SUSTAIN Application User's Guide for EPA Region 10

by

John Riverson, Jr.
Khalid Alvi, P.E.
Jenny X. Zhen, Ph.D., P.E.
Ryan Murphy

Tetra Tech, Inc.
10306 Eaton Place, Suite 340
Fairfax, VA 22030

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Task Manager
Dino Marshalonis, Ph.D.
Office of Water and Watersheds
U.S. Environmental Protection Agency - Region 10
1200 Sixth Ave, Suite 900, OWW -137
Seattle, WA 98101

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Disclaimer

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Abstract

U.S. Environmental Protection Agency (EPA) Office of Research and Development (ORD) contracted with Tetra Tech to provide ongoing technical support for four EPA Region 10 grant funded projects from August 2011 to December 2014. The projects all focused on addressing impacts of urban development on the Puget Sound and used the System for Urban Stormwater Treatment and Analysis Integration (*SUSTAIN*) in various ways to assess predicted effects of BMP implementation. Tetra Tech's technical assistance included providing ongoing consulting and helpdesk type support, model enhancements to support specific project objectives, and eliminate software bugs and coding errors, and two on-site training workshops. The project resulted in an updated version of *SUSTAIN* (version 1.2) and a written report that includes documentation of the details of all model enhancements, step by step exercises derived from the two training workshops, and discussion of critical insights regarding setup and application that should be considered by future users of *SUSTAIN*.

Executive Summary

Region 10 of the U. S. Environmental Protection Agency (EPA) funded four pilot projects in 2010 to address impacts of urban development on Puget Sound by developing watershed assessment and planning projects focused on identifying retrofits, land use planning and green infrastructure investments. Implementation options were evaluated using the System for Urban Stormwater Treatment and Analysis Integration (*SUSTAIN*), developed by EPA's Office of Research and Development. This *SUSTAIN* Application Guide was developed to document technical support and model enhancements related to the EPA Region 10 pilot projects. The Guide contains exercises derived using local Puget Sound models and configuration considerations. When used in conjunction with the associated model installation and input files, those exercises can provide helpful support for users applying *SUSTAIN*.

Ongoing project-specific technical guidance was provided to grantees working on the four pilot projects which included direct access to the *SUSTAIN* application development team and an on-line library of questions and answers. In addition, two on-site training workshops were conducted to provide tailored guidance on the use of *SUSTAIN* features.

The *SUSTAIN* software was also enhanced in order to address several of the management questions raised during pilot projects in the Puget Sound region. Various bugs and coding errors were also identified and eliminated through the applications process. New features added to *SUSTAIN* version 1.2 and described in this document, include:

1. Groundwater/aquifer component for tracking baseflow and infiltrated water
2. Ability to define a best management practice or routing segment using an F-table
3. Ability to define a flow-exceedance frequency optimization target
4. Ability to optimize goodness-of-fit between two flow duration curves

This *SUSTAIN* Application Guide (Guide) was developed to provide technical support and document the model enhancements that were implemented to support the pilot projects. The Guide contains exercises derived using local Puget Sound models and configuration considerations. When used in conjunction with the associated model installation and input files, those exercises can provide helpful support for users applying *SUSTAIN*. This User's Guide includes a series of application exercises to assist the modeler in using these enhancements and developing meaningful and effective *SUSTAIN* applications. They also showcase how the grantees applied *SUSTAIN* to answer relevant stormwater management questions in the Puget Sound region. The step-by–step exercises presented in this documentation provide the model user with an advanced level of training using *SUSTAIN*.

Two key insights were recognized over the course of this project: (1) Upfront planning is the key to efficient and successful *SUSTAIN* application and (2) Application needs drive model development and enhancement. Having a thorough understanding of the model as well as focusing on the important management questions being asked is critical to ensuring a successful project. *SUSTAIN* has also proven to be a versatile framework that can be readily expanded with new functionalities and features.

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We also acknowledge the Washington State Department of Ecology and Herrera Consultants for their efforts in developing and sharing a customized Puget Sound regional *SUSTAIN* BMP cost database for use by the other grantees.

Finally, we would like to sincerely thank all the *SUSTAIN* Region 10 Users' Group participants and the *SUSTAIN* training workshop attendees for their keen interest in learning and applying this tool. Our development process and work products have been enriched by their valuable feedback.

Abbreviations and Acronyms

BMP	Best Management Practice
EPA	United States Environmental Protection Agency
FDC	Flow-Duration Curve
GI	Green Infrastructure
GIS	Geographic Information System
HPC	High Pulse Count
HPR	High Pulse Range
HRU	Hydrologic Response Unit
HSPF	Hydrologic Simulation Program—FORTRAN
LID	Low Impact Development
ORD	Office of Research and Development
PEAK:BASE	2-year frequency peak flow : mean winter base flow ratio
SUSTAIN	System for Urban Stormwater Treatment and Analysis Integration
SWMM	Storm Water Management Model
TMDL	Total Maximum Daily Load
TSS	Total Suspended Solids
USGS	United States Geological Survey
WDOE	Washington State Department of Ecology
WRIA	Water Resources Inventory Area

Chapter 1. Background and Introduction

Many of the water bodies in the Puget Sound region are impaired due to stormwater impacts. Urbanization, specifically increasing impervious cover, grading, construction of drainage networks, loss of vegetation, and soil compaction, are yielding larger volumes of stormwater to area water bodies during and after storm events. Conventional understanding from hydrograph analyses suggests that urban development reduces baseflow during the wet season as less water infiltrates, while it increases surface runoff. Other studies have suggested that moderate levels of development along the urban fringe and their associated water management activities can have a greater impact on hydrology than impervious cover alone, especially with respect to summer low flow (USGS 2002 and Konrad 2005). Energy from storm driven flows contributes to eroding stream channels and shoreline areas, resulting in higher instream sediment levels, unstable riparian and shoreline areas, and degradation of beneficial uses for those waters. In addition to the problems associated with hydrologic regime change and sediment erosion, stormwater runoff from urban and suburban areas also introduces high levels of pollutants such as bacteria, nutrients, and metals. Changes in hydrology and peak flow, combined with increases in pollutant loads, have also degraded aquatic stream habitats. In short, urban stormwater has profoundly altered the natural hydrologic patterns and water quality of streams in the Puget Sound region.

Several regional studies have been conducted to develop locally relevant criteria and implementation targets focused on restoring natural condition hydrology as a means of reversing the trends associated with stream degradation caused by stormwater. These standards are flow-duration based, with objectives of reducing peak flows and increasing baseflow as a means to dissipate stormwater energy (WDOE 2012). Implementation of certain urban Best Management Practices (BMPs), including Low Impact Development (LID)/Green Infrastructure (GI) practices have been shown to be effective at restoring the natural hydrologic responses in a watershed and protecting streams due to retention and attenuation benefits. While other water quality restoration and protection efforts, such as Total Maximum Daily Loads (TMDLs) and Section 319 watershed management plans, can establish goals based on the needs and conditions of the receiving waters, there remains the significant challenge of identifying which combinations of BMPs of what size should be placed where in order to reduce stormwater volumes and loadings to a level where the water quality goals can be achieved. Among all proposed strategies, there are differences in capital, operation, and maintenance costs, which must also be considered while formulating management strategies. State TMDL writers, State NPDES stormwater permit writers, community stormwater program managers, and planners need informative tools for integrating data and knowledge when formulating those management strategies.

One such tool is the System for Urban Stormwater Treatment and Analysis Integration (*SUSTAIN*), developed by EPA's Office of Research and Development (ORD). *SUSTAIN* was designed to support planners, engineers, and other stormwater practitioners in:

- Developing cost-effective implementation plans for municipal stormwater programs;
- Evaluating and selecting BMPs to achieve loading targets set by a TMDL or a Section 319 Watershed Management Plan; and
- Selecting cost-effective GI practices to help meet optimal flow reduction goals.

In 2010, EPA Region 10 awarded four grants to local Puget Sound governments (City of Seattle, King County, City of Bremerton, and Washington State Department of Ecology) to address the impacts of urban development on Puget Sound by developing watershed assessment and planning projects focused on identifying retrofit opportunities, improving/informing land use planning and implementing/prioritizing green infrastructure investments. Each grantee set forth to use *SUSTAIN* to evaluate stormwater implementation options, and identified different management questions to be evaluated. EPA Region 10 developed a new task order through Tetra Tech's existing *SUSTAIN* development contract with EPA ORD to provide for:

- Ongoing project-specific technical guidance for grantees,
- Software modifications and enhancements to accommodate cost-benefit optimization based on Region 10-specific management standards, and
- Two training courses and materials to orient Puget Sound grantees in the use of new and existing *SUSTAIN* features and functions for developing management plans.

The task order was also issued to overcome some of the functional limitations of addressing certain management questions using the initial release version 1.0 of *SUSTAIN*, to fix evolving software bugs and errors discovered during application, to provide more detailed guidance on the usage of updated model software, and to extend on-call support to align with the schedule of grant projects.

This chapter provides a description of evaluation needs of the grantees, the features and functionalities that were added to *SUSTAIN* for Puget Sound grantees as part of this task order, and a general overview of the *SUSTAIN* application process. Chapter 2 provides a series of step-by-step exercises that highlight the use of new features and functionalities. Finally, Chapter 3 concludes the report with project insights gained through *SUSTAIN* applications and interactions with and among the Puget Sound grantees.

1.1. Evaluation Needs of Puget Sound Grantees

In addition to meeting state and local water quality objectives, stormwater management objectives and numeric indicators in the Puget Sound region are also designed to reestablish the hydrological and ecological health of the receiving water, and restore the chemical, physical, and biological integrity of the region's waters. Water quality indicators are mostly measured concentrations of various pollutants as defined in the Washington State Department of Ecology (WDOE) regulatory water quality criteria. Hydrologic indicators applied in the region include duration and peak flows with various return frequencies, and statistics measuring peak and base flows over a long continuous period (Horner 2013)—some example indicators are presented in Table 1-1. Research has shown that hydrologic indicators have a statistically significant correlation with the ecological health of lotic waters (USGS 2002; Konrad 2005; DeGasperi et al. 2009; Horner 2013).

Table 1-1 Examples of regional hydrologic indicators (Source: Horner 2013)

Indicator	Description
High Pulse Count (HPC)	A count of the number of times that observed stream flow exceeds 2 × water-year mean flow
High Pulse Range (HPR)	The number of days in the time span between the first and last excursions of the hydrograph above 2 × water-year mean flow
2-year Peak Flow (PEAK)	The statistically-derived maximum flow rate that occurs within a 2-year period of time
Mean Winter Base Flow (BASE)	The average baseflow occurring within the winter months of January through March
PEAK:BASE ratio	The ratio of 2-year peak flow to mean winter base flow

Four grantees benefited from the work products of this effort. Each grantee formulated unique stormwater management objectives and applied *SUSTAIN* in different ways to address their needs. Table 1-2 illustrates the model objectives for each project and the model enhancements that were required to address certain objectives. Table 1-3 provides a description of the *SUSTAIN* applications by grantee.

Table 1-2 Management objectives and enhancement needs of Puget Sound grantees

Stormwater Management Objectives		City of Bremerton: Gorst Creek Watershed	WDOE, City of Federal Way: Basin CBB	City of Seattle: Piper's Creek	King County: Water Resource Inventory Area 9 (WRIA9)
		Legend: ● = Evaluation objective available in *SUSTAIN* v.1.0; ○ = Enhancement needed in order to represent objective; – = Not an evaluation objective for the study			
Hydrologic	Peak Flow	●	–	●	–
	Flow Exceedance Frequency	–	–	–	○
	Flow Duration	–	–	○	○
	Base Flow	–	–	○	○
Non-Hydrological	Water Quality	–	●	–	●
	Biological	–	–	–	○

Table 1-3 Description of *SUSTAIN* applications by Puget Sound grantees

Grantee	Project Location and Study Objective	How *SUSTAIN* is Applied	Related *SUSTAIN* Enhancements
King County	Develop a cost estimate and prioritization plan for systematically implementing BMP and LID techniques in Water Resources Inventory Area 9 (WRIA9) to meet in-stream hydrologic and water quality goals	Applied *SUSTAIN* to derive the cost-effectiveness (CE) curve for unique combinations of land use, climate region, soil, slope, and land cost; extrapolate the CE-curve to estimate the total stormwater management cost for the entire WRIA9 study area	Groundwater aquifer component; Exceedance frequency calculation; Flow-Duration Curve (FDC) calculation; F-table
Washington State Department of Ecology	In the City of Federal Way, characterizing toxic chemical loading in the Puget Sound watershed and identifying management strategies for reducing these loads	Used *SUSTAIN's* optimization routine and aggregate BMP approach to estimate cost-effective BMP scenarios for a series of water quality management goals	None
City of Bremerton	Gorst Creek Watershed, develop a BMP implementation strategy to mitigate flooding risk.	Applied aggregate BMP approach and optimization routine to identify solutions for peak flow reduction	F-table
Seattle Public Utility	Piper's Creek Watershed, evalaute the implications of applying various flow control targets for BMP design on stream health.	Applied *SUSTAIN* to size BMPs for meeting flow control targets	FDC calculation F-table

1.2. *SUSTAIN* Enhancements to Address Evaluation Needs

EPA supported the addition of several new optimization evaluation factors to *SUSTAIN* to address the evaluation needs of the Puget Sound grantees. First, because some of the management objectives were frequency-based instead of volume or mass based, a new intermediate metric needed to be calculated that could track exceedance frequency. Second, formulating a hydrologically-based optimization objective involving a segment of a flow duration curve (FDC) required (1) adding the ability to compute FDCs internally during model simulation and (2) comparing that curve segment against *another* FDC segment representing the target condition. In addition to the evaluation factors, some new computational features were added. Below is a summary of the new features added to *SUSTAIN*:

1. Groundwater/aquifer component for tracking baseflow and infiltrated water
2. Ability to define a BMP or routing segment using an F-table
3. Ability to define a flow-exceedance frequency optimization target
4. Ability to optimize goodness-of-fit between two FDCs

Figure 1-1 illustrates the original and enhanced *SUSTAIN* routing network options.

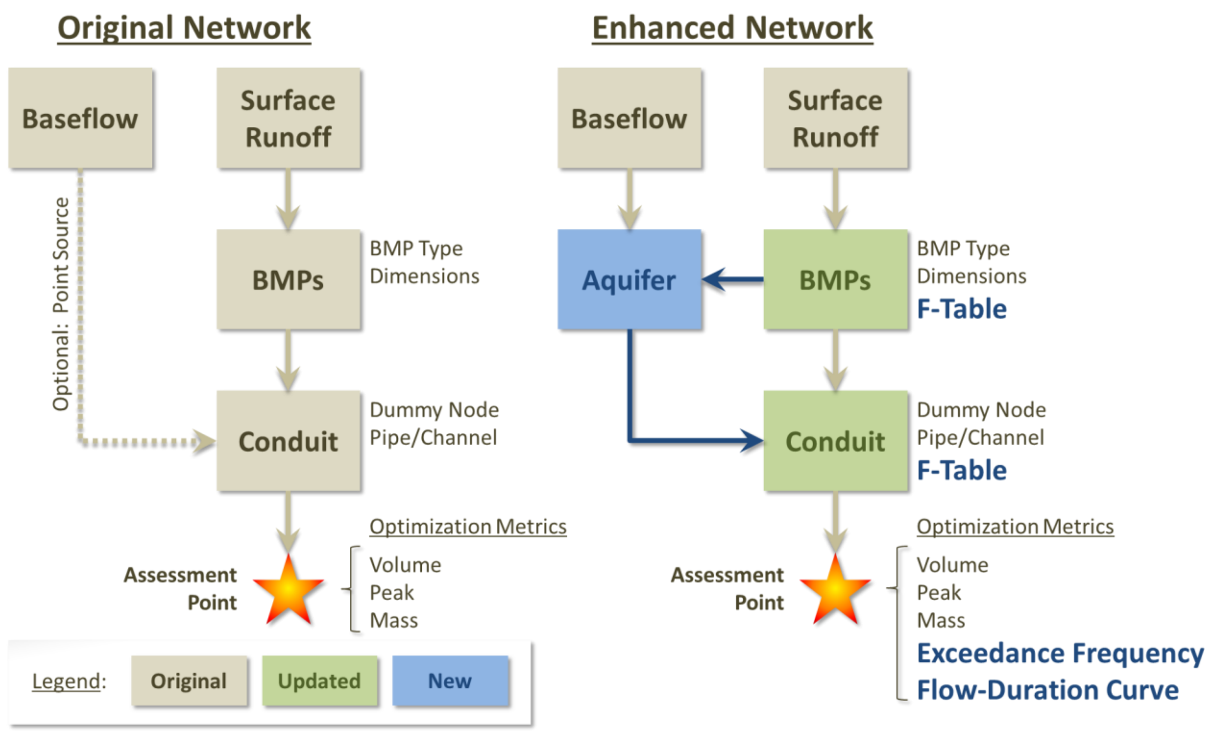


Figure 1-1. Original and enhanced *SUSTAIN* routing network options.

1.3. Overview of *SUSTAIN* Application Process

SUSTAIN is a comprehensive decision support tool with many useful features and functions. Successful and meaningful application largely depends on first establishing a representative baseline from which to measure change, selecting a simulation time period that is reflective of critical conditions of interest, and finding and using the best, locally relevant supporting information available for characterizing the watershed, BMP design, performance, and cost. The *SUSTAIN* application process is iterative and adaptive, meaning that once the *SUSTAIN* modeling framework is established, it is designed to be adapted to answer various management questions and for testing the modeler's underlying assumptions. As previously shown in Table 1-2 and Table 1-3, each of the grantees applied *SUSTAIN* to evaluate different management objectives with differing degrees of complexity and sophistication. Although there is no single regiment that works for all situations, it takes some practice to learn how to formulate problems to address management needs. This report highlights some of the key modeling considerations.

Figure 1-2 is a conceptual flowchart of the *SUSTAIN* application process; illustrating how the starting point must be to address the two formative drivers that frame a typical *SUSTAIN* application. The first driver is the set of management questions to be addressed. Thoughtfully outlining the management questions is essential to the development of a representative model application and selection of the appropriate level of complexity, processes to be simulated, and required testing and analysis. For example, because local standards are flow-duration based, the model needed to be able to track surface and baseflow water movement at a watershed scale. The second driver is translating the management questions into numeric objectives that are used for optimization. These two formative drivers inform all subsequent decisions regarding the model setup including data, complexity, and interpretation of results. For example, the updated model needs to optimize BMPs based on maximizing the goodness-of-fit between developed-condition-with-BMPs and predeveloped-condition FDCs. As shown, data or process deficiencies drive both future information gathering and model refinements.

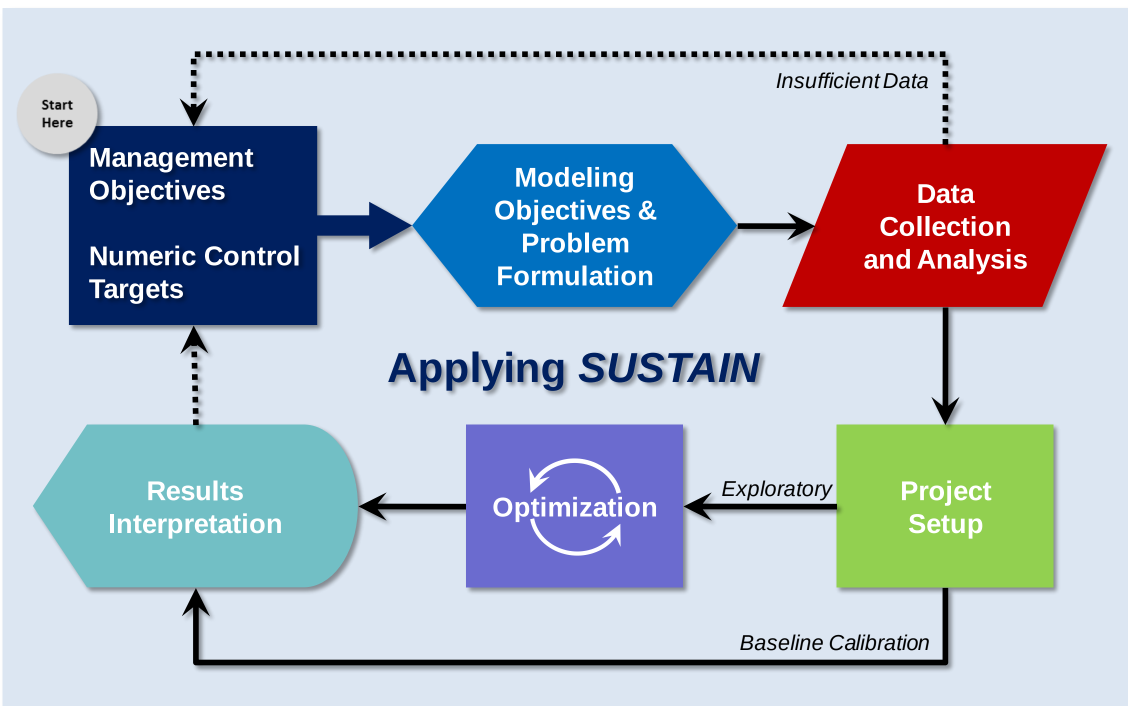


Figure 1-2. *SUSTAIN* application sequence, beginning in the upper left corner.

Identifying BMP opportunities is an important step in the process for which much attention should be paid. In the context of an optimization model, that range of opportunity should include as many variables (i.e. feasible management alternatives) as possible that need to be tested, so as not to bias the decision space toward a particular set of actions. For larger scale evaluations, some degree of simplification may become important in order to efficiently run optimization. The aggregate BMP concept and utility provided in *SUSTAIN* has been shown to be a viable and useful technique for evaluating GI practices networked across a large area (Shoemaker 2009; Shoemaker 2012). In the context of flow-duration based analyses, insight on how infiltrated stormwater is recharged to streams is also helpful in parameterizing the collective response at the watershed scale. When the aggregate BMP tools are used, it is a good idea to also perform sensitivity tests to assess the impact of different degrees of aggregation on model prediction to ensure reasonable predictive accuracy. Previous sensitivity analysis showed that aggregation within approximately 100 acres will not have significant impact on modeled hydrograph and pollutograph when *SUSTAIN* is run at an hourly timestep (Shoemaker 2009). Further aggregation to a larger scale might be feasible depending upon the drainage network characteristics and site topography, but as with any modeling exercise, site specific sensitivity tests are always recommended.

Notice that Figure 1-2 shows two *feedback* loops, further emphasizing the fact that a *SUSTAIN* application is an iterative and adaptive process. If and when new information becomes available that better characterizes the baseline or critical conditions, model setup can be updated to incorporate that new information. Moreover, if new management questions arise through that process, or if the results provide new insights into the management options, new formulations can be tested.

Chapter 2. Application Exercises

This chapter includes a series of step-by-step exercises to illustrate the basic steps and procedures for developing *SUSTAIN* model applications—each exercise builds upon the previous exercise. Whenever applicable, the exercises highlight the relevant features that were added to *SUSTAIN* specifically for Puget Sound applications. Figure 2-1 is a schematic showing the build-up of concepts associated with each successive exercise. These exercises were refined from materials presented at two training workshops conducted for Puget Sound grantees. When used in conjunction with the associated computer files and model installation, they can serve as helpful step-by-step training materials for learning different aspects of *SUSTAIN*, especially for learning how to use *SUSTAIN* independently of ArcGIS.

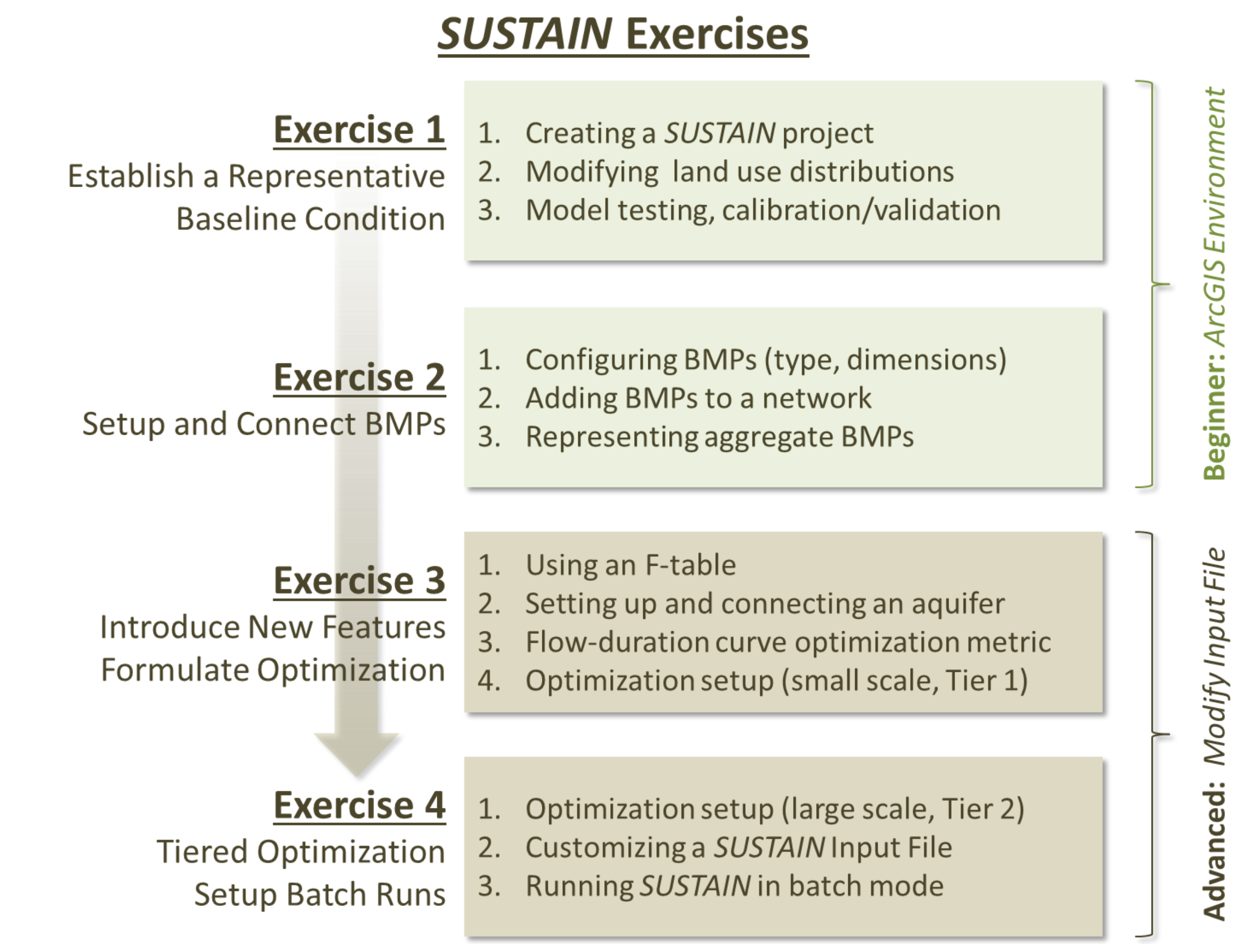


Figure 2-1. Overview and sequence of *SUSTAIN* exercises.

This document should be used in conjunction with other previously prepared *SUSTAIN* documents to have a complete understanding of the model's operational procedures and its application implications. Table 2-1 summarizes the previously available documents and how they supplement the use of this application guide. This application guide presumes that the reader has a general understanding of watershed modeling (e.g. HSPF, SWMM, and the like), and also has a basic knowledge of *SUSTAIN*. The reader should refer to the previous documents (listed in Table 2-1) for more background information.

Table 2-1 *SUSTAIN* Documents Summary

Document Name	Reference	Remarks
SUSTAIN—A Framework for Placement of Best Management Practices in Urban Watersheds to Protect Water Quality (Shoemaker, et. al., 2009)	EPA's *SUSTAIN* website, EPA/600/R-09/095	It can be used as a technical guide. It is the first EPA published *SUSTAIN* report, it summarizes the rationale of this model, and the model's technical information.
Report on Enhanced Framework (*SUSTAIN*) and Field Applications to Placement of BMPs in Urban Watersheds (Shoemaker, et. al., 2012)	EPA's *SUSTAIN* website, EPA/600/R-11/144	It can be used as an application reference guide. It documents the application process from start to finish, including problem formation, modeling procedure, and results interpretation. The application focused on CSOs.
Stormwater Management for TMDLs in an Arid Climate: A Case Study Application of *SUSTAIN* in Albuquerque, New Mexico (Shoemaker, et. al., 2013)	EPA's *SUSTAIN* website, EPA/600/R-13/004	It can also be used as an application reference guide. This application focused addressing water quality issues in arid climate.
SUSTAIN Step-by-Step Application Guide Version 1.2 for ArcGIS 9.3.1 Service Pack2	EPA's *SUSTAIN* website, *SUSTAIN* version 1.2 installation package	It can be used as an operation guide for beginner level users.
SUSTAIN Training Materials – Exercise A and Exercise B	EPA's *SUSTAIN* website, *SUSTAIN* version 1.2 installation package	It can be used in conjunction with the Step-by-Step Application Guide to further learn how to setup a *SUSTAIN* model.

For a typical *SUSTAIN* application that uses boundary conditions from an existing watershed model, required data sets include:

- Unit area surface runoff and pollutant (optional) timeseries for each representative land use or hydrologic response unit (HRU)
- Evapotranspiration boundary condition (constant or monthly rates, timeseries, or air temperature timeseries for internal calculation)
- BMP design specifications
- Information about background soil conditions or infiltration rates for BMP simulation
- Land use or HRU distribution raster (required for using ArcGIS setup)
- Conveyance network information of sufficient detail to represent the network in the *SUSTAIN* model environment.

The data used for these exercises were graciously provided by King County, with the exception of some of the hypothetical conveyance conduits that were represented as dummy nodes (i.e. inflow = outflow, without transport simulation) to streamline the network. At the time this application guide was written only the King County model datasets were finalized. In addition, King County's modeling objectives were the main drivers for model enhancement (as previously shown in Table 1-2); However, these exercises were derived from and encapsulate the work of all Region 10 grantees using *SUSTAIN*. Together with this document, an installation package that includes the *SUSTAIN* software (version 1.2) GIS version, command line executable, and the data package used in the exercises is available. The system requirements for the *SUSTAIN* software are:

- GIS *SUSTAIN* version 1.2 and the *SUSTAIN* Post-processor have been tested and perform on Windows XP, service pack 3 using ArcGIS 9.3.1 and Microsoft Office 2003 or newer.
- GIS *SUSTAIN* version 1.2 can be used for data set development and input file compilation on ArcGIS 9.3.1 in a Windows 7 environment under XP compatibility mode. The *SUSTAIN* post-processor can be used in Excel 2010 in macro-enabled mode.
- The Non-GIS *SUSTAIN* version 1.2 command line executable has been tested and shown to perform as expected in a Windows XP and Windows 7 environment. It requires Microsoft.NET Framework version 4 installed that can be downloaded from the Microsoft website free of cost.

All exercises included in this document were executed using *SUSTAIN* version1.2. The *SUSTAIN* input files for non-GIS exercises are included in Appendix A for reference purposes.

