Final Report
Green Stormwater Infrastructure
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Abstract

The primary objective of this project was to quantify and to communicate the benefits of implementing green storm water infrastructure in the Western Lake Erie Basin. Project activities included characterizing stormwater inputs at UT, analyzing green stormwater infrastructure alternatives, developing a green stormwater infrastructure projects list for implementation at UT, and communicating findings to and collaborating with local and regional stakeholders. Analyses indicated that stormwater best management practices (BMPs) at UT should have the capability of removing solids, indicator bacteria (coliform), and low levels of nutrients. For alternatives analysis, we considered siting constraints, local sentiments, the cost and life-cycle of the infrastructure, the potential for contaminant and flow reduction, and the environmental impact each solution would have on the Lake Erie Basin with a specific focus on nutrients. Research for this project confirmed that stormwater BMPs produce widely varying efficiencies of nutrient removal depending on the design specifications. The project activities have resulted in the preparation, submission, and funding of three additional proposals in 2013. These projects are expected to contribute to the local and regional knowledge of green stormwater infrastructure, resulting in an increase in local implementation.

This project was funded in part through the Lake Erie Protection Fund (LEPF), administered by the Ohio Lake Erie Commission. The LEPF is supported by the voluntary contributions of Ohioans through donation or purchase of a Lake Erie license plate displaying the Marblehead Lighthouse or the Lake Erie life ring.

Project Report Overview

This project report summarizes the findings for the Small Lake Erie Protection Fund project entitled "Green Storm Water Infrastructure." The primary objective of this proposal was to quantify and to communicate the benefits of implementing green storm water infrastructure in the Western Lake Erie Basin. We focused our work on the potential environmental benefits of reduction in nutrient (N and P) release to waterways since eutrophication is a significant issue in our region. During the project period, I participated in monthly Storm Water Action Group (SWAG) meetings at TMACOG with local and regional stormwater stakeholders. The networking that occurred from this regular interaction has resulted in significant and meaningful collaboration between the University of Toledo and other stakeholders including Lynette Hablitzel and Cherie Blair of Ohio EPA, Patekka Bannister and Andy Stepnick from the City of Toledo, Toledo Metroparks, Don Nelson from the City of Oregon, Jay Dorsey from the Ohio Department of Natural Resources, Mike Melnyk Lucas and Brian Miller from Lucas County, Cheryl Rice from USDA and others. Since this Small LEPF project was funded, we have subsequently received local and regional funding for three additional stormwater grants. Two grants will provide funding for stormwater BMP demonstration sites on campus. The third grant will enable performance monitoring of stormwater BMPs in Lucas County and sharing of data amongst demonstration sites. This would not have been possible without the networking and communication that was established as a result of this initial funding from the Small Lake Erie Protection Fund.

Specific deliverables from this project proposal included:

1. A proposed capital projects list for storm water retrofit opportunities to be implemented at the University of Toledo Main Campus. Through the duration of the project, we considered several potential project sites. Our current list includes four project sites on UT Main Campus that have significant potential for BMP implementation. In fact, we have acquired funding for two of these sites through the Ohio EPA from Lucas County Stormwater Improvement Funds (SWIF). These projects are in the design phase and will be constructed in the spring of 2014.

2. A model approach for institutions to analyze their current storm water management practices toward the implementation of green storm water infrastructure. We developed a comprehensive approach for BMP selection that included cost and environmental benefits of the

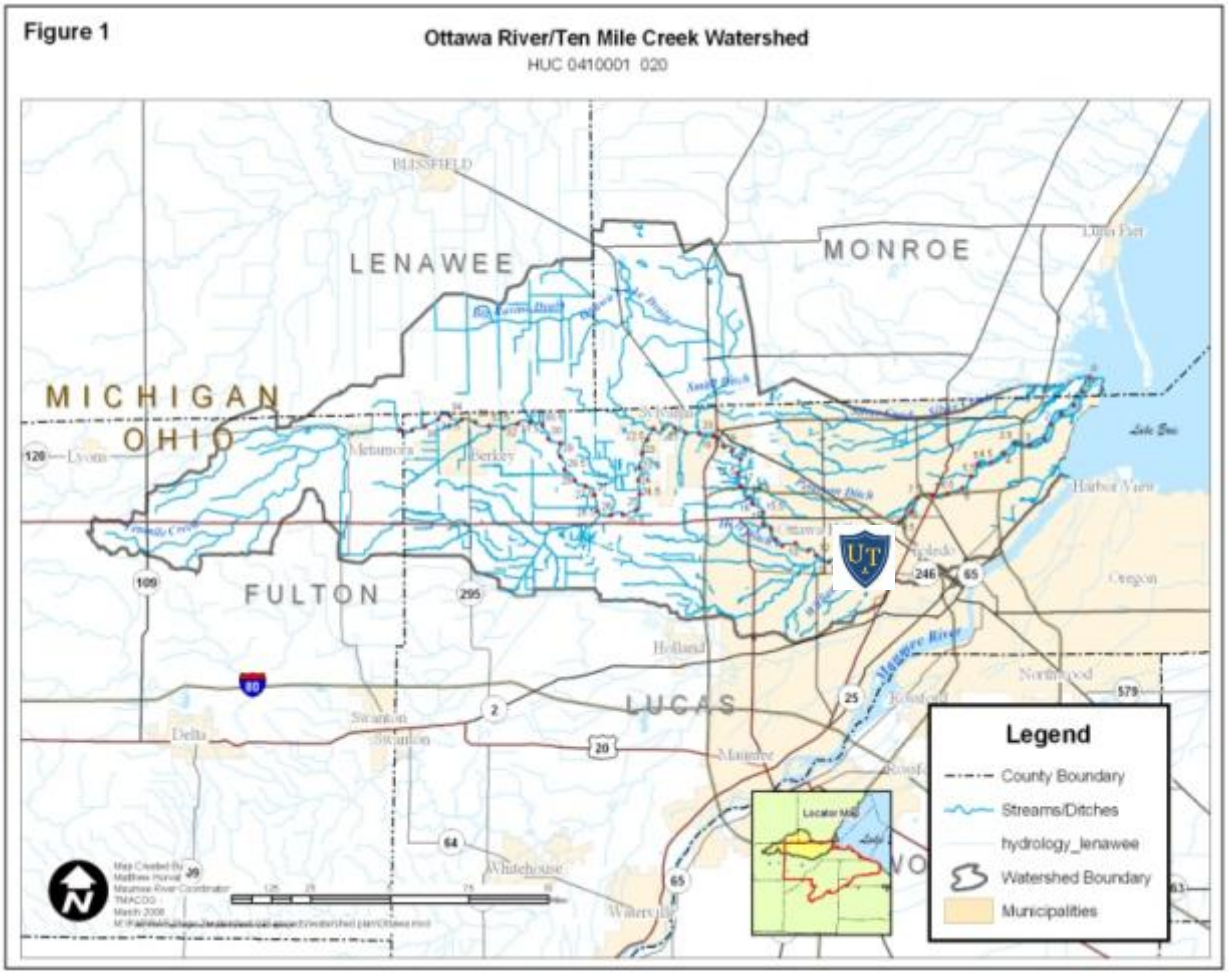
implementation of green infrastructure. This is an Excel-based (spreadsheet) tool. We used this approach to evaluate BMP alternatives at UT. These findings were presented at the Ohio Stormwater Association Conference in Cincinnati in May of 2013. They are also available in a thesis entitled "Development of a Method to Compare Storm Water Best Management Practices at The University of Toledo" by Christopher Michael Wancata. We also used the Center for Neighborhood Technology's National Stormwater Calculator to consider green infrastructure as compared to no action. The OHSWA presentation is attached to the report to summarize this work. Limitations to the model include a lack of local monitoring and cost data.

3. Data, including local cost data, to encourage the adoption of green water infrastructure in our region. We collected stormwater samples at UT from summer of 2012 through summer of 2013 to characterize the contaminants present. We used local cost data in our Excel-based model to assist with BMP selection. We, in collaboration with TMACOG (Kari Gerwin), were recently funded by the UM Water Center to monitor the performance of stormwater BMPs in Lucas County which received SWIF funding. There has been enthusiastic response from other SWIF project coordinators and entities.

4. A final report that includes literature review, methods and materials, results, discussion and conclusions including implications of the findings on the implementation of green storm water infrastructure in the Western Lake Erie Basin. The following document is the final report for the project which will summarize the project deliverables. Section 1 is the literature review that includes discussion of the approach to alternatives analysis and the research on nutrient removal through stormwater BMP implementation. Section 2 is a summary of the stormwater data collected at UT. Section 3 includes the four sites identified for stormwater BMP implementation on UT main campus. The Appendix includes the Ohio Stormwater Association presentation highlighting the Excel tool for alternatives analysis.

Section 1: Literature Review

The Ottawa River/Ten Mile Creek Watershed is Hydrologic Unit 04100001 020180. The Ottawa River is contained in the Maumee Area of Concern, which identified 10 of 14 beneficial use impairments in 1990. The downstream section of Ottawa River in the City of Toledo has been the focus of many efforts and research studies to address these impairments including eradicating industrial discharges and dredging contaminated sediments. Over the past two decades, stakeholders have invested tens of millions of dollars in an effort to restore the river. These efforts are ongoing. One main concern in this region is the formation of harmful algal blooms (HABs) in the Western Lake Erie Basin. The HABs have been caused by eutrophication due to excess nutrients often attributed to agricultural activities as well as urban inputs including wastewater overflows and stormwater run-off.



The middle reach of the Ottawa River passes through the University of Toledo's Main Campus. River and storm water discharge sampling over the past several years have indicated that the levels of dissolved solids, suspended solids and nutrients can be high and have significant temporal variation. Also, fecal coliform levels are generally higher than the standard for recreational use. In 2005, the University of Toledo (UT) President's Commission on the River was established to emphasize restoration of the river which is a central element to our campus. This has resulted in significant fundraising (over $400,000). These funds are being applied toward several projects including restoration of the approximately 4000 square feet of river located on the UT main campus.

In recent years, strong storms have traveled through the area, dumping rainfall amounts as high as 7.25 inches during one rain event. Due to improper flood controls, damages caused were estimated as high as $1,000,000. These storms have drastically overwhelmed drainage ditches, as well as the storm sewer system in Toledo. These overflows are creating a situation in which wastewater treatment plants, which are part of the combined sewer network, must bypass overflowing raw sewage into the Maumee River, as well as local streams in the surrounding area. The raw sewage is leading to *E. coli* concerns for the surrounding waters. Aquatic life is becoming hindered and algae blooms are starting to also become of concern. (US Army Corps of Engineers, Buffalo Division, 2011) Studies performed by the US Army Corps of Engineers are now being done to assess the current state of the watershed in Northwest Ohio. The assessment will develop a means for assessing the situation, as well as cost breakdown and project management. (US Army Corps of Engineers, Buffalo Division, 2011)

Stormwater Non-Point Source Pollutants

Historically, water quality management had been directed towards point source pollution (i.e. an individual source of pollution, such as a factory). In this case, pollution sources are relatively easy to address once identified. However, recent studies have shown that even though

point source pollution is being regulated, storm water quality is of primary concern. A study performed by the Council of Environmental Quality showed that 75% of urban areas were impacted by nonpoint source pollution. Some factors that play into nonpoint source pollution can be seen in the table below:

Origins of Nonpoint Source Pollutants

Nonpoint Source Pollutant Origins			
Automotive Traffic	**Construction**	**Air Quality**	**Refuse**
Heavy Metals	Dirt	Smokestack Debris	Animal
Acid-Producing Substances	Asphalt	Coal	Plant
Salts	Paint	Dirt	Street Debris
	Oil		Trash

(The Pennsylvania State University Institute of State and Regional Affairs, 1980)

As seen in the table above, construction sites pose a large problem for overall water quality in storm water. Due to loose, non-compacted materials, runoff rates from construction sites can be up to one hundred times greater than that of a non-construction site. (The Pennsylvania State University Institute of State and Regional Affairs, 1980)

Urban storm water runoff that is of the most concern usually occurs during the first 30-60 minutes of an event. This is also known as the first flush, in which most contaminants that will be collected in storm water runoff enter into the ecosystem. Even though the first flush lasts for a short duration, storm water has a much larger impact on the environment as compared to treated wastewaters. When compared to treated wastewater, urban runoff contains much larger amounts of suspended solids (TSS), metals, and nutrients that enter back into a water source during the storm event. Large storm events, such as thunderstorms that last 15-30 minutes, contribute the largest amount of pollution in urban runoff. Large amounts of rain lead to heavy runoff. The heavy runoff can pick up any contaminant it can come in contact with, as well as contribute to erosion. Erosion is of concern due to high velocities and flow rates through man-made channels and storm sewer systems, as well as natural streams and rivers. (The Pennsylvania State University Institute of State and Regional Affairs, 1980)

Storm Water Pollutants and Their Sources

Decreased water quality hinders aquatic ecosystems and limits the amount of use for humans. When contaminants are in storm water that is being collected and released at high flow rates, the delivery of contaminants to waters can be quite significant. Stormwater contaminants of concern include physical, chemical, and biological pollutants. In this project, the focus is on nutrients.

