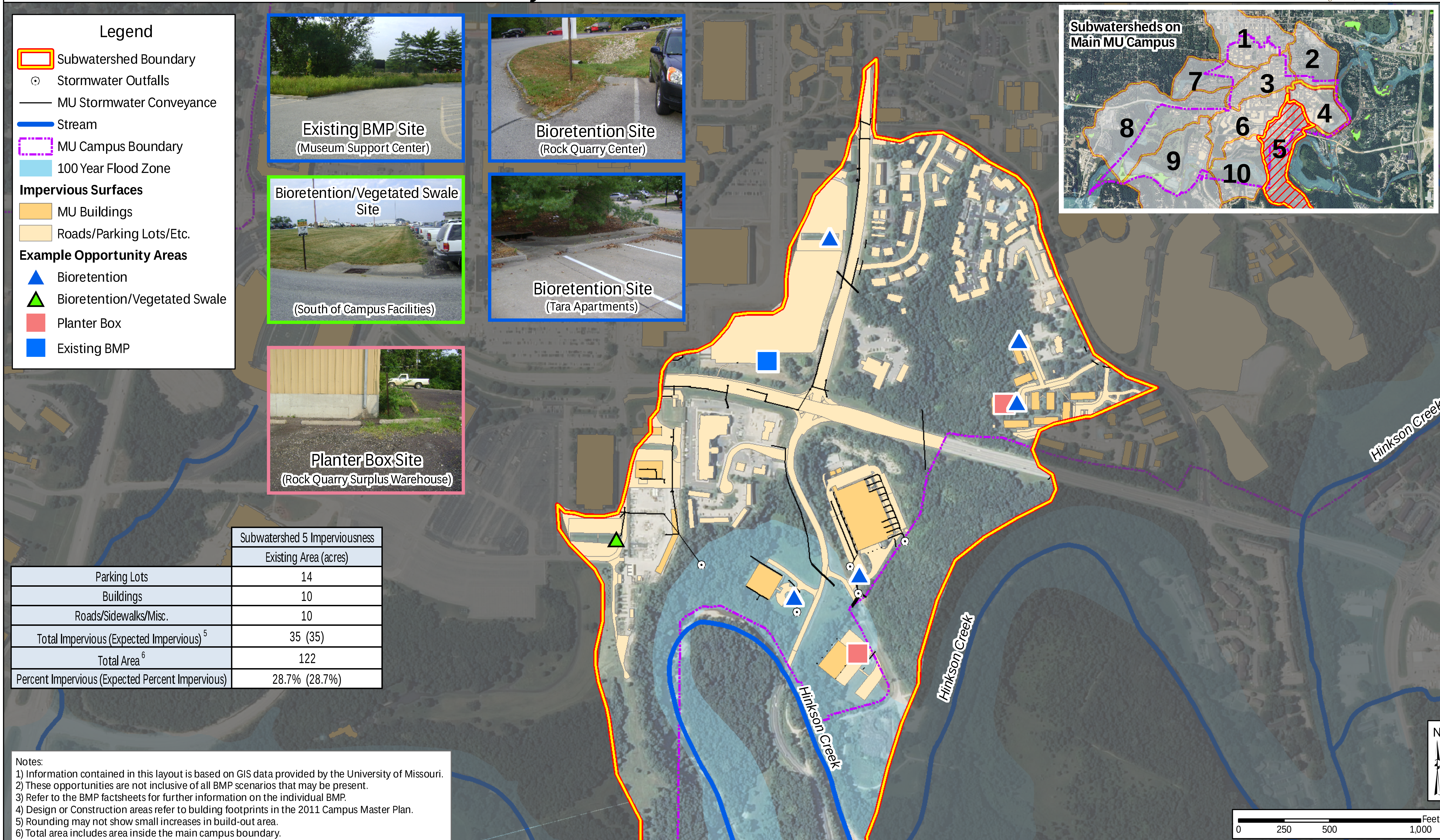

Existing BMP Site
(Museum Support Center)

Bioretention Site
(Rock Quarry Center)

Bioretention/Vegetated Swale Site
(South of Campus Facilities)

Bioretention Site
(Tara Apartments)

Planter Box Site
(Rock Quarry Surplus Warehouse)

Legend

- Subwatershed Boundary
- Stormwater Outfalls
- MU Stormwater Conveyance
- Stream
- MU Campus Boundary
- 100 Year Flood Zone

Impervious Surfaces

- MU Buildings
- Roads/Parking Lots/Etc.

