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# Connecting TMDL Implementation to Stormwater Management

## Swan Creek Watershed Pilot

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Prepared for

U.S. Environmental Protection Agency -- Region 5
Ohio Environmental Protection Agency

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## Acronyms and Abbreviations

| | |
|---|---|
| AOC | Area of Concern |
| BMP | Best Management Practice |
| CIP | Capital Improvement Project |
| CSO | Combined Sewer Overflow |
| CWA | Clean Water Act |
| DEM | Digital Elevation Model |
| GI | Green Infrastructure |
| GIS | Geographic Information System |
| GLRI | Great Lakes Restoration Initiative |
| HSG | Hydrologic soil group |
| HSPF | Hydrologic Simulation Program FORTRAN |
| LA | Load Allocations |
| LID | Low Impact Development |
| LSPC | Loading Simulation Program C++ |
| MS4 | Municipal Separate Storm Sewer System |
| NCDC | National Climatic Data Center |
| NLCD | National Land Cover Database |
| NPDES | National Pollutant Discharge Elimination System |
| NPS | Nonpoint Source |
| PCS | Partners for Clean Streams |
| Ohio EPA | Ohio Environmental Protection Agency |
| RAP | Remedial Action Plan |
| SWMM | Storm Water Management Model |
| SUSTAIN | System for Urban Stormwater Treatment and Analysis Integration |
| TMACOG | Toledo Metropolitan Council of Governments |
| TMDL | Total Maximum Daily Load |
| USEPA | U.S. Environmental Protection Agency |
| WLA | Waste Load Allocations |
| WQv | Water quality volume |

# Executive Summary

As part of the overall Great Lakes Restoration Initiative (GLRI), work is underway to strategically pilot implementation of tools that can help guide stormwater Best Management Practice (BMP) planning in several Great Lakes area watersheds. Problems resulting from stormwater runoff associated with urban development exist throughout the basin. Many metropolitan areas in the Great Lakes region have waterbodies that are impaired due to stormwater sources, while 30 toxic hotspot *"Areas of Concern"* are still in need of cleanup.

Using information from the Swan Creek TMDL in northwest Ohio, the purpose of this pilot effort is to develop a regionalized framework that guides stormwater BMP implementation planning for the City of Toledo and the surrounding MS4 communities in Lucas County. One tool of particular interest is the System for Urban Stormwater Treatment and Analysis INtegration (SUSTAIN). Because SUSTAIN identifies cost-effective methods to address problems caused by urban stormwater, use of this tool could be an essential part of restoring the Great Lakes. The purpose and goals of this pilot project include:

- Providing a summary of cost-effective BMPs that will address existing stormwater runoff problems in the Swan Creek watershed.
- Providing a summary of optimal reduction strategies for runoff volumes and peak flows in one of the Swan Creek priority management areas.

The regionalized framework used by this pilot effort is built on a multi-scale analysis that evaluates Geographic Information System (GIS) data and identifies high priority catchments within the Swan Creek watershed for BMP implementation. High priority catchments are critical areas that have a disproportionate effect on water quality. This approach is consistent with a focus advocated by USEPA and a number of states; one that recognizes BMPs placed in critical locations can help treat small areas that produce disproportionate amounts of pollution. In addition, first and second order streams represent areas within an overall drainage network where the benefits of implementing green infrastructure (GI) and low impact development (LID) are most noticeable.

Key parts of the multi-scale analysis used to identify areas in the Swan Creek watershed where low order streams are likely affected by stormwater include:

- Reviewing water quality, flow, and general land use patterns at the watershed (10-digit HUC) and subwatershed (12-digit HUC) levels, highlighting areas where stormwater management efforts will be most effective in meeting TMDL allocations **[Section 3.1.1]**.

- Focusing on the Wolf Creek subwatershed because it has a range of different development intensities and is an area facing growth pressure. TMDL monitoring indicated that TSS levels in Wolf Creek are elevated relative to other parts of the Swan Creek watershed, and there is evidence that sediment from Wolf Creek causes higher TSS levels in the mainstem of Swan Creek. Wolf Creek also includes several jurisdictions, making it well suited to demonstrate the approach and tools for connecting TMDL implementation to stormwater management **[Section 3.1.1]**.

- Delineating catchments and estimating impervious cover associated with developed land use classes to target priority areas for BMP evaluation **[Section 3.1.2]**.

- Using National Land Cover Dataset (NLCD) information to prepare area estimates of stormwater source categories (e.g., parking, roads, roofs). Determining the approximate mix of impervious cover (type and amount) in priority catchments increases the value of BMP targeting and optimization by identifying those practices that will lead to achieving reduction goals for stormwater volume, peak flow, and pollutant loads **[Section 3.1.3]**.

The Loading Simulation Program C++ (LSPC) watershed model and SUSTAIN were both used to examine the Wolf Creek watershed and identify the key issues for addressing problems caused by urban stormwater. Among the important findings are the following:

- LSPC modeling showed that, on average, nearly three quarters of the water leaving Wolf Creek is from groundwater and interflow; the remainder is from surface runoff. Another way to look at these results is that stormwater BMPs have the potential to treat or retain over one quarter of the water currently leaving the Wolf Creek subwatershed. Similar analyses could be conducted in other Toledo area streams that would help quantify the potential benefit of BMP implementation for specific locations of concern **[Section 3.4]**.

- Roughly three quarters of the sediment entering Wolf Creek is due to bank and gully erosion caused by increased stream velocities from excess flow off impervious surfaces. These impervious areas are where stormwater BMPs have the greatest potential to provide maximum benefit for sediment reductions to meet TMDL management objectives **[Section 3.5]**.

- A variety of BMPs were evaluated and compared in terms of their ability to provide for volume reduction. Based on this analysis, assumptions associated with several design parameters exert a major effect on BMP selection and optimization results. Effectiveness curves generated with SUSTAIN's BMP assessment module should be used to develop sensitivity analyses, which bracket a range of assumptions for more significant parameters (e.g., capture depth, infiltration rate), prior to conducting full-scale targeting and optimization **[Section 4]**.

- The BMP effectiveness curves presented in the screening analysis are very informative for evaluating opportunities and constraints; particularly in identifying those practices that produce the greatest reductions at lower levels of implementation **[Section 5.2]**.

In short, the multi-scale analysis presented in this document is a logical approach that can be applied to other watersheds where stormwater is a water quality concern. Regardless of specific techniques used, it is important to have a methodology that targets critical areas for more detailed BMP evaluations. SUSTAIN does provide a viable tool to conduct these detailed assessments. Findings and recommendations on the use of the model from testing in other Great Lakes area watersheds has been documented in a separate report (TetraTech 2012).

Finally, assumptions (both design parameters and costs) exert a major effect on BMP assessment results. The BMP assessment module in SUSTAIN provides the ability to explore different types of implementation options. For instance, the level of implementation curve defines a relative range of volume (or pollutant) reductions that might be expected using BMP configurations of interest. It also highlights where there may be a point of diminishing returns. This information points stormwater managers towards potential solutions. However, ultimate BMP performance is driven by design specifications determined through actual field measurements.

# 1. Introduction

Located in the Western Lake Erie Basin, Swan Creek is a major tributary of the lower Maumee River. Although Swan Creek itself is only approximately 40 miles long, over 200 miles of creeks and ditches drain this 204-square mile watershed situated in northwest Ohio's Lucas, Fulton, and Henry counties. The watershed contains a mixture of development and land uses, ranging from ultra-urban to new development. Most of the Toledo area's recent growth and new construction has occurred in this watershed; it appears likely this trend will continue. Swan Creek has special ecological importance within its reaches buffered by metro parks such as Oak Openings -- the largest oak savanna / wet prairie complex in Ohio. This area sustains more state listed species than any other region of similar size in the state. Fishing and other recreational opportunities occur in the lower portions of the Swan Creek watershed.

In 2009, Ohio EPA established the Swan Creek Total Maximum Daily Load (TMDL) to address biological impairments in the watershed. The TMDL report lists urbanization and stormwater as having a direct effect on Swan Creek's water quality. The TMDL identified targets for several pollutants including total suspended solids (TSS), based on information in Ohio EPA guidance documents. The TMDL also established wasteload allocations (WLAs) for Municipal Separate Storm Sewer Systems (MS4s) located in the Swan Creek watershed. Because of the relationship between sediment and hydrology, stormwater management plays an important role in guiding Swan Creek TMDL implementation efforts.

Using information from the Swan Creek TMDL, the purpose of this pilot effort is to develop a regionalized framework that guides stormwater Best Management Practice (BMP) implementation planning for the City of Toledo and the surrounding MS4 communities in Lucas County. This pilot effort uses a multi-scale analysis to evaluate Geographic Information System (GIS) data and identify high priority catchments within the Swan Creek watershed for evaluating BMP implementation planning tools. One component of that effort is to test the System for Urban Stormwater Treatment and Analysis INtegration (SUSTAIN). The purpose and goals of the SUSTAIN pilot application include:

- Providing a summary of cost-effective BMPs that will address existing stormwater runoff problems in the Swan Creek watershed.
- Providing a summary of optimal reduction strategies for runoff volumes and peak flows in one of the Swan Creek priority management areas.

# 2. Approach

Development of effective stormwater management strategies is an important part of the transition from water quality program planning to implementation. The underlying goal of this project is to provide technical support for local stormwater planning and implementation efforts. A major focus of the work is analyzing and selecting the most appropriate suite of BMPs to achieve targeted flow volume and / or pollutant load reductions.

The general approach used to develop this pilot effort considers two aspects related to watershed planning and implementation. The first involves using a framework to address the scale issues associated with watershed management. A multi-scale analysis was used to examine problems caused by excess stormwater volumes and peak flows at the watershed-scale, building on information in the Swan Creek TMDL and the Swan Creek Watershed Plan of Action. The multi-scale analysis moves to progressively smaller levels based on priority concerns and implementation opportunities.

The second aspect of the general approach is the use of a five-step process to identify optimal BMPs for the Swan Creek watershed. The five-step process was conducted in tandem with the multi-scale analysis, and involves (1) establishing baseline conditions; (2) identifying potential BMPs; (3) evaluating opportunities and constraints; (4) estimating costs; and (5) building a stormwater management strategy.

## *2.1 Multi-scale Analysis*

Scale of analysis is an extremely important aspect of stormwater management. Any size land area can be selected for assessment. At the broadest scales (e.g., citywide), analyses of stormwater problems provide the context for policy formulation, laws, regulations, codes, and ordinances. At the finest scales (e.g., specific streets or residential lots), technical analyses provide the basis for project implementation and can be used to evaluate site-specific impacts. Mid-scale analyses (e.g., conducted at a watershed level) provide the context for management through a description and understanding of typical stormwater problems, as well as examining the capabilities that exist to address those problems.

Stormwater management often occurs in the mid-scale range, which allows for broad pattern recognition and process identification that in turn sets priorities for subsequent analysis. Information at this scale is typically used to guide decisions facing MS4 jurisdictions. For example, an assessment of water quality issues within a small urban watershed (e.g., 1,000 acres) might show that a priority problem is stream channel instability caused by unnaturally high peak flows associated with new development. Controlling peak flow can therefore be established as a high priority for the stormwater program.

Mid-scale analysis, however, does not work well for certain aspects of stormwater planning and implementation. For example, a watershed manager might not know if it is more effective to reduce peak flows through retrofitting existing detention ponds, or promoting distributed BMPs such as residential rain gardens. Furthermore, differences in the design of various BMPs can have a big impact on their performance. Analyses at a site level are better able to assess the potential effects of specific management activities, because specific BMPs and design criteria for those BMPs can be evaluated.

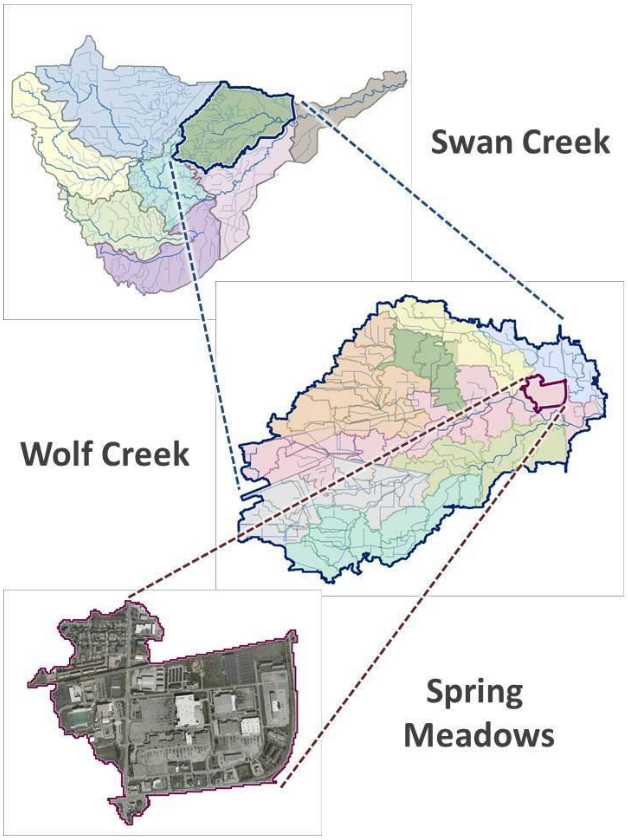


Figure 2-1. Swan Creek multi-scale analysis framework.

Regardless of the physical area selected, each level of stormwater analysis should draw context from one another and work together (Figure 2-1). For example, the technical assessments used to develop the Swan Creek Watershed Balanced Growth Plan, the Swan Creek Watershed Plan of Action, and the Swan Creek TMDL guide site-level project planning and decision-making by providing the overall watershed context.

Key problems and watershed goals are identified in the Balanced Growth Plan, the TMDL, and the Plan of Action; details of implementation are determined through analyses at finer scales. In turn, lessons learned from site level planning (e.g., site suitability evaluations, identification of the most cost effective BMPs, including their design specifications and their effectiveness) should be fed back to the Watershed Plan of Action and Balanced Growth Plan to provide refined context as management of the watershed progresses.

Stormwater managers should keep in mind that sometimes simplifying or generalizing the effects of management practices is appropriate. Sometimes very detailed simulation or testing of BMPs can be performed and the results extrapolated to a larger scale, with such studies described as *"nested"* modeling studies. A detailed evaluation of rain gardens or porous pavement, for instance, can be performed at the street scale using modeling or monitoring. Study results can then be used to evaluate the implications of using similar practices throughout the watershed.

In larger watersheds there are additional considerations in applying results to the entire watershed, as well as accounting for physical and chemical processes that occur on a large scale (e.g., in-stream nutrient uptake, the timing and duration of storm event peak flow at the mouth of the watershed). If the upstream conditions of a watershed significantly influence the downstream portions, it might be necessary to use a watershed model to evaluate the link between upstream and downstream indicators.

With these basic principles in mind, this pilot effort uses the following levels to address scale issues.

*Level 1* examines water quality, flow, and general land use patterns at the watershed (10-digit HUC) and subwatershed (12-digit HUC) levels. Key information that affects stormwater (e.g., rainfall-runoff relationships; distribution of pollutant loads; identification of higher density development) is used to target priority areas for subsequent analyses (e.g. catchments several hundred acres in size; groups of catchments with similar land use patterns). Delineating catchments and estimating impervious cover associated with developed land use classes are important components of Level 1.

Level 1 utilizes the BMP assessment module of SUSTAIN to generate performance curves. These curves bracket a range of assumptions for more significant parameters (e.g., capture depth, infiltration rate) to evaluate potential BMP effectiveness. The emphasis in Level 1 is on practices that could be applied in priority catchments, which will lead to achieving reduction targets for stormwater volume, peak flow, and pollutant loads. Level 1 can also be used to evaluate key factors affecting BMP performance. The example shown in Figure 2-2 illustrates the use of performance curves to examine the effect of different background infiltration rate assumptions on BMP performance.

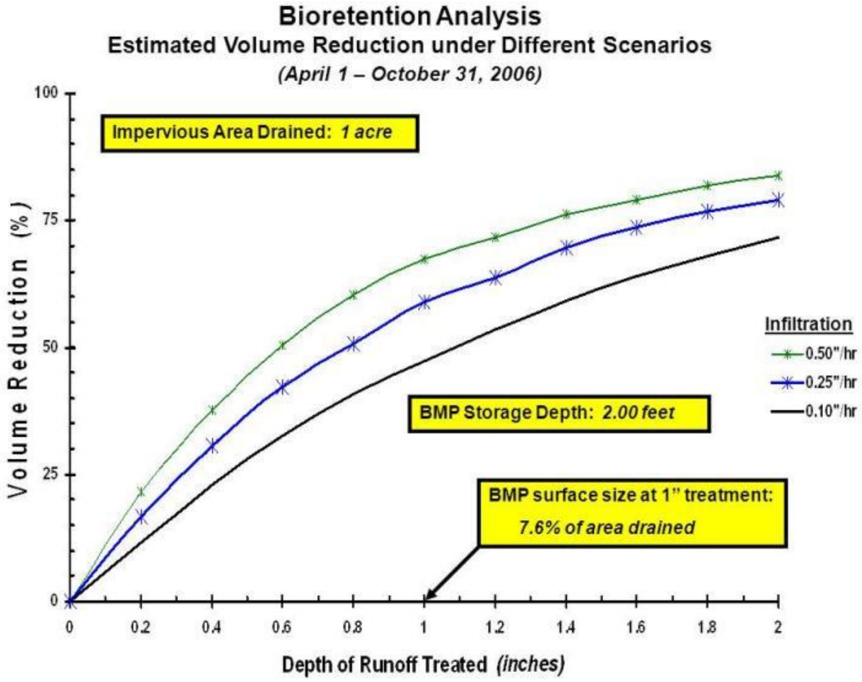


Figure 2-2. General BMP performance curve -- bioretention.

This figure demonstrates that the assumption for background infiltration rate has a relatively large effect on the estimated volume reduction and is therefore an important SUSTAIN input variable. Performance curves generated under Level 1 can be used to target areas within priority catchments where the use of certain BMPs might be encouraged (e.g., financial incentives offered through stormwater utility credits). In summary, the focus of Level 1 is to target priority areas for subsequent analyses and to highlight the sensitivity of key factors to be considered in identifying implementation opportunities or constraints that could prohibit the use of certain BMPs. The application and utility of Level 1 is described in greater detail later in Sections 2 and 4 of this document.

*Level 2* moves to a smaller scale by examining the mix of development and impervious cover present in priority catchments. This information enables the Level 2 analysis to develop estimates of stormwater volumes produced by various source areas (e.g., commercial parking, roads, residential roof). Figure 2-3 shows an example Level 2 schematic that serves as an organizational tool for determining where certain categories of BMPs could actually be implemented (e.g., porous pavement for parking, streets, and driveways; rain barrels coupled with rain gardens for residential roofs).

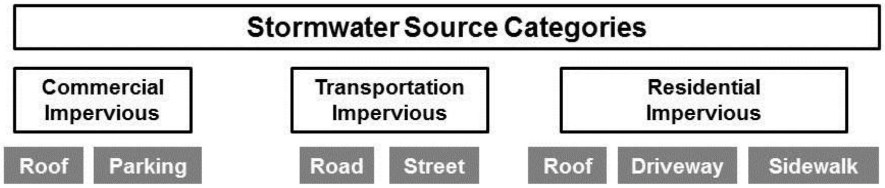


Figure 2-3. Stormwater source area types associated with Level 2 impervious cover analysis.

Because Level 2 is aimed at the catchment scale, the information on impervious cover type is more detailed. Example inventory data at this level includes: size of parking lots, street lengths and widths, number of homes, average driveway size, average roof size, sidewalk presence and size, etc. Prioritizing the impervious areas for treatment is also a component of Level 2. Pervious space is also inventoried; both for its contribution to runoff and for consideration of potential BMPs that could be incorporated into implementation planning.

Level 2 catchment inventories enable development of estimates that describe the maximum extent to which BMPs could be applied for each impervious surface type. In addition to assessing individual practices, Level 2 factors include the potential use of treatment trains (e.g., rain barrels followed by rain gardens, flow from porous pavement systems to bioswales, etc.). The Level 2 analysis utilizes the BMP assessment module of SUSTAIN to develop curves that describe reductions associated with different management strategies (basically, level of implementation curves). The application and utility of Level 2 is described in greater detail Sections 4 and 5.

*Level 3* draws information from Levels 1 and 2 to expand the analysis to include costs. A Level 3 evaluation uses the cost and optimization features of SUSTAIN to develop trade-off curves, such as the one shown in Figure 2-4. Each of the hundreds of circles within this curve represents a separate modeling run scenario with different assumptions for the number, type, and characteristics of BMPs. This type of analysis is best applied at the neighborhood (200 to 500 acre) scale because it allows for a detailed assessment of the potential BMPs and their design specifications.

The model simulates the ability of each of the practices individually, and in combination, to reduce peak stream flows, runoff volumes, or pollutant loads, taking into account the site-specific characteristics of the project area. Calculations are made at an hourly scale over a multi-year period to provide a full assessment of the response to each individual storm. At the same time, SUSTAIN assigns a locally-derived cost to each practice to achieve a total cost for each scenario. Plotting the combination of effectiveness and total cost for each of the hundreds of model runs results in the graph shown in Figure 2-4. The set of solutions at the far left and far top creates a cost-effectiveness curve.

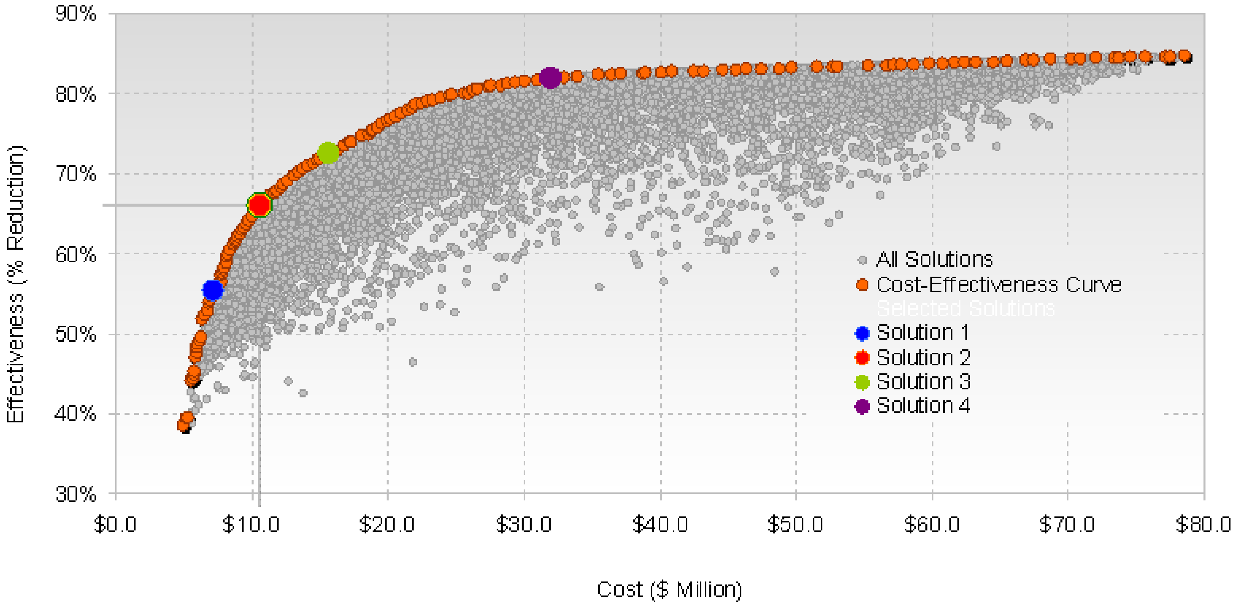


Figure 2-4. Example SUSTAIN trade-off curve.

## 2.2 Five-Step Process

Several activities included in this project support targeting and optimization. In particular, focus is placed on evaluating and design of stormwater BMPs (both structural and non-structural) that improve water quality conditions surrounding documented problems. A key objective is to prioritize source area and delivery mechanisms, in order to ensure effective use of available resources. The process used in this pilot effort to evaluate stormwater management opportunities involves five general steps. These include:

- ✓ Establish baseline conditions
- ✓ Identify BMPs to consider
- ✓ Evaluate opportunities and constraints
- ✓ Estimate costs
- ✓ Build targeting and optimization strategy

Figure 2-5 presents a general flow diagram of the process, identifying considerations and inputs. Basically, the process employed uses information on BMP effectiveness coupled with cost information to identify the most economical alternatives through an optimization step. The goal is to target specific implementation activities that address water quality problems related to stormwater.

*Baseline Conditions*. The initial step in evaluating and selecting BMPs to achieve stormwater management program goals is to understand baseline conditions. Identifying baseline conditions establishes a starting point from which improvements are made and progress is measured. Baseline conditions reflect the *existing* flow volume and / or pollutant loading from stormwater source areas and provide a yardstick for measuring BMP effectiveness.

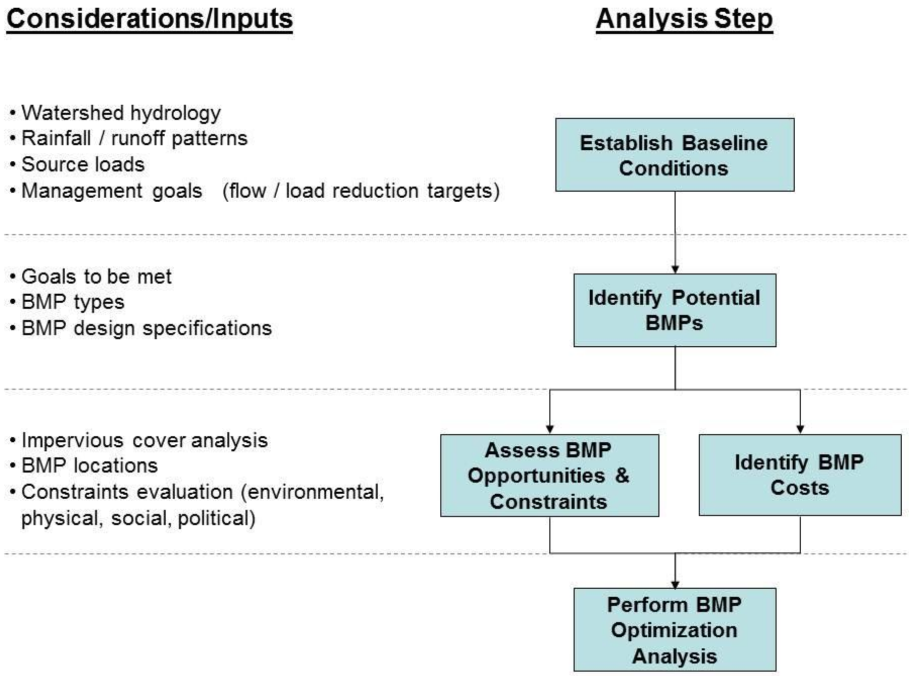


Figure 2-5. Process for BMP targeting and optimization.

*Potential BMPs*. Information about baseline conditions provides a benchmark that helps stormwater planners identify potential BMPs and / or combinations of BMPs to achieve overall program goals. In its simplest form, for example, the runoff volume produced by a certain design storm can be used to estimate detention needs. However, it is also important to understand other factors that might affect successful BMP implementation. These include environmental, physical, social, and political considerations. The goal of this step is to use baseline condition information coupled with local factors to generate a list of potential BMPs.

A task under this step includes inventorying existing BMPs to estimate current volume / pollutant reductions and identifying opportunities to maximize BMP performance. Understanding the existing suite of BMPs helps determine the type, quantity, and possible locations for additional BMPs to achieve progress toward implementation objectives.

*Opportunities and Constraints*. The goal of this step is to evaluate the list of potential BMPs and determine their overall performance at the watershed-scale. The intent is to identify options prior to selecting final BMP strategies. This involves examining the array of opportunities for placing identified BMPs in the subwatersheds or catchments of interest. Constraints (e.g., impervious cover types, soil infiltration rates, grading plans, local ordinances, social acceptance) are major considerations factored into this step.

Based on a comparison of the baseline conditions to watershed management goals, stormwater planners will have defined reduction targets. The baseline conditions analysis establishes the level of pollutant load reduction or other changes needed (e.g., reduction in peak flow, change in percent impervious area). Assessing configuration opportunities, stormwater planners can examine the expected performance of potential BMPs to help select those that will meet the goals identified in Step 1. Although challenging, this activity is essential to selecting BMPs with the most potential for making progress toward management objectives. For purposes of describing the overall process, this is discussed as a separate step after compiling the list of possible BMPs. However, stormwater planners can make assumptions about BMP opportunities and performance while generating the list.

*Costs*. Identifying BMP costs is an important undertaking for stormwater planners. Resource constraints can affect the number and type of BMPs that can be used to achieve progress toward program goals. At a minimum, stormwater planners should compare costs and expected pollutant reductions to ensure the final suite of BMPs will provide the most reductions for the least amount of money. For stormwater planners engaged in a more rigorous BMP optimization analysis, cost information on potential BMPs is essential for developing cost-effectiveness ratios (i.e., cost per unit of pollutant removed) to compare different BMPs for one type of land use or across several types of land uses.

*Targeting and Optimization*. A goal of targeting and optimization is to examine management strategies based on opportunities consistent with site suitability considerations. For example, slope and soil infiltration rates are key factors that affect successful performance of structural BMPs. At this stage, stormwater planners have identified the suite of feasible BMPs based on site-specific needs, goals, opportunities and constraints. Depending on the size of the planning area, the implementation goals and the resources available, there could be any number of combinations of BMP types and locations to meet goals.

To select the final BMP strategy, stormwater planners generally evaluate, prioritize or rank the potential BMPs based on relevant decision criteria, either qualitatively or quantitatively. Decision criteria likely include short-term and long-term costs, BMP performance, expected progress toward watershed goals, and compatibility with other planning priorities and objectives. Depending on the area and number of BMPs needed, a stormwater planner might use a qualitative evaluation of potential BMPs and targeted locations based on professional and local knowledge. Simple spreadsheet analysis could also be employed to identify the most appropriate and cost-effective scenario. While adaptive management can support the short-term implementation of priority BMPs with subsequent evaluation and modification, a stormwater planner tries to identify the most effective scenario first to minimize the need for additional BMPs and associated implementation costs. Therefore, the level of detail for the evaluation to select final BMPs can be driven by the benefit of the additional analyses compared to the potential costs to correct ineffective implementation.

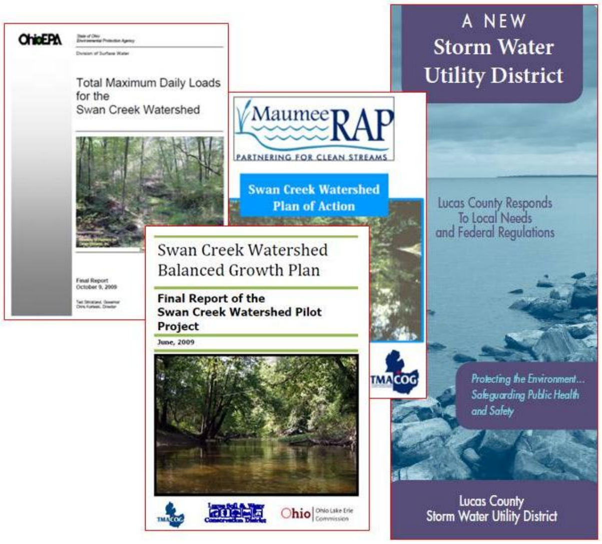
## 2.3 Key Questions

One aspect of this pilot project is to examine the applicability of SUSTAIN for use as part of the overall effort to connect TMDL implementation to stormwater management in the Swan Creek watershed. In contemplating the use of SUSTAIN to assess BMP opportunities and constraints, key questions can guide planning efforts. These questions bracket the range of viable options and ultimately help frame stormwater management decisions. Relative to this pilot effort, key questions include:

- Where and what amount of paved areas could be converted to bioretention or porous pavement to meet a volume reduction target?
- Do bioswales offer viable options? Are there any suitable locations where infiltration trenches could be used (e.g., along arterial roads, in large parking areas)?