Nutrients. Specifically, nitrogen and phosphorus, are required by plants and algae to grow. However, high levels of these nutrients lead to eutrophication, which leads to increased rates of photosynthesis. This increased rate can cause algae blooms, which can then lead to hypoxia in the water source. Agricultural activities, fossil fuel combustion and sewage lead to increased nutrient levels. The following are the typical forms of nitrogen and phosphorus found in surface waters:

Common Forms of Nitrogen and Phosphorus in Receiving Waters

Dissolved Inorganic Nitrogen (DIN)	includes forms of nitrogen that include NH_4^+ (ammonium), NH_3 (ammonia), and NO_3^- (nitrates). All of these forms are typically used by plants during photosynthesis
Total Nitrogen	includes both DIN and organic nitrogen. Organic nitrogen reflects the amount of nitrogen that has entered into organic matter through photosynthesis
Dissolved Inorganic Phosphorus (DIP)	commonly found as an orthophosphate (PO_4^{3-})
Total Phosphorus	includes DIP and organic phosphorus

(Anisfeld, 2010**)**

Nitrates are of concern in urban storm water runoff. High levels of nitrates can lead to eutrophication. Eutrophication (also an implication of high phosphorus and carbon levels) can lead to algae blooms, which deplete oxygen levels in rivers, streams, and lakes, making it difficult for fish and other aquatic life to exist. Due to health concerns, nitrate levels in drinking

water can be no more than 10 mg/L. Consequently, it is important to limit the amount of nitrogen entering a water supply. (Kim, Seagren & Davis, 2003)

Phosphorus is found naturally in receiving waters in the form of phosphates. (Geosyntec Consultants, Inc. & Wright Water Engineers, Inc., 2010) Phosphates are also another source of storm water pollution. Phosphorus can enter into storm water through the use of fertilizers and other home use. Like nitrates, phosphates can lead to eutrophication. To limit eutrophication, phosphate concentrations should be limited to 0.1 mg/L. (Pretorius & De Villiers, 2000) Also excess phosphorus concentrations can lead to hindered water clarity, odors, and loss of aquatic habitats. Excess phosphorus can also indicate the presence fecal indicator bacteria. (Geosyntec Consultants, Inc. & Wright Water Engineers, Inc., 2010)

Urban Stormwater Controls

Control of water quantity (controls for flow and volume) will always be the front-runner in storm water management since pollutant concentrations will always be dependent upon flow quantity. Pollutant removal using best management practices follows the same routines found in conventional water and wastewater treatment, which use physical, chemical, and biological principles to treat water. Best management practices not only treat water, but also involve the storage, filtration, and education behind storm water issues. (Transportation Research Board, 2006)

Hydraulic Controls. Hydraulic controls are a significant factor in determining a best management practice to implement. Flow alteration is the leading idea behind hydraulic controls. The goals of hydraulically controlling runoff are to reduce volume, reduce peak flows, and to create uniform flow rates at all times. Hydraulic controls can be broken into two different ideas: flow attenuation and volume reduction. (Transportation Research Board, 2006) Flow attenuation aims to reduce peak flow discharge quantities, and can be broken down into interception, conveyance, and detention. Reduction of volume can occur through any of the following ideas: retention, infiltration, or evapotranspiration. Retention, introduced earlier, captures storm water and never releases it back into a storm sewer system. Flow alteration solutions include practices such as runoff, infiltration, detention, storage, and evaporation.

Unit Processes. The second way of characterizing best management practices involves unit processes. Unit operations (physical processes) or unit processes (biological or chemical

processes) can be used to carry out pollutant removal. Physical processes may include sedimentation, filtration, or flotation. Biological processes use organisms such as plants, algae, and microbe to remove organic and inorganic pollutants found in storm water. Chemical processes target the following problems commonly found in storm water: pH, alkalinity, hardness, redox conditions, organic carbon, and ions. Typically, treatment options from a chemical standpoint involve sorption, coagulation, or chemical disinfection.

Similar to wastewater treatment technologies, some BMPs can be considered both a unit operation and a unit process. Certain variables can determine the effectiveness and practicality of each BMP, and are known as static and state variables. Static variables deal with design parameters of a given system, which include volumes and dimensions, location, size, slope, state of permeability, amount of vegetation, and soil type. State variables take into account rainfall volumes and intensities, detention times, season, vegetation, and maintenance. (Transportation Research Board, 2006)

Structural BMPs listed by Fundamental Process Category and Unit Operation

Fundamental Process Category (FPC)	Unit Operation or Process	BMPs
Hydrologic Operations	Flow/Volume Attenuation	Extended detention basins Retention/detention ponds Wetlands Tanks/vaults Equalization basins
	Volume Reduction	Infiltration/exfiltration trenches Permeable pavement Bioretention cells Dry swales Dry well Extended detention basins
Physical Treatment Options	Particle Size Alteration	Comminutors Mixers
	Physical Sorption *Nutrients, metals, petroleum, compounds*	Engineered media, activated carbon, and sands
	Size Separation	Screens/bars/trash racks Biofilters Permeable pavement Infiltration/exfiltration trenches Manufactured bioretention systems Engineered media Hydrodynamic separators Catch basin filters
	Density, Gravity, and Inertial Separation	Extended detention basins Retention/detention ponds

		Wetlands Settling basins Tanks/vaults Swales with check dams Oil-water separators Hydrodynamic separators
	Aeration and Volatilization	Sprinklers Aerators Mixers
	Physical agent disinfection	Shallow detention ponds Ultraviolet systems
Biological Processes	Microbiotically Mediated Transformation *Metals, nutrients and organics*	Wetlands Bioretention systems Biofilters Retention ponds Engineered media
	Uptake and Storage *Metals, nutrients and organics*	Wetlands/wetland channels Bioretention systems Biofilters Retention ponds
Chemical Processes	Chemical Sorption Processes	Subsurface wetlands Engineered media Infiltration/exfiltration trenches
	Coagulation/flocculation	Detention/retention ponds Coagulant/flocculent injection systems
	Ion Exchange	Engineered media
	Chemical Disinfection	Custom devices for mixing chlorine or aerating with ozone

(Transportation Research Board, 2006)

Criteria for BMP Selection

In order to properly select a best management practice to incorporate into a storm water management plan, proper storm water goals must be in place, such as flow reduction percentage and water quality goals. Pollutants of concern (nitrates, phosphates, coliform, *E.coli*) must be addressed. If the overall pollutants are addressed, quality of effluent and percent capture can be designed to meet NPDES standards. The following process should help any entity plan and install the proper BMP system for a site. (Transportation Research Board, 2006)

1. *Problem Definition*

Before any solution can be designed, a quality understanding of the pollutant and runoff issues (i.e. high flow, high concentrations of pollutants) associated with the site must be defined. The end result for the storm water plan must also be determined, so that a proper system can be designed. The problem statement should have all criteria needed for the project to be specified (i.e. strictly retrofitting and new construction). All objectives for the project also need to be listed and ranked based on importance to the project. Also accompanying these objectives should be

specific goals the project is required to meet (reduction of volume by a certain percentage, removal of pollutants).

2. *Site Characterization*

The next step in selecting a best management practice is to characterize the site in question. It is imperative to know all site conditions and constraints before the design process even begins. This step can initially eliminate some options that simply are not feasible for a given site. Hydrologic and soil conditions also help narrow down which BMPs will work at the given site. Infiltration rates of certain soil types are imperative for the success of BMPs. High infiltration rates allow BMPs to handle a higher quantity of flow, thus allowing for more effective treatment of runoff.

3. *Identification of Fundamental Process Categories*

Once site conditions and constraints, as well as initial water quality, are documented, certain processes need to be evaluated and ranked based on how well they can reduce flow and treat contaminants. Soil types and infiltration rates are a key factor in this step, simply because these factors depict how well a BMP can operate given the site conditions. As discussed earlier, these FPC's can be divided into hydrologic, physical, biological, and chemical operations. The selection of the best available process should be done based on the types of pollutants found, and specific site goals for effluent storm water quality.

4. *Selection of BMPs and Other Treatment Options*

Once the overall unit processes available to the site are specified, specific best management practices can be identified and selected. A general understanding behind how certain BMPs work (i.e. hydrological, chemically, biologically) is key to selecting the proper solution. The goal should be to select a BMP that addresses all issues on site. However, if one solution does not address all issues, multiple solutions may need to be bundled together to create a "treatment train". Once feasible solutions are addressed, the next step is to analyze the solutions to see if one BMP works better given site constraints than any other potential solution.

5. *Practicability of Proposed Treatment Systems*

Once certain BMPs are selected as potential solutions for storm water runoff issues, the practicality of each solution needs to be evaluated. The evaluation process is based on the

following criteria:

- Performance for target pollutants
- Hydrology and hydraulics
- Space availability, both above surface and subsurface
- Maintenance
- Economics
- Aesthetics

Other factors go into the practicality of each solution, including downstream impacts, health effects, climate, and overall budget for the project. This process should once again narrow down which BMP would be most effective for the problem at hand.

6. *Sizing the Conceptual BMP*

Once the selection process is complete, a conceptual design for the BMP needs to be completed. This conceptual design not only needs to meet projects criteria, it also needs to be designed within the restraints of EPA. Typically, the conceptual design is based on hydrology, in which the BMP is designed for flow attenuation, volume reduction, or flow duration. The sizing of the BMP can be done using factors such as design storms, rainfall frequency analyses, and continuous runoff models.

7. *Development of Performance Monitoring and Evaluation*

Once design is completed, a long-term evaluation plan must be developed. This plan should aim to address management, regulatory and research goals. These goals are based on the success of project objectives, which includes hydraulics and water quality. This monitoring plan, like the rest of the project is based upon cost and time available. Overall, it is important to get long-term data to effectively analyze the performance of the BMP selected and installed. (Transportation Research Board, 2006)

Overall, the selection of the correct best management practice can seem like an open-ended question. Multiple solutions could potentially work just as well as another solution. As a general guideline, the following criteria should be taken into account, which is shown in the BMP objective checklist table below:

BMP Objective Checklist

Category	Typical Objectives for Urban Runoff
Hydraulics	Manage flow characteristics
Hydrology	Eliminate flooding while improving runoff quality
Water Quality	Reduce pollutants loads downstream
	Improve downstream temperature impacts
	Obtain desired pollutant concentrations
	Remove trash and other debris
Toxicity	Reduce acute and chronic toxicity of runoff
Regulatory	Comply with NPDES permitting
	Comply with local, state, and national water quality regulations
Implementation	Function within management structure
Cost	Minimize life-cycle costs
Aesthetics	Improve appearance of site while reducing odors
Maintenance	Operate within maintenance and repair schedule
	Design BMP to allow for future retrofitting
Longevity	Allow for long-term functionality
Resources	Improve downstream aquatic life/erosion control
	Improve wildlife habitats
	Achieve multiple use functionality
Safety, Risk, Liability	Function without significant risk or liability
	Minimize environmental risk downstream
	Contain any spills
Public Perception	Help the public understand the importance of runoff quality, quantity, and impacts on receiving waters

(Transportation Research Board, 2006)

Efficacy of BMPs in Controlling Nutrients

In response to the existing regulations regarding nutrients, solids, runoff volume US professionals need reliable performance data for BMP. USEPA is urging states to adopt numeric nutrient criteria. Which BMPs should be used and why? How reliable will they be? To help answer these questions, the International Storm water BMP Database project has recently completed a comprehensive storm water BMP performance analysis technical paper series relying on data contained in the International Storm water BMP Database. The BMP database is a long term research database that contains results of storm water studies independently conducted by researchers.

Performance data for total phosphorous removal is included in the table below. By statistically analyzing the data, 25th percentile, 75th percentile and 95% confidence interval data are included for influent and effluent water. This data represents 10s of thousands of studies. In order to determine the efficacy of BMPs on total phosphorus removal, we can compare in (influent) and out (effluent) numbers. Generally speaking, the BMPs remove phosphorous. However, the bioretention and bioswale BMPs show an increase in total phosphorus, suggesting that these techniques are not suitable for removing phosphorous.

Influent/Effluent Summary Statistics for Total Phosphorus (mg/L) (2012)

BMP TYPE	**Count of studies**		**25th Percentile**		**95% Confidence**		**75th Percentile**	
	IN	**OUT**	**IN**	**OUT**	**IN**	**OUT**	**IN**	**OUT**
Bioretention	18271	20280	0.08	0.10	0.14	0.18	0.26	0.35
Bioswale	20331	18249	0.06	0.05	0.11	0.09	0.22	0.35
Manufactured devices	45602	52641	0.09	0.06	0.19	0.12	0.46	0.30
Media filter	28433	28403	0.10	0.05	0.15	0.09	0.32	0.17
Porous Pavement	13231	22389	0.09	0.05	0.15	0.09	0.29	0.17
Retention pond	46657	48654	0.15	0.06	0.0	0.13	0.53	0.23
Wetland basin	13283	13278	0.09	0.04	0.13	0.08	0.20	0.15

(International storm water Database 2012)

The next table includes BMP performance data for total nitrogen removal. Again, the 25th percentile, 75th percentile, 95% confidence interval for both influent and effluent water are shown. This data represents findings from thousands of studies conducted internationally. In most cases, the BMPs indicate total nitrogen removal when comparing influent to effluent numbers. The one exception to this is porous pavement which resulted in an increase in total nitrogen.