Example Opportunity Areas

- Bioretention
- Bioretention/Vegetated Swale
- Planter Box
- Existing BMP

	Subwatershed 5 Imperviousness
	Existing Area (acres)
Parking Lots	14
Buildings	10
Roads/Sidewalks/Misc.	10
Total Impervious (Expected Impervious) 5	35 (35)
Total Area 6	122
Percent Impervious (Expected Percent Impervious)	28.7% (28.7%)

Notes:
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4) Design or Construction areas refer to building footprints in the 2011 Campus Master Plan.
5) Rounding may not show small increases in build-out area.
6) Total area includes area inside the main campus boundary.

Structural BMP Opportunities in Subwatershed 6

University of Missouri Stormwater Master Plan

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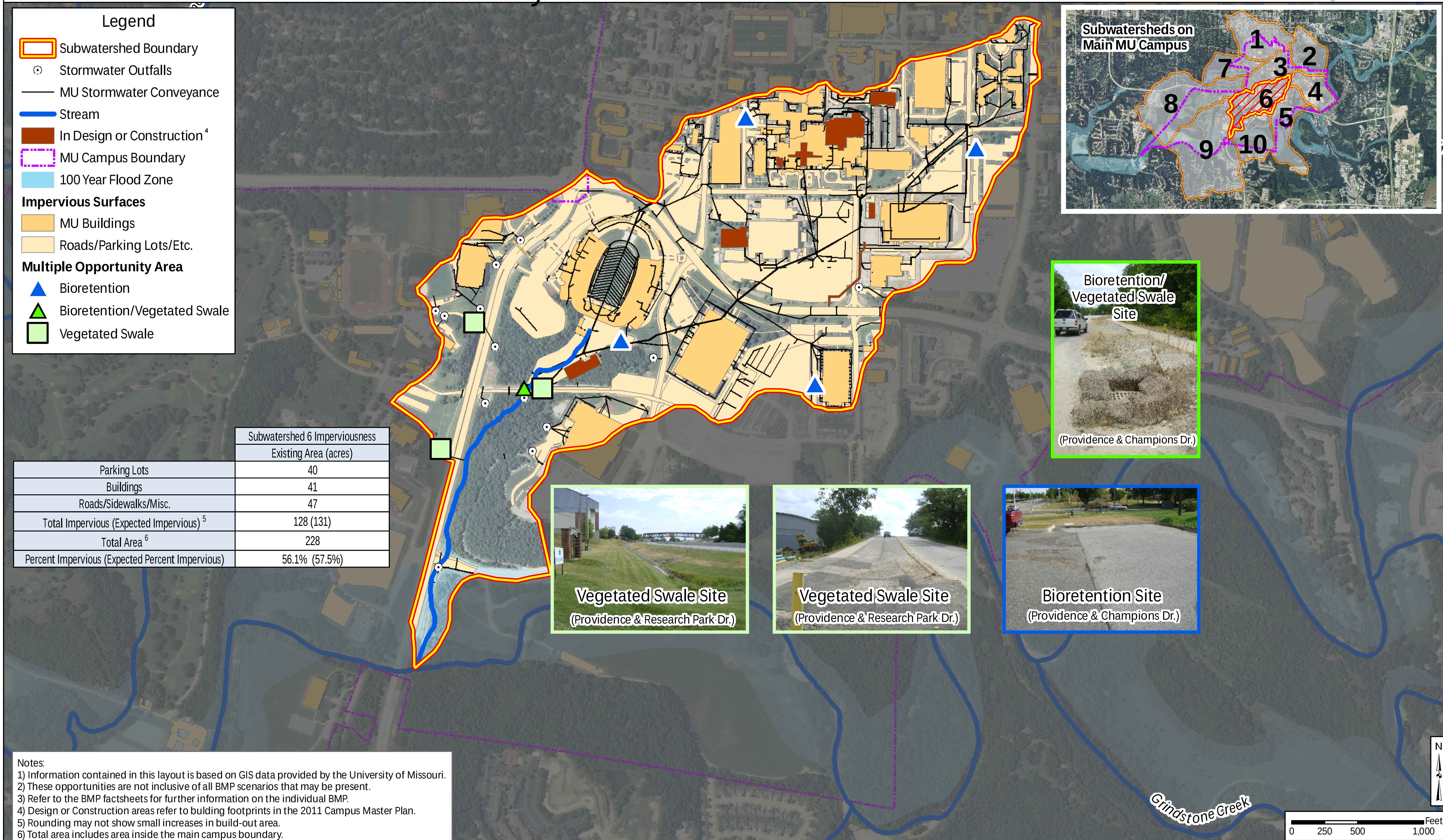