2.1. Exercise 1 – Establish a Baseline Condition

Establishing a baseline condition using *SUSTAIN* involves developing unit area land use flow and water quality timeseries and establishing the routing network for the study area. This exercise demonstrates the work flow to establish a baseline condition for a *SUSTAIN* application. The case shown here is part of the King County project to develop a stormwater retrofit plan for WRIA9 (King County 2013a).

Highlights:

- Setting up a *SUSTAIN* baseline model
- Verifying a *SUSTAIN* baseline model

2.1.1. *Exercise Overview*

King County was awarded a grant by Region 10 of the EPA to develop a stormwater retrofit plan for WRIA 9. The goal of this grant-funded study was to develop a cost estimate and prioritization plan for systematically implementing stormwater BMPs and LID techniques in previously developed areas of WRIA 9. *SUSTAIN* was used to perform BMP prioritization and optimization which supported a management plan to meet in-stream goals at the minimum cost. The overall study area (Figure 2-2) includes the Green/Duwamish River and central Puget Sound watersheds in WRIA 9.

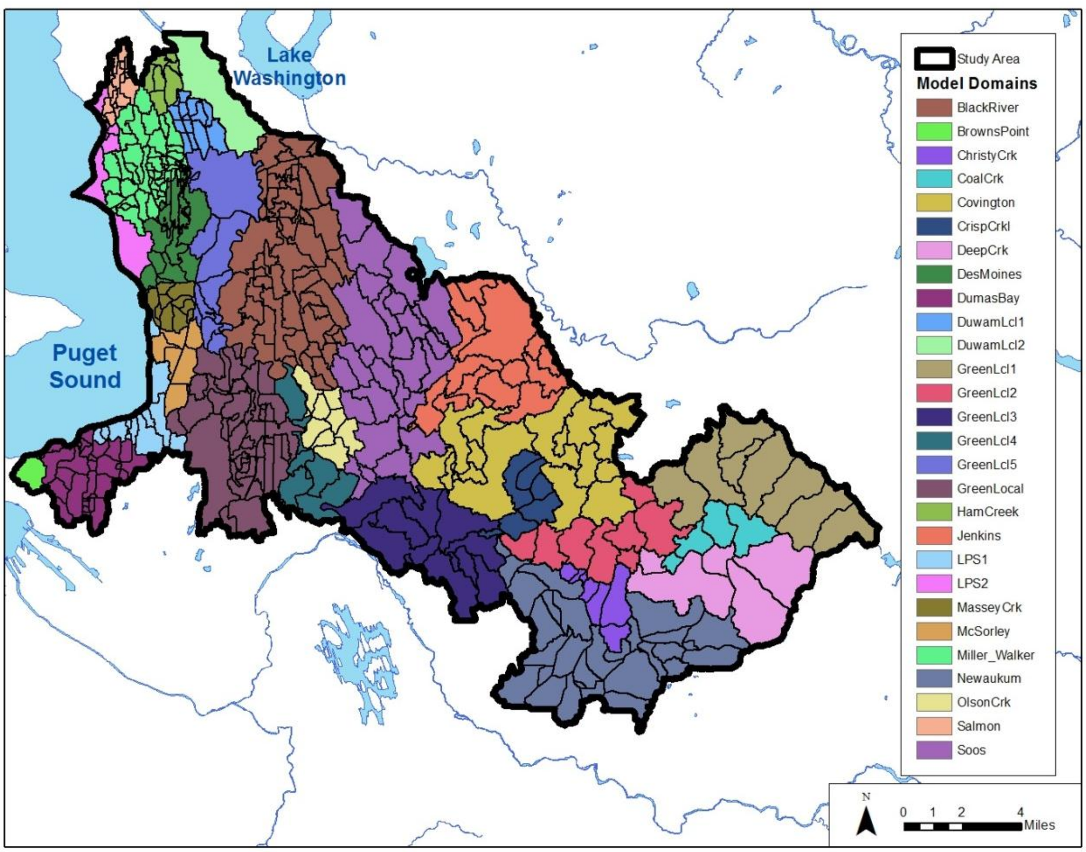


Figure 2-2. WRIA 9 watershed area represented in the baseline HSPF model (Source: King County, 2013b).

The watershed model selected to develop the unit area land use flow and water quality timeseries was HSPF. This model has been used by King County as a stormwater and basin planning tool since the late 1980s. Most of the HSPF models for WRIA 9 were previously developed as part of earlier watershed hydrologic and water quality studies. These models were updated using 2007 land cover data and calibrated using additional data (flow and total suspended solids [TSS]) collected since the previous studies were conducted.

The area modeled using HSPF covers 278 square miles of the middle and lower Green River watershed below Howard Hanson Dam and the Puget Sound drainages of WRIA 9. The established HSPF model was calibrated using standard watershed model calibration metrics (e.g., comparison of modeled to observed mean daily flow) and evaluated for its ability to predict particular hydrologic metrics selected for use in retrofit goal setting. King County (2013a) describes the selection of hydrologic metrics for use in this study, which include High Pulse Count (HPC), High Pulse Range (HPR), and the ratio of the 2-year peak return flow to the winter baseflow (PEAK:BASE). King County (2013a) also documents the detailed model calibration process. The urban sub-basin of Newaukum Creek (approximately 270 acres) was selected for the *SUSTAIN* pilot study (Figure 2-3). The purpose of the pilot study was to confirm that *SUSTAIN* could be applied to model a regionally representative BMP treatment train. The *SUSTAIN* application presented herein was prepared by Curtis DeGasperi of King County.

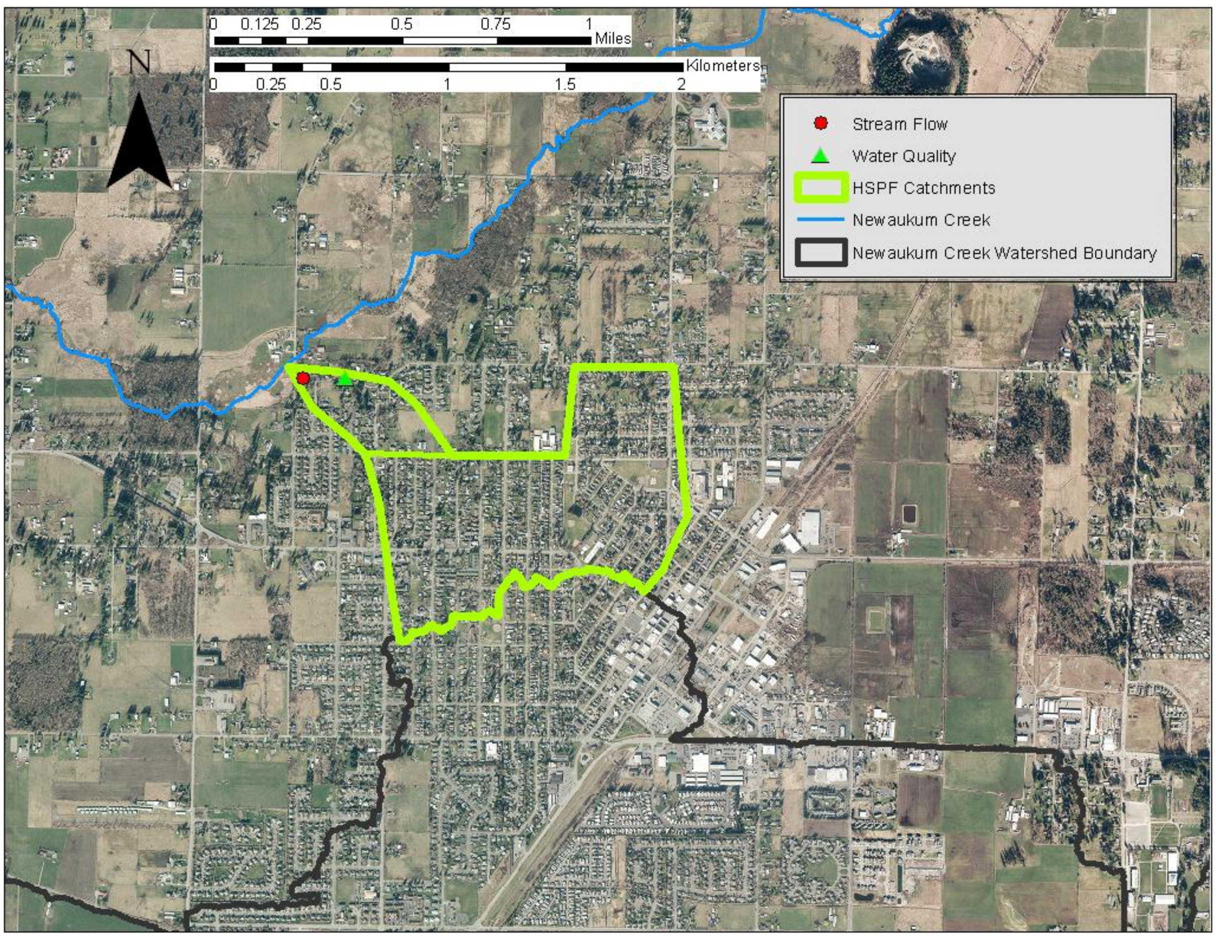


Figure 2-3. Map showing the King County urban Newaukum Creek sub-basin (Source: King County, 2013a).

The pilot study area was represented by two adjacent catchments. The HSPF model included a routed flow channel to nominally represent the creek that routes flow between the catchments. However, the stormwater drainage system was not explicitly represented in HSPF because the drainage system was modeled implicitly through subbasin flow routing. The same area was represented in *SUSTAIN* with a dummy conduit routing the flow from the upstream catchment to the outlet of the downstream catchment to simulate the creek from HSPF (Figure 2-4). The *SUSTAIN* model output was compared with the HSPF model output to confirm that the translation from HSPF to *SUSTAIN* mimicked the HSPF output.

Hourly timeseries for flow (in cubic feet per second) and total suspended solids (TSS in pounds per hour) from eight HRUs in HSPF were formatted for input into a *SUSTAIN* model for the pilot area. The HRUs and associated areas represented in the HSPF and *SUSTAIN* models are provided in Table 2-2. The simulation time period for this exercise was shortened to eleven years (October 1, 1998 – September 30, 2009) to save run time for this exercise, although the actual King County study used a 61-year simulation time period (October 1, 1948 – September 30, 2009).

Once the unit area land use flow and water quality timeseries are developed, the next step for establishing the baseline condition is to set up the routing network in *SUSTAIN*, and then confirm that the *SUSTAIN* model output at the designated assessment point matches with the calibrated HSPF watershed model output.

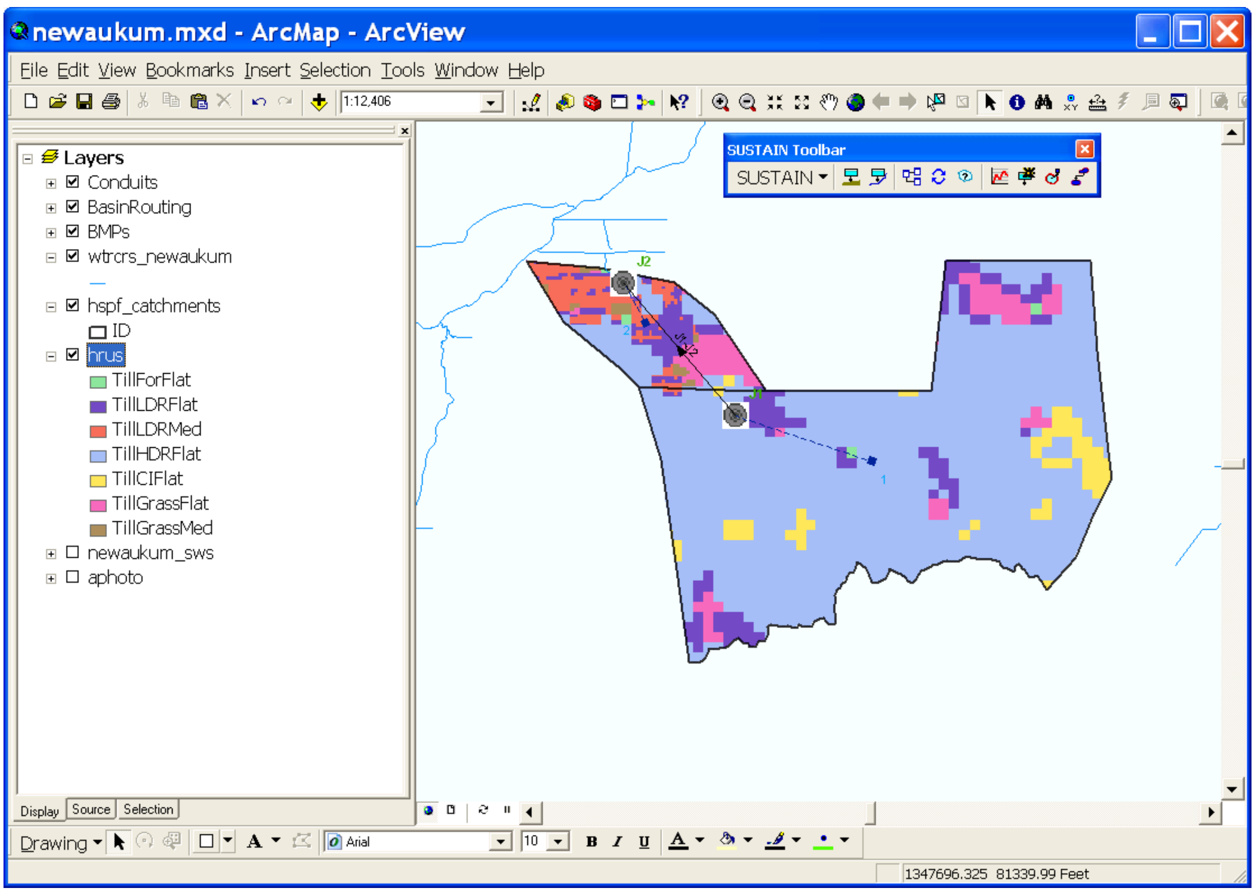


Figure 2-4. *SUSTAIN* Newaukum sub-basin model setup.

Table 2-2 HRUs represented in the HSPF and *SUSTAIN* models

HRU	Area (acres)
Forest	0.89
Low Density Residential [a]	1.30
Medium-High Density Residential [a]	35.27
Commercial-Industrial [a]	5.53
Roads [a]	13.48
Till Commercial-Industrial	13.65
Till Medium-High Density Residential	154.55
Till Low Density Residential	42.93

a. Includes HSPF modeled *effective* impervious area.

2.1.2. *Step-by-Step Instructions*

This section documents the steps for setting up a new *SUSTAIN* project to represent a baseline condition.

1. Setup a New GIS Project
2. Define Project Data
3. Load and Define the Data Layers
4. Choose Land Simulation Option
5. Define Pollutants
6. Assign External Land Use Timeseries
7. Delineate Drainage Area
8. Setup Routing Network
9. Define Assessment Point
10. Create Input File

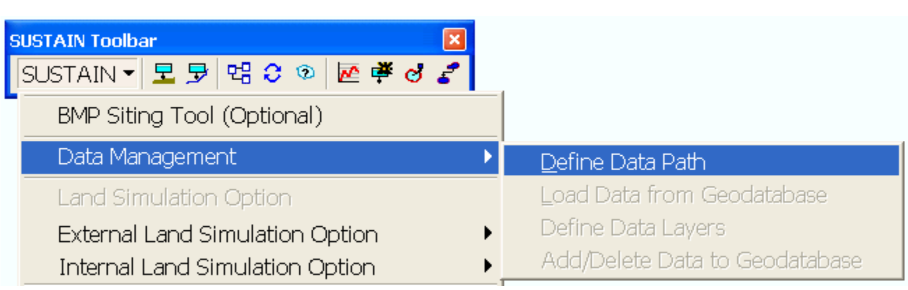
Setup *SUSTAIN* Model / Create *SUSTAIN* Input File

1. <u>Setup a New GIS Project</u>

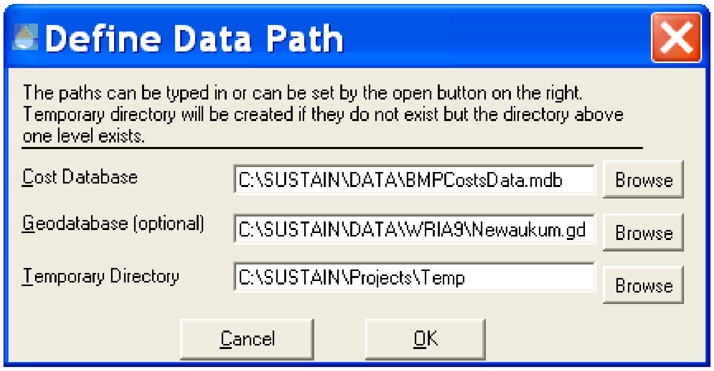
Open ArcMap version 9.3.1 and give your project a name by saving it on your local hard drive. It is not recommended to save your project on a network drive. In this exercise a project folder named **Projects** was created under the *SUSTAIN* installation folder path **C:\SUSTAIN**. The ArcMap project was named as **newaukum.mxd** and was saved under the **Projects** folder.

2. <u>Define Project Data</u>

From the *SUSTAIN* Toolbar, under the Data Management menu, click the **Define Data Path** as shown below.



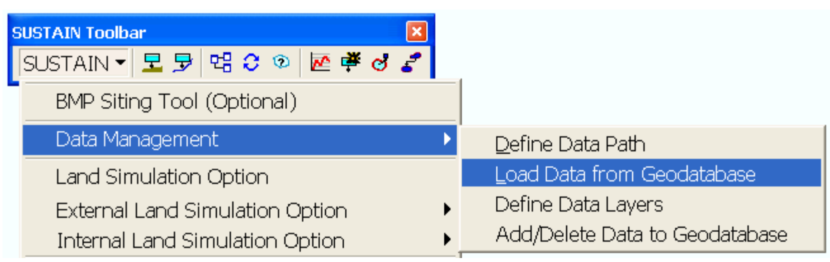
Define the data paths as shown below.



In this exercise the BMP cost database (**BMPCostsData.mdb**) is taken from the *SUSTAIN* installation package; however a Puget Sound regional cost database has been developed (Herrera 2013) and was used in the actual WRIA9 study. For documentation on creating or modifying a cost database, please see **SUSTAIN_BMPCostDatabase.pdf**, which is located in the **DATA** folder. GIS data are stored in a geodatabase file named **Newaukum.gdb** which is placed in the **WRIA9** folder included in the *SUSTAIN* installation package. (Note: exercise 3 and 4 in this document will describe how to generate a model using the non-GIS version of *SUSTAIN*). A temporary folder named **Temp** was created under the **Projects** folder to store the intermediate GIS data created and used by the *SUSTAIN* interface. Notice that the *SUSTAIN* application requires that folder names and file paths must not contain any spaces.

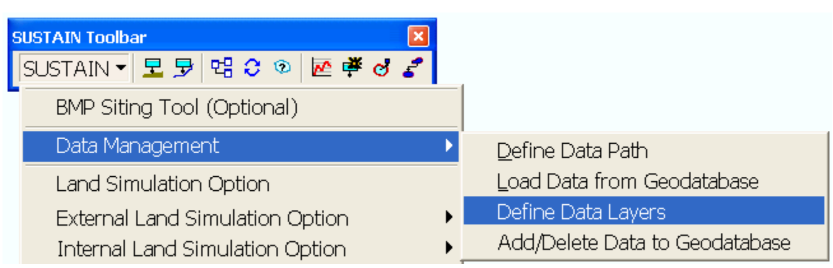
3. <u>Load and Define the Data Layers</u>

From the *SUSTAIN* Toolbar, under the Data Management menu, click **Load Data from Geodatabase** as shown below.

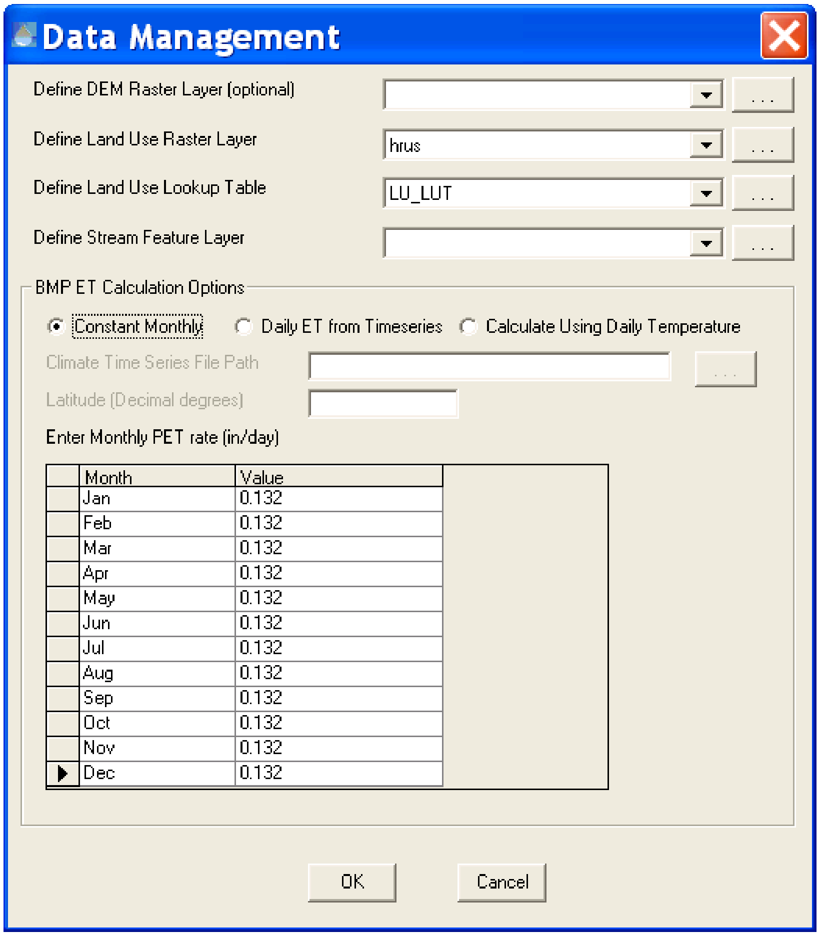


Notice that if the GIS data are not stored in a geodatabase file you can also add the data in your ArcMap project by using the standard **Add** data option available on the ArcMap menu. The *SUSTAIN* application requires all the GIS layers used in the project to be in the same projected coordinate system.

From the *SUSTAIN* Toolbar, under the Data Management menu, click **Define Data Layers** as shown below.



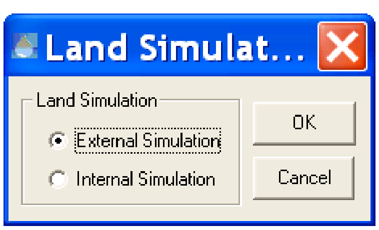
On the Data Management menu, use the drop-down list to select the appropriate data for each item. Minimum required data include a land use raster layer and land use lookup table. For this exercise, use **hrus** as the land use raster and **LU_LUT** for the land use lookup table.



Notice that the land use lookup table is the mapping table for the land use classification describing each land use raster value. Reviewing the **SUSTAIN_DataNeeds.pdf** document (part of the *SUSTAIN* installation package) is highly recommended to fully understand the required data format used in *SUSTAIN* applications.

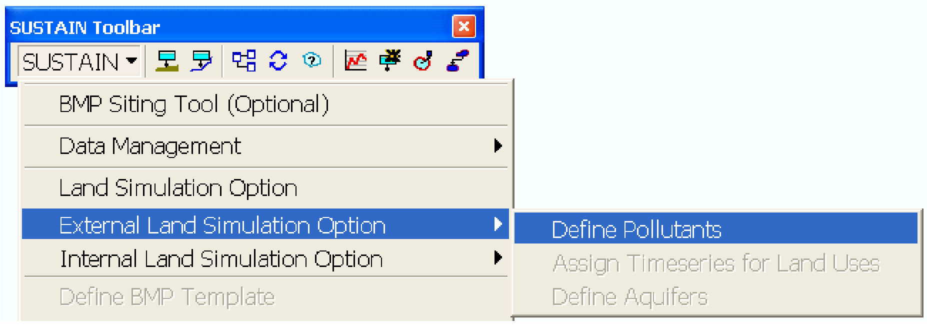
4. <u>Choose Land Simulation Option</u>

This project uses externally generated land use timeseries representing runoff and pollutant load derived from the King County HSPF model. On the *SUSTAIN* Menu, click **Land Simulation Option**, then select **External Simulation**, and click **OK**.



5. *Define Pollutants*

For this external land use simulation, we define a single pollutant, TSS, which corresponds to the hourly runoff and loading timeseries files generated in HSPF. On the *SUSTAIN* Menu, under the **External Land Simulation Option**, click **Define Pollutant** as shown below.



To add a pollutant to the Define Pollutants dialog box:

a) Click **Add**

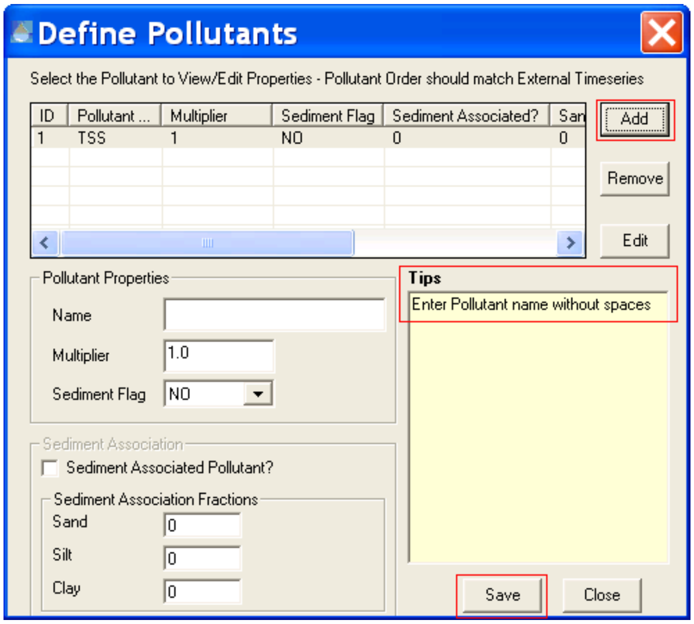
b) Set the Name = TSS

c) Set the Multiplier = 1 since sediment is presented as pounds in the timeseries

d) Set the Sediment Flag = NO

e) Click Save, and then Close

Notice that *SUSTAIN* requires the pollutant load to be in pounds. The **Multiplier** parameter is used as a factor to convert the pollutant load provided in the external timeseries file into pounds. In this exercise the sediment load in the external timeseries is already in pounds, hence the **Multiplier** is defined as 1. The sediment flag selected is **No** because TSS is not simulated as "sediment" for this study (a **Yes** flag would require the user to specify additional information such as deposition and resuspension parameters for sediment transport). Choosing **No** eliminates the need for further defining sediment-related information. In this exercise sediment is simulated as a generic water quality constituent and a first order decay rate is used to calculate the sediment loss. If sediment is the primary pollutant of concern, and representing transport dynamics is desired, then it is recommended that the sediment flag be selected as **SEDIMENT**. You would then also have to add information related to the sediment fractions (i.e., sand/silt/clay) in addition to transport parameters for each particle size class. Further calibration of the sediment related parameters would also be needed *after* the hydrology calibration to establish a representative baseline condition.

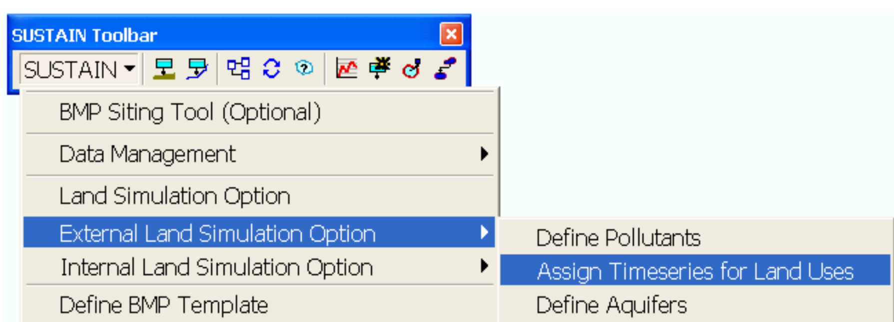


Pollutant Definition

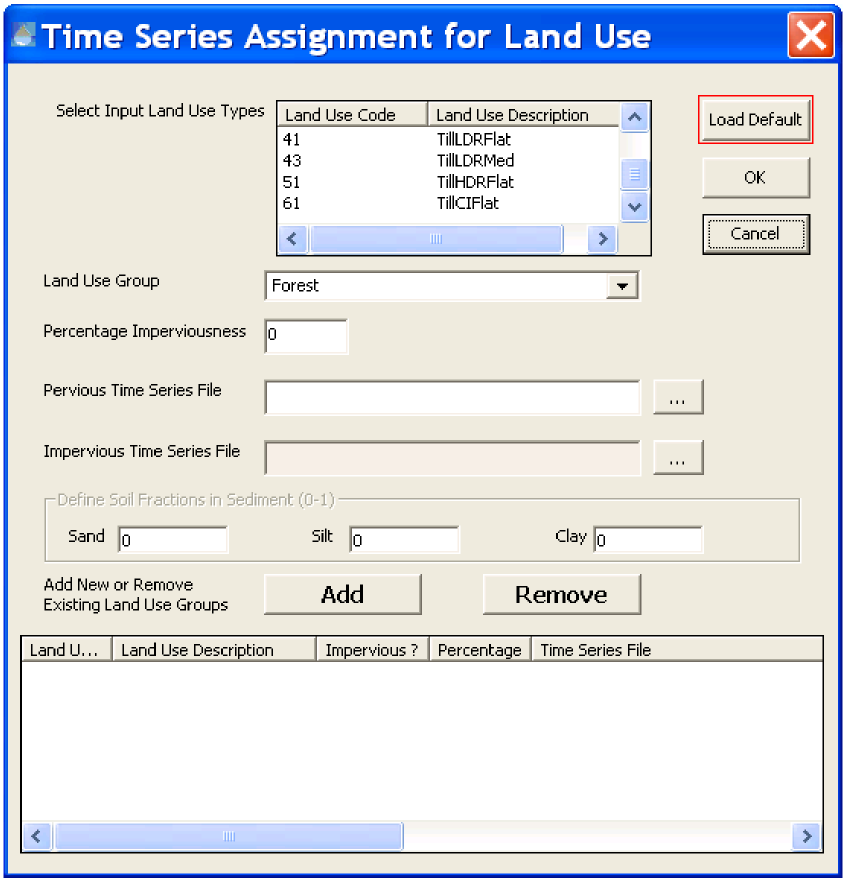
The *SUSTAIN* application requires at least one pollutant to set up the project. If your study objective is not related to water quality add a dummy pollutant as a place holder and select default parameters for the pollutant.

6. *Assign External Land Use Timeseries*

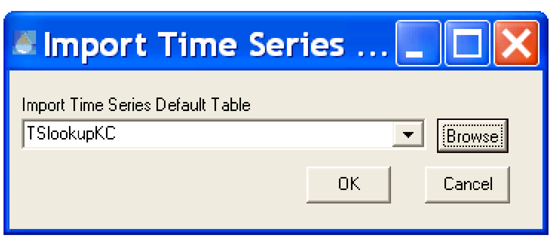
Assign the external land use timeseries to each land use type represented by the land use raster. Click on **External Land Simulation Option**, then **Assign Timeseries for Land Uses** as shown below.