Influent/Effluent Summary Statistics for Total Nitrogen (mg/L) (2012)

BMP TYPE	**Count of studies**		**25th percentile**		**95% Confidence**		**75th percentile**	
	IN	**OUT**	**IN**	**OUT**	**IN**	**OUT**	**IN**	**OUT**
Bioretention	12218	12200	0.77	0.53	1.25	0.90	1.99	1.54

Bioswale	6181	8238	0.41	0.43	0.75	0.71	1.60	1.54
Manufactured devices	8133	8117	1.29	1.40	2.37	2.22	3.58	3.29
Media filter	5100	587	0.67	0.46	1.06	0.82	2.25	2.13
Porous Pavement	114	9136	1.20	0.73	1.26	1.49	1.42	2.28
Retention pond	19259	19272	1.05	0.86	1.83	1.28	2.87	1.78
Wetland basin	6222	6223	0.80	0.89	1.14	1.19	1.90	1.66

(International storm water Database 2012)

It should be noted that the International Storm Water Database is a comprehensive summary of data collected using benchmarked protocols for sampling and analysis. The composition of the actual BMPs that were tested are not specified. For example, the specific mix design used for Porous Pavement is not considered. In addition, the engineered filtration media provided in bioretention and filtration techniques will likely vary widely between individual applications. However, this large data set does provide some indication as to which technologies might be most effective for nutrient removal. These findings are empirical and do not necessarily support the generally agreed removal criteria that is found in many BMP manuals as shown in the table below.

Typical nitrogen and phosphorous removal criteria:

TECHNOLOGY	**Removal criteria**	**% removal of phosphorous**	**% removal of nitrogen**
Wet detention ponds	Phosphorous and nitrogen	20-30	10-20
Green technology (green sorption media)	Phosphorous and nitrogen	30-40	40-50
Bio swale	Phosphorous and nitrogen	51-55	52-58
Bio retention system (rain gardens)	Phosphorous and nitrogen	20-60	20-30
Sand filters	Phosphorous and nitrogen	50-60	Up to 50
Manufactured devices	Phosphorous and nitrogen	80-90	40-50
Infiltration structure (porous pavement)	Phosphorous and nitrogen	56-60	50-60

(Geosyntec Consultants, 2012) (University of New Hampshire storm water center, 2012). (New Jersey Stormwater BMP manual, 2004) (Scott Perry).

Conclusions

Recent trends in storm water management have identified innovative practices and techniques that are showing increased promise in the management of storm water. Practices can be structural. This includes the adoption of best management practices (BMPs) that address storm water at its source such as impervious surface reduction and utilization of vegetated swales and biofilters. Barriers to implementing storm water BMPs in our region include shared knowledge of previous installations as well as comprehensive and comparable monitoring data and local cost data (capital cost and maintenance costs). It is important for local stakeholders to have a process to select appropriate stormwater BMPs. The selection process involves initially characterizing the project objective and the site. Subsequent steps involve knowledge of stormwater BMPs, BMP design, installation, and performance monitoring. Due to seasonal water quality issues, much of the focus in Northwest Ohio is on nutrients in surface waters. Many folks primarily attribute eutrophication to agricultural activities. It is important to recognize that urban inputs can also be significant, depending on run-off quantities. The data available on BMP performance related to nutrient removal is widely variable. The BMP design specifications consider the goals of the project. If phosphorous removal is a priority, bioretention systems will need to be intentionally designed perhaps to exclude some of the soil amendments (compost) that have been attributed to phosphorous release.

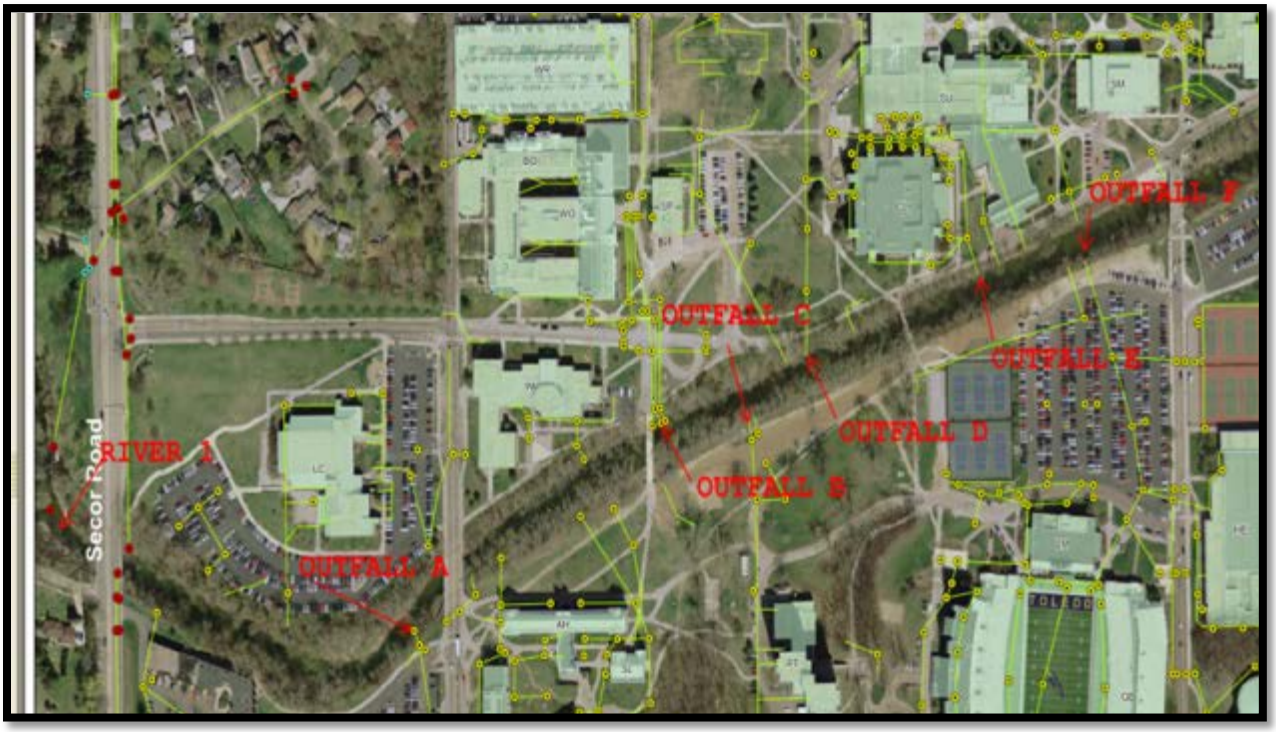
Section 2: Stormwater Sampling at the University of Toledo Main Campus

The following figures and data represent findings from grab samples of stormwater collected between Summer of 2012 and Summer of 2013 on the Main Campus at the University of Toledo. This information was used to assist in determining the range of concentrations of contaminants of interest during wet weather events. Samples were collected in 1liter HDPE bottles and stored at 4°C until further analysis. Grab samples were initiated during or following precipitation.

Analyses included total suspended solids, orthophosphate, nitrate, coliform counts, and *e. coli* counts (Figure 1). Nutrients were measured using a Hach colorimeter, while coliform and *e. coli* counts were measured using Petrifilm Plates. Total suspended solids were quantified by filtering known quantities of stormwater samples (300 to 500mL) and drying the filter paper at 100C for 24 hours prior to cooling and subsequent analysis for solids.

Laboratory analysis of stormwater contaminants

From the Summer of 2012 through the Spring of 2013, stormwater samples were collected from eight outfalls on the UT campus. Figures 2 indicates the location of the outfalls that were sampled. In addition, samples were collected from upstream (west) of campus near Secor Rd. and downstream (east) near Douglas Rd. for comparison. These samples were initially collected in an effort to develop a list of potential stormwater best management practices (BMPs) that could be employed to address contaminant concerns identified on campus.



Sample locations from the east (TOP) and west (BOTTOM) side of UT campus.

Results from the sample analyses have been summarized in Table 1. The values measured during sampling dates that occurred in Summer 2012, Fall 2012, and Spring 2013 are varied. No seasonal pattern was observed. In the case of coliform and *e. coli*, the presence of either in any of the sampling events is indicated by Yes in Table 1. Note, total suspended solids were only measured in Spring 2013 at the sites indicated. The nitrate concentration ranged from below detection (0) to 3.61 mg/L. The orthophosopate concentration was below 0.08 mg/L in all instances. Coliform were present in all sample locations except Outfall E adjacent to the Student Union.

Stormwater contaminant data for outfall sites located on UT campus.

Site Location	Nitrate (mg/L)	Orthophosphate (mg/L)	coliform (presence)	E. coli (presence)	Suspended Solids (g/L)
River Upstream	0.04	0.01	Yes	Yes	1.2
A	0 - 3.08	0.01	Yes	Yes	2
B	0 - 4.14	0 – 0.01	Yes	Yes	2.86
C	0.09 - 0.44	0.03 – 0.06	Yes	Yes	2.6
D	1.67 - 2.64	0.04	Yes	Yes	0.2
E	2.19	0	No	No	NA
F	0 - 3.61	0.07	Yes	Yes	0.8
G	1.32 - 2.68	0.03	Yes	No	NA
H	0.04 - 0.40	0.01	Yes	Yes	NA
River Downstream	0.26	0.02	Yes	Yes	1.3

During the Summer of 2013, an undergraduate student was investigating the efficacy of the stormwater BMPs already installed at UT on the main campus. The main objective of this work was to study the rain garden adjacent to Lot 10 and the green roof on Savage Hall. Grab samples were collected in the rain garden, in parking lots, exiting stormwater outfalls, and in the open river. In total, 14 samples were analyzed. The locations for the 14 samples are indicated on Figure 3.

Sampling sites for Summer 2013 on UT Campus

As observed in the previous sampling analyses, the concentrations of stormwater contaminants varied widely. There were no observable trends in terms of site type sampled (e.g., parking lot vs. rain garden). In this case, samples were collected directly in parking lots and catch basins in parking lots. That may explain the higher concentrations of contaminants because the samples were not likely diluted prior to sample collection. Notably, the coliform bacteria numbers were very high in some instances. Also, the orthophosphate concentration in one instance was considerably higher (0.21 mg/L) than that measured in the previous analysis where the maximum was 0.08 mg/L.

Stormwater contaminant data for sites sampled in Summer 2013.

Parameter	Range of Concentration Measured	Average
Total suspended solids	0 – 1.1 g/L	0.2 g/L
Nitrate	0.88 - 5.28 mg/L	4.07
Phosphate	0 - 0.21 mg/L	0.04
Coliform	16.6 – TNTC cfu/mL	TNTC cfu/mL