	Subwatershed 6 Imperviousness
	Existing Area (acres)
Parking Lots	40
Buildings	41
Roads/Sidewalks/Misc.	47
Total Impervious (Expected Impervious) [5]	128 (131)
Total Area [6]	228
Percent Impervious (Expected Percent Impervious)	56.1% (57.5%)

Notes:
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2) These opportunities are not inclusive of all BMP scenarios that may be present.
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5) Rounding may not show small increases in build-out area.
6) Total area includes area inside the main campus boundary.

Structural BMP Opportunities in Subwatershed 7

University of Missouri Stormwater Master Plan

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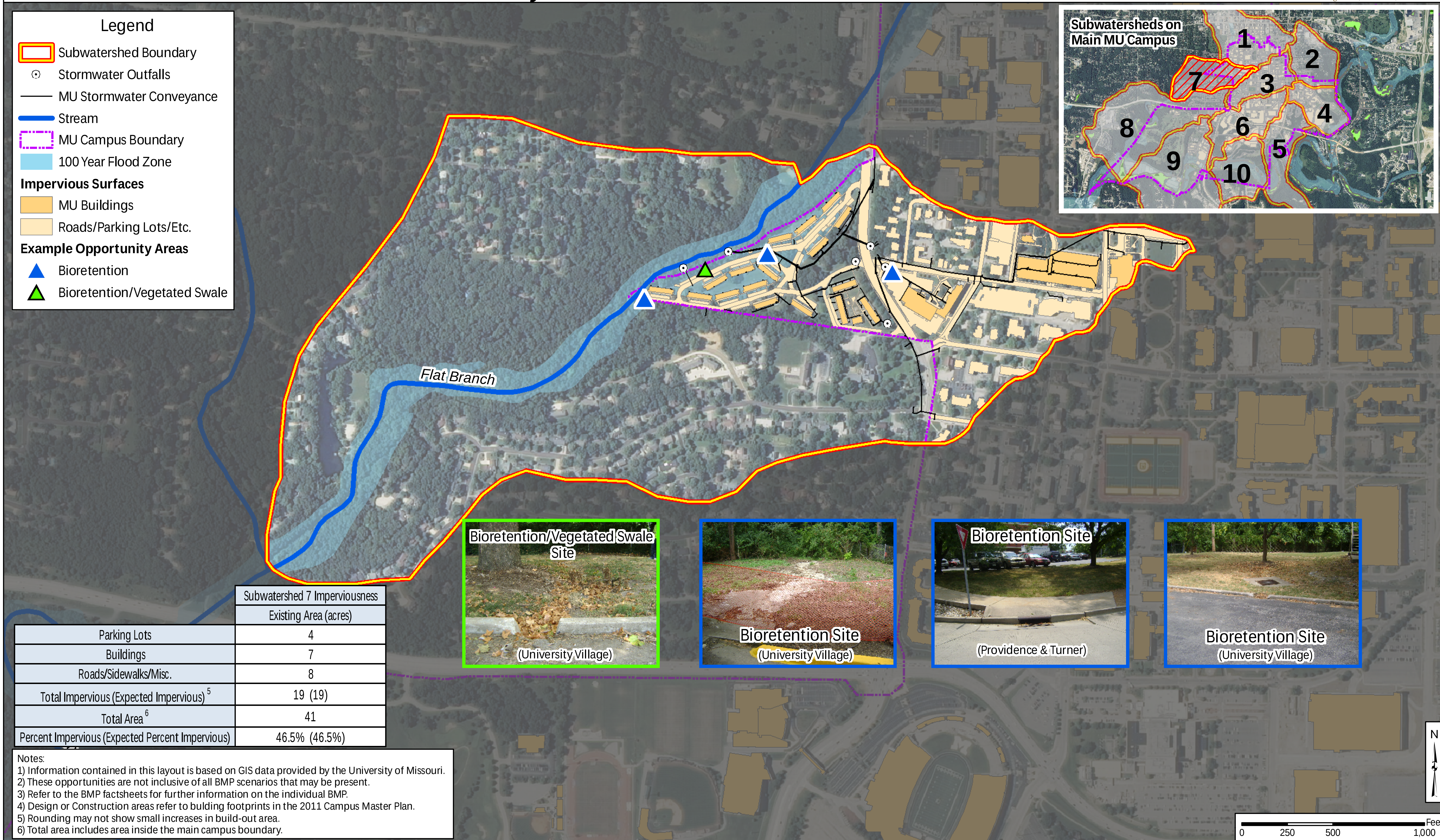