On the **Assign Timeseries for Land Use** window, the user can choose to (1) assign the timeseries manually by selecting one or multiple land use categories and specifying a land use group name, impervious percentage, and corresponding timeseries file; or (2) use a timeseries assignment lookup table. When manually assigning the timeseries (option 1), a land use category can only be assigned a maximum of two timeseries (e.g., pervious and impervious). If more than two subcategories are needed (e.g. pervious, roof, road, and parking) for a single land use provided in the raster, then the second option must be used. The King County HRU raster does not include explicitly represented impervious areas but does contain two impervious area categories (i.e., road and other impervious) that have corresponding timeseries files, therefore the timeseries assignment lookup table approach is used (option 2).



By clicking the **Load Default** button in the **Assign Timeseries for Land Use** window, you will be asked to define the timeseries lookup table (located in **WRIA9** folder) as shown below.

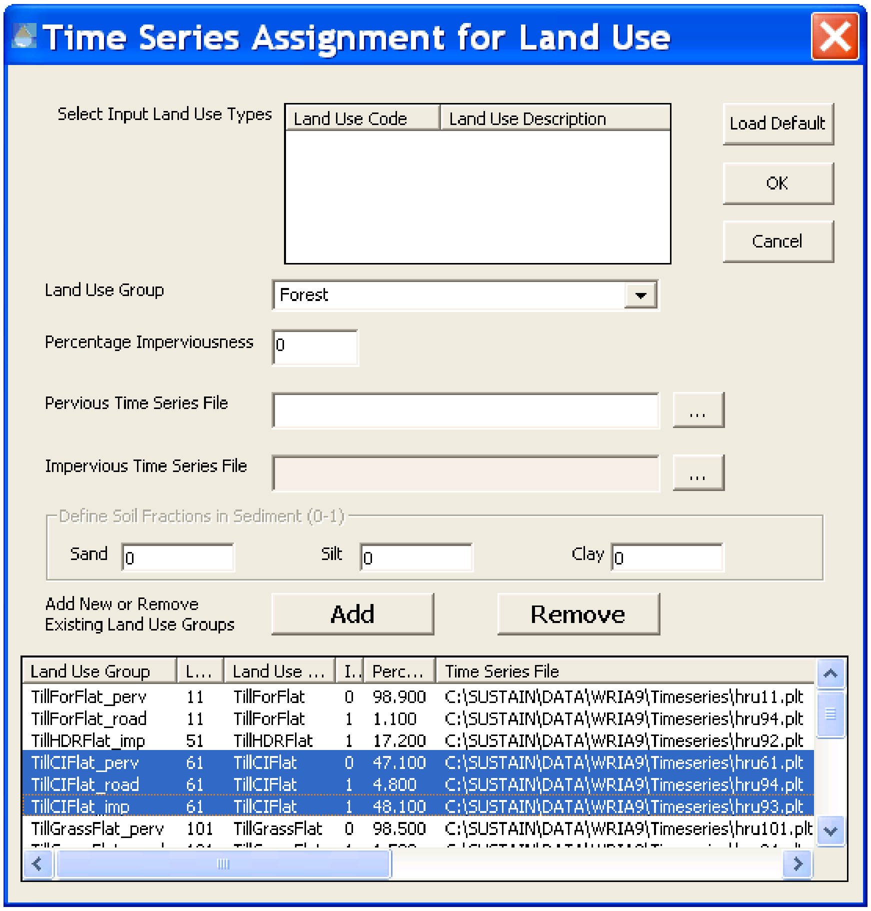


After you select the lookup table, the **Assign Timeseries for Land Use** window will automatically populate the timeseries assignment defined in the lookup table as shown next.

Land Use Distribution Assignment Options

Option 1: Only two timeseries can be assigned for any given land use category (e.g. pervious and impervious).

Option 2: A lookup is used to assign more than two timeseries for any given land use category (e.g., pervious, impervious rooftop, impervious road).



Note that the land use code 61 has three HRU timeseries allocated for a single land use category. The *SUSTAIN* application requires that the file path given in the timeseries lookup table be valid and not have any space.

The pervious and impervious area percentages for each land use category contained in the King County HRU raster are shown in Table 2-3.

Table 2-3 Pervious and impervious area distribution of King County HRU raster

LUCODE	Description	Pervious Area (%) (Timeseries File)	Road Area (%) (Timeseries File)	Other Impervious (%) (Timeseries File)
11	Forest, Low	98.9% (hru11.plt)	1.1% (hru94.plt)	
41	Light Urban, Low	92.5% (hru41.plt)	3.7% (hru94.plt)	3.8% (hru91.plt)
43	Light Urban, Medium	92.5% (hru43.plt)	3.7% (hru94.plt)	3.8% (hru91.plt)
51	Medium Urban	77.2% (hru51.plt)	5.6% (hru94.plt)	17.2% (hru92.plt)
61	Heavy Urban (Commercial/Industrial)	47.1% (hru61.plt)	4.8% (hru94.plt)	48.1% (hru93.plt)
101	Grassland, Low	98.5% (hru101.plt)	1.5% (hru94.plt)	
103	Grassland, Medium	98.5% (hru103.plt)	1.5% (hru94.plt)	

Table 2-4 lists the HRU timeseries file name and corresponding descriptions.

Table 2-4 King County HRU timeseries file description

HRU Timeseries File Name	Description
hru11.plt	Pervious, Forest, Low
hru41.plt	Pervious, Light Urban, Low
hru43.plt	Pervious, Light Urban, Medium
hru51.plt	Pervious, Medium Urban
hru61.plt	Pervious, Heavy Urban (Commercial/Industrial)
hru101.plt	Pervious, Grassland, Low
hru103.plt	Pervious, Grassland, Medium
hru91.plt	Impervious, Low
hru92.plt	Impervious Medium
hru93.plt	Impervious, High
hru94.plt	Impervious, Road

The user needs to create a timeseries assignment lookup table by combining the above information. The function of the lookup table is to assign various timeseries files to fractions of a land use category, which is identified by a unique LUCODE. The King County timeseries lookup table **TSLookupKC.dbf** is illustrated below. The lookup table needs to have the following fields, as shown below: LUGROUPID, LUGROUP, LUCODE, IMPERVIOUS, LUDESCRIP, PERCENTAGE, TIMESERIES, SANDFRAC, SILTFRAC, and CLAYFRAC.

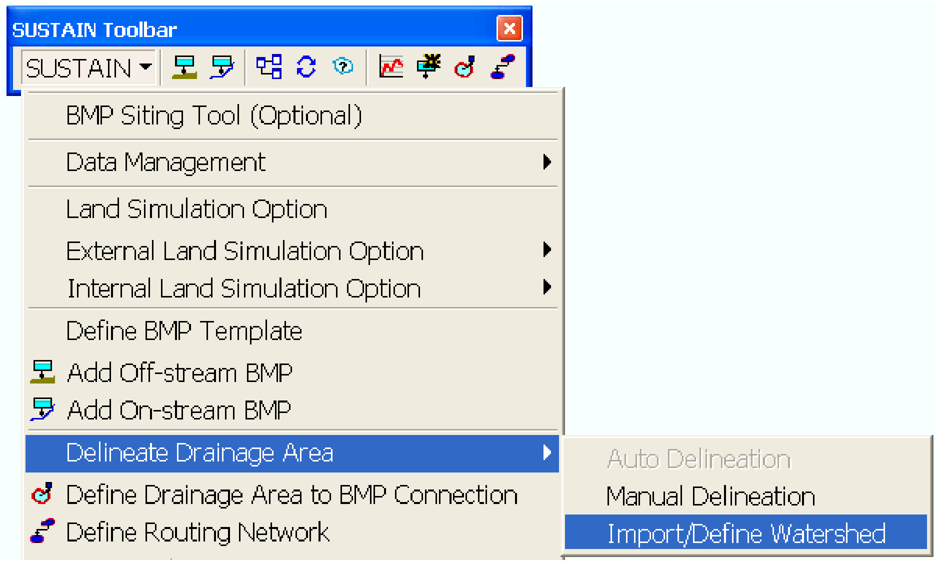
Attributes of TSlookupKC

OID	LUGROUPID	LUGROUP	LUCODE	IMPERVIOUS	LUDESCRIP	PERCENTAGE	TIMESERIES	SANDFRAC	SILTFRAC	CLAYFRAC
0	1	TillForFlat_perv	11	0	TillForFlat	0.989	C:\SUSTAIN\DATA\WRIA9\Timeseries\hru11.plt	0	0	0
1	2	TillForFlat_road	11	1	TillForFlat	0.011	C:\SUSTAIN\DATA\WRIA9\Timeseries\hru94.plt	0	0	0
2	3	TillLDRFlat_perv	41	0	TillLDRFlat	0.925	C:\SUSTAIN\DATA\WRIA9\Timeseries\hru41.plt	0	0	0
3	4	TillLDRFlat_road	41	1	TillLDRFlat	0.037	C:\SUSTAIN\DATA\WRIA9\Timeseries\hru94.plt	0	0	0
4	5	TillLDRFlat_imp	41	1	TillLDRFlat	0.038	C:\SUSTAIN\DATA\WRIA9\Timeseries\hru91.plt	0	0	0
5	6	TillLDRMed_perv	43	0	TillLDRMed	0.925	C:\SUSTAIN\DATA\WRIA9\Timeseries\hru43.plt	0	0	0
6	7	TillLDRMed_road	43	1	TillLDRMed	0.037	C:\SUSTAIN\DATA\WRIA9\Timeseries\hru94.plt	0	0	0
7	8	TillLDRMed_imp	43	1	TillLDRMed	0.038	C:\SUSTAIN\DATA\WRIA9\Timeseries\hru91.plt	0	0	0
8	9	TillHDRFlat_perv	51	0	TillHDRFlat	0.772	C:\SUSTAIN\DATA\WRIA9\Timeseries\hru51.plt	0	0	0
9	10	TillHDRFlat_road	51	1	TillHDRFlat	0.056	C:\SUSTAIN\DATA\WRIA9\Timeseries\hru94.plt	0	0	0
10	11	TillHDRFlat_imp	51	1	TillHDRFlat	0.172	C:\SUSTAIN\DATA\WRIA9\Timeseries\hru92.plt	0	0	0
11	12	TillCIFlat_perv	61	0	TillCIFlat	0.471	C:\SUSTAIN\DATA\WRIA9\Timeseries\hru61.plt	0	0	0
12	13	TillCIFlat_road	61	1	TillCIFlat	0.048	C:\SUSTAIN\DATA\WRIA9\Timeseries\hru94.plt	0	0	0
13	14	TillCIFlat_imp	61	1	TillCIFlat	0.481	C:\SUSTAIN\DATA\WRIA9\Timeseries\hru93.plt	0	0	0
14	15	TillGrassFlat_perv	101	0	TillGrassFlat	0.985	C:\SUSTAIN\DATA\WRIA9\Timeseries\hru101.plt	0	0	0
15	16	TillGrassFlat_road	101	1	TillGrassFlat	0.015	C:\SUSTAIN\DATA\WRIA9\Timeseries\hru94.plt	0	0	0
16	17	TillGrassMed_perv	103	0	TillGrassMed	0.985	C:\SUSTAIN\DATA\WRIA9\Timeseries\hru103.plt	0	0	0
17	18	TillGrassMed_road	103	1	TillGrassMed	0.015	C:\SUSTAIN\DATA\WRIA9\Timeseries\hru94.plt	0	0	0

Record: 1 Show: All Selected Records (0 out of 18 Selected) Options

7. *Delineate Drainage Area*

This option uses an existing watershed boundary layer. On the *SUSTAIN* Toolbar, click **Delineate Drainage Area** and choose **Import/Define Watershed** as shown below.



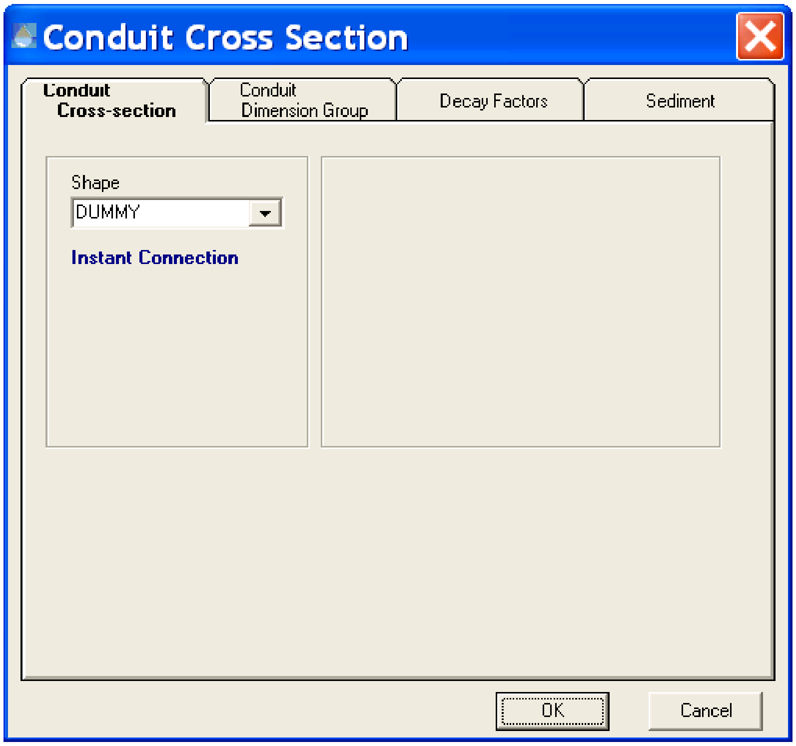
For this exercise **hspf_catchments** was selected as the drainage area boundary (as shown below) which has two sub-basins with a total area of 267 acres.

8. *Setup Routing Network*

In this step, you will place one Junction in each sub-basin (two totals) and establish routing connections. Follow these steps to create the project shown in Figure 2-4.

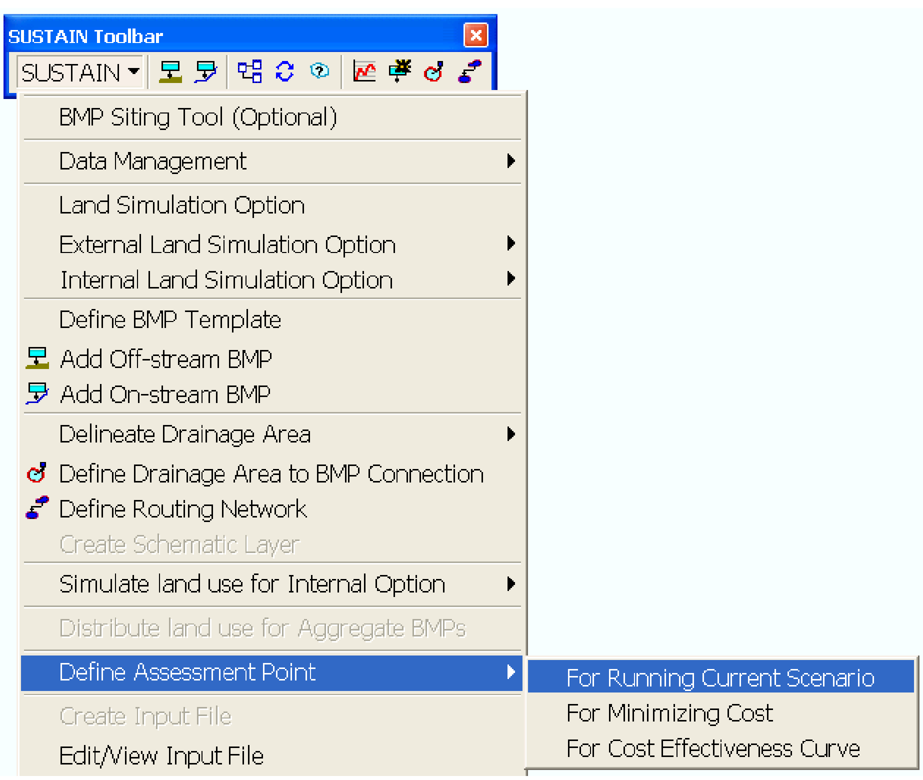
- Place 2 Junctions (one in each sub-basin)
- On the *SUSTAIN* Menu, click **Define Drainage Area to BMP Connection**, or click ( ) on the *SUSTAIN* Toolbar to establish drainage areas to Junction connections
- On the *SUSTAIN* Menu, click **Define Routing Network**, or click ( ) on the *SUSTAIN* Toolbar; draw the routing connection from the upstream Junction to the downstream Junction (use a **Dummy** connection)

Notice that the drainage areas are automatically connected to the Junction located within the drainage area. The connections between drainage areas and Junctions are indicated by dark blue dashed lines. If there are more than one Junction and/or BMP within a drainage area then you have to manually define the watershed-Junction connection. To do so, click the target watershed, drag the line to the target Junction point, and click the Junction point. Similarly using the routing network tool, click on one Junction and drag the line to the downstream Junction, and click the Junction point to define the routing network.

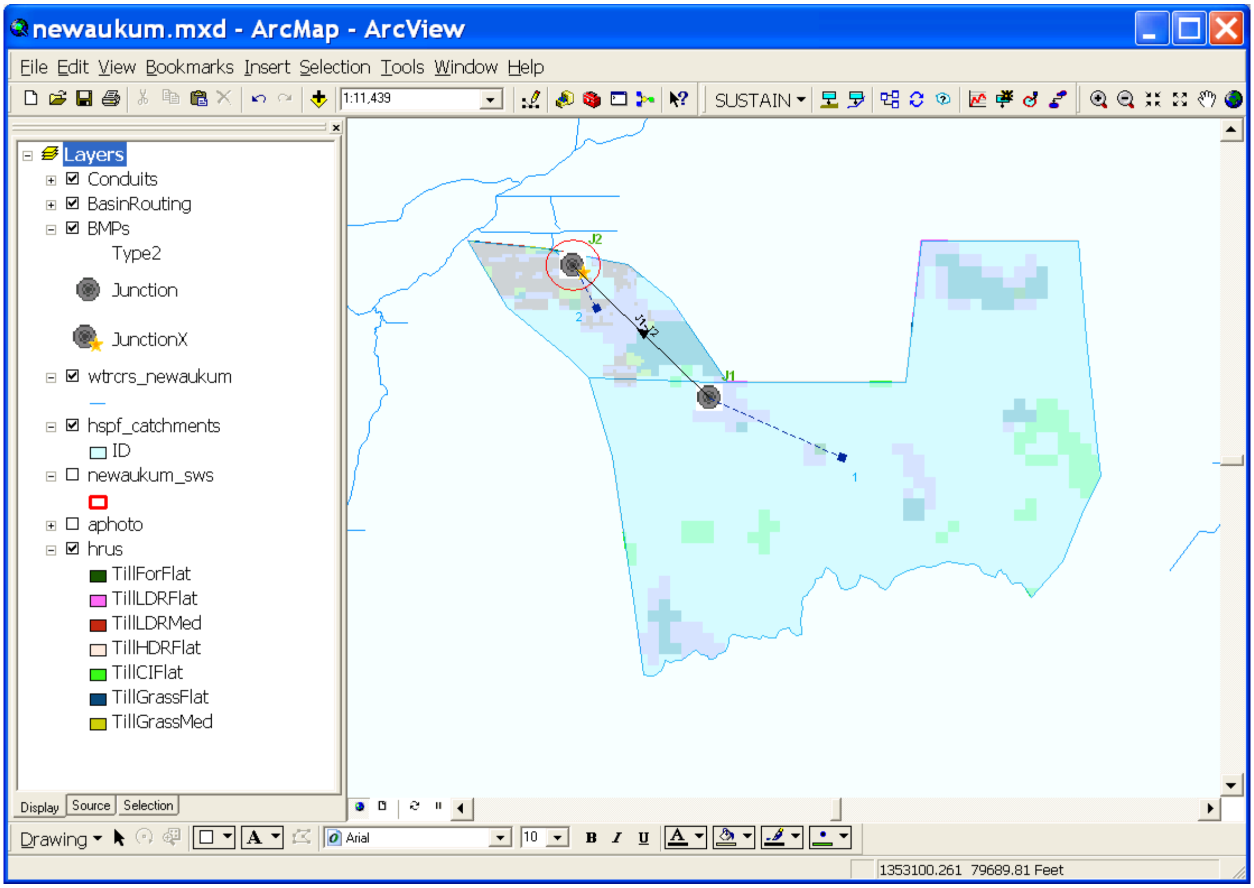


9. Define Assessment Point

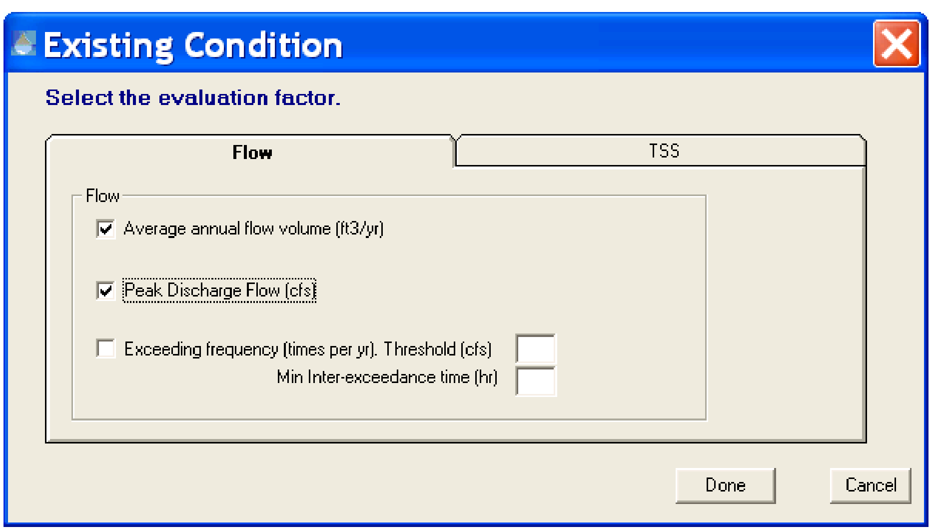
On the *SUSTAIN* Menu, click **Define Assessment Point**, and select **For Running Current Scenario**, as shown below.



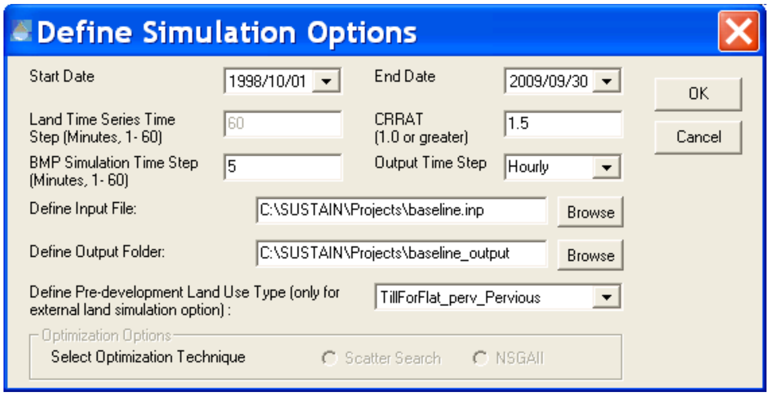
Use the icon ( ) to select the desired point feature. For this exercise, define the downstream Junction as an assessment point as shown next.



Set up the evaluation factors as shown below.



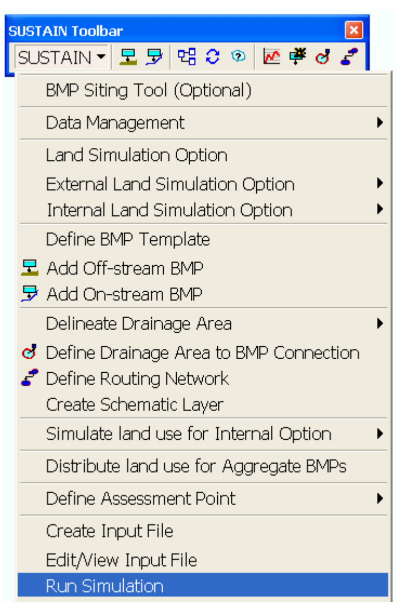
10. <u>Create Input File</u>
On the *SUSTAIN* Menu, click **Create Input File**, and fill in the **Define Simulation Options** form (as shown below).



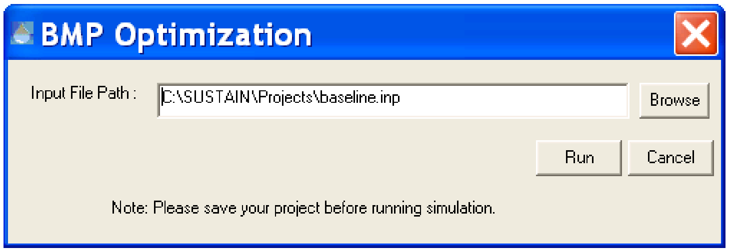
What is CRRAT?
CRRAT is the ratio of the maximum velocity to the mean velocity in the stream channel cross section under typical flow conditions. CRRAT must be ≥1.0, where 1.0 represents completely uniform velocity across the stream channel. If CRRAT is greater than 1.0, then the outflow is assumed to also include water entering the reach during that time interval. In that case, inflow alters the outflow. Given the relatively small scale of *SUSTAIN* applications, using a value of 1.5 better captures the flashiness of the system, especially when using an hourly simulation timestep.

Run *SUSTAIN* Simulation

In this exercise the baseline input file is named **baseline.inp** and the output folder is named **baseline_output**. Once the input file is created successfully, run the baseline scenario by clicking **Run Simulation** on the *SUSTAIN* Menu as shown below.

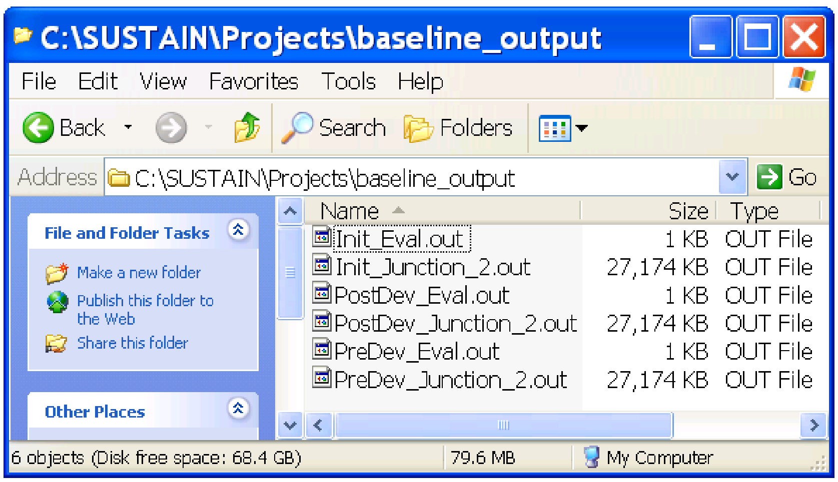


Click on the **Run** button to start the simulation.



Validate *SUSTAIN* Model

The *SUSTAIN* model input file, which contains one dummy conduit (meaning no routing performed), is run using the hourly input HRU timeseries (and a 60 minute timestep). The output files generated in the output folder are shown below.



Under the **Running Current Scenario** mode, the model runs three scenarios, i.e. pre-developed single land use scenario (PreDev), post-developed scenario (PostDev) without BMPs, and existing scenario (Init) with existing BMPs.

The model run generates six files which are described below.

- **PreDev _Eval.out** summarizes the user selected evaluation factors for the **Pre-Development** scenario
- **PreDev _Junction _2.out** is the output timeseries of the user defined assessment point(s) for the **Pre-Development** scenario, in this exercise the assessment point is Junction_2
- **PostDev_Eval.out** summarizes the user selected evaluation factors for the **Post-Development** scenario
- **PostDev _Junction _2.out** is the output timeseries of the user defined assessment point(s) for the **Post-Development** scenario, in this exercise the assessment point is Junction_2
- **Init_Eval.out** summarizes the user selected evaluation factors for the **Existing** scenario
- **Init_Junction _2.out** is the output timeseries of the user defined assessment point(s) for the **Existing** scenario, in this exercise the assessment point is Junction_2

Various Scenarios

Pre-Development: The condition prior to development, it is represented using a single land use timeseries specified as “pre-development land use type”, the most commonly used land use type is forest.

Post-Development: A developed condition without any BMPs.

Existing: A developed condition with existing BMPs, it would be identical to post-development condition if there were no existing BMPs.

Next, we will compare the hourly and daily average output at the outlet of the study area (Junction_2) to the output from the HSPF model representing the flow and TSS load at the outlet of the sub-basin. Table 2-5 shows that the hourly and daily average simulated flow between the two models is the same, but the average TSS load simulated by *SUSTAIN* is slightly lower than HSPF (This is because the HSPF model includes a routing channel in the downstream catchment, which includes an active sediment bed which can serve as either a sink or source of sediment. For comparison, Figure 2-5 through Figure 2-8 present scatter plots showing the hourly and daily average output from the two models.

Note that the tendency for the HSPF model to simulate higher TSS loads is most apparent in Figure 2-6, which compares the simulated daily average TSS loads from the two models. Inspection of Figure 2-8 indicates that the higher TSS loads are simulated by HSPF when TSS loads are highest, which is likely the result of net sediment resuspension from the HSPF channel during the higher flows associated with the greatest sediment export and resuspension. The fact that the HSPF and *SUSTAIN* models generated the same hourly and daily average flow values validated the *SUSTAIN* baseline hydrologic model. Considering that the objective of this study focuses on flow, the difference in simulated TSS load is not a concern in this case. However, if the study objective were related to TSS, a conduit would need to be added in the *SUSTAIN* model to better simulate sediment transport.