- How many homes in need to install rain gardens to achieve noticeable reductions in stormwater volume? Where would be the best locations to target?
- What are some treatment train design alternatives (including use of rain barrels)?
- What is the minimum acceptable operation and maintenance needed?
- How do assumptions associated with the different scales affect information needed by stormwater program managers to make subsequent decisions regarding development of cost-effective strategies?

## *2.4 Local Stormwater Management Efforts*



A key aspect of the approach towards this pilot project is to build on local stormwater management work and activities. Concurrent with growth and development in the Swan Creek drainage, several efforts have occurred over the years that relate to stormwater management. Most recently, Lucas County created a Storm Water Utility District to provide a funding source for support of Capital Improvement Projects (CIPs) that address water quality and flooding problems. The majority of the Swan Creek watershed is also located within the Maumee Area of Concern (AOC). The Maumee Remedial Action Plan (RAP) was established to address the array of water quality problems in the AOC. The Maumee RAP is a cooperative effort of citizens, businesses, and industry working together with governments to restore the areas waters to *"fishable and swimmable"* conditions.

The RAP is focused on the implementation of projects to improve the water quality of the region. One effort conducted through the RAP was the Swan Creek Plan of Action; a watershed plan to guide future restoration and preservation efforts on Swan Creek and its tributaries. The plan took a comprehensive look at the watershed, breaking it into prioritized categories that describe the water quality impairments and make recommendations to address those issues. Other planning efforts include the Swan Creek Watershed Balanced Growth Initiative and Swan Creek Watershed Balanced Growth Plan (Swan Creek BGP). These watershed-scale land use planning activities are designed to protect water quality in Lake Erie, improve the quality of life, and ensure economic growth throughout the watershed.

# 3. Baseline Conditions

Effective implementation planning starts with a review of baseline conditions and watershed-scale factors that contribute to documented water quality problems in Swan Creek. In particular, an understanding of the setting, water quality concerns, and basic hydrologic processes at work in this watershed is the heart of stormwater management. Land use and climate are the dominant drivers of baseline conditions. A key component of protecting water resources is keeping the water cycle in balance (SEMCOG, 2008).

The movement of rainfall from the atmosphere to the land, then back to the atmosphere, is a naturally continuous process. The balanced water cycle of precipitation, evapotranspiration, infiltration, groundwater recharge, and stream base flow is a key part of sustaining fragile water resources (Figure 3-1). A critical part of this analysis involves an assessment of watershed characteristics and rainfall patterns that affect the resultant runoff. Source areas and delivery mechanisms that will be the focus of targeted BMPs are driven by watershed response to precipitation. Describing the frequency and magnitude of rain events in conjunction with an analysis of associated runoff are key considerations in determining appropriate stormwater management strategies for Swan Creek.

Approximately 34 inches of precipitation falls on the Swan Creek watershed each year, based on climate records collected from 1955 – 2010 at Toledo Express Airport. This precipitation results in approximately 12 inches of runoff, based on USGS stream flow data for the Ottawa River during that same period. The Ottawa River was used as a proxy for flow in the Swan Creek watershed because 1) there are no USGS flow gages in the watershed and 2) the Ottawa River provides the best land use comparison of USGS flow gages in the area (TetraTech, 2012). Although runoff at the Ottawa gage does not represent a completely undeveloped area, it does provide information that can be used to frame a discussion of baseline conditions for the Swan Creek watershed. This includes a review of the project area setting, precipitation patterns and local factors that influence runoff.

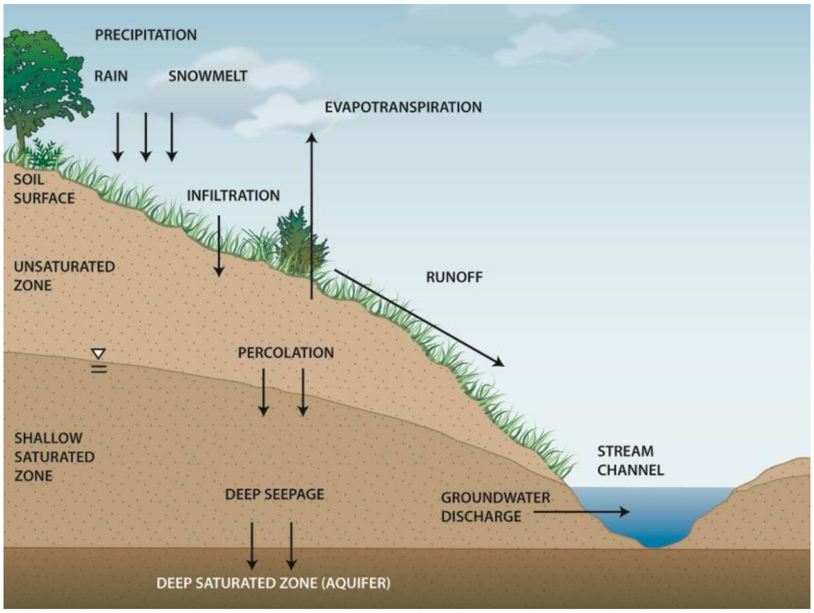
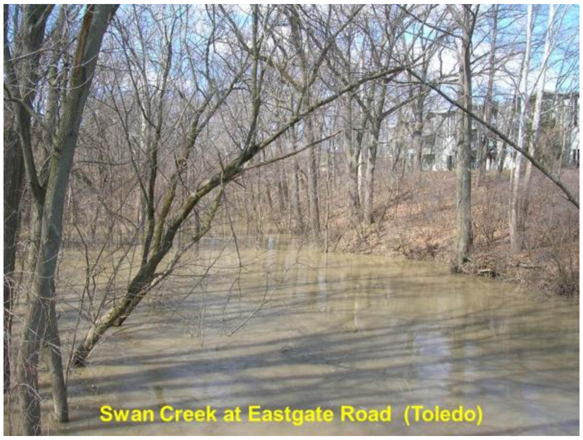


Figure 3-1. Water cycle.

## 3.1 Project Area Setting and Concerns

### 3.1.1 Swan Creek Watershed



Although Swan Creek itself is only about 40 miles long, over 200 miles of creeks and ditches drain this 204-square mile watershed situated in northwest Ohio (Figure 3-2). Land use in the Swan Creek watershed, shown in Figure 3-3, has changed rapidly over the past several decades. In 1970, the watershed was primarily rural / agricultural outside of the City of Toledo. However, rapid growth in the 1980's and 1990's has transformed the landscape. Between 1988 and 1995, agricultural land use declined nearly 20% (over 16,000 acres), with a corresponding increase in residential and commercial land uses during the same period (Levine, et al, 2000). Although Swan Creek can still be considered a rural watershed in the general sense, suburban features, such as strip malls and residential subdivisions are increasingly more visible.

Commercial development along State Route 2 (Airport Highway), residential development in Monclova, Springfield, and Spencer Townships, and extended water service to Delta in Fulton County have begun suburbanizing large portions of the Swan Creek watershed. This development has resulted in channelization of waterways, habitat alteration, loss of open space and natural floodways, while facilitating further development. Although the shifts in land use has been economically beneficial to the region, the increase in impervious surface area (roads, parking lots, buildings, etc.) produces additional stormwater draining into Swan Creek and its tributaries.

In 2006, the Ohio Environmental Protection Agency (Ohio EPA) evaluated the biological health and water quality of Swan Creek. Results indicated that most segments are in partial or non-attainment of the Warm Water Habitat (WWH) designated aquatic life use. Degraded habitat and sedimentation are high concerns relative to biological impairments in the Swan Creek watershed. This assessment resulted in Ohio EPA establishing the Swan Creek TMDL in 2009. The TMDL included targets and allocations for total suspended solids (TSS), based on information in Ohio EPA guidance documents. Because of the relationship between sediment and hydrology, stormwater management plays an important role of stormwater in guiding Swan Creek TMDL implementation efforts.

Development of a regionalized framework to guide stormwater BMP planning efforts starts with a review of land use information (Level 1 in the multi-scale analysis). Figure 3-2 shows the major subwatersheds that comprise the Swan Creek watershed, while Figure 3-3 presents 2006 National Land Cover Database (NLCD) information. As indicated earlier, development in the Swan Creek watershed has led to an increase in impervious surface area where it has occurred. In turn, the conversion of pervious land to impervious surfaces results in additional stormwater draining into Swan Creek and its tributaries.

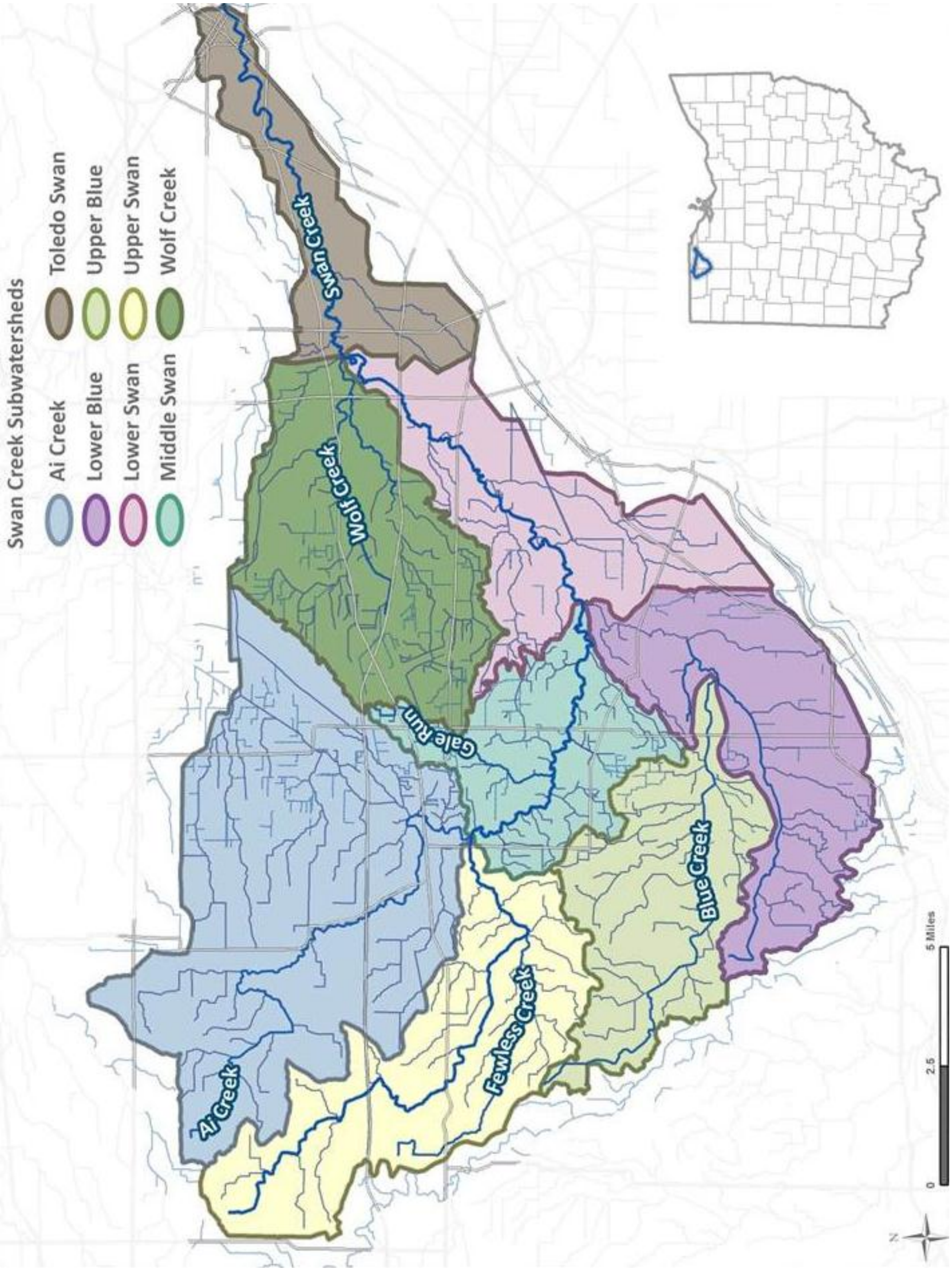


Figure 3-2. Swan Creek watershed.

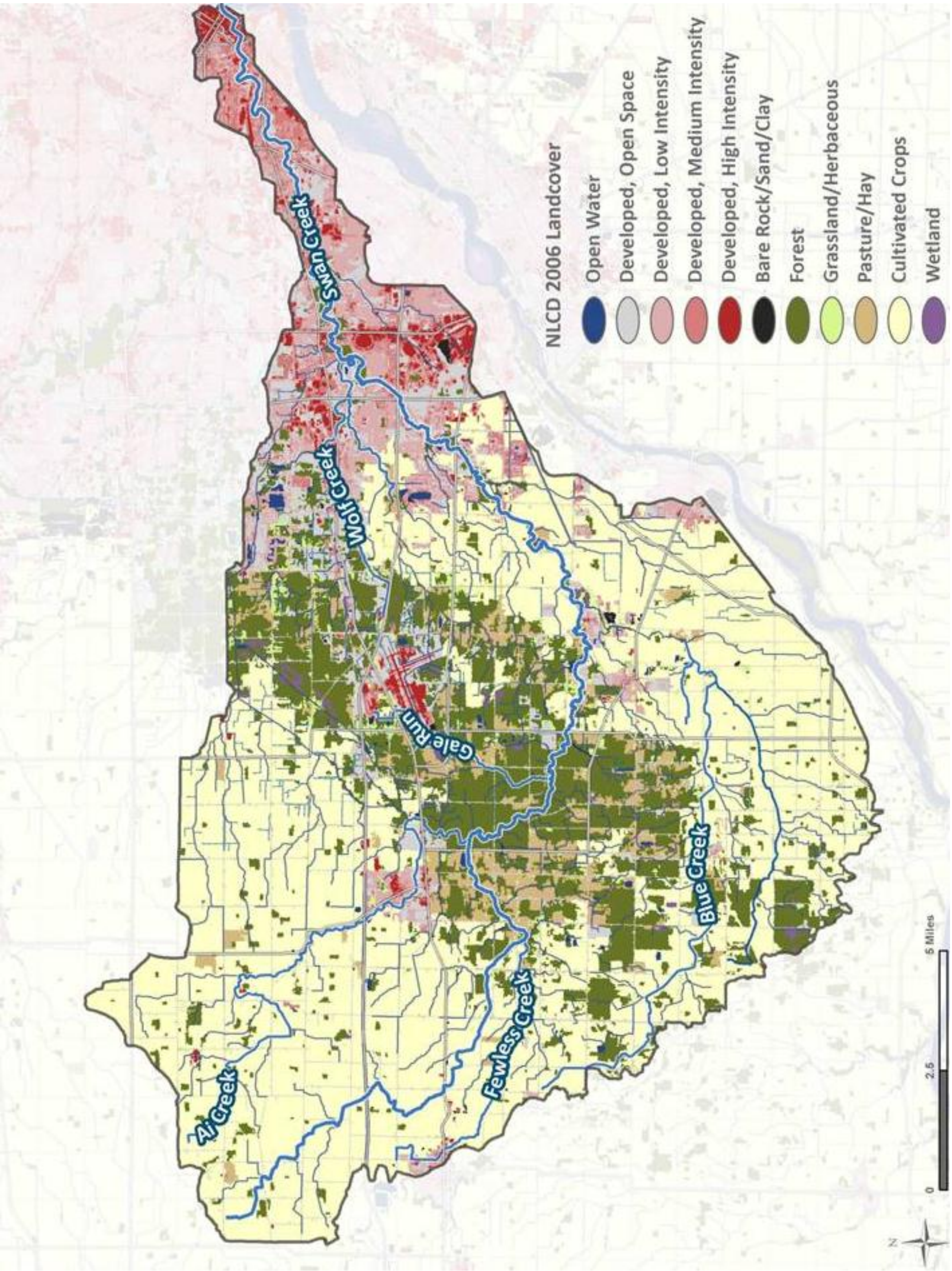


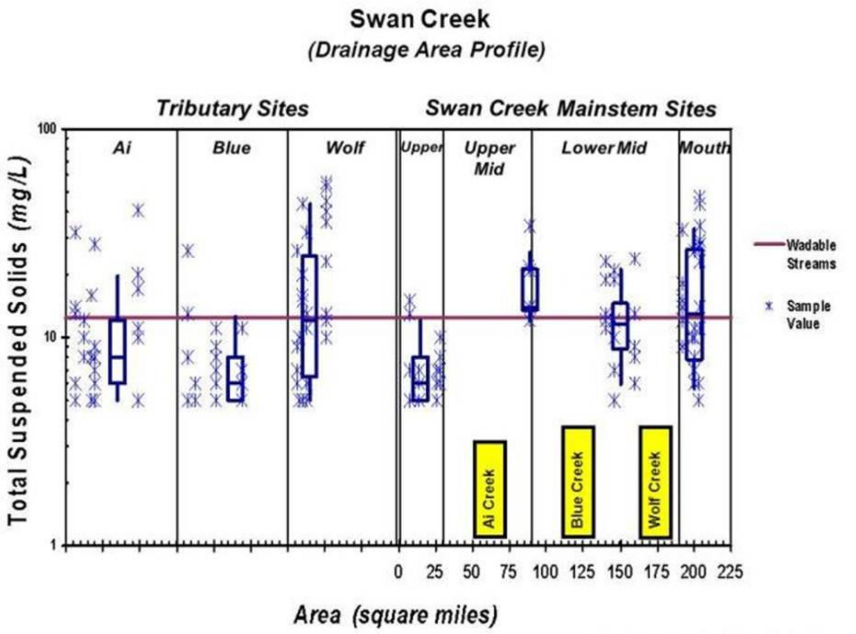
Figure 3-3. Swan Creek watershed land use *(2006 NLCD)*.

NLCD provides a summary of land use information; the highest development intensities occur in the lower three subwatersheds (Table 3-1). Wolf Creek represents an interesting subwatershed in terms of stormwater management; it has a range of different development intensities and is an area facing growth pressure. TMDL monitoring indicated that TSS levels in Wolf Creek are elevated relative to other parts of the Swan Creek watershed (data shown in Figure 3-4 and sample locations in Figure 3-5). Consistent with this observation, TSS levels increase in the mainstem of Swan Creek below its confluence with Wolf Creek.

Wolf Creek includes several jurisdictions, making it well suited to demonstrate the approach and tools for connecting TMDL implementation to stormwater management. The map presented in Figure 3-5 displays catchments within the Wolf Creek subwatershed that can be used to examine potential stormwater source areas and evaluate BMP implementation opportunities.

Table 3-1. Swan Creek subwatershed land cover summary *(2006 NLCD)*.

| **Subwatershed** | **Development Intensity** | | | | **Crop** | **Pasture / Grass** | **Forest** | **Other** |
|---|---|---|---|---|---|---|---|---|
| | ***High*** | ***Med*** | ***Low*** | ***Open*** | | | | |
| Upper Swan | 0% | 0% | 2% | 6% | *74%* | *6%* | *11%* | *1%* |
| Ai Creek | 0% | 1% | 3% | 7% | *70%* | *5%* | *13%* | *1%* |
| Middle Swan | 1% | 1% | 3% | 9% | *10%* | *19%* | *55%* | *2%* |
| Upper Blue | 0% | 0% | 2% | 6% | *78%* | *2%* | *10%* | *2%* |
| Lower Blue | 0% | 0% | 2% | 7% | *48%* | *10%* | *32%* | *1%* |
| Lower Swan | 1% | 4% | 13% | 13% | *54%* | *3%* | *9%* | *3%* |
| Wolf Creek | 3% | 6% | 15% | 24% | *14%* | *9%* | *26%* | *3%* |
| Toledo Swan | 14% | 25% | 38% | 15% | *0%* | *0%* | *6%* | *2%* |



*(Data reported by Ohio EPA)*

Figure 3-4. Swan Creek total suspended solids -- drainage area profile.

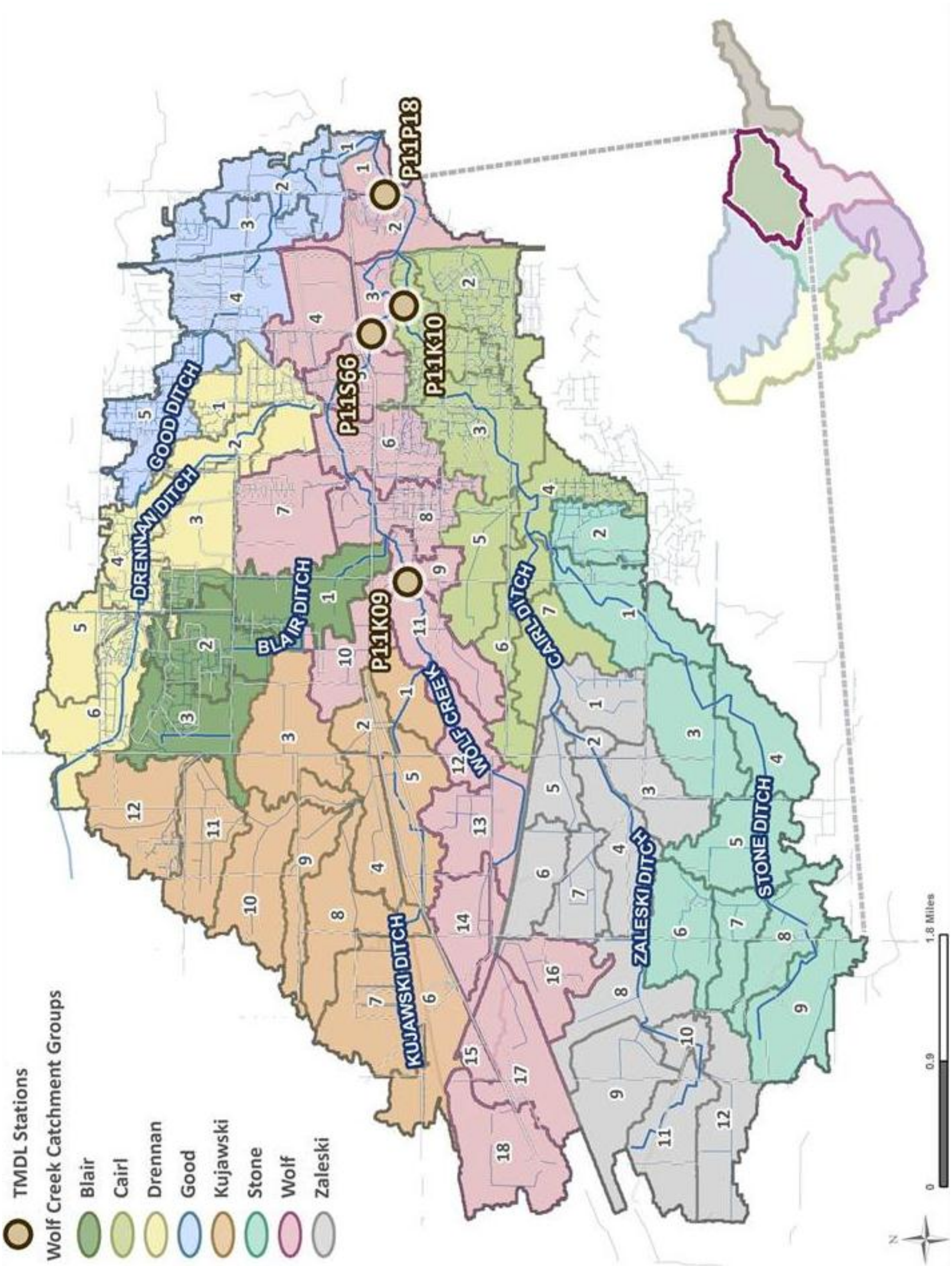


Figure 3-5. Wolf Creek subwatershed TMDL monitoring sites and catchment groups.

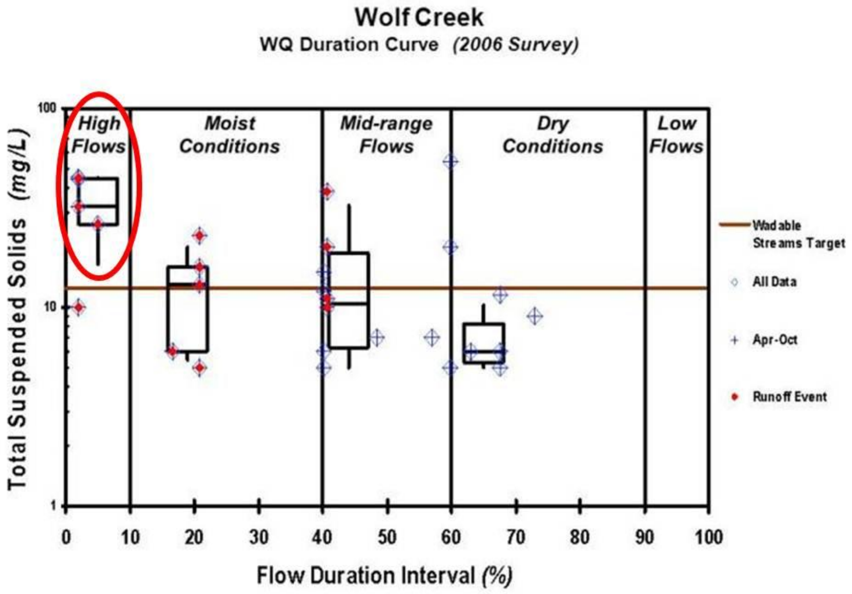
### *3.1.2 Wolf Creek Subwatershed*

Wolf Creek serves as an example subwatershed to demonstrate use of the multi-scale analysis for connecting Swan Creek TMDL targets to stormwater management program implementation. As shown in Figure 3-4, Wolf Creek exceeds the wadeable streams target for TSS. The TMDL used a duration curve framework to establish loading capacities and WLAs for MS4 communities. Table 3-2 summarizes the TSS reduction targets based on TMDL assessment sites shown in Figure 3-5. Figure 3-6 displays the TMDL monitoring data using the duration curve framework. The graph shows that elevated TSS levels occur either under high flow conditions or are associated with runoff events.

It is important to again note that methods presented in this report can be applied to other locations in the Swan Creek watershed (as well as to other areas in the Maumee AOC). The Wolf Creek subwatershed and priority catchments are simply used to illustrate the framework and process.

Table 3-2. Wolf Creek TMDL reduction targets for total suspended solids.

| **TMDL Assessment Site** | | **TSS Reduction Target *(%)*** | | | | |
|---|---|---|---|---|---|---|
| **ID** | **Location** | **High Flows** | **Moist Conditions** | **Mid-Range Flows** | **Dry Conditions** | **Low Flows** |
| **P11K09** | *Wolf Creek (RM 4.06)* | 0% | 0% | 0% | 0% | No Data |
| **P11S66** | *Wolf Creek (RM 1.96)* | **24%** | 0% | 0% | 0% | No Data |
| **P11K10** | *Cairl Creek (RM 1.32)* | **85%** | **88%** | **75%** | **82%** | No Data |
| **P11P18** | *Wolf Creek (RM 0.48)* | **73%** | **67%** | **52%** | **53%** | No Data |



*Flow duration interval based on Ottawa River gage* *(Data reported by Ohio EPA)*

Figure 3-6. Total suspended solids water quality duration curve -- Wolf Creek.

The TMDL establishes TSS reduction needs for Wolf Creek. Monitoring data indicates that stormwater management plays an important role in meeting these reductions. The next step is to extend the multi-scale analysis to a finer resolution by targeting potential priority stormwater source areas using GIS tools. Locations with high levels of impervious cover are logical focus points. Figure 3-7 shows the 2006 NLCD GIS data layer for Wolf Creek; data that includes development intensity for estimating impervious area. GIS technology also enables Wolf Creek to be delineated into catchments, shown earlier in Figure 3-5. In combination, this provides a method to identify priority locations that warrant a detailed assessment of potential BMP implementation opportunities based on impervious surface area estimates.

Table 3-3 describes typical land uses associated with the NLCD development intensity categories. Impervious cover estimates can be assigned to each class (it is important to note that a range is also specified). This provides a framework for prioritizing catchments using relative impervious surface estimates, as illustrated in Table 3-4 for two catchments. Estimates were also developed using the upper and lower values in Table 3-3; this resulted in similar priority ratings.

A study area was selected from the larger Wolf Creek subwatershed for this pilot effort (Figure 3-8). Catchments were selected because they include a mixture of commercial areas, newer and older residential development with varying lot sizes and degrees of stormwater retention, apartment complexes, and a high school with significant impervious area.

Table 3-3. NLCD developed land class impervious cover estimates.

| **NLCD Development Category** | **Typical Land Uses** | **Impervious Cover Estimate** ***(percent)*** | |
|---|---|---|---|
| | | **Average** | ***Range*** |
| High Intensity | Commercial *(retail, office)*<br>Institutional *(school, hospital),* Apartments | 85 | *(80-90)* |
| Medium Intensity | Residential | 55 | *(50-60)* |
| Low Intensity | Residential, Recreational | 20 | *(15-25)* |
| Developed Open Space | | 5 | *(0-10)* |

Table 3-4. Impervious area estimates for two priority Wolf Creek catchments.

| **Catchment** | **Area** *(acres)* | **NLCD Development Category** *(acres)* | | | | **Impervious Area Estimate** | |
|---|---|---|---|---|---|---|---|
| | | *High* | *Medium* | *Low* | *Open* | *(acres)* | *(%)* |
| Wolf 4 | 282.7 | 89.4 | 93.4 | 48.1 | 50.2 | 139.5 | 49% |
| Good 2 | 253.5 | 35.3 | 107.1 | 44.5 | 64.6 | 101.0 | 40% |

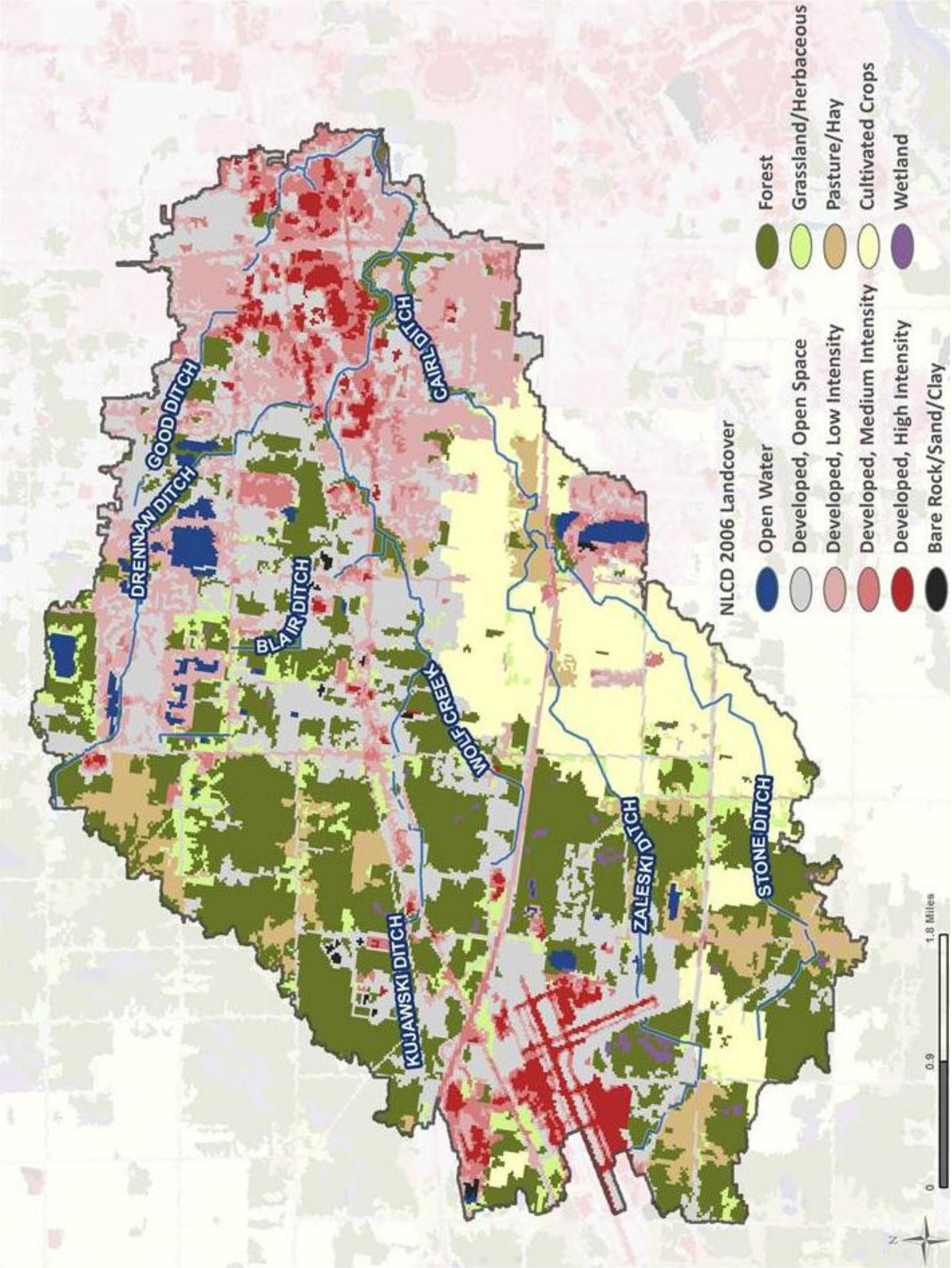


Figure 3-7. Wolf Creek subwatershed land use.