	Subwatershed 7 Imperviousness
	Existing Area (acres)
Parking Lots	4
Buildings	7
Roads/Sidewalks/Misc.	8
Total Impervious (Expected Impervious) [5]	19 (19)
Total Area [6]	41
Percent Impervious (Expected Percent Impervious)	46.5% (46.5%)

Notes:
1) Information contained in this layout is based on GIS data provided by the University of Missouri.
2) These opportunities are not inclusive of all BMP scenarios that may be present.
3) Refer to the BMP factsheets for further information on the individual BMP.
4) Design or Construction areas refer to building footprints in the 2011 Campus Master Plan.
5) Rounding may not show small increases in build-out area.
6) Total area includes area inside the main campus boundary.

Structural BMP Opportunities in Subwatershed 8

University of Missouri Stormwater Master Plan

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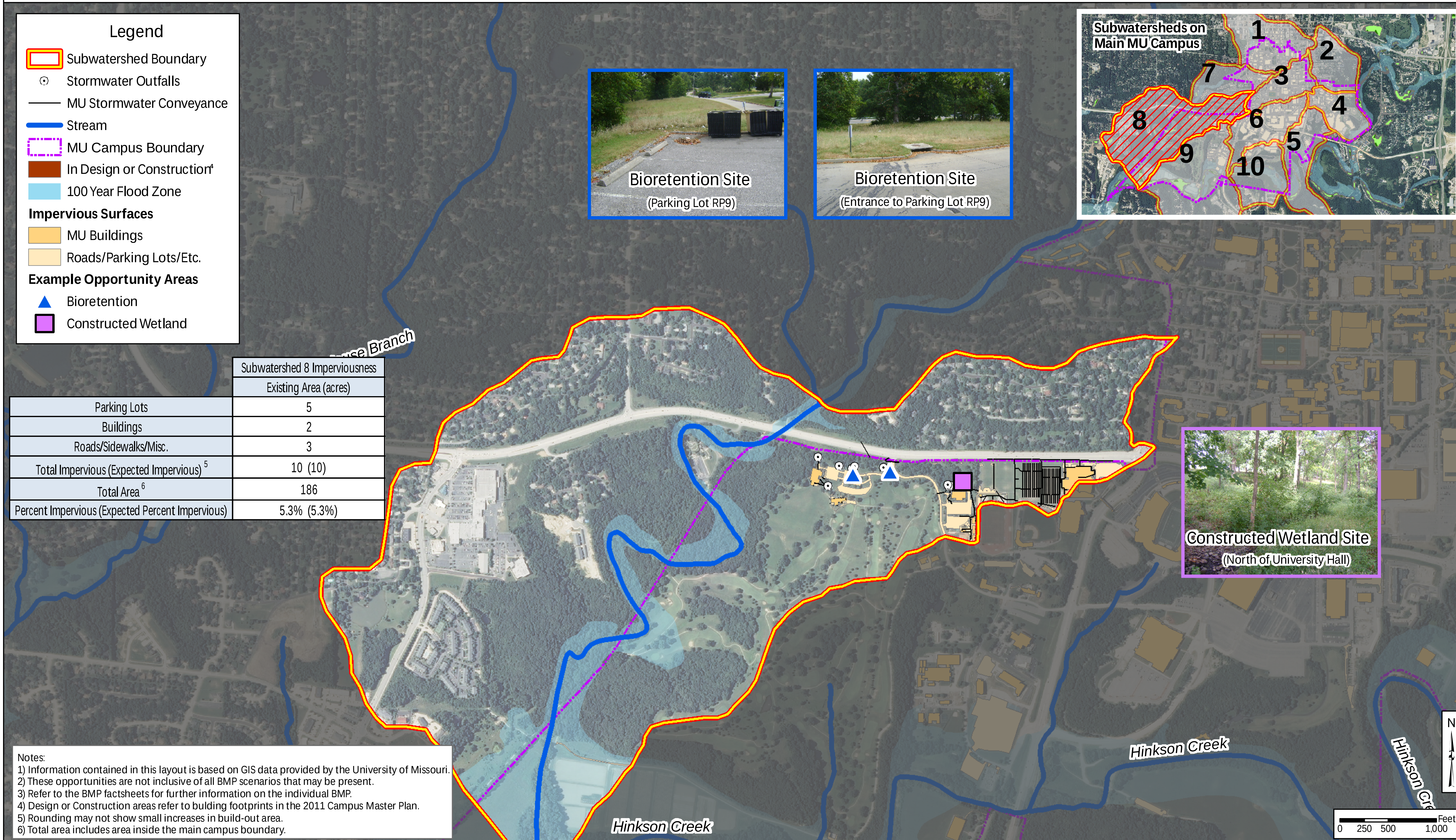