Table 2-5. Comparison of simulation results from HSPF and *SUSTAIN*

	Hourly Average		Daily Average	
	Flow	TSS	Flow	TSS
Model	cfs	lb/hr	Cfs	lb/day
HSPF	0.94	3.84	0.94	92.2
SUSTAIN	0.94	3.63	0.94	87.1

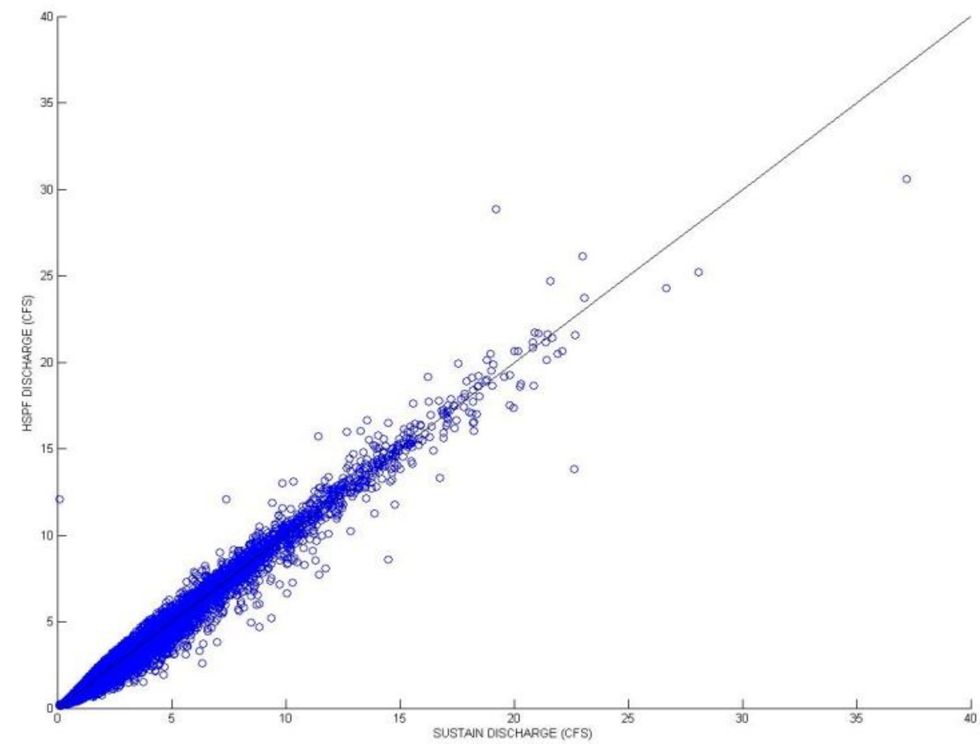


Figure 2-5. Scatter plot of hourly discharge from Newaukum_urban basin (Oct 1998-Sep 2009).

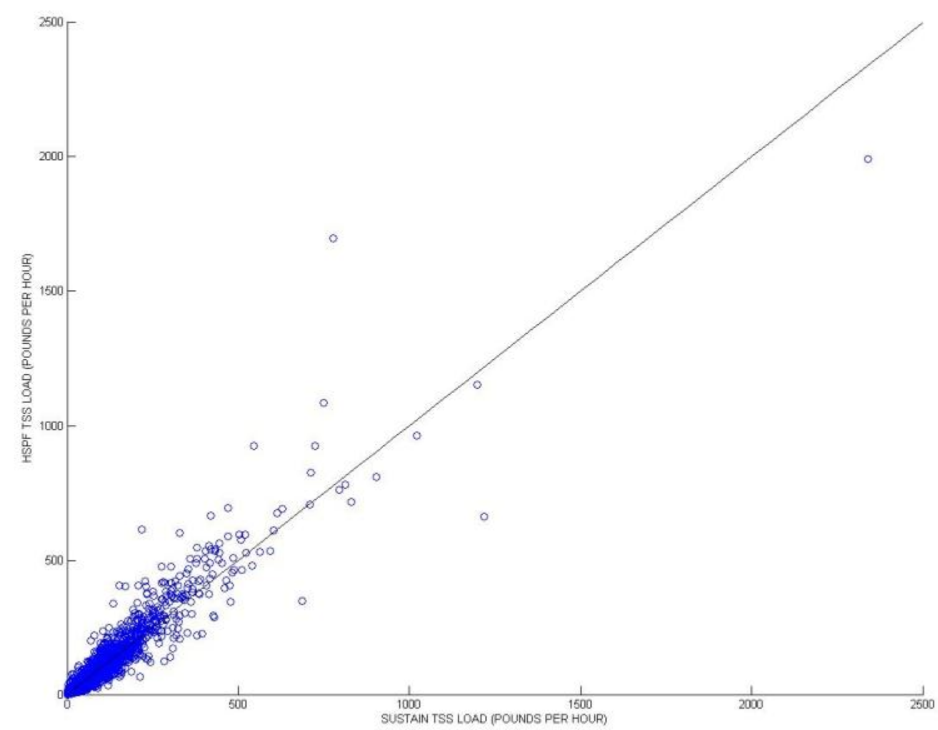


Figure 2-6. Scatter plot of hourly TSS load (lbs/hr) from Newaukum_urban basin (Oct 1998-Sep 2009).

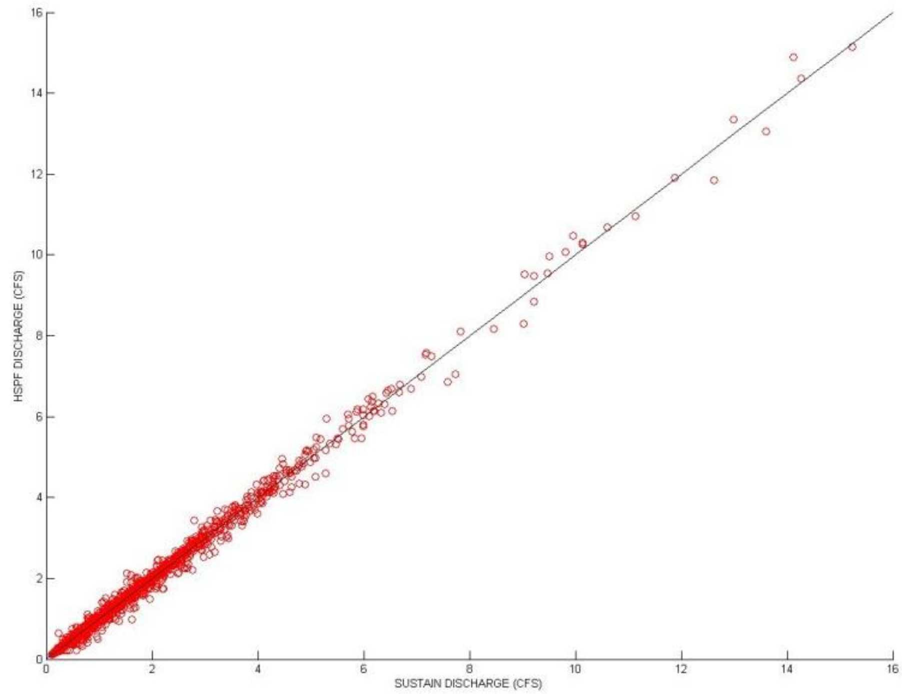


Figure 2-7. Scatter plot of daily discharge from Newaukum_urban basin (Oct 1998-Sep 2009).

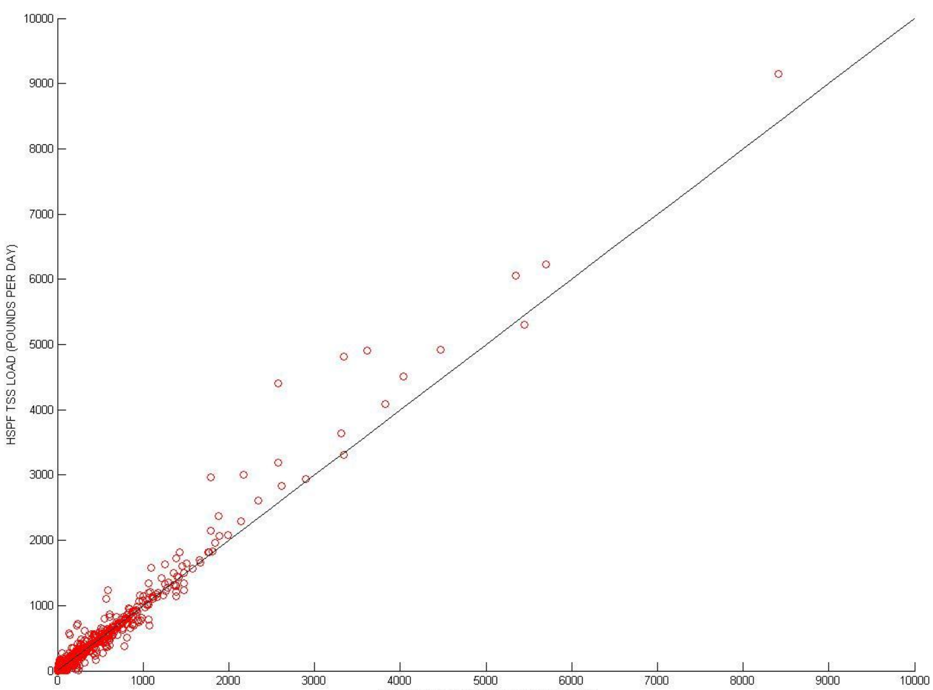


Figure 2-8. Scatter plot of daily TSS load (lbs/day) from Newaukum_urban basin (Oct 1998-Sep 2009).

2.1.3. *Summary*

This exercise demonstrated a procedure for setting up a *SUSTAIN* baseline model in an ArcGIS environment using the existing King County HSPF model. Outputs from the existing HSPF model were used as inputs to the *SUSTAIN* baseline model, in the form of flow and pollutant (TSS) load timeseries. The baseline model in *SUSTAIN* represented multiple HRUs and includes a mix of two types of impervious areas, which provides a more representative level of resolution for the BMP analysis. Comparison of the King County HSPF model and *SUSTAIN* baseline model results showed reasonable agreement, which provides the foundation for subsequent analysis. Differences were also investigated and explained in order to understand and anticipate possible implications on subsequent steps of the analysis that depend on the use of the timeseries as boundary conditions.

2.2. Exercise 2 – Add and Configure BMPs, and Generate Cost-Effectiveness Curve

This exercise demonstrates how to add and configure BMPs, including an aggregate BMP, and set up an optimization run to generate cost-effectiveness curves.

2.2.1. *Exercise Overview*

Once the *SUSTAIN* model representing the baseline condition is verified, BMPs can be added to the model and optimization can occur in order to generate a cost-effectiveness curve. In a *SUSTAIN* application, the user can either add BMPs as single entities or as a group of BMPs (i.e. aggregate BMPs) that are either in sequence or parallel.

This exercise will demonstrate the steps to add and configure aggregate BMPs in a *SUSTAIN* application and builds on Exercise 1. The two sub-basins in Exercise 1 are lumped in this exercise for simplicity. The lumped sub-basin layer is called **newaukum_sws**. In addition, this exercise demonstrates how to generate a cost-effectiveness curve and use the post-processor to evaluate solutions.

Merge Subwatersheds

The lumped sub-basin layer can be created by using the **merge selected feature** ( ) function in the **Manual Delineation Toolbar** ( ). To learn how to use the **Manual Delineation Toolbar** read the *SUSTAIN* Step-by-Step Application Guide Version 1.2 for ArcGIS 9.3.1 Service Pack 2 document.

Highlights

- Adding and configuring aggregate BMPs
- Setting up an optimization model for generating a cost-effectiveness curve based on flow-exceedance frequency, which is used as a surrogate for High Pulse Count (HPC)

2.2.2. *Step-by-Step Instructions*

To setting up a new *SUSTAIN* project, you will perform the following steps:

1. Setup a New GIS Project (follow Steps 1-7 from Exercise 1)
2. Define BMP Templates
3. Setup Routing Network
4. Distribute Land Use for Aggregate BMP
5. Edit BMPs
6. Define Assessment Point
7. Create Input File

Setup *SUSTAIN* Model / Create *SUSTAIN* Input File

1. *Setup a New GIS Project (follow Steps 1-7 from Exercise 1)*

   1. Setup a new GIS project
   2. Define project data
   3. Load and define the data layers
   4. Choose land simulation option
   5. Define pollutants
   6. Assign external land use timeseries
   7. Delineate drainage area

Use the new lumped sub-basin layer (**newaukum_sws**) in Step 7 as shown below.

After **Delineate Drainage Area** (Step 7), continue with the following:

2. *Define BMP Templates*

The initial aggregate BMP proposed for this exercise uses rain barrels to treat roof runoff from low density and medium-high density residential areas which then discharge to bioretention (rain gardens). Paved areas (driveways and sidewalks) drain to bioretention on each residential parcel. Parking areas in commercial-industrial land uses are treated by porous pavement and roofs are routed to bioretention facilities. Overflow from porous pavement drains to bioretention facilities. Road runoff is directed to bioretention facilities. The aggregate also includes regional detention storage (wet pond) downstream of the bioretention facilities. Pervious runoff from each land use type (except agriculture) is untreated and routed directly to the drainage outlet.

The schematic (Figure 2-9) represents the aggregate BMP treatment proposed for this exercise. Representation of this aggregate treatment scenario can be accomplished using four BMP templates defined in *SUSTAIN* (Table 2-6).

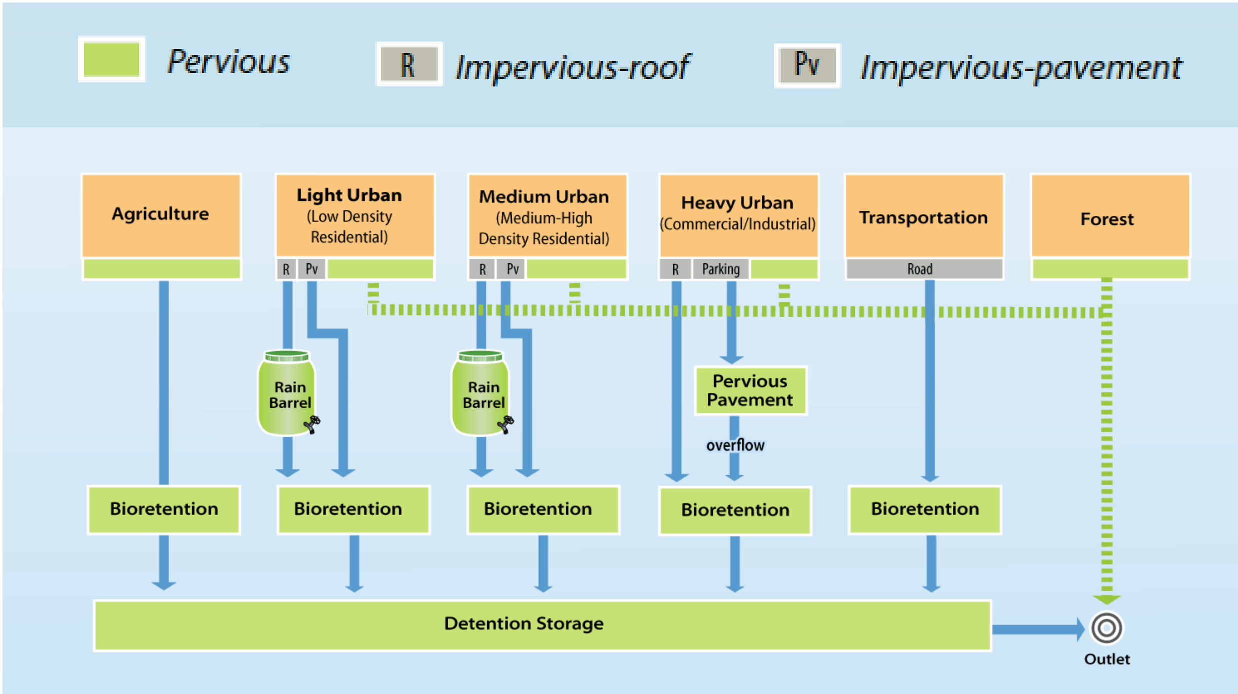
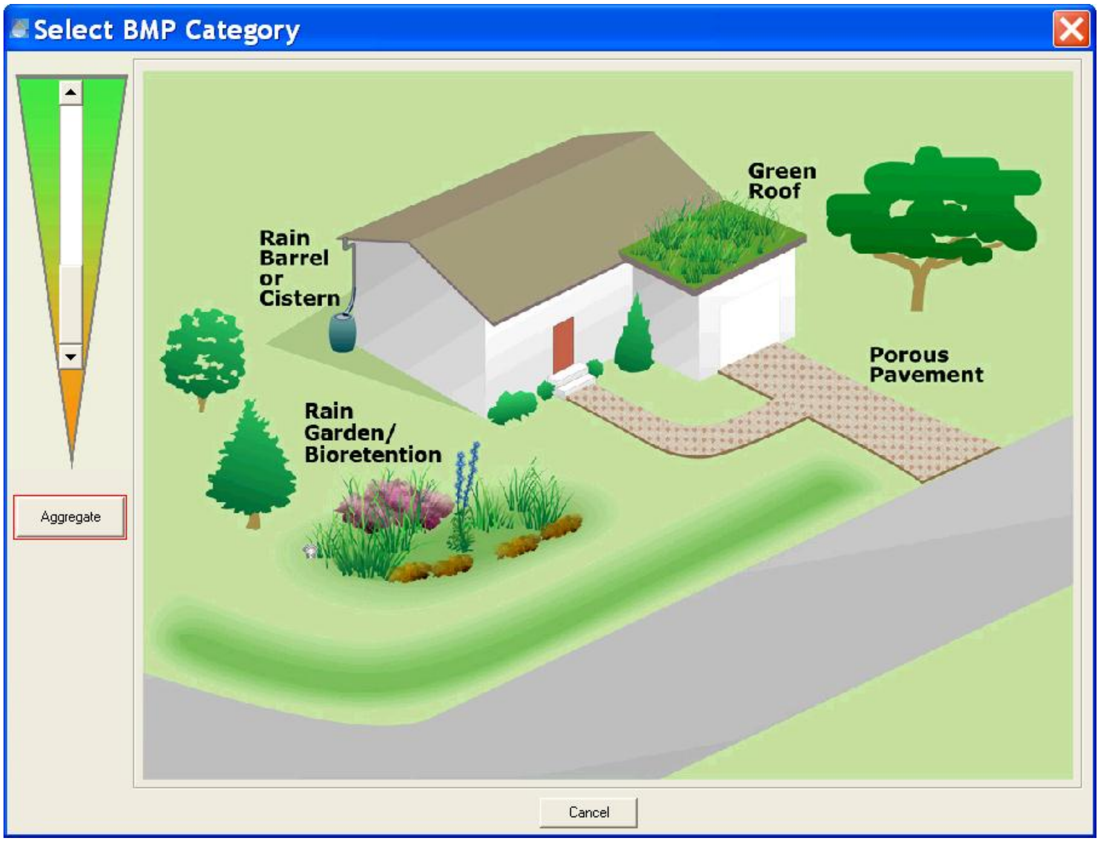


Figure 2-9. An Aggregate BMP treatment train schematic.

Table 2-6 BMP Types in the Aggregate BMP

BMP Category	BMP Type
On-Site Interception	Rain Barrel
On-Site Treatment	Bioretention
	Porous Pavement
Regional Storage / Treatment	Wet Pond

On the *SUSTAIN* **Menu**, click **Define BMP Template** to launch the Select BMP Category interface, shown below.



Use Table 2-7 to define **Aggregate BMP** template parameters. A detailed description of BMP processes parameters is documented in EPA report: *SUSTAIN*—A Framework for Placement of Best Management Practices in Urban Watersheds to Protect Water Quality (Shoemaker, 2009) section 3.3. The BMP configuration parameter values should be based on local BMP design guidelines and local soil conditions. The Design Drainage Area should be determined based on realistic understanding of drainage area that can be treated by a unit size BMP. For example, as listed in Table 2-7, King County assumed a rain barrel can collect runoff from 0.005 acre (218 square feet) of roof surface.

Table 2-7. Aggregate BMP Component Parameters

Model Parameter	Rain Barrel	Bioretention	Porous Pavement	Wet Pond
Surface Properties				
Design Drainage Area (acre)	0.005	0.05	0.03	0
Length (ft)	Use *SUSTAIN* Default Values	20	20	80
Width (ft)		5	6	25
Orifice Height (ft)		0	0	0
Orifice Diameter (in)		0	0	0
Weir Height (ft)		1	0.1	5

Model Parameter	Rain Barrel	Bioretention	Porous Pavement	Wet Pond
Weir Width (ft)		5	6	5
Substrate Properties				
Depth of Soil (ft)	n/a	1.5	1	0
Soil Porosity (0-1)	n/a	0.4	0.4	n/a
Infiltration Method	n/a	Holtan	Holtan	n/a
Background Soil Saturation Infiltration Rate (in./hr)	n/a	0.5	0.5	0
Underdrain Properties				
Underdrain Depth (ft)	n/a	n/a	n/a	n/a
Underdrain Void (0-1)	n/a	n/a	n/a	n/a
Infiltration Rate (in/hr)	n/a	n/a	n/a	n/a
Cost Data				
Construction Cost [a]	\$16.86 / ft^2 [c]	\$30.55 / ft^2	\$13.90 / ft^2	\$7.97 / ft^3
Design Cost [b]		\$16.80 / ft^2	\$2.78 / ft^2	\$0.61 / ft^3

a. Values initially based on Herrera QAPP (Draft December 2011).
b. Design cost of porous pavement assumed as 20% of construction cost.
c. Based on *SUSTAIN* BMP cost database, national average value adjusted to 2013 value.

Design Drainage Area

Design drainage area is the intended drainage area for a specified BMP. The design drainage area is particularly important for aggregate BMPs. As an aggregate BMP is applied to a large area, *SUSTAIN* uses the design drainage area to maintain the desired drainage area-to-BMP ratio. If a **0** value is specified, the design drainage area feature becomes inactive.

3. <u>*Setup Routing Network*</u>

Next you will place an Aggregate BMP in the sub-basin and establish routing connections. Follow these steps to create the project.

- Place an Aggregate BMP and a Junction in the sub-basin
- On the *SUSTAIN* Menu, click **Define Drainage Area to BMP Connection**, or click ( ) on the *SUSTAIN* Toolbar to establish drainage area to Aggregate BMP connection
- On the *SUSTAIN* Menu, click **Define Routing Network**, or click ( ) on the *SUSTAIN* Toolbar. Draw the routing connection from the upstream Aggregate BMP to the downstream Junction (use a **Dummy** connection).

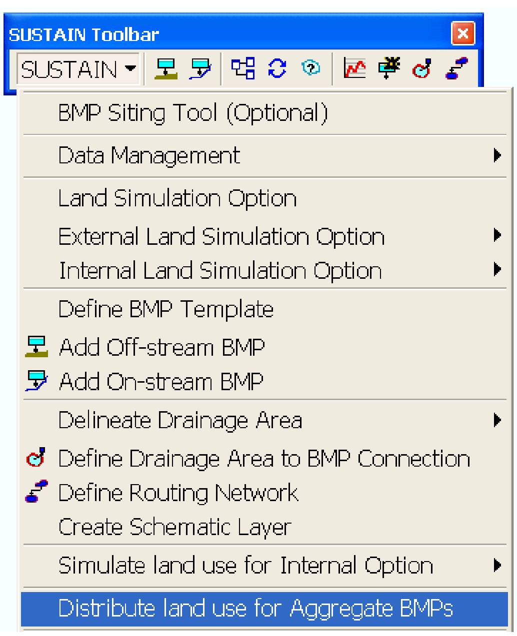
4. *Distribute Land Use for Aggregate BMP*

This step assigns the land areas that are treated by various components of the aggregate BMP. In this exercise pervious areas are not treated and are directly routed to the outlet (Table 2-8 and BMP schematic). In other words, 100 percent of the runoff from the pervious land uses are routed directly to the outlet. If you have multiple aggregates, each can have a different distribution. The percent areas assigned to each BMP component must be estimated based on estimates of BMP opportunities and corresponding drainage area that can be potentially routed to the BMP sites. The numbers listed in Table 2-8 were derived for this exercise based on local best professional judgment.

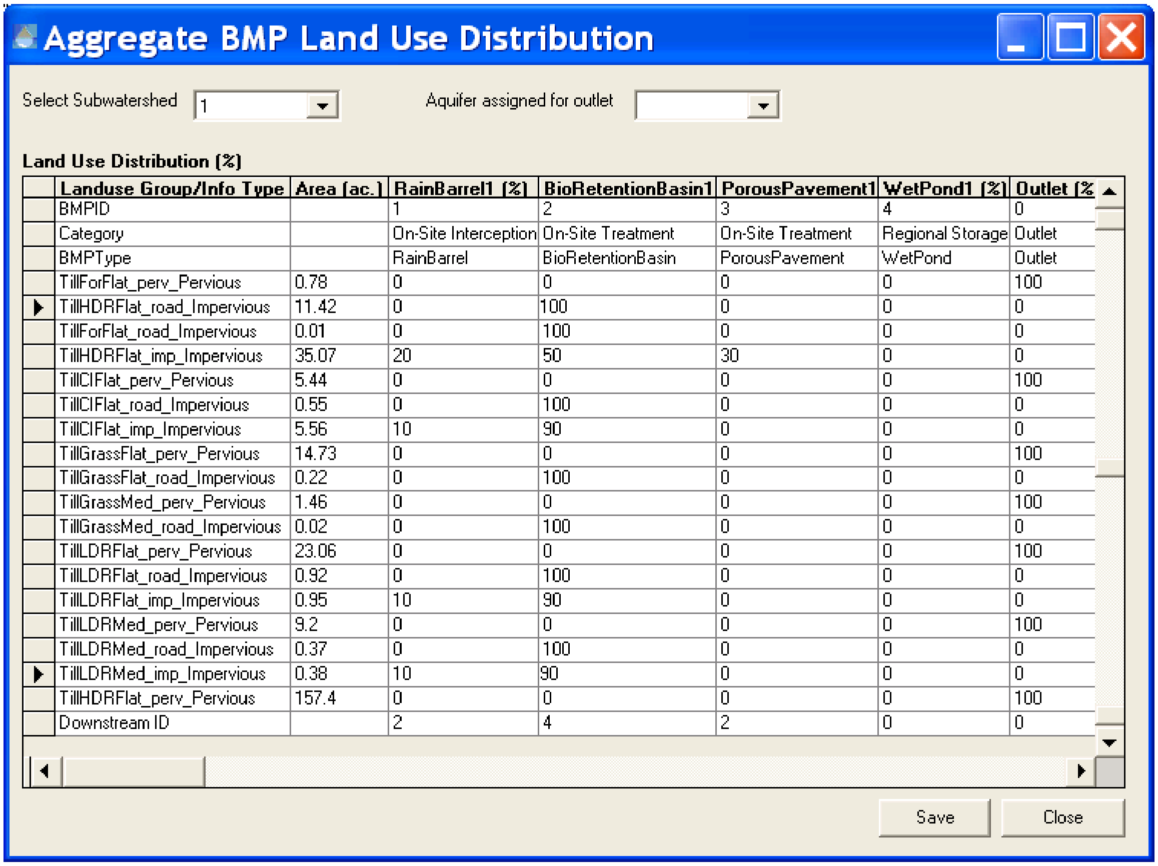
Table 2-8. Land area distribution to aggregate BMP components

Land Use Routing Percentages						
Land Type	**HRU Description**	**Rain Barrel (1)**	**Porous Pavement (2)**	**Bioretention (3)**	**Wet Pond (4)**	**Outlet (5)**
1	GrassFlat_Pervious	-	-	-	-	100
2	GrassMed_Pervious	-	-	-	-	100
3	ForestFlat_Pervious	-	-	-	-	100
4	LDRFlat_Pervious	-	-	-	-	100
5	LDRMed_Pervious	-	-	-	-	100
6	HDRFlat_Pervious	-	-	-	-	100
7	Forest_Pervious	-	-	-	-	100
8	Developed_Low_Impervious	10	-	90	-	0
9	Developed_Med_Impervious	10	-	90	-	0
10	Developed_High_Impervious	20	30	50	-	0
11	Road_Impervious	-	-	100	-	0

On the *SUSTAIN* Menu click **Distribute Land Use for Aggregate BMP** as shown below.



Wait until the cursor changes to an icon and then click on the subwatershed to launch the Aggregate BMP Land Use Distribution Table (shown below).



Landuse Group/Info Type	Area (ac.)	RainBarrel1 (%)	BioRetentionBasin1	PorousPavement1	WetPond1 (%)	Outlet (%
BMPID		1	2	3	4	0
Category		On-Site Interception	On-Site Treatment	On-Site Treatment	Regional Storage	Outlet
BMPType		RainBarrel	BioRetentionBasin	PorousPavement	WetPond	Outlet
TillForFlat_perv_Pervious	0.78	0	0	0	0	100
TillHDRFlat_road_Impervious	11.42	0	100	0	0	0
TillForFlat_road_Impervious	0.01	0	100	0	0	0
TillHDRFlat_imp_Impervious	35.07	20	50	30	0	0
TillClFlat_perv_Pervious	5.44	0	0	0	0	100
TillClFlat_road_Impervious	0.55	0	100	0	0	0
TillClFlat_imp_Impervious	5.56	10	90	0	0	0
TillGrassFlat_perv_Pervious	14.73	0	0	0	0	100
TillGrassFlat_road_Impervious	0.22	0	100	0	0	0
TillGrassMed_perv_Pervious	1.46	0	0	0	0	100
TillGrassMed_road_Impervious	0.02	0	100	0	0	0
TillLDRFlat_perv_Pervious	23.06	0	0	0	0	100
TillLDRFlat_road_Impervious	0.92	0	100	0	0	0
TillLDRFlat_imp_Impervious	0.95	10	90	0	0	0
TillLDRMed_perv_Pervious	9.2	0	0	0	0	100
TillLDRMed_road_Impervious	0.37	0	100	0	0	0
TillLDRMed_imp_Impervious	0.38	10	90	0	0	0
TillHDRFlat_perv_Pervious	157.4	0	0	0	0	100
Downstream ID		2	4	2	0	0

Enter the percentage numbers as defined in Table 2-8. In addition, make sure to define the routing between BMP components using the DownstreamID row, i.e. **Rain Barrel** (BMPID=**1**) drains to **Bioretention (**BMPID=**2)**, **Porous Pavement** (BMPID=**3**) drains to **Bioretention**, **Bioretention** to **Wet Pond (**BMPID=**4)**, and **Wet Pond** to **Outlet (**BMPID=**0)**. Click **Save**.

5. Edit BMPs

The purpose of the step is to update the number of units of each Aggregate BMP component based on the land use area distributed to each component. In this step, we also specify decision variables, which are the number of units of each aggregate BMP component, and size of the wet pond.

On the *SUSTAIN* Toolbar, click the **Edit BMPs** button ( ) to launch the Edit BMP Toolbar shown below.

On the Edit BMP Toolbar, click ( ) and click on the aggregate BMPs. Then select the BMP type, and click **Redefine**.

