Appendix J.

SUSTAIN Modeling Results

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Abbreviations and Acronyms

BMP	best management practice
EPA	Environmental Protection Agency (Ohio or U.S.)
GIS	geographic information system
LSPC	Load Simulation Program in C++
SUSTAIN	System for Urban Stormwater Treatment and Analysis INtegration
SWCD	Soil and Water Conservation District
TMDL	total maximum daily load
WQv	water quality volume

1. Introduction

Developing effective stormwater management strategies for the lower Grand River will be a key component to successfully implement the lower Grand River total maximum daily load (TMDL). Significant investments are anticipated to evaluate, design, and construct structural and nonstructural stormwater best management practices (BMPs) that improve water quality conditions surrounding documented problems. U.S. Environmental Protection Agency's (U.S. EPA's) System for Urban Stormwater Treatment and Analysis INtegration (SUSTAIN) is a model developed to support practitioners in developing cost-effective management plans for municipal stormwater programs and evaluating and selecting BMPs to achieve water quality or hydrologic targets, like those set by a TMDL. SUSTAIN was applied in the lower Grand River watershed to help develop an implementation plan for the TMDL.

The SUSTAIN model was used in two locations in the lower Grand watershed, both in Lake County. To help with model development, a local workgroup was designated including representatives from Lake County and the Lake County Soil and Water Conservation District (SWCD). SUSTAIN was applied to evaluate cost-effective combinations of BMPs that can achieve the lower Grand River flow regime TMDLs and protection strategies.

The primary objectives for the SUSTAIN application within the lower Grand River watershed are to model representative examples of the following:

- A retrofit implementation plan with expected outcomes that can be used to achieve TMDL targets in impaired watersheds
- Stormwater management in an existing development that will help determine future land use planning and ordinance development needs to demonstrate how changes in stormwater requirements can help protect unimpaired streams

2. BMP Optimization Analysis

The SUSTAIN model was applied to two pilot areas in the lower Grand River watershed to allow for a more detailed analysis and to determine the most cost-effective set of BMPs for flow regime TMDL implementation.

2.1 Description of SUSTAIN

SUSTAIN is a model developed by U.S. EPA to evaluate alternative plans for water quality management and flow abatement techniques in urban areas. SUSTAIN's development represents an intensive effort to create a tool for evaluating, selecting, and placing BMPs in an urban watershed on the basis of user-defined cost and effectiveness criteria. SUSTAIN provides a public domain tool capable of evaluating the optimal location, type, and cost of stormwater BMPs needed to meet water quality goals. It is a tool designed to provide critically needed support to watershed practitioners at all levels in developing stormwater management evaluations and cost optimizations to meet their existing program needs.

SUSTAIN incorporates the best available research that can be practically applied to decision making, including the tested algorithms from the Storm Water Management Model (SWMM), the Hydrologic Simulation Program in Fortran (HSPF) model, and other BMP modeling techniques. SUSTAIN links those various methods into a seamless system with a goal to provide a balance between computational complexity and practical problem solving. The modular approach used in SUSTAIN also facilitates updates if the user considers new or reconfigured BMP solutions.

A key feature of the SUSTAIN model is its ability to evaluate numerous potential combinations of BMPs to determine the optimal combination that meets a specified objective. For example, Figure 2-1 portrays a SUSTAIN cost-effectiveness curve that evaluates different sets of practices (e.g., varying combinations and sizing of BMPs) to achieve a reduction in peak stream flow.

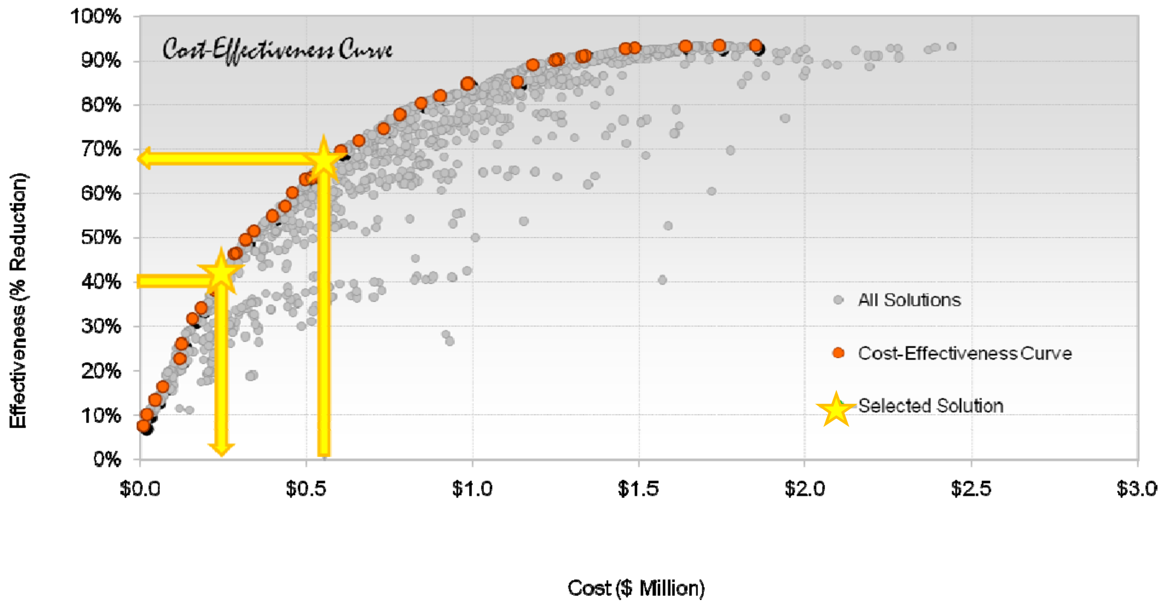

Figure 2-1. Example SUSTAIN cost-effectiveness curve.

Each of the circles (e.g., *All solutions* in the legend) in the curve represents a separate modeling run scenario with different assumptions for the number, type, and characteristics of practices. For example, one scenario includes the use of only 100 rain barrels; another includes the use of 50 rain barrels and 10 rain gardens; and a third scenario includes a combination of 20 rain barrels, 10 rain gardens, and 50,000 square feet of porous pavement.

The model simulates the ability of each of those practices individually, and in combination, to reduce peak stream flows, taking into account the site-specific characteristics of the project area (e.g., soil types, land uses, precipitation patterns). Practitioners can specify scenarios with specific practices (e.g., a stormwater wetland at location), nonspecific practices (e.g., *X* number of houses on a city block have rain gardens of *Y* storage volume) or both. Widely accepted modeling algorithms are used to compute infiltration, evapotranspiration, runoff, and pollutant loading. 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. SUSTAIN model simulation methods and algorithms are described in U.S. EPA's report, *SUSTAIN – A Framework for Placement of Best Management Practices in Urban Watersheds to Protect Water Quality*, available at http://www.epa.gov/nrmrl/pubs/600r09095/600r09095.pdf (U.S. EPA 2009).

Plotting the combination of effectiveness—which, in this study is measured as percent reduction of stormwater runoff volume—as a function of total cost for each of the modeled solutions results in a graph similar to what is shown in Figure 2-1. The set of solutions at the far left and far top creates a cost-effectiveness curve. Planners and decision makers can use that curve to select their solution to obtain a specific target at the lowest modeled cost. As shown by the arrows in Figure 2-1, the curve also allows planners and decision makers to determine the best set of practices on the basis of either (a) a given peak stream flow reduction target or (b) a set budget. The curve can also identify points of diminishing returns across a range of costs. Similar cost-effectiveness curves can be created for other objectives, such as runoff volume or pollutant loading reductions.

SUSTAIN includes the following components (U.S. EPA 2009):

- Framework Manager—to serve as the command module of SUSTAIN, manage data for system functions, provide linkages between the system modules, and create a simulation network to guide the modeling and optimization activities
- Land module—to generate runoff and pollutant loads from the landscape through internal land simulation or importing pre-calibrated land simulation time series
- Best Management Practice (BMP) module—to perform simulation of flow and water quality through BMPs, accounting for specific design criteria, and hydrologic/hydraulic processes
- Conveyance module—to perform routing of flow and water quality in a pipe or a channel
- Optimization module—to evaluate and identify cost-effective BMP placement and selection strategies for a preselected list of potential sites, applicable BMP types, and ranges of practice size
- Post-Processor—to perform analysis and summarization of the simulation results for decision making

Figure 2-2 shows the SUSTAIN framework design, including system components, relationships between components, and the general flow of information. Setting up a SUSTAIN project involves using locally collected data to establish a geographic information system (GIS) representation of the land and pollutant sources in the watershed, the routing network, assessment points, evaluation factors, and management practices to be evaluated.

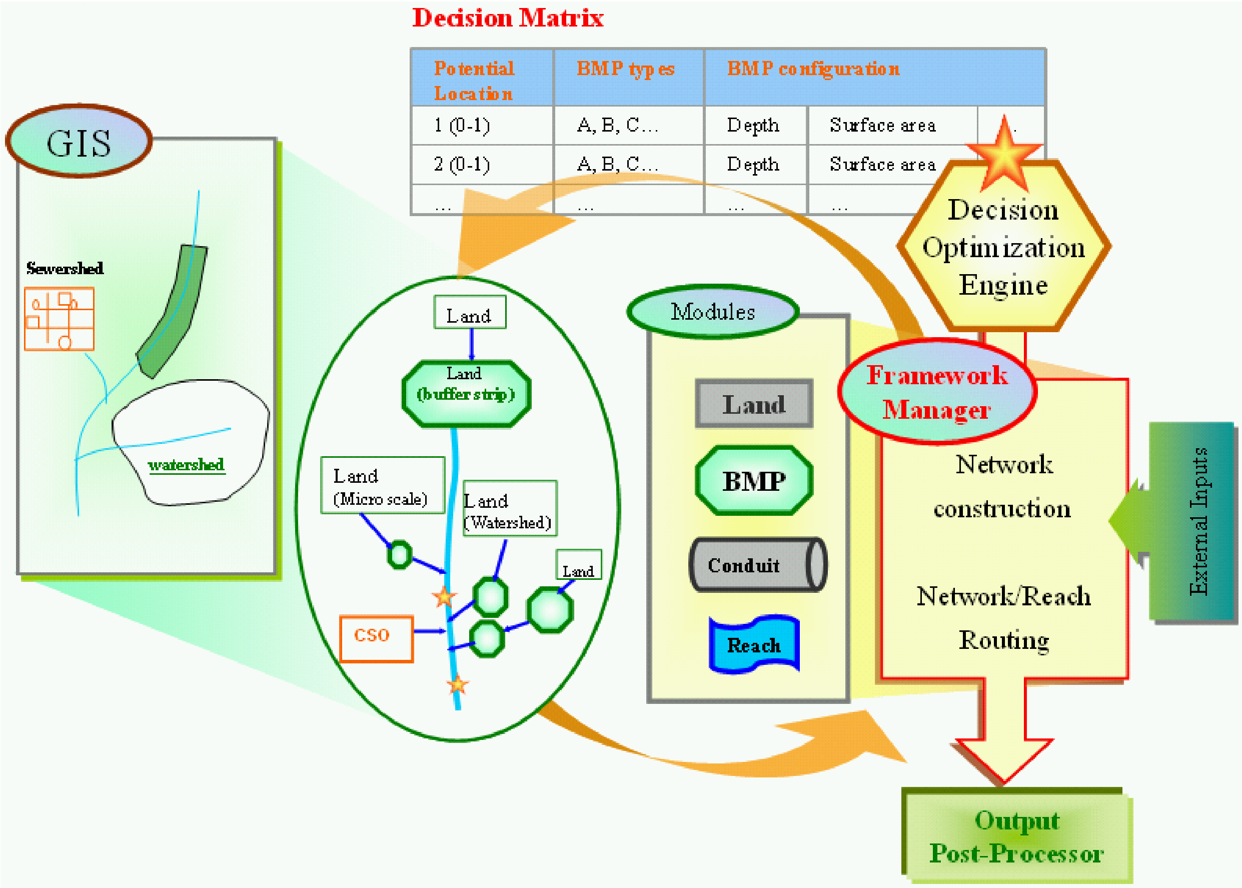

Figure 2-2. SUSTAIN components and flow chart.