Legend

- Subwatershed Boundary
- Stormwater Outfalls
- MU Stormwater Conveyance
- Stream
- MU Campus Boundary
- In Design or Construction[4]
- 100 Year Flood Zone

Impervious Surfaces

- MU Buildings
- Roads/Parking Lots/Etc.

Example Opportunity Areas

- Bioretention
- Constructed Wetland

	Subwatershed 8 Imperviousness
	Existing Area (acres)
Parking Lots	5
Buildings	2
Roads/Sidewalks/Misc.	3
Total Impervious (Expected Impervious) [5]	10 (10)
Total Area [6]	186
Percent Impervious (Expected Percent Impervious)	5.3% (5.3%)

Notes:
1) Information contained in this layout is based on GIS data provided by the University of Missouri.
2) These opportunities are not inclusive of all BMP scenarios that may be present.
3) Refer to the BMP factsheets for further information on the individual BMP.
4) Design or Construction areas refer to building footprints in the 2011 Campus Master Plan.
5) Rounding may not show small increases in build-out area.
6) Total area includes area inside the main campus boundary.

Structural BMP Opportunities in Subwatershed 9

University of Missouri Stormwater Master Plan

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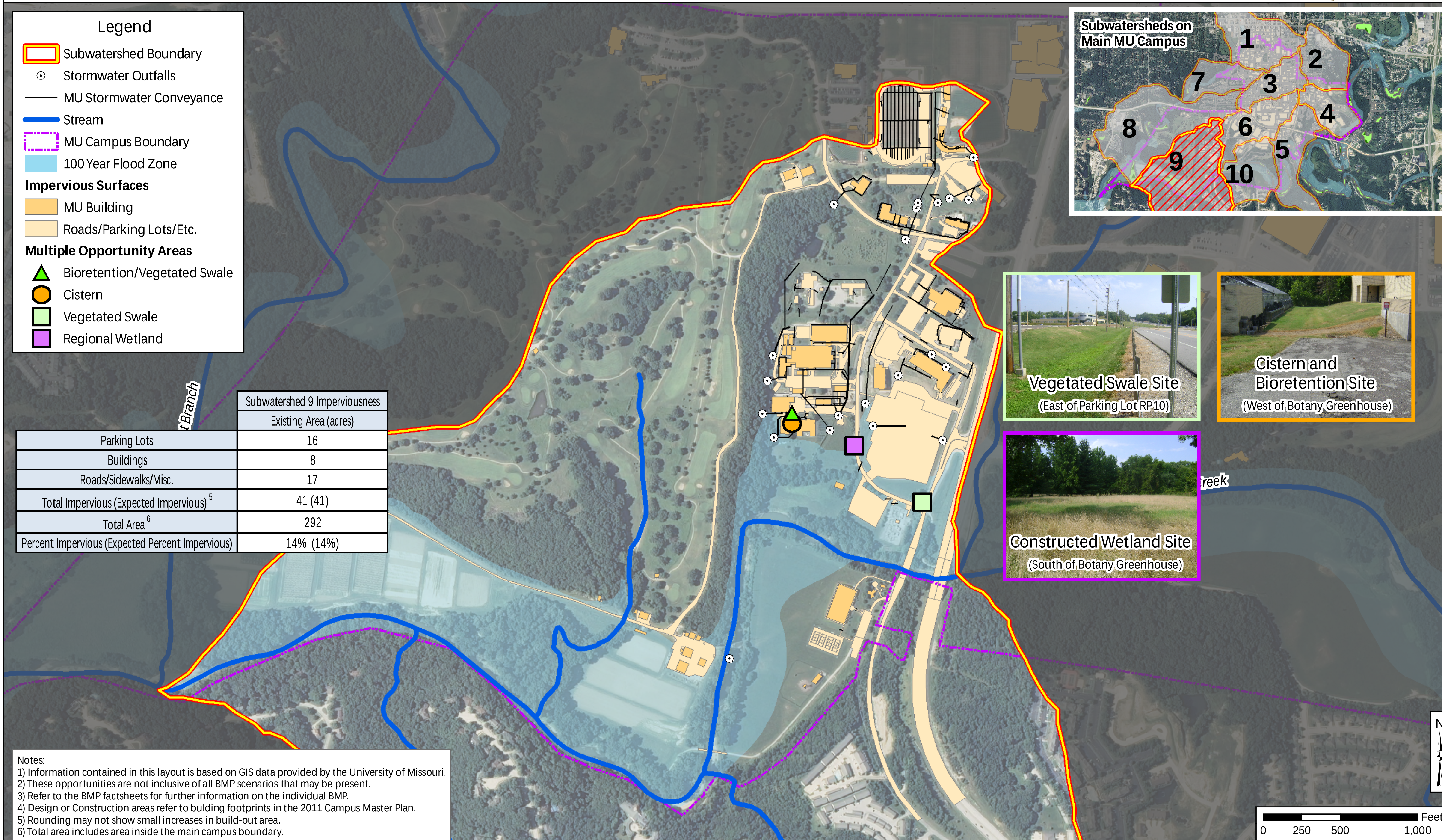

Legend

- Subwatershed Boundary
- Stormwater Outfalls
- MU Stormwater Conveyance
- Stream
- MU Campus Boundary
- 100 Year Flood Zone

Impervious Surfaces

- MU Building
- Roads/Parking Lots/Etc.

Multiple Opportunity Areas

- Bioretention/Vegetated Swale
- Cistern
- Vegetated Swale
- Regional Wetland

	Subwatershed 9 Imperviousness
	Existing Area (acres)
Parking Lots	16
Buildings	8
Roads/Sidewalks/Misc.	17
Total Impervious (Expected Impervious) [5]	41 (41)
Total Area [6]	292
Percent Impervious (Expected Percent Impervious)	14% (14%)

Notes:
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6) Total area includes area inside the main campus boundary.