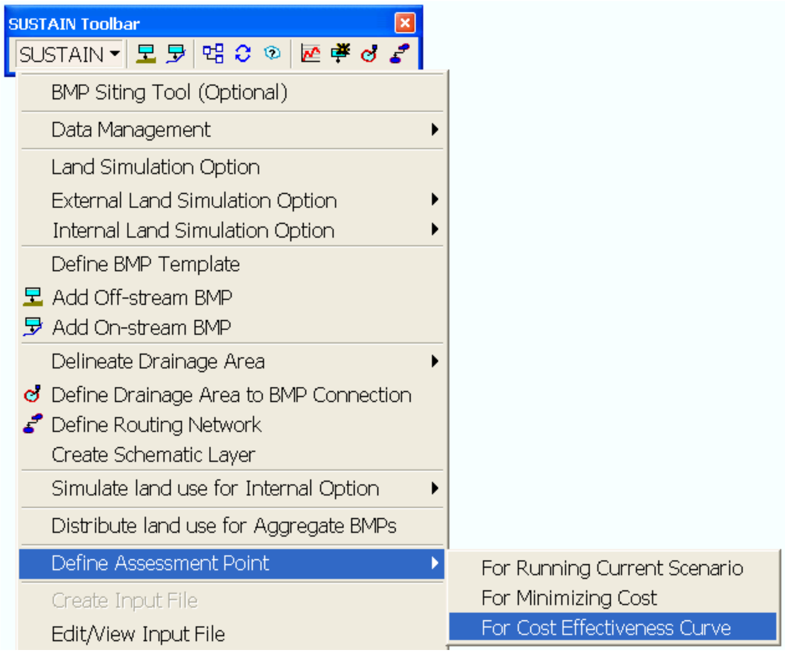
For each component of the aggregate BMP, click on the **BMP Dimensions** interface, change the number of units to **0** (this value indicates no BMPs under existing condition), and click the define decision variable button ( ) to specify the minimum, maximum and search increment values (Table 2-9). The minimum and maximum values bracket the ranges of the decision variable values, and the search increment (step) dictates the resolution of the search domain. In this case, the decision variables are the number of units of each BMP type. Minimum values are set to "**0**" to include "**no BMPs**" as an option; a value of "**1**" would indicate that the optimization search space starts with 1. Maximum values are determined by the maximum drainage area that is treated by each of the BMP types and the design drainage area of each BMP. Dividing the maximum drainage area by design drainage area calculates the maximum number of units. The search increments, or steps, are set as 1 percent of the maximum value (e.g., 10 is 1 percent of 1,000 in the porous pavement BMP). When deciding the search increment, users should keep in mind that the finer the resolution the more iterations are needed to find the near-best solutions. Users need to exercise best judgment to strike a balance between resolution and run-time, especially for a complex project when run-time is critical. However, as a general rule, steps in the 1 to 10 percent range provide enough resolution while holding to a reasonable run-time.

Table 2-9. Number of BMP units defined as decision variables

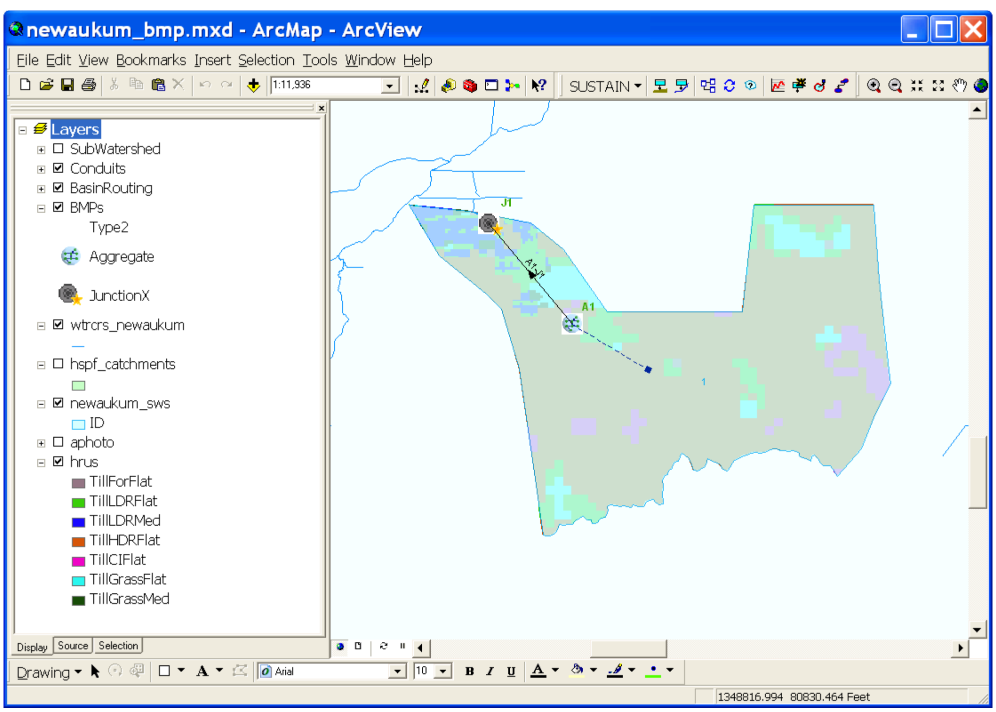
BMP Type	Minimum	Maximum	Step
Rain Barrel	0	250	5
Bioretention	0	2,500	25
Porous Pavement	0	1,000	10
Wet Pond	0	100	1

6. <u>Define Assessment Point</u>

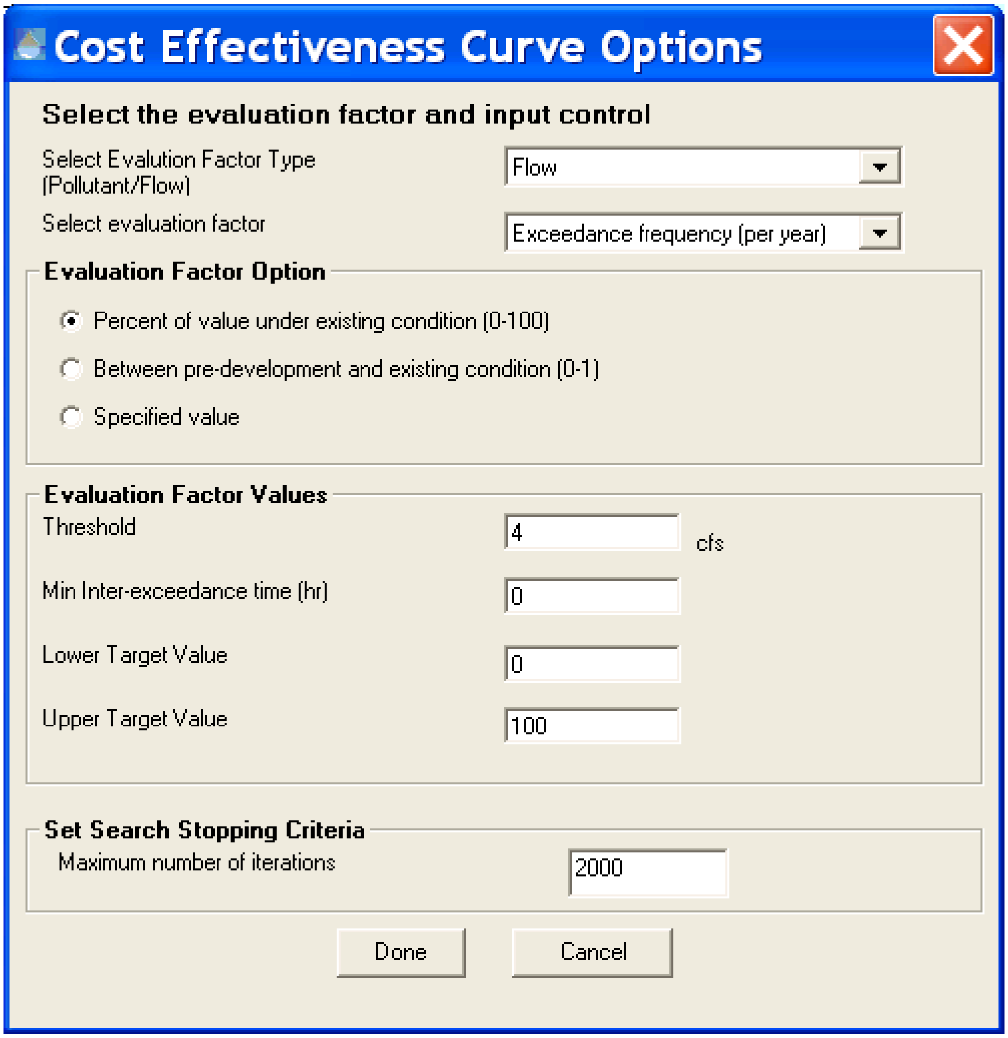
On the *SUSTAIN* Menu, click **Define Assessment Point**, and select the **For Cost Effectiveness Curve** option, as shown below.



Use the icon ( ) to select the desired point feature. In this exercise, define the Junction as the assessment point as shown below.



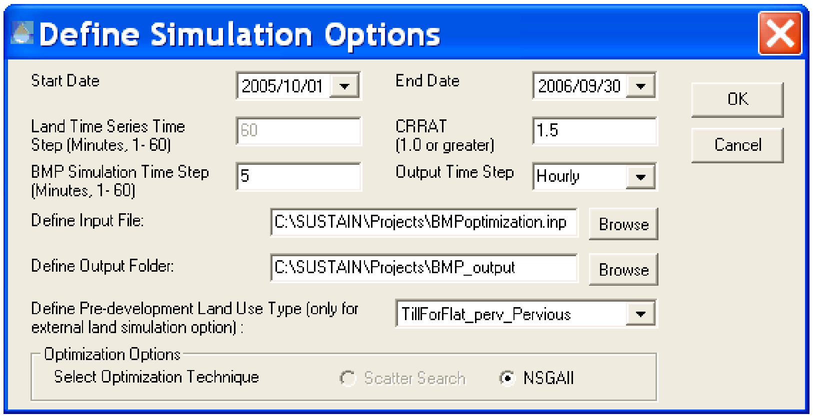
The evaluation factor is set to **Exceedance frequency**. Exceedance frequency measures the number of times per year when the flow values within a simulation timestep exceed the threshold value (in this case 4 cfs) beyond the minimum inter-exceedance time in hours. The **minimum inter-exceedance time** is used to avoid over-counting the number of exceedances for an event with multiple close peaks. In this case, the minimum inter-exceedance time is set to **0** so that each time the flow exceeds the threshold value it is counted as one exceedance. Set up the optimization as shown below.



The pilot study on which this exercise was based uses *SUSTAIN*'s cost-effectiveness analysis option of minimizing the cost of reducing the frequency with which flow exceeds a specified flow threshold. This option is consistent with one of the three hydrologic metrics, High Pulse Count (HPC) (Horner 2013). HPC is the number of times the daily mean flow exceeded a high pulse flow threshold set as twice the long-term mean annual flow. The objective in the optimization is to reduce the number of HPCs observed under current conditions to numbers more typical of the pre-development forested condition. The threshold value for the exceedance frequency evaluation factor is set to be **4 cfs**, which is twice the long-term mean annual flow to the watershed outlet.

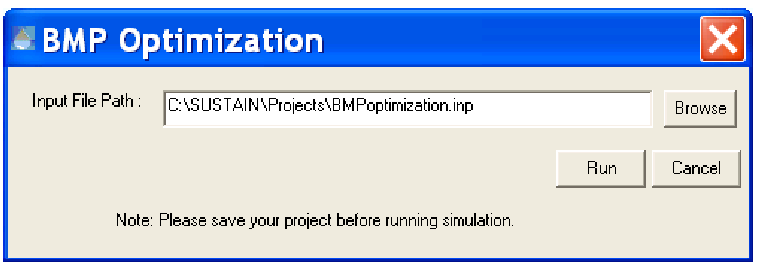
7. Create Input File

On the *SUSTAIN* Menu, click **Create Input File**, and fill the **Define Simulation Options** form as shown below. Name the input file as **BMPoptimization.inp** and the output folder as **BMP_output**. The software will then create the input file and the output folder in the specified locations.

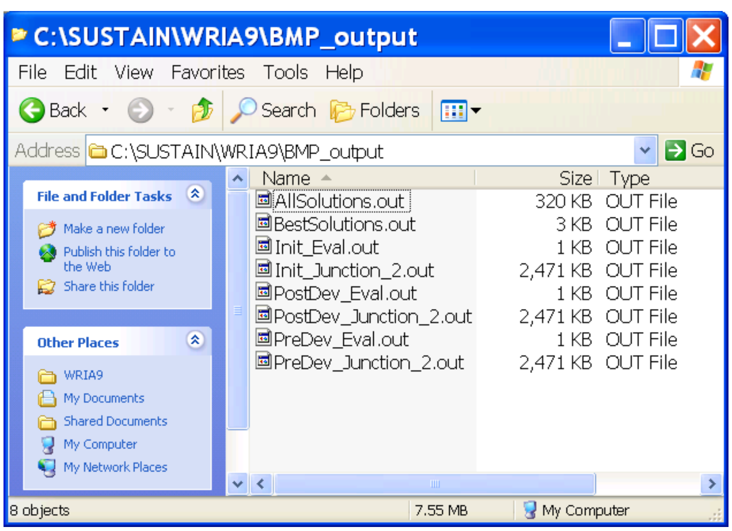


Run *SUSTAIN* Simulation

On the *SUSTAIN* menu select **Run Simulation** and click the **Run** button on the **BMP Optimization** window as shown below.



After the simulation is complete, the following eight files are generated in the output folder.

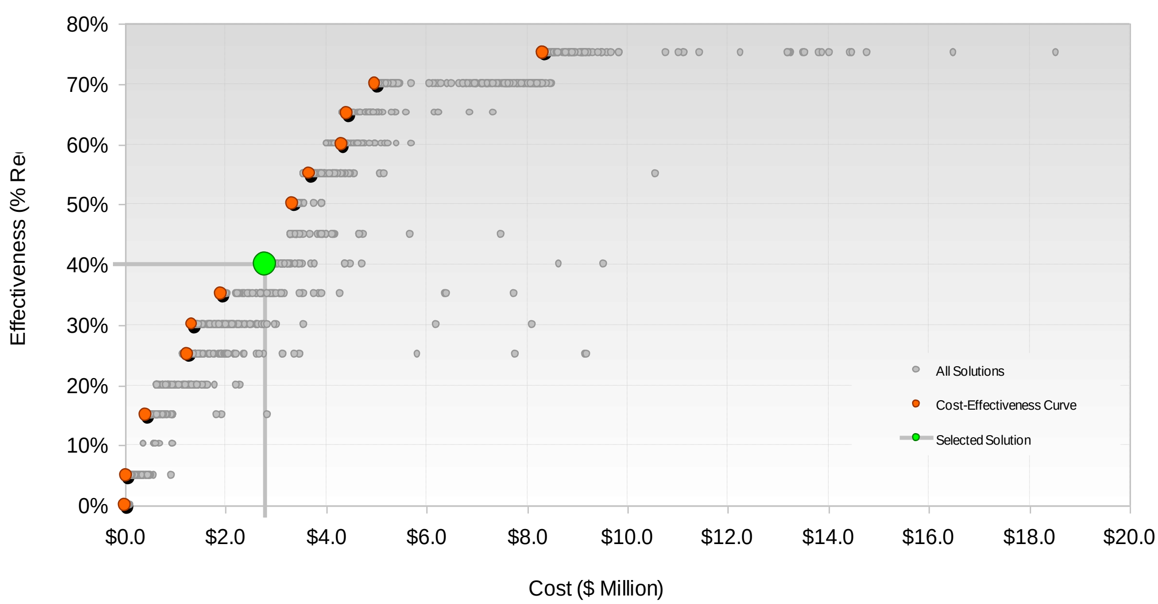


Besides the output files under the **Running Current Scenario** mode, two additional files (AllSolutions.out and BestSolutions.out) are generated under **Cost-Effectiveness Curve** mode. **AllSolutions.out** lists all the solutions that were evaluated during the optimization run process; and **BestSolutions.out** lists only the solutions that are along the cost-effectiveness curve. Notice that the solutions in the BestSolutions.out file are not ranked, and each solution has a unique ID, which is named as the BestPop ID. It is used to index and identify solutions when a solution is run from either the post-processor or in batch-mode run. When the "BestSolutions.out" file is loaded into the PostProcessor spreadsheet, the solutions are ranked by cost and effectiveness from low to high, at which point a new set of IDs (Solution ID) is generated for display purposes.

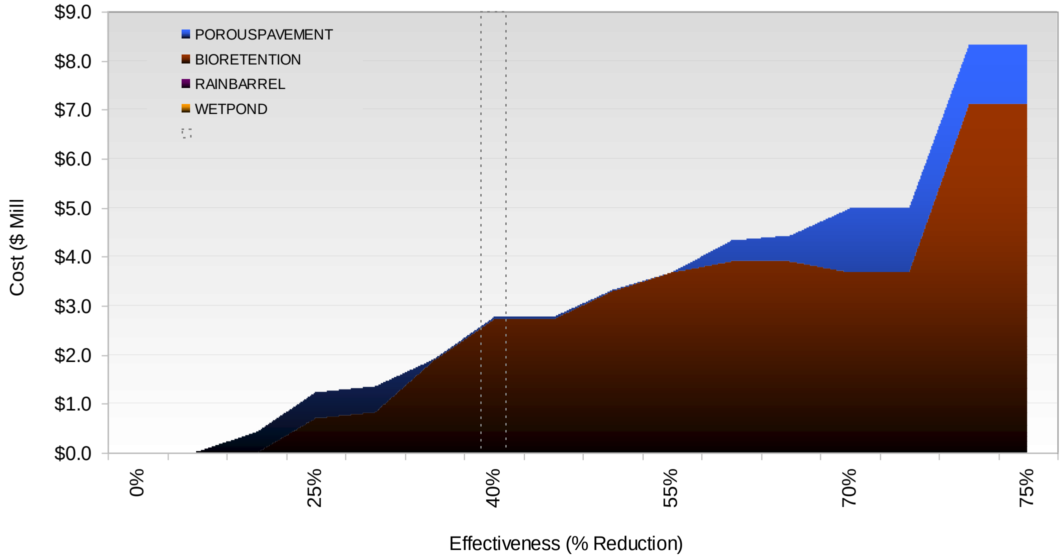
The other six files, for Init, PostDev, and PreDev scenarios, are also generated for each optimization run, and the new model run overwrites the older versions of those files. If you want to save model output from a previous run, you should rename those files or save them in another directory.

View *SUSTAIN* Results

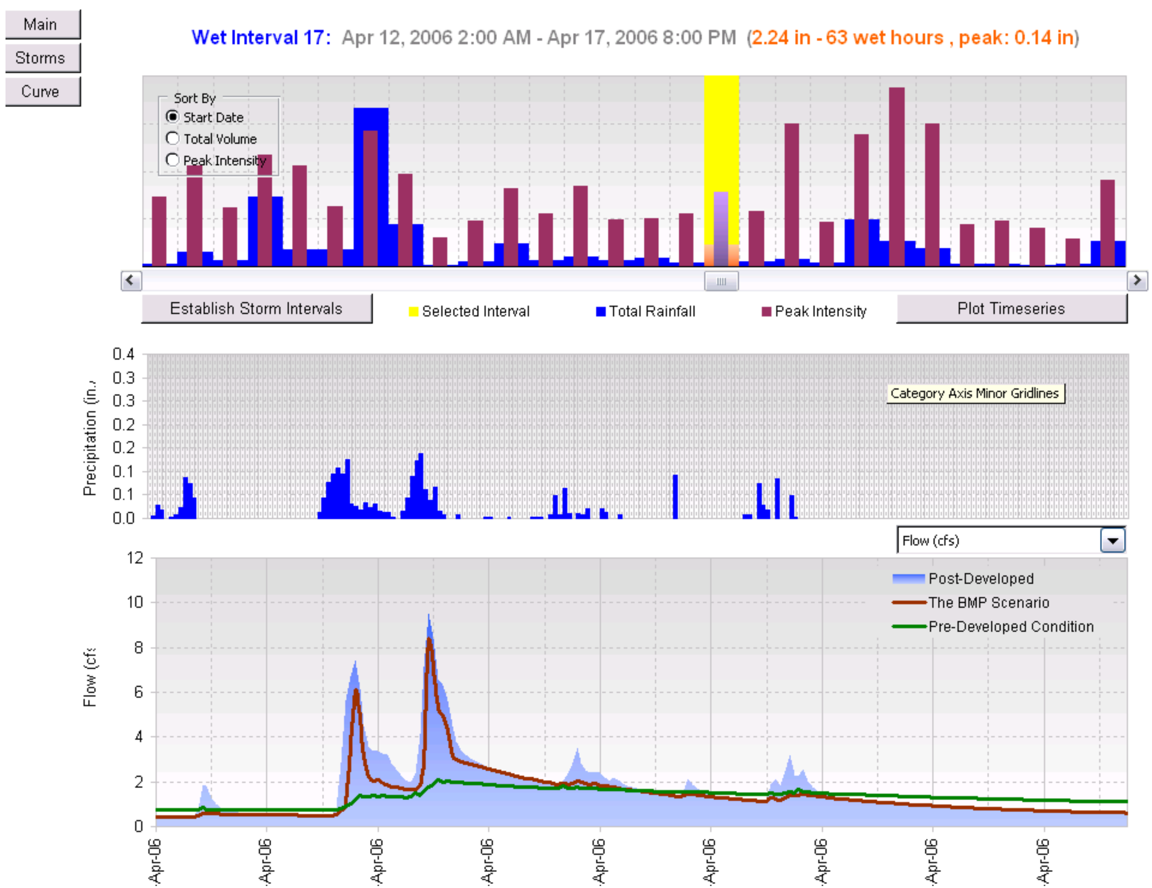
The *SUSTAIN* post-processor can be used to view the cost-effectiveness curve. An example cost-effectiveness curve generated for this exercise will look similar to the image presented below. The stepwise pattern of the "All Solutions" grey dots are caused by using exceedance frequency as the evaluation factor, which has discrete integer intervals. As more BMPs are implemented (with higher cost) the peak flows are reduced, but not until one or more peak flow values dips below the threshold value will the exceedance frequency value be affected. The discrete nature of the threshold is the reason why the cost-effectiveness curve shows a coarse step pattern.



A graph of BMP utilization is shown in the figure below. Notice that this example favors bioretention.



The postprocessor also includes plots of flow and water quality timeseries for any selected solution on the cost-effectiveness curve using the post-processor. An example of the output will look similar to the timeseries plots shown below.



2.2.3. *Summary*

Exercise 2 demonstrated how to set up and configure an Aggregate BMP in *SUSTAIN* and presented the optimization results using the baseline model set up in Exercise 1. The Aggregate BMP allows the user flexibility in designing the BMP treatment train and assigning the various source pathways (e.g., rooftop, road) that are routed to each BMP type. Decision variables are used to develop numerous BMP solutions during optimization which result in the most cost-effective combinations of BMPs.

Projected BMP utilization is based on the BMP assumptions and model configuration. The optimization engine performs iterative searches to identify cost-effective solutions. The search process is dependent on the cost and BMP treatment effectiveness values of each BMP. Therefore, all factors that affect the BMP cost-effectiveness dictate the selection and utilization of certain BMPs over others. Consider a simple example: among BMPs that have similar effectiveness, the one with the least cost will be selected and exhausted first before the next BMP is selected. All of the factors that affect the BMP effectiveness, for example infiltration rates, drainage area to BMP capacity ratio, and so on, need to be well researched. Thus, it is crucial to have calibrated watershed and BMP simulation modules, as well as good BMP cost data, to ensure meaningful results.

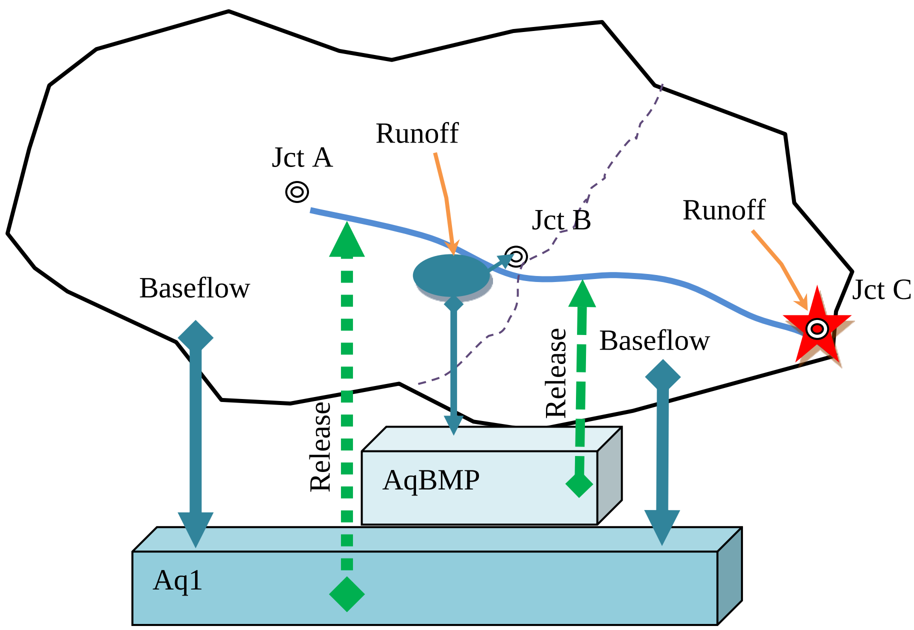
2.3. Exercise 3 – Region 10 New Features and Work With *SUSTAIN* Input File

This exercise focuses on demonstrating the new features in *SUSTAIN* that have been developed for the Region 10 User's Group and working with *SUSTAIN* input files directly.

2.3.1. *Exercise Overview*

The Figure below illustrates a hypothetical project area and modeling elements for use in this exercise:

- Total area is 300 acres, including 100 acres of impervious area, 100 acres of developed pervious area, and 100 acres of forest area
- An infiltration basin is proposed to control runoff from a 200 acre developed area (100 acres of impervious area plus 100 acres of developed pervious area)
- The management objective is to restore hydrology so that the post-developed FDC at Junction C matches the pre-development FDC, which is modeled as 300 acres of forest
- Groundwater flow components from pervious land use timeseries are routed to Aq1 for immediate release (recession coefficient = 1), while the infiltrated flow from the infiltration basin is routed to AqBMP for delayed release (recession coefficient = 0.0001)



Highlights

- Use of FDC as evaluation criteria for BMP optimization
- Demonstrate the use of multiple aquifers with different release rates
- Demonstrate the use of F-tables for BMP representation
- Direct modification of a *SUSTAIN* model from the input file

2.3.2. *Step-by-Step Instructions*

To complete this exercise, you will perform the following steps:

1. Prepare Required Data
2. Create and Edit *SUSTAIN* Input File
3. Setup Optimization
4. Run *SUSTAIN* Simulation
5. View *SUSTAIN* Results

1. Prepare Required Data

The GIS interface of *SUSTAIN* version 1.2 does not accommodate the FDC and F-table features; therefore users must edit the input file manually to use the new features. The following information is needed to edit the input file:

- Defined pre-development condition
- *SUSTAIN* optimization run input file representing the study area (this input file can be either generated using the *SUSTAIN* GIS interface following the instructions demonstrated in Exercise 1, or manually compiled using a text editor)
- Runoff timeseries for all land use types from a hydrologic model
- BMP F-table and unit cost (see Step 2 for further instructions on creating an F-table)
- Upper and lower flow thresholds (optional) for calculation of FDC evaluation factor

Two options for specifying the pre-developed condition FDC

Options	Advantages	Disadvantages
Internal (*SUSTAIN* PreDev output timeseries)	Quick and easy	The timeseries file is generated by replacing all existing land uses with a single user specified pre-developed land use (e.g., forest, see c715 input card).
External (User provided time - series)	Flexible	Set up a separate project to model the pre-developed condition. This might be an aggregate response from multiple land uses.

2. Create and Edit SUSTAIN Input File

Follow the steps outlined in exercises 1 and 2 to create a new *SUSTAIN* project in GIS environment and create an input file. For this exercise the optimization input file, ***FDC_optimization.inp,*** and the unit-area land based timeseries files are provided in the *SUSTAIN* installation package. Also, Appendix A has the complete *SUSTAIN* input file for this exercise, i.e. *FDC_optimization.inp*. Appendix B lists the mapping tables showing the dependency among various cards of the model input text file. The dependency mapping tables describes information that is repeated on multiple input file cards. For instance, BMPs are defined in Card 715, have their surface properties specified in Card 725, and subsurface parameters specified in Card 745. Any change made to BMPs in the input file will need to consider information at multiple locations within the file.

This section demonstrates how to edit the corresponding input cards to apply the new features. Input files or cards can be opened and edited using a text editor.

Using F-tables for BMPs or Conduits

Begin by creating an F-table:

1) Gather the following information describing the BMP geometry, paying attention to units:
   - Width (feet)
   - Length (feet)
   - Orifice diameter (inch)
   - Orifice height (feet)
   - Weir heights (feet)
   - Weir width (feet)
2) Using the BMP geometry, develop an F-table using EPA's online Gray Infrastructure Tool (www.epa.gov/athens/research/HSPFWebTools/gray/index.html), or some other tool. Be sure to select a representative template for the BMP (e.g., trapezoid, cylinder, etc.).
3) Edit the input files

Two input cards (i.e., **c714** and **c715**) are associated with the F-table feature. **Card 714** is used to define one or multiple F-tables. The card header and format is shown below. Each F-table is identified with a unique FTABLE_ID. In the example shown below, the FTABLE_ID are Ftable1 and FtableX, and the order of the F-tables as listed within the input file does not matter.

Copy and paste the F-table into **Card 714**. Be sure to include the input file header as the first record as it includes special information regarding the F-table name, flow length, slope, and number of records. Below that line, the column order and expected units (English) are the same as what is produced by the online tool. When adding more than one F-table, as illustrated in the example below, the subsequent F-table begins with the first record (F-table name, flow length, slope, and number of records). The flow length is the distance between the inlet and outlet, slope is the longitudinal bed slope. The various outflow components defined in the F-table, such as the weir and orifice, can be routed to either the same or different downstream receiving location(s) in c795.

Notice that when an F-table is used for BMPs or conduits, it overwrites related parameters defined in various cards. Table 2-10 lists the ignored parameters in the input file when using an F-table.