After a project is set up in the GIS, the optimization module synthesizes information from the BMP, land, and conveyance (stream reaches or man-made conduits) modules and generates solutions that are looped back for evaluation using the same modules again. Via that iterative search process, the optimization engine identifies the best or most cost-effective solutions creating a decision matrix according to the user's specific conditions and objectives.

Finally, the post-processor analyzes optimization results using specific graphical and tabular reports that facilitate the classification of storm events for analysis, viewing the time series of specific storm events, evaluating performance by storm event, and developing the cost-effectiveness curves for treatment alternatives.

2.2 Selecting the Pilot Areas in Lower Grand River Watershed

Selecting pilot areas was discussed with stakeholders at a meeting on January 20, 2011. Lake County, Lake County SWCD, Geauga County SWCD, and the city of Chardon expressed interest in using SUSTAIN within their jurisdictional areas. The following factors were taken into account while selecting the proposed pilot locations:

1. Representativeness of existing and expected land uses
2. Representativeness of existing and expected stormwater treatment
3. Size of potential sites
4. Availability of data

5. Location in a watershed impaired or threatened by flow alteration
6. Interested and willing stakeholders

Potential sites were discussed with all the interested stakeholders. The two pilot locations were selected in Lake County because of the availability of numerous pilot areas representing existing and expected land uses throughout impaired and threatened watersheds in all counties in the lower Grand watershed. Lake County has also been the most actively developing county in the watershed. Also, data management practices and the availability of specific GIS data and electronic grading and utility plans in Lake County allowed the most detailed SUSTAIN analysis at those locations.

A follow-up meeting was held with representatives from Lake County and the Lake County SWCD to identify potential pilot areas. Several sites were evaluated, and two subdivisions in Concord Township were chosen for the pilot SUSTAIN applications (Figure 2-3). The subdivisions were chosen because they are considered representative of the land uses, soil conditions, topography, and stormwater management in the TMDL watersheds listed as impaired by urban runoff. The following sections provide a more detailed description of each subdivision.

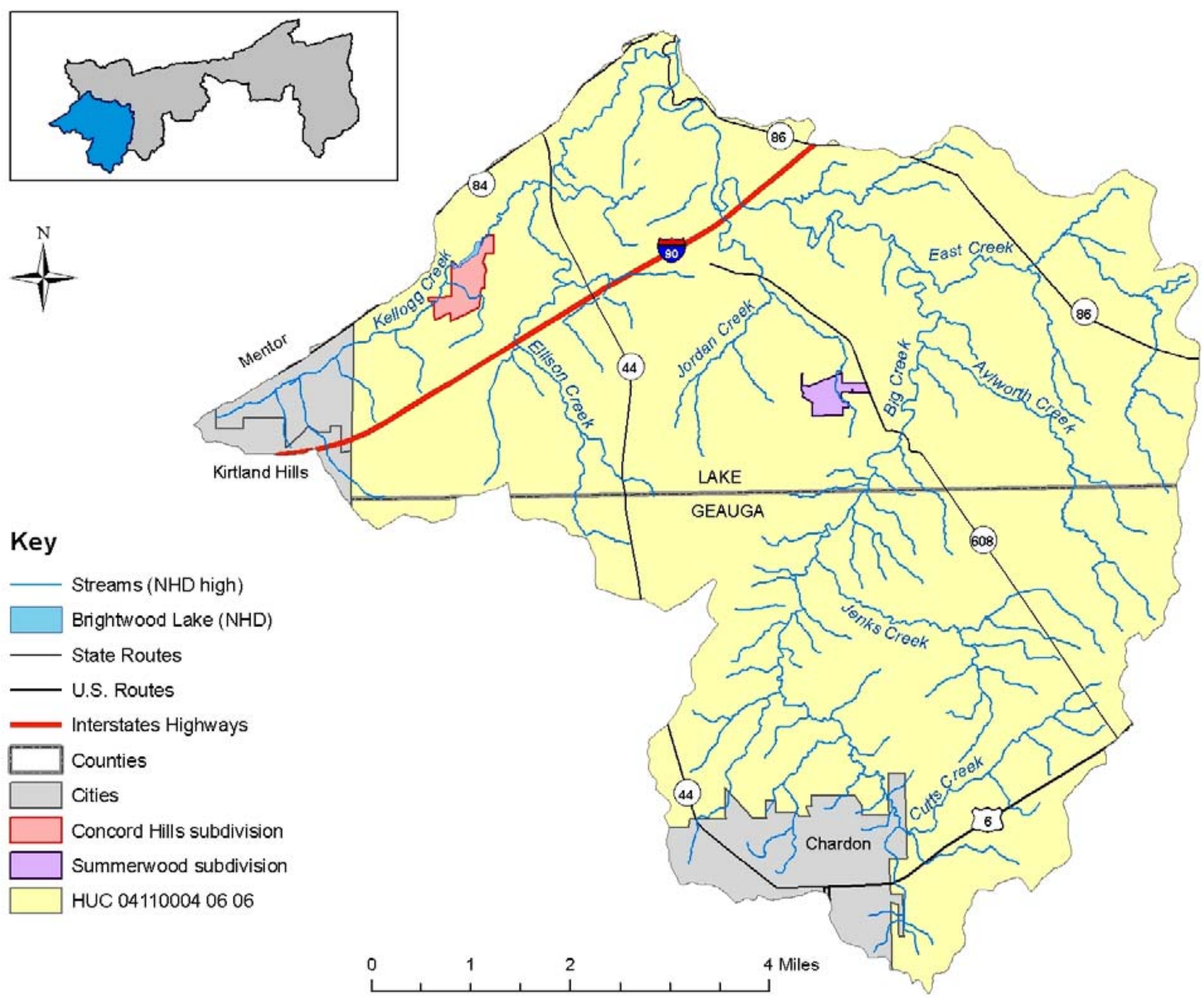

Figure 2-3. SUSTAIN pilot locations.

2.2.1 Concord Hills Subdivision

The Concord Hills subdivision (Figure 2-4) is 151.5 acres and is in the Kellogg Creek watershed, adjacent to the Brightwood Lake impoundment. The development was built during the late 1970s and early 1980s and is typical of much of the development in this portion of the watershed. No stormwater treatment (flow or water quality) is provided on the site. The development consists of 215 single-family residential lots, with street widths approximately 26 feet. Lots vary in size, with an average of 0.56 acre. The overall site is 19.8 percent impervious cover.

The subdivision is served by curb and gutter, which discharge directly to Brightwood Lake or Kellogg Creek. The Lake County Stormwater Management Department provided grading and utility plans for use in the analysis.

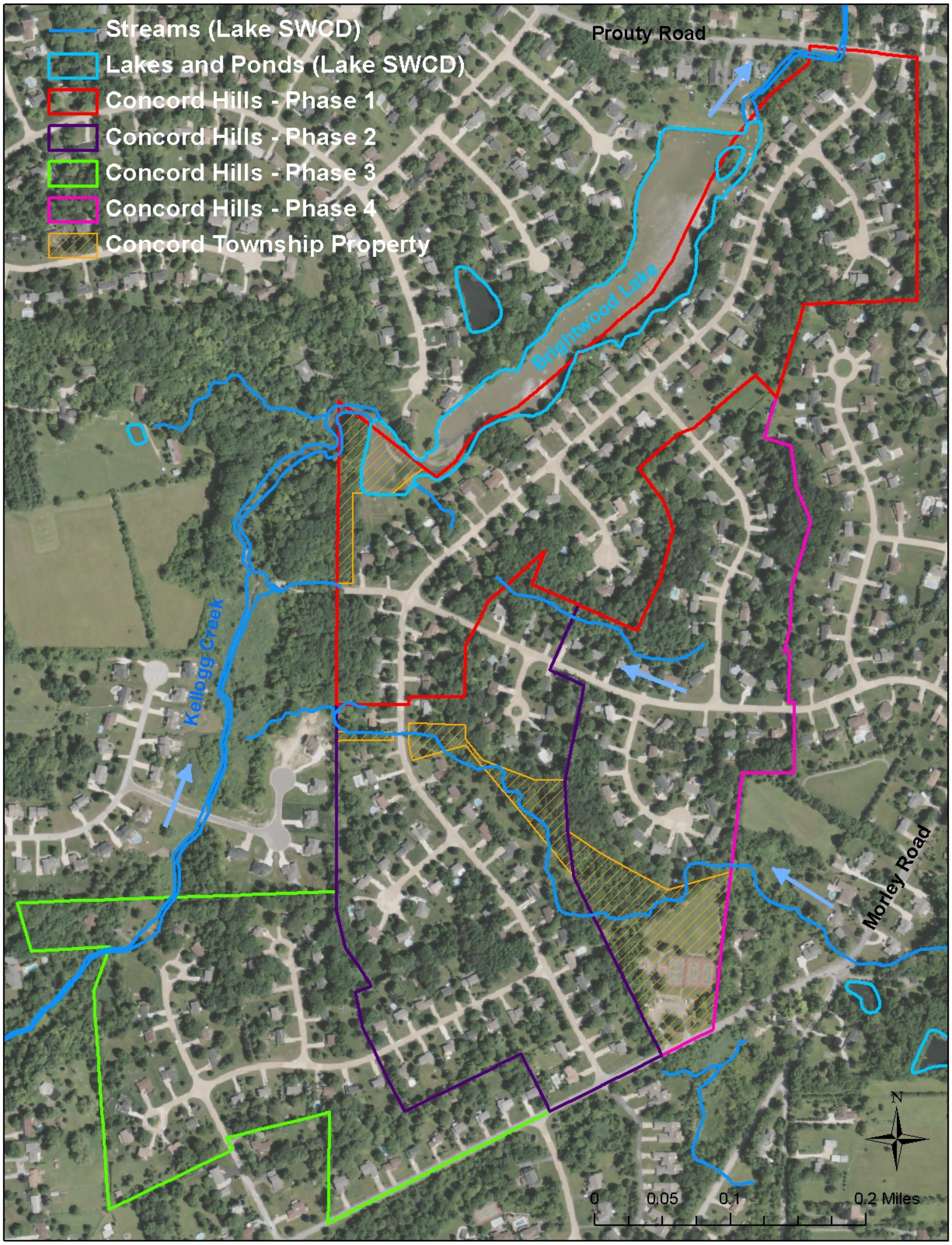

Figure 2-4. Concord Hills subdivision.