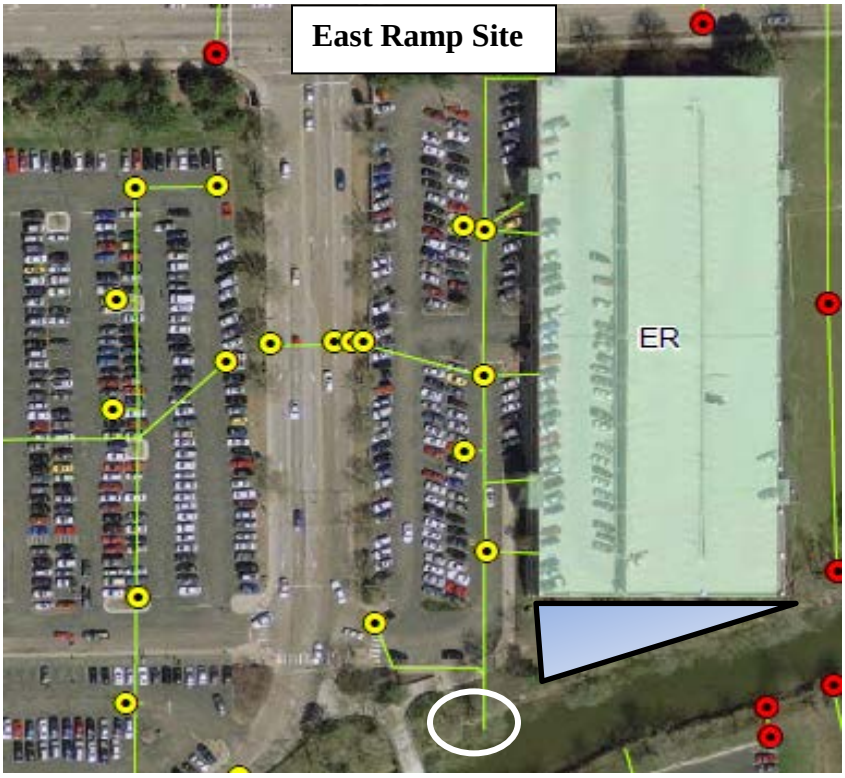
*TNTC

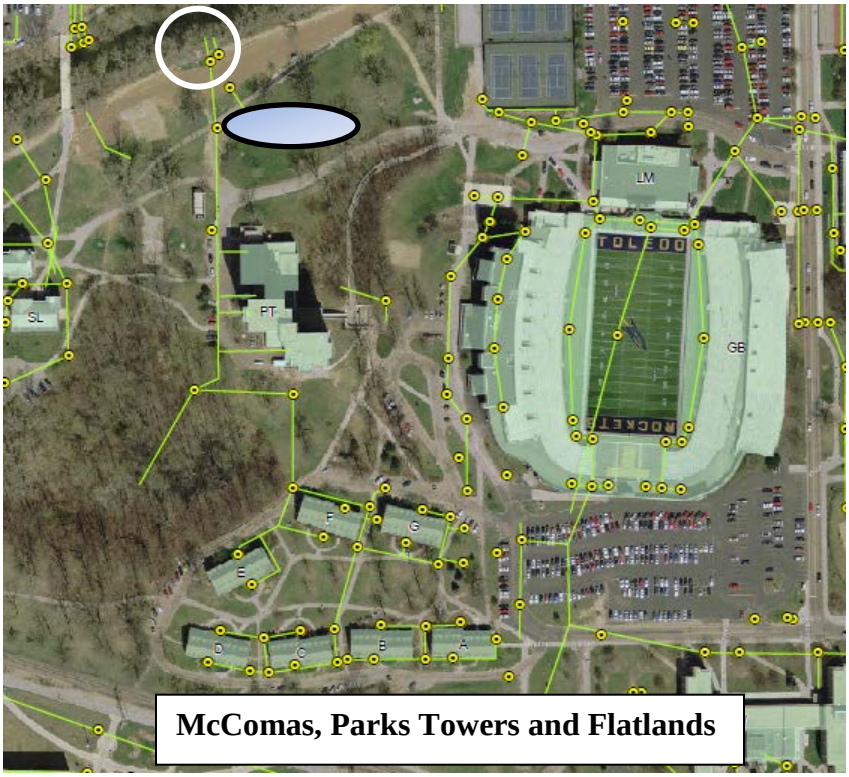
Conclusions

The stormwater samples collected from stormwater outfalls and the Ottawa River on the UT main campus indicate that contaminant concentrations vary widely with both spatial and temporal variations observed. UT does contribute nutrients as contaminants to the Ottawa River. Although the concentrations are typically low and within the range of the receiving waters, large quantities of run-off could still result in a significant contribution of nutrients to receiving waters. It appears that indicator bacteria (coliform) are also being contributed in some locations. This may result from wildlife activity in or near stormwater infrastructure. In order to have a more robust and representative dataset, we anticipate moving to online monitoring of water quality in some locations on campus.

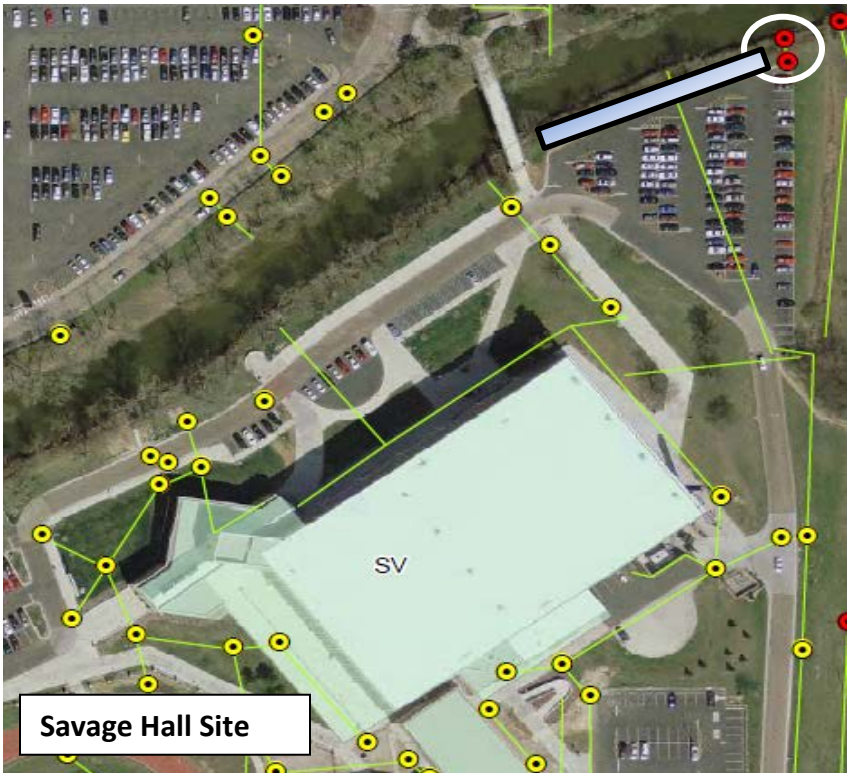
Section 3: Potential Stormwater Retrofit Sites at UT

During the course of this project, we have identified four sites that have high potential for installation of stormwater BMPs on the UT Main Campus. Several locations (up to 10) were initially chosen based on availability of space for BMP design and implementation. Subsequently, we consulted with UT Facilities to acquire drawings of infrastructure and to determine the long range plans for these sites and their suitability for stormwater BMP construction. Many sites were eliminated due to infrastructure limitations, hydraulic limitations (no gravity flow), or future construction plans. The selected sites to advance include the following drainage areas: East Ramp Parking Structure and Adjacent Lot, McComas Village, Parks Tower and Flatlands, Lower Parking Lot Adjacent to Savage Hall, and West End of Law School Parking Lot. The figures below are stormwater infrastructure maps of the sites. The white circles indicate the outfalls associated with the drainage area. The grey area outlined in black indicates the space available for green infrastructure at each location. At the East Ramp, Savage, and Law School Sites, the green infrastructure would be located between the impervious surfaces and the discharge to the river. The Flatlands site provides an opportunity to capture stormwater where it is generated rather than immediately prior to discharge since more land is available. In all cases, there is land available that is located in a hydraulically favorable location that will allow treatment prior to gravity discharge.





McComas, Parks Towers and Flatlands



Savage Hall Site

Once we selected the sites, we calculated design flows (10 year storm and first flush) for each site. Prior to selecting candidate BMPs for each site, we reviewed the contaminant data collected at or near these sites as well as published information on anticipated stormwater contaminants. The Green Values Stormwater Calculator (cnt.org) and the New EPA National Stormwater Calculator could both be used to quantify flows generated by run-off from the impervious surfaces and the flows that can be captured using the green infrastructure.

Flow Calculated from Each Site (Rational Formula Components)

Site	**C**	**i (inch/hr)**	**A (acres)**	**Q=cia (ft^3/s)**	**Q=cia(gpm)**
East Ramp Parking Structure and Adjacent Lot	0.9	2.83	3.5	8.91	4000
McComas Village, Parks Tower and Flatlands	0.39	2.83	22	24.28	10897
Lower Savage Lot Adjacent to Ottawa River	0.9	2.83	0.9	2.29	1029
Law School Parking Lot (West End)	0.8	2.83	1.04	2.35	1057

(NOAA ATLAS 14 POINT PRECIPITATION FREQUENCY ESTIMATES: OH)

First Flush Calculation (1/2 inch over impervious area)

Preferred Site	**Impervious area (acres)**	**Run=off volume in (gallons)**	**Run-off volume in (ft^3)**
East Ramp Parking Structure and Adjacent Lot	3.5	47,516	6,352
McComas Village, Parks Tower and Flatlands	3.5	47, 516	6,352
Lower Savage Lot Adjacent to Ottawa River	0.9	12,218	1,633
Law School Parking Lot (West End)	1.04	14,097	1,885

BMP Selection

We narrowed down our BMP selection based on feasibility of construction including siting and cost constraints. We worked to develop a spreadsheet tool for comparing BMP alternatives. These findings were presented at the Ohio Stormwater Association Conference in Cincinnati in May of 2013 (presentation attached). They are also publicly available in a thesis entitled "Development of a Method to Compare Storm Water Best Management Practices at The University of Toledo" by Christopher Michael Wancata. We also used the Green Values National Stormwater Calculator (cnt.org) to compare costs (capital and lifecycle) as well as environmental benefits. This calculator was designed to compare alternatives for undeveloped sites. With this calculator, it is possible to compare green alternatives to conventional alternatives in terms of cost (below). In this example, we compared the implementation of permeable pavement, a raingarden, and a swale to the Savage Site for comparison.

Costs

	Construction Cost ($)				Annual Maintenance Cost ($)				Life Cycle Cost ($, NPV)			
	Conventional	Green	Difference	%	Conventional	Green	Difference	%	Conventional	Green	Difference	%
Parking Lot	$225,629	$6,873	$-218,756	-97%	$6,142	$187	$-5,955	-97%	$469,295	$14,296	$-454,999	-97%
Conventional Stormwater Storage	$19,707	$0	$-19,707	-100%	$51	$0	$-51	-100%	$25,611	$0	$-25,611	-100%
Permeable Pavement- Porous Asphalt	$0	$246,636	$246,636	0%	$0	$7,391	$7,391	0%	$0	$534,443	$534,443	0%
Turf	$9	$0	$-9	-100%	$4	$0	$-4	-100%	$127	$0	$-127	-100%
Rain Garden	$0	$700	$700	0%	$0	$34	$34	0%	$0	$1,929	$1,929	0%
Swales in Parking Lot	$0	$12,000	$12,000	0%	$0	$96	$96	0%	$0	$17,650	$17,650	0%
Downspout Disconnection	$0	$35	$35	0%	$0	$0	$0	0%	$0	$51	$51	0%
Additional Soil	$0	$13,500	$13,500	0%	$0	$10	$10	0%	$0	$16,762	$16,762	0%
Total	$245,344	$279,744	$34,400	14%	$6,197	$7,719	$1,522	25%	$495,034	$585,131	$90,097	18%

Detailed cost sheet.

Although it is not specifically adaptable for retrofit sites, the cost comparison data can be useful for eliminating a particular BMP based on comparison of construction or maintenance costs. The Center for Neighborhood Technology site has an abundance of useful data available on costs

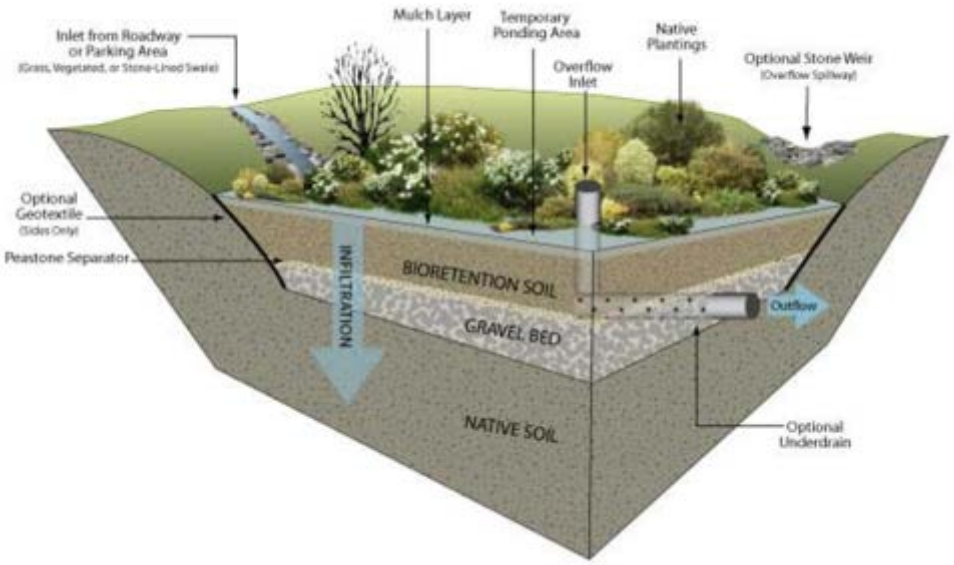
for BMP construction (low, average, high) and on quantifying environmental benefits. The site does not allow modification of BMPs to specific site conditions.