Table 2-10. Parameters ignored when using an F-table

BMP Class	BMP Type	Parameters Ignored when using F-table
A	Bioretention, Dry Pond, Wet Pond, Porous Pavement, Infiltration Basin	Parameters associated with weir and orifice (c725)
B	Swale	Length and slope (c735)
C	Conduit	Length and invert elevations (c750) and cross section parameters (c755 and c760)

Card 715 is used to assign the F-table to its corresponding BMP or Conduit using the last column FTABLE_ID. In this exercise, the wet pond WP1 has Ftable1 assigned to it. Notice that, for the BMPs that do not use F-tables, the last column must be left blank. The presence of an F-table assignment in this card supersedes other redundant geometric parameters defined elsewhere.

```
c-------------------------------------------------------------------------------------------
c714 Ftable for BMP Class A, B, and C
c
c FTABLE_ID        = Unique Ftable identifier (continuous string)
c FLOW_LENGTH      = Flow length (ft)
c BED_SLOPE        = Longitudinal bed slope (ft/ft)
c NUM_RECORD       = Number of layers in the Ftable
c
c DEPTH            = Water depth (ft)
c SURFACE_AREA     = Water surface area at the given depth (acre)
c VOLUME           = Storage volume at the given depth (ac-ft)
c FLOW_WEIR        = Overflow or weir outflow rate at the given depth (cfs)
c FLOW_ORIFICE     = Channel flow or orifice outflow rate at the given depth (cfs)
c
c FTABLE_ID   FLOW_LENGTH   BED_SLOPE   NUM_RECORD
c DEPTH   SURFACE_AREA   VOLUME   FLOW_WEIR   FLOW_ORIFICE
Ftable1   100   0.001   3
0.0000     0.122     0.000     0.000     0.000
0.0556     0.122     0.006     0.000     0.005
0.1111     0.122     0.013     0.100     0.010
FtableX   100   0.001   4
0.0000     0.122     0.000     0.000     0.000
0.1111     0.122     0.013     0.000     0.050
0.1667     0.122     0.020     0.010     0.060
0.2222     0.122     0.027     0.015     0.080
c-------------------------------------------------------------------------------------------

c715 BMP SITE INFORMATION
c
c BMPSITE          = Unique BMP site identifier
c BMPNAME          = BMP template name or site name
c BMPTYPE          = Unique BMP Types (must use the exact same keyword)
c                    (BIORETENTION, WETPOND, CISTERN, DRYPOND, INFILTRATIONTRENCH, GREENROOF,
c                     POROUSPAVEMENT, RAINBARREL, REGULATOR, SWALE, CONDUIT, BUFFERSTRIP,
c                     AREABMP)
c DArea            = Total Drainage Area in acre
c NUMUNIT          = Number of BMP structures
c DDAREA           = Design drainage area of the BMP structure (acre)
c PreLUType        = Predevelopment land use type (for external land simulation option)
c AquiferID        = Unique Aquifer ID, 0 --- no aquifer (for external land simulation option)
c FtableFLG        = Ftable flag, 0 = no, 1 = yes (for BMP Class A, B, and C)
c FTABLE_ID        = Unique Ftable identifier (continuous string) as in card 714
c
c BMPSITE   BMPNAME   BMPTYPE   DArea   NUMUNIT   DDAREA   PreLUType   AquiferID   FtableFLG   FTABLE_ID
c-------------------------------------------------------------------------------------------
1        J1       JUNCTION      200      1       0       9       1       0
2        C2       CONDUIT       0        1       0       9       1       0
3        J3       JUNCTION      0        1       0       9       1       0
4        C4       CONDUIT       0        1       0       9       2       0
5        J5       JUNCTION      100      1       0       9       1       0
6        WP1      WETPOND       0        0       0       9       2       1       Ftable1
c-------------------------------------------------------------------------------------------
```

Aquifer Assignment (c712 and c715)

Two input cards (i.e. **c712 and c715**) are associated with the aquifer feature. **Card 712** is used to define the aquifer(s). In *SUSTAIN*, shallow groundwater is modeled as a simple linear reservoir (Haan 1972). Groundwater discharge G(t) is routed to the receiving stream, and deep seepage D(t) is considered as lost from the system to deep aquifers not part of the model network. Groundwater discharge $G(t)$ and deep seepage $D(t)$ from the shallow groundwater storage $S(t)$ at time t are calculated as:

$$G(t) = r \times S(t)$$
$$D(t) = s \times S(t)$$

where r and s are groundwater recession and seepage constants, respectively (per hour). Please note that the shallow groundwater storage S has an unlimited volume.

As shown below in card 712, each aquifer is identified with a unique ID (AquiferID). In **Card 715**, the aquifers are assigned to corresponding BMPs or Conduits in the AquiferID column. The following notes describe implications for assigning aquifers to Junctions, BMPs, and Conduits:

- Assigning an aquifer to Junctions: When an aquifer is assigned to a Junction, the groundwater component in the timeseries files that are added to the Junction are routed to aquifer storage.
- Assigning aquifer to BMPs: When an aquifer is assigned to a BMP, the groundwater component in the timeseries file that is added to the BMP is routed to the aquifer storage and the flow component that infiltrates into the background soil from the BMP is also added to the assigned aquifer storage.
- Assigning aquifer to Conduits: When an aquifer is assigned to a Conduit, the released groundwater from the aquifer is routed to the Conduit. The aquifer to conduit assignment is a one-to-one relationship. In other words, one particular aquifer can only be assigned to one conduit, and only an individual conduit can receive routed water from a single aquifer. If the user accidentally assigns an aquifer to more than one conduit, there is no check in the simulation model to prevent an error, but the GIS interface restricts the user to pick the same aquifer once it is assigned to a receiving conduit. Values are entered in **Card 712** to represent aquifer properties and routing is assigned in **Card 715** (see above).

```
c-------------------------------------------------------------------------------------------
c712 Aquifer INFORMATION
c
c AquiferID          = Unique Aquifer identifier
c AquiferNAME        = Aquifer name
c Initial Storage    = Initial Storage (ac-ft)
c RecessionCoef      = Recession Coefficient (1/hr)
c SeepageCoef        = Seepage Coefficient (1/hr)
c
c AquiferID   AquiferNAME   InitialStorage   RecessionCoef   SeepageCoef
1             Aq1           0                1               0
2             AqBMP         10               0.0001          0
c-------------------------------------------------------------------------------------------
```

The groundwater inflow data in the timeseries files are written in the column immediately following the surface runoff flow data (the user should refer to ***SUSTAIN*****_DataNeeds.pdf** for more details). Once the contributing land uses are linked to an aquifer through either receiving junctions or BMPs, the groundwater inflow data in the timeseries are routed to the aquifer storage. If no aquifer is defined and linked, that column is ignored. The flow released from the aquifer to receiving conduits is computed using the recession coefficient. In the case when the groundwater flow component in the timeseries files represents already routed flow (e.g. baseflow outflow from HSPF), the recession coefficient should be set to 1 to allow the groundwater flow directly added to the receiving conduit without further attenuation. For example, in the King County timeseries data set, the groundwater component is using the HSPF AGWO plus IFWO output, which is the routed groundwater output to the receiving stream; therefore the recession coefficient of the aquifer that receive groundwater flow from the land use timeseries is set to 1.

It is important to note that when an aquifer is assigned to BMP(s), the aquifer will receive the groundwater outflow component from both the timeseries files that are routed to the BMP(s) and the infiltrated flow from the BMP(s), thereby preserving the water balance. In the case where the groundwater outflow from the timeseries files represents already routed/attenuated outflow that needs an instant release to the receiving water (recession coefficient = 1), while the infiltrated water from BMPs needs attenuation, a separate aquifer should be defined to receive the infiltrated water from the BMPs. In this exercise, Aq1 has a recession coefficient = 1, while AqBMP has a recession coefficient = 0.0001.

FDC Evaluation Factor

The FDC Evaluation Factor is computed as the *area* between the evaluated condition and pre-developed condition FDCs, measured between the user-defined upper and lower percentile flow limits. In Figure 2-10, the green line shows the predevelopment FDC, the blue line shows the existing condition FDC, and the brown line is the FDC with BMPs. The dashed lines show the user defined upper and lower flow limits (or thresholds) that bound the FDC comparison. That range is determined using the predevelopment condition FDC, hence the green-colored dashed line. The orange highlighted area between the red and green lines AND that falls within the upper and lower limits is the area computed for the FDC Evaluation Factor. When using the FDC evaluation factor for optimization, the objective is to *minimize* the area between the two curves bounded by the green and brown lines AND ALSO bounded by the upper and lower percentile thresholds; flows outside of the target range are not considered.

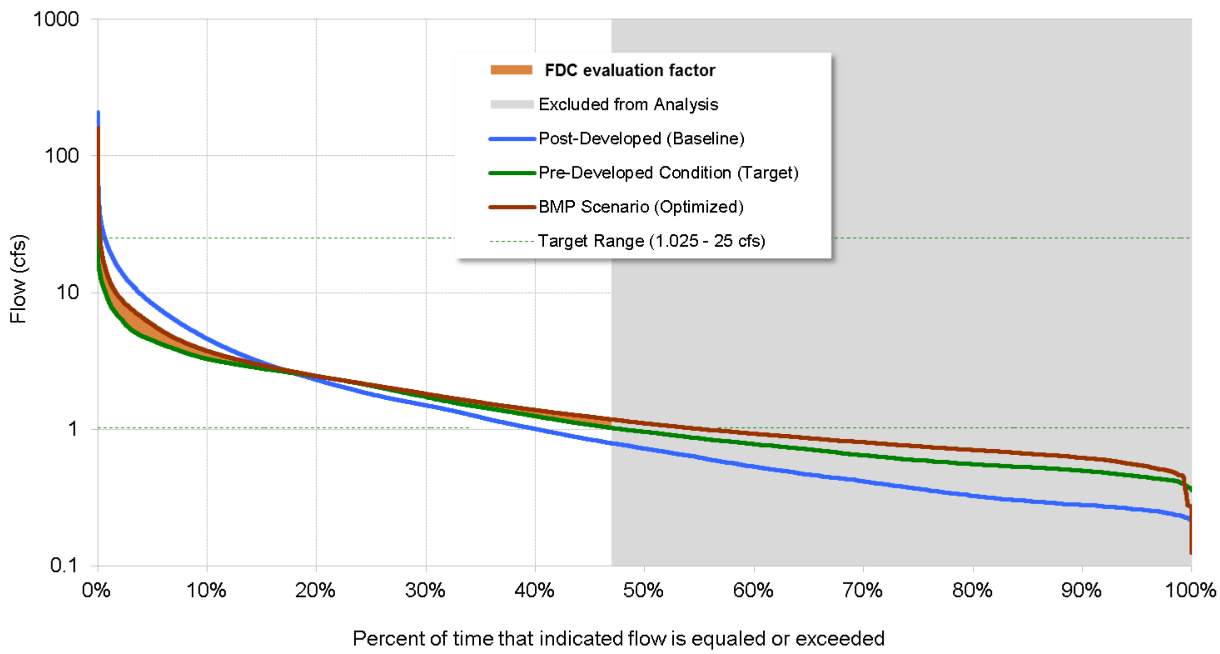
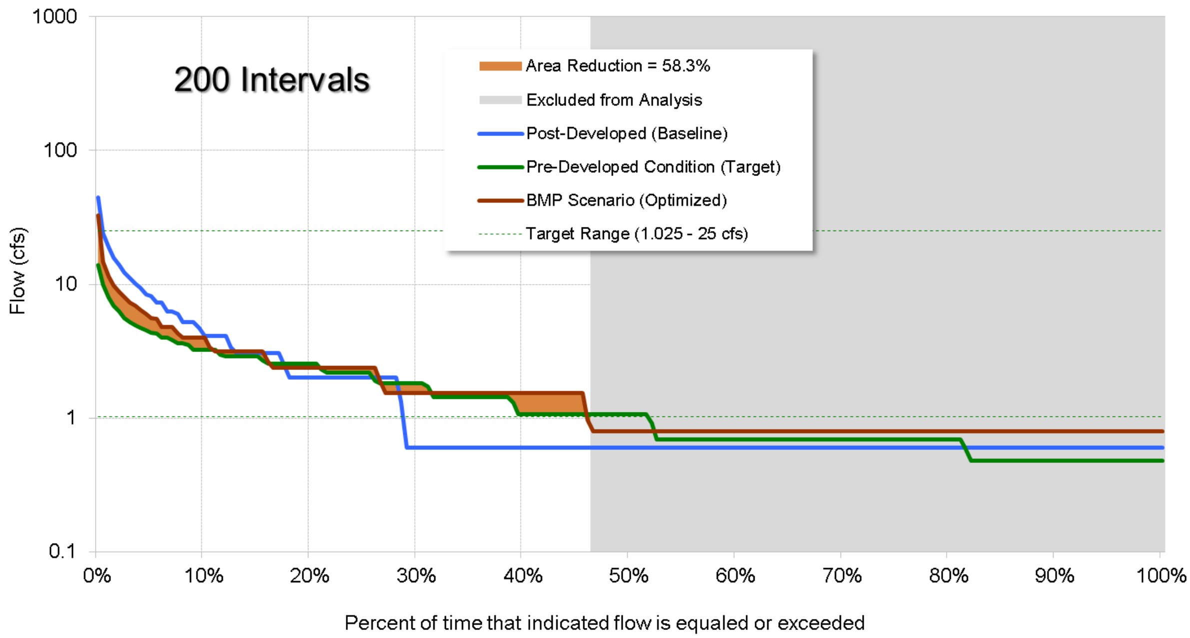


Figure 2-10. Flow duration curve (FDC) evaluation factor.

Two cards (**c814 and c815**) are related to the FDC Evaluation Factor. As shown below, **Card 814** specifies the pre-developed condition for the FDC evaluation factor. The number of bins is also specified on **Card 814** (**NumBins** in the input file). This user input defines the number of bins (i.e. discrete integration intervals) used to estimate the area between the FDCs. Each bin is represented on the FDC by an average flow value derived from all the flow records within each bin. Therefore, fewer bins will result in a coarser curve.

```
c------------------------------------------------------------------------------------------
c814 Predeveloped Timeseries at Assessment Point for Flow Duration Curve
c
c BMPSITE        = BMP site identifier in card 715 if it is an assessment point
c NumBins        = Number of bins for flow duration curve
c PreDevFlag     = Pre-developed timeseries option (1-internal,2-external)
c PreDevFile     = Pre-developed timeseries file path for external option
c                  The timeseries file format (AssessmentPoint_ID  Year  Month  Day  Hour  Minute  Flow_cfs)
c                  The first line is skipped (comment line) and data start from the second line in the required format.
c
c BMPSITE   NumBins   PreDevFlag   PreDevFile
5           20000       1
c------------------------------------------------------------------------------------------
```

As shown below, with 200 bins the curve shows a stepped pattern, while with 20,000 bins the curve is smooth. Using more bins increases precision, but also increases overall run time, given that this area calculation must be done with each optimization iteration. Model testing suggests that using 20,000 bins (also referred to as intervals) is an optimal number considering both model precision and run time implications. Table 2-11 shows the comparison of sort time and precision by number of approximation bins.



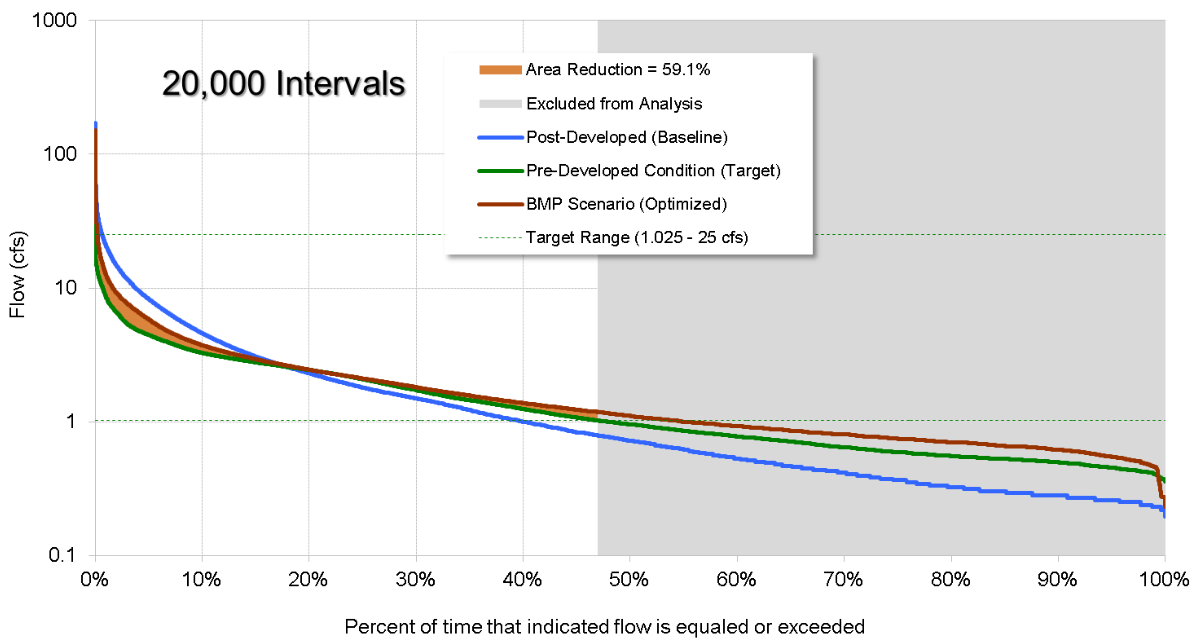


Table 2-11. Sort time (10-year run) by number of bins

Number of Bins	Processing time (seconds)	Percent Error
87,600	8	0.00%
40,000	0.5	0.19%
20,000	< 0.5	0.18%
10,000	< 0.5	0.85%
2,000	< 0.5	-0.51%
200	< 0.5	-1.19%

In **Card 815** the FDC option can be selected by using **-4** as FactorType, while specifying the low and high flow limits in **FactorVal1** and **FactorVal2** columns, respectively.

```
c------------------------------------------------------------------------------------------
c815 Assessment Point and Evaluation Factor
c
c BMPSITE -- BMP site identifier in card 715 if it is an assessment point
c FactorGroup -- Flow or pollutant related evaluation factor group
c    -1 = flow related evaluation factor
c     # = pollutant ID in card 705
c FactorType -- Evaluation Factor Type (negative number for flow related and positive number for pollutant related)
c    -1 = AAFV Annual Average Flow Volume (ft3/yr)
c    -2 = PDF  Peak Discharge Flow (cfs)
c    -3 = FEF  Flow Exceeding frequency  (#times/year)
c    -4 = FDC  Flow Duration Curve (sum of sorted flow difference with pre-developed condition, cfs)
c     1 = AAL  Annual Average Load (lb/yr)
c     2 = AAC  Annual Average Concentration (mg/L)
c     3 = MAC  Maximum #days Average Concentraion (mg/L)
c FactorVal1 -- if FactorType = 3 (MAC): Maximum #Days;
c             -- if FactorType = -3 (FEF): Threshold (cfs)
c             -- if FactorType = -4 (FDC): Low flow limit (cfs)
c             -- all other FactorType : -99
c FactorVal2 -- if FactorType = -3 (FEF): Minimum inter-exceedance time (hr)
c                                  if =  0 then daily running average flow exceeding frequency
c                                  if = -1 then daily average flow exceeding frequency
c                                  otherwise minimum inter-exceedance time for simulation interval
c             -- if FactorType = -4 (FDC): High flow limit (cfs)
c             -- all other FactorType : -99
c CalcMode -- Evaluation Factor Calculation Mode
c   -99 for Option 0 (card 800): no optimizaiton
c     1 = % percent of value under existing condition (0-100)
c     2 = S scale between pre-develop and existing condition (0-1)
c     3 = V  absolute value in the unit as shown in FactorType (third block in this card)
c TargetVal1 -- Target value for evaluation factor calculation mode
c    -99 for Option 0 (card 800): no optimizaiton
c    Target value for minimize cost Option 1 (card 800)
c    Lower limit of target value for cost-effective curve Option 2 (card 800)
c TargetVal2 -- Target value for evaluation factor calculation mode
c    -99 for Option 0 (card 800): no optimizaiton
c    -99 for Option 1 (card 800): minimize cost
c    Upper limit of target value for cost-effective curve Option 2 (card 800)
c Factor_Name -- Evaluation factor name (user specified without any space), e.g. FlowVolume or SEDIMENT
c
c BMPSITE   FactorGroup   FactorType   FactorVal1   FactorVal2   CalcMode   TargetVal1   TargetVal2   FactorName
5          -1            -4           0.23         16           1          0            100          FDC_%
c------------------------------------------------------------------------------------------
```

In this exercise, the low flow limit is 8 percent of the 2-year flow, and high limit is the 100 percent of the 50-year peak flow. The basis for the flow limits is Ecology's flow duration standards for stream protection, which stipulates that the FDC for the developed condition with BMPs should matching the predevelopment FDC between 50 percent of the 2-year to 100 percent of the 50-year peak flow. In some cases, the LID standard also applies, which stipulates that the developed condition with BMPs should match the predevelopment runoff FDC from 8 percent of the 2-year to 50 percent of the 2-year peak flow. In some instances both FDC standards apply (such as the example above), while in other instances only the LID standard will apply. By allowing **FactorVal1** and **FactorVal2** to be user-defined variables, the user has the flexibility to customize the evaluation factor as needed.

3. Setup Optimization

The optimization setup in the *SUSTAIN* input file includes **Cards 800** and **810**. As shown below, **Card 800** defines the optimization controls, including optimization technique, optimization option and other parameters. In this exercise, NSGAII is applied to generate the cost-effectiveness curve, with a maximum of 100 iteration runs. **Card 810** defines the decision variables, including the BMP site, variable type, and minimum, maximum, and search increment values. In this exercise, the infiltration basin's number of units is the decision variable, and its value changes from 0 to 1,000 with 10 as the search increment step.

```
c-------------------------------------------------------------------------------------------
c800 Optimization Controls
c
c Technique -- Optimization Techniques
c    0 = no optimization
c    1 = Scatter Search
c    2 = NSGAII
c Option -- Optimization options
c    0 = no optimization
c    1 = specific control target and minimize cost
c    2 = generate cost effectiveness curve
c StopDelta -- Criteria for stopping the optimization iteration
c           in dollars($), meaning if the cost not improved by this criteria, stop the search (for Option 1)
c MaxRuns -- Maximum number of iterations
c NumBest -- Number of best solutions for output (for Option 1)
c
c Technique   Option   StopDelta   MaxRuns   NumBest
2             2        0           100       2
c-------------------------------------------------------------------------------------------
c810 BMP SITE Adjustable Parameters
c
c BMPSITE        = BMP site identifier in card 715
c VARIABLE       = Variable name (must use the exact same keyword)
c                    LENGTH --- BMP length,
c                    NUMUNIT --- number of units,
c                    WEIRH --- weir height,
c                    SDEPTH --- soil media depth,
c                    DCIA --- directly connected impervious area for area BMP type,
c                    MAXDEPTH --- maximum surface storage depth for swale,
c                    CECURVE --- cost-effectiveness curve for Tier-1 solution
c FROM           = From value in the range
c TO             = To value in the range
c STEP           = Increment step
c
c BMPSITE   VARIABLE   FROM   TO   STEP
6           NUMUNIT    0      1000   10
c-------------------------------------------------------------------------------------------
```

4. Run SUSTAIN Simulation

SUSTAIN can then be run using a batch file. For this example, launch ***Exercise3.bat*** by clicking on the file**,** which will start the optimization run. The file is located under the *SUSTAIN* installation folder (e.g., *C:\SUSTAIN\DATA\WRIA9*). Running *SUSTAIN* in batch mode provides some convenient benefits—after an input file is created, running in batch mode requires no GIS software to launch the simulation. Additionally, one might be interested in using the same physical model to run alternative optimization scenarios using different management objectives, which would only require changing one or two lines for each scenario file. See exercise 4 for more detailed information on how to execute a batch mode model run.

Don't forget to change your output file paths! Also be mindful of disk space!
When cloning an input file to run multiple scenarios in batch mode, in addition to changing the desired evaluation factors, you should ensure that the corresponding output file paths (in Card 700) are unique for each scenario input file you make. Otherwise, subsequent runs will overwrite previous outputs if the same output file path is used. Also be mindful of available disk size. There is no limit on the number of batch runs allowed; however, depending on the output configurations, disk space requirements are compounded when run in batch mode.

The instructions to compile the batch file are summarized in the **SUSTAINOPT.readme** file located under the *SUSTAIN* installation folder (e.g., *C:\SUSTAIN\ETC*). The content is also copied below.

SUSTAIN command line executable. The structure and flags are as follows:

> SUSTAINOPT.exe [FLAG] [INPUT FILE] [OPTIONAL: SOLUTION NUMBER]

Flag
0 – Single run, standard mode, and the message boxes are enabled.
1 – Batch Mode w/ Timeseries output, and the message boxes are disabled
2 – Batch Mode w/o Timeseries output, and the message boxes are disabled
3 – Run using selected solution from the BestSolutions.out file
(NOTE: If more than one solution, should be space delimited list with quotation marks)

Examples - Run the input file as is, not in batch mode
> SUSTAINOPT.exe 0 C:\SUSTAIN\Projects\MyProject\MyInputFile.inp

Examples - Run the input file with selected solution #5 & #12 from BestSolutions.out
> SUSTAINOPT.exe 3 C:\SUSTAIN\Projects\MyProject\MyInputFile.inp "5 12"

If any unknown flag is specified, too few parameters are given, or the user gives a '-h' flag for help; the tool will print example usage and options to the console.

Note: SUSTAINOPT.exe and batch file (.bat) should be located at the same location otherwise enter the full file path for SUSTAINOPT.exe in the batch file as shown below.*

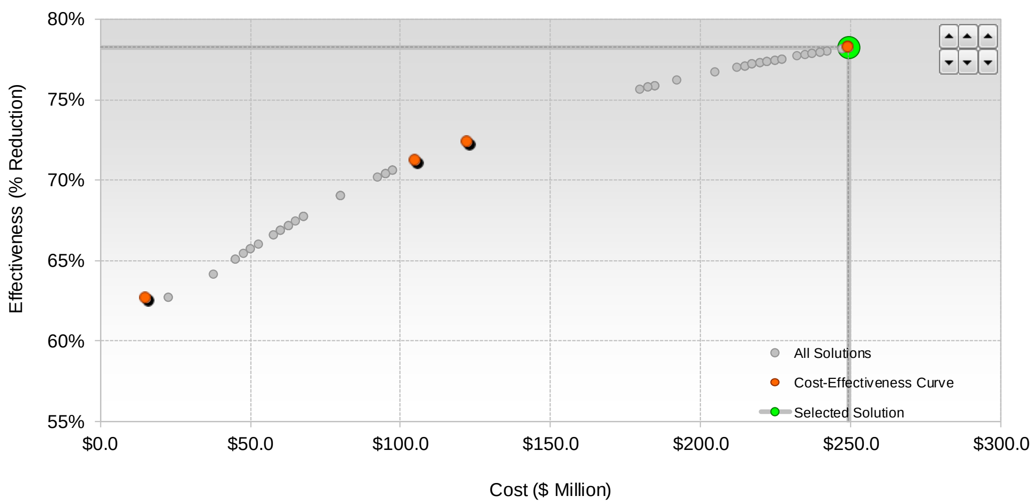
> C:\SUSTAIN\ETC\SUSTAINOPT.exe 0 C:\SUSTAIN\Projects\MyProject\MyInputFile.inp

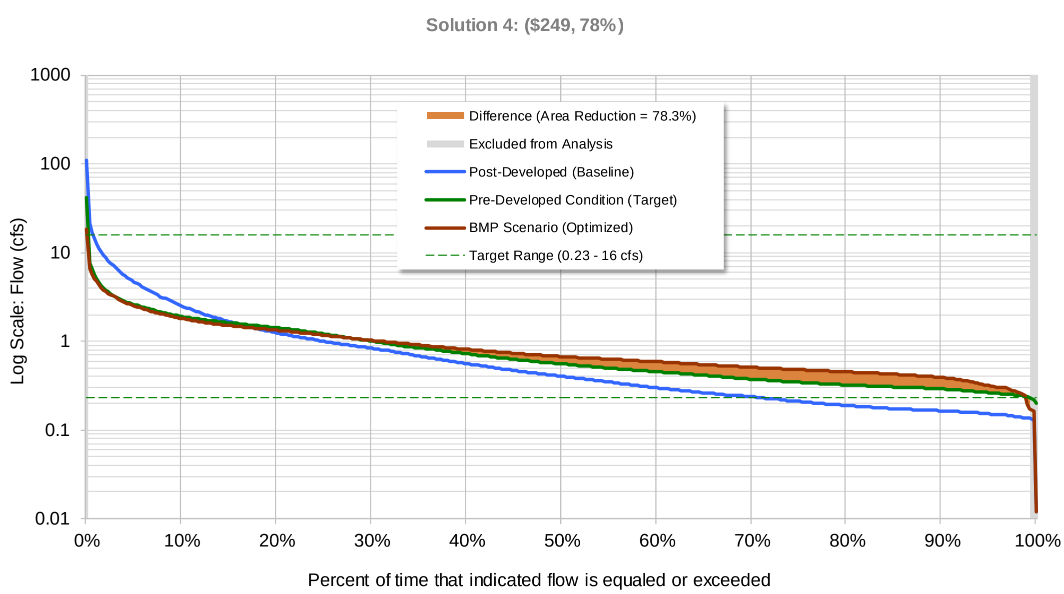
5. <u>View SUSTAIN Results</u>

Once the run is complete, the files shown below are generated in the output folder. With the FDC option applied, a file containing the FDC data (exceedance frequency and corresponding flow values) is generated for each of the Init, PostDev, and PreDev scenarios.

Name	Size	Type
AllSolutions	11 KB	OUT File
BestSolutions	1 KB	OUT File
Init_Eval	1 KB	OUT File
Init_FDC	217 KB	OUT File
Init_J5_5	24,706 KB	OUT File
PostDev_Eval	1 KB	OUT File
PostDev_FDC	217 KB	OUT File
PostDev_J5_5	24,706 KB	OUT File
PreDev_Eval	1 KB	OUT File
PreDev_FDC	216 KB	OUT File
PreDev_J5_5	24,706 KB	OUT File

The FDCs can then be plotted in the post-processor. As shown below, the selected solution (BMP scenario) along with the pre-developed and post-developed FDCs are plotted. As with other evaluation factors, the FDC evaluation factor between the user-defined flow target range is also calculated as a percent reduction between the selected solution and the pre-developed FDCs.





2.3.3. *Summary*

This exercise demonstrated each of the three new features in *SUSTAIN*, including using F-tables to define BMPs and/or reach segments, aquifers to represent groundwater storage and release to baseflow, and the FDC evaluation factor for BMP optimization. Each of these new features relies on advanced knowledge of the *SUSTAIN* model and requires modification to input cards. This exercise also reviewed the process of optimization setup/configuration from within an input file as well as running *SUSTAIN* input files in batch mode.

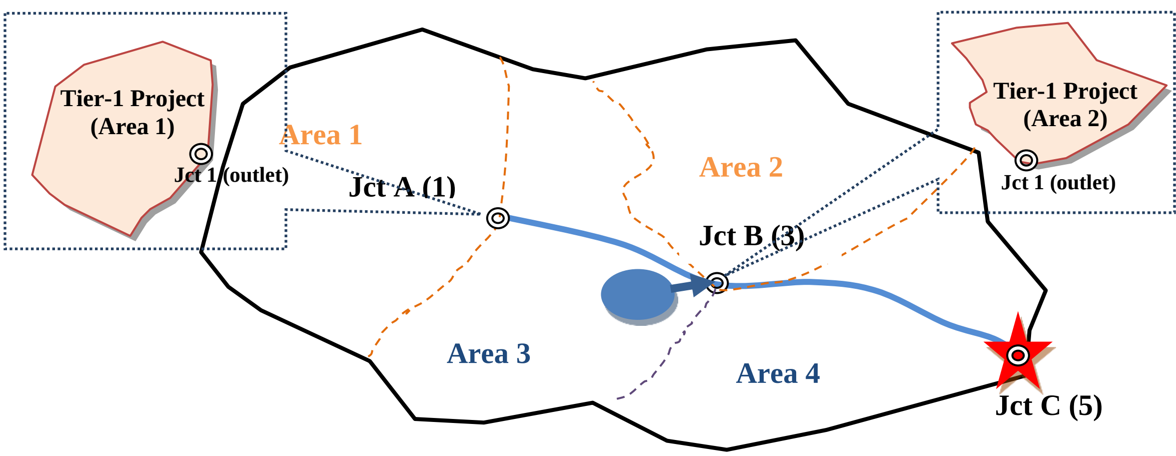
2.4. Exercise 4 – Tiered Optimization Setup

This exercise demonstrates the methodology of using a tiered analysis to extrapolate small scale BMP optimization results to a larger area. It is important to note that the term *tiered* refers to spatially nested units, for example, subwatershed to watershed or HRU to watershed.