2.2.2 Summerwood

The Summerwood development, in Concord Township (Figure 2-5), provides an opportunity to quantify the benefits of existing stormwater practices, relative to the needed reduction associated with the TMDL. The development was constructed between 2004 and 2006, is 100.7 acres of single-family residential homes, and is representative of expected future land use development throughout the lower Grand River watershed. There are 100 residential lots (on average 0.47 acre per lot) with large, forested conservation areas surrounding the lots. The overall site is 18.1 percent impervious.

Phase I of the site does not include specific water quality treatment, but it does have a dry detention basin to mitigate for peak flows. Phase II of the site is in compliance with current National Pollutant Discharge Elimination System stormwater regulations and includes a dry detention basin with a gravel filter. The area is served by curb and gutter, which outlets to a tributary of Jordan Creek. The subdivision has several vacant lots, which could provide a possible opportunity for additional stormwater management. The Lake County Stormwater Management Department provided grading and utility plans for use in the analysis. On the basis of watershed delineation, 39.2 acres of the site are connected to the existing detention ponds.

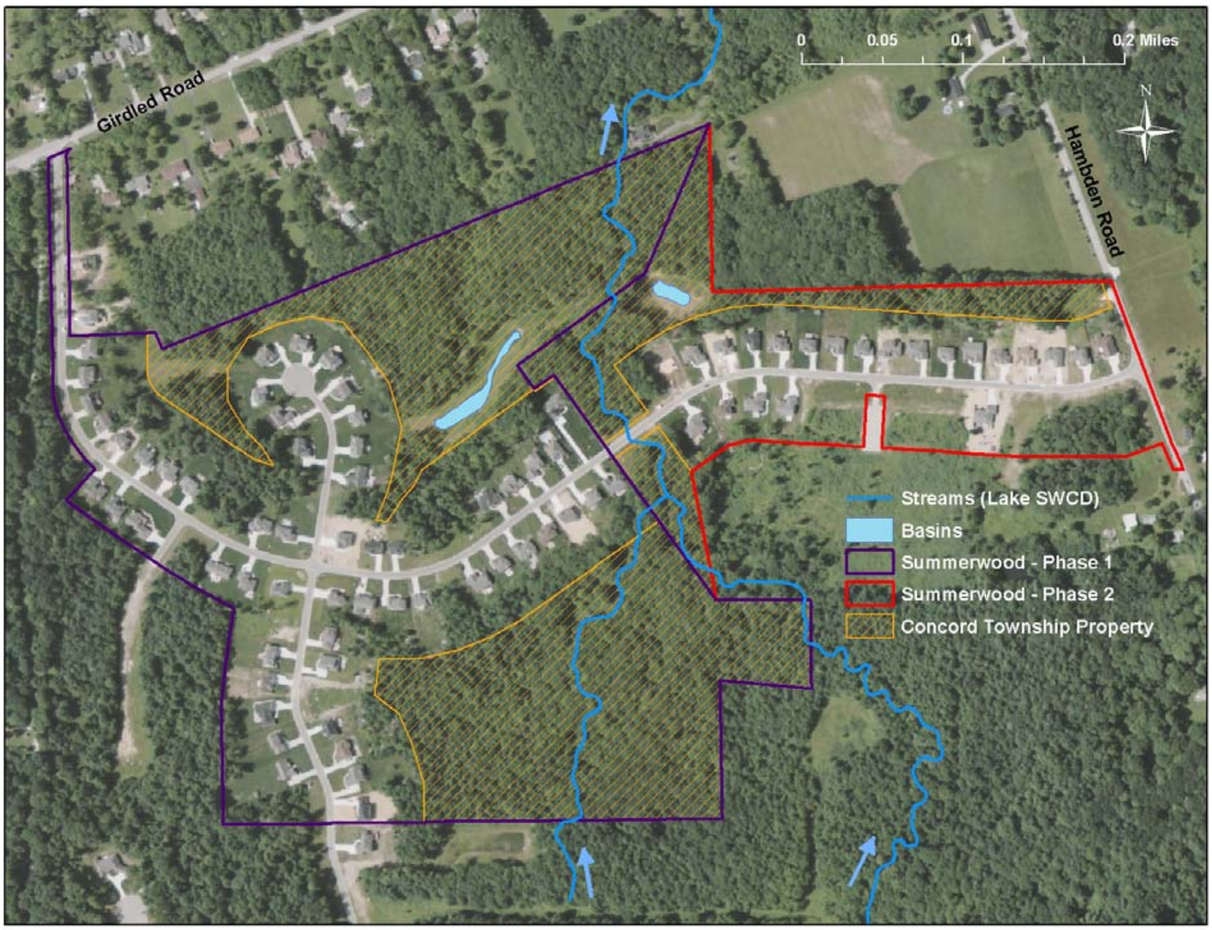

Figure 2-5. Summerwood subdivision.

2.3 Assessment of BMP Opportunities

Examples of some of the BMPs that can be modeled in 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. Therefore, those points were considered when determining which BMPs to include in the BMP module of SUSTAIN for the lower Grand River watershed analyses.

The selected pilot areas, along with much of the watershed, are susceptible to a high water table and contain soils with relatively low permeability. Because of those known natural constraints, infiltration basins and trenches were eliminated from the suite of applicable practices for the two subdivisions. However, note that other areas are in the lower Grand River watershed where such practices would be effective, specifically in areas with hydrologic soil group A and B type soils. There is also limited potential use of green roofs and cisterns in the watershed because of the types of land uses and buildings in the pilot subdivisions; therefore, such practices were also eliminated. Areas in the lower Grand River watershed that include commercial or government buildings would be candidates for those two practices.

Bioretention areas were chosen to be represented in place of vegetated swales because, in practice, they typically provide more volume control. Vegetated swales were modeled primarily as conveyance systems in SUSTAIN and provide little volume control or water quality treatment. Wetlands were also not modeled because the goal of optimization is volume control, and wetlands are not primarily used for that purpose. It is important to recognize that wetlands are effective dissipaters of energy (i.e., peak flow control), and provide certain water quality benefits; however, because of the volume control objective, their inclusion is not expected to contribute cost-effectively.

The following BMPs were identified as applicable to the pilot study sites in the lower Grand River watershed:

- Bioretention (rain garden, block bioretention, and regional bioretention)
- Porous pavement
- Rain barrels
- Detention ponds (wet or dry)

Each of those practices was evaluated for applicability in the pilot areas on the basis of a review of aerial imagery, site and grading plans, and field reconnaissance. Candidate locations were selected according to available land area and proximity to sources of runoff and pollutants.

The assessment of BMP opportunities also involved analyzing various combinations of practices (i.e., treatment trains). Using a treatment train approach, stormwater management begins with simple methods that minimize the amount of runoff that occurs from a site. Typically those practices involve either on-site interception (e.g., rain barrels) or on-site treatment (e.g., bioretention, porous pavement). Following efforts to minimize site runoff, stormwater is collected and managed either locally or regionally.

The following sections provide a description of each BMP and the considerations made during the applicability analysis. Modeled design specifications for each practice are described in Section 2.5 and are based on best professional judgment and available literature.

2.3.1 Bioretention

Two types of bioretention practices were included in the SUSTAIN model: (1) rain garden and (2) bioretention. The bioretention BMP includes block bioretention and regional bioretention.

Rain Garden

Rain gardens were modeled in SUSTAIN as an aggregate practice, which means that specific locations are not identified; however, within each discrete drainage area boundary, a template was designed and applied to treat the relevant associated land sources upstream. With that approach, the fraction of area treated or untreated was also defined. BMP sizing and treatment distribution are the optimization variables of concern. Rain garden areas were assumed to be located in front or back yards of residential areas and would serve the overflow from rain barrels and runoff from the surrounding area. The small bioretention areas were also assumed to be constructed and maintained by the homeowner with little costs associated with design. Soil amendment was assumed, with no underdrain. Front yard size was considered when setting the upper limit on the area of the bioretention practices (100 square feet). It was assumed that a maximum of 50 percent of homes in the residential areas could be served by rain gardens.

Bioretention

Bioretention areas are typically larger rain gardens with underdrains. Two different bioretention areas were modeled including block and regional bioretention. Block bioretention areas are adjacent to roadways and provide offline retention for road runoff. Potential locations for block bioretention in residential areas were identified through aerial imagery analysis and field reconnaissance and are modeled in combination with porous pavement to represent bioretention areas in curb bump out areas that treat overflow from porous pavement areas. The practices were represented in the model similarly to rain gardens.

Block bioretention opportunity areas were assumed to be up to 320 square feet in size with 12 inches of ponded depth, 24 inches of plant and soil media, and including free-flow perforated pipe underdrains set one foot below the bottom of the basin. The drainage area to the bioretention areas was assumed to be equal to the drainage area associated with the porous pavement practice.

Regional bioretention opportunity areas were identified adjacent to the existing detention ponds in the Summerwood development. The bioretention areas were modeled as offline areas fed by a regulator that diverts flows from the existing detention ponds during low-flow events. The drainage area to each regional bioretention area was assumed to be the contributing area to Phase 1 and 2 detention ponds, which was 26 acres 13 acres, respectively. However, only a portion of the runoff generated in the watershed is routed to the regional bioretention areas.

2.3.2 Porous Pavement

Porous pavement was assumed to be applicable in each of the pilot subdivisions. It was assumed that the entire roadway surface area (not including driveways or aprons) could be converted into porous pavement. The porous pavement design includes a 2-foot-deep gravel bed with a free-flowing underdrain set one foot below the pavement. The contributing drainage area would be equal to the roadway itself, driveways, and contributing roof and urban lawn areas, according to topography. Roads were delineated using GIS, and driveway areas were estimated using a representative number of homes in each of the pilot areas.

2.3.1 Rain Barrels

Rain barrels are typically applied in residential areas. It was assumed that up to 100 percent of homes in the residential area could be retrofitted with rain barrels, and 50 percent of those would be in sequence with rain gardens. The sequence assumed that the entire rain barrel volume is released by opening a bottom orifice 2 days after the end of a storm. The stored water is used to irrigate rain garden vegetation, where applicable. The rain barrel capacity at any point during the simulation is a function of the amount of water released after a previous event. Back-to-back events can show bypass, with no rain barrel benefit, if filled to capacity. During cold-weather conditions, the rain barrels are assumed to be disconnected from rooftop downspouts.

The standard size of rain barrels in this application was 60 gallons, with a maximum of two units per home. Average roof areas for the Concord Hills and Summerwood subdivisions were estimated to be 2,617 and 3,740 square feet, respectively, on the basis of a review of aerial photography.

2.3.1 Detention Ponds

In the Summerwood subdivision, the existing ponds (Figure 2-6) were modeled in SUSTAIN to represent existing conditions on the basis of grading and utility plans. An infiltration rate of 0.02 inch per hour was assigned to one of the detention ponds that exhibit dry conditions between storm events. The other detention pond was not assigned any infiltration because field investigation indicated a perpetually wet environment in the pond.

Figure 2-6. Existing detention ponds in the Summerwood subdivision, 2011.