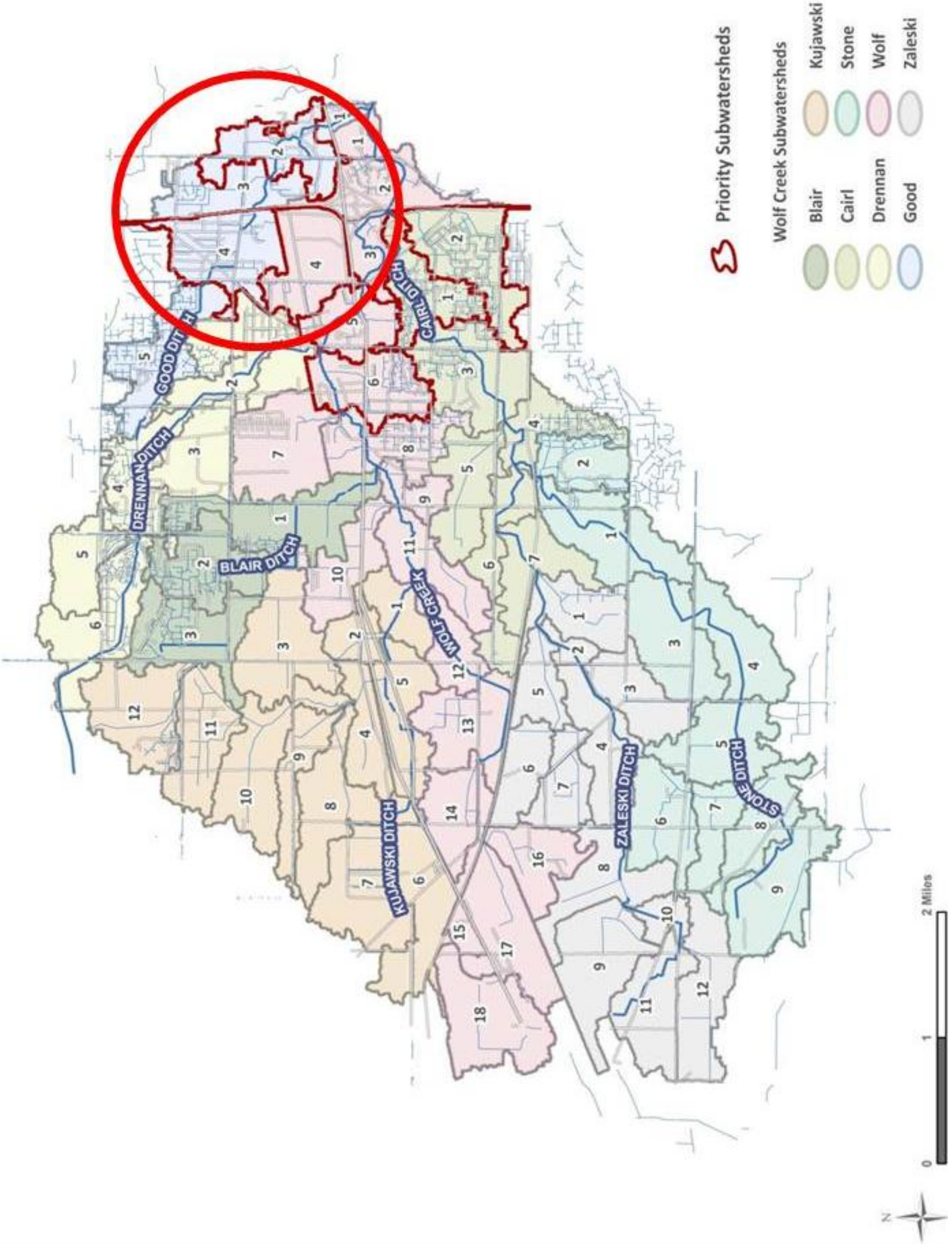


Figure 3-8. Wolf Creek subwatershed -- priority catchments.

### 3.1.3 Area Evaluation

The purpose of this pilot project is to develop a regionalized framework that guides stormwater BMP implementation planning for the City of Toledo and the surrounding MS4 communities in Lucas County. Broad patterns and assumptions provide a context at the watershed-scale (e.g., rainfall – runoff relationships, distribution of pollutant loads, etc.). However, site-specific information is also needed to assess the potential effectiveness of different stormwater management strategies.

As discussed earlier, the types of impervious cover present determines the categories of BMPs that could actually be implemented (Figure 2-3). Developing detailed estimates often involve air photo interpretation and advanced GIS processing, which can be time-consuming and resource intensive. However, preliminary impervious cover type estimates can be developed using NLCD information as part of the multi-scale analysis.

These estimates can be used to screen options in support of a regionalized stormwater TMDL implementation framework. The application of this approach is illustrated by using two study areas within the Wolf Creek subwatershed to demonstrate the process. Again, the methods presented can be applied to other locations in the Swan Creek watershed, as well as to other areas in the Maumee AOC.

The first study area, Good Ditch (Figure 3-9 and Figure 3-10), drains five catchments with a mix of different development intensities. Land use in the middle and lower reaches is predominantly residential with some commercial properties. In addition, Good Ditch is a first order stream. First and second order streams represent areas within an overall drainage network, where the benefits of implementing green infrastructure (GI) and low impact development (LID) are most noticeable.

The second area is the catchment identified as Wolf #4 (Figure 3-11). This location is dominated by high intensity development, which includes Spring Meadows Mall. Spring Meadows Mall was constructed in 1987 and redeveloped in 2006. It contains nearly 15 acres of commercial shopping space not including adjacent parking. The surrounding area also contains other commercial businesses including several restaurants and hotels, offices, and Springfield High School. This catchment has the highest level of impervious area in the entire Wolf Creek subwatershed. Many locations within this catchment are eligible to receive credits under the Lucas County Storm Water Utility District.

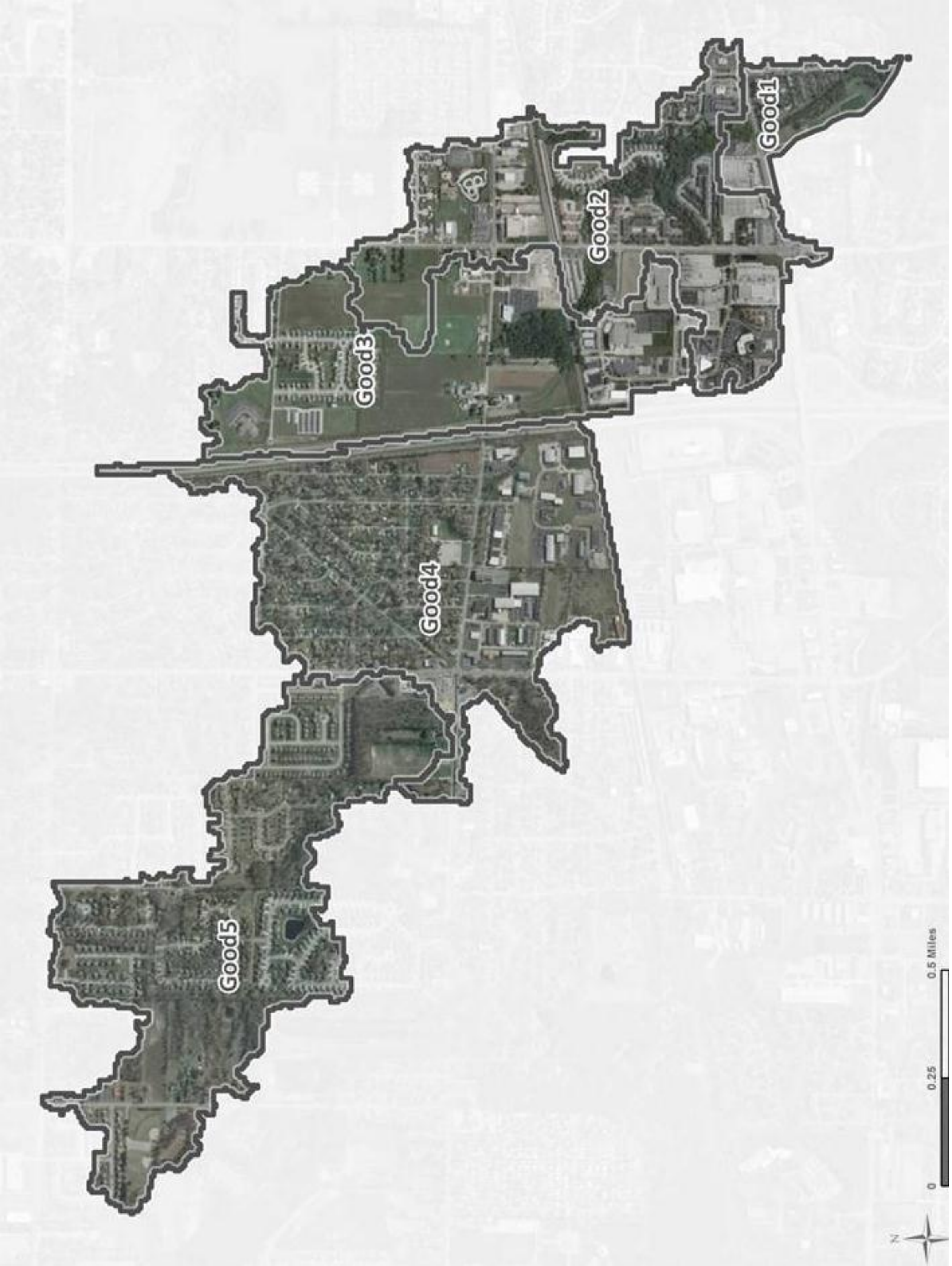


Figure 3-9. Good Ditch catchments -- air photo.

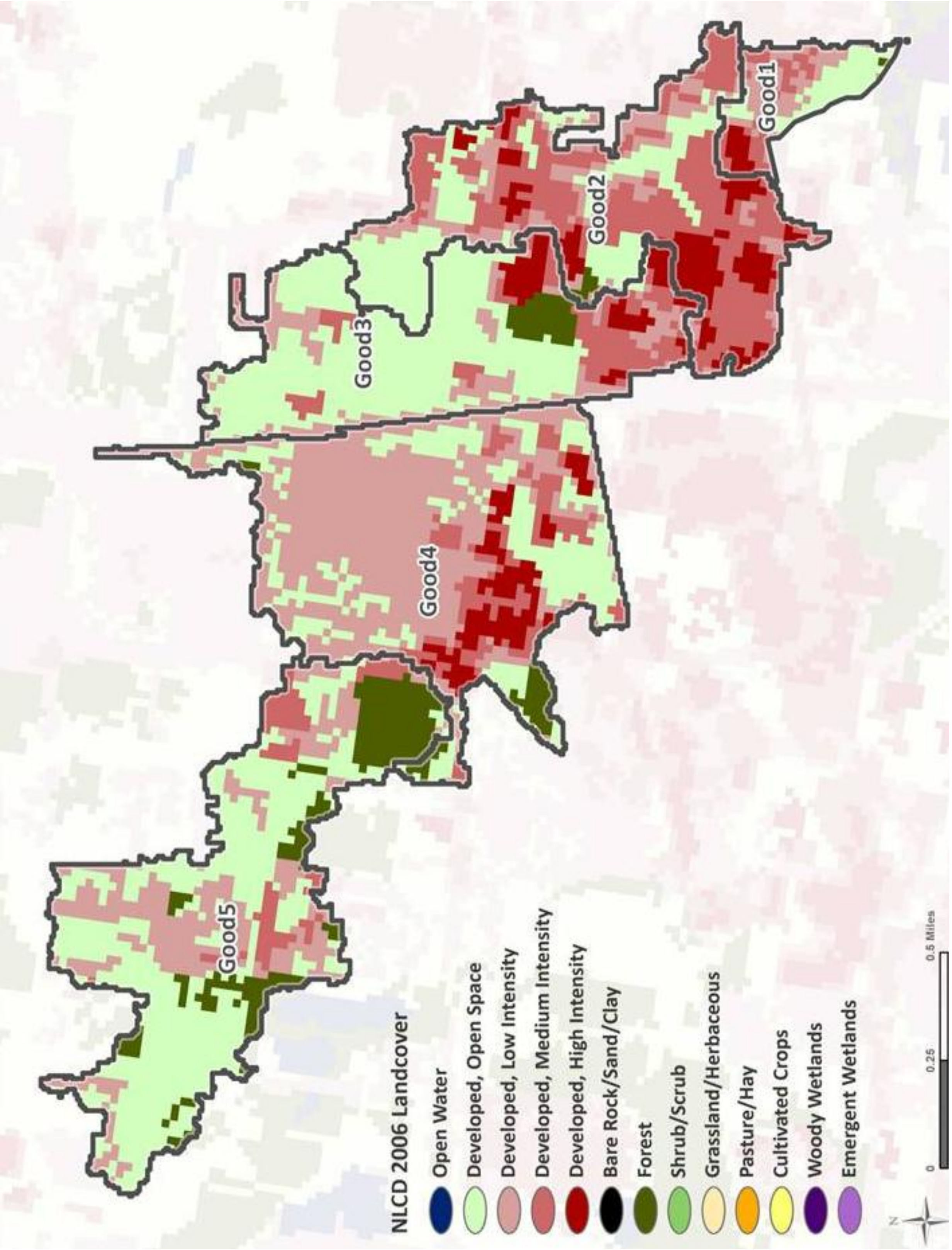


Figure 3-10. Good Ditch catchments -- land use.

Figure 3-11. Wolf #4 priority catchment -- air photo.

Table 3-5 compares land use in the two study areas to that of the overall Wolf Creek subwatershed. Mapped soils in both study areas are predominantly hydrologic group B with several areas with group A. Hydrologic soil group (HSG) B is general silt loam or loam. These soils tend to have moderate permeability that support infiltration BMPs. Topography is mainly flat through both study areas.

Estimates of impervious cover for catchments in both study areas are summarized in Table 3-6. These estimates represent effective impervious area and are based on techniques described in Sutherland (1995) using 2006 NLCD information.

Table 3-5. Wolf Creek land cover *(2006 NLCD)*.

| **Land Cover Description** | **Wolf Creek** | | **Good Ditch** | | **Wolf #4** | |
|---|---|---|---|---|---|---|
| | **Area *(acres)*** | **Percent of Watershed *(%)*** | **Area *(acres)*** | **Percent of Watershed *(%)*** | **Area *(acres)*** | **Percent of Watershed *(%)*** |
| Developed High Intensity | 574 | 3% | 84 | 7% | 89 | 32% |
| Developed Medium Intensity | 1030 | 6% | 213 | 18% | 95 | 32% |
| Developed Low Intensity | 2589 | 15% | 353 | 30% | 47 | 17% |
| Developed Open Space | 4148 | 24% | 447 | 39% | 50 | 18% |
| Cultivated Crops | 2358 | 13% | --- | --- | --- | --- |
| Pasture / Grassland | 1731 | 10% | --- | --- | --- | --- |
| Forest | 4748 | 27% | 73 | 6% | 1 | 1% |
| Other | 422 | 2% | --- | --- | --- | --- |
| **TOTAL** | **17,600** | | **1,170** | | **282** | |

Table 3-6. Impervious cover estimates for study area catchments.

| **Catchment** | **Area** *(acres)* | **NLCD Development Category** *(percent total area)* | | | | **NLCD Impervious Cover[1]** | |
|---|---|---|---|---|---|---|---|
| | | ***High*** | ***Medium*** | ***Low*** | ***Open*** | *(acres)* | *(percent)* |
| Good 1 | 46 | 8.7 | 23.7 | 34.3 | 31.9 | 13.6 | 30 |
| Good 2 | 256 | 13.9 | 42.4 | 17.2 | 25.7 | 107.8 | 42 |
| Good 3 | 231 | 7.0 | 15.3 | 18.2 | 55.1 | 49.2 | 21 |
| Good 4 | 327 | 8.5 | 10.7 | 53.3 | 24.4 | 82.7 | 25 |
| Good 5 | 310 | 0.0 | 7.6 | 24.9 | 51.4 | 39.1 | 13 |
| Wolf 4 | 282 | 31.6 | 33.6 | 16.6 | 17.7 | 147.4 | 52.2 |

**Note:** [1] These numbers assume effective impervious area based on Sutherland *(1995)*

In addition to estimating the effective impervious area in each study catchment, it is necessary to move to a smaller scale by examining the approximate mix of development and surface types. As discussed earlier relative to Figure 2-3, estimates of parking, road, driveway, sidewalk, and roof surfaces are needed to determine relative stormwater volumes produced by various source areas. This, in turn, helps identify BMP implementation options and priorities.

Several templates were developed to organize information derived from NLCD, the review of air photos, and other available GIS data (e.g., county lot parcel size, commercial impervious areas). The organizational templates presented in Table 3-7 and Table 3-8 provide an estimated percentage breakdown of impervious surface type for each NLCD development category and land use. For example, the highlighted cells in Table 3-7 summarize relative impervious surface values used for the high development intensity area of Good Ditch. Impervious surfaces in the NLCD category are divided between the following land uses: retail (65%), office (25%), and school (10%). Within the retail land use, impervious surface types are: parking (50%), road (5%), sidewalk (5%), and roof (40%). It is worth noting that within residential areas, the mix of impervious surface types tends to vary with the age of development, and is accounted for in the template.

These templates are incorporated into spreadsheets, which allow the percentages to be applied to NLCD category acreages to determine estimated areas of each impervious surface type (Table 3-9 and Table 3-10). As refined information becomes available, surface areas for each type can be revised. The template framework also allows for examining the sensitivity of assumptions regarding values used.

Table 3-7. Good Ditch impervious surface type percentage estimates.

| **NLCD Development Category** | **Land Use** | | **Percent of Category Area** | **Impervious Surface Type** *(percent of land use area)* | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | **Parking** | **Road** | **Driveway** | **Sidewalk** | **Roof** |
| **High** | Commercial | Retail | 65 | 50 | 5 | | 5 | 40 |
| | | Office | 25 | 45 | 5 | | 5 | 45 |
| | Institutional | School | 10 | 40 | 5 | | 5 | 50 |
| **Medium** | Commercial | | 10 | 45 | 5 | | 5 | 45 |
| | Apartment/Condo | | 10 | 35 | 10 | | 5 | 50 |
| | Residential *(based on development age)* | <15 years | 15 | | 32 | 10 | 10 | 48 |
| | | 15-30 years | 30 | | 41 | 10 | 10 | 39 |
| | | >30 years | 35 | | 45 | 27 | 3 | 25 |
| **Low** | Transportation | | 10 | | 100 | | | |
| | Residential *(based on development age)* | <15 years | 25 | | 32 | 10 | 10 | 48 |
| | | 15-30 years | 30 | | 41 | 10 | 10 | 39 |
| | | >30 years | 35 | | 45 | 27 | 3 | 25 |
| **Open** | Recreational | | 100 | 30 | 30 | 5 | 5 | 30 |

Table 3-8. Wolf #4 impervious surface type percentage estimates.

| NLCD Development Category | Land Use | | Percent of Category Area | Impervious Surface Type *(percent of land use area)* | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Parking | Road | Driveway | Sidewalk | Roof |
| **High** | Commercial | Retail | 80 | 50 | 5 | | 5 | 40 |
| | | Office | 5 | 45 | 5 | | 5 | 45 |
| | Institutional | School | 15 | 40 | 5 | | 5 | 50 |
| **Medium** | Commercial | Retail | 25 | 50 | 5 | | 5 | 40 |
| | | Office | 25 | 45 | 5 | | 5 | 45 |
| | Institutional | School | 25 | 40 | 5 | | 5 | 50 |
| | Residential / Apartment | | 25 | 35 | 10 | | 5 | 50 |
| **Low** | Commercial | | 10 | 50 | 5 | | 5 | 40 |
| | Transportation | | 50 | | 100 | | | |
| | Institutional | | 15 | 40 | 5 | | 5 | 50 |
| | Residential | | 25 | | 32 | 10 | 10 | 48 |
| **Open** | Recreational | | 100 | 30 | 30 | 5 | 5 | 30 |

Table 3-9. Good Ditch impervious surface type area estimates.

| NLCD Development Category | Land Use | | Impervious Area *(acres)* | Impervious Surface Type *(acres)* | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Parking | Road | Driveway | Sidewalk | Roof |
| **High** | Commercial | Retail | 46.2 | 23.1 | 2.3 | | 2.3 | 18.5 |
| | | Office | 17.8 | 8.0 | 0.9 | | 0.9 | 8.0 |
| | Institutional | School | 7.1 | 2.8 | 0.4 | | 0.4 | 3.6 |
| **Medium** | Commercial | | 11.7 | 5.3 | 0.6 | | 0.6 | 5.3 |
| | Apartment/Condo | | 11.7 | 4.1 | 1.2 | | 0.6 | 5.9 |
| | Residential *(based on development age)* | <15 years | 17.6 | | 5.6 | 1.8 | 1.8 | 8.4 |
| | | 15-30 years | 35.2 | | 14.4 | 3.5 | 3.5 | 13.7 |
| | | >30 years | 41.1 | | 18.5 | 11.1 | 1.2 | 10.3 |
| **Low** | Transportation | | 7.1 | | 7.1 | | | |
| | Residential *(based on development age)* | <15 years | 17.7 | | 5.7 | 1.8 | 1.8 | 8.5 |
| | | 15-30 years | 21.2 | | 8.7 | 2.1 | 2.1 | 8.3 |
| | | >30 years | 24.7 | | 11.1 | 6.7 | 0.7 | 6.2 |
| **Open** | Recreational | | 22.3 | 6.7 | 6.7 | 1.1 | 1.1 | 6.7 |

Table 3-10. Wolf #4 catchment impervious surface type area estimates.

| **NLCD Development Category** | **Land Use** | | **Impervious Area** *(acres)* | **Impervious Surface Type** *(acres)* | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | **Parking** | **Road** | **Driveway** | **Sidewalk** | **Roof** |
| **High** | Commercial | Retail | 60.6 | 30.3 | 3.0 | | 3.0 | 24.2 |
| | | Office | 3.8 | 1.7 | 0.2 | | 0.2 | 1.7 |
| | Institutional | School | 11.4 | 4.5 | 0.6 | | 0.6 | 5.7 |
| **Medium** | Commercial | Retail | 13.0 | 6.5 | 0.7 | | 0.7 | 5.2 |
| | | Office | 13.0 | 5.9 | 0.7 | | 0.7 | 5.9 |
| | Institutional | School | 13.0 | 5.2 | 0.7 | | 0.7 | 6.5 |
| | Residential / Apartment | | 13.0 | 4.6 | 1.3 | | 0.7 | 6.5 |
| **Low** | Commercial | | 0.9 | 0.5 | 0.0 | | 0.0 | 0.4 |
| | Transportation | | 4.7 | | 4.7 | | | |
| | Institutional | | 1.4 | 0.6 | 0.1 | | 0.1 | 0.7 |
| | Residential | | 2.3 | | 0.7 | 0.2 | 0.2 | 1.1 |
| **Open** | Recreational | | 2.5 | 0.7 | 0.7 | 0.1 | 0.1 | 0.7 |

## 3.2 Precipitation Patterns

A major objective in developing effective management strategies and implementing LID practices is to keep as much stormwater on site as possible. Understanding rainfall patterns is a key part of identifying options. Annual and seasonal variations, for example, are two considerations (as shown in Figure 3-12 and Figure 3-13 for the Toledo Express Airport).

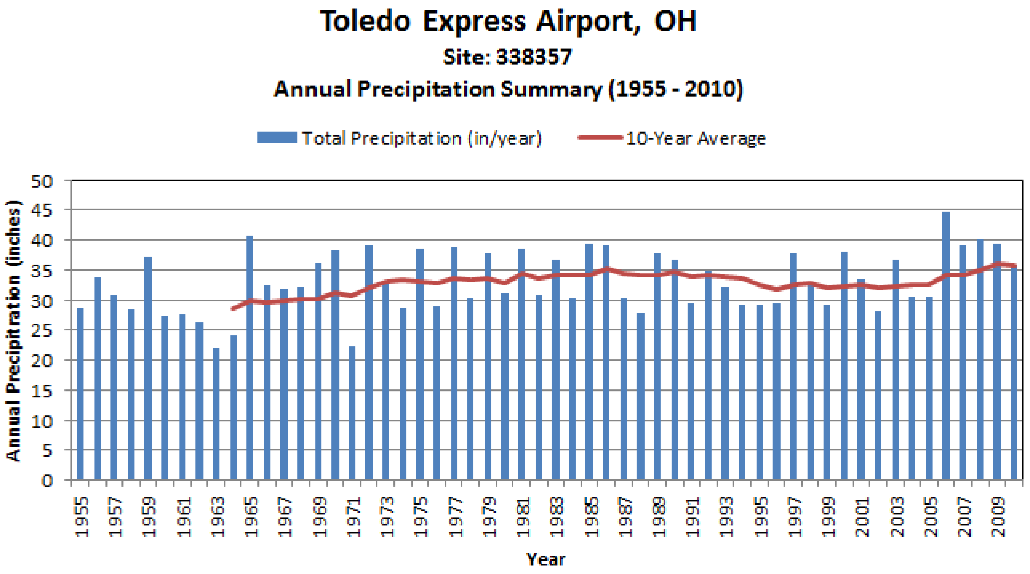


Figure 3-12. Annual precipitation summary for Toledo Express Airport.

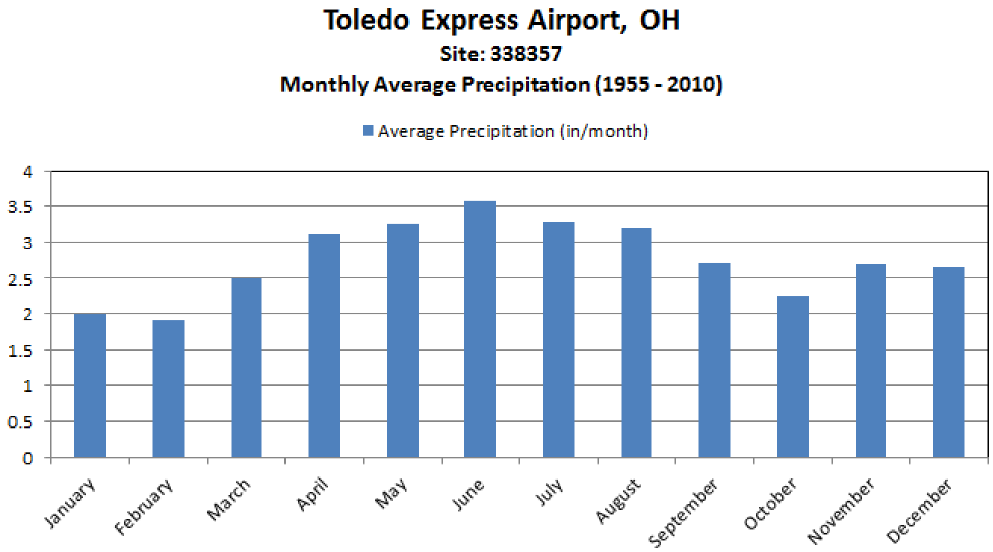


Figure 3-13. Monthly average precipitation summary for Toledo Express Airport.

Many BMPs are designed using storm frequency data. This information can be obtained through the National Weather Service (NWS) Precipitation Frequency Data Server (NWS, 2004). This data is often used to address local stormwater regulations that include peak discharge control (Dorsey et. al, 2009). The Critical Storm Method (CSM) provides one approach to examine peak discharge control needs. The CSM requires rainfall depth for the 1 through 100 years, 24-hour events. Table 3-11 summarizes rainfall depth – duration frequency information for the Toledo Express Airport precipitation station.

Table 3-11. Rainfall depth – duration frequency for Toledo Express Airport.

| **Recurrence Interval** *(years)* | **Precipitation Frequency Estimates** ***(inches)*** | | | |
|---|---|---|---|---|
| | **Duration** *(hours)* | | | |
| | **3** | **6** | **12** | **24** |
| **1** | 1.23 | 1.41 | 1.65 | 1.97 |
| **2** | 1.48 | 1.7 | 1.98 | 2.37 |
| **5** | 1.88 | 2.14 | 2.48 | 2.95 |
| **10** | 2.19 | 2.51 | 2.9 | 3.42 |
| **25** | 2.63 | 3.04 | 3.51 | 4.09 |
| **50** | 2.99 | 3.47 | 4.01 | 4.63 |
| **100** | 3.37 | 3.94 | 4.55 | 5.2 |
| | Data for Toledo Express Airport retrieved from: http://hdsc.nws.noaa.gov/hdsc/pfds/ | | | |

Stormwater source inputs to receiving waters are ultimately a function of rainfall and snowmelt. Not all storms are equal; differences in frequency, magnitude, and duration play a major role in determining appropriate implementation strategies. Although large storms are critical in terms of flooding, most rainfall in the Swan Creek watershed actually occurs in relatively small storm events. An examination of precipitation patterns is a key part of stormwater implementation planning. This includes an analysis of rainfall intensity and timing to assess BMP performance relative to water quality goals.

While design storms provide a valuable long-term planning tool, the distribution of rainfall event depth is also an important factor. The effect of different rainfall patterns on runoff and stormwater source loads (and subsequent BMP performance) should be accounted for in the technical analysis. Figure 3-14 illustrates one method used to characterize rainfall distribution for the Toledo Express Airport precipitation gage. As shown in Figure 3-14, 8 percent of measurable precipitation events at Toledo Express Airport are exceeding Ohio's WQv benchmark (e.g., 0.75 inches over a 24-hour period).

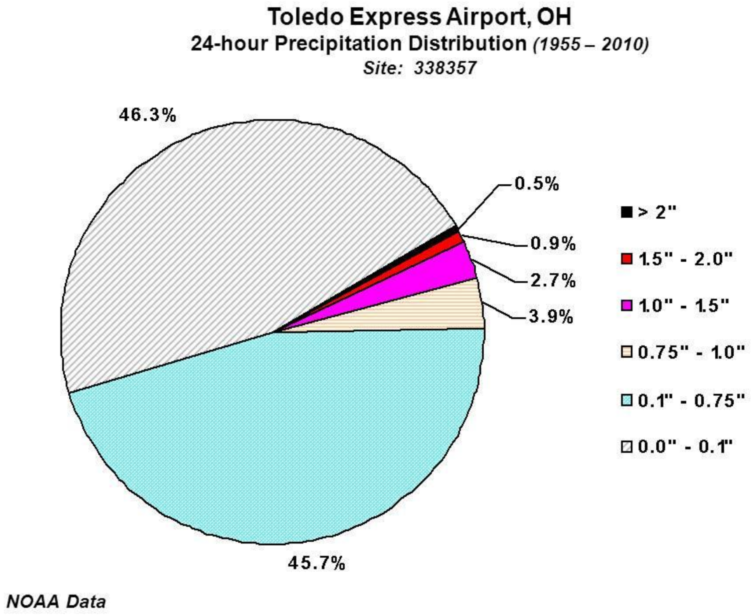


Figure 3-14. Rainfall distribution for Toledo Express Airport.