Lessons Learned in BMP Selection

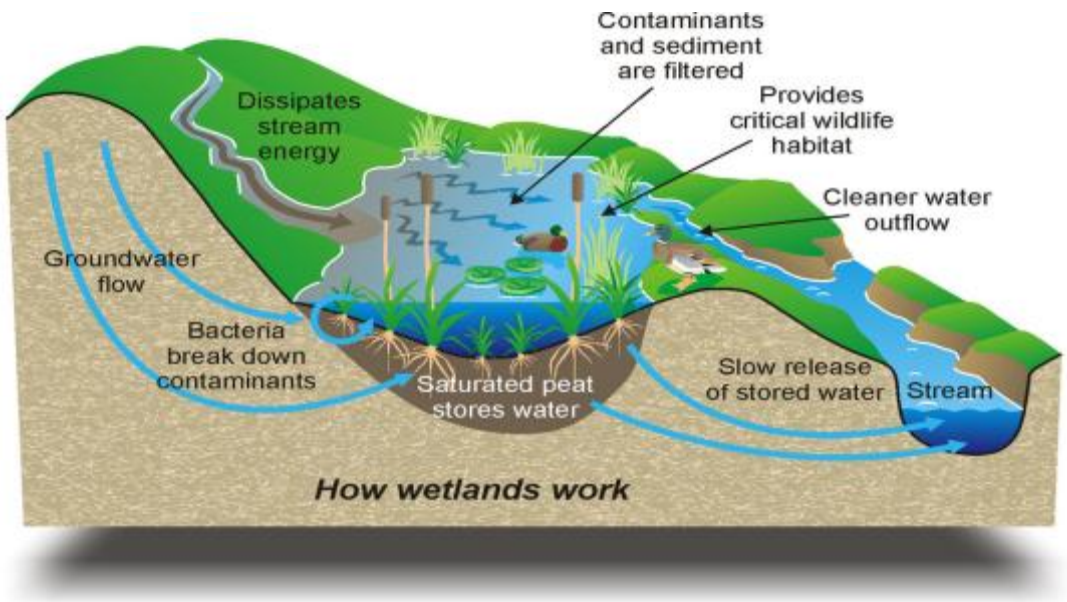
It is difficult to carry out BMP alternatives analysis specific to our region because there is a lack of performance, capital cost, and maintenance data. In addition, most entities are not interested in a comprehensive tool or calculator that considers all possible BMP alternatives for a site. Rather, certain BMP technologies are favored by local stakeholders, perhaps due to previous experience or knowledge. The pool of options begins here. For example, we eliminated permeable pavement/asphalt as a design BMP since UT Facilities and Administration does not support this technology after failed implementation in a few locations on campus. Rather, bioretention technologies are favored.

BMP Proposals for UT Main Campus

East Ramp Site. The East Ramp Site includes a significant amount of impervious surface. The parking lot is already graded, and it would be quite difficult to change grading to incorporate BMPs within the parking lot structure. However, the parking garage drainage can easily be configured to deliver flows to available space. The east side of the parking garage has been earmarked for construction of an access road to relieve congestion in the area. Therefore, the only space available is South of the East Ramp (parking garage). We recommend the implementation of a rain garden at this site to capture flow from the parking garage. Rain gardens are typically sized at 5 to 10% of the drainage area for best results. The parking garage is approximately 1 acre, so the rain garden should cover a minimum area of 2,000 ft^2.



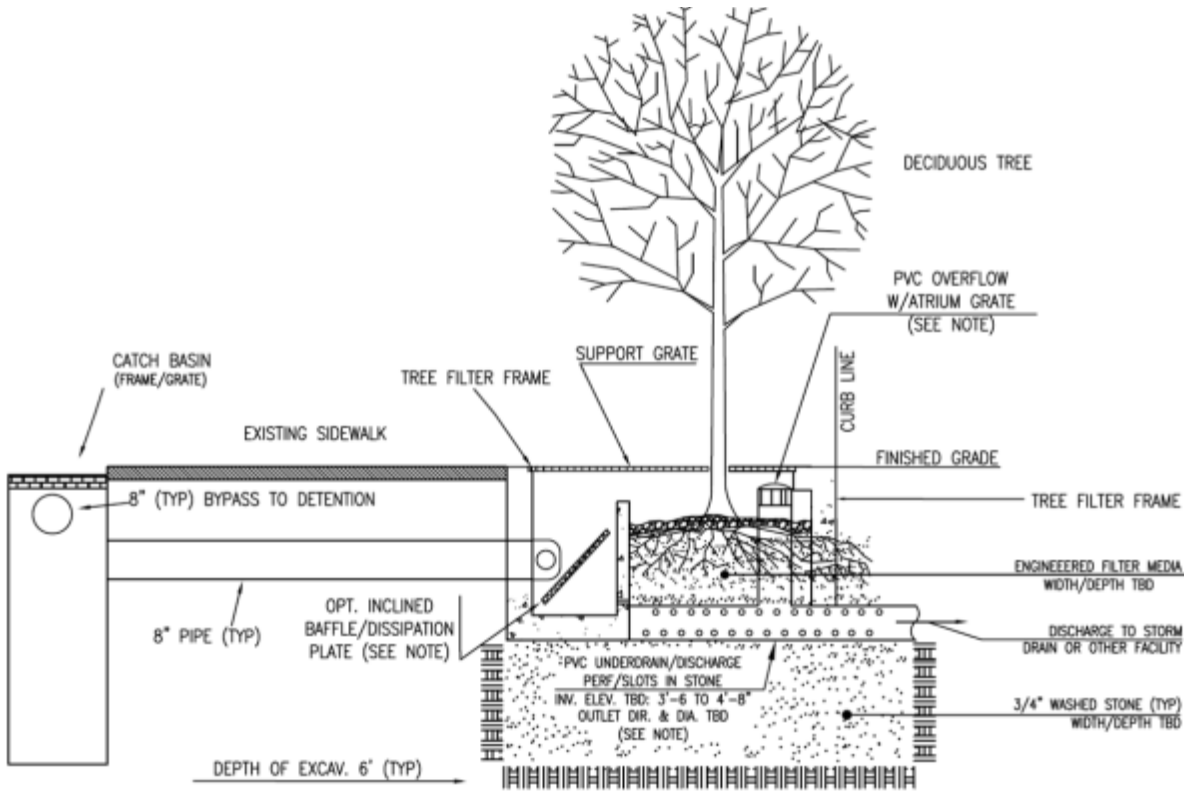
Crossings and Flatlands Site. This site has the largest contributing drainage area of those we considered (22 acres), however only 3.5 acres of the area is impervious. We considered treating the stormwater flow near the buildings by detaching roof drains and directing the flow to rain gardens. Based on the current infrastructure located near the buildings, this would be difficult. The downstream area available (Flatlands) was significant, so we decided to focus on placing green stormwater infrastructure in that location. This could provide an aesthetically pleasing environment to facilitate student use of that area. We suggest the construction of a pocket wetland. Naturally occurring native plants are commonly found in these constructed pocket wetlands. Pocket wetlands are very effective when treating stormwater runoff; a constructed stormwater wetland varies greatly from an existing pond/ marsh wetland. "Stormwater wetlands are designed specifically for the purpose of treating stormwater runoff, and typically have less biodiversity than natural wetlands in terms of both plant and animal life" (*US EPA Stormwater Wetland 2012*).



Wetlands should include zones of both very shallow (< 6 inches) and moderately shallow (< 18 inches) water, using underwater earth berms to create the zones. This design will provide a longer flow path through the wetland to encourage settling, and it provides two depth zones to encourage plant diversity. The wetland should be longer than it is wide to better promote downstream flow. The normal ratio is roughly 1.5:1 to ensure the water does not bypass any treatment zone. The last major design consideration is that the surface area of the wetland must be roughly 2-4% of the total drainage area to be treated. In this case, 4% of 22 acres is approximately 0.88 acres.

Savage Site. The Savage Parking Lot Site includes flow from the lower parking lot. The drainage area is approximately 0.9 acres. The flow travels downhill and is caught by a curb and carried to an existing catch basin. See the figure to the right. We propose demolition of the curb to allow the flow to be transferred into a bioswale along the back of the parking lot (right side of this image). The purpose of the bioswale (85' long x 8' wide) is to both convey and infiltrate the stormwater that is collected from the site. Infiltration will result in removal of suspended solids and bacteria. If detention times are adequate, nutrient removal is also possible. The construction of the bioswale would be very similar to a rain garden with 12" of gravel on the bottom for the underdrain system, covered by up to 24" of engineered media (sand, clay, organics), and compost and plantings on the surface. In this case, the bioswale will be graded toward the catch basin to address system overflows.

Law School Site. The Law School Site includes only the western most portion of the parking lot. Flow is collected in a series of catch basins covering about 1.0 acre. The flow is discharged through an 18" pipe directly to the Ottawa River. Since the embankment available for construction has a subsurface is composed of construction debris and is often in the flood plain. We had originally planned a rain garden at this site, but we recognized the grade change and the flood plain would be prohibitive. Instead, we are proposing to install a tree filter bioretention system, which is designed to have a smaller footprint while still treating flows prior to discharge. This tree filter would be the first of its kind in Lucas County. The tree filter can provide an attractive landscaping alternative. The tree filter selected is a manufactured system with an open bottom and open sides to facilitate tree growth. The other design details are provided in the image below.



STORMTREE TREE FILTER
SECTION A–A
NOT TO SCALE

Project Costing. Cost estimates were prepared for all four sites. There are few contractors experienced in stormwater design, so it is difficult to acquire good costing data. However, we were able to make reasonable estimates based on other local projects, help from UT Facilities, and the Center for Neighborhood Technology Web-site. The capital costs include labor and materials. Design costs are not included.

Site	**Proposed BMP**	**Details**	**Cost**
East Ramp	Rain Garden (2,000 ft^2)	Excavation, Gravel, Sand, Compost, Plantings, Underdrain pipe, Modifications to existing piping	$25,000
Park Towers and Flatlands	Pocket Wetland (1 acre)	Excavation, Gravel, Sand, Compost, Plantings, Overflow structure at inlet and outlet, Modifications to existing piping.	$85,000
Savage Lot	Bioswale (700 ft^2)	Excavation, Gravel, Engineered Media, Compost, Plantings,	$25,000

		Underdrain pipe, Modification to existing piping.	
Law School Lot	Tree Filter	Excavation, Disposition of construction debris from the site, Manufactured tree filter with all components included, 20ft rip rap lined outfall, Modifications to existing piping, gravel	$40,000

Conclusions

Several sites were considered for the implementation of green stormwater infrastructure at the University of Toledo. Through the evaluation process, many sites were eliminated based on unfavorable hydrologic conditions, space constraints, or uncertain future expansion plans. We have selected four sites with the assistance of UT Facilities that are suitable for stormwater BMP installation. We have prepared conceptual designs that are summarized in this document. Two of the projects, Law School Lot and Savage Lot, have been funded through Ohio EPA Lucas County SWIF funding and will be constructed in spring of 2014. Contrary to expectations at the beginning of this project, there is a minimal amount of costing and performance data available on stormwater BMPs in Lucas County, Ohio. Although there have been and continue to be many installations, there is no mechanism for sharing data amongst stakeholders. Our goal moving forward is to facilitate sharing of information related to the recently funded SWIF projects amongst stormwater stakeholders in our region. In this way, we hope to incentivize additional implementation of green stormwater BMPs throughout our region.

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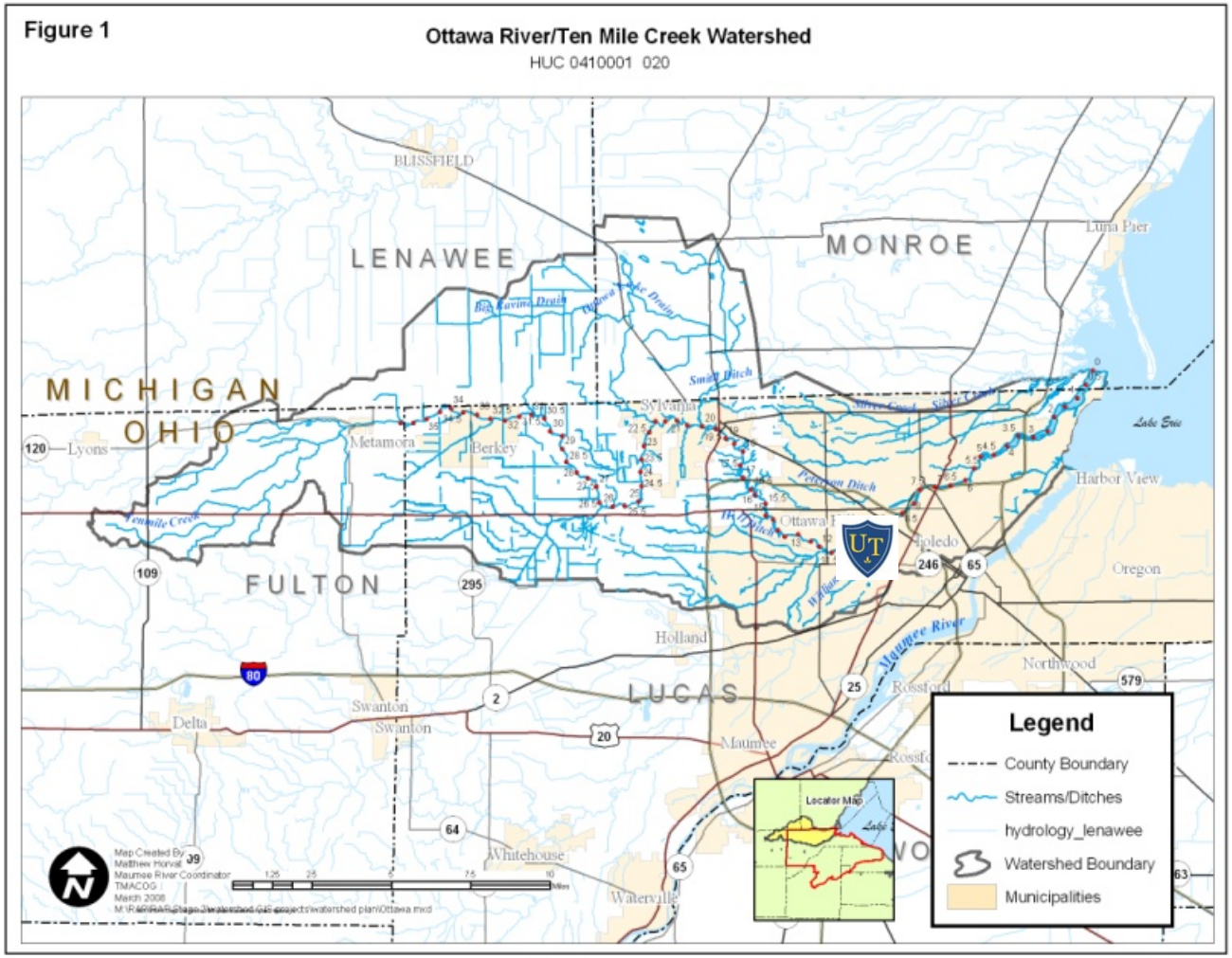
Cost & Environmental Benefits Analysis of Potential BMPs at UT