2.4 Maximum Extent of Practices by Sewershed

For modeling purposes, the Summerwood subdivision was divided into three drainage areas on the basis of contributing areas to each of the two existing ponds. One of the drainage areas is primarily forested and includes only disconnected impervious areas that do not drain to either of the two existing detention ponds and, therefore, was not modeled. It is assumed that that area will already be in compliance with TMDL requirements. The maximum areal extent of each type of BMP was determined through aerial photography analysis, review of site grading and utility plans, and field reconnaissance and on the basis of best professional judgment.

Table 2-1 summarizes the maximum extent of each practice used to set the maximum opportunity boundaries for BMPs in SUSTAIN.

Table 2-1. Maximum extent of BMPs by subwatershed

BMP	Summerwood 1	Summerwood 2	Concord Hills
Porous pavement (acre)	2.27	1.47	8.63
Rain gardens (unit)	26	11	108
Block bioretention (acre)	0.06	0.03	0.13
Regional bioretention (acre)	1.6	0.4	--
Rain barrel (unit)	102	42	430

2.5 SUSTAIN Model Setup

This section describes how the SUSTAIN model was set up to simulate BMPs in the pilot areas. The steps consisted of (1) model input, (2) simulation period selection, (3) BMP network representation, and (4) optimization problem formulation. Results and observations are summarized in Section 2.6.

2.5.1 Model Input

The data collection process for a SUSTAIN application is similar to that of other modeling projects and involves a thorough compilation and review of information available for the study area. The more site-specific and detailed the available data, the better the model representation. This SUSTAIN application builds on an existing Load Simulation Program in C++ (LSPC) watershed model that was calibrated and validated as part of the lower Grand River TMDL.

Watershed Representation – Land Use

Land use and associated impervious areas from the lower Grand River watershed LSPC model (see Section 6 of the TMDL document) were used in SUSTAIN to represent watershed runoff boundary conditions for the Concord Hills subdivision. For the Summerwood subdivision, which was constructed after the land use and impervious data were originally mapped, unique land cover types were delineated in GIS on the basis of aerial photography. Impervious cover estimates were determined by sampling and digitizing impervious surfaces in GIS for a representative number of homes. Twelve homes in the Concord Hills subdivision and six in the Summerwood subdivision were evaluated to derive impervious cover estimates. The measured footprint of those homes was extrapolated to the total number of homes at each site.

The average roof area, including attached garages, is 3,740 square feet and 2,617 square feet for Summerwood and Concord Hills, respectively. Average driveway area, including the apron, is 1,479 square feet and 1,268 square feet for Summerwood and Concord Hills, respectively. Roadway imperviousness was measured using aerial photography.

2.5.2 Simulation Period

The optimization component of SUSTAIN typically requires numerous iterations of model simulation. Three years (1996–1998) of the validation period used in the TMDL LSPC model were used to simulate the runoff boundary condition from the watershed model for SUSTAIN. Those three consecutive years were selected because they represented wet, average, and dry years in the watershed. Figure 2-7 shows the annual rainfall totals for the TMDL LSPC validation period and the years selected for the SUSTAIN simulations.

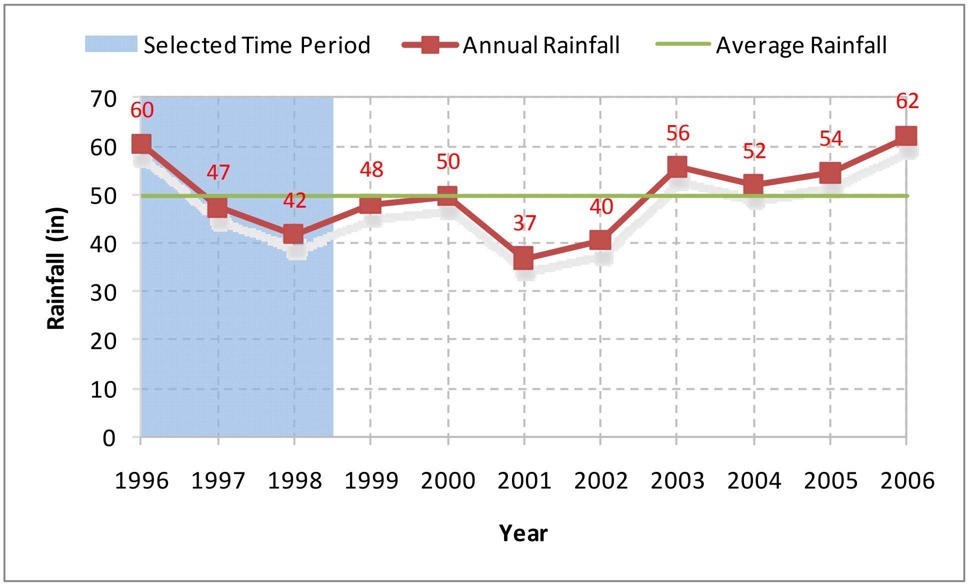

Figure 2-7. Annual rainfall totals for the TMDL validation and SUSTAIN simulation periods.

2.5.3 Representation of BMPs

BMPs are simulated in SUSTAIN according to specific design specifications, with the performance modeled using a unit-process parameter-based approach. That contrasts with and has many advantages over most other techniques that simply assign a single percent effectiveness value to each type of practice. SUSTAIN predicts BMP performance as a function of its physical configuration, storm size and associated runoff intensity and volume, and moisture conditions in the BMP.

As previously noted, many of the distributed practices were simulated in aggregate, recognizing the scale and model resolution of the original watershed models. The aggregate approach is a computationally efficient and analytically robust approach that SUSTAIN provides for evaluating relative management practice selection and performance at a small subwatershed scale.

An aggregate BMP consists of a series of process-based optional components, including on-site interception, on-site treatment, routing attenuation, and regional storage/treatment. Each aggregate BMP component evaluates storage and infiltration characteristics from multiple practices simultaneously without explicit recognition of their spatial distribution and routing characteristics in the selected watershed. For example, rain barrels in the aggregate BMP network are modeled in series with rain gardens, and service residential rooftop runoff area.

The model is configured so that up to 100 percent of homes in the residential area can have rain barrels. Likewise, an upper limit of 50 percent of them can be in sequence with rain gardens. In lieu of modeling discrete rain barrel and bioretention, the approach allows the user to define generalized application rules on the basis of field reconnaissance of BMP opportunity and typical practice. The role of optimization is to determine the relative size (or number) of each BMP component in the generalized aggregate network that achieves the defined management objective at the lowest cost. For this application, the aggregate practice included five component practices—rain barrels, rain gardens, block and regional bioretention, and porous pavement. Figure 2-8 is a schematic diagram of aggregate components, drainage areas, and practice-to-practice routing networks.

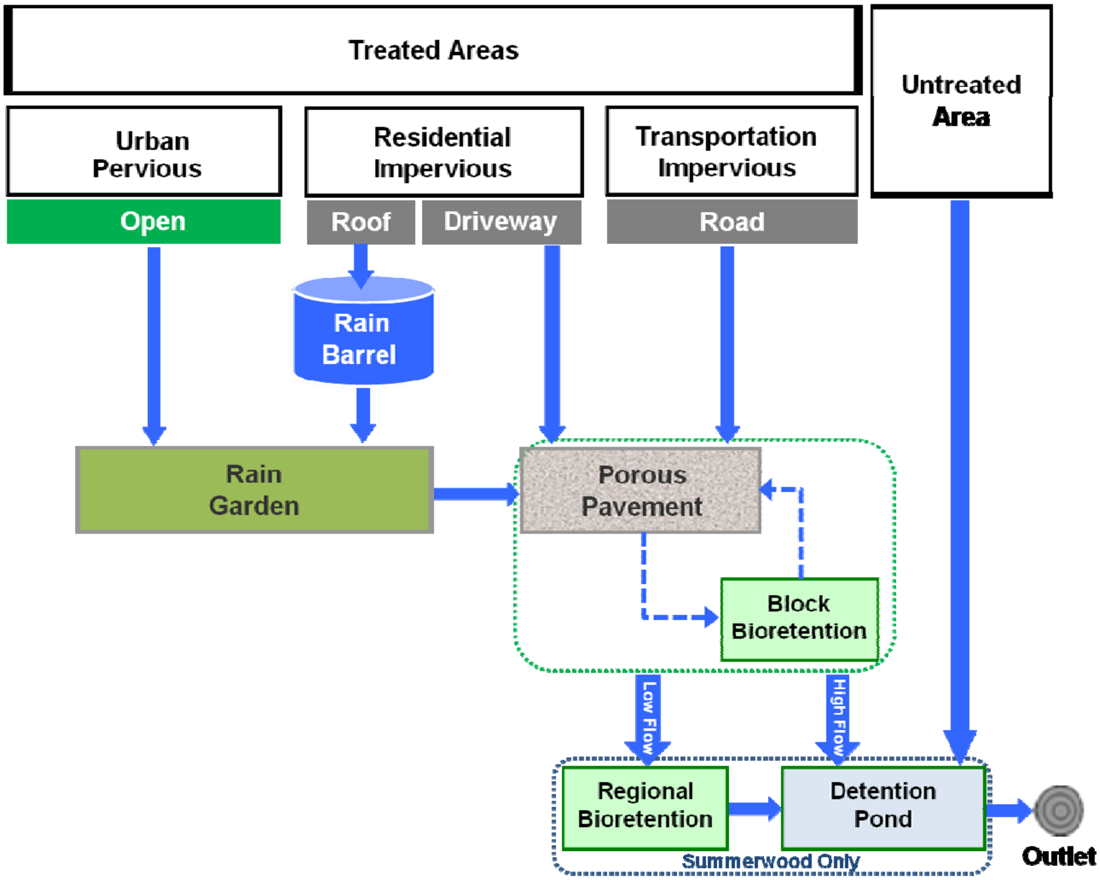

Figure 2-8. Aggregate BMP schematic identifying treatment train options.

As shown in Figure 2-8, the rain barrel component collects runoff from rooftops (as part of the impervious surfaces) in residential areas. Outflow and bypass from the rain barrel is assumed to flow directly to residential rain gardens, as are urban open areas. Other impervious pavement areas can be treated by porous pavement, and outflow from porous pavement is routed to block bioretention. Under field conditions, block bioretention could then flow back to porous pavement if downstream areas with surface storage capacity are not being fully used. The simplification of the aggregate BMP setup does not explicitly represent that feedback loop, however. That is because BMPs can be designated only as either upstream or downstream of one another in an aggregate BMP unit. The aggregate setup generally represents the treatment provided by the feedback loop, though, by representing the maximum optimized area of all BMPs, where the overall volume treated is the same.

Rain garden overflow is also assumed to be captured by porous pavement. In the Summerwood area, outflows from porous pavement and block bioretention are captured by regional bioretention during low flows (i.e., orifice/underdrain outflow) and by the existing detention ponds during high flows (i.e., weir overflow). Overflows from regional bioretention are routed to the ponds, as are untreated areas. In the

Concord area, outflows from porous pavement and block bioretention, and any other runoff from any type of land use that is not subject to treatment by any aggregate practice components, are routed directly to the outlet. Note that the aggregate BMP setup is a tool to determine which BMP(s) are most efficient at achieving an environmental outcome without representing each individual BMP explicitly (e.g., representing a rain barrel for each roof in the study area). The configuration of BMP routing in the aggregate setup are meant to represent a treatment train that makes sense given the BMP design characteristics. Just because a type of BMP is included in the aggregate, it does not mean that it will be used after optimization analysis is performed, as described below.