Ohio's WQv establishes a metric that guides design of post-construction BMPs (e.g., filtration, infiltration, detention) to achieve targets for volume and peak rate controls. WQv has two protection objectives: reducing the pollutants suspended in runoff and reducing the energy of common storm events responsible for most channel erosion (Ohio DNR, 2006). In Ohio, WQv is the volume that results from a 0.75 inch event over a 24-hour period. The choice of 0.75 inches as the WQv rainfall capture depth and the requirement that the extended detention (24-48 hour) drawdown come from a *"brimful"* condition allows this single requirement to function both as a water quality requirement and a channel protection requirement.

The water quality volume is calculated using the following equation, adapted from *"Urban Runoff Quality Management"* (ASCE / WEF, 1998):

$$WQv = C * P * (A/12)$$

where:

$C$ = runoff coefficient
$= 0.858*i^3 - 0.78*i^2 + 0.774*i + 0.04$
$i$ = watershed imperviousness ratio *(percentage divided by 100)*
$P = 0.75$ = amount of precipitation occurring in a 24-hour period *(inches)*
$A$ = area treated by the BMP(s) *(acres)*

Source loads associated with many small storms can be equally important in terms of their effect on receiving streams. In the case of Toledo Express Airport, 92 percent of the measureable precipitation events are at or below WQv. For instance, there may be a "critical" precipitation depth where measurable stormwater loads begin to occur, depending on subwatershed characteristics. From this perspective, BMP targeting and optimization efforts should examine issues such as the full range of flows associated with all storms, as well as flows associated with the design storms such as WQv.

Related to the identification of design storms, it is useful to examine the cumulative frequency distribution of 24-hour precipitation events. A frequency distribution of daily precipitation data can be viewed in several ways (Figure 3-15). The first is to determine the frequency interval by considering all days (whether or not there was measurable precipitation), as shown by the lower curve in Figure 3-15. This approach allows for comparison with flow duration curves because daily precipitation values are sorted from high to low; the total number of days is used to calculate to recurrence percentage.

Over the past few years, there has been an increased emphasis on volume-based hydrology in stormwater management (Reese, 2009). The premise is that reductions in stormwater volume will lead to reductions in pollutant loading (National Research Council, 2008). USEPA technical guidance has identified using the 95th percentile rainfall event as one option to meet stormwater runoff reduction requirements for Federal facilities (USEPA, 2009). The 95th percentile storm is calculated through the use of a frequency distribution of all daily rainfall values with small precipitation events removed (i.e., those less than 0.1 inches). This design volume captures all but the largest five percent of storms, as depicted by the upper curve in Figure 3-15. For the Toledo Express Airport precipitation gage, this corresponds to 1.22 inches.

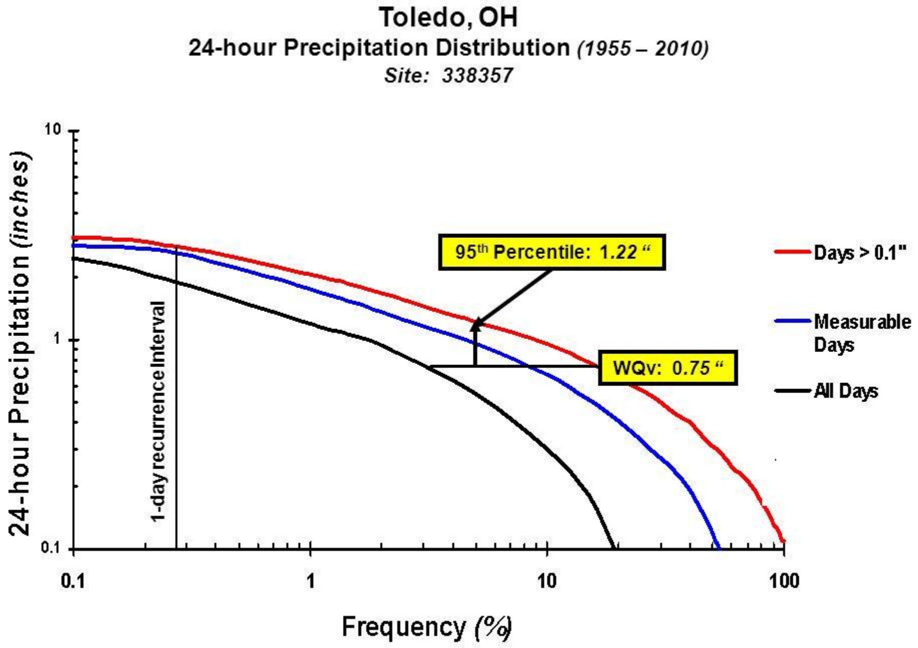


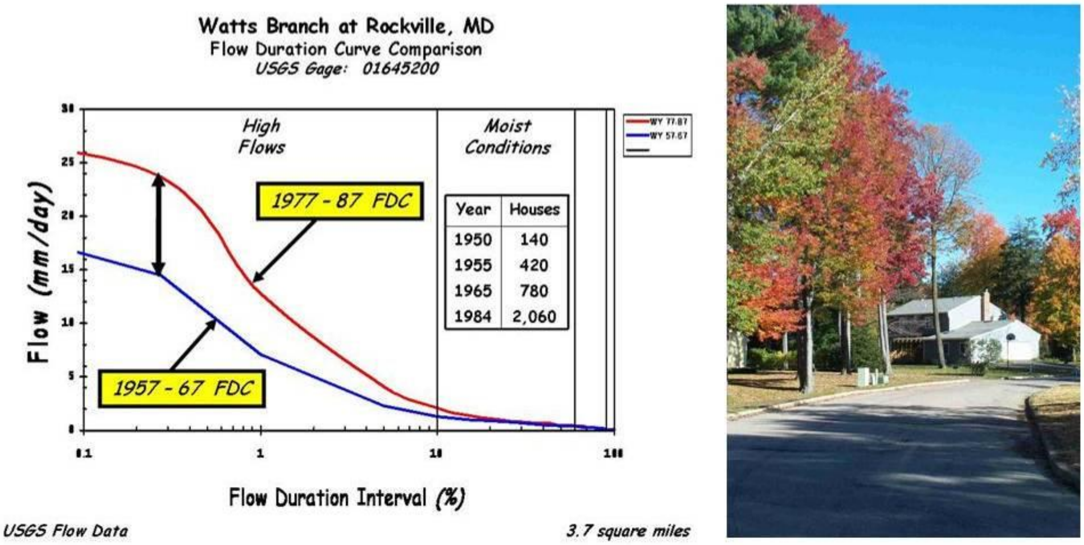
Figure 3-15. Cumulative frequency distribution of precipitation events for Toledo Express Airport.

### *3.3 Rainfall-Runoff Models*

Watershed response to precipitation events is an equally important part of BMP targeting and implementation. While rainfall and snowmelt act as driving forces, the resultant runoff serves as a key focal point for stormwater management programs. Hydrologic measures such as total runoff volume, peak flow rate, runoff hydrograph, and duration curves are often used to guide the design of protection, control, and restoration strategies associated with stormwater management.

A key objective of analyzing runoff patterns is to prioritize source area and delivery points / mechanisms to help ensure effective BMP targeting. Figure 3-16 illustrates the utility of flow duration curves in assessing the effects of land use change on watershed hydrology. In this example, land use changed dramatically from 1950 to 1984. The conversion from low density to high density residential increased both the magnitude and frequency of high flow events. As discussed earlier, implementation of LID practices strive to minimize the effect of altered hydrology.

Ideally, real time, fine scale monitoring of stream flow and water quality could guide the design of BMP implementation strategies. However, the costs associated with this level of data collection are generally much greater than available resources. For this reason, computer models are often used to develop information that describes watershed response to precipitation events.



| Year | Houses |
|---|---|
| 1950 | 140 |
| 1955 | 420 |
| 1965 | 780 |
| 1984 | 2,060 |

Figure 3-16. Effect of land use change on flow duration curve.

Figure 3-17 illustrates a simple conceptualization of the relationship between rainfall – runoff models and their use in assessing BMPs. In this hypothetical scenario, rain falls on the land producing runoff (depicted by the "LAND" box). The resultant runoff is routed to the stormwater BMP for subsequent evaluation of its performance.

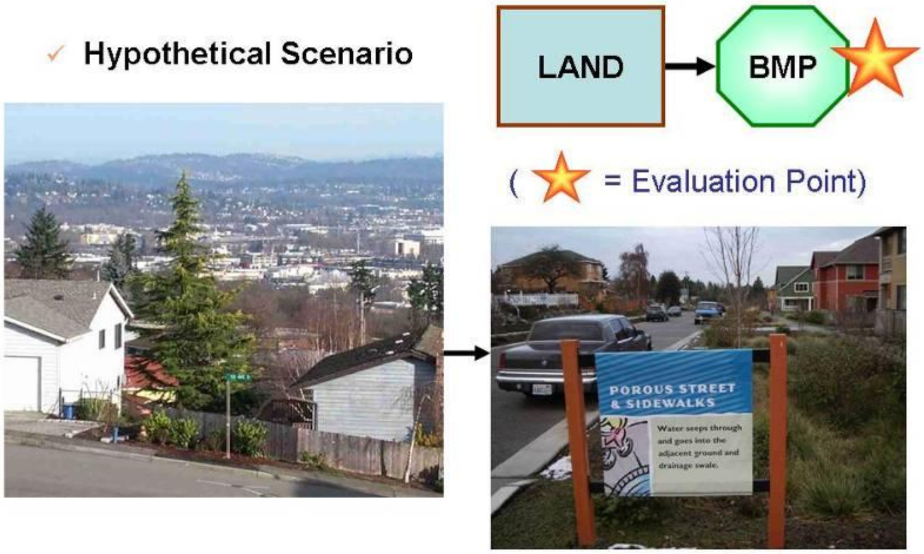


Figure 3-17. Stormwater modeling concepts.

There are a wide variety of models available that have been used to assistance stormwater management activities in describing runoff patterns. Similarly, the approaches range from simple to complex, and include:

- ✓ Storm Water Management Model (SWMM)
- ✓ Hydrologic Simulation Package FORTRAN (HSPF)
- ✓ Loading Simulation Program C++ (LSPC)
- ✓ P8 Urban Catchment Model (P8-UCM)
- ✓ Source Loading and Management Model (SLAMM)
- ✓ HEC Hydrologic Modeling System (HEC-HMS)
- ✓ SCS / NRCS Win TR-20 and Win TR-55

This above list is by no means complete. However, it does reflect the most common models used to address urban runoff concerns.

### *3.3.1 Wolf Creek LSPC Model*

The Loading Simulation Program C++ (LSPC) was used to represent the hydrologic, sediment, and total phosphorus baseline conditions in the Wolf Creek watershed. LSPC is a watershed modeling system that includes HSPF algorithms for simulating watershed hydrology, erosion, and water quality processes, as well as in-stream transport processes. One objective of the overall pilot effort is to identify challenges associated with using SUSTAIN. In the case of the Wolf Creek pilot effort, long-term flow records were not available for watershed model calibration and validation. Additionally, total phosphorus and sediment data were limited to a few samples collected during the summer of 2006 in support of the Swan Creek TMDL (Ohio EPA, 2009). For a more detailed discussion on the approach taken to calibrate the model and to view the calibration results refer to the Watershed Hydrology and Water Quality Modeling Report for Wolf Creek Watershed, Ohio (TetraTech, 2012).

Due to the fact that very little observed data exists in the watershed, outputs of a calibrated LSPC watershed model were utilized to help establish the hydrologic, sediment, and total phosphorus baseline conditions in the Wolf Creek watershed. Following a brief discussion on the use of Hydrologic Response Units (HRUs), a description of the model calibration process and several outputs used in the BMP assessment process are presented.

### *3.3.2 Hydrologic Response Units*

One of the most significant technical challenges in the targeting and optimization process is connecting watershed runoff information to a BMP assessment framework. A technique being used in conjunction with rainfall – runoff modeling to address stormwater concerns is the use of HRUs. Example applications of this method include project work in Vermont, the Charles River, and Los Angeles County. Dominant factors considered when developing HRUs include land use, soil type, and slope.

In a watershed model, land unit representation is sensitive to the features of the landscape that most affect hydrology. Important features include surface cover, soils, and slope. In urban settings, it is important to estimate the division of land use into pervious and impervious components. Slope might also be an important factor in some areas, particularly where it varies noticeably. For the Wolf Creek pilot effort, the combination of land cover, imperviousness and hydrologic soil group were considered in the definition of HRUs.

*Land Cover*. The 2006 NLCD land cover obtained from the Seamless Data Warehouse was used to identify the land cover distribution in the Wolf Creek watershed.

*Impervious Surface Type*. The 2006 NLCD impervious cover obtained from the Seamless Data Warehouse was used to identify imperviousness in the Wolf Creek watershed.

*Hydrologic Soil Group*. GIS data sets of hydrologic soil group obtained from the Natural Resources Conservation Service (NRCS) were used to identify the infiltration potential of soils. Hydrologic soil groups are used to classify the infiltration capacity of soils, rating them as either class A, B, C or D. Hydrologic soil group A has the highest infiltration potential, while D has the lowest. Unknown and predominately urban soil types are also identified.

The land cover raster and impervious cover raster were combined with a raster of the subwatershed delineation with the raster calculator in ArcGIS. The resultant database provided land use composition (cover and imperviousness) for each watershed in the delineation. At this point the imperviousness was modified to represent the effective impervious area and not the total mapped impervious area.

The hydrologic soil group coverage was processed to provide percent of area of each hydrologic soil group in each subwatershed. Each subwatershed was represented by the hydrologic soil group that had the greatest percent of coverage. Each of the soil groups has 13 HRUs with nine being for pervious areas representing three classes of urban land, forest, cropland, pasture, grassland, wetland, and barren and four for impervious areas representing the three urban classes and then all other impervious areas. The model has two soil groups, A and B/C for a grand total of 26 HRU’s.

## *3.4 Hydrology*

Stream gaging has not been conducted in the Wolf Creek subwatershed, creating a challenge to describe the full range of hydrologic conditions. The U.S. Geological Survey (USGS) monitors flow in a nearby watershed: the Ottawa River at the University of Toledo. The observed flows at the Ottawa River gage were used as a proxy for flows in the Wolf Creek subwatershed. Figure 3-18 shows the yearly rainfall-runoff pattern from 1980 through 2010 with data from the Toledo Express Airport precipitation station and the USGS Ottawa River flow gage. Approximately 34 inches of precipitation falls on the Wolf Creek subwatershed each year; this precipitation results in approximately 12 inches of runoff. Figure 3-18 also highlights precipitation and flow for 2004-06. This period represents consecutive dry, average, and wet years used for SUSTAIN testing.

Flow duration curves are an effective method to characterize hydrologic conditions and are an important component of an overall hydrologic analysis. Duration curves provide a quantitative summary that represents the full range of flow conditions, including both magnitude and frequency of occurrence (USEPA, 2007). Development of a flow duration curve is typically based on daily average stream discharge data. A typical curve runs from high flows to low flows along the x-axis, as illustrated in Figure 3-19.

This graph depicts flow duration curves for Ottawa River for a dry year (1991), a wet year (2006) and the 31 year period from 1980 – 2011. These duration curves are expressed as unit area flows in inches per day for easy extrapolation to the Wolf Creek subwatershed. Note the flow duration interval of ten (i.e., ten percent of all observed stream discharge values equal or exceed) is associated with a stream discharge of 0.12 inches per day for a wet year, 0.06 inches per day for a dry year, and 0.08 inches per day using a 31 year period of record. This comparison highlights the pronounced effect that wet and dry years have on flows observed in the Ottawa River.

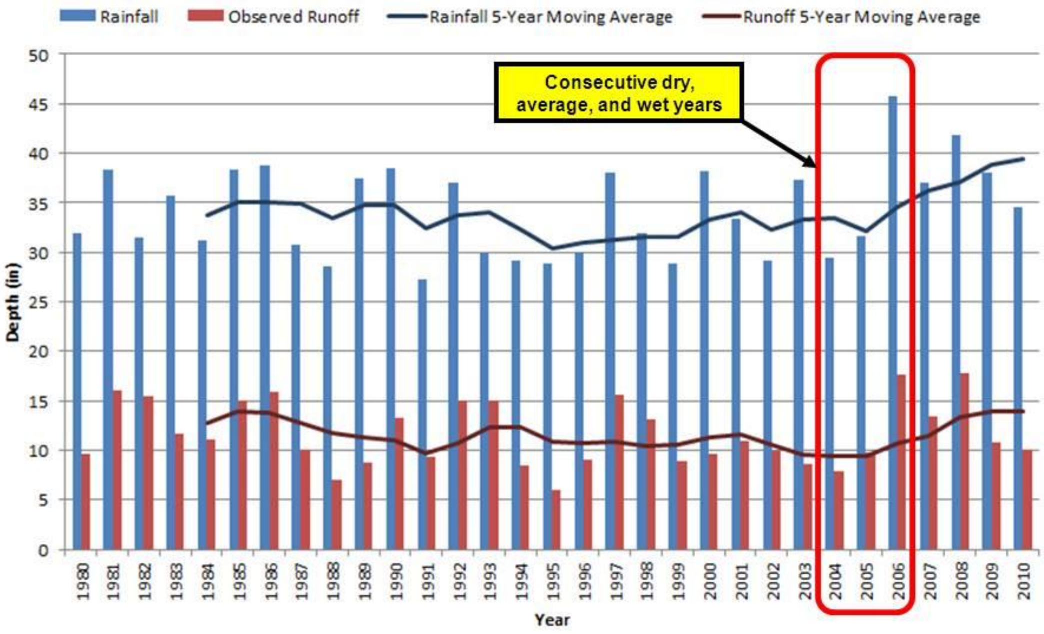


Figure 3-18. Ottawa River watershed yearly rainfall-runoff patterns *(1980-2010)*.

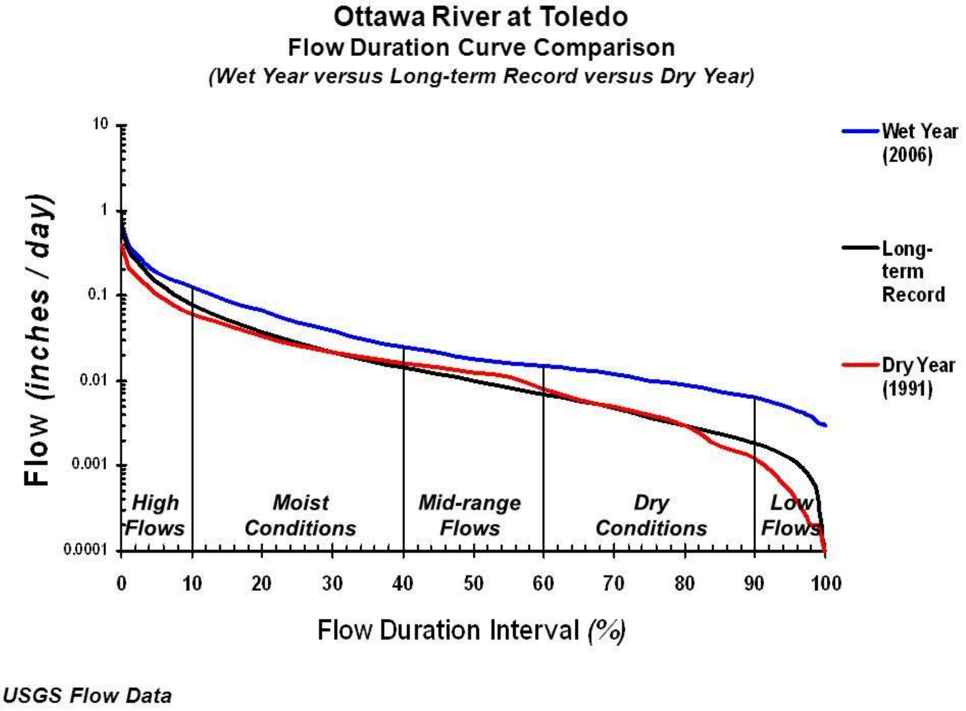


Figure 3-19. Ottawa River unit area flow duration curves.

LSPC model output was used to characterize flows in the Wolf Creek watershed. Each individual subwatershed has its own unique hydrologic response based on land use and soil types. The outlet of Wolf Creek at its confluence with Swan Creek was used to examine overall watershed patterns; characterizing the cumulative effect of all land use and soil type combinations. It also ensures that each subwatershed in the model is considered in the analysis.

Figure 3-20 shows the distribution of simulated flow paths. On average, 68 percent of the water leaving Wolf Creek is from groundwater, four percent is from interflow, and 28 percent is from surface flow. Another way to look at these results is that stormwater BMPs have the potential to treat or retain 28 percent of the water (i.e., the surface component) that is currently leaving the Wolf Creek subwatershed.

Figure 3-21 shows the percent of the total volume leaving Wolf Creek; generally governed by the percent of each land use present in the watershed. As can be seen in Figure 3-21, the impervious areas in the Wolf Creek subwatershed contribute a larger proportion of flow relative to their respective land use percentage. These impervious areas are where stormwater BMPs have the potential to provide maximum benefit for stormwater control.

Figure 3-22 presents another view, depicting a simple water budget for each land use. This shows the relative difference between surface runoff, evapotranspiration, and storage. Similar to the total volume contribution analysis, this provides a quantitative estimate of stormwater volumes produced by different areas within the Wolf Creek subwatershed. This information could also be extrapolated to the larger Swan Creek watershed; one of the multi-scale analysis framework objectives.

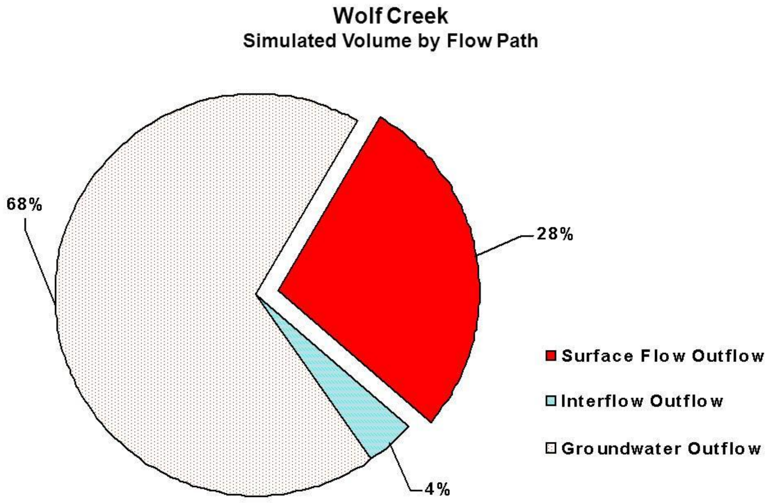


Figure 3-20. Wolf Creek watershed simulated volume by flow path.

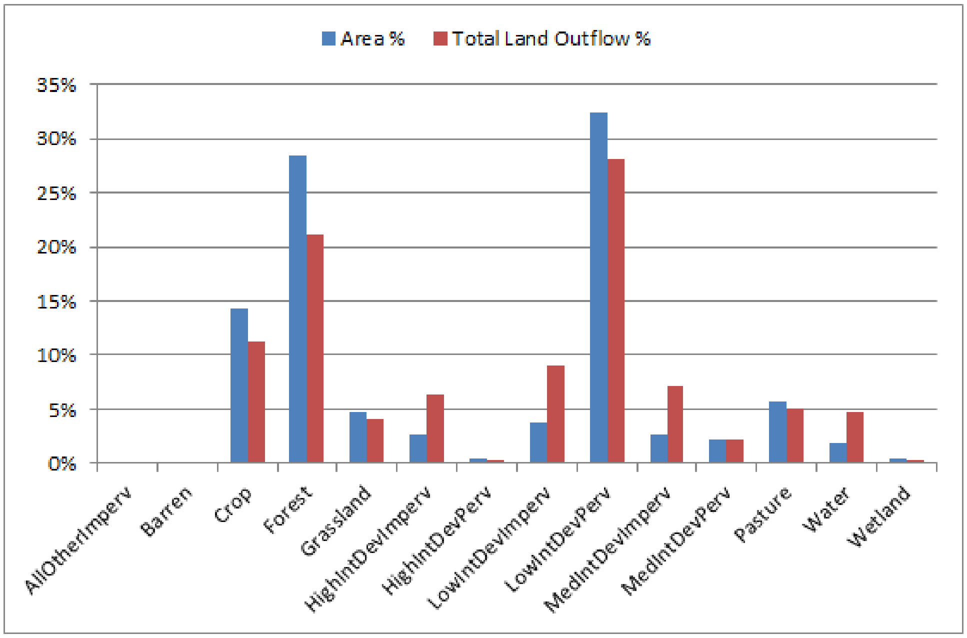


Figure 3-21. Wolf Creek watershed simulated volume by land use.

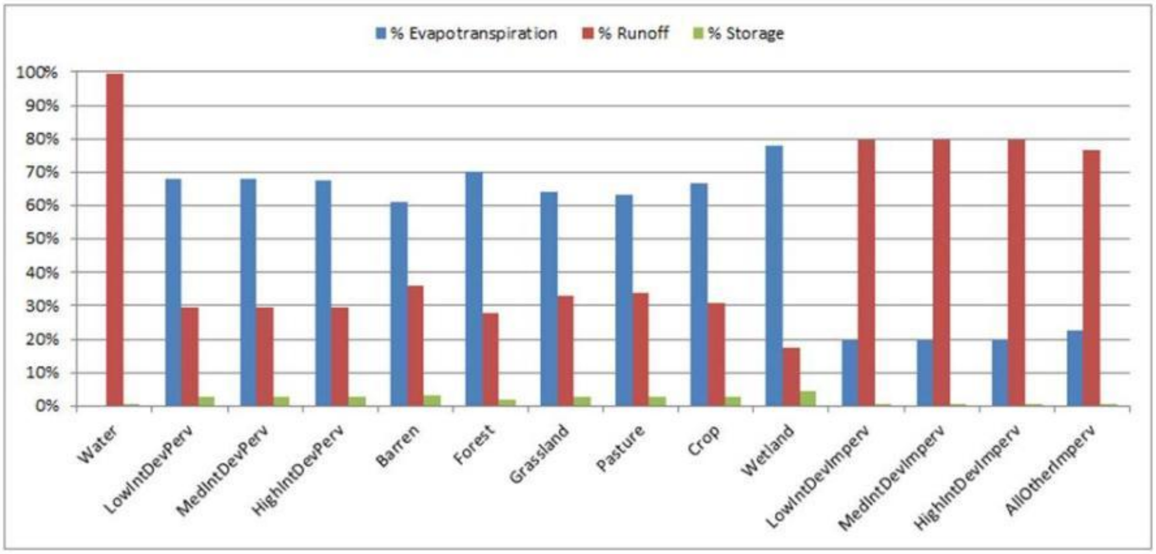
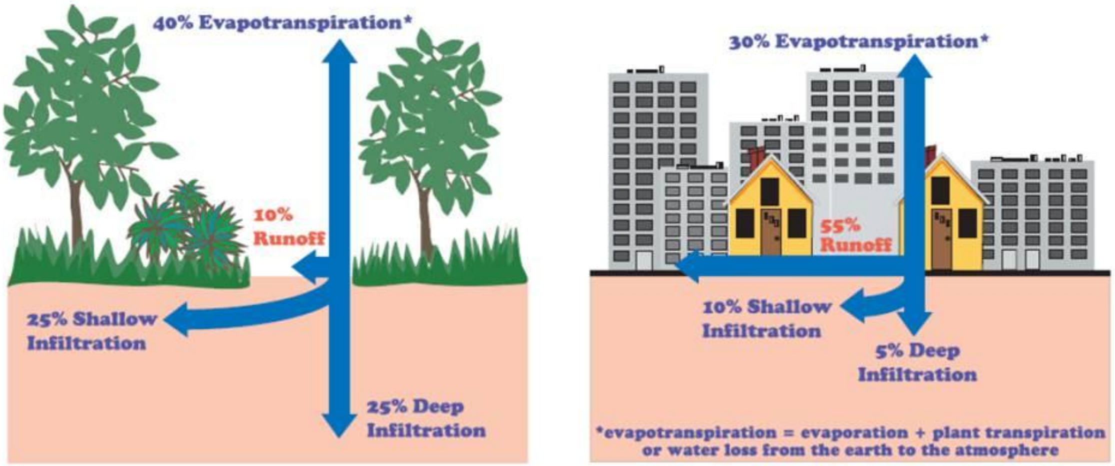


Figure 3-22. Wolf Creek watershed simulated simple water budget by land use.

Patterns observed in the simple water balance analysis are similar to hydrologic effects documented by other studies. Figure 3-23 displays a graphic from the *"Low Impact Development Manual for the Lower Maumee and Ottawa River Watersheds"* (American Rivers, 2010), which shows the effect of land use on hydrologic regime. Because a major objective of stormwater management is volume reduction, it is helpful to show the quantitative relationship between impervious cover and runoff (Figure 3-24). This simple analysis demonstrates the benefit of decreasing the amount of impervious surface in terms of volume reduction. It also provides a benchmark for comparing BMP performance using different practices (e.g., detention, bioretention, infiltration, etc.).



from "Low Impact Development Manual for the Lower Maumee and Ottawa River Watersheds" (American Rivers, 2010)

Figure 3-23. Effect of land use on hydrologic regime.

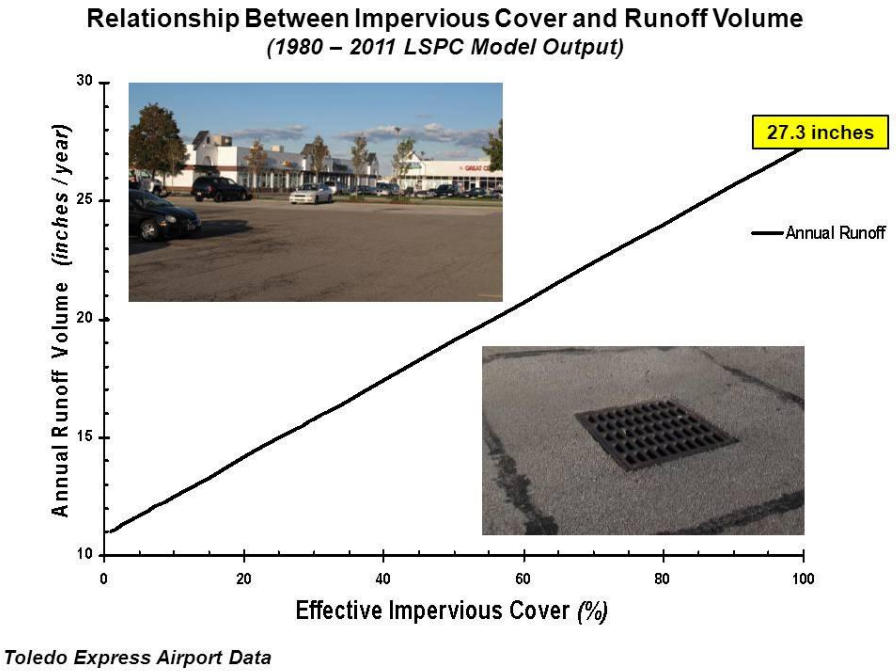


Figure 3-24. Relationship between impervious surface and runoff volume.

Hydrologic response is often more pronounced in first and second order streams. For this reason, it is useful to examine patterns in Good Ditch (one of the areas identified for SUSTAIN testing) relative to a similar-sized stream with less development, such as upper Kujawski Ditch (Figure 3-25). Both are first order streams; land use characteristics are significantly different (Table 3-12 and Figure 3-26). In addition, a comparison of these two areas is useful because of concerns regarding the effect of future development on stormwater management in the Swan Creek watershed.