Cyndee L. Gruden, PE, PhD
Christopher Wancata and Thomas Hasson
Department of Civil Engineering
University of Toledo

Location: University of Toledo



Ottawa River On UT Campus

Source: Kevin Czajkowsky

- **Main Feature**
- **Channelized**
- **Flooding**
- **Research Opps**

Source: Forbes.com

Green Infrastructure at UT

Green Roof

Cistern

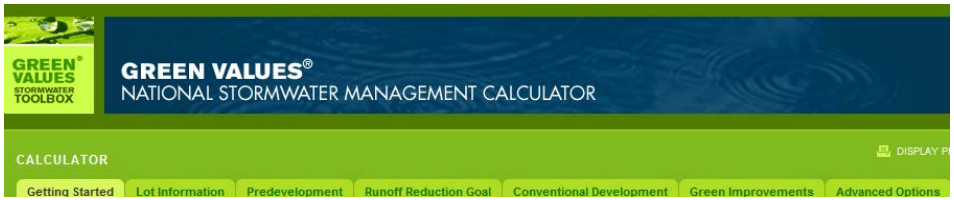
Rain Garden

BMP Selection – *Often Qualitative*

Category	Typical Objectives for Urban Runoff
Hydraulics	Manage flow
Hydrology	Eliminate flooding while improving runoff quality
Water Quality	Reduce pollutants loads downstream
	Improve downstream temperature impacts
	Obtain desired pollutant concentrations
	Remove trash and other debris
Toxicity	Reduce acute and chronic toxicity
Regulatory	Comply with NPDES
	Comply with local, state, and national water quality regulations
Implementation	Function within management structure
Cost	Minimize life-cycle costs
Aesthetics	Improve appearance of site
Maintenance	Operate within maintenance and repair schedule
	Design BMP to allow for future retrofitting
Longevity	Allow for long-term functionality
Resources	Improve downstream aquatic life/erosion control
	Improve wildlife habitats
	Achieve multiple use functionality
Safety, Risk, Liability	Function without significant risk or liability
	Minimize environmental risk downstream
	Contain any spills
Public Perception	Help the public understand the importance of runoff quality, quantity, and impacts on receiving waters

(Transportation Research Board, 2006)

Existing Tools



Center for Neighborhood Technology

- Green Values Stormwater Management Calculator
- www.cnt.org
  - National Tool
  - Chicago Area (Local) Tool
- Evaluates BMPs for new site development by comparing green to conventional alternatives
- Includes environmental benefits assessment

Input

- Lot information
- Predevelopment
- Run off reduction goal
- Conventional development
- Green improvements
- Advanced options

Results

Volume Control

Required Volume Capture from 0.5" over Impermeable Surface (ft^3)	417
Volume Captured by current BMPs (ft^3)	1,250
Permeable Pavement on Parking (ft^3)	1,250
Percentage of Required Volume Captured by current BMPs (%)	300
Decrease in Impervious Area (%)	43

Coefficients and Runoff

	Predevelopment	Conventional	Green	Predevelopment to Conventional Difference (%)	Conventional to Green Difference (%)
Average Annual Rainfall					
Total Runoff (in)	18.43	17.92	16.36	-3%	-9%
Total Runoff Volume (ft^3)	66,900	65,049	59,370	-3%	-9%
Cumulative Abstractions (in)		1.78	3.02		69.71
90% Storm					
Total Runoff (in)	0.14	0.08	0	-44%	-96%
Total Runoff Volume (ft^3)	504	280	11	-44%	-96%
Cumulative Abstractions (in)		0.35	0.1		-71.09
CN	87	84	74		

Land Use

	Conventional Area (ft^2)	Green (Using BMPs) Area (ft^2)
Conventional Roof	10,000	10,000
Green Roof	0	0
Parking Lot	7,500	0
Permeable Parking Lot	0	7,500
Swales in Parking Lot	0	0
Streets	0	0
Reduced Street Width	0	0
Roadside Swales	0	0
Driveway and Alleys	0	0
Permeable Driveway and Alleys	0	0
Sidewalks	0	0
Permeable Sidewalks	0	0
Lawn	26,060	26,060
with Amended Soil	0	0
Native Vegetation	0	0

Benefits

	Annual Benefits ($) Green Benefits	Life Cycle Benefits ($, NPV) Green Benefits
Reduced Air Pollutants	0	0
Carbon Dioxide Sequestration	0	0
Compensatory Value of Trees	0	0
Groundwater Replenishment	7	183
Reduced Energy Use	0	0
Reduced Treatment benefits	4	102
Total	**11**	**285**

Costs

	Construction Cost ($)				Annual Maintenance Cost ($)				Life Cycle Cost ($, NPV)			
	Conventional	Green	Difference	%	Conventional	Green	Difference	%	Conventional	Green	Difference	%
Parking Lot	$41,325	$0	$-41,325	-100%	$1,125	$0	$-1,125	-100%	$70,610	$0	$-70,610	-100%
Conventional Stormwater Storage	$8,422	$0	$-8,422	-100%	$22	$0	$-22	-100%	$8,991	$0	$-8,991	-100%
Standard Roof	$75,000	$75,000	$0	0%	$500	$500	$0	0%	$88,015	$88,015	$0	0%
Permeable Pavement- Pavers	$0	$53,250	$53,250	0%	$0	$270	$270	0%	$0	$60,278	$60,278	0%
Turf	$5,473	$5,473	$0	0%	$2,345	$2,345	$0	0%	$66,526	$66,526	$0	0%
Total	**$130,219**	**$133,723**	**$3,503**	**3%**	**$3,992**	**$3,115**	**$-877**	**-22%**	**$234,142**	**$214,819**	**$-19,323**	**-8%**

Project Objective:

To develop a tool to compare potential BMPs for ***retrofit*** *situations using decision analysis including* ***cost-benefit analysis****.*

Selected BMPs for this Project:

- Porous pavement
- Bioswales
- Rain gardens

Well-studied
Local interest
Work well in a retrofit environment
Effectively reduce flow and contaminant levels

Porous Pavement

- ***Infiltration (up to 97%)***
- ***P Reduction (up to 17%)***
- ***Reduction of bacteria***
- ***Groundwater recharge***

Best used in a light/medium traffic setting

Drastically increase infiltration potential

Asphalt, concrete, or paver-like structure

Rain Gardens

- ***Infiltration (up to 99%)***
- ***P Reduction (up to 60%)***
- ***Reduce pathogens***
- ***Groundwater recharge***

Trees, shrubs and other plants covered with mulch

12 to 24 inches of storage

Underdrains may be needed

Bioswales

Reduction based on retention time

- ***Flow reduction (up to 48%)***
- ***P Reduction (up to 33%)***
- ***Remove pathogens***

Swale or ditch

- Fully vegetated swales are excellent pollutant-removing options
- Channels are effective flow reduction options

Tool Framework (in Excel)

- Input Site Data
  - Flow and Contaminants
- Construction Costs – based on area and BMP
- Projected Flow and Contaminant Reduction
  - Based on literature review or local data
- Decision Analysis –
  - Site/user specific goals
  - User specified rankings of the goals

Methods: User Input

Site Specific Goals

- Flow Reduction (50%)
- Phosphorus Reduction (0.03mg/L SRP)
- Pathogen Elimination

Methods: User Input

Input Parameters

Water quality data
- Phosphorous and pathogens

Site characteristics (based on map)
- % impermeable area
- Potential siting locations of BMPs

Flow quantity
- Impermeable area

Methods:

User Interface: Drainage Areas

Q = ciA method	Rainfall Intensity (IN/HR)*		Runoff Coefficient "c" **		*Time estimated at a duration of 60 minutes
c = runoff coefficient	2 year	1.2	Permeable Surfaces	0.2	**Runoff coefficient estimate for Toledo, Ohio
I = rainfall intensity (in/hr)	5 year	1.6	Impermeable Surfaces	0.825	
A = area (acres)	10 year	1.9			
Q= ft^3/sec	25 year	2.35			

Porous Pavement Area		Bioswale Area		Rain Garden Area	
ENTER AREA (SQ. FT.)		ENTER AREA (SQ. FT.)		ENTER AREA (SQ. FT.)	
ENTER RUNOFF COEFFICIENT (c)		ENTER RUNOFF COEFFICIENT (c)		ENTER RUNOFF COEFFICIENT (c)	
ENTER RAINFALL INTENSITY (IN/HR)		ENTER RAINFALL INTENSITY (IN/HR)		ENTER RAINFALL INTENSITY (IN/HR)	
RUNOFF FLOW RATE (Q) (FT^3/SEC)	0.000	RUNOFF FLOW RATE (Q) (FT^3/SEC)	0.00	RUNOFF FLOW RATE (Q) (FT^3/SEC)	0.00

Existing Runoff Conditions (Permeable Area)		Existing Runoff Conditions (Impermeable Area)	
ENTER AREA (SQ. FT.)		ENTER AREA (SQ. FT.)	
ENTER RUNOFF COEFFICIENT (c)		ENTER RUNOFF COEFFICIENT (c)	
ENTER RAINFALL INTENSITY (IN/HR)		ENTER RAINFALL INTENSITY (IN/HR)	
RUNOFF FLOW RATE (Q) (FT^3/SEC)	0.000	RUNOFF FLOW RATE (Q) (FT^3/SEC)	0.000

Methods:

<u>User Interface</u>: Runoff and Pollutant Reduction

Flow and Reduction of Pollutant Potential for Selected BMP's					
Porous Pavement		Bioswales		Rain Gardens	
Overall Flowrate From Original Area (FT^3/SEC)	0.000	Overall Flowrate From Original Area	0.000	Overall Flowrate From Original Area	0.000
Calculated Runoff from Porous Pavement Area (FT^3/SEC)	0.000	Calculated Runoff from Bioswale Area (FT^3/SEC)	0.000	Calculated Runoff from Rain Garden Area (FT^3/SEC)	0.000
Flow Reduction Analysis					
Percentage of Flow Reduced*	96.69%	Percentage of Flow Reduced*	48.00%	Percentage of Flow Reduced*	98.90%
Actual Flow Reduced (FT^3/SEC)	0.000	Actual Flow Reduced (FT^3/SEC)	0.000	Actual Flow Reduced (FT^3/SEC)	0.000
Phosphorus Reduction Analysis					
Concentration of Phosphorus (water quality data)(mg/L)		Concentration of Phosphorus (water quality data)(mg/L)		Concentration of Phosphorus (water quality data)(mg/L)	
Percentage of Phosphorus Removed*	16.67%	Percentage of Phosphorus Removed*	33.33%	Percentage of Phosphorus Removed*	60.00%
Total Amount of Phosphorus Removed (mg/L)	0.000	Total Amount of Phosphorus Removed (mg/L)	0.000	Total Amount of Phosphorus Removed (mg/L)	0.000

Methods:

User Interface: Construction/Maintenance Costs

Porous Pavement				
Item	Unit	Quantity	Unit Price	Price
Existing Pavement Removal	SF		$1.80	$0.00
Porous Asphalt Pavement	SF		$6.66	$0.00
Porous Concrete Pavement	SF		$7.70	$0.00
Maintenance Cost (Based on Average Life Cycle)	SF		$0.04	$0.00
Pavement Cleaning Sweeper	EA		$62,310.00	$0.00
Average Life Cycle for Porous Pavement (years)	28			
			TOTAL COST	$0.00

Bioswale (sizing of Bioswale is roughly 20% of the total runoff area calculated)				
Item	Unit	Quantity	Unit Price	Price
Bioswale Construction	SF		$14.83	$0.00
Bioswale Landscaping	SF		$0.13	$0.00
Maintenance Costs (Based on Average Life Cycle)	SF		$0.08	$0.00
Average Life Cycle for Bioswales (years)	30			
			TOTAL COST	$0.00

Rain Garden (sizing of Rain Garden is roughly 20% of the total runoff area calculated)				
Item	Unit	Quantity	Unit Price	Price
Rain Garden Construction	SF		$9.40	$0.00
Reconnect Downspouts to Rain Gardens including concrete splash pads and rip rap flow channels	EA		$66.67	$0.00
Rain Garden Landscaping	SF		$0.08	$0.00
Maintenance Cost (Based on Average Life Cycle)	SF		$0.34	$0.00
Average Life Cycle for Rain Gardens (years)	30			
			TOTAL COST	$0.00

Methods:

Approximating Environmental Benefits

Phosphorous Reduction

- $8.00/lb of phosphorous

Aquifer Recharge

- $86.42 per acre-ft.