To run the optimization analysis, a set of decision variables was identified to explore the best possible combinations of the various BMP practices. For this analysis, the decision variables consisted of the following:

- Number of fixed-size rain barrel and rain garden units
- Surface area of regional and block bioretention areas and porous pavement

Because the decision variable values can range anywhere between zero to a maximum number or size, it is possible for one component in the treatment train to never be selected if it is not cost-effective toward achieving the objective. For example, even though the aggregate BMP setup includes rain barrels, if rain gardens are found to be a more cost-effective solution under all conditions, all roof runoff will be directly routed to available rain gardens. In other words, the aggregate BMP provides a menu of options that might or might not be selected, depending on cost-effectiveness. During an optimization run, if the size value of zero for a practice is selected, that point will act as a transfer node in the network (i.e., inflow = outflow with no treatment), and the associated cost that is a function of the number of practices or surface area will, in turn, compute to be zero. Table 2-1 summarizes the maximum extent of each practice in each subdivision, as derived from GIS and field reconnaissance. Those values define the upper boundary of the optimization search space. The physical configuration data, infiltration parameters, and cost assumptions for each BMP component are listed in Table 2-2.

Table 2-2. BMP configuration parameters

Parameter	Rain barrel	Rain garden	Block bioretention	Regional bioretention	Porous pavement
Physical configuration					
Unit size	60 gal	100 ft^2	N/A	N/A	N/A
Design drainage area (acre)	0.021 (Summerwood) 0.015 (Concord Hills)	0.12 (Summerwood) 0.14 (Concord Hills)	N/A	N/A	N/A
Substrate depth (ft)	N/A	1	2	2	2
Underdrain depth (ft)	N/A	N/A	1	1	1
Ponding depth (ft)	N/A	0.5	1.0	1.0	0.1
Infiltration					
Substrate layer porosity	N/A	0.45	0.45	0.45	0.5
Substrate layer field capacity	N/A	0.25	0.25	0.25	0.055
Substrate layer wilting point	N/A	0.1	0.1	0.1	0.05
Underdrain gravel layer porosity	N/A	N/A	0.5	0.5	0.5
Vegetative parameter, A	N/A	1	1	1	1
Background infiltration rate (in/hr)	N/A	0.10	0.10	0.10	0.10
Media final constant infiltration rate (in/hr)	N/A	0.5	0.5	0.5	0.5
Cost Data					
Unit Cost	$95 ea.	$6/ft^2	$33/ft^2	$15/ft^2	$9/ft^2

Infiltration parameters were determined on the basis of the assumed soil substrate. The background infiltration rate refers to the infiltration rate of the native soils below the engineered media. The vegetative parameter, or the percent vegetative cover, and wilting point values were provided by Tetra Tech, Inc. (2001). Wilting point is defined as the minimal soil moisture required to prevent vegetation from wilting.

Schueler et al. (2007) was used to estimate a capital cost of $15 per square foot for the regional bioretention practices, for which unit costs are expected to be higher than rain gardens because of including (1) an underdrain and (2) the need for more extensive excavation and structural retrofits. The block bioretention practice unit costs were estimated according to work completed in Burnsville, Minnesota, which included a neighborhood retrofit project in a neighborhood very similar to the Concord Hills and Summerwood subdivisions. Those costs reflect a significant effort to move underground utilities in road rights of way and professional planning and excavation. The remaining costs were derived from a variety of sources including Schueler et al. (2007), University of New Hampshire (2008), Ohio EPA (2010), and Federal Highway Administration (2009). Costs reflect the design, construction, and contingency costs. Operation and maintenance were not included in those figures.

Operation and maintenance activities could include sweeping or vacuuming porous pavement; vegetation management including mowing, weeding and plant replacement; soil amendment replacement for rain gardens and bioretention areas; and sediment clean out from rain gardens and bioretention areas. In addition to those costs, programmatic costs would also be incurred for BMP retrofit programs focused on private property. Operation and maintenance costs were derived from Tetra Tech (2009) and adjusted to account for design specification. Annual operation and maintenance costs are estimated as follows:

- Rain garden: $1/square foot
- Bioretention area: $1.50/square foot
- Porous pavement: $0.13/square foot

2.5.4 Optimization Formulation and TMDL Targets

The optimization objectives were to (1) maximize annual volume reduction, while (2) minimizing total implementation cost (design, construction, and contingency costs only). The NSGA-II optimization approach was the computation approach used for this analysis. NSGA-II is a multi-objective, evolutionary algorithm that uses the elitist approach where solutions are sorted on the basis of the degree of dominance in the population (i.e., if a solution is not dominated by any other solution, that solution has the highest possible fitness). In addition, the algorithm seeks to preserve diversity along the first non-dominated front so that the entire Pareto-optimal region is found (U.S. EPA 2009). As a result, the optimization outcome defines a set of solutions that show the maximum achievable volume reduction at each minimum-cost interval.

The hydrologic targets used to derive the flow regime TMDLs were also used to determine the implementation targets from among the solutions presented along the cost-effectiveness curve. SUSTAIN was optimized to flow volume reduction; therefore, flow volume reductions targets were needed that would ensure that aquatic life designated uses could be met and thus stream health improved or maintained. The TMDL presents reductions and increases in flow rates per unit area (as presented in Section 9 of the TMDL), rather than volumetric reductions and increases. The implementation targets used in SUSTAIN were calculated as volumetric differences between the reference and impaired streams under different flow conditions. An example is presented later in this section.

Figure 2-9 illustrates how the flow volume reduction targets used in the SUSTAIN analysis were derived using an example of the impaired and reference stream flow duration curves for Kellogg Creek, normalized by watershed area (for a detailed description of the hydrologic targets, see Section 7 of the TMDL document). The area between the impaired and reference curve was calculated, which represents the volume reduction or increase needed on the impaired stream to attain reference stream flow regimes (i.e., TMDL targets). The areas were then used to calculate percentages of volume change that were used to determine the SUSTAIN implementation targets (Table 2-3).[1]. The theoretical calculations for the example displayed in **Error! Reference source not found.** are shown below:

$$V_{\text{high flow decrease}} = (V_{Kellogg\ (0\text{-}13)} - V_{East\ (0\text{-}13)}) \,/\, V_{Kellogg\ (0\text{-}100)}$$

$$V_{\text{low flow increase}} = (V_{East\ (14\text{-}100)} - V_{Kellogg\ (14\text{-}100)}) \,/\, V_{Kellogg\ (0\text{-}100)}$$

where $V_{Kellogg\ (0\text{-}13)}$ and $V_{East\ (0\text{-}13)}$ are the volumes of flow under the flow duration curves from the 0^{th} through 13^{th} percentiles for Kellogg Creek (river mile [RM] 3.3) and the reference stream East Creek, respectively; $V_{East\ (14\text{-}100)}$ and $V_{Kellogg\ (14\text{-}100)}$ are the volumes of flow under the flow duration curves from the 14^{th} through 100^{th} percentiles for Kellogg Creek (RM 3.3) and East Creek, respectively; and $V_{Kellogg\ (0\text{-}100)}$ is the volume of flow under the entire flow duration curve for Kellogg Creek (RM 3. 3).

[1] Note that the table includes the targets for each stream included in the TMDL.

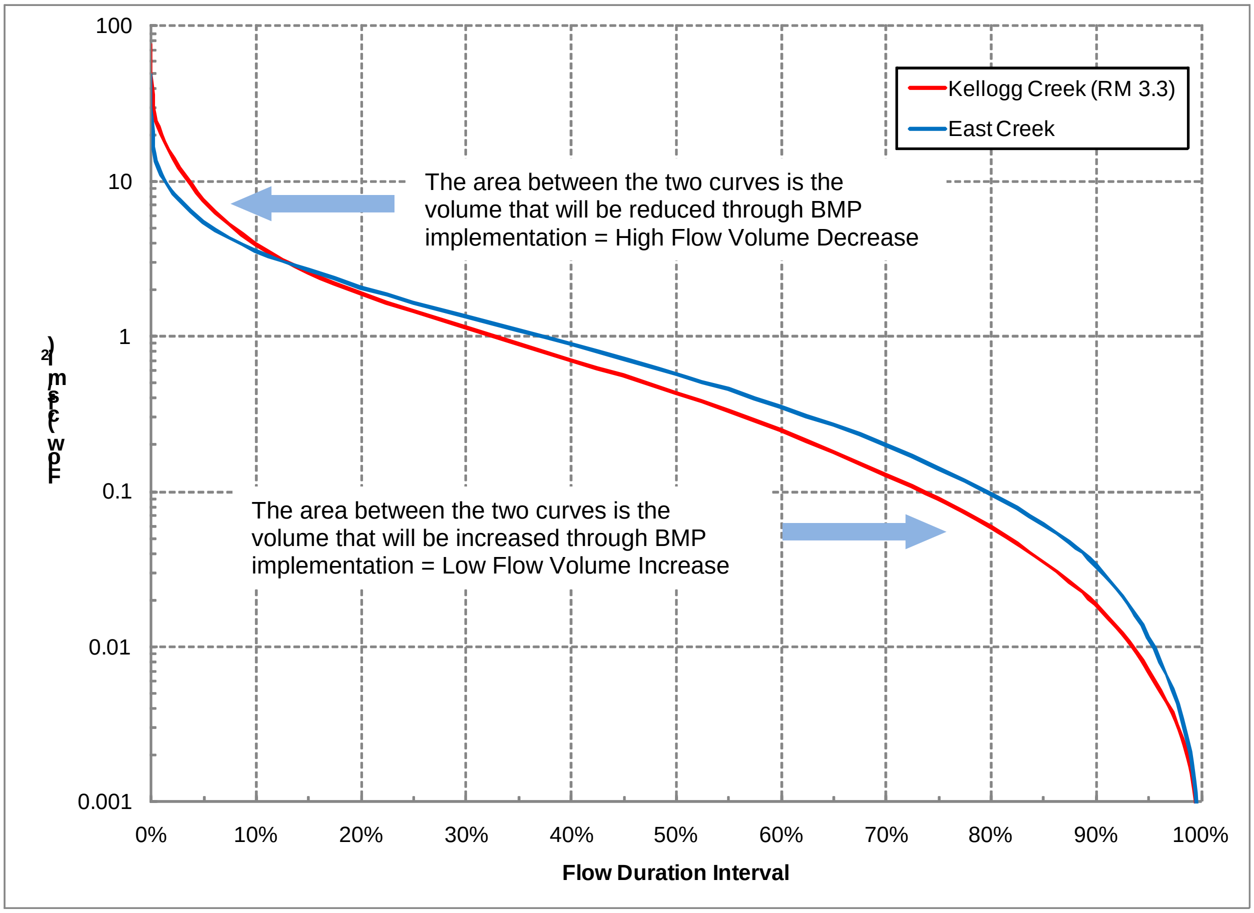

Figure 2-9. Graphical example of flow volume reduction targets.