Table 3-12. Land cover comparison -- Good Ditch and Upper Kujawski Ditch *(2006 NLCD)*.

| **Land Cover Description** | **Good Ditch** | | **Upper Kujawski Ditch** | |
|---|---|---|---|---|
| | **Area *(acres)*** | **Percent of Watershed *(%)*** | **Area *(acres)*** | **Percent of Watershed *(%)*** |
| Developed High Intensity | 84 | 7% | 2 | 0.2% |
| Developed Medium Intensity | 213 | 18% | 15 | 2% |
| Developed Low Intensity | 353 | 30% | 13 | 1.6% |
| Developed Open Space | 447 | 39% | 70 | 8% |
| Cultivated Crops | --- | --- | --- | --- |
| Pasture / Grassland | --- | --- | 306 | 31% |
| Forest | 73 | 6% | 550 | 57% |
| Other | --- | --- | 2 | 0.2% |
| **TOTAL** | **1,170** | | **959** | |

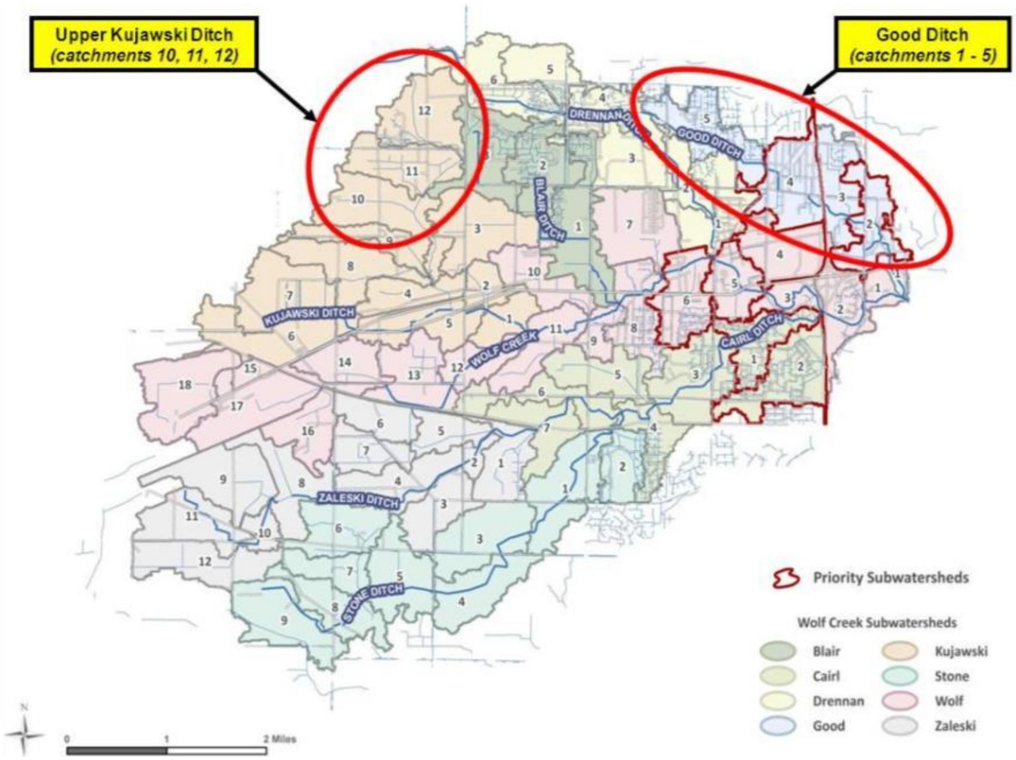


Figure 3-25. Good Ditch and Upper Kujawski Ditch -- catchment location map.

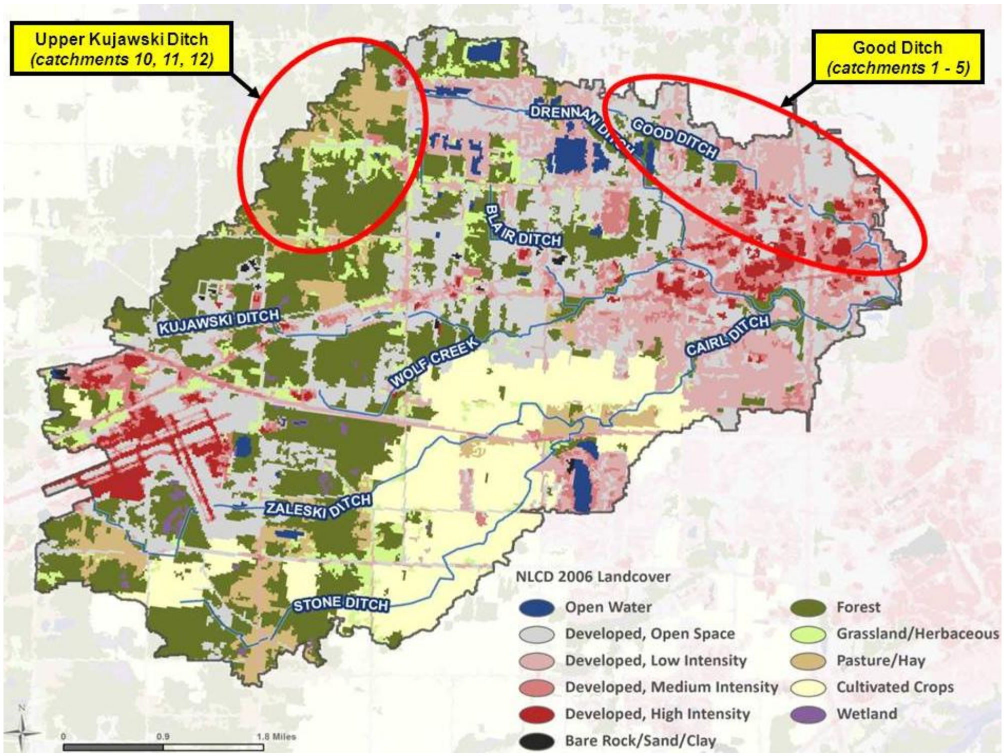


Figure 3-26. Good Ditch and Upper Kujawski Ditch -- catchment land use.

Unit area flow duration curves provide a visual way to compare the hydrologic response of these two first order streams (Figure 3-27). Of particular interest to stormwater management is the average daily maximum flow (i.e., the $FDC_{1\text{-day}}$ or the flow associated with the one day recurrence interval from the flow duration curve). This is a commonly used indicator on TMDL flow duration curves because it connects to the daily maximum value.

The Swan Creek TMDL was developed to address biological impairments due to degraded habitat and siltation. Hydrology can be a major factor that affects aquatic communities (thus influencing bioassessment scores). Stable flow regimes support the establishment of healthy macroinvertebrate populations. *"Flashy"* flows (e.g., due to urban runoff) disrupt aquatic community structure and increase the transport of TSS loads that cause downstream siltation problems. *"Flashiness"* is an indicator of the frequency and rapidity of short-term changes in stream flow, particularly during runoff events (Baker, et.al, 2004). Increased *"flashiness"* is typically associated with unstable watersheds and degraded habitat that adversely affects aquatic life. Table 3-13 compares the $FDC_{1\text{-day}}$ and Richards – Baker Flashiness Index values between Good Ditch and upper Kujawski Ditch.

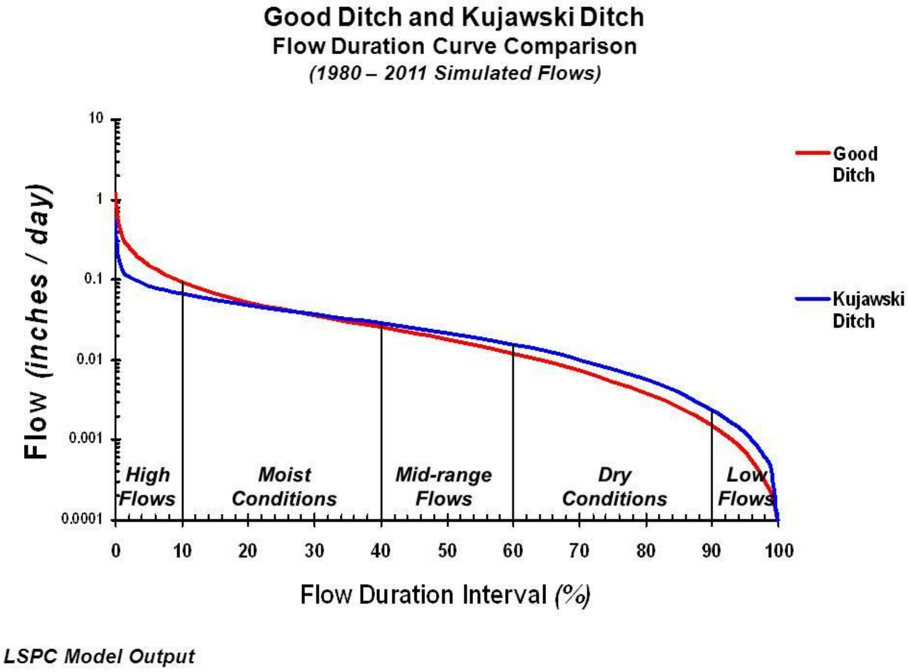


Figure 3-27. Good Ditch and Upper Kujawski Ditch unit area flow duration curves.

Table 3-13. Empirical assessment summary for key hydrologic indicators.

| LSPC Outlet ID | Area (mi.$^2$) | Hydrologic Indicator | | Stream Name |
|---|---|---|---|---|
| | | $FDC_{1\text{-day}}$ (in/day) | R-B Index | |
| Good #1 | 1.83 | 0.523 | 0.777 | Good Ditch |
| Kujawski #10 | 1.50 | 0.193 | 0.160 | Upper Kujawski Ditch |

## 3.5 Total Suspended Solids

Ohio EPA (Ohio EPA, 1999) identified TSS targets that were used to establish TMDL allocations. These targets are 13.5 mg/l for headwater drainage areas less than 20 square miles, and 12.5 mg/l for wadeable streams whose drainage area is greater than 20 but less than 200 square miles. Wolf Creek has very limited observed TSS data; four TMDL study locations were sampled six times during the summer of 2006 (Figure 3-28).

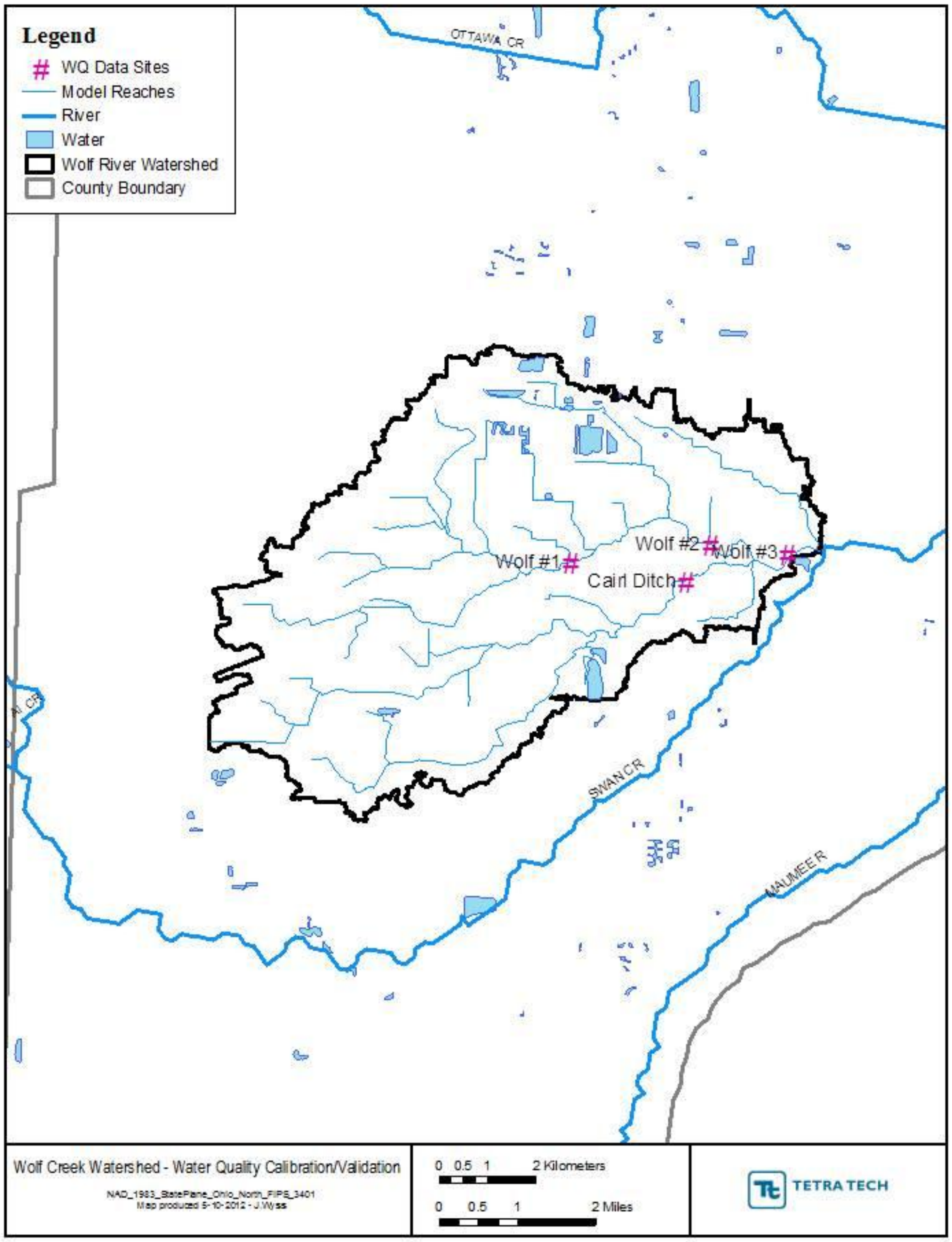


Figure 3-28. Wolf Creek watershed model -- water quality calibration sites.

TSS model simulation results for two sites (Wolf #1 and Wolf #3) are presented in Figure 3-29 and Figure 3-30 using a duration curve framework. Monitoring data from the 2006 TMDL survey is also shown. These two locations represent the most upstream and downstream sites sampled. The upstream site (Wolf #1) is dominated by rural land uses, while the downstream station is affected by urban stormwater. Model results are displayed using the *"box and whisker"* format. This allows analysis of general patterns by conveying information on the distribution of simulated TSS values. TSS model results for Wolf #3 are noticeably higher that Wolf #1, warranting a closer evaluation of sediment sources.

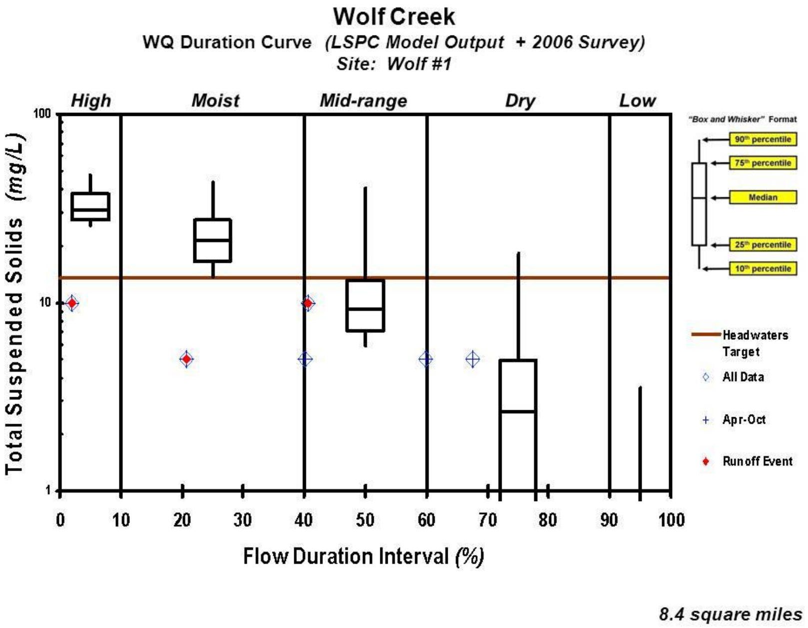


Figure 3-29. Wolf #1 total suspended solids water quality duration curve *(1980-2010)*.

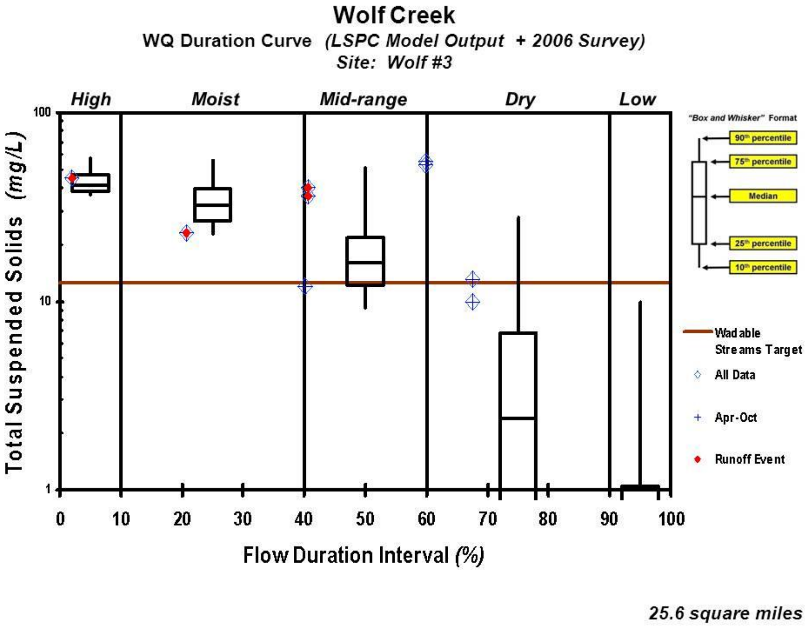


Figure 3-30. Wolf #3 total suspended solids water quality duration curve *(1980-2010)*.

Most of the sediment supply that enters streams affected by stormwater, such as Wolf Creek, is generated by erosion processes including: bank erosion, surface erosion, and gully erosion. Bank erosion and channel scour (or in-stream sediment sources) are driven by channel stability, discharge volumes, and stream velocities. Surface and gully erosion, on the other hand, result from excess water runoff. Because erosion and hydrology are connected, the timing of delivery and transport mechanisms is extremely important considerations, particularly when evaluating BMP planning to meet TMDL targets.

The LSPC simulation enables an in-depth analysis of TSS to help characterize stormwater sources in the Wolf Creek subwatershed. As part of the flow calculations, the model simulates stream velocities. Sediment supply in LSPC originates from either upland sources (e.g., surface erosion) or in-stream sources (e.g., bank erosion, channel scour). The model outlet for Wolf Creek at the confluence with Swan Creek serves as an analysis point to help characterize TSS sources in the subwatershed. Figure 3-31 shows the percent area of each land use in the Wolf Creek watershed model as well as the percent that each land use contributes to the total mass of sediment entering Wolf Creek. LSPC also estimates the overall percentage of sediment export from upland and in-stream sources (Figure 3-32).

Figure 3-31 and Figure 3-32 suggest that roughly 75 percent of the sediment entering Wolf Creek is due to increased stream velocities from excess flow off impervious surfaces. The upland sediment source is only a small component of the total sediment that is being exported out of the Wolf Creek watershed. Similar to hydrology results, these impervious areas are where stormwater BMPs have the greatest potential to provide maximum benefit for sediment reductions to meet TMDL management objectives.

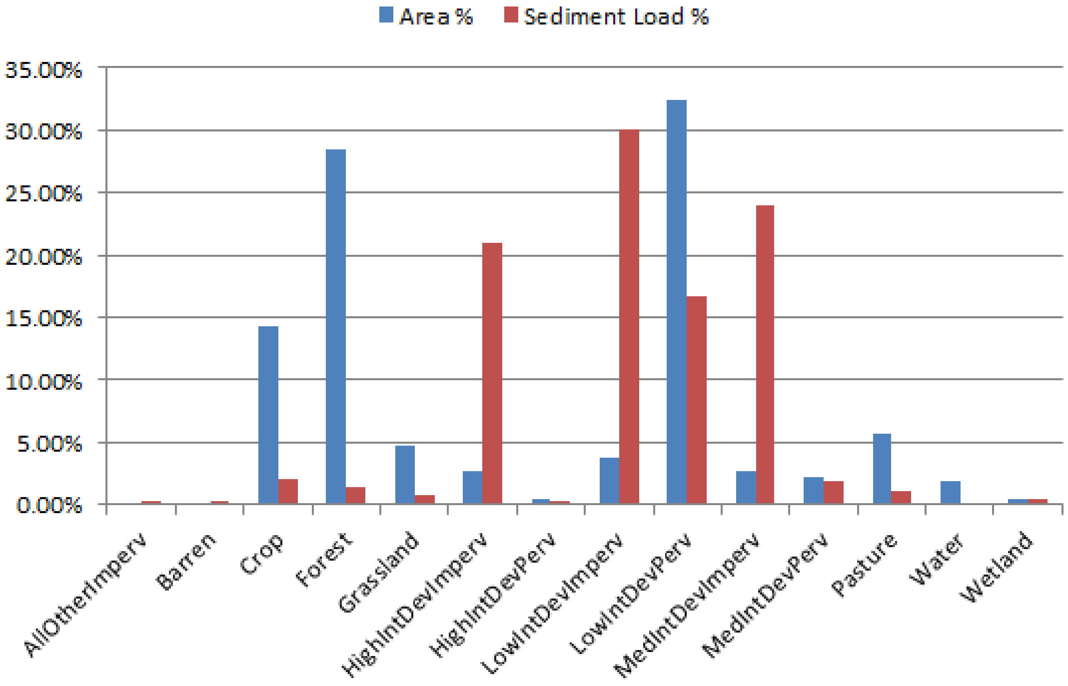


Figure 3-31. Wolf Creek watershed simulated sediment loading by land use.

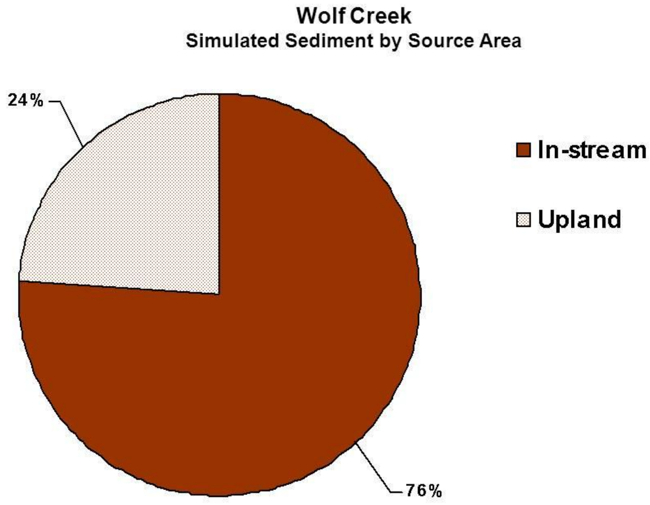


Figure 3-32. Wolf Creek watershed simulated sediment export source percentages.

Lastly with respect to TSS, it is useful to examine the response on similar-sized low order streams with different land uses. Figure 3-33 extends the comparison between Good Ditch and Upper Kujawski Ditch to TSS using the duration curve framework. Again, the effect of increased stormwater from developed areas on TSS is particularly evident under high flows, moist conditions, and mid-range flows.

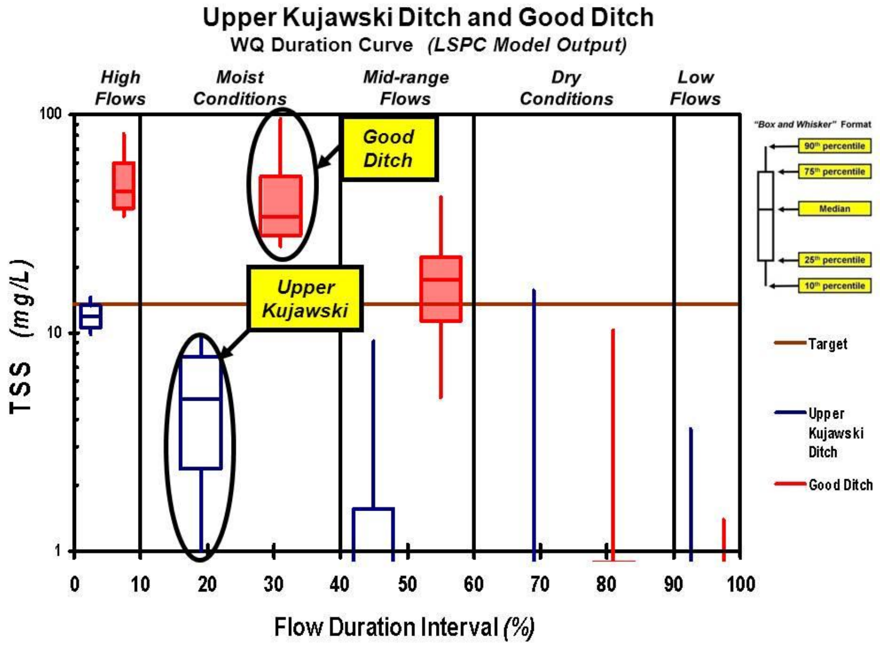


Figure 3-33. Good Ditch and Upper Kujawski Ditch TSS patterns using duration curve framework.

# 4. BMPs Considered

Examples of the stormwater management practices that can be assessed with SUSTAIN include bioretention, rain barrels, cisterns, detention ponds, infiltration trenches, vegetative swales, porous pavement, and green roofs. However, not all BMPs are equally suitable to all site conditions and performance goals across watersheds. Consequently, several important site-specific factors were considered when identifying those BMPs to include in the project analysis. This section presents a brief overview describing the general representation of practices within SUSTAIN.

The BMP module within SUSTAIN is designed to provide a process-based simulation of flow and pollutant transport routing for a wide range of structural practices. The BMP module performs the following hydrologic processes to reduce land runoff volume and attenuate peak flows: evaporation of standing surface water, infiltration of ponded water into the soil media, deep percolation of infiltrated water into groundwater, and outflow through weir or orifice control structures. A simplified schematic of the BMP simulation process is included in the SUSTAIN manual and is shown in Figure 4-1.

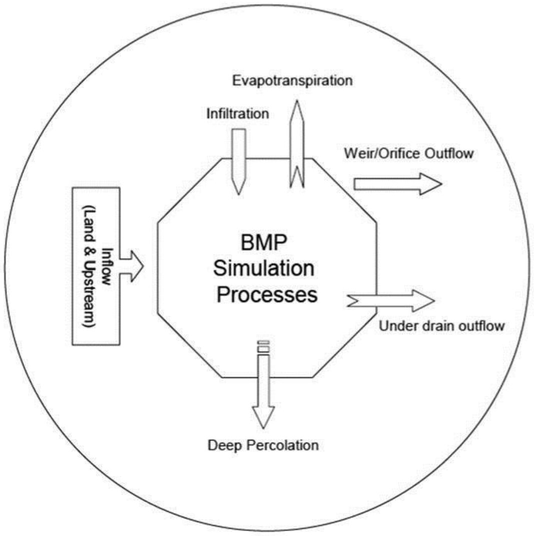
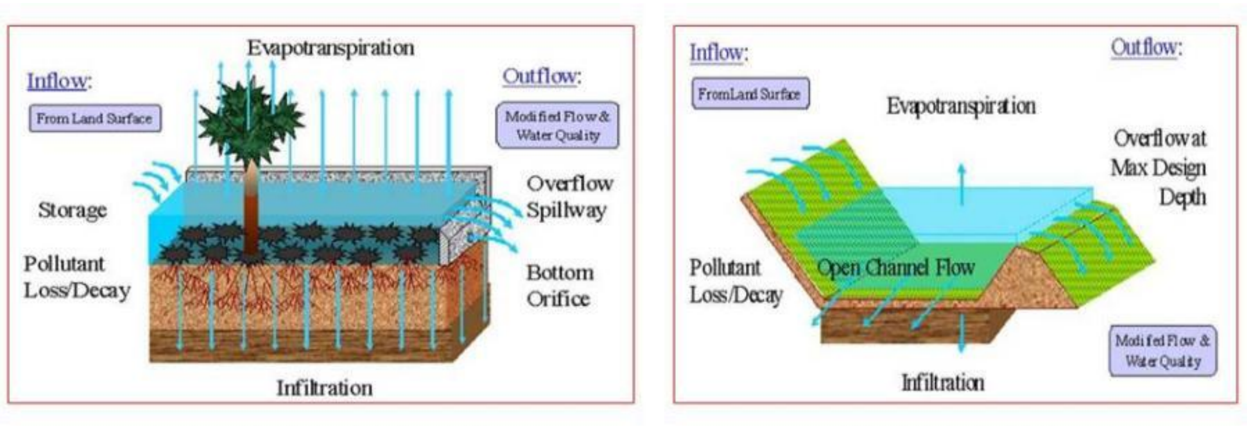


Figure 4-1. BMP simulation processes.

Urban stormwater BMPs in SUSTAIN are simulated according to a set of design specifications using a unit-process parameter-based approach *(Figure 4-2)*. This has many advantages over most other modeling tools, which simply assign a single percent effectiveness value to each type of practice. Overall BMP performance in SUSTAIN is a function of its physical configuration, storm size, associated runoff intensity and volume, as well as moisture conditions in the BMP.

A general estimate of BMP performance can be developed for each practice being considered. One way to view this information is in in terms of sizing. Sizing of BMPs is typically focused on capturing a certain depth of runoff (e.g., WQv). Curves can be developed that show the performance of a BMP over a long-term period (rather than as a single storm or design storm event). This is an important aspect of the BMP opportunity assessment. Inherently, assumptions must be made when transitioning from a location specific analysis (e.g., site-scale) to an evaluation of larger areas, such as the neighborhood or watershed scale *(Figure 4-3)*.



**Storage / Infiltration BMPs** **Channelized BMPs**

Figure 4-2. Major processes included in BMPs.

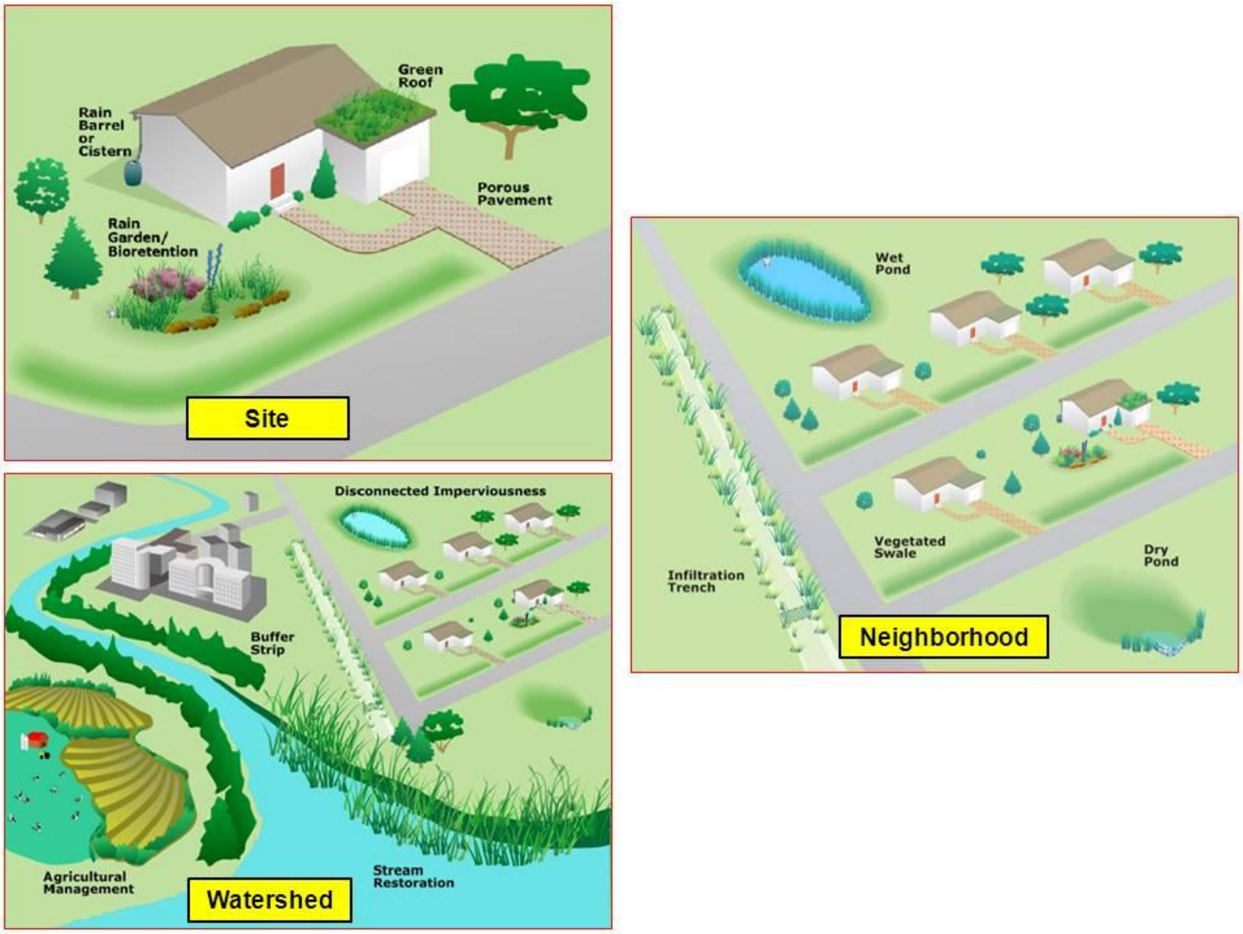


Figure 4-3. BMP assessment scales.