2.4.1. *Project Overview*

Study Area Description

Because none of the Region 10 grantees utilized a tiered analysis, a hypothetical study watershed composed of four areas was created for this exercise. Area 1 and Area 2 have the same land use distribution as the pilot area used in Exercise 1. However, Area 1 and Area 2 differ in background soil characteristics, Area 1 (100 acres) is on till soil (less permeable) and Area 2 (100 acres) is on outwash soil (more permeable). Area 3 (200 acres), which is on till, is developed and can be potentially treated by a detention pond. Area 4 (100 acres) is not developed (forested), therefore no BMPs are proposed. The figure below shows the layout and routing network of the four areas, proposed detention pond, junctions, and connecting stream reaches. Notice that Junction B (3) is the common outlet for Area 2 and Area 3 in the Tier-2 project. The Tier-1 projects were created separately for Area 1 and Area 2 and each has an assigned Junction 1 (outlet) as the assessment point from the Tier-1 analysis as shown in the figure below. The output timeseries files "*_*Junction_1.out*" from the Tier-1 projects are linked to Tier-2 Junctions 1 and 3 in the input card 722.



Reach AB (connecting Junction A and Junction B) and Reach BC (connecting Junction B and Junction C) are modeled in *SUSTAIN* as dummy conduits. Junction C is the watershed outlet, and is designated as the assessment point. The project objective is to develop a cost-effectiveness curve that shows the improvement in FDC (measured relative to the FDC under forested condition) versus cost.

For this exercise, results from the King County pilot-study areas are used to represent each of the individual Tier-1 subwatersheds at different points in the network (shown as Areas 1 and 2 above). Those results are then routed back into the hypothetical network above, which represents the Tier-2 search space. Besides each of the two Tier-1 subwatersheds (Areas 1 and 2 draining to Junctions 1 and 3, respectively), the Tier-2 watershed area also includes Area 3, which is controlled by a detention pond, and forested Area 4. The Tier-2 optimization decision variables will include the BMP solutions from the two Tier-1 cost-effectiveness curves as well as the size of the detention pond treating Area 3.

Highlights

- Demonstrate the use of tiered analysis to extrapolate BMP optimization results from small scale analysis to a larger study area
- Demonstrate how to run *SUSTAIN* in batch mode

2.4.2. *Step-by-Step Instructions*

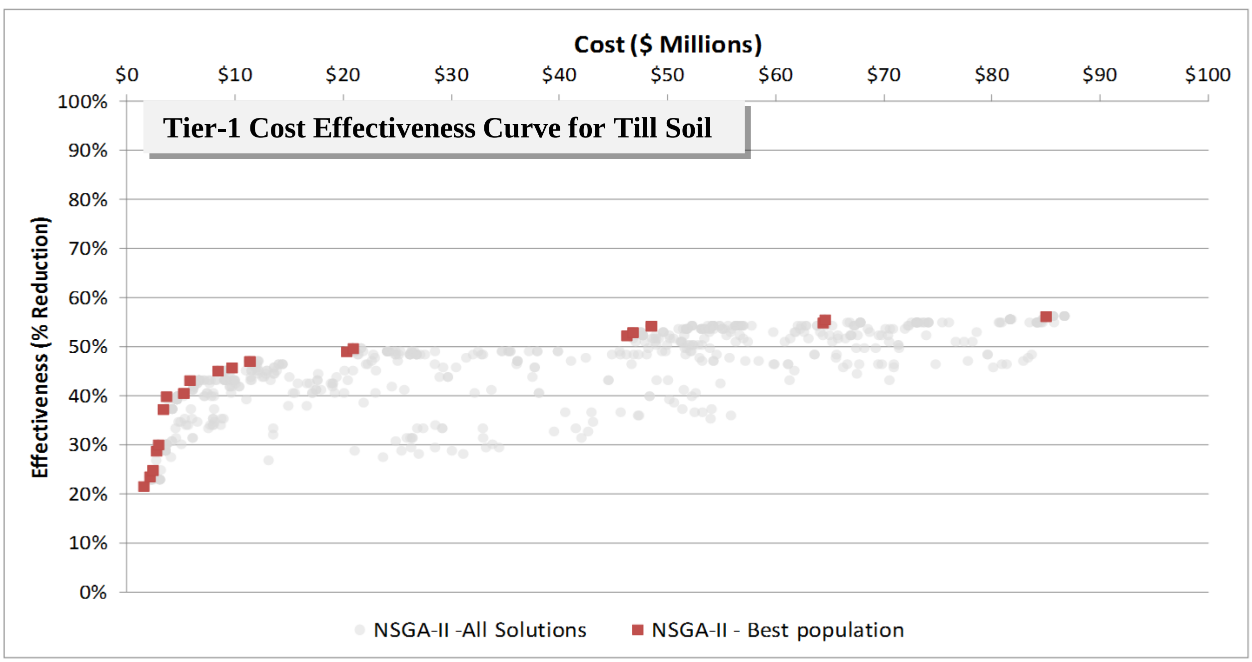
To complete this exercise, you will perform the following steps:

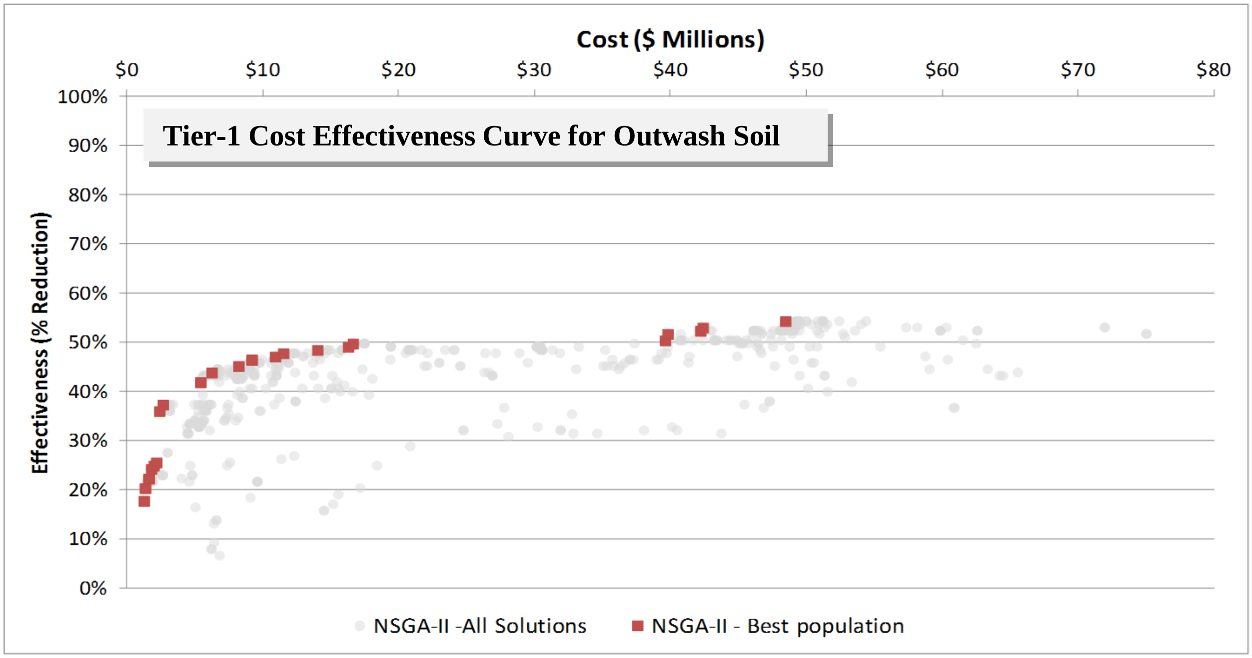
1. Prepare Required Data
2. Run Tier-1 Selected Best Solutions in Batch Mode
3. Compile Tier-2 Optimization File
4. Run Tier-2 Optimization
5. View Tier-2 Optimization Results

1. <u>Prepare Required Data</u>

The GIS interface of *SUSTAIN* version 1.2 does not create a Tier-2 input file; therefore users must edit the input file manually to create a Tier-2 optimization file. For this exercise, the following information is needed to edit the input file:

- Runoff timeseries for all land use types (HRUs)
- Infiltration basin design (F-table) and unit cost (see Exercise 3 for the instructions on creating an F-table)
- Tier-1 input files and Tier-1 optimization run output files. The results from the King County pilot study (two Tier-1 projects) are used in this exercise (see cost effectiveness curves for till soil and outwash soil below).





2. *Run Tier-1 Selected Best Solutions in Batch Mode*

Two sets of files are used for this exercise: (1) Tier-1 optimization input files "***Tier1_till.inp and Tier1_outwash.inp"***, output files for each Tier-1 optimization run to be used for the Tier-1 areas, and (2) the unit-area land based timeseries files provided in the *SUSTAIN* installation package to be used for the remainder of the watershed. A batch file, ***Exercise4_Tier1.bat***, is also provided in the software installation package that will be used to generate the **CECurve_Solutions.out** file and the **timeseries files** for the selected best solutions on the Tier-1 cost effectiveness curve. The content of the batch file is shown below.

C:\SUSTAIN\ETC\SUSTAINOPT.exe 3 C:\SUSTAIN\DATA\WRIA9\Tier1_till.inp "1 9 11 12 10"
C:\SUSTAIN\ETC\SUSTAINOPT.exe 3 C:\SUSTAIN\DATA\WRIA9\Tier1_outwash.inp "20 5 10 12 3"

As described in the **SUSTAINOPT.readme file** located under the *SUSTAIN* installation folder (e.g., C:\SUSTAIN\ETC\), running the *SUSTAIN* command line executable with **Flag = 3** will run selected solutions from the **BestSolutions.out** file (Tier-1 optimization output file). The selected solutions are identified by the solution IDs, which are listed in the first column ("NO") of BestSolutions.out file, as shown below.

1	5 NSGA-II - Best population		
NO.	TotalCost($)	TotalSurfaceArea(ac)	
1	1514305.600000	0.738223	3.634185
2	84948726.400000	31.179858	114.921031
3	46181995.600000	15.491215	47.784934
4	20884071.200000	7.586222	26.247042
5	84948726.400000	31.179858	114.921031
6	64525465.600000	20.931965	61.045212
7	64336345.600000	20.863094	60.838601
8	3319461.200000	1.560075	7.411029
9	2882515.600000	1.392491	6.354559
10	48452781.200000	16.504919	52.245562
11	5778021.200000	2.455388	10.096969
12	20272341.200000	7.207436	24.353111
13	11322921.200000	4.432948	16.678997

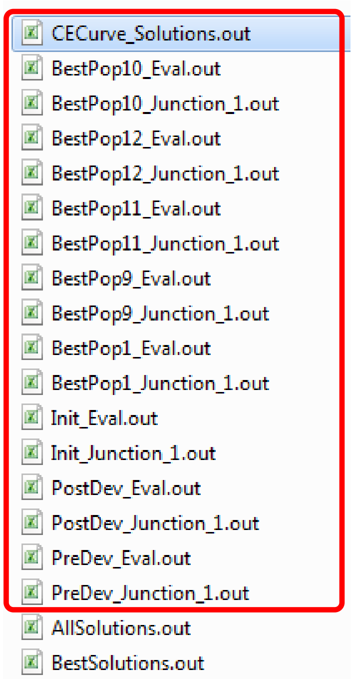
Notice that when outputted from the model, the solutions in **BestSolutions.out** file are not sorted by cost. The Tier-1 solution set is composed of a user-selected subset of optimization solutions, which should be sorted in order of increasing cost. When adding a Tier-1 solution to the Tier-2 input file, the solution IDs should be reordered by increasing associated cost as shown in the text box below.

Be sure to reorder your Tier-1 solutions by cost (from lowest to highest).

For the example of Tier-1 till soil:
C:\SUSTAIN\ETC\SUSTAINOPT.exe 3 C:\SUSTAIN\DATA\WRIA9\Tier1_till.inp "1 9 11 12 10"

Cost of solution 1 < 9 < 11 < 12 < 10, with 10 having the highest cost. An easy way to do this is to open the BestSolutions.out file in a spreadsheet and sort the solutions by the **TotalCost($)** column. Plotting the solutions also helps to pick a set of solution IDs ("**NO"**) that are well distributed across the cost-benefit response range of interest.

The output files generated by running the *SUSTAIN* command line executable with Flag 3 are listed below marked in the redline box. The files include the three default conditions (Init, PostDev, PreDev), plus a BestPop file associated with the Tier-1 solutions. Each set of files contains an "*_Eval.out" file with the computed evaluation factor and a "*_Junction_1.out" file with the associated timeseries.



Also a file called "CECurve_Solutions.out" is generated. As illustrated below, the CECurve_Solutions.out file includes a newly assigned solution ID, which follows the new order of the selected Tier-1 solutions. Notice that the cost column (the third column) is sorted from low to high, as arranged in the model configuration file.

NSGA-II Cost-Effectiveness Curve Solutions

BestPop#	Solution#	Cost($)	1_FEF_1	1_1_NUMUNIT	1_2_NUMUNIT	1_3_NUMUNIT	1_4_NUMUNIT	1_7_NUMUNIT	1_5_NUMUNIT	1_6_NUMUNIT
1	1	1514305.600000	78.431373	0.000000	30.000000	0.000000	0.000000	60.000000	10.000000	0.000000
2	1	2882515.600000	69.934641	0.000000	240.000000	0.000000	0.000000	180.000000	10.000000	0.000000
3	1	5778021.200000	56.862745	0.000000	30.000000	0.000000	0.000000	570.000000	20.000000	0.000000
4	1	20272341.200000	50.980392	0.000000	30.000000	2160.000000	0.000000	480.000000	20.000000	0.000000
5	1	48452781.200000	45.751634	0.000000	30.000000	6120.000000	0.000000	570.000000	20.000000	0.000000

3. *<u>Compile Tier-2 Optimization File</u>*

For this exercise, use the ***Tier2_optimization.inp*** file which is provided in the *SUSTAIN* installation package (e.g., *C:\SUSTAIN\DATA\WRIA9*). Also, Appendix A has the complete *SUSTAIN* input file for this exercise, i.e. *Tier2_optimization.inp*. The Tier-2 optimization objective is to restore a critical portion of the stream FDC at the Tier-2 watershed outlet to the pre-developed (forested) condition.

The *SUSTAIN* GIS interface does not accommodate a tiered analysis, so the user must manually edit input files to apply this feature. A Tier-2 input file has the same structure as any other *SUSTAIN* input file to describe the drainage area and BMP (only at Tier-2 level) information. For the Tier-2 input file, the user must populate two additional cards: **Cards 721 and 722**. Also, the user must specify the decision variable name/type in **Card 810** as **CECurve** in order to integrate the Tier-1 outlet.

Card 721 is used to specify the Tier-1 area/subwatershed outlet site ID, the number of solutions for the Tier-1 cost-effectiveness curve, and the file path of the **CECurve_Solutions.out**. Please note that the Tier-1 outlet site ID is defined in the Tier-2 input file, and is **unrelated** to the IDs defined in the Tier-1 input files. For example Tier-1 subwatershed outlet ID for Area 2 was defined as 1 in the Tier-1 input file but it is defined as 3 in the Tier-2 input file. Input one line for each of the Tier-1 analyses being used to run the Tier-2 analysis. It is helpful for the user to draw and label the multi-tiered routing network as an aid to model setup. In the example below there are two sets of Tier-1 solutions for Junctions 1 and 3, respectively, each with five points defined along the respective cost effectiveness curves.

```
c-----------------------------------------------------------------------------------------
c721 Tier-1 Watershed Outlets Definition
c
c BMPSITE        = BMP site (watershed outlet) identifier in card 715
c NUMBREAKS      = Number of break points on the cost-effectiveness curve
c BMPSITE    NUMBREAKS    TRADEOFFCURVEFILE
1           5           C:\SUSTAIN\DATA\WRIA9\Tier1_till_output\CECurve_Solutions.out
3           5           C:\SUSTAIN\DATA\WRIA9\Tier1_outwash_output\CECurve_Solutions.out
c-----------------------------------------------------------------------------------------
```

Card 722 is used to define the timeseries files for the best solutions included in the **CECurve_Solutions.out** file for each Tier-1 outlet. In **Card 722**, as shown below, the user must specify the following:

- BMPSITE is the Junction ID given in Tier-2 input file where the Tier-1 watershed output timeseries files are added (in this exercise, Junction 1 for Tier-1 subwatershed area 1 and Junction 3 for Tier-1 subwatershed area 2).
- BREAKPOINTID indicates the condition (i.e. initial, pre-developed, post-developed, best solutions) that the timeseries is representing; Breakpoint 0 indicates initial condition, -1 for pre-development condition, -2 for post-development condition, positive numbers (in this example from 1 to 5) correspond to the solution IDs specified in the first column of the CECurve_Solutions.out file.
- MULTIPLIER is needed only if the timeseries represents a different area as opposed to the entire drainage area. The MULTIPLIER will be applied to the timeseries file when it is added to the site, when the timeseries is for a unit area; the multiplier is an indicator of the drainage area to the site. In this example, the multiplier is 0.5 because the timeseries files are for 200 acres, and each

of the two tier-1 areas at junctions 1 and 3 is 100 acres. A multiplier of 0.5 scales the 200-acre timeseries to 100-acres.

- TIMESERIESFILE is the directory and file name of the Tier-1 output timeseries file. The timeseries files are the flow and water quality timeseries corresponding to each solution along the tier-1 cost-effectiveness curve for each tier-1 junctions. Notice that Tier-1 output timeseries file names (*_Junction_1.out) shown in this example correspond to the Tier-1 subwatershed outlet IDs that are also unrelated to the site ID defined in Tier-2.

```
c-------------------------------------------------------------------------------------------
c722 Tier-1 Watershed Timeseries Definition
c
c BMPSITE              = BMP site (watershed outlet) identifier in card 721
c BREAKPOINTID         = Unique break point id on cost-effectiveness curve
c                        (0 for initial, -1 for PreDev, and -2 for PostDev condition)
c MULTIPLIER    = Multiplier applied to the timeseries file
c TIMESERIESFILE       = Timeseries output file corresponding to the breakpoint id
c
c  BMPSITE   BREAKPOINTID   MULTIPLIER   TIMESERIESFILE
1      -2      0.5      C:\SUSTAIN\DATA\WRIA9\Tier1_till_output\PostDev_Junction_1.out
1      -1      0.5      C:\SUSTAIN\DATA\WRIA9\Tier1_till_output\PreDev_Junction_1.out
1      0       0.5      C:\SUSTAIN\DATA\WRIA9\Tier1_till_output\Init_Junction_1.out
1      1       0.5      C:\SUSTAIN\DATA\WRIA9\Tier1_till_output\BestPop1_Junction_1.out
1      2       0.5      C:\SUSTAIN\DATA\WRIA9\Tier1_till_output\BestPop9_Junction_1.out
1      3       0.5      C:\SUSTAIN\DATA\WRIA9\Tier1_till_output\BestPop11_Junction_1.out
1      4       0.5      C:\SUSTAIN\DATA\WRIA9\Tier1_till_output\BestPop12_Junction_1.out
1      5       0.5      C:\SUSTAIN\DATA\WRIA9\Tier1_till_output\BestPop10_Junction_1.out
3      -2      0.5      C:\SUSTAIN\DATA\WRIA9\Tier1_outwash_output\PostDev_Junction_1.out
3      -1      0.5      C:\SUSTAIN\DATA\WRIA9\Tier1_outwash_output\PreDev_Junction_1.out
3      0       0.5      C:\SUSTAIN\DATA\WRIA9\Tier1_outwash_output\Init_Junction_1.out
3      1       0.5      C:\SUSTAIN\DATA\WRIA9\Tier1_outwash_output\BestPop20_Junction_1.out
3      2       0.5      C:\SUSTAIN\DATA\WRIA9\Tier1_outwash_output\BestPop5_Junction_1.out
3      3       0.5      C:\SUSTAIN\DATA\WRIA9\Tier1_outwash_output\BestPop10_Junction_1.out
3      4       0.5      C:\SUSTAIN\DATA\WRIA9\Tier1_outwash_output\BestPop12_Junction_1.out
3      5       0.5      C:\SUSTAIN\DATA\WRIA9\Tier1_outwash_output\BestPop3_Junction_1.out
c-------------------------------------------------------------------------------------------
```

BMP decision variables include Tier-1 optimal BMP solutions for Area 1 and Area 2 (BMPSITE ID's 1 and 3 to represent the drainage junctions for each area), and size (number of units) of detention pond treating the developed area in Area 3 (BMPSITE ID 6). The decision variables are assigned in **Card 810** as shown below. Please note that the variable name/type for the Tier-1 solutions must be defined as **CECurve** in **Card 810** to integrate the decision variables as the Tier-1 solutions.

```
c-------------------------------------------------------------------------------------------
c810 BMP SITE Adjustable Parameters
c BMPSITE       = BMP site identifier in card 715
c VARIABLE      = Variable name
c FROM          = From value in the range
c TO            = To value in the range
c STEP          = Increment step
c
c BMPSITE       VARIABLE       FROM   TO       STEP
6      NUMUNIT        0        200      5
1      CECurve        0        5        1
3      CECurve        0        5        1
c-------------------------------------------------------------------------------------------
```

4. *Run Tier-2 Optimization*

Run the Tier-2 optimization input file either from the GIS interface or using the batch file demonstrated previously with the *SUSTAIN* executable (SUSTAINOPT.exe) file. Tier-2 optimization runs will generate the same set of output files as Tier-1 optimization runs.

5. *View Tier-2 Optimization Results*

The decision variable values in the **AllSolutions.out** and **BestSolutions.out** files from the Tier-2 optimization outputs correspond to the solution IDs specified in the Tier-1 **CECurve_Solutions.out** file. Those IDs are the link whereby the user can trace back to the details of the Tier-1 solutions to find the resulting BMP sizes associated with that solution. As illustrated below in the example **BestSolutions.out** file, the last three columns list the decision variable values for the best solutions. 1_CECurve and 3_CECurve are the two Tier-1 decision variables; the values corresponding to the solutions IDs listed in the **CECurve_Solutions.out** files. In this example below, solution number 12 selected the 3rd point in the Junction 1 curve for Area 1 ("1_CECurve"). This corresponds to solution 11 from the Tier-1 analysis, which selected 30 units of the "Cistern1" BMP, 570 units of the "BioRetentionBasin3" BMP, and 20 units of the "WetPond1" BMP (BMP Site 1_2, 1_7, and 1_5 respectively in *Tier1_till.inp file*). For Junction 3 curve ("3_CECurve"), Tier-2 optimization selected the 2nd point in the curve. This corresponds to solution 5 from the Tier-1 analysis, which selected 120 units of the "Cistern1" BMP, 120 units of the "BioRetentionBasin3" BMP, and 10 units of the "WetPond1" BMP (BMP Site 1_2, 1_7, and 1_5 respectively in *Tier1_outwash.inp file*). For Area 3 ("6_NUMUNIT"), Tier-2 optimization selected 30 units of the "WP1" BMP (BMP Site 6 in *Tier2_optimization.inp* file).

Tier-1 Definition Runs:

Area 1 – C:\SUSTAIN\ETC\SUSTAINOPT.exe 3 C:\SUSTAIN\DATA\WRIA9\Tier1_till.inp "1 9 11 12 10"

Area 3 – C:\SUSTAIN\ETC\SUSTAINOPT.exe 3 C:\SUSTAIN\DATA\WRIA9\Tier1_outwash.inp "20 5 10 12 3"

Tier-2 Solution IDs	Original IDs (Tier-1)	
	Area 1 (Till)	Area 2 (Outwash)
1	1	20
2	9	5
3	11	10
4	12	12
5	10	3

BestSolutions.out:

NO.	TotalCost ($)	TotalSurfaceArea(ac)	TotalExcavatnVol(ac-ft)	TotalSurfStorVol(ac-ft)	TotalSoilStorVol(ac-ft)	TotalUdrnStorVol(ac-ft)	5_FDC_%_1	WETPOND	1_CECurve	6_NUMUNIT	3_CECurve
1	72373087	20.739756	124.438535	104.038775	7.258915	0	21.358106	42397845.46	5	170	4
2	2004148	0.609993	3.659957	3.059964	0.213497	0	71.539922	1246995.455	1	5	0
3	63960607	18.909777	113.458664	94.858883	6.618422	0	25.870639	38656859.1	5	155	2
4	37457214	3.659957	21.959741	18.359784	1.280985	0	28.017348	7481972.728	5	30	4
5	32785721	3.659957	21.959741	18.359784	1.280985	0	32.135952	7481972.728	5	30	2
6	16119834	3.659957	21.959741	18.359784	1.280985	0	35.534119	7481972.728	3	30	4
7	3081506	0.609993	3.659957	3.059964	0.213497	0	68.768206	1246995.455	1	5	2
8	4328502	1.219986	7.319914	6.119928	0.426995	0	56.444335	2493990.909	1	10	2
9	6992130	3.049964	18.299785	15.29982	1.067487	0	47.233956	6234977.274	1	25	0
10	3251144	1.219986	7.319914	6.119928	0.426995	0	58.491047	2493990.909	1	10	0
11	10201346	3.049964	18.299785	15.29982	1.067487	0	41.350772	6234977.274	3	25	2
12	11448341	3.659957	21.959741	18.359784	1.280985	0	40.021756	7481972.728	3	30	2

CECurve_Solutions.out (Tier-1 Area 1):

NSGA-II Cost-Effectiveness Curve Solutions

BestPop#	Solution#	Cost($)	1_FEF_1	1_1_NUMUNIT	1_2_NUMUNIT	1_3_NUMUNIT	1_4_NUMUNIT	1_7_NUMUNIT	1_5_NUMUNIT	1_6_NUMUNIT
1	1	1514305.600000	78.431373	0.000000	30.000000	0.000000	0.000000	60.000000	10.000000	0.000000
2	1	2882515.600000	69.934641	0.000000	240.000000	0.000000	0.000000	180.000000	10.000000	0.000000
3	1	5778021.200000	56.862745	0.000000	30.000000	0.000000	0.000000	570.000000	20.000000	0.000000
4	1	20272341.200000	50.980392	0.000000	30.000000	2160.000000	0.000000	480.000000	20.000000	0.000000
5	1	48452781.200000	45.751634	0.000000	30.000000	6120.000000	0.000000	570.000000	20.000000	0.000000

CECurve_Solutions.out (Tier-1 Area 2):

NSGA-II Cost-Effectiveness Curve Solutions

BestPop#	Solution#	Cost($)	1_FEF_1	1_1_NUMUNIT	1_2_NUMUNIT	1_3_NUMUNIT	1_4_NUMUNIT	1_7_NUMUNIT	1_5_NUMUNIT	1_6_NUMUNIT
1	1	1237795.600000	82.352941	0.000000	0.000000	0.000000	0.000000	30.000000	10.000000	0.000000
2	1	2154715.600000	74.509804	0.000000	120.000000	0.000000	0.000000	120.000000	10.000000	0.000000
3	1	5399781.200000	58.169935	0.000000	30.000000	0.000000	0.000000	510.000000	20.000000	0.000000
4	1	11497701.200000	52.287582	0.000000	270.000000	720.000000	0.000000	570.000000	20.000000	0.000000
5	1	16619991.200000	50.326797	0.000000	240.000000	1440.000000	0.000000	600.000000	20.000000	0.000000

2.4.3. *Summary*

This exercise demonstrated using a multi-scale optimization approach to evaluate a larger watershed. A tiered approach was used to simplify the optimization search while preserving the physically-based process response. In this exercise, the user split an optimization problem with a large number of decision variables into subsets, or tiers. The advantage of using a tiered approach is that subsets of the area (Tier-1) can be pre-optimized to streamline the larger-scale search space (Tier-2) so that it only has to select from optimized solutions along the Tier-1 cost-effectiveness curves instead of searching through all of the Tier-1 opportunity space.

Multi-scale optimization builds upon the model development steps previously described in the previous exercises. When interpreting Tier-2 optimization results, it should be noted that decision variable values for the Tier-2 solution set is comprised of Tier-1 solutions IDs, instead of BMP sizes. Those IDs represent BMPs associated with points along the Tier-1 cost-effectiveness curves.

Chapter 3. Project Summary

In 2010, EPA Region 10 awarded four grants to local Puget Sound governments (City of Seattle, King County, Washington State Department of Ecology, and City of Bremerton) to address the impacts of urban development on Puget Sound by developing watershed assessment and planning projects focused on identifying retrofits, land use planning and green infrastructure investments. Each grantee set forth to use *SUSTAIN* to evaluate stormwater implementation options, and identified different management questions to be evaluated. This task order was developed by EPA Region 10 through Tetra Tech's existing *SUSTAIN* development contract with EPA ORD to provide for:

1. Ongoing project-specific technical guidance for grantees,
2. Software modifications and enhancements to address evaluation needs of grantees, and
3. Development of two training workshops (and associated materials) to assist grantees in the use of new and existing *SUSTAIN* features and functions for developing management plans.

Though brief, this important chapter discusses insights and lessons learned during the course of Tetra Tech's support to the grantees throughout the course of their projects. Tetra Tech provided ongoing project-specific technical guidance for grantees, implemented software modifications and enhancements to address evaluation needs of grantees, and developed and presented two training workshops (including associated materials) to assist grantees in the use of new and existing *SUSTAIN* features and functions.

Technical guidance was provided through bi-weekly conference calls to field questions and discussed technical issues of interest from the Region 10 Users' Group. Periodic interactive online meetings were also conducted to provide hands-on technical support to grantees for trouble-shooting and brainstorming on problem formulation. A SharePoint site was established to log discussions, questions, and responses to technical questions and archive associated materials and files. The following is a summary of the products and outcomes from this effort and a discussion of insights gained into best practices for *SUSTAIN* applications.

3.1. Project Products

The project produced the following products and materials:

- Enhanced *SUSTAIN* version 1.2, including an enhanced post-processer to plot FDCs. *SUSTAIN* version 1.2 was improved to provide the following:
    - Flexibility for the user to represent stream reach segments and BMPs using an F-table. This enhancement accommodated the need to represent complex BMP and conduit configurations that cannot be represented in *SUSTAIN* otherwise. This feature is particularly useful because Washington state regulations require complex BMP configurations in order to meet flow peak and duration control performance standards
    - A groundwater/aquifer component to track water that infiltrates from land areas as well as from BMPs into groundwater, and a mechanism to allow water stored in groundwater to be released back to surface stream segments

   - New optimization evaluation factors: Flow exceedance frequency and FDC goodness-of-fit comparing two conditions (pre-developed and post-developed)
   - Ability to plot and compare FDCs in the post-processor
   - Creation of a command-prompt executable that allows for batch-mode simulation
- Training workshop materials and exercises. Materials from these training sessions are stored on the project SharePoint site and project ftp site.
- Q&A records on SharePoint site.

While not directly generated under this contract, the following deliverables were significantly influenced by this project:

- City of Bremerton, King County and Washington State Department of Ecology *SUSTAIN* Application Project Reports.
- *SUSTAIN* Puget Sound Stormwater BMP Cost Database. An updated cost database was developed based on local cost information (EPA's *SUSTAIN* website, *SUSTAIN* version 1.2 installation package).

3.2. *SUSTAIN* Application Insights

3.2.1. *Upfront Planning is Key to Efficient and Successful SUSTAIN Application*

SUSTAIN's optimization feature is a powerful and important function that differentiates *SUSTAIN* from other watershed modeling systems (e.g. SWMM, HSPF). However, because the optimization engine employs meta-heuristic techniques that depend on the number of decision variables, the optimization process can involve hundreds, thousands, or more iterative evaluation runs. As a result, run time often becomes a concern when applying *SUSTAIN*, especially for large and complex problems. For example, the King County modelers ran 120 model runs in batches of twenty, with each batch run taking approximately seven days to complete. Therefore, careful strategic planning is necessary to warrant an efficient and successful *SUSTAIN* application.