Table 2-3. Flow volume targets from the lower Grand River TMDL

Implementation area (*flow duration metric*)	Flow duration interval (%)	Flow volume target (%)
Big Creek RM 16.0 with reference stream Jenks Creek		
High Flow Volume Decrease	0%–25%	–12%
Low Flow Volume Increase	26%–99%	+1%
Kellogg Creek RM 3.3 with reference stream East Creek		
High Flow Volume Decrease	0%–13%	–20%
Low Flow Volume Increase	14%–100%	+5%
Red Creek at Outlet with reference stream Talcott Creek		
High Flow Volume Decrease	0%–30%	–15%
Low Flow Volume Increase	31%–99%	+1%
Cemetery Creek RM 2.1 with reference stream Askue Run		
High Flow Volume Decrease	0%–61%	–7%
Low Flow Volume Increase	62%–100%	0%

Note: This includes the targets for each stream in the TMDL.

2.6 Model Results

Model results are presented below for the Concord Hills and Summerwood subdivisions. Cost-effectiveness curves, BMP utilization, and hydrologic parameters are presented for both pilot study sites. Optimization results are highly dependent on model assumptions and problem formulation (defined objectives and constraints). The objective defined in this study is reducing the annual average flow volume. Cost-effectiveness is therefore defined as the least costly BMPs that result in the optimization goal of volume reduction. It is not possible to optimize to both high-flow volume reductions and low-flow volume increases. Other conceivable factors such as peak flow attenuation, pollutant reduction, aesthetic appeal, and energy reduction benefit, were not considered but would be additional benefits of green infrastructure and the resultant volume reduction. In addition, it is important to note that cost data represent only design and construction costs; therefore, optimization results should be interpreted on that basis only. Operation and maintenance or land acquisition costs were not considered. It is conceivable that the selection order of different practices could change if operation and maintenance costs were factored into the analysis. Some practices could become either more or less cost-effective than represented. In any case, the analysis assumes that maintenance of private parcel BMPs would be the responsibility of the individual homeowners or association where applicable.

2.6.1 Cost-Effectiveness Curves

Figure 2-10 and Figure 2-11 show the average annual volume reduction cost-effectiveness curve in the Concord Hills and Summerwood subdivisions, respectively, as defined by the aggregate BMP decision variables. In the figures, the small points represent *All Solutions* that were evaluated during optimization; the larger orange points along the left- and upper-most perimeter of the curve represent the lowest cost options at each volume reduction target interval. The largest yellow points show the TMDL flow volume reduction targets (see Table 2-3). The closest SUSTAIN result along the cost-effectiveness curve was evaluated for each of the TMDL volume reduction targets. Table 2-4 summarizes implementation costs for the set of solutions along the curve that would achieve the TMDL volume reduction targets.

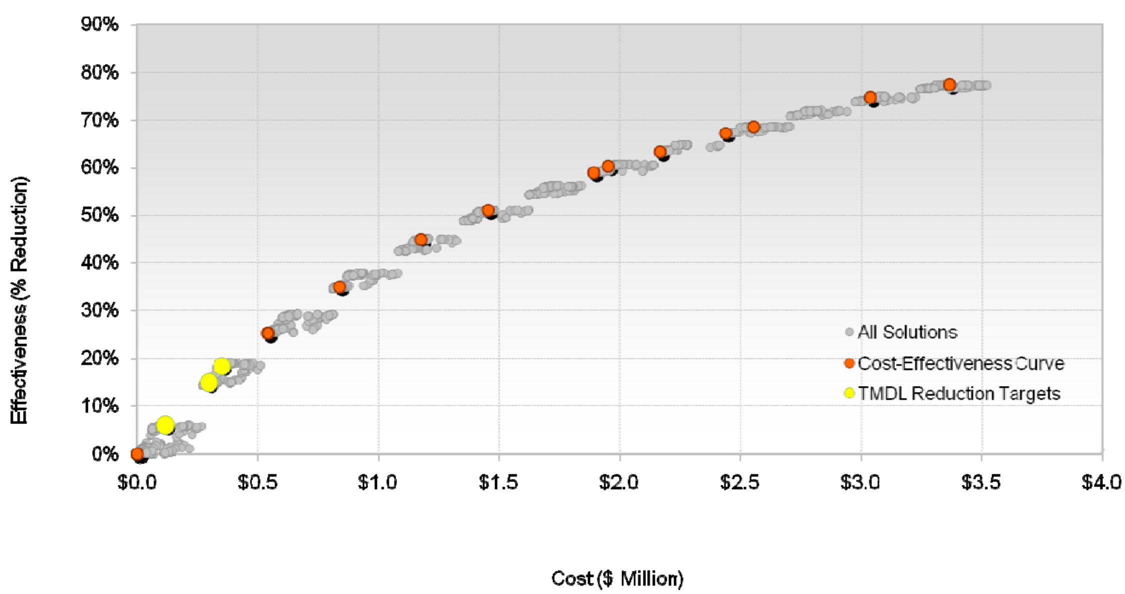

Figure 2-10. Maximum volume control cost-effectiveness curve, Concord Hills.

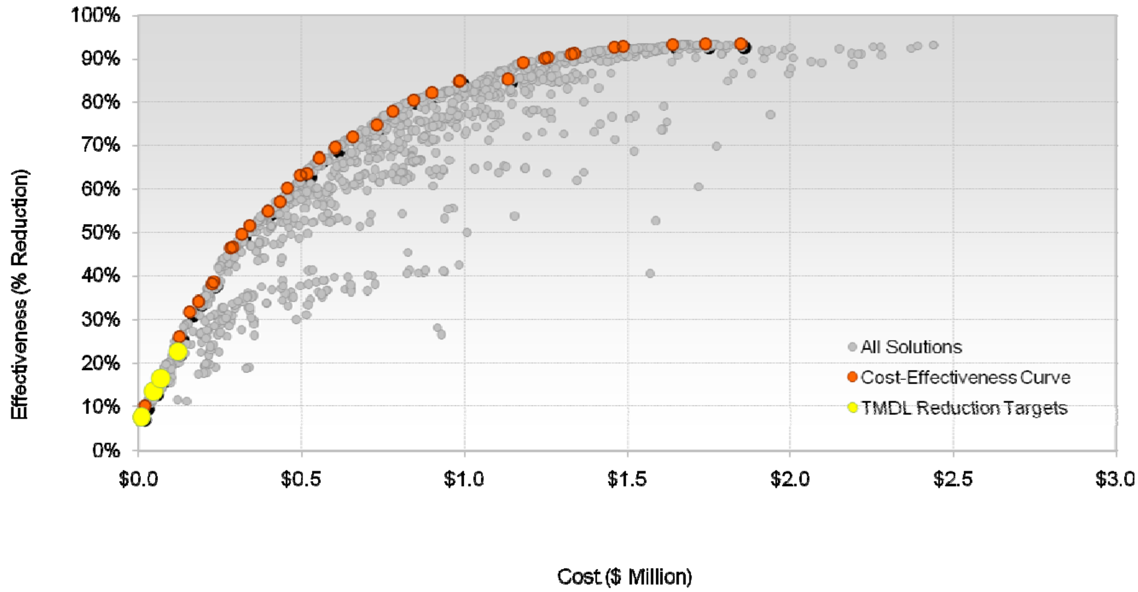

Figure 2-11. Maximum volume control cost-effectiveness curve, Summerwood.

Table 2-4. Selected solutions on the cost-effectiveness curve

TMDL flow volume reduction target	Closest applicable SUSTAIN result	Cost (2010)	
		Concord Hills	Summerwood
7%	6%	$117,405.00	$9,780.00
12% and 15%	15%	$296,178.00[a]	$45,830.00
20%	18%	$352,008.00	$118,544.00

a. The Concord Hills cost-effectiveness curve does not contain unique solutions applicable to the 12% and 15% flow volume reduction targets; therefore, one solution represents both targets.

2.6.2 Concord Hills Results

The utilization percentage of each BMP practice for the three Concord Hills solutions is plotted in Figure 2-12. Percent utilization for each solution is defined as the ratio of how much of the available opportunity was used divided by the total available opportunity. Figure 2-12 illustrates how utilization changes for each BMP as cost and percent volume control increases, while Figure 2-13 shows the total volume reduction provided by each BMP for the selected flow reduction solutions. The extent to which each practice is used for the three selected solutions is presented in Table 2-5. The total area for each practice and the percentage of the total maximum extent (from Table 2-1) is also presented. Table 2-6 presents the hydrologic parameters associated with each of the selected solutions. The flow volume reduction target is achieved through a combination of groundwater recharge and evapotranspiration.

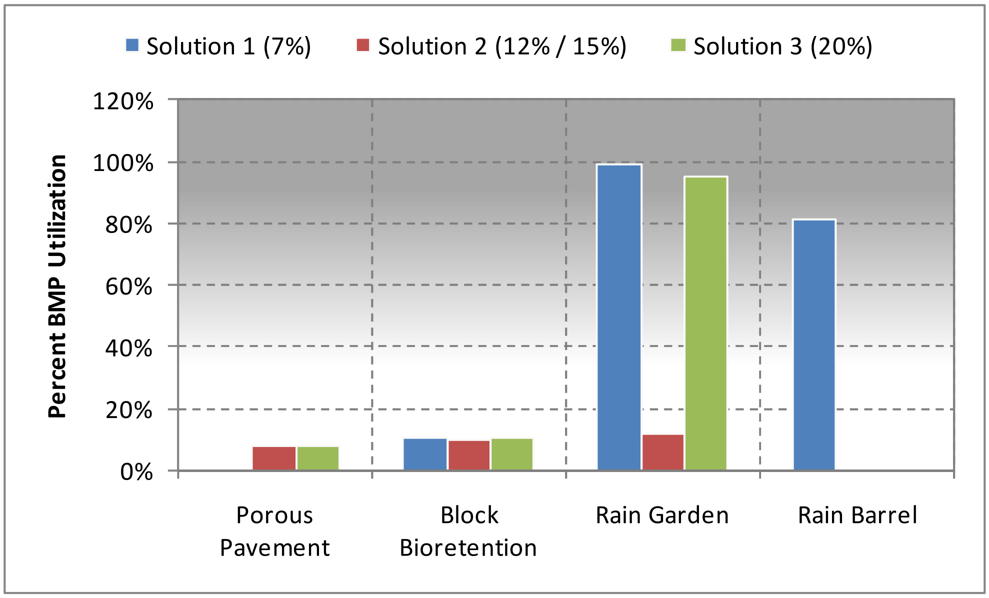

Figure 2-12. Percent utilization of various BMPs, Concord Hills.