Figure 4-4 shows an example performance curve for a BMP of interest in the Swan Creek watershed: bioretention. One benefit of developing these curves is that they illustrate the sensitivity of BMP performance to the range of key variables (e.g., infiltration rates, storage depth). The curves also provide a way to quantify uncertainty regarding assumptions. In addition, the performance curves highlight those design parameters that are most important when developing specifications for implementation projects. Example design parameters that can be varied in SUSTAIN for bioretention are listed in Table 4-1. Finally, the curves can help guide decisions where cost trade-offs are involved (e.g., size of area to treat, amount of amendment material to promote greater infiltration, underdrain system design, etc).

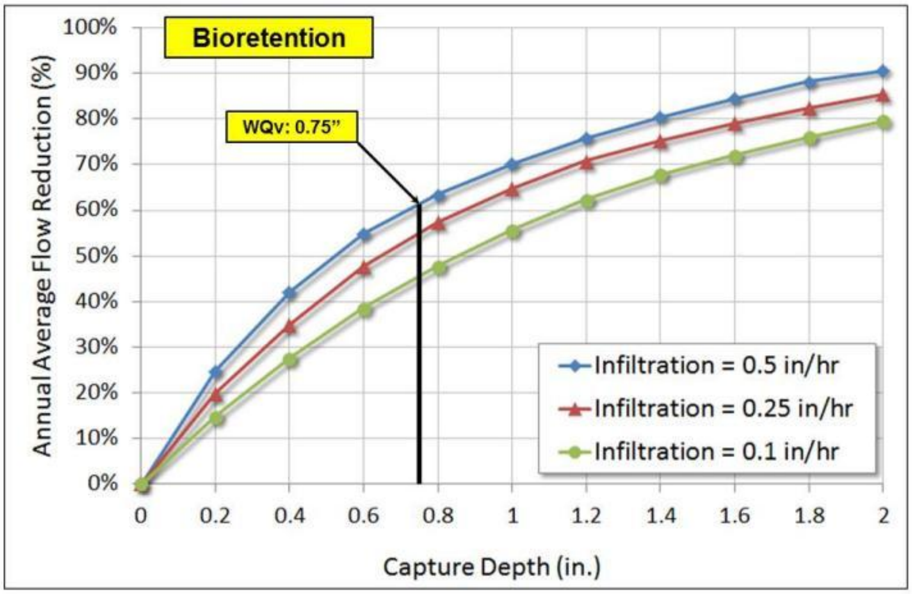


Figure 4-4. General BMP performance curve -- bioretention.

Table 4-1. Example key BMP design parameters -- bioretention.

| ***Dimensions*** | |
|---|---|
| • Length *(feet)*<br>• Width *(feet)* | • Design drainage area *(acre)* |
| • Ponding depth defined through one of following options:<br>✓ Orifice height *(feet)*<br>✓ Weir height *(feet)* | |
| ***Substrate Properties*** | |
| • Depth of soil *(feet)*<br>• Soil porosity *(0 - 1)*<br>• Soil field capacity | • Soil wilting point<br>• Vegetative parameter A<br>• Soil layer infiltration *(inches / hour)* |
| • Underdrain structure *(if applicable)*<br>○ Storage depth *(feet)*<br>○ Media void fraction *(0 - 1)* | ○ Background infiltration *(inches / hour)* |

This part of the five-step process complements reduction calculations under a stormwater credit program. The Lucas County Storm Water Credit program, for instance, provides a financial incentive to non-residential or regional residential property owners who conduct good stewardship practices. The concept recognizes that the entire community benefits from these improvements or enhancements through reduced flooding and better water quality (Lucas County, 2012).

The focus of the credit program is to implement activities that reduce stormwater volume and improve water quality. The performance curve depicted in Figure 4-4 provides information that can help quantify the benefit of a proposed stormwater credit practice (e.g., bioretention). Volume reduction for BMPs, which could be constructed in the Swan Creek watershed, illustrates the potential utility of performance curves in quantitatively evaluating proposed activities under the stormwater credit program.

As discussed in Section 3.1.3, the study areas (Wolf #4 including Spring Meadows Mall and Good Ditch) offer a range of settings to examine BMP effectiveness. Differences between the two catchments (e.g., percent of developed land, impervious cover type) include factors that are major determinants relative to specific types of BMPs to assess. The Wolf #4 catchment, for example, is completely dominated by commercial land (32% high intensity). The primary stormwater source areas of concern are approximately 60 acres of parking and 50 acres of commercial roofs. Conversely, Good Ditch is dominated by residential land (70 percent low intensity and developed open space) with a mix of impervious surface types (e.g., roofs, driveways, streets, sidewalks). Good Ditch also contains commercial impervious areas.

BMPs applicable to the Spring Meadows Mall area include the existing detention pond, porous pavement, regional bioretention, and infiltration trenches (although space available for regional BMPs may be more limited). Potential practices applicable to the Good Ditch include regional facilities as well as distributed (site scale) BMPs such as rain gardens and rain barrels. The following BMPs were identified as applicable to these catchments:

- Detention ponds
- Bioretention (rain garden, bioswale, regional bioretention)
- Rain barrels in series with rain gardens
- Infiltration trench
- Porous pavement

Each of those practices was identified for applicability in the watershed on the basis of a review of aerial imagery, NLCD mapped land use, soils information, and acceptability. The following sections provide a description of each BMP and the considerations made during the applicability analysis.

## 4.1 Detention Pond

Detention ponds are surface water structures that provide temporary storage of stormwater runoff to prevent downstream flooding. The primary purpose of a detention pond is the attenuation of stormwater runoff peaks. Generally, detention basins may be dry ponds, wet ponds, or constructed wetlands. Wet ponds, for example, can be effective for pollutant removal and peak rate mitigation. In Ohio, detention ponds are commonly used to meet the WQv requirement for new development. However, they do not achieve significant groundwater recharge or volume reduction.

Good Ditch and the Wolf #4 catchment contain both wet and dry ponds. More recent residential development in upper Good Ditch includes several wet ponds. Stormwater runoff from Spring Meadows Mall is directed to a dry pond located in the southeast corner of the complex. Figure 4-5 depicts a set of general BMP performance curves for detention ponds. Each curve is based on a different background infiltration rate. The lower infiltration rate is more indicative of a wet pond where the focus is to provide a pool for water quality pollutant removal. A capture depth associated with Ohio's WQv (0.75 in.) is included for reference. While the wet pond produces greater benefits for TSS and nutrient reduction, its value for volume reduction is limited.

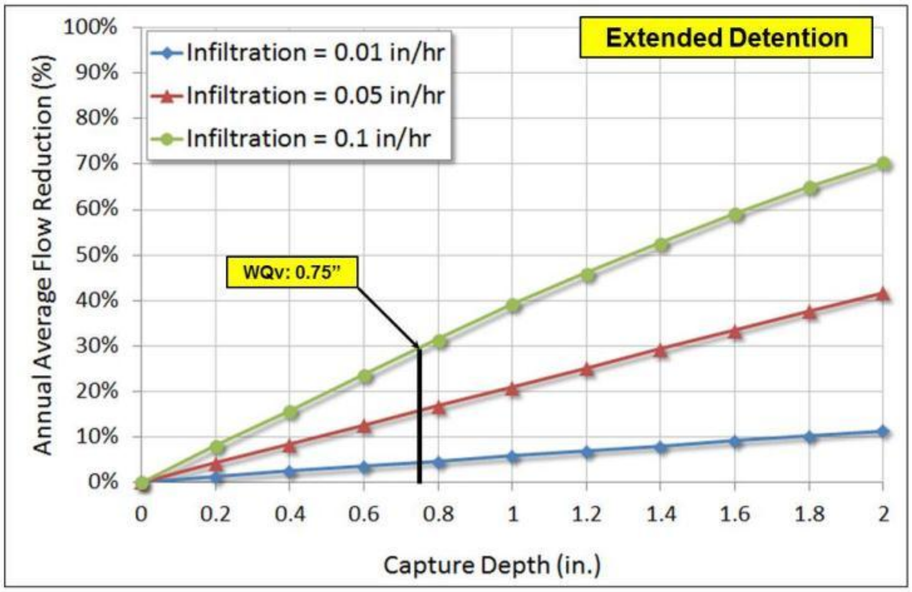


Figure 4-5. General BMP performance curve – detention pond.

## 4.2 Bioretention

Bioretention practices are stormwater basins that utilize a soil media, mulch, and vegetation to treat runoff and improve water quality for small drainage areas (Ohio DNR, 2006). The *"Low Impact Development Manual for the Lower Maumee and Ottawa River Watersheds"* (American Rivers, 2010) describes the benefits, limitations, suitable applications, and required design data for bioretention practices. Basically, a bioretention area consists of a depression that allows shallow ponding of runoff and gradual percolation through a soil media or uptake by vegetation. Water that percolates then either infiltrates through undisturbed soils or enters a storm sewer system through an underdrain system.

Bioretention is able to attenuate flow and reduce volume. These BMPs use biological, chemical, and physical processes to remove a variety of pollutants. Bioretention is generally applicable to small drainage areas, is good for highly impervious areas, and provides an option for retrofit situations. Bioretention can be a landscape feature; the practice generally has relatively low maintenance requirements. Common examples of bioretention are rain gardens, bioswales, and regional facilities to accommodate larger drainage areas.

Numerous design applications exist for bioretention. These include use in residential lots, on commercial / industrial sites, as off-line facilities adjacent to parking lots, and along highways and roads. Bioretention practices are typically sized for common storm events (e.g., WQv). In addition to varying the surface area, other design parameters are usually evaluated relative to achieving a performance goal (Table 4-1). Figure 4-6 illustrates one example that depicts volume reduction versus capture depth using different media depths in the design.

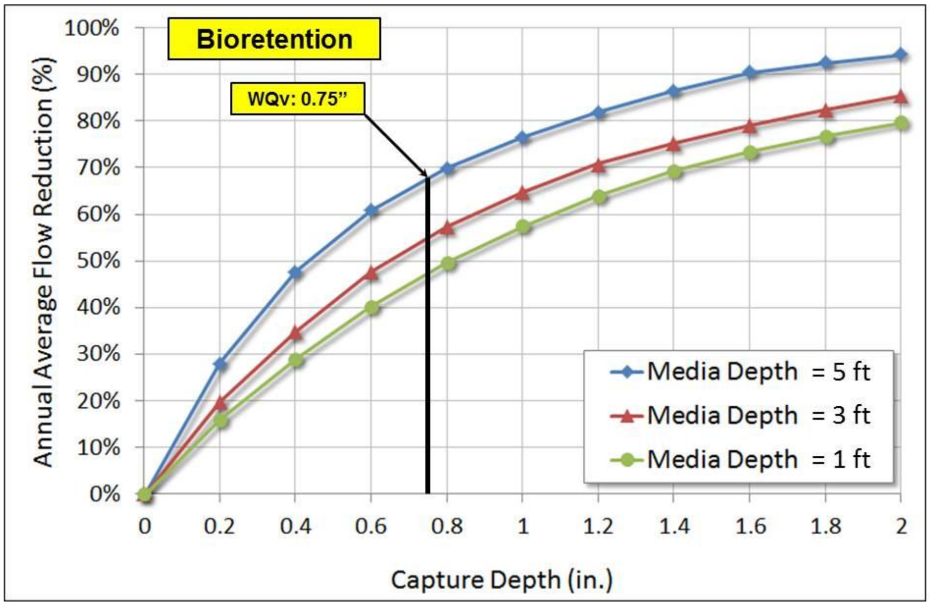


Figure 4-6. General BMP performance curve -- bioretention.

### *4.2.1 Rain Gardens*

Rain gardens are shallow surface depressions planted with specially selected native vegetation to capture and treat runoff from rooftops, streets, and parking lots. In residential areas, rain gardens are generally located in front yards; frequently designed to operate as a system accepting overflow from rain barrels. Driveways can also be routed to rain gardens through trench drains, capturing this impervious area before discharging into a road. Rain gardens are assumed to be constructed and maintained by the homeowner with little costs associated with design.

### *4.2.2 Bioretention Facilities*

Bioretention facilities (regional bioretention) are typically larger rain gardens with underdrains. These practices are typically designed to capture and retain runoff from roads, driveways, and other areas contributing to the storm drain network.

### *4.2.3 Bioswales*

A bioswale is a modified swale that uses bioretention media to improve water quality, reduce the runoff volume, and modulate the peak runoff rate while also providing conveyance of excess runoff. Bioswales are well suited for use within the rights-of-way of linear transportation corridors. They perform the same functions as grassed swales by serving as a conveyance structure and filtering and infiltrating runoff. Because bioretention media is used, they provide enhanced infiltration, water retention, and pollutant removal. Runoff reduction is achieved by infiltration and retention in the soils and interception, uptake, and evapotranspiration by the plants. Removal of pollutants has been positively linked to the length of time that the stormwater remains in contact with the herbaceous materials and soils (Colwell, 2000).

## *4.3 Rain Barrel Systems*

Rain barrels capture and store rainwater as a means of reducing stormwater runoff and providing a non-potable water source for irrigation. This practice is very simple and is used primarily on single-family homes. Rain barrels are usually situated at the discharge point of roof down spouts, and are a convenient source of water for gardening. Rain barrels are sold commercially or sometimes available through local municipalities. Due to their small size, rain barrels usually do not have a measurable effect on reducing runoff volumes.

## 4.4 Infiltration Trench

from "Low Impact Development Manual for the Lower Maumee and Ottawa River Watersheds" (American Rivers, 2010)

An infiltration trench is an excavated trench lined with filter fabric and backfilled with stone to allow stormwater to infiltrate into subsurface soils. Infiltration trenches are well suited for roadway medians and shoulders, particularly where available space is limited. This practice allows the volume of stormwater discharges to be reduced by promoting infiltration and allowing runoff to percolate into native soils through the sides and bottom of the trench.

Infiltration trenches must be used in conjunction with pretreatment BMPs such as filter strips or other sediment capturing devices to prevent sediments from clogging the trench. Infiltration trenches are typically sized for common storm events (e.g., WQv).

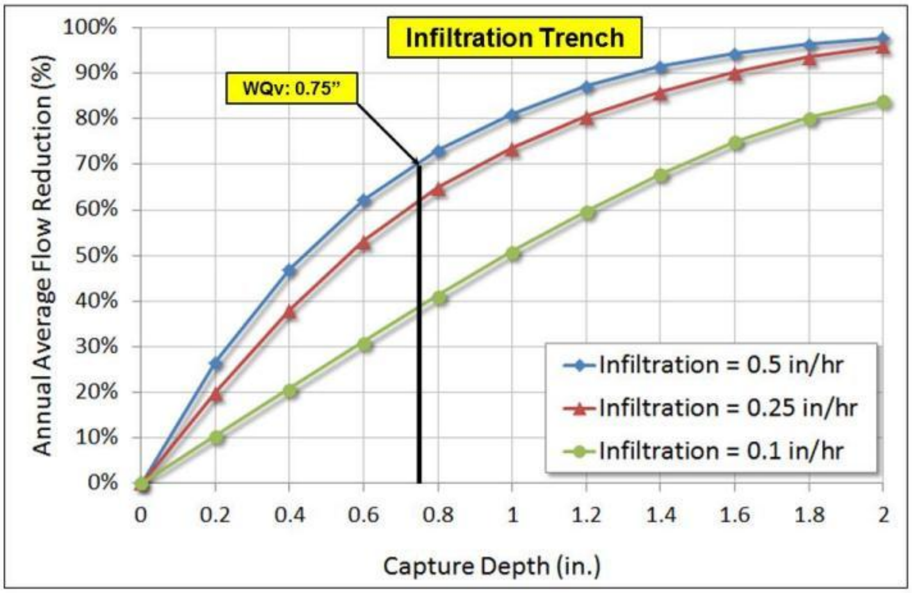


Figure 4-7. General BMP performance curve -- infiltration trench.

## 4.5 Porous Pavement

Porous pavements contain small voids that allow stormwater to drain through the surface to an aggregate storage area, then infiltrate into the soil. Site applications include modular paving systems (concrete pavers, grass-pave, gravel-pave) or poured in place solutions (pervious concrete, pervious asphalt).

Porous pavement is an alternative to impervious hardscapes, reducing the effective impervious area. This practice is able to attenuate flow and reduce volume. The pavement layer and aggregate subbase provide rapid infiltration. Total volume retention is dependent on properties of native soils. Porous pavement is generally used to manage rain that falls on the surface, rather than *"run on"* from other areas but can provide treatment for *"run on"* if the available treatment capacity is not fully utilized (e.g., for Spring Meadow Mall it is assumed that porous pavement in the parking areas could treat *"run on"* from commercial rooftop area.

Porous pavement is typically used to replace traditional impervious pavement for most pedestrian and vehicular applications, other than high-volume / high-speed roadways. Example applications include pedestrian walkways, sidewalks, driveways, parking lots, and low-volume roadways*)*. Porous pavement systems are typically sized for common storm events (e.g., WQv).

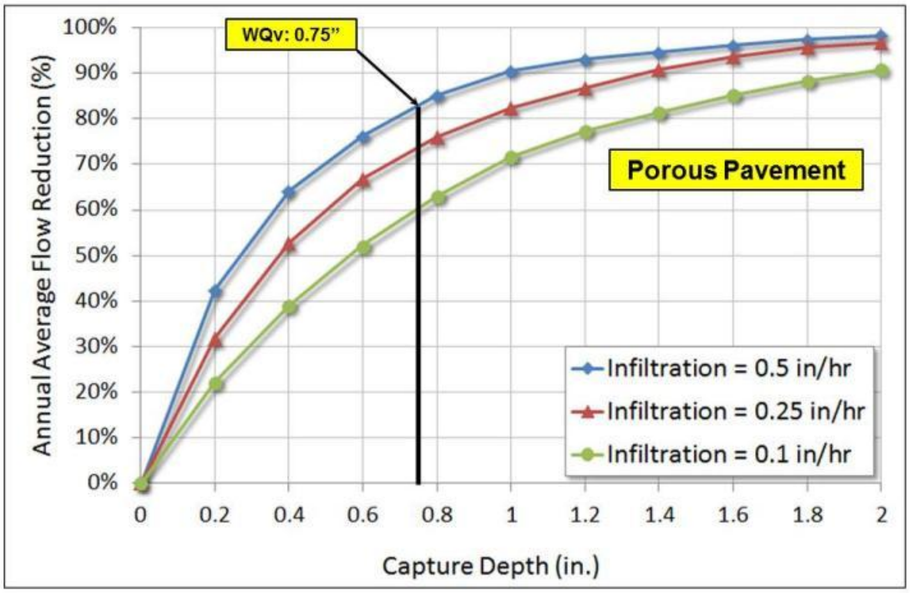


Figure 4-8. General BMP performance curve -- porous pavement.

## *4.6 Summary*

This step is a very important part of connecting TMDL implementation to stormwater management. Many TMDL implementation plans identify stormwater management as a key element and often list a suite of BMPs to consider. The intent of this part of the five-step process is to go beyond simply naming practices to quantitatively examining their potential effectiveness in the specific context of the Swan Creek watershed.

Developing performance curves from local climate provides a starting point to estimate actual reductions that could be achieved. Performance curves highlight the need to think about design parameters relative to TMDL allocations (i.e., what range is suitable or acceptable for the watershed, subwatershed, or catchment). These curves also show the sensitivity of assumptions and how certain variables can affect results.

### *4.6.1 Comparative Performance*

Example performance curves were presented for practices under consideration in the Swan Creek watershed (Figure 4-4 through Figure 4-8). Each graph displays BMP sensitivity to key design parameters (e.g., media depth) or assumptions (e.g., background infiltration rate). These curves also allow relative performance between different practices to be examined (Figure 4-9). The vertical line compares volume reductions between different practices when the BMP capture depth is sized at Ohio's WQv.

Similar comparison curves can be developed that focus on other design parameters or different response variables (e.g., pollutant loads). For example, performance curves evaluating TSS reduction would likely show different results. In short, the curves provide the ability to identify key variables where additional information may be needed. The curves also provide the ability to identify the range of trade-offs that may need to be considered.

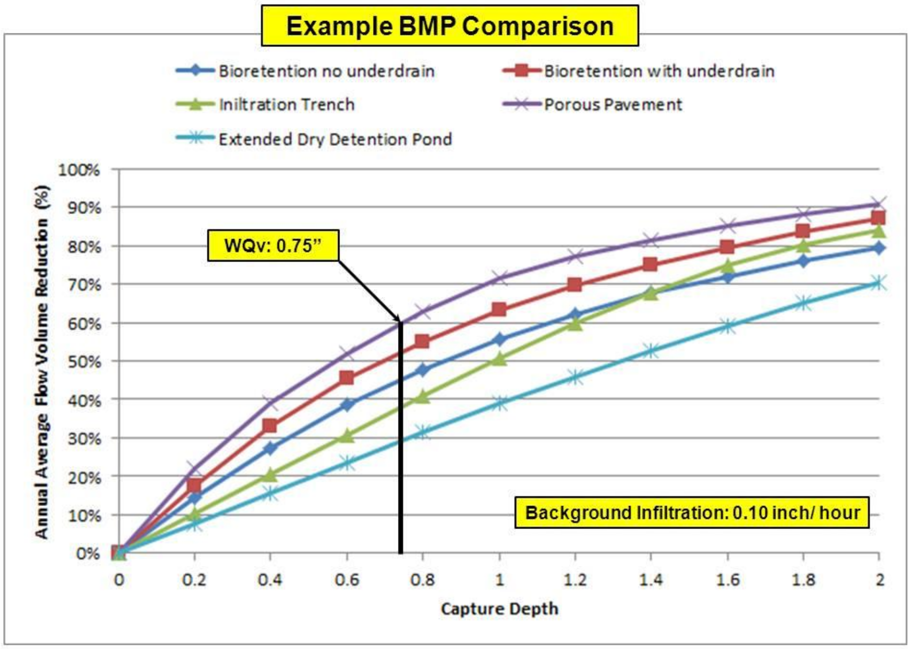
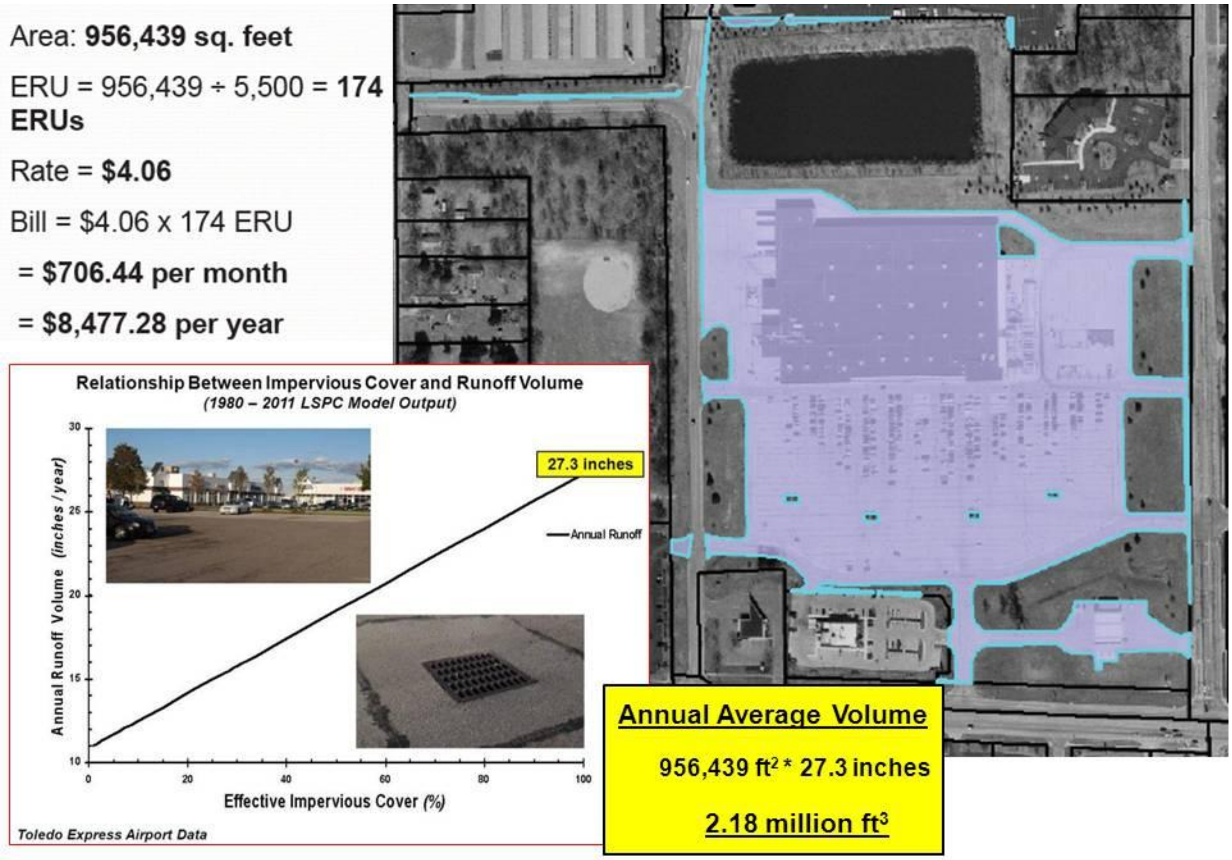


Figure 4-9. General BMP performance curve -- comparison of different practices.

### 4.6.2 *Example Application -- Stormwater Utility Credits*

A potential application of SUSTAIN's BMP module was identified for the Swan Creek watershed at the onset of this pilot effort. Lucas County recently created a Storm Water Utility District to provide a funding source for CIPs that address water quality and flooding problems. A component of the program is the ability for non-residential or regional residential property owners to apply credits that reduce their fees. During deliberations prior to establishment of the District, a presentation was made to the Storm Water Advisory Committee that provided credit calculation examples (http://www.co.lucas.oh.us/documents/Engineer/SWAC%205.PDF). One particular example from the presentation illustrates how the performance curves provide supplemental information that could assist the credit review process (Figure 4-10).

Calculations in the stormwater credit application are based on the amount of impervious surfaces. The example site has 956,439 square feet of impervious surface. As discussed earlier in Section 3.2, the annual average runoff from a surface that is 100 percent impervious is approximately 27 inches (Figure 3-24). Annual average runoff from this site would therefore be 2.18 million cubic feet. The example credit application presented three scenarios; all focused on the use of extended detention (Figure 4-11).



Area: **956,439 sq. feet**

ERU = 956,439 ÷ 5,500 = **174 ERUs**

Rate = **$4.06**

Bill = $4.06 x 174 ERU

= **$706.44 per month**

= **$8,477.28 per year**

**Annual Average Volume**

**956,439 ft² * 27.3 inches**

**2.18 million ft³**

**Example site information from presentation to Lucas County Storm Water Advisory Committee (June 23, 2010)**

Figure 4-10. Example stormwater utility credit application situation.

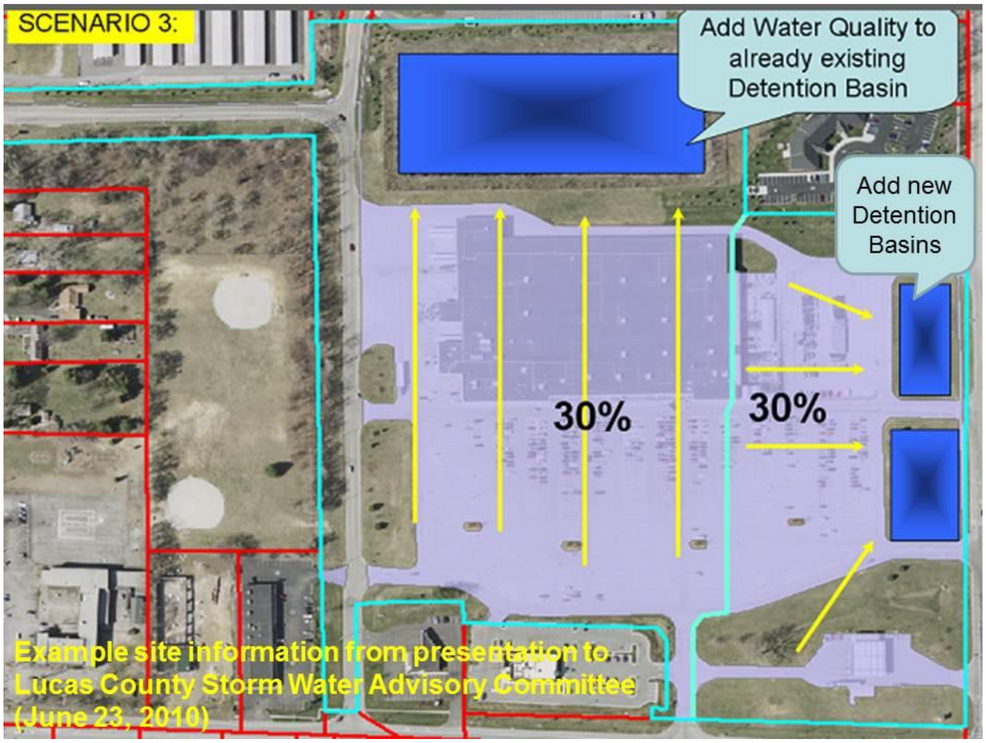


Figure 4-11. Example stormwater utility credit application hypothetical proposed BMPs.

The stormwater credit program provides an incentive for non-residential or regional residential property owners to conduct good stewardship practices. Recognizing that participation is voluntary, the performance curves provide a way to quantify benefits from proposed improvements or enhancements. Depending on the location of the proposed credit activity, performance curves could serve as a public education tools.

Quantitative information from performance curves could also provide a platform for discussing other options with credit applicants. If the proposed credit practice is upstream of an area where flooding has been a problem, for instance, a BMP comparison curve (e.g., Figure 4-9) could provide useful. Similarly, if the proposed credit activity is in a priority catchment for pollutant load reductions associated with TMDL implementation, performance curves could help provide quantitative documentation of the County’s efforts towards meeting those goals.