Reduction of Pathogens

- $1.80 per 1000 ft^3 of water

Green Values National Storm Water Calculator (www.cnt.org)
U.S. Bureau of Water Reclamation

Methods:

User Interface: Decision Analysis

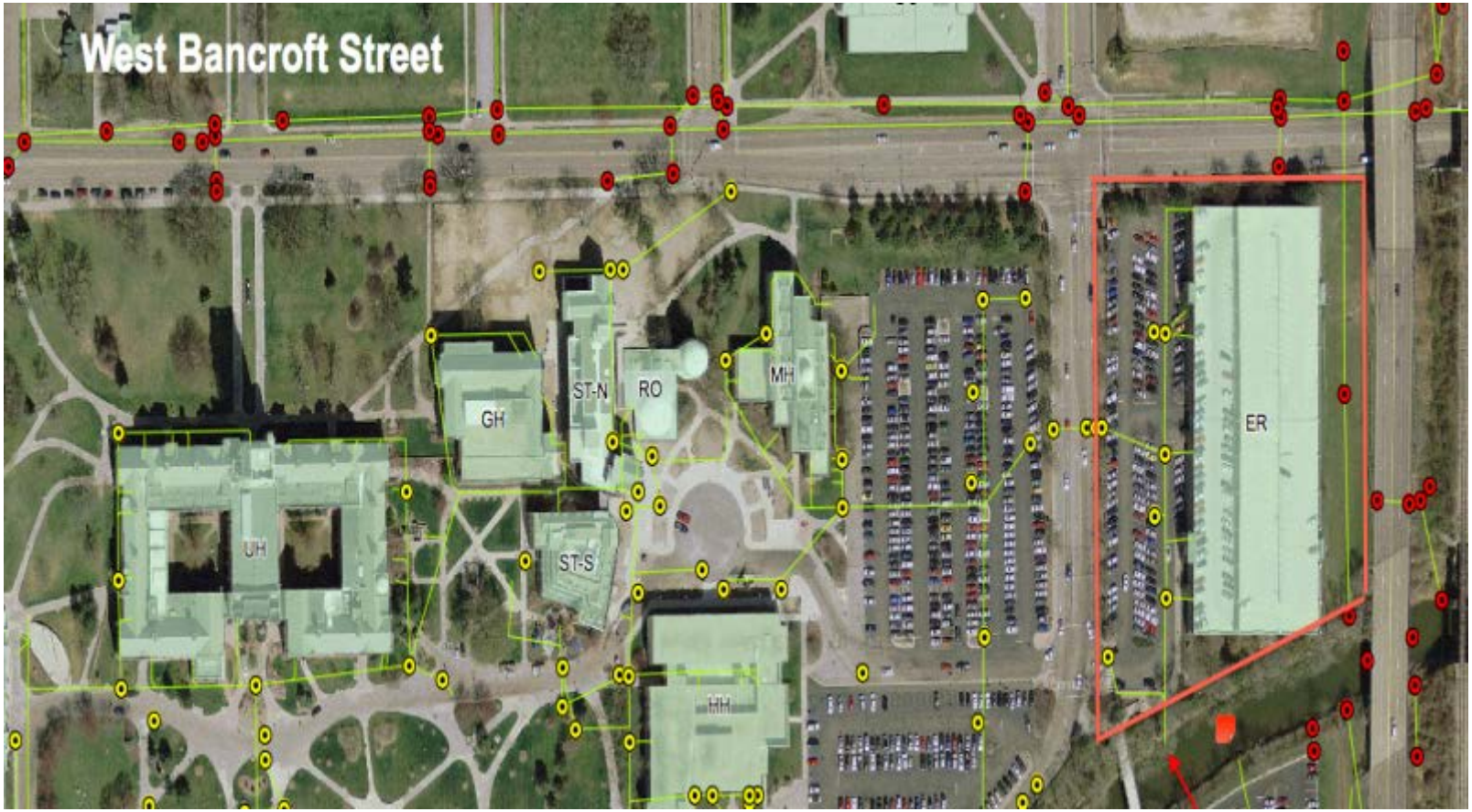
Results (Combined BMP Processes)			
	Goal	Actual	Goal Met (yes or no)
Flow Reduction	25.00%	#DIV/0!	
Phosphorus Reduction	0.05 mg/L	0	
Pathogen Reduction	Yes	Removed	
Payback Period	< 10 years	#DIV/0!	

Criteria for Water Quantity/ Quality Goals									
	Porous Pavement			Bioswales			Rain Gardens		
	Goal	Actual	Percentage	Goal	Actual	Percentage	Goal	Actual	Percentage
Flow Reduction (%)	25.00%	#DIV/0!	#DIV/0!	25.00%	#DIV/0!	#DIV/0!	25.00%	#DIV/0!	#DIV/0!
Phosphorus Reduction (mg/L)	0.05	0.000	0.00%	0.05	0.000	0.00%	0.05	0.000	0.00%
Pathogen Reduction	YES	YES	-	YES	YES	-	YES	YES	-
Payback Period (years)	10	#DIV/0!	#DIV/0!	10	#DIV/0!	#DIV/0!	10	#DIV/0!	#DIV/0!

BMP Ranking by Individual Technology (see notes on right for Weight Value)			
BMP Technology	Goal Weighting	Total Value	Comments
Porous Pavement		0	The highest total value is becomes the best option available based on flow reduction, pollutant reduction, and payback period
Flow Reduction			
Phosphorus/ Pathogen Reduction			
Payback Period			
Bioswale		0	
Flow Reduction			
Phosphorus/ Pathogen Reduction			
Payback Period			
Rain Garden		0	
Flow Reduction			
Phosphorus/ Pathogen Reduction			
Payback Period			

Notes for BMP Ranking	
Percentile	Weight
0-10%	1
11-20%	2
21-30%	3
31-40%	4
41-50%	5
51-60%	6
61-70%	7
71-80%	8
81-90%	9
91-100%	10

Results: East Ramp



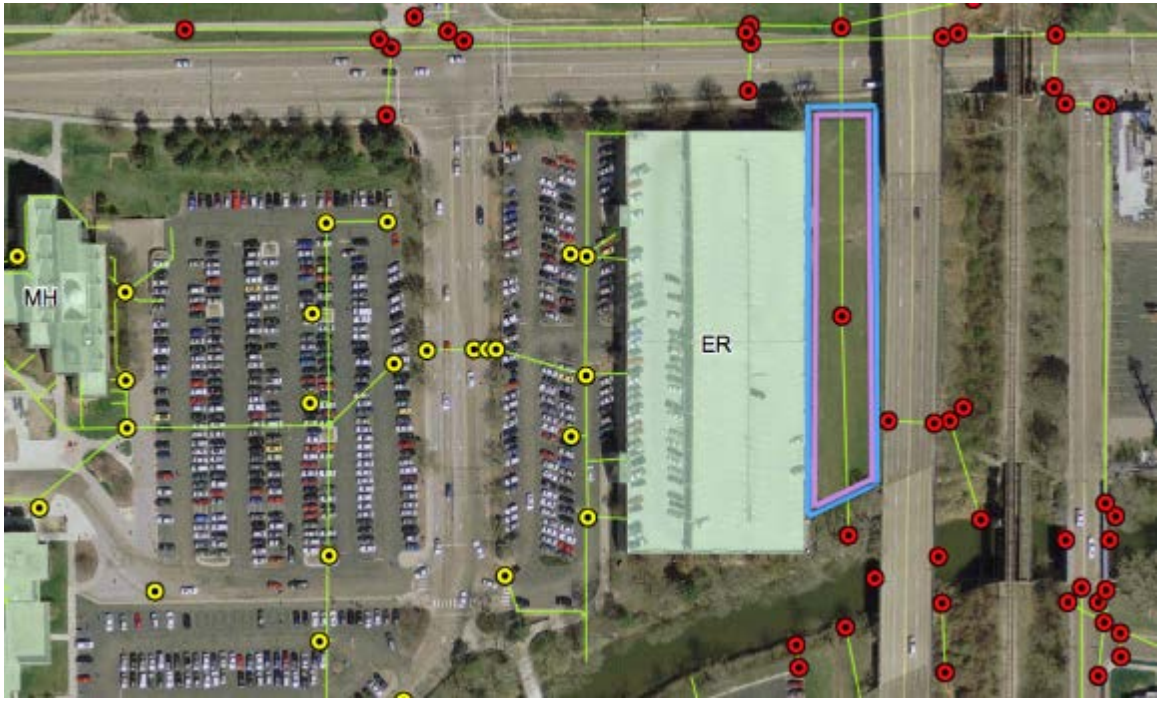
- 0. 05 mg/L P as orthophosphate
- Coliform and e. coli present

Site Characteristics

- Drainage Area
  - Flow rate = 3.72 ft^3/sec (2-year storm)
  - Total area approx. 4.5 acres
  - Northeast corner of campus
- Contaminant Data
  - 0. 05 mg/L P as orthophosphate
  - Coliform and e. coli present

Experimental Results

Proposed Solutions



3 Alternatives Considered

1. **Porous Pavement** (1 acre)
   - Convert portion of parking to permeable asphalt

2. **Bioswale** (East of Parking Garage)
   - contributing area (approx.160,000 ft^2)

3. **Rain Garden** (East of Parking Garage
   - contributing area (approx.160,000 ft2)

Construction and Maintenance Costs

Porous Pavement				
Item	Unit	Quantity	Unit Price	Price
Existing Pavement Removal	SF	43,650	$1.80	$78,570.00
Porous Asphalt Pavement	SF	43,650	$6.66	$290,709.00
Porous Concrete Pavement	SF		$7.70	$0.00
Maintenance Cost (Based on Average Life Cycle)	SF	43,650	$0.04	$48,888.00
Pavement Cleaning Sweeper	EA	1	$62,310.00	$62,310.00
Average Life Cycle for Porous Pavement (years)	28			
			TOTAL COST	$480,477.00

Bioswale (sizing of Bioswale is 10% of the total runoff area calculated)				
Item	Unit	Quantity	Unit Price	Price
Bioswale Construction	SF	155,575	$14.83	$230,717.73
Bioswale Landscaping	SF	155,575	$0.13	$2,022.48
Maintenance Costs (Based on Average Life Cycle)	SF	155,575	$0.08	$37,338.00
Average Life Cycle for Bioswales (years)	30			
			TOTAL COST	$270,078.20

Rain Garden (sizing of Rain Garden is 10% of the total runoff area calculated)				
Item	Unit	Quantity	Unit Price	Price
Rain Garden Construction	SF	155,575	$9.40	$146,240.50
Reconnect Downspouts to Rain Gardens including concrete splash pads and rip rap flow channels	EA	4	$66.67	$266.68
Rain Garden Landscaping	SF	155575	$0.08	$1,244.60
Maintenance Cost (Based on Average Life Cycle)	SF	155575	$0.34	$158,686.50
Average Life Cycle for Rain Gardens (years)	30			
			TOTAL COST	$306,438.28

Experimental Results

Cost Benefit Analysis

Bioswales		
Item	**Amount**	**Total**
Reduction of Flow (acre-ft)(per 2 year storm)	$86.42	$80.76
Reduction of Flow per year		$854.19
Reduction in Phosphorus (pounds)(per 2 year storm)	$9.00	$0.76
Reduction in Phosphorus per year		$8.06
Reduction in Pathogens (per 2 year storm)	$0.001800	$73.28
Reduction in Pathogens per year		$774.99
Total Cost for Construction and Maintenance	$270,078.20	
Savings per Year	$1,637.24	
Life Cycle Cost	$220,961.05	

Similarly:

Porous Pavement: $2,018.87/year

Rain Garden: $1890.76/year

Used these benefits to develop a cost benefit ratio – lifecycle benefits/lifecycle costs

Goals Assessment

		Porous Pavement		Bioswale		Rain Garden	
Flow Reduction (%)	50.00%	27.13%	**54.26%**	48.00%	**96.00%**	98.90%	**197.80%**
Phosphorus Reduction (mg/L)	0.03	0.042	**72.00%**	0.033	**90.00%**	0.020	**150.00%**
Pathogen Reduction	YES	YES		YES		YES	
Cost Benefit Ratio	1.00	0.12		0.18		0.19	

- Cost Benefit Ratio = Ratio of the life cycle environmental benefits to the life cycle costs