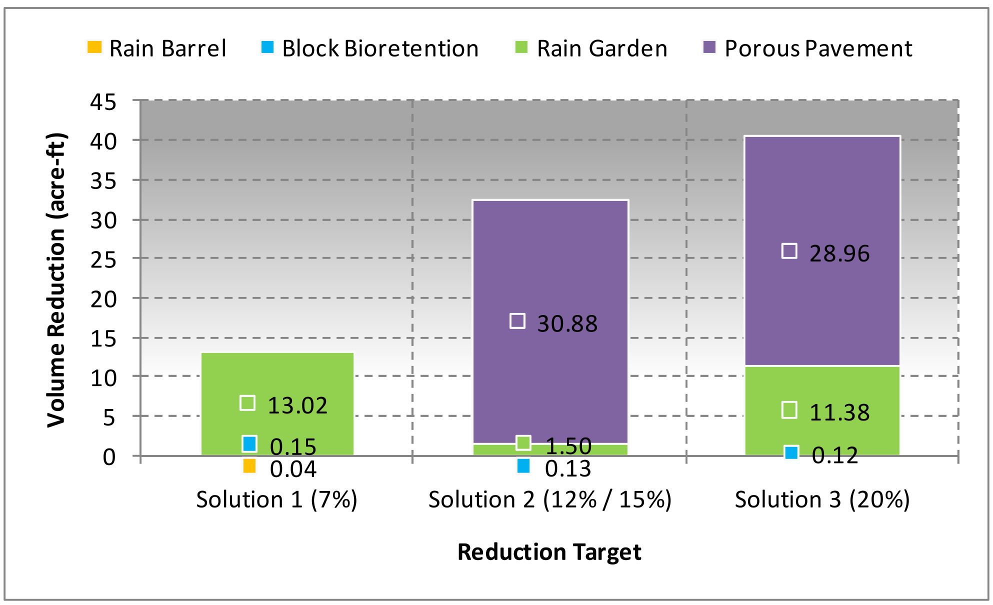

Figure 2-13. Concord Hills BMP volume reduction for the each reduction target.

Table 2-5. The extent a BMP is used under each solution to meet the three respective flow reduction targets in Concord Hills

Practices	Maximum potential extent of BMP	Flow volume reduction target		
		7%	12% and 15%	20%
Porous pavement (sq ft)	375,922	0	30,052	30,052
Block bioretention (sq ft)	5,663	600	550	600
Rain garden (unit)	108	107	13	103
Rain barrel (unit)	430	351	0	0

Table 2-6. Modeled effect on hydrologic parameters at Concord Hills as a result of solutions that would achieve 7, 12, 15, or 20 percent flow volume reduction

Flow volume reduction target	Peak flow reduction (%)	Groundwater recharge increase (%)
7%	0.09%	5.55%
12% and 15%	0.86%	14.15%
20%	0.95%	17.43%

Below is a summary of observations from the analysis:

- The maximum achievable volume control through the use of all potential BMPs in the Concord Hills subdivision is 78 percent.
- Figure 2-12 shows that rain gardens are the most used practice in two out of the three selected solutions. (Recall that percent utilization is defined as the ratio of how much of the available opportunity was used in each solution divided by the total available opportunity.) That indicates that, in general, rain gardens are one of the most cost-effective practices, which is partially reflected in its unit cost. The utilization rate of rain gardens is above 80 percent in solutions 1 and 3 but drops below 20 percent in solution 2. That is likely because of the similar costs between rain gardens and porous pavement where they are largely interchangeable. Figure 2-13 shows that the actual volume reduction provided by rain gardens is consistently greater than all BMP practices except porous pavement for all three scenarios.
- Figure 2-12 shows that the use of porous pavement increases as flow volume reduction increases, and Figure 2-13 shows that porous pavement provides the most volume reduction in solutions 2 and 3. The higher utilization is because of the significantly larger potential extent of porous pavement as compared to the other BMP practices. In fact, Figure 2-13 appears to show that above the 12 percent treatment level, only porous pavement can provide cost-effective volume reduction. The reason porous pavement is not used in scenario 1 is likely because of the interchangeability between it and rain gardens.
- The low utilization of block bioretention is fairly consistent across all three scenarios, indicating that it is not a very cost-effective solution. Increasing the use of the practice only increases cost without providing any additional benefit. Rain barrel utilization exceeds 80 percent in scenario 1, but the actual treatment volume provided is fairly insignificant as shown in Figure 2-13. That explains why the model optimization does not include the use of rain barrels for the other two solutions because its inclusion has little relative impact on overall volume reduction.
- Peak flow reductions are minimal for all the selected solutions; however, the BMPs do provide for significantly higher groundwater recharge over current conditions. All the flow volume reduction targets result in meeting the low-flow volume increases identified in Table 2-3.

2.6.3 Summerwood Results

The utilization percentage of each practice for the four Summerwood solutions is plotted in Figure 2-14. Percent utilization for each solution is defined as the ratio of how much of the available opportunity was used divided by the total available opportunity. Figure 2-14 illustrates how utilization changes for each practice as cost and percent volume control increases, while Figure 2-15 shows the total volume reduction provided by each BMP for the selected flow reduction solutions. The extent to which each practice is used for the four selected solutions is presented in Table 2-7. The total area for each practice and the percentage of the total maximum extent (from Table 2-1) is also presented. Table 2-8 presents the modeled effect on hydrologic parameters associated with each of the selected solutions. The flow volume reduction target is achieved through a combination of groundwater recharge and evapotranspiration.

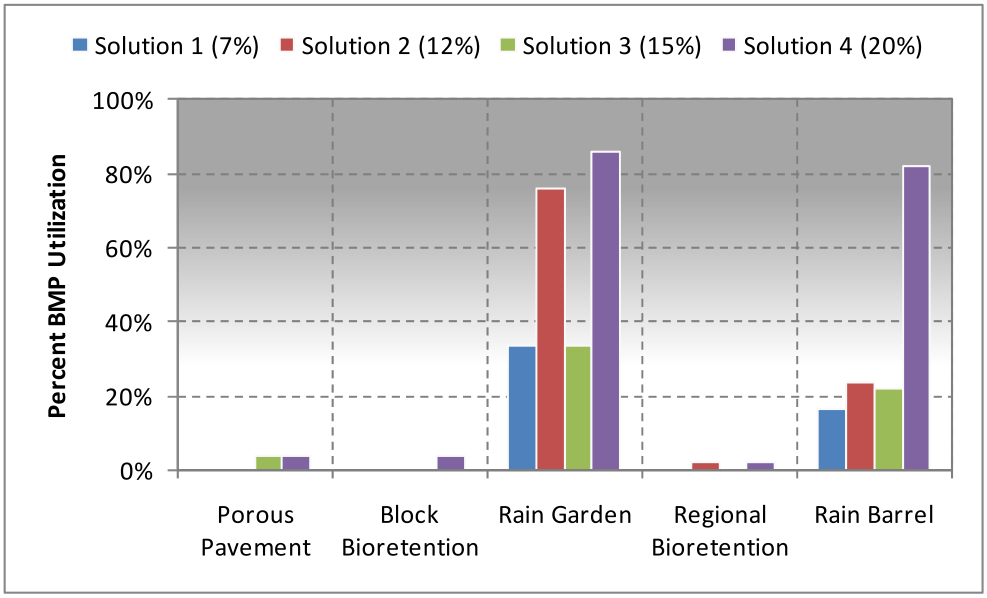

Figure 2-14. Percent utilization of various BMPs, Summerwood.

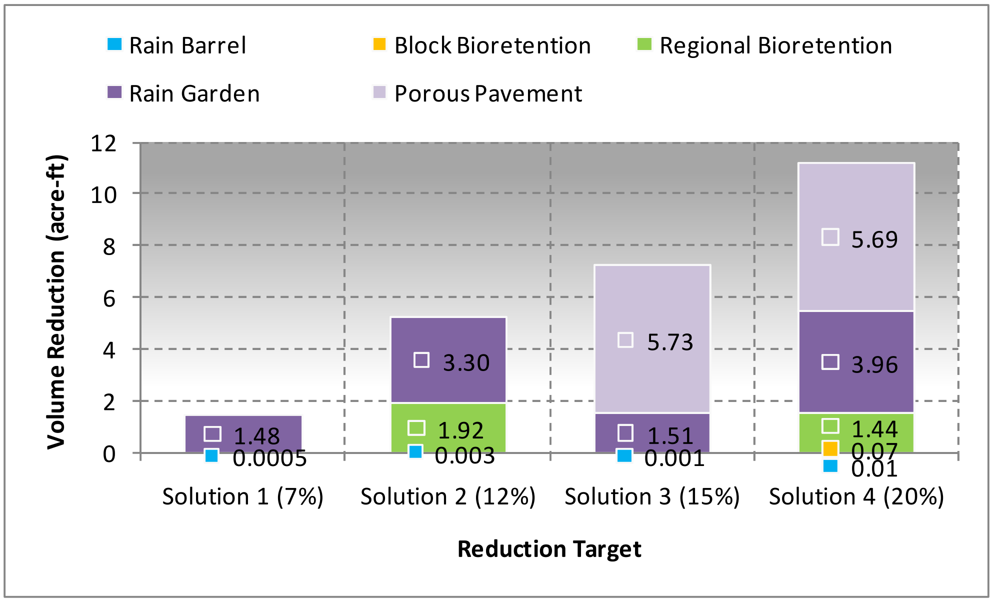

Figure 2-15. Summerwood BMP volume reduction for the each reduction target.

Table 2-7. BMP extents by solution, Summerwood

Practices	Maximum potential extent of BMP	Flow volume reduction target			
		7%	12%	15%	20%
Porous pavement (sq ft)	162,914	0	0	6,396	6,396
Block bioretention (sq ft)	3,920	0	0	0	150
Rain garden (unit)	37	12.5	28.1	12.5	31.8
Regional bioretention (sq ft)	87,120	0	1,716	0	1,716
Rain barrel (unit)	144	24	34	32	118

Table 2-8. Modeled effect on hydrologic parameters at Summerwood as a result of solutions that would achieve 7, 12, 15, or 20 percent flow volume reduction

Flow volume reduction target	Peak flow reduction (%)	Groundwater recharge increase (%)
Existing Conditions	59.26%	2.88%
7%	59.34%	5.11%
12%	59.69%	10.68%
15%	59.73%	14.27%
20%	60.23%	20.09%

Below is a summary of observations from the analysis:

- The maximum achievable volume control through the use of all potential BMPs in the Summerwood subdivision is 92 percent.
- Figure 2-14 shows that rain gardens were the most used practice for each of the four selected solutions. That indicates that rain gardens are the most cost-effective practice. Figure 2-15 shows that the actual volume reduction provided by rain gardens is consistently greater than all BMP practices, except porous pavement in scenarios 3 and 4.
- Figure 2-14 illustrates that the utilization of porous pavement begins when treatment levels reach 15 percent. That indicates that porous pavement is not a cost-effective practice for lower levels of volume reduction, but it is needed to achieve volume reductions above 15 percent.
- Figure 2-14 shows that a low utilization of block bioretention is consistent across all four scenarios, with three of four not using block bioretention at all. That indicates that it is not a very cost-effective solution. Regional bioretention also shows low utilization (Figure 2-14), but it provides much greater actual volume reduction (Figure 2-15). Its design specifications are the same as for block bioretention, but its unit costs are less and its maximum potential extent is second only to porous pavement, potentially allowing for significant runoff capture.
- Figure 2-14 shows that rain barrel utilization exceeds 80 percent in scenario 4, but the actual treatment volume provided is fairly insignificant (Figure 2-15). Thus, the level of utilization does not significantly affect overall volume reduction, explaining why the utilization can vary across the scenarios.
- The utilization of all BMPs is always less than 100 percent (Figure 2-14). That indicates that the maximum potential extent of the practices can capture more runoff than the solutions target.