# 5. Opportunities and Constraints

The multi-scale analysis and five-step process allow estimates to be developed of stormwater volumes produced by various source areas, as discussed in Section 2.1. Figure 2-3 provides an example schematic that serves as an organizational tool for identifying potential stormwater source areas where certain types of BMPs could be implemented. Figure 5-1 extends that schematic into the Wolf Creek study catchments. This general schematic (or variations) could also be applied to other parts of the Swan Creek watershed, as well as the greater Toledo area and Maumee AOC. In fact, the Maywood Avenue Green Streets Revitalization project in Toledo provides information that can be used to examine BMP opportunities in the Wolf Creek test areas.

The Maywood Avenue effort is a neighborhood scale project that utilized LID and GI to reduce stormwater runoff and improve water quality. The physical layout is typical of other well-established older urban neighborhoods in Toledo; similar to older residential areas in the lower portions of Swan and Wolf Creeks. Key GI components of the Maywood effort are among those shown in Figure 5-1; notably bioswales, porous concrete on sidewalks, and rain barrel / rain garden systems. Basic design parameters from the Maywood work can be applied in the Swan Creek pilot to examine the potential effect of various treatment options in the study areas.

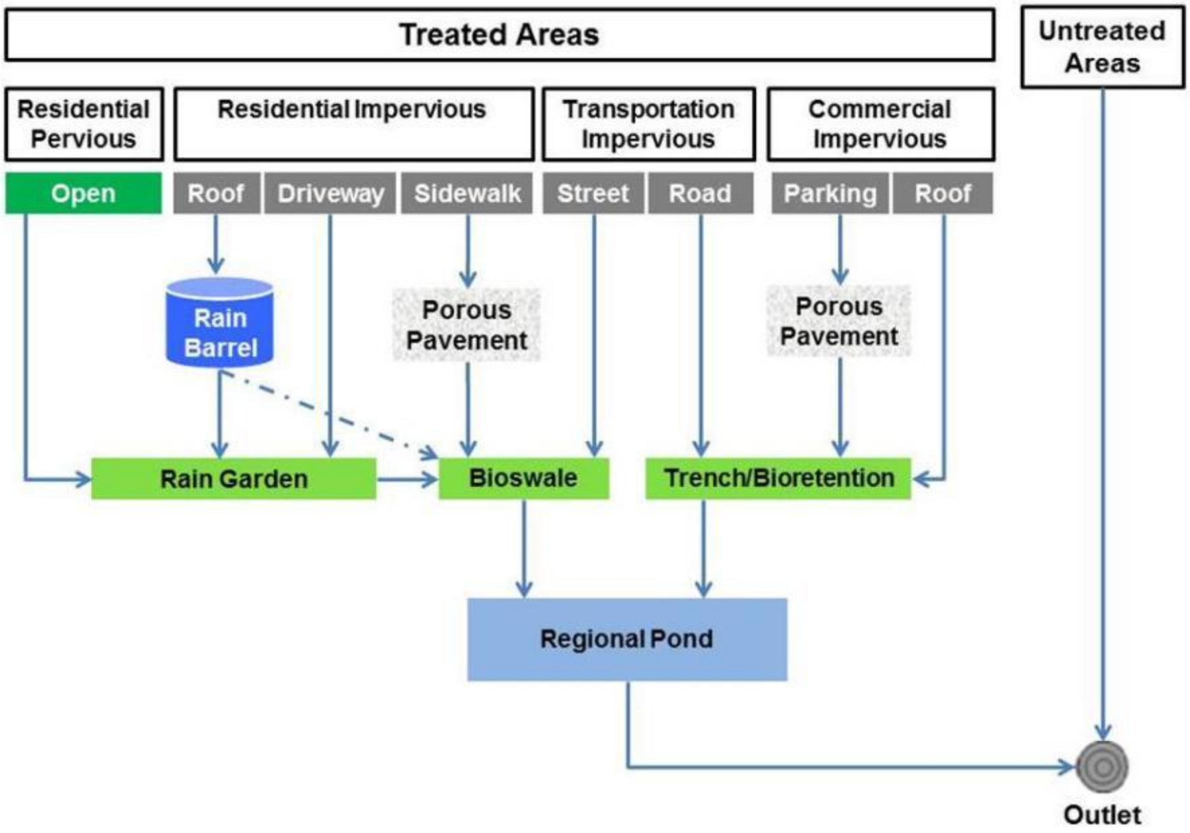


Figure 5-1. Schematic identifying BMP treatment train options for impervious surface types.

## 5.1 Study Area Options

All BMPs discussed in Section 4 were considered for use in the Good Ditch and Wolf #4 study areas. An important part of evaluating opportunities to implement these BMPs is assessing options. This involves examining the level of implementation that may be needed for BMP treatment alternatives by estimating the general performance of these practices beyond the site scale (e.g., catchment or subwatershed levels). Determining the maximum extent to which BMPs could be used to treat impervious surface types shown in Figure 5-1 is also part of this assessment. The distribution of impervious surfaces for the study areas was presented earlier in Table 3-9. Roads and parking areas are high priority surfaces for treatment; these represent surface types most likely to be directly connected to storm sewer systems. The following discussion illustrates factors to consider in evaluating level of implementation questions and determining maximum extents for BMPs.

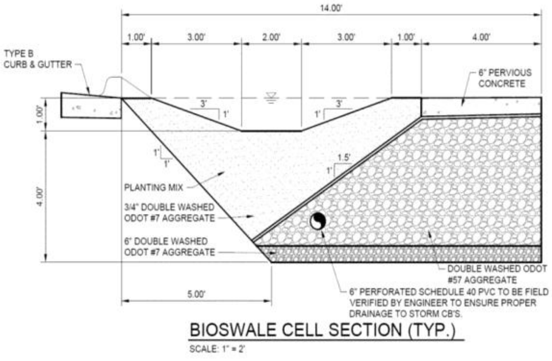
Impervious transportation surfaces in the Good Ditch study area, for example, are estimated at 83 acres. This includes both residential streets and arterial roads. Building on the Maywood Avenue experience, residential areas could be retrofitted with bioswales between sidewalks and streets (or along residential streets without sidewalks). Infiltration trenches would be considered for use on arterial roads. The presence of sidewalks helps draw a distinction between residential streets and arterial roads for the purpose of developing example calculations. Using the estimated area of sidewalks presented in Table 3-9 and an assumed sidewalk width of 4.5 feet results in approximately 34 acres of the Good Ditch impervious area that are residential streets. The remaining 49 acres is arterial roads. Assumptions on average widths for each pavement type are presented in Table 5-1; this allows street and sidewalk lengths to be estimated.

Table 5-1. Pavement summary.

| Study Area | Pavement Type | Length *(ft)* | Average width *(ft)* | Area *(acres)* | BMP Options *(not all inclusive)* |
|---|---|---|---|---|---|
| Good Ditch | Residential Streets | 59,500 | 25 | 34.0 | Bioswale |
| | Sidewalks | 119,000 | 4.5 | 12.3 | Porous Pavement, Bioswale |
| | Arterial Roads | 53,400 | 40 | 49.0 | Infiltration Trench |
| | Driveways | | | 28.0 | Porous Pavement, Bioswale |
| | Parking Lots | | | 50.0 | Porous Pavement, Bioretention |
| Wolf #4 | Residential Streets | 9,200 | 25 | 5.3 | Bioswale |
| | Sidewalks | | 4.5 | | Porous Pavement |
| | Arterial Roads | 8,400 | 40 | 7.7 | Infiltration Trench |
| | Driveways | | | | Porous Pavement, Bioswale |
| | Parking Lots | | | 60.0 | Porous Pavement, Bioretention |

## 5.2 Screening Analysis

Pavement dimension estimates are presented in Table 5-1; BMP options for each surface type are also included. For example, bioswales are a viable option for residential streets in the Swan Creek watershed (as demonstrated by the Maywood Avenue project). These linear practices are designed to provide off-line retention for road runoff and surrounding areas. In addition to the NLCD-based estimates shown in Table 5-1, soil information and air photos of the Good Ditch and Wolf #4 catchments were reviewed to confirm that bioswales are suitable for use in the study areas.



**from Maywood Avenue Project (City of Toledo)**

It is seldom practical (or even necessary) to attempt to build a model that includes all individual BMPs in each catchment, subwatershed, or watershed. Data and resource constraints often outweigh the benefit of incorporating details for every site into the overall assessment. However, there are methods to represent a consolidated response within specific BMP categories or catchments. This can greatly reduce the computational effort, yet still provide a powerful tool to assess potential BMP performance beyond the site scale.

A screening level analysis provides a starting point to evaluate the benefits of green infrastructure and low impact development. The primary focus of the screening analysis is to examine the level of treatment that could be applied in a catchment (e.g., BMP treatment capacity and percent area treated). Treatment capacity is quantified as consolidated storage (e.g., BMP surface area, ponding volume, etc.).

At a small scale (site or local), the BMP representation framework can be applied using models to explicitly simulate the benefits of individual practices. However, beyond the site scale, there are many more BMP units scattered across the landscape. This poses a challenge in terms of evaluating the collective benefits of distributed BMPs. The required simulations and cost comparisons for the range of distributed BMP opportunities place a significant burden on the computational accuracy and simulation time for system modeling.

One approach to address this challenge is to conduct a screening analysis using a *“consolidated network”* of BMPs. A *“consolidated network”* examines various options looking at different practices and configurations for impervious surface types of interest. The screening analysis is structured to evaluate the relative effect of different BMP configurations that focus on treating runoff from specific impervious surface types. A critical aspect is to examine the sensitivity of key design variables and assumptions. For bioswales, these include the percentage of available street length where the practice is installed, BMP design parameters (e.g., planting mix or media depth, underdrain features, ponding depth), and the native soil infiltration rate.

Figure 5-2 presents the results of a screening analysis for bioswales applied to residential streets. This particular graph depicts volume reduction as a function of the percentage of total residential street length where bioswales are installed (addressing a key question related *“level of implementation”*). The screening analysis is constructed in a way that shows the sensitivity major design variables (e.g., media depth, native soil infiltration rate).

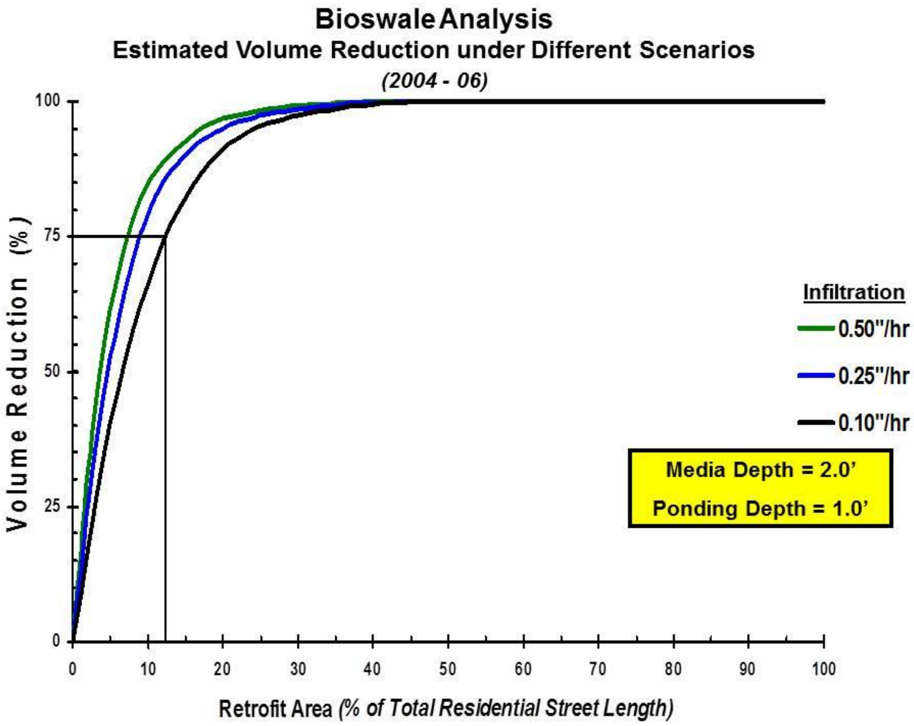


Figure 5-2. Bioswale volume reduction estimates at background infiltration rates.

In the Figure 5-2 example, a *"consolidated network"* was employed (in practice, however, bioswales would likely be implemented at a variety of points throughout the residential street network). Hourly output from the LSPC model was used to generate stormwater volumes. Under a *"consolidated network"*, the entire street runoff was then routed to one treatment area. The BMP assessment module estimated the amount of water leaving the treated area (either through infiltration or runoff) to determine volume reduction based on the design parameters.

There are several points to note from this screening analysis example. First, the level of implementation results in significant volume reductions when the retrofit area is less than 20 percent of the total street length. There are clearly diminishing returns above that level of implementation for this particular situation. This reflects the regional nature of the consolidated network; specifically, there are efficiencies gained from central treatment systems. In the case of more dispersed BMPs (e.g., small rain gardens on individual residential yards), the rate of reduction with increased implementation would likely be linear (rather than exponential).

The second observation relates to connecting TMDL implementation with stormwater management. The Wolf Creek TMDL reduction target for TSS is around 75 percent. Information presented in the baseline conditions discussion (Section 0) showed a clear relationship between stormwater flow volume and TSS. The level of implementation needed for bioswales to meet a 75 percent volume reduction is somewhere between 7 and 13 percent, depending on background infiltration rate. This provides a starting point for stormwater management planning to address TMDL allocations (at least with respect to stormwater resulting from residential streets).

Screening analyses for other practices under consideration in the study areas (Table 5-1) are presented in Figure 5-3 and Figure 5-4. Figure 5-3 depicts volume reduction as a function of the percentage of arterial roads converted to infiltration trenches. Figure 5-4 shows volume reduction as a function of parking area converted to porous pavement. It should be noted that actual implementation of these practices will also have to consider infiltration rules found in the Ohio *"Rainwater and Land Development"* manual (Ohio DNR, 2006).

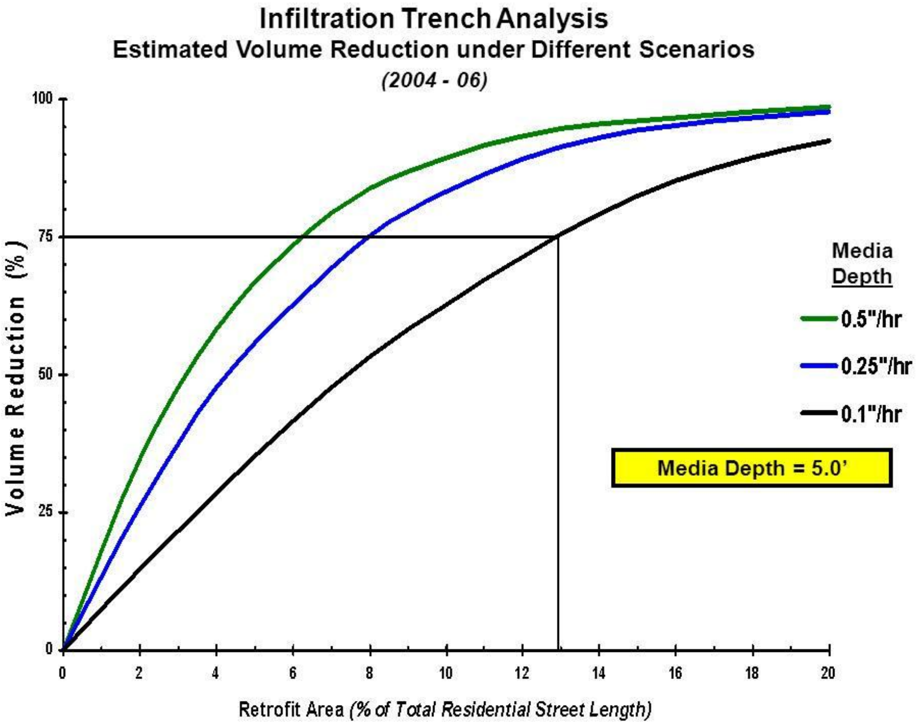


Figure 5-3. Infiltration trench volume reduction estimates at different infiltration rates.

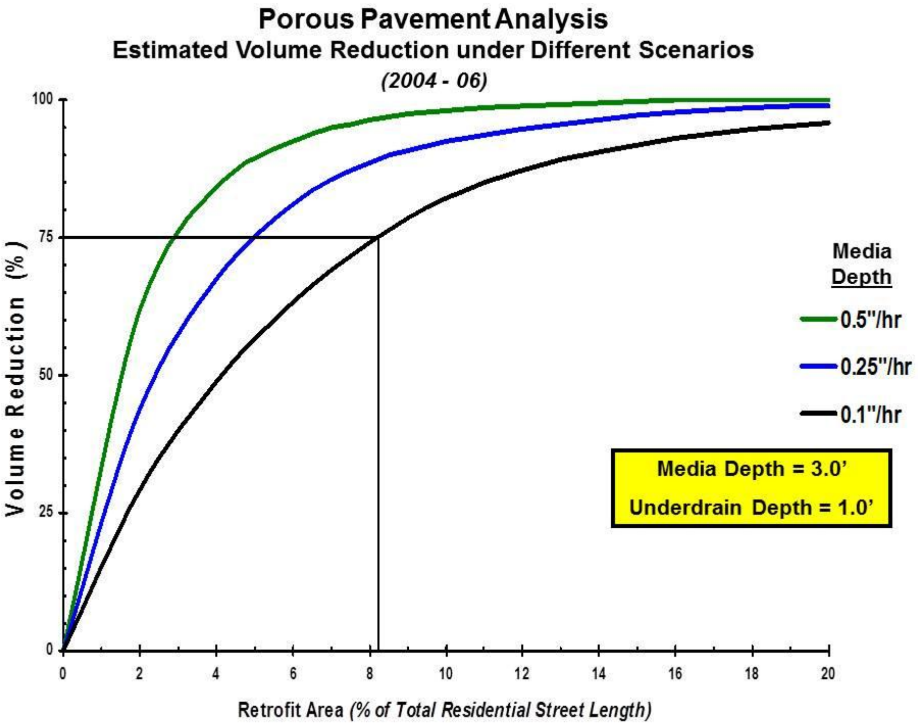


Figure 5-4. Porous pavement volume reduction estimates at different infiltration rates.

## 5.3 Adaptive Management

The BMP module within SUSTAIN provides a valuable method to examine an array of design assumptions and stormwater management strategies. Many other curves could be generated to further assess variations of the practices presented here, as well as treatment train options depicted in Figure 5-1. The important point, though, is that the screening analysis curves provide a tool that assists advance TMDL implementation planning efforts. In particular, the tool supports an adaptive management approach towards TMDL implementation.

Under adaptive management, an iterative approach is used that continues while better data are collected, results analyzed, and implementation plans enhanced. The BMP assessment module in SUSTAIN provides the ability to explore different types of implementation options. The level of implementation curve defines a relative range of volume (or pollutant) reductions that might be expected using BMP configurations of interest. This information points stormwater managers towards potential solutions. However, ultimate BMP performance is driven by design specifications determined through actual field measurements.

# 6. Costs

Cost functions are mathematical formulations used to estimate financial expenditures associated with BMP implementation. These represent the combined costs of specific BMP designs, materials, land / space requirements, and operation / maintenance. Cost estimates are essential for the optimization phase of the project.

The purpose of this activity is to ensure that occurs to develop appropriate cost functions. Comprehensive work on stormwater BMP costs was conducted as part of the Rogue River National Wet Weather Demonstration Project in Michigan (*"Cost Estimating Guidelines: Best Management Practices and Engineering Controls"*, 1997 and 2001 update). Some cost estimates for stormwater BMPs are available as part of local watershed plans, such as the *"St. Joseph River Watershed Management Plan"* (Indiana / Michigan).

Other work conducted in the Great Lakes Region includes a University of Minnesota (UMN) report *"The Cost and Effectiveness of Stormwater Management Practices"*. UMN staff collected and analyzed construction, operation, and maintenance cost data for a range of stormwater management practices. These included dry detention basins, wet basins, sand filters, constructed wetlands, bioretention filters, infiltration trenches, and swales using literature reported on existing sites across the United States.

Cost information has also been compiled in other parts of the country to support BMP targeting and optimization efforts. Examples include work in the Charles River, Massachusetts, Vermont, and Southern California.

Cost data represents life cycle costs by considering three categories of BMP costs:

- Probable Construction Costs – The initial cost to construct the BMP
- Annual Operation & Maintenance – The annual costs to maintain the BMP
- Repair & Replacement Costs – The additional costs to repair or replace the BMP

A standard unit cost was defined for each BMP category, since the range of BMPs was unknown and expected to vary significantly. Each unit cost was converted to 2012 dollars by applying a three percent inflation rate from the published year of the cost data to 2012. A discount rate of 3 percent was used for converting annual O&M and repair and renewal costs to present value.

The lifecycle period was defined as 20-years to take into account costs for replacing some BMPs. Several of the sources used to derive costs data defined engineering and design and/or contingency factors based upon a percent of the base construction cost, while other sources intentionally omitted them. A default 15% engineering and design cost factor and 25% contingency cost factor were assigned to probable construction costs when no values were provided. No land, administration, demolition, or legal cost factors were defined for any of the probable construction costs.

The following sources were reviewed when defining the lifecycle costs:

- WERF. 2009. BMP and LID Whole Life Cost Models version 2.0. Water Environment Research Foundation.
- Center for Neighborhood Technology. June 30, 2009. National Green Values Calculator.

- University of Minnesota. Peter T. Weiss, John S. Gulliver, Andrew J. Erickson. June 2005. “The Cost and Effectiveness of Stormwater Management Practices”. Prepared for Minnesota Department of Transportation.
- Low Impact Development Center, Inc. November, 2005. “Low Impact Development for Big Box Retailers”. Prepared for U.S. Environmental Protection Agency. Prepared by the Low Impact Development Center, Inc.

The City of Toledo, Ohio and Burnsville, Minnesota provided cost data for design and construction of bioswales and bioretention, respectively, and Chagrin River Watershed Partners provided review and input on cost data based on watershed experience. Additional Tetra Tech projects and best professional judgment were also considered when defining the range of lifecycle unit costs.

Table 6-1. BMP costs.

| Parameter | Rain Barrel | Rain Garden | Bioswale | Infiltration Trench | Porous Pavement | Detention Pond |
|---|---|---|---|---|---|---|
| **Life Cycle Cost Data** | | | | | | |
| Lifecycle Unit Cost [A+B+C] (NPV) | \$165.69 ea | \$13.6/ft$^2$ | \$36.80/ft$^2$ | \$38.73/ft$^2$ | \$16.58/ft$^2$ | \$18.95/ft$^2$ |
| A) Probable Unit Cost | \$95.00 ea. | \$7.80/ft$^2$ | \$26.07/ft$^2$ | \$28.00/ft$^2$ | \$12.38/ft$^2$ | \$11.53/ft$^2$ |
| Annual O&M | \$0 | \$0 | \$0.72/ft$^2$ | \$0.72/ft$^2$ | \$0.28/ft$^2$ | \$0.15/ft$^2$ |
| B) Annual O&M (NPV) | \$0 | \$0 | \$10.73/ft$^2$ | \$10.73/ft$^2$ | \$4.20 | \$2.17/ft$^2$ |
| A) Repair & Replacement (NPV) | \$70.69 ea. | \$5.8/ft$^2$ | 0 | 0 | 0 | \$5.25/ft$^2$ |
| BMP Lifecycle Period | 10-yrs | 10-yrs | 20-yrs | 20-yrs | 20-yrs | 10-yrs (Repair & sediment removal) |
| NPV – Net Present Value | | | | | | |

# 7. Targeting and Optimization

One objective of this pilot effort is to examine the BMP targeting and optimization capabilities of SUSTAIN. This aspect of the project focused on the Wolf #4 catchment, which includes Spring Meadows Mall. This catchment has the highest development intensity in the Wolf Creek subwatershed. As a result, greater stormwater volumes are likely produced in this catchment relative to other parts of the Wolf Creek subwatershed, making it a logical area to examine optimization tools.

## *7.1 Assumptions*

The optimization component of SUSTAIN requires a defined set of design parameters for each BMP component in the treatment train. Presented in Table 7-1, these values are for illustrative purposes only. BMP performance is driven by design specifications determined through actual field measurements. Consequently, optimization results presented in this section are solely to demonstrate model capabilities and to highlight the effect that design parameter assumptions may have on model results.

Table 7-1. Example BMP configuration parameters used to illustrate targeting and optimization.

| Parameter | Rain Barrel | Rain Garden | Bioswale | Infiltration Trench | Porous Pavement | Detention Pond |
|---|---|---|---|---|---|---|
| **Physical configuration** | | | | | | |
| Unit size | 55 gal | 175 $ft^2$ | 5 ft wide x variable length | 15 ft wide x variable length | 50 ft wide x variable length | Drainage Area Dependent |
| Design drainage area (acre) | 0.01 | 0.1 | N/A | N/A | N/A | N/A |
| Substrate depth (ft) | N/A | 2 | 3 | 5 | 2 | 0.1 |
| Underdrain storage depth (ft) | N/A | N/A | 2 | N/A | 1 | N/A |
| Ponding depth (ft) | N/A | 0.5 | 0.5 | 1 | 0.1 | 5 |
| **Infiltration** | | | | | | |
| Substrate layer porosity | N/A | 0.4 | 0.4 | 0.5 | 0.45 | 0.3 |
| Substrate layer field capacity | N/A | 0.25 | 0.25 | 0.06 | 0.055 | 0.25 |
| Substrate layer wilting point | N/A | 0.1 | 0.1 | 0.02 | 0.05 | 0.1 |
| Underdrain gravel layer porosity | N/A | N/A | 0.5 | N/A | 0.5 | N/A |
| Vegetative parameter, A | N/A | 1 | 1 | 0.6 | 1 | 1 |
| Background infiltration rate (in/hr) | N/A | 0.1 | 0.1 | 0.25 | 0.1 | 0.05 |
| Media final constant infiltration rate (in/hr) | N/A | N/A | 0.5 | N/A | 1 | N/A |

The SUSTAIN simulation used rainfall - runoff data generated by the Wolf Creek watershed LSPC model. SUSTAIN uses a series of model runs to arrive at a near optimal set of solutions (as opposed to running a single model simulation). The optimization analysis used three consecutive years (2004 through 2006) to evaluate different implementation strategies. These represent a low flow year, an average year, and a high flow year (see Figure 3-18 for a frame of reference).

All BMPs in the treatment train were routed from stormwater source areas, shown earlier in Figure 5-1. The optimization component of SUSTAIN requires establishment of an upper limit, which represents the maximum extent that each BMP could be applied in the test area for simulation purposes (defined in Table 7-2). As with BMP design parameters, these maximum extent values are strictly for illustrative purposes.

Table 7-2. Example maximum extent of BMPs.

| **BMP** *(measure)* | **Maximum BMP Extent** | **Maximum Drainage Area** *(acres)* |
|---|---|---|
| Bioswale *(acres [A])* | 0.63 | 9.6 |
| Porous Pavement *(acres)* | 60 | 60.0 |
| Infiltration Trench / Bioretention *(acres [B])* | 1.4 | 21.0 |
| Regional Pond *(acres [C])* | 3.7 | 187 |
| Rain Barrel *(unit [D])* | 48 | 0.45 |
| Rain Garden *(unit [E])* | 12 | 1.8 |

**Note:**
[A] 5,520 linear feet by 5 feet wide
[B] 4,200 linear feet by 15 feet wide
[C] 2% of contributing drainage area
[D] each rain barrel is 55 gallons
[E] each rain garden is 175 $ft^2$

Life cycle cost information, presented in Table 6-1, was obtained from information used in other USEPA Region 5 SUSTAIN pilot efforts. All decision variables (length of infiltration trench, amount of parking converted to porous pavement, area of pond, length of bioswale, number of rain barrels, number of rain gardens) were allowed to vary at one percent increments of their maximum value. The optimization models were set to simulate 5,000 – 6,000 model runs and took just under two hours to complete.

## *7.2 Total Volume*

A major stormwater management goal is volume reduction to protect downstream resources. Each SUSTAIN simulation run used a unique set of BMP design specifications to calculate volume reduction and an associated relative cost. Design specifications varied across the range of decision variables described above (length of infiltration trench, etc). Figure 7-1 shows the results of all simulations. The small gray points represent each BMP combination evaluated; the larger orange points along the left-and-upper-most perimeter of the curve represent the lowest cost options at each volume reduction interval on the y-axis.

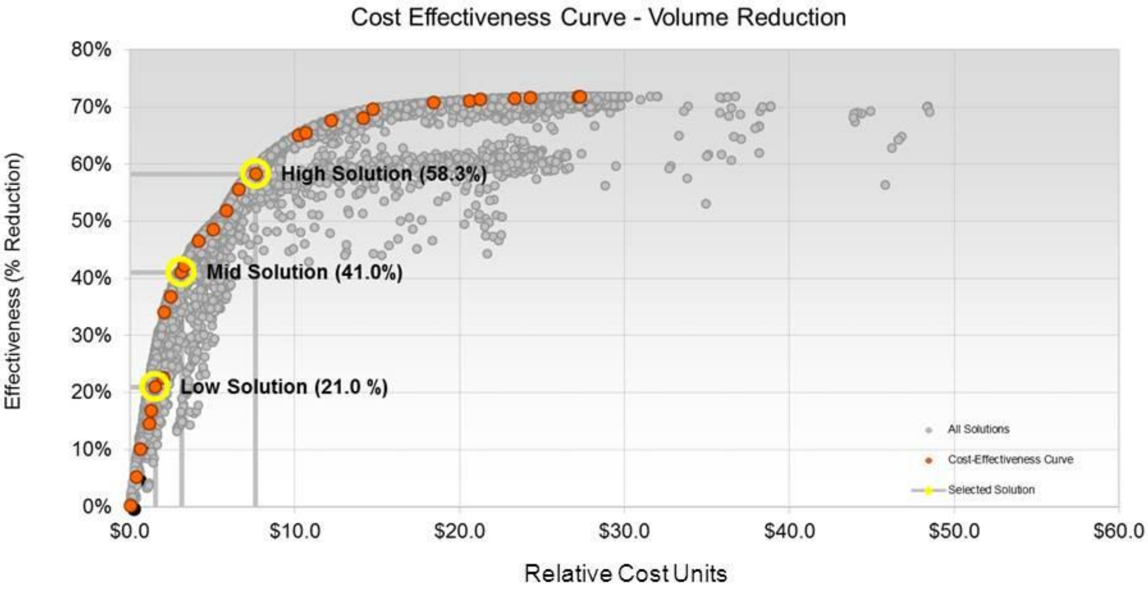


Figure 7-1. Cost-effectiveness curve for annual flow volume reduction in Wolf #4 catchment.

Potential implementation strategies can be examined in greater detail by focusing on several points along the cost effectiveness curve. Three individual solutions representing a low stormwater volume reduction level (21 percent), a mid-reduction level (41 percent), and high reduction level (58.3 percent) are displayed in Figure 7-1. Each individual solution of interest is shown as a large yellow circle, pinpointed with an intersecting line. Table 7-3 summarizes relative costs for each solution of interest.

Table 7-3. Selected near-optimal solutions for evaluating BMP utilization.

| **Solution Level** | **Relative Cost Units** | **Annual Total Volume Reduction** *(%)* |
|---|---|---|
| Low | 1.54 | 21.0 |
| Mid | 3.13 | 41.0 |
| High | 7.64 | 58.3 |

The functionality and effectiveness of those BMPs comprising the three solutions can be examined in greater detail. An independent model run for each solution of interest provides information that describes the amount of treatment afforded by each BMP. How much each BMP was utilized to achieve a particular volume reduction can also be calculated. Finally, a detailed examination of each solution allows for a close review of design assumptions or other factors that may have contributed to one practice being selected over others.

*BMP Treatment*. Figure 7-2 and Table 7-4 summarize the volume reduction provided by each BMP at the three different volume reduction levels (low, mid, and high). Flow volume reductions provided by each BMP are achieved through a combination of infiltration and evapotranspiration. The relative volume reduction of each BMP is largely consistent across all solutions. Infiltration trenches show the largest volume reductions for all scenarios except low level treatment; porous pavement provides the largest reduction in this situation (41.7 acre feet).