Structural BMP Opportunities in Subwatershed 10

University of Missouri Stormwater Master Plan

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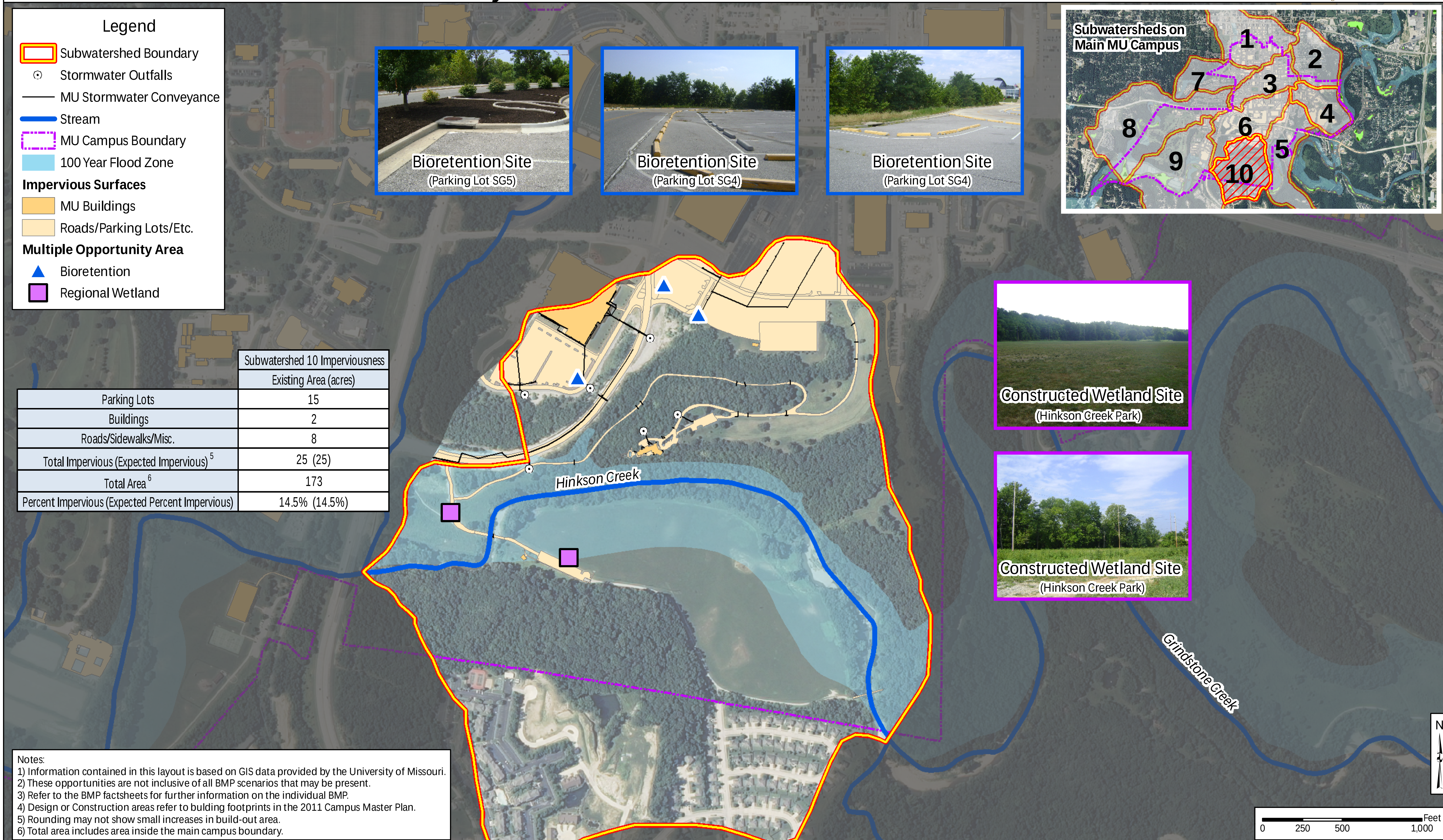

	Subwatershed 10 Imperviousness
	Existing Area (acres)
Parking Lots	15
Buildings	2
Roads/Sidewalks/Misc.	8
Total Impervious (Expected Impervious) 5	25 (25)
Total Area 6	173
Percent Impervious (Expected Percent Impervious)	14.5% (14.5%)

Notes:
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4) Design or Construction areas refer to building footprints in the 2011 Campus Master Plan.
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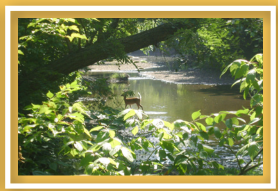

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