- The existing detention ponds provide for approximately 60 percent reduction in peak flows. The BMPs (e.g., bioretention, porous pavement) do not provide much additional peak flow control but provide for significantly higher groundwater recharge over current conditions, resulting in meeting low-flow volume target increases identified in Table 2-3.

3. TMDL Implementation

Implementation of the flow regime TMDLs will be based significantly on stormwater retrofitting. Protecting unimpaired streams and high-quality areas draining to impaired streams will require additional considerations and potentially stormwater regulations to address the need for flow volume reduction and protection of groundwater base flow conditions during the development process.

3.1 Stormwater Retrofitting

Stormwater retrofitting will be a significant component of implementation in the flow regime TMDL watersheds. The Concord Hills subdivision provides a representative example of an untreated single-family residential neighborhood, the predominant land use in the impaired watersheds.

Results of the SUSTAIN model according to area of BMPs, are extrapolated for each of the flow regime TMDL watersheds to provide an estimate of BMPs and associated costs that will be needed to implement the TMDLs in Big Creek (RM 16.0), Kellogg Creek (RM 3.3), and Red Creek (at outlet). Ohio EPA determined that Cemetery Creek (RM 2.1) was in nonattainment of its biocriteria because of flow alteration from urbanization, and thus, the creek was evaluated for this report. However, Ohio EPA will declare that location to be impaired by natural conditions in the 2012 Integrated Report, and no TMDL will be completed. The results of the evaluations could still be used to mitigate the anthropogenic factors that detrimentally affect Cemetery Creek. The extrapolation was based on linearly up-scaling the results from Concord Hills to the entire watershed area minus forested areas and land cover that was indicated water or wetlands. Table 3-1 summarizes the extrapolated results for each impaired watershed. Watershed areas that were identified as forested were assumed to be meeting the TMDL hydrologic targets and were disconnected to the existing stormwater system and, therefore, were not included in the extrapolation. The remaining watershed is assumed to be contributing to the stream with similar land uses and stormwater management as the Concord Hills subdivision.

Table 3-1. Extrapolated results based on Concord Hills

BMPs	Cemetery Creek (7%)	Big Creek (12%)	Red Creek (15%)	Kellogg Creek (20%)
Porous pavement (acre)	0.0	2.8	21.6	11.3
Block bioretention (acre)	7,433.7	0.05	0.4	0.2
Rain garden (unit)	1,325.7	52.7	407.5	1,681.3
Rain barrel (unit)	4,348.7	0.0	0.0	0.0
Estimated Costs (2010)	$1,454,580	$1,200,350	$9,284,150	$5,745,980

The county and local governments can use the results presented in Table 3-1 to inform watershed planning and TMDL implementation strategies at the local level. The extrapolated results provide for a cost-effective combination of BMPs for specific watershed (e.g., Big Creek) that would meet flow regime TMDL requirements. Existing capital improvement plans should be evaluated to determine where existing opportunities exist. For example, because porous pavement and block bioretention have been identified as cost-effective retrofit practices, road and sidewalk replacement schedules should be evaluated for opportunities to install both of those practices. By leveraging existing opportunities, the additional costs to install BMPs will be the difference between the traditional practices and BMPs, for example, the difference in cost associated with traditional asphalt and porous asphalt, which is not reflected in Table 3-1.

Smaller scale retrofits such as rain barrels and rain gardens (see Figure 3-1) are often led by the local government, watershed, or SWCD through programmatic initiatives. TMDL implementation will rely on those entities to continue existing education programs on small-scale BMPs. In addition, a focused effort should be used to target the homeowners in the TMDL watersheds. Grant funding could be sought to conduct neighborhood retrofit programs and fund multiple rain garden and rain barrel installations. Rain barrels are available for purchase through both the Lake and Geauga SWCDs.

Example rain garden programs include Central Ohio Rain Garden Initiative, http://www.centralohioraingardens.org/; Maplewood, Minnesota Rain Garden Program, http://ci.maplewood.mn.us/index.aspx?NID=456; and Metro Blooms, http://metroblooms.org/neighborhood-of-gardens.php#subsection2.

Figure 3-1. Front yard rain garden, Maplewood, MN

3.2 Land Use Planning and Controls

Protecting streams from degradation under future land uses will also be critical to ensure that the impaired streams are not further degraded and that unimpaired streams are protected. The protection strategies included in Section 10 of the TMDL identify key streams that are unimpaired but are in areas that are likely to be threatened by development in the next 30 years.

3.2.1 Comparison between Existing Stormwater Requirements and TMDL Requirements

The Summerwood subdivision provides a representative example of expected future land uses and the current level of treatment required as part of the construction stormwater permitting process. The subdivision is designed as a conservation development and includes a cluster of homes surrounded by large, forested and natural areas. The SUSTAIN analysis does not take into account the disconnected natural areas.

An evaluation of the stormwater treatment provided in the Summerwood subdivision versus the requirements of the TMDL was completed. That evaluation compared the results of stormwater regulations at the time of the Summerwood subdivision development to those that would be needed to effectively implement the TMDL. An existing condition model was developed for the Summerwood subdivision that includes the two existing detention ponds. SUSTAIN was then run to determine what additional practices were most cost-effective to achieve the TMDL targets. Table 3-2 presents the comparison between the existing Summerwood subdivision conditions and the four selected solutions. One of the detention ponds in the Summerwood subdivision was modeled to include a small amount of infiltration according to field observations. That infiltration volume, in combination with estimated evapotranspiration, accounts for 5.3 percent reduction in flow volume with roughly half of that reduction translating to groundwater recharge (2.9 percent). The total flow volume reduction is the sum of groundwater recharge and evapotranspiration. For example, the 16 percent flow volume reduction scenario is divided into groundwater recharge equal to 14.3 percent of flow volume reduction and evapotranspiration equal to 1.7 percent of flow volume reduction, resulting in groundwater recharge accounting for 89 percent of the flow volume reduction. Groundwater recharge accounts for 64–89 percent of the flow volume reduction for the selected solutions.

Table 3-2. Comparison of existing conditions to TMDL requirements, Summerwood results

Comparison metric	Existing conditions	Proposed conditions at various flow volume reduction percentages			
Flow Volume Reduction (%)	5.3%	8%	13%	16%	23%
Costs (2010 $)/acre [a]	$0	$249.49	$1,169.13	$1,737.35	$3,024.08
Peak Flow Reduction (%)	59.3%	59.3%	59.7%	59.7%	60.2%
Groundwater Recharge (%)	2.9%	5.1%	10.7%	14.3%	20.1%

a. Costs do not include existing conditions

The selected solutions provide a summary of the SUSTAIN results that can be applied to other watersheds on the basis of flow volume reduction targets. For example, in the Big Creek watershed (upstream of RM 16.0, which requires a flow volume reduction of 15 percent), compliance with the TMDL could be achieved by implementing the suite of BMPs identified in the 16 percent flow volume reduction scenario for a cost of approximately $1,737 per acre, resulting in increased groundwater recharge of 14.3 percent.

3.2.2 Comparison with Ohio EPA General Construction Requirements

Concord Hills subdivision results were compared to Ohio EPA's General Construction Stormwater Permit water quality standards (Ohio EPA 2008) using the SUSTAIN results. The general permit requires a treated water quality volume (WQv) equal to the runoff associated with a 0.75-inch rainfall event. That translates to 1.6 acre-feet for the Concord Hills subdivision using the rational method as described in the construction stormwater permit. Table 3-3 summarizes the comparison between Ohio EPA's WQv and the SUSTAIN results. The BMP volumes associated with each of the flow volume reduction targets are all less than the WQv required by Ohio EPA. That indicates that only a portion of the existing required WQv would need to be converted to an infiltration requirement.

Table 3-3. Comparison of Ohio EPA's water quality volume and BMP volume, Concord Hills

Flow volume reduction target	SUSTAIN BMP volume (acre-feet)	Ohio EPA'S WQv (acre-feet)[a]
7%	0.32	1.6
15%	0.74	
20%	0.94	

a. Determined using the rational method for the Concord Hills subdivision

3.2.3 Potential Stormwater Regulations

In addition to retrofitting areas that already have some form of water quality treatment, infiltration is needed. Two types of infiltration standards could be considered.

A standard could be used that would require all new development to meet pre-settlement hydrology (typically forested) for both flow and volume. At least 80 percent of the required flow volume reduction (the difference in flow volume between pre- and post-development scenario) should be though infiltration to ensure groundwater recharge. For example, if a given parcel can infiltration 100 cubic feet under a forested condition, the standard would require that under a developed condition, 80 cubic feet would be required to be infiltrated. This type of standard accounts for site constraints such as soils with low infiltration capacity, high water table, and bedrock near the surface by not requiring more water to infiltrate than is possible under a natural condition.

The pre-settlement condition is conservative in that the reference streams presented in the TMDL include some level of development. However, that conservative requirement would allow for an additional margin of safety for the downstream receiving water because failure of infiltration practices is frequently documented. Such a standard is more difficult to implement because it requires pre- and post-development site modeling to determine compliance.

A standard could also be developed similar to the existing Ohio EPA WQv that would require a portion of that WQv to be infiltrated. For example, a numeric standard could state that the applicant is required to infiltrate the runoff associated with a certain depth of runoff over the proposed site. Analysis to determine the specific volume is beyond the scope of this study and will be dependent on the downstream receiving waterbody and the associated TMDL requirements. Such a standard is simple to implement, although it does not take into account different conditions that influence stormwater infiltration such as soil type, geology, and depth to the water table.

4. References

Federal Highway Administration. 2009. *Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring*. <http://www.fhwa.dot.gov/environment/ultraurb/index.htm>.

Ohio Environmental Protection Agency (Ohio EPA). 2008. *Authorization for Storm Water Discharges Associated with Construction Activity under the National Pollutant Discharge Elimination System*. Ohio Permit Number OHC000003. Ohio Environmental Protection Agency, Columbus, OH.

Ohio Environmental Protection Agency (Ohio EPA). 2010. Personnel communication with Russ Gibson, Nonpoint Source Section Manager, Ohio Environmental Protection Agency,Division of Surface Water, Columbus, OH.

Schueler, T., D. Hirschman, M. Novotney, and J. Zielinkski. 2007. *Urban Stormwater Retrofit Practices V 1.0*, Appendices. Prepared for U.S. Environmental Protection Agency, Office of Wastewater Management, Washington, DC, by Center for Watershed Protection, Ellicott City, MD.

Tetra Tech, Inc. 2001. Low–Impact Development Management Practices Evaluation Computer Module User's Guide. Prepared for Prince George's County, Department of Environmental Resources, by Tetra Tech, Inc., Fairfax, VA.

Tetra Tech. 2009. *Green Best Management Practice (BMP) Operation and Maintenance Study*. Prepared for the City of Columbus, Ohio, Public Utilities Department, Columbus, OH, by Tetra Tech, Inc., Fairfax, VA.

University of New Hampshire. 2008. Treatment Unit Fact Sheets. <http://www.unh.edu/erg/cstev/fact_sheets/index.htm>. Accessed October 2010.

U.S. Environmental Protection Agency (U.S. EPA). 2009. *SUSTAIN—A Framework for Placement of Best Management Practices in Urban Watersheds to Protect Water Quality*. EPA/600/R-09/095. U.S. Environmental Protection Agency, Office of Research and Development, Washington, DC.