Decision Analysis

BMP Ranking by Individual Technology (see notes on right for Weight Value)			
BMP Technology	Goal Weighting	Total Value	Comments
Porous Pavement		17	The highest total value is becomes the best option available based on flow reduction, pollutant reduction, and payback period
Flow Reduction	6		
Phosphorus/ Pathogen Reduction	8		
life cycle ratio	3		
Bioswale		23	
Flow Reduction	10		
Phosphorus/ Pathogen Reduction	9		
life cycle ratio	4		
Rain Garden		24	
Flow Reduction	10		
Phosphorus/ Pathogen Reduction	10		
life cycle ratio	4		

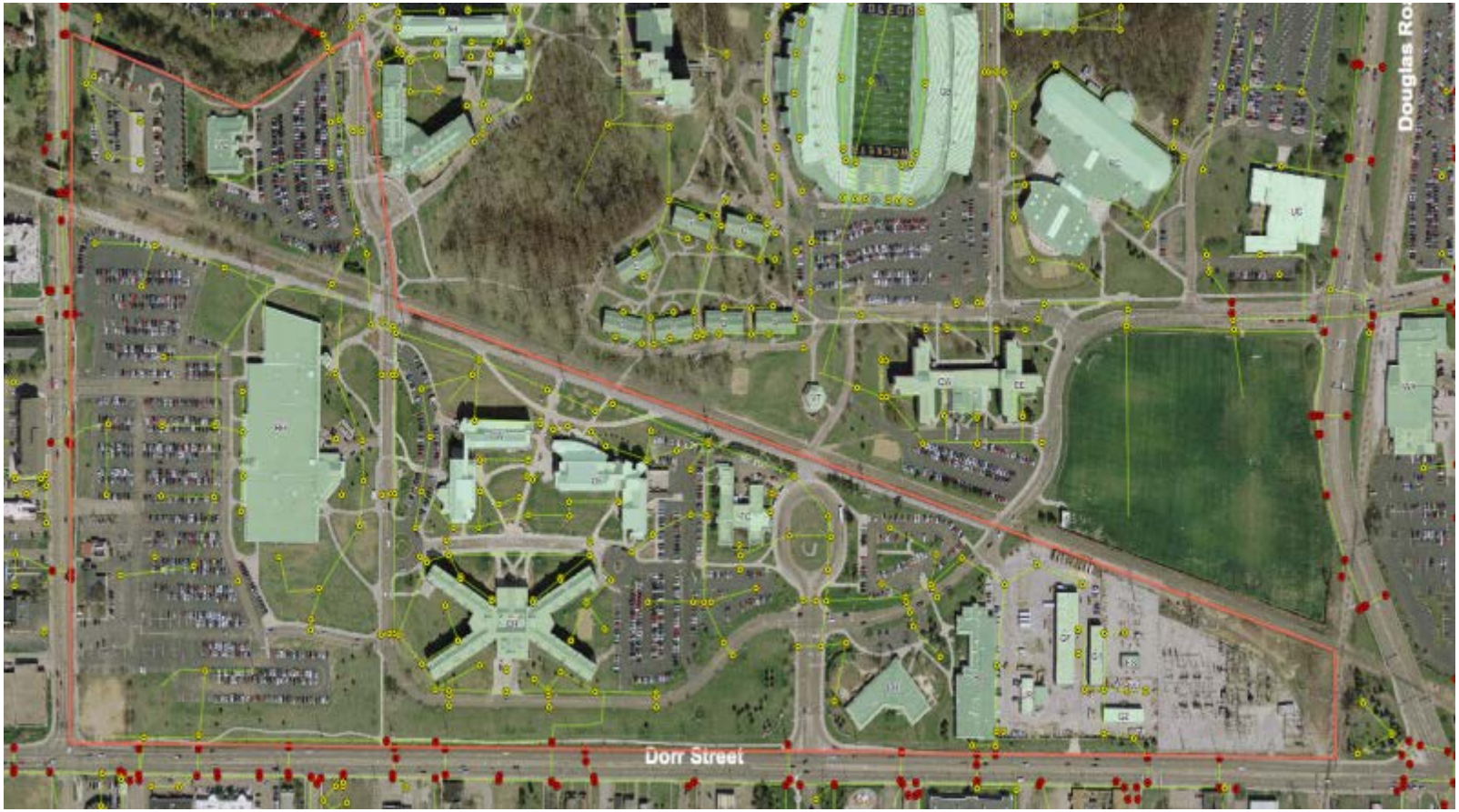
Notes for BMP Ranking		
Percentile	Cost Benefit	Weight
0-10%	0.0-0.05	1
11-20%	0.05-0.1	2
21-30%	0.1-0.15	3
31-40%	0.15-0.2	4
41-50%	0.2-0.25	5
51-60%	0.25-0.3	6
61-70%	0.3-0.35	7
71-80%	0.35-0.4	8
81-90%	0.4-0.45	9
91-100%	0.45-0.5	10

Discussion: East Ramp

Rain Garden is BEST Alternative

- Flow and Environmental Goals
  - Superior Flow Reduction
  - Superior P removal
- Costs
  - Slightly higher cost benefit ratio
  - However higher maintenance costs

Results: Southwest Corner

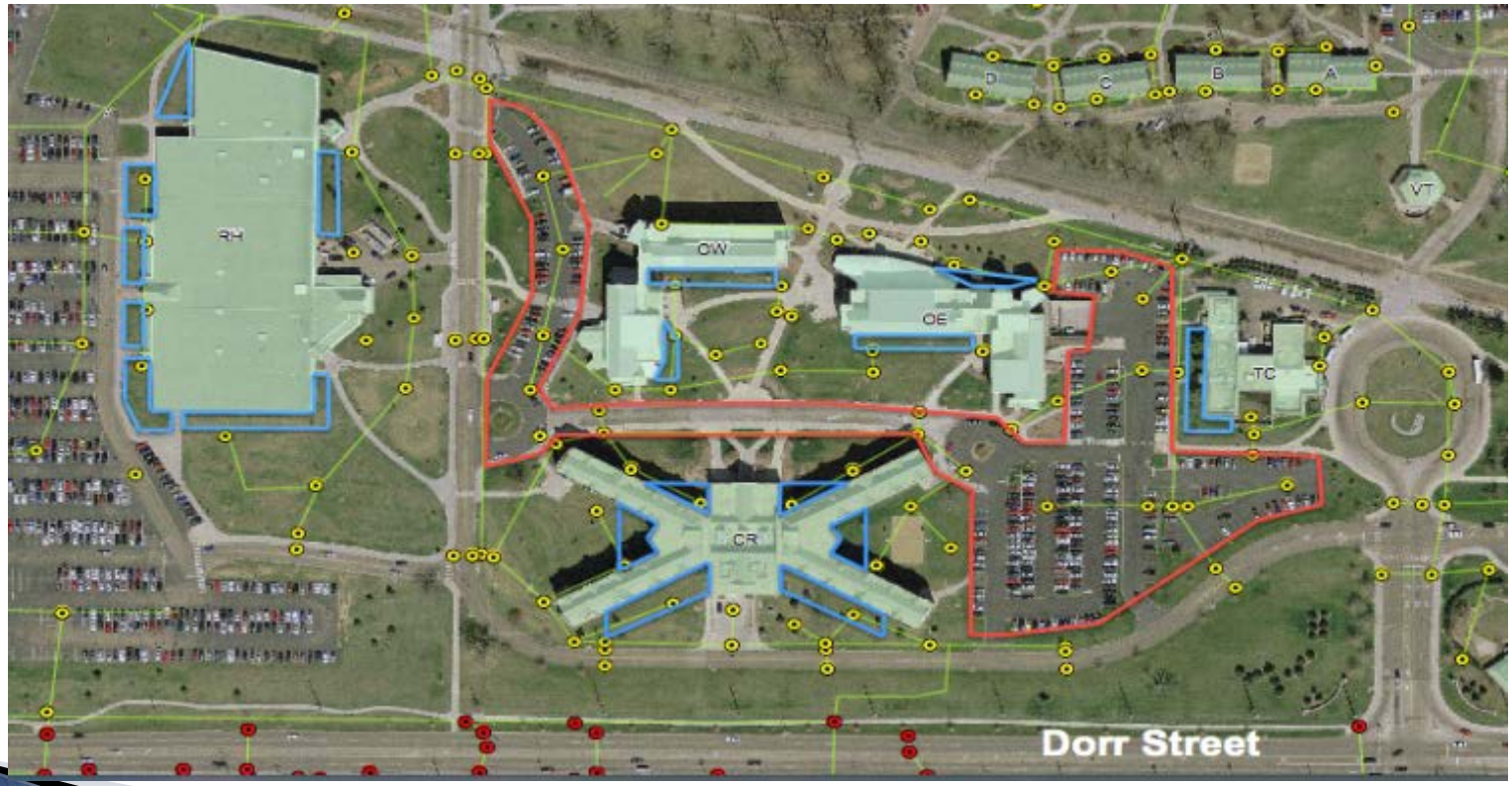


Site Characteristics

- Drainage Area
  - Largest flow rate on campus = 39.9 ft^3/sec (2-year storm)
  - Total area approx. 71 acres
  - Southwest corner of campus
- Contaminant Data
  - 0.07 mg/L phosphate as P
  - Mixed results on bacteria

Experimental Results

Proposed Solutions



Experimental Results

Construction And Maintenance Costs

Porous Pavement				
Item	Unit	Quantity	Unit Price	Price
Existing Pavement Removal	SF	197,162	$1.80	$354,891.60
Porous Asphalt Pavement	SF	197,162	$6.66	$1,313,098.92
Porous Concrete Pavement	SF		$7.70	$0.00
Maintenance Cost (Based on Average Life Cycle)	SF	197,162	$0.04	$220,821.44
Pavement Cleaning Sweeper	EA	1	$62,310.00	$62,310.00
Average Life Cycle for Porous Pavement (years)	28			
			TOTAL COST	$1,951,121.96

Bioswale				
Item	Unit	Quantity	Unit Price	Price
Bioswale Construction	SF		$14.83	$0.00
Bioswale Landscaping	SF		$0.13	$0.00
Maintenance Costs (Based on Average Life Cycle)	SF		$0.08	$0.00
Average Life Cycle for Bioswales (years)	30			
			TOTAL COST	$0.00

Rain Garden (10% of the contributing area)				
Item	Unit	Quantity	Unit Price	Price
Rain Garden Construction	SF	182562	$9.40	$171,608.28
Reconnect Downspouts to Rain Gardens including concrete splash pads and rip rap flow channels	EA	10	$66.67	$666.70
Rain Garden Landscaping	SF	182562	$0.08	$1,460.50
Maintenance Cost (Based on Average Life Cycle)	SF	182562	$0.34	$186,213.24
Average Life Cycle for Rain Gardens (years)	30			
			TOTAL COST	$359,948.72

Experimental Results

Cost Benefit Analysis

Porous Pavement			Rain Gardens		
Item	Amount	Total	Item	Amount	Total
Reduction of Flow (acre-ft)(per 2 year storm	$86.42	$98.97	Reduction of Flow (acre-ft)(per 2 year storr	$86.42	$93.73
Reduction of Flow per year		$1,046.73	Reduction of Flow per year		$991.33
Reduction in Phosphorus (pounds)(per 2 yea	$9.00	$0.29	Reduction in Phosphorus (pounds)(per 2 ye	$9.00	$0.00
Reduction in Phosphorus per year		$3.06	Reduction in Phosphorus per year		$0.00
Reduction in Pathogens (per 2 year storm)(per cubic foot of water treated)	$0.0018	$89.79	Reduction in Pathogens (per 2 year storm)(per cubic foot of water treated)	$0.001800	$85.04
Reduction in Pathogens per year		$949.69	Reduction in Pathogens per year		$899.43
Total Cost for Construction and Maintenance	$1,951,121.96		Total Cost for Construction and Maintenanc	$359,948.72	
Savings per Year	$1,999.49		Savings per Year	$1,890.76	
Life Cycle Cost	$1,895,136.27		Life Cycle Cost	$303,225.96	

Discussion: Southwest Corner

Best Alternative: Rain Garden

- Better cost benefit ratio (0.16 vs 0.03)
  - Lower construction cost
  - Higher O&M cost
- Superior P removal
- However, MINIMAL flow reduction
  - Does the rain garden really address the overall issues?
  - The tool does not reflect these challenges

Conclusion

1. BMPs have been developed to address storm water concerns but have not been quantitatively compared for retrofit sites using cost and environmental benefits analysis
   - Porous pavement, rain gardens, and bioswales selected as alternatives
   - Real site data was implemented
2. Decision Analysis
   - Produced quantitative environmental benefits that could be used to calculate a cost benefits
     - Reduction of flow and phosphorus
     - Payback period
3. Suitable for developed sites

Future Work

The Stormwater BMP Model should be expanded to include:

- More best management practices
- More site goals (nitrates, solids)

Challenges

- Reliable data
  - BMP performance data (wide ranging findings in literature)
  - O&M cost data
- Can we assign a monetary value to aesthetics and habitat restoration?

Ultimately, the Storm Water BMP Tool is a starting point for a decision analysis in retrofit situations

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- Ohio Lake Erie Commission – Small LEPF project titled “Green Storm Water Infrastructure”
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