Porous pavement also provides the second largest volume reductions for the mid- and high level treatment scenarios. Bioswale and detention pond BMPs show a similar trend; relatively small volume reductions are achieved for the low and mid-level treatment solutions. However, significantly larger volumes are reduced for the high level treatment scenario. Rain gardens and rain barrels provide the smallest volume reductions consistently across all solutions; rain barrels providing negligible volume reduction for all scenarios.

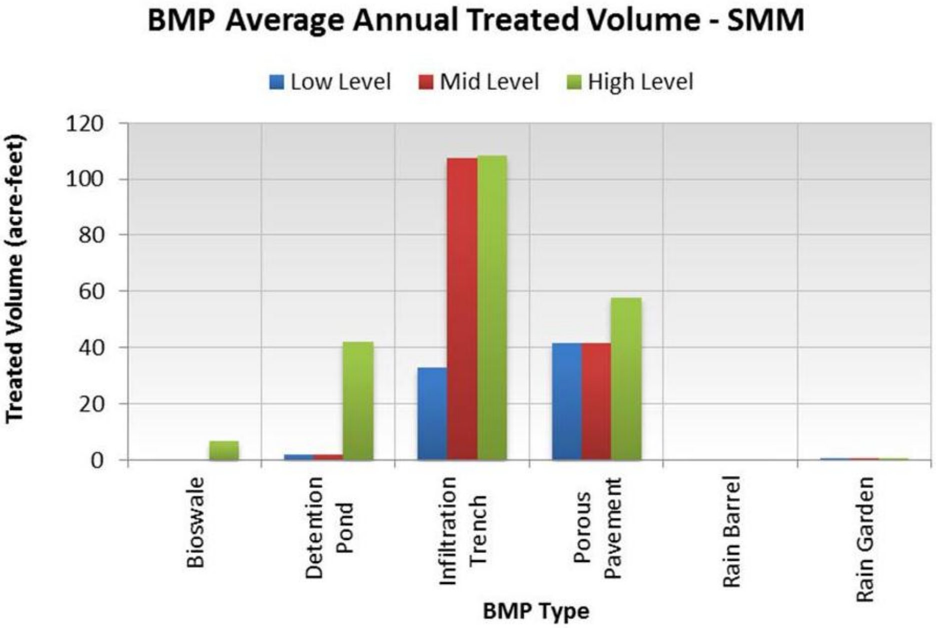


Figure 7-2. BMP annual flow volume reduction in the Wolf #4 catchment.

Table 7-4. BMP flow volume reduction in the Wolf #4 catchment.

| BMP | BMP Volume Treatment *(acre-feet)* | | |
|---|---|---|---|
| | **Low Level** | **Mid-Level** | **High Level** |
| Bioswale | 0.10 | 0.10 | 6.67 |
| Detention Pond | 2.07 | 1.94 | 42.24 |
| Infiltration Trench | 33.16 | 107.46 | 108.20 |
| Porous Pavement | 41.73 | 41.73 | 57.96 |
| Rain Barrel | 0.00 | 0.00 | 0.00 |
| Rain Garden | 0.54 | 0.54 | 0.54 |
| **Total** | 77.60 | 151.77 | 215.61 |

Another way of viewing the analysis is shown in Figure 7-3. The volume reduction of each scenario is broken out as a percentage attributable to each BMP. Percentages closely mirror overall volumes; infiltration trenches and porous pavement provide the majority of treatment, followed by detention ponds. Similar to the total volumes treated shown in Figure 7-2, bioswales provide significant volume reduction for the high level treatment scenario. Rain gardens and rain barrels provide little or no treatment for all three scenarios.

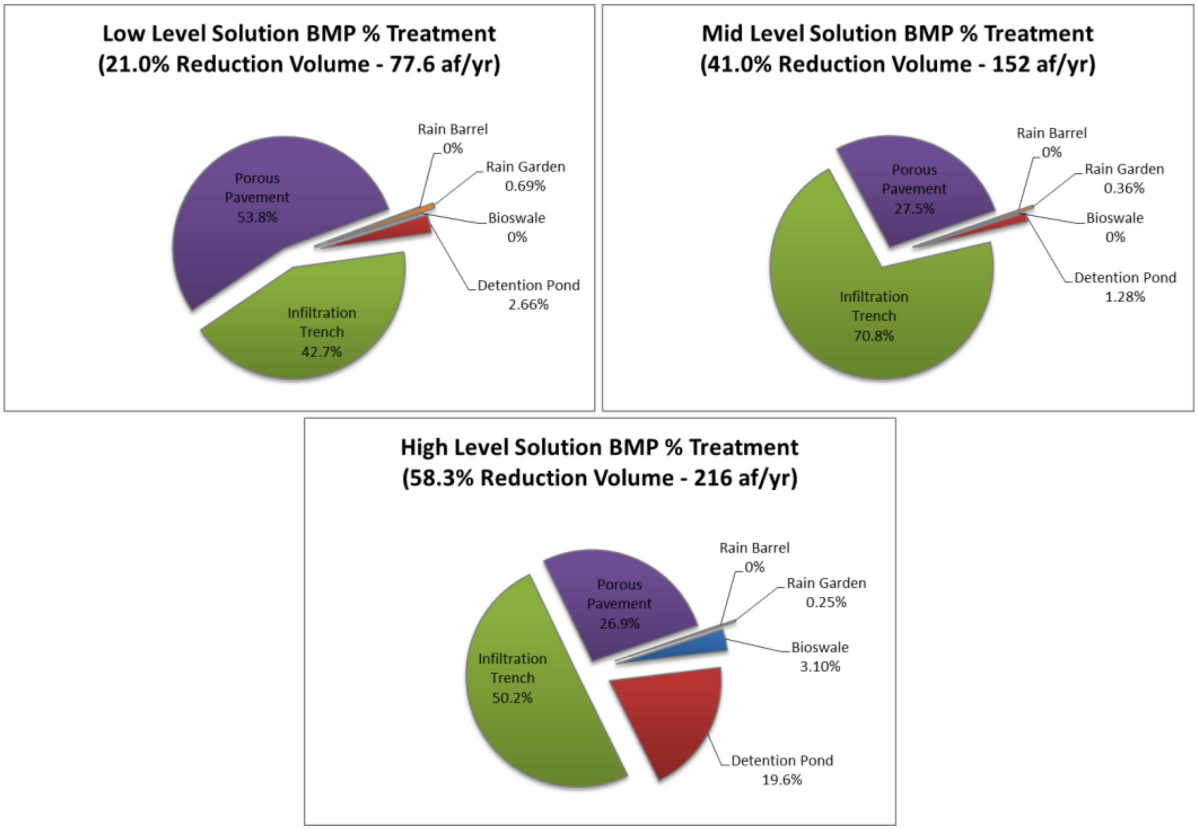


Figure 7-3. BMP contributions to annual flow volume reduction in the Wolf #4 catchment.

*BMP Utilization*. The percent utilization of each BMP for the three solutions of interest is shown in Figure 7-4. Percent utilization for each solution is the area or number of BMPs in the selected solution divided by the maximum area or number of BMPs SUSTAIN examined (Table 7-2). Figure 7-4 illustrates how utilization changes for each BMP as cost and percent volume control increase. The extent to which each practice is used for the three selected solutions is also presented in Table 7-5, including the maximum area for each practice defined in Table 7-2.

In general, as the level of treatment increases from low to high volume reduction levels, the utilization of each BMP either increases or remains relatively constant. BMPs for which the increasing trend is observed include bioswales, detention ponds, and infiltration trenches. The utilization of porous pavement, rain barrels, and rain gardens remains relatively constant throughout all scenarios. The reasons for these trends can be attributed to several factors, including the unit cost, the maximum extent of each BMP, and values associated with key design parameters (e.g., background infiltration rate).

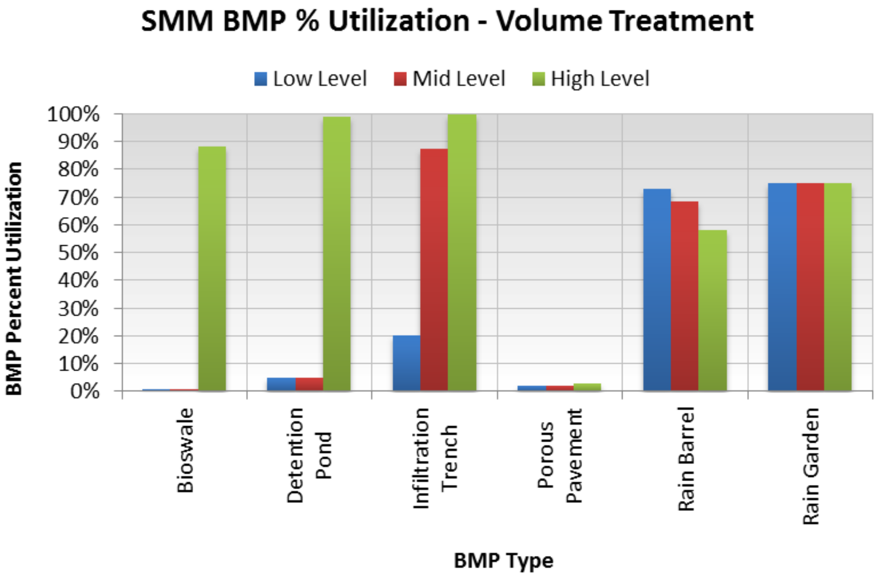


Figure 7-4. BMP utilization for annual flow voulume reduction in Wolf # catchment.

Table 7-5. BMP opportunity and percent utilization for flow volume treatment in Wolf #4 catchment

| BMP | Extent Units | Maximum Extent | Volume Treatment BMP Utilization | | |
|---|---|---|---|---|---|
| | | | Low Level | Mid-Level | High Level |
| Bioswale | Acres | 0.63 | 1.0% | 1.0% | 88.2% |
| Detention Pond | Acres | 3.7 | 5.1% | 5.1% | 99.0% |
| Infiltration Trench | Acres | 1.4 | 20.2% | 87.7% | 99.8% |
| Porous Pavement | Acres | 60 | 2.0% | 2.0% | 3.0% |
| Rain Barrel | Units | 48 | 72.9% | 68.8% | 58.3% |
| Rain Garden | Units | 12 | 75.0% | 75.0% | 75.0% |

*Observations*. The detailed analyses presented in Figure 7-3 (BMP treatments selected) and in Figure 7-4 (utilization) point to several observations taken from the optimization process. Some BMPs were highly favored and almost always utilized; others were relied on more heavily for increasing levels of management; yet still others were never considered to be cost effective treatment options. The following observations warrant highlighting, as use of SUSTAIN's optimization capability is considered for other parts of the Swan Creek watershed:

- Porous pavement was consistently used at all three volume reduction levels evaluated. This practice was likely selected not only based on cost, but also due to the large area of opportunity (notably the Spring Meadows Mall parking lot). Porous pavement was the most favored BMP under the low level reduction solution. This is consistent with the BMP effectiveness curve presented in the screening analysis for this practice; the largest reductions were achieved at low levels of implementation (Figure 5-4).

- Infiltration trenches provide the greatest reductions for the mid- and high level solutions. This highlights the effect that assumptions may have on optimization results. Although the unit cost for infiltration trenches is higher than that for porous pavement, the assumed backgound infiltration rate is much larger (Table 7-1).

- Detention ponds, though primarily used to hold stormwater for controlled release (and attenuation of peak flows), provide some volume reduction during the simulation through background infiltration and evaporation. However, this practice was only selected for the high reduction solution.

- Bioswales were only selected for achieving the highest flow reduction. This BMP was parameterized with a relatively high unit cost and a relatively low background infiltration rate. It is also noted that unit cost for this SUSTAIN optimization setup was based on BMP footprint, and not on storage volume. Again, assumptions play a major role in determining optimization results.

## *7.3 Total Suspended Solids*

Total suspended solids reductions were also evaluated using SUSTAIN's optimization component. Similar to volume reduction, potential implementation strategies are examined in greater detail by focusing on several points along the cost effectiveness curve. Three individual solutions representing a low stormwater volume reduction level (19.8 percent), a mid-reduction level (36.8 percent), and high reduction level (59.1 percent) are displayed in Figure 7-5. Table 7-6 summarizes implementation costs for the set of selected TSS load reduction solutions.

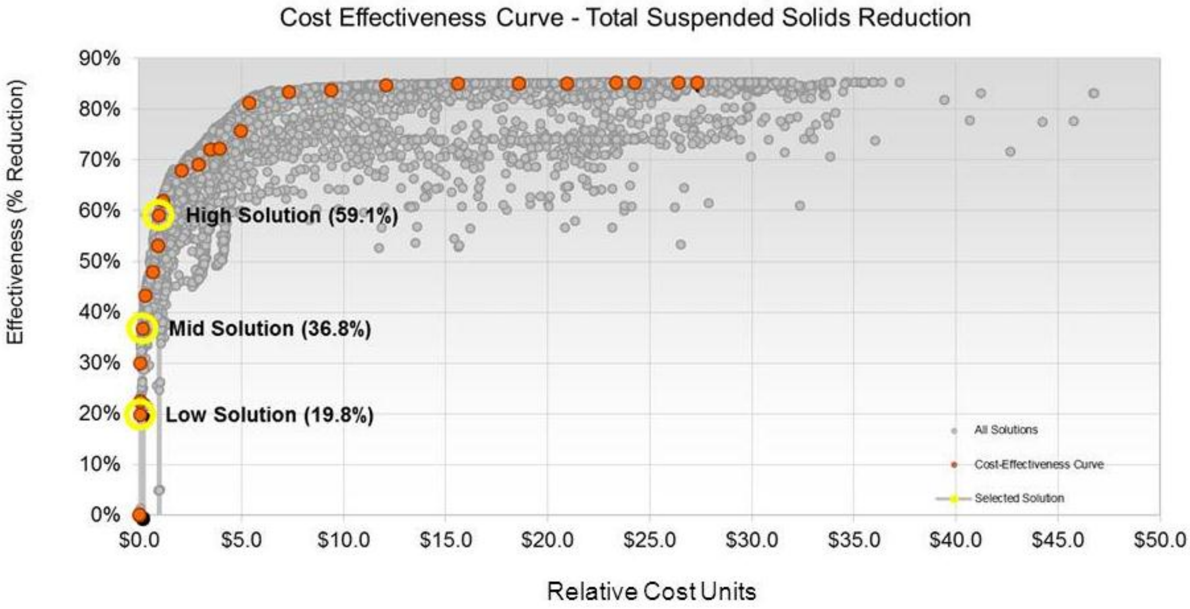


Figure 7-5. Cost-effectiveness curve for annual TSS reduction in the Wolf #4 catchment.

Table 7-6. Selected near-optimal solutions for BMP TSS treatment in the Wolf #4 catchment.

| **Solution Level** | **Relative Cost Units** | **Annual TSS Reduction** *(%)* |
|---|---|---|
| Low | 0.03 | 19.8 |
| Mid | 0.18 | 36.8 |
| High | 0.97 | 59.1 |

*BMP Treatment*. Figure 7-6 shows the TSS load reduction provided by each BMP for the selected solutions in the Wolf #4 catchment. The TSS load reduction provided by each BMP is achieved through a combination of infiltration and settling processes.

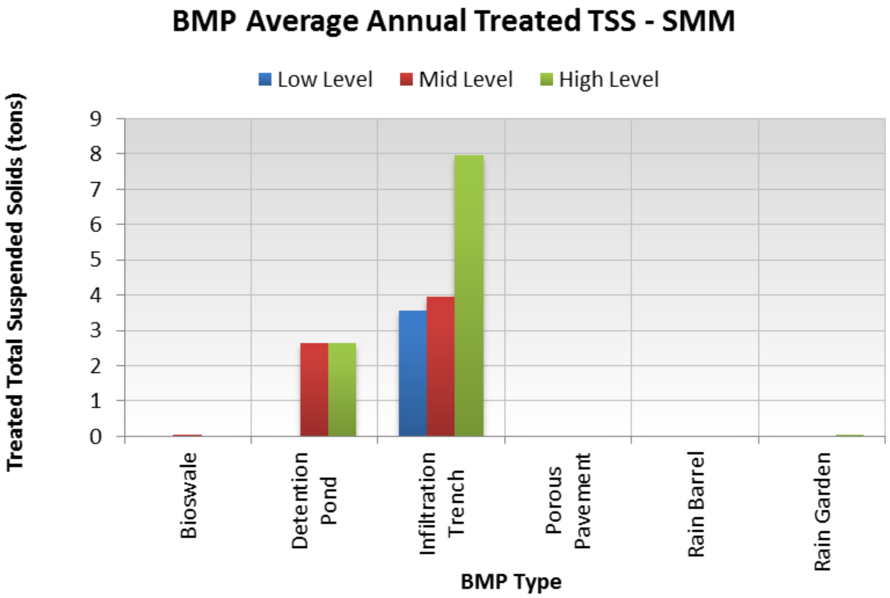


Figure 7-6. BMP annual TSS reduction in the Wolf #4 catchment.

Table 7-7. BMP annual TSS reduction in the Wolf #4 catchment.

| **BMP** | **BMP TSS Treatment** *(tons)* | | |
|---|---|---|---|
| | **Low Level** | **Mid-Level** | **High Level** |
| Bioswale | 0.00 | 0.04 | 0.00 |
| Detention Pond | 0.00 | 2.64 | 2.64 |
| Infiltration Trench | 3.57 | 3.94 | 7.97 |
| **Total** | 3.57 | 6.62 | 10.61 |

Similar to treated volume, infiltration trenches provide the largest TSS load reductions for all scenarios. The large load reductions provided by infiltration trenches seem to be attributed, in large part, to BMP design where filter strips are used in advance of water being routed to the trench. Also, the large substrate depth (5 feet) allows for large volumes of runoff to be infiltrated, retained, and treated. Unlike the total volume reduction simulations, detention ponds provide significant load reductions for the mid, as well as the high level treatment scenarios and porous pavement provides no treatment across all treatment levels. Bioswales provide relatively small TSS load reductions consistently across the three solutions.

Figure 7-7 shows the percent of the TSS load reduction attributable to each BMP for the low, mid, and high level treatment scenarios. Percentages closely mirror total load reductions, where infiltration trenches provide the majority of treatment for all scenarios and detention ponds show significant load reduction for the mid and high level scenarios.

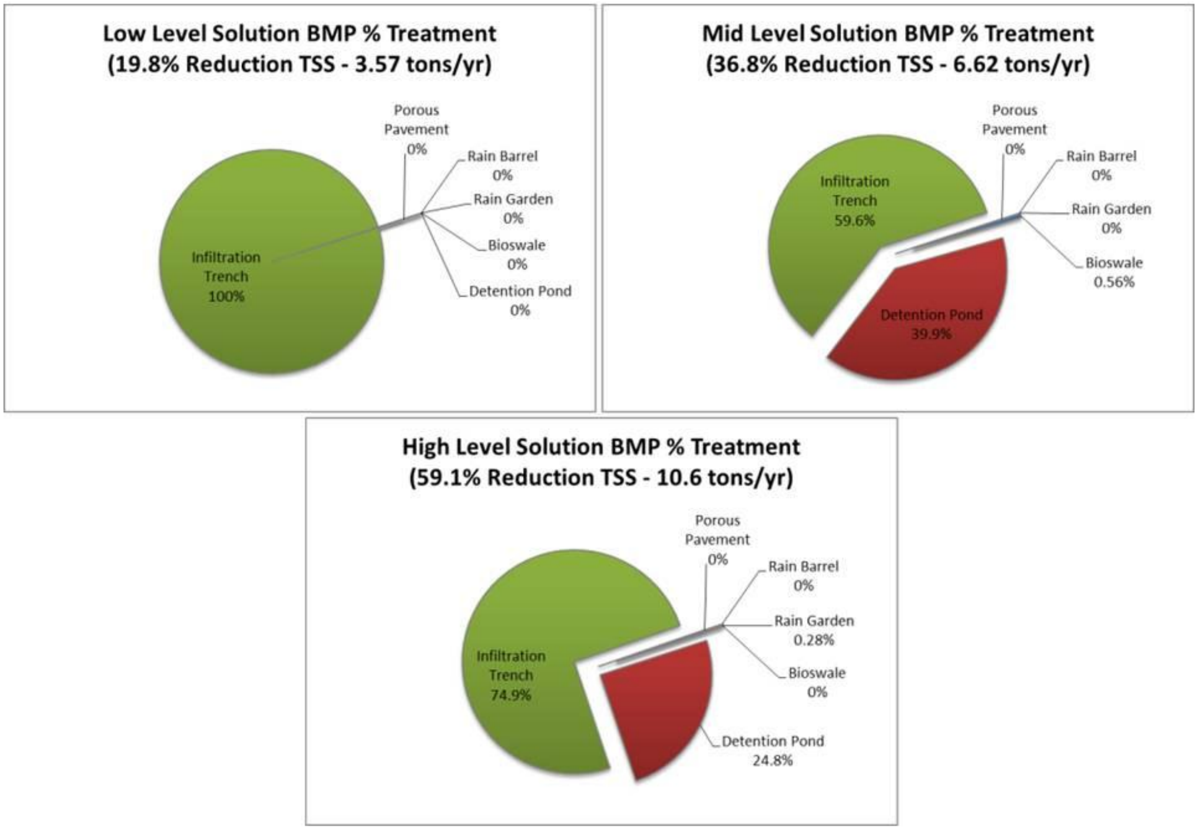


Figure 7-7. BMP contributions to annual TSS reduction in the Wolf #4 catchment.

*BMP Utilization*. The percent utilization of each BMP for the three TSS load reduction solutions is shown in Figure 7-8. Percent utilization for each solution is the area or number of BMPs in the selected solution divided by the maximum potential area or number of BMPs in the model. Figure 7-8 illustrates how utilization changes for each BMP as cost and percent load reductions increase. The extent to which each practice is used for the three selected solutions is also presented in Table 7-8, including the maximum area for each practice as defined by the BMP opportunity assessment and the solution area represented in the SUSTAIN model simulations.

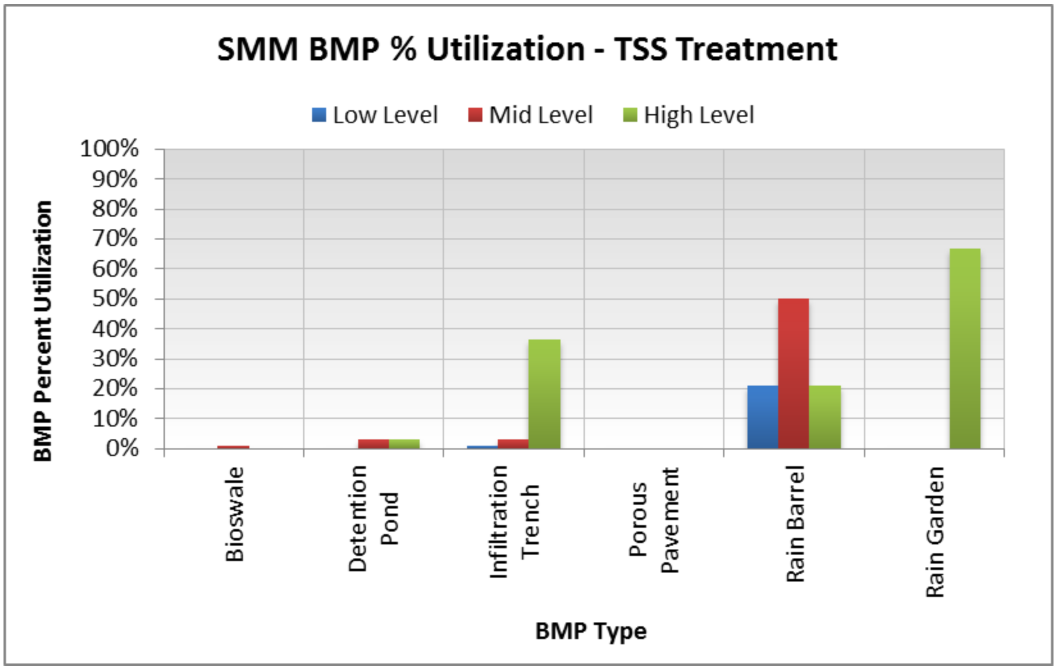


Figure 7-8. BMP utilization for annual TSS reduction in the Wolf #4 catchment.

Table 7-8. BMP total opportunity and percent utilization for TSS treatment in the Wolf #4 catchment.

| BMP | Extent Units | Maximum Extent | TSS Treatment BMP Utilization | | |
|---|---|---|---|---|---|
| | | | Low Level | Mid-Level | High Level |
| Bioswale | Acres | 0.63 | 0.0% | 1.0% | 0.0% |
| Detention Pond | Acres | 3.7 | 0.0% | 3.0% | 3.0% |
| Infiltration Trench | Acres | 1.4 | 1.0% | 3.0% | 36.3% |

Like the trend observed for total volume reduction, in general, as the level of treatment increases from low level to high level, the utilization of each BMP either increases or remains relatively constant. Best management practices that show increasing utilization as the level of load reduction increases generally have comparable implementation opportunities that are intermediate to the other BMPs where incremental implementation causes load reductions, as well as utilization to noticeably increase. Unlike for the other treatment simulations, porous pavement provides no reduction in TSS loads for all scenarios. Even though there is a very large opportunity area for implementation, the configuration of the BMP and contributing land uses must be such that increased utilization provides no benefit. This is also similar to what is seen for bioswales, though the opportunity for implementation is much smaller than for porous pavement. That utilization is relatively high, but actual load reduction is negligible explains why its utilization tends to fluctuate across levels of treatment.

## *7.4 Summary*

Testing of the BMP targeting and optimization capabilities of SUSTAIN focused on the Wolf #4 catchment, which includes Spring Meadows Mall. This catchment has the highest development intensity in the Wolf Creek subwatershed. As a result, potentially greater stormwater volumes are produced in this catchment making it a logical area to examine optimization tools. The optimization analysis used three consecutive years (2004 through 2006) to evaluate different implementation strategies. These represented a low flow year, an average year, and a high flow year.

One stormwater management goal is volume reduction to protect downstream resources. Each SUSTAIN simulation run used a unique set of BMP design specifications to calculate volume reduction and an associated relative cost. Design specifications varied across the range of decision variables (length of infiltration trench, amount of parking converted to porous pavement, area of pond, length of bioswale, number of rain barrels, number of rain gardens).

SUSTAIN simulated the ability of each of the practices individually, and in combination, to reduce runoff volumes and TSS loads, taking into account the site-specific characteristics of the Wolf #4 catchment. At the same time, the model assigned a relative cost to each practice to achieve a total cost for each scenario. Plotting the combination of effectiveness and total cost for each of the hundreds of model runs resulted in two graphs (Figure 7-1 for total volume reduction; Figure 7-5 for TSS reduction). The set of solutions at the far left and far top created a cost-effectiveness curve.

Potential implementation strategies can be examined in greater detail by focusing on several points along the cost effectiveness curve. Three individual solutions representing a low reduction level, a mid-reduction level, and high reduction level (58.3 percent) were evaluated. The detailed analyses pointed to several observations worth noting.

- Cost clearly plays a major role in selecting the most optimal strategies. Every effort should be made to obtain the most accurate cost data for the area of interest prior to optimization.

- The amount of opportunity available for BMP implementation can have a significant effect on optimization results. The BMP effectiveness curves presented in the screening analysis (Figure 5-2 through Figure 5-4) are extremely informative in identifying those practices that produce the greatest reductions at lower levels of implementation. These level of implementation screening analysis curves should be produced for each BMP under consideration prior to running SUSTAIN's optimization component.

- The assumptions associated with several parameters exert a major effect on optimization results. Background infiltration rate is one example noted in the Wolf #4 catchment analysis. Again, effectiveness curves generated with SUSTAIN's BMP assessment module can be used to develop informative sensitivity analyses prior to conducting targeting and optimization.

# 8. Project Summary

Using information from the Swan Creek TMDL, the purpose of this pilot effort is to develop a regionalized framework that guides stormwater Best Management Practice (BMP) implementation planning for the City of Toledo and the surrounding MS4 communities in Lucas County. This pilot effort uses a multi-scale analysis to evaluate Geographic Information System (GIS) data and identify high priority catchments within the Swan Creek watershed for evaluating BMP implementation planning tools. One component of that effort is to test the System for Urban Stormwater Treatment and Analysis INtegration (SUSTAIN). The purpose and goals of the SUSTAIN pilot application include:

- Providing a summary of cost-effective BMPs that will address existing stormwater runoff problems in the Swan Creek watershed.
- Providing a summary of optimal reduction strategies for runoff volumes and peak flows in one of the Swan Creek priority management areas.

First and second order streams represent areas within an overall drainage network, where the benefits of implementing green infrastructure (GI) and low impact development (LID) are most noticeable. Even under natural conditions, hydrologic response as measured through stream flashiness is more pronounced. Increased impervious cover resulting from development exacerbates that response; this in turn has an adverse effect on water quality. A multi-scale analysis starting with GIS data was used to identify areas in the Swan Creek watershed where low order streams are likely affected by stormwater associated with development. Level 1 of the multi-scale analysis included:

- Reviewing water quality, flow, and general land use patterns at the watershed (10-digit HUC) and subwatershed (12-digit HUC) levels to identify areas where stormwater management efforts will be most effective in meeting TMDL allocations **[Section 3.1.1]**.

The Wolf Creek subwatershed was a focus of this effort because it has a range of different development intensities and is an area facing growth pressure. TMDL monitoring indicated that TSS levels in Wolf Creek are elevated relative to other parts of the Swan Creek watershed, and there is evidence that sediment from Wolf Creek causes higher TSS levels in the mainstem of Swan Creek. Wolf Creek also includes several jurisdictions, making it well suited to demonstrate the approach and tools for connecting TMDL implementation to stormwater management. The Level 1 analysis continued by:

- Delineating catchments and estimating impervious cover associated with developed land use classes to target priority areas for BMP evaluation **[Section 3.1.2]**.

The emphasis in Level 1 is on practices that could be applied in priority catchments, which will lead to achieving reduction targets for stormwater volume, peak flow, and pollutant loads. Level 2 move to a smaller scale by examining the mix of development and impervious cover present in priority catchments. In the Swan Creek pilot, Level 2 focused on:

- Using NLCD information to develop estimates of the areas associated with stormwater source area types (e.g., commercial parking, roads, residential roofs) **[Section 3.1.3]**.

The LSPC watershed model and SUSTAIN were both used to study the Wolf Creek watershed and identify the key issues for addressing problems caused by urban stormwater. Among the important findings are the following:

- On average, nearly three quarters of the water leaving Wolf Creek is from groundwater and interflow; the remainder is from surface runoff. Another way to look at these results is that stormwater BMPs have the potential to treat or retain over one quarter (the surface runoff component) of the water that is currently leaving the Wolf Creek subwatershed **[Section 3.4]**.

- Roughly three quarters of the sediment entering Wolf Creek is due to increased stream velocities from excess flow off impervious surfaces. These impervious areas are where stormwater BMPs have the greatest potential to provide maximum benefit for sediment reductions to meet TMDL management objectives **[Section 3.5]**.

- The assumptions associated with several design parameters exert a major effect on BMP selection and optimization results. Effectiveness curves generated with SUSTAIN's BMP assessment module should be used to develop sensitivity analyses, which bracket a range of assumptions for more significant parameters (e.g., capture depth, infiltration rate), prior to conducting targeting and optimization **[Section 4]**.

- The amount of opportunity available for BMP implementation can have a significant effect on optimization results. The BMP effectiveness curves presented in the screening analysis are extremely informative for evaluating opportunities and constraints; particularly in identifying those practices that produce the greatest reductions at lower levels of implementation. These level of implementation screening analysis curves should be produced for each BMP under consideration prior to running SUSTAIN's optimization component **[Section 5.2]**.

- Cost clearly plays a major role in selecting the most optimal strategies. Every effort should be made to obtain the most accurate cost data for the area of interest prior to running optimization [**Section 6]**.

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