During the planning process, two main factors should be considered: (1) the simulation time period, and (2) the representation of drainage routing network including BMPs. In general, the shorter the simulation time period and the less complex the routing network and fewer decision variables, the faster the optimization process. Prior to setting up a *SUSTAIN* model for a specific project, it is strongly recommended that users consider the following questions:

- What is the study objective, and what are the questions that need to be answered?
- How long is the desired simulation time period, and why was this period selected? Can a shorter time period, for example a representative year, meet project needs?
- How large is the study area, what are the intended BMP types, and how many decision variables will be used? Can the number of decision variables be reduced without compromising the study objective?
- Would a tiered optimization approach be more efficient?

When *SUSTAIN* is applied to a large area, a fully represented model is often not feasible because of long run times. In these cases, a tiered analysis approach can be employed. The tiered approach is used to extrapolate small scale BMP optimization results to a larger area. In this context, the term *tiered* refers to spatially nested units such as subwatershed to watershed, or HRU to subwatershed. King County's WRIA

9 pilot project is such an example. The tiered approach is used to disaggregate a large optimization problem, which otherwise takes an infeasible amount of time to solve, into a few smaller optimization problems that can be solved within an acceptable time frame.

In summary, careful evaluation of the application objectives, use of a representative time period, limited number of decision variables, and when necessary, application of the tiered optimization approach will greatly improve the optimization applicability and efficiency.

3.2.2. *Application Needs Drive Model Development and Enhancement*

During the course of this project, specific needs were identified that required enhancements to the *SUSTAIN* model including:

- Ability to use F-tables to describe routing segments and BMPs because pond design requirements to match FDCs are complex.
- Aquifer component that tracks infiltrating water and allows release into stream segments as baseflow because evaluating the entire hydrograph is integral to permit compliance.
- Ability to optimize to goodness-of-fit between two flow duration curves in accordance with Washington state permit performance standards.

Ability to use F-tables to describe routing segments and BMPs

The option to use an F-table was added as a feature to represent Conduits and BMPs with irregular shapes or BMPs with complex orifice and/or weir structures. The HSPF model is widely used in the Puget Sound region to simulate watershed processes and F-tables are commonly used to represent Conduits and BMPs. This new *SUSTAIN* feature allows for convenient migration of conduit representation into the *SUSTAIN* model using F-tables. For BMPs, an F-table can be used to represent an outflow-stage relationship that cannot be accommodated using the weir and orifice outlet options provided in previous versions of *SUSTAIN*.

Aquifer component to track and release infiltrated water into streams as baseflow

To effectively develop a FDC, both stormflow and baseflow are needed, as are the effects of stormwater infiltration on baseflow conditions. In previous versions of *SUSTAIN*, water that was infiltrated into the ground was eliminated from the system and did not appear in downstream waterbodies. *SUSTAIN* version 1.2 was enhanced to represent aquifer interactions beneath land surfaces and stormwater practices and to link those interactions to baseflow conditions to the stream in the hydrology simulation. This enhancement allows for representation of the low flow conditions in the stream resulting from development and stormwater practices.

Ability to optimize to goodness-of-fit between two flow duration curves

In Region 10, a key metric applied to determine the impact of development scenarios on the environment is a comparison of pre-developed and post-developed FDCs according to the permit performance standard in Washington State. The goal is to match the pre-developed FDC under a developed condition using BMPs. *SUSTAIN's* post-processor was enhanced to provide visual results for FDC comparison. Another optimization target based on flow-exceedance frequency was also added to represent other regional management standards such as high-pulse count (HPC), a hydrologic indicator that measures the flashiness of a stream system.

3.3. Closing Remarks

Through the enhancements made under this contract, *SUSTAIN* was demonstrated to be a versatile framework that could be readily expanded and customized with new functionalities and features to accommodate the various evaluation needs of users, as was done for the Puget Sound grantees. EPA has no plans at the moment to further expand or customize *SUSTAIN*; however, following this effort, all of the new enhancements and associated source codes will be available in the public domain.

Chapter 4. References

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Appendix A - Exercise 3 and Exercise 4 Input Files

FDC_optimization.inp

```
c-----------------------------------------------------------------------------------------
c
c SUSTAIN: System for Urban Stormwater Treatment and Analysis INtegration
c Version 1.2 - May 2013
c
c Designed and maintained by:
c           Tetra Tech, Inc.
c           10306 Eaton Place, Suite 340
c           Fairfax, VA 22030
c           (703) 385-6000
c
c NOTE:   The line starting with the letter c and followed by space or - is a comment line.
C           There must be no comment line in between the data lines
C           The input text field must be a continuous string without any space in between the characters
c
c-----------------------------------------------------------------------------------------
c700 Model Controls
c
c LINE1 = Land simulation control (0-external,1-internal),
c           Land output directory (containing land output timeseries),
c           external land timeseries data must be in this order;  flow (in./timestep), groundwater recharge (in./timestep), pollutant 1
c           (lb/acre/timestep), pollutant2, ...
c           Mixed land use output file name (for internal control),
c           PreDeveloped land use output file name (for internal control)
c LINE2 = Start date of simulation (Year Month Day)
c LINE3 = End date of simulation (Year Month Day)
c LINE4 = Land Timeseries timestep (Min),
c           BMP simulation timestep (Min),
c           CRRAT = The ratio of max velocity to mean velocity under typical flow conditions (value of 1.0 or greater)
c           Model output control (0-the same timestep as land timeseries; 1-hourly),
c           Model output directory
c LINE5 = ET Flag (0-constant monthly ET,1-daily ET from the timeseries,2-calculate daily ET from the daily temperature data),
c           Climate timeseries file path (required if ET flag is 1 or 2),
c           Latitude (Decimal degrees) required if ET flag is 2
c LINE6 = Monthly ET rate (in/day) if ET flag is 0   OR
c           Monthly pan coefficient (multiplier to ET value) if ET flag is 1   OR
c           Monthly variable coefficient to calculate ET values
c
0           C:\SUSTAIN\DATA\WRIA9\TS_130414\
1999        10          1
2009        9           30
60          5           1.5         1           C:\SUSTAIN\DATA\WRIA9\FDC_Output
0
0.017081  0.020101382  0.030222  0.057060215  0.093066  0.121471  0.152994  0.143218  0.106247  0.06039  0.035044  0.024387
c-----------------------------------------------------------------------------------------
c705 Pollutant Definition
c
c POLLUT_ID        = Unique pollutant identifier (Sequence number same as in land output timeseries)
c POLLUT_NAME      = Unique pollutant name
c MULTIPLIER       = Multiplying factor used to convert the pollutant load to lbs (external control)
c SED_FLAG         = The sediment flag (0-not sediment,1-sand,2-silt,3-clay,4-total sediment)
c                    if = 4 SEDIMENT will be splitted into sand, silt,and clay based on the fractions defined in card 710.
c SED_QUAL         = The sediment-associated pollutant flag (0-no, 1-yes)
c                    if = 1 then SEDIMENT is required in the pollutant list
c SAND_QFRAC       = The sediment-associated qual-fraction on sand (0-1), only required if SED_QUAL = 1
c SILT_QFRAC       = The sediment-associated qual-fraction on silt (0-1), only required if SED_QUAL = 1
c CLAY_QFRAC       = The sediment-associated qual-fraction on clay (0-1), only required if SED_QUAL = 1
c
c POLLUT_ID   POLLUT_NAME   MULTIPLIER   SED_FLAG   SED_QUAL   SAND_QFRAC   SILT_QFRAC   CLAY_QFRAC
1           TSS         1           0           0           0           0           0
c-----------------------------------------------------------------------------------------
c710 LAND USE DEFINITION (required if land simulation control is external)
c
```

```
c LANDTYPE         = Unique land use definition identifier
c LANDNAME         = land use name
c IMPERVIOUS       = Distinguishes pervious/impervious land unit (0-pervious; 1-impervious)
c TIMESERIESFILE   = File name containing input timeseries
c SAND_FRAC        = The fraction of total sediment from the land which is sand (0-1)
c SILT_FRAC        = The fraction of total sediment from the land which is silt (0-1)
c CLAY_FRAC        = The fraction of total sediment from the land which is clay (0-1)
c
c LANDTYPE  LANDNAME  IMPERVIOUS  TIMESERIESFILE  SAND_FRAC  SILT_FRAC  CLAY_FRAC
1     EIA_Roads                  1     HRU153sro.plt    0     0     0
2     EIA_Low_Den_Residential    1     HRU150sro.plt    0     0     0
3     EIA_High_Den_Residential   1     HRU151sro.plt    0     0     0
4     EIA_Commercial             1     HRU152sro.plt    0     0     0
5     TILL_Forest_FLAT           0     HRU61sro.plt     0     0     0
6     TILL_Forest_FLAT           0     HRU61gw.plt      0     0     0
7     TILL_HDGrass_FLAT          0     HRU21sro.plt     0     0     0
8     TILL_HDGrass_FLAT          0     HRU21gw.plt      0     0     0
9     TILL_Forest_FLAT           0     HRU61.plt        0     0     0
c------------------------------------------------------------------------------------------
```

c712 Aquifer INFORMATION

```
c
c AquiferID        = Unique Aquifer identifier
c AquiferNAME      = Aquifer name
c Initial Storage  = Initial Storage (ac-ft)
c RecessionCoef    = Recession Coefficient (1/hr)
c SeepageCoef      = Seepage Coefficient (1/hr)
c
c AquiferID  AquiferNAME  InitialStorage  RecessionCoef  SeepageCoef
1     Aq1      0      1        0
2     AqBMP    10     0.0001   0
c------------------------------------------------------------------------------------------
```

c713 Aquifer Pollutant Background Concentration

```
c
c AquiferID        = Unique Aquifer identifier as in c712
c Ci               = Background concentration for pollutant i (mg/l)
c                    Where i = 1 to N (N = Number of QUAL from card 705)
c
c AQUIFER_ID  QUALC1  QUALC2 ... QUALCN
1     0
2     0
c------------------------------------------------------------------------------------------
```

c714 Ftable for BMP Class A, B, and C

```
c
c FTABLE_ID        = Unique Ftable identifier (continuous string)
c FLOW_LENGTH      = Flow length (ft)
c BED_SLOPE        = Longitudinal bed slope (ft/ft)
c NUM_RECORD        = Number of layers in the Ftable
c
c DEPTH            = Water depth (ft)
c SURFACE_AREA     = Water surface area at the given depth (acre)
c VOLUME           = Storage volume at the given depth (ac-ft)
c FLOW_WEIR        = Overflow or weir outflow rate at the given depth (cfs)
c FLOW_ORIFICE     = Channel flow or orifice outflow rate at the given depth (cfs)
c
c FTABLE_ID  FLOW_LENGTH  BED_SLOPE  NUM_RECORD
c DEPTH  SURFACE_AREA  VOLUME  FLOW_WEIR  FLOW_ORIFICE
Ftable1  100  0.001  92
0.0000   0.122   0.000   0.000   0.000
0.0556   0.122   0.006   0.000   0.000
0.1111   0.122   0.013   0.000   0.000
0.1667   0.122   0.020   0.000   0.000
0.2222   0.122   0.027   0.000   0.000
0.2778   0.122   0.034   0.000   0.000
0.3333   0.122   0.040   0.000   0.000
0.3889   0.122   0.047   0.000   0.000
0.4444   0.122   0.054   0.000   0.000
0.5000   0.122   0.061   0.000   0.000
0.5556   0.122   0.068   0.000   0.000
0.6111   0.122   0.074   0.000   0.000
0.6667   0.122   0.081   0.000   0.000
```

0.7222	0.122	0.088	0.000	0.000
0.7778	0.122	0.095	0.000	0.000
0.8333	0.122	0.102	0.000	0.000
0.8889	0.122	0.108	0.020	0.000
0.9444	0.122	0.115	0.020	0.000
1.0000	0.122	0.122	0.021	0.000
1.0556	0.122	0.129	0.022	0.000
1.1111	0.122	0.136	0.022	0.000
1.1667	0.122	0.142	0.023	0.000
1.2222	0.122	0.149	0.023	0.000
1.2778	0.122	0.156	0.024	0.000
1.3333	0.122	0.163	0.024	0.000
1.3889	0.122	0.170	0.025	0.000
1.4444	0.122	0.176	0.025	0.000
1.5000	0.122	0.183	0.026	0.000
1.5556	0.122	0.190	0.026	0.000
1.6111	0.122	0.197	0.027	0.000
1.6667	0.122	0.204	0.027	0.000
1.7222	0.122	0.210	0.028	0.000
1.7778	0.122	0.217	0.028	0.000
1.8333	0.122	0.224	0.029	0.000
1.8889	0.122	0.231	0.029	0.000
1.9444	0.122	0.238	0.029	0.000
2.0000	0.122	0.244	0.030	0.000
2.0556	0.122	0.251	0.030	0.000
2.1111	0.122	0.258	0.031	0.000
2.1667	0.122	0.265	0.032	0.000
2.2222	0.122	0.272	0.034	0.000
2.2778	0.122	0.278	0.036	0.000
2.3333	0.122	0.285	0.038	0.000
2.3889	0.122	0.292	0.040	0.000
2.4444	0.122	0.299	0.043	0.000
2.5000	0.122	0.306	0.045	0.000
2.5556	0.122	0.312	0.048	0.000
2.6111	0.122	0.319	0.051	0.000
2.6667	0.122	0.326	0.054	0.000
2.7222	0.122	0.333	0.057	0.000
2.7778	0.122	0.340	0.060	0.000
2.8333	0.122	0.346	0.063	0.000
2.8889	0.122	0.353	0.066	0.000
2.9444	0.122	0.360	0.069	0.000
3.0000	0.122	0.367	0.072	0.000
3.0556	0.122	0.374	0.075	0.000
3.1111	0.122	0.380	0.079	0.000
3.1667	0.122	0.387	0.082	0.000
3.2222	0.122	0.394	0.086	0.000
3.2778	0.122	0.401	0.090	0.000
3.3333	0.122	0.408	0.094	0.000
3.3889	0.122	0.414	0.098	0.000
3.4444	0.122	0.421	0.102	0.000
3.5000	0.122	0.428	0.125	0.000
3.5556	0.122	0.435	0.130	0.000
3.6111	0.122	0.442	0.136	0.000
3.6667	0.122	0.448	0.142	0.000
3.7222	0.122	0.455	0.147	0.000
3.7778	0.122	0.462	0.153	0.000
3.8333	0.122	0.469	0.159	0.000
3.8889	0.122	0.476	0.165	0.000
3.9444	0.122	0.482	0.171	0.000
4.0000	0.122	0.489	0.177	0.000
4.0556	0.122	0.496	0.369	0.000
4.1111	0.122	0.503	0.719	0.000
4.1667	0.122	0.510	1.172	0.000
4.2222	0.122	0.516	1.709	0.000
4.2778	0.122	0.523	2.317	0.000
4.3333	0.122	0.530	2.990	0.000
4.3889	0.122	0.537	3.722	0.000
4.4444	0.122	0.544	4.508	0.000
4.5000	0.122	0.550	5.345	0.000
4.5556	0.122	0.557	6.229	0.000

```
4.6111   0.122   0.564   7.159   0.000
4.6667   0.122   0.571   8.132   0.000
4.7222   0.122   0.578   9.147   0.000
4.7778   0.122   0.584   10.20   0.000
4.8333   0.122   0.591   11.29   0.000
4.8889   0.122   0.598   12.42   0.000
4.9444   0.122   0.605   13.59   0.000
5.0000   0.122   0.612   14.79   0.000
5.0556   0.122   0.618   16.02   0.000
c-------------------------------------------------------------------------------------------
c715 BMP SITE INFORMATION
c
c BMPSITE          = Unique BMP site identifier
c BMPNAME          = BMP template name or site name
c BMPTYPE          = Unique BMP Types (must use the exact same keyword)
c                     (BIORETENTION, WETPOND, CISTERN, DRYPOND, INFILTRATIONTRENCH, GREENROOF,
c                      POROUSPAVEMENT, RAINBARREL, REGULATOR, SWALE, CONDUIT, BUFFERSTRIP,
c                      AREABMP)
c DArea            = Total Drainage Area in acre
c NUMUNIT          = Number of BMP structures
c DDAREA           = Design drainage area of the BMP structure (acre)
c PreLUType        = Predeveloped land use type (for external land simulation option)
c AquiferID        = Unique Aquifer ID, 0 --- no aquifer (for external land simulation option)
c FtableFLG        = Ftable flag, 0 = no, 1 = yes (for BMP Class A, B, and C)
c FTABLE_ID        = Unique Ftable identifier (continuous string) as in card 714
c
c BMPSITE  BMPNAME  BMPTYPE   DArea  NUMUNIT  DDAREA  PreLUType  AquiferID  FtableFLG  FTABLE_ID
1          J1       JUNCTION  200    1        0       9          1          0
2          C2       CONDUIT   0      1        0       9          1          0
3          J3       JUNCTION  0      1        0       9          1          0
4          C4       CONDUIT   0      1        0       9          2          0
5          J5       JUNCTION  100    1        0       9          1          0
6          WP1      WETPOND   0      0        0       9          2          1          Ftable1
c-------------------------------------------------------------------------------------------
c720 Point Source Definition
c
c point source timeseries data must be in this order;  flow (in.-acre/timestep), pollutant 1 (lbs/timestep), pollutant2, ...
c
c POINTSOURCE      = Unique point source identifier
c DESCRIPTION      = Point source description (a continuous string without any space)
c BMPSITE          = BMP site identifier in card 715
c MULTIPLIER       = Multiplier applied to the timeseries file (flow and pollutants). It will be in addition to the pollutant multiplier
c                    in card 705
c TIMESERIESFILE   = File name containing input timeseries
c SAND_FRAC        = The fraction of total sediment which is sand (0-1)
c SILT_FRAC        = The fraction of total sediment which is silt (0-1)
c CLAY_FRAC        = The fraction of total sediment which is clay (0-1)
c
c POINTSOURCE   DESCRIPTION   BMPSITE   MULTIPLIER   TIMESERIESFILE   SAND_FRAC  SILT_FRAC  CLAY_FRAC
c-------------------------------------------------------------------------------------------
c721 Tier-1 Watershed Outlets Definition
c
c BMPSITE          = BMP site (watershed outlet) identifier in card 715
c NUMBREAKS        = Number of break points on the cost-effectiveness curve
c CECurveFile      = CECurve_Solutions file for the project cost (sorted cost value) of each break point
c
c BMPSITE   NUMBREAKS   CECurveFile
c-------------------------------------------------------------------------------------------
c722 Tier-1 Watershed Timeseries Definition
c
c BMPSITE          = BMP site (watershed outlet) identifier in card 721
c BREAKPOINTID     = Unique break point id on cost-effectiveness curve
c                    (0 for initial, -1 for PreDev, and -2 for PostDev condition)
c MULTIPLIER       = Multiplier applied to the timeseries file
c TIMESERIESFILE   = Timeseries output file corresponding to the breakpoint id
c
c  BMPSITE   BREAKPOINTID   MULTIPLIER   TIMESERIESFILE
c-------------------------------------------------------------------------------------------
c723 Pump Curve (applies if PUMP_FLG is ON in card 725)
c
```

```
c PUMP_CURVE      = The unique name of pump curve (continuous string without space)
c NUM_RECORD      = Number of points on the curve
c
c DEPTH           = Depth (ft)
c FLOW            = Pumping flow rate (cfs)
c
c PUMP_CURVE   NUM_RECORD
c DEPTH   FLOW
c------------------------------------------------------------------------------------------
c725 CLASS-A BMP Site Parameters (required if BMPSITE is CLASS-A in card 715)
c
c BMPSITE         = Class A BMP dimension group identifier in card 715
c WIDTH           = Basin bottom width (ft)
c LENGTH          = Basin bottom length (ft) / diameter (ft) for rain barrel or cistern
c OHEIGHT         = Orifice Height (ft)
c DIAM            = Orifice Diameter (in)
c EXTP            = Exit Type (1 for C=1,2 for C=0.61, 3 for C=0.61, 4 for C=0.5)
c RELTP           = Release Type (1-Cistern, 2-Rain barrel, 3-others)
c PEOPLE          = Number of persons (Cistern Option)
c DDAYS           = Number of dry days (Rain Barrel Option)
c WEIRTP          = Weir Type (1-Rectangular,2-Triangular)
c WEIRH           = Weir Height (ft)
c WEIRW           = (weir type 1) Weir width  (ft)
c THETA           = (weir type 2) Weir angle  (degrees)
c ET_MULT         = multiplier to PET
c PUMP_FLG        = pump option (0-OFF, 1-ON)
c DEPTH_ON        = water Depth (ft) at which the pump is started
c DEPTH_OFF       = water Depth (ft) at which the pump is stopped
c PUMP_CURVE      = The unique name of pump curve (continuous string without space)
c
c BMPSITE   WIDTH   LENGTH   OHEIGHT   DIAM   EXITYPE   RELEASETYPE   PEOPLE   DDAYS   WEIRTYPE   WEIRH
c WEIRW   THETA   ET_MULT   PUMP_FLG   DEPTH_ON   DEPTH_OFF   PUMP_CURVE
6        103.27    51.63    0        0.9      1        3        0        0        1        5        4.4      0
         1         0        0        0
c------------------------------------------------------------------------------------------
c730  Cistern Control Water Release Curve (applies if release type is cistern in card 725)
c
c BMPSITE         = Class A BMP dimension group identifier in card 715
c Flow            = Hourly water release per capita from the Cistern Control (ft3/hr/capita)
c
c BMPSITE   FLOW
6        0        0        0        0        0        0        0        0        0        0        0        0
         0        0        0        0        0        0        0        0        0        0        0        0
c------------------------------------------------------------------------------------------
c735 CLASS B BMP Site DIMENSION GROUPS
c
c BMPSITE         = BMP Site identifier in card 715
c WIDTH           = basin bottom width (ft)
c LENGTH          = basin bottom Length (ft)
c MAXDEPTH        = Maximum depth of channel (ft)
c SLOPE1          = Side slope 1 (ft/ft)
c SLOPE2          = Side slope 2 (ft/ft)   (1-4)
c SLOPE3          = Side slope 3 (ft/ft)
c MANN_N          = Manning  's roughness coefficient
c ET_MULT         = multiplier to PET
c
c BMPSITE   WIDTH   LENGTH   MAXDEPTH   SLOPE1   SLOPE2   SLOPE3   MANN_N   ET_MULT
c------------------------------------------------------------------------------------------
c740 BMP Site BOTTOM SOIL/VEGITATION CHARACTERISTICS
c
c BMPSITE         = BMPSITE identifier in c715
c INFILTM         = Infiltration Method (0-Green Ampt, 1-Horton, 2-Holtan)
c POLROTM         = Pollutant Routing Method (1-Completely mixed, >1-number of CSTRs in series)
c POLREMM         = Pollutant Removal Method (0-1st order decay, 1-kadlec and knight method )
c SDEPTH          = Soil Depth (ft)
c POROSITY        = Soil Porosity (0-1)
c FCAPACITY       = Soil Field Capacity (ft/ft)
c WPOINT          = Soil Wilting Point (ft/ft)
c AVEG            = Vegetative Parameter A (0.1-1.0) (Empirical), only required for Holtan infiltration method
c FINFILT         = Soil layer infiltration rate (in/hr)
```

```
c UNDSWITCH      = Consider underdrain (1), Do not consider underdrain (0)
c UNDDEPTH       = Depth of storage media below underdrain (ft)
c UNDVOID        = Fraction of underdrain storage depth that is void space (0-1)
c UNDINFILT      = Background infiltration rate, below underdrain (in/hr)
c SUCTION        = Average value of soil capillary suction along the wetting front, value must be greater than zero (in), only
c                  required for Green-Ampt infiltration method
c IMDMAX         = Difference between soil porosity and initial moisture content, value must be greater than or equal to zero (a
c                  fraction), only required for Green-Ampt infiltration method
c MAXINFILT      = Maximum rate on the Horton infiltration curve (in/hr), only required for Horton infiltration method
c DECAYCONS      = Decay constant for the Horton infiltration curve (1/hr), only required for Horton infiltration method
c DRYTIME        = Time for a fully staurated soil to completely dry (day), only required for Horton infiltration method
c MAXVOLUME      = Maximum infiltration volume possible (in), only required for Horton infiltration method
c
c BMPSITE  INFILTM  POLROTM  POLREMM  SDEPTH  POROSITY  FCAPACITY  WPOINT  AVEG  FINFILT
c UNDSWITCH  UNDDEPTH  UNDVOID  UNDINFILT  SUCTION  IMDMAX  MAXINFILT  DECAYCONS  DRYTIME
c MAXVOLUME
6      2      1      0      1      0.35   0.25   0.1    1      1      0      0      0
       1      3      0.3    3      4      7      0
c------------------------------------------------------------------------------------------
c745 BMP Site HOLTAN GROWTH INDEX
c
c HOLTAN EQUATION:    F = GI * AVEG * (Computed Available Soil Storage)^1.4 + FINFILT
c
c BMPSITE        = BMPSITE identifier in card 715
c GIi            = 12 monthly values for GI in HOLTAN equation
c                  Where i = jan, feb, mar ... dec
c
c BMPSITE  jan  feb  mar  apr  may  jun  jul  aug  sep  oct  nov  dec
6      0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
c------------------------------------------------------------------------------------------
c747 BMP Site Initial Moisture Content
c
c BMPSITE        = BMP Site identifier in card 715
c WATDEP_i       = initial surface water depth (ft)
c THETA_i        = initial soil moisture (ft/ft)
c
c BMPSITE   WATDEP_i   THETA_i
6      0      0
c------------------------------------------------------------------------------------------
c750 Class-C Conduit Parameters (required if BMPSITE is CLASS-C in card 715)
c
c BMPSITE        = BMP site identifier in card 715
c INLET_NODE     = BMP Id at the entrance of the conduit
c OUTLET_NODE    = BMP Id at the exit of the conduit
c LENGTH         = Conduit length (ft)
c MANNING_N      = Manning's roughness coefficient
c INLET_IEL      = Invert Elevation at the entrance of the conduit (ft)
c OUTLET_IEL     = Invert Elevation at the exit of the conduit (ft)
c INIT_FLOW      = Initial flow in the conduit (cfs)
c INLET_HL       = Head loss coefficient at the entrance of the conduit
c OUTLET_HL      = Head loss coefficient at the exit of the conduit
c AVERAGE_HL     = Head loss coefficient along the length of the conduit
c
c BMPSITE   INLET_NODE   OUTLET_NODE   LENGTH   MANNING_N   INLET_IEL   OUTLET_IEL   INIT_FLOW
c INLET_HL   OUTLET_HL   AVERAGE_HL
2      1      3      3364.1   0.14   0      0      0      0      0      0
4      3      6      3364.1   0.14   0      0      0      0      0      0
c------------------------------------------------------------------------------------------
c755 Class C Conduit Cross Sections
c
c LINK           = BMP site identifier in card 715
c TYPE           = Conduit Type (rectangular, circular...)
c GEOM1          = Geometric cross-sectional property of the conduit
c GEOM2          = Geometric cross-sectional property of the conduit
c GEOM3          = Geometric cross-sectional property of the conduit
c GEOM4          = Geometric cross-sectional property of the conduit
c BARRELS        = Number of Barrels in the conduit
c
c LINK   TYPE   GEOM1   GEOM2   GEOM3   GEOM4   BARRELS
2      DUMMY  0      0      0      0      0
```

```
4           DUMMY  0          0          0          0          0
c------------------------------------------------------------------------------------------
```

c760 Irregular Cross Sections

```
c
c Format of transect data follows:
c NC       nLeft      nRight     nChannel
c X1       name       nSta       xLeftBank xRightBank          0          0          0          xFactor     yFactor
c GR       Elevation  Station  ...
c------------------------------------------------------------------------------------------
```

c761 BufferStrip BMP Parameters (required if BMPTYPE is BUFFERSTRIP in card 715)

```
c
c BMPSITE            = BMP site identifier in card 715
c Width              = BMP width (ft)
c FLength            = Flow length (ft)
c DStorage           = Surface depression storage (in)
c SLOPE              = Overland slope (ft / ft)
c MANNING_N          = Overland Manning's roughness coefficient
c POLREMM            = Pollutant Removal Method (0-1st order decay, 1-kadlec and knight method)
c ET_MULT            = Multiplier to PET
c
c BMPSITE   Width   FLength   DStorage   SLOPE   MANNING_N   POLREMM   ET_MULT
c------------------------------------------------------------------------------------------
```

c762 Area BMP Parameters (required if BMPTYPE is AREABMP in card 715)

```
c
c BMPSITE            = BMP site identifier in card 715
c Area               = BMP area (ft2)
c FLength            = flow length (ft) note: area width = area / flow length
c DStorage           = Surface depression storage (in)
c SLOPE              = Overland slope (ft / ft)
c MANNING_N          = Overland Manning's roughness coefficient
c SAT_INFILT         = Saturated infiltration rate (in/hr)
c POLREMM            = Pollutant Removal Method (0-1st order decay, 1-kadlec and knight method)
c DCIA               = Percentage of Directly Connected Impervious Area (0-100)
c TOTAL_IMP_DA       = Total Impervious Drainage Area (acre)
c
c BMPSITE   Area   FLength   DStorage   SLOPE   MANNING_N   SAT_INFILT   POLREMM   DCIA   TOTAL_IMP_DA
c------------------------------------------------------------------------------------------
```

c765 BMP SITE Pollutant Decay/Loss rates

```
c
c BMPSITE            = BMP site identifier in card 715
c QUALDECAYi         = First-order decay rate for pollutant i (hr^-1)
c                      Where i = 1 to N (N = Number of QUAL from card 705)
c
c BMPSITE   QUALDECAY1   QUALDECAY2... QUALDECAYN
6           0.02
2           0
4           0
c------------------------------------------------------------------------------------------
```

c766 Pollutant K' values (applies when pollutant removal method is kadlec and knight method in card 740)

```
c
c BMPSITE            = BMP site identifier in card 715
c K 'i               = Constant rate for pollutant i (ft/yr)
c                      Where i = 1 to N (N = Number of QUAL from card 705)
c
c BMPSITE   QUALK'1   QUALK'2... QUALK'N
6           3280
2           0
4           0
c------------------------------------------------------------------------------------------
```

c767 Pollutant C* values (applies when pollutant removal method is kadlec and knight method in card 740)

```
c
c BMPSITE            = BMP site identifier in card 715
c C*i                = Background concentration for pollutant i (mg/l)
c                      Where i = 1 to N (N = Number of QUAL from card 705)
c
c BMPSITE   QUALC*1   QUALC*2... QUALC*N
6           12
2           0
4           0
c------------------------------------------------------------------------------------------
```

c770 BMP Underdrain Pollutant Percent Removal (applies when underdrain is on in card 740)
c
c BMPSITE = BMPSITE identifier in card 715
c QUALPCTREMi = Perecent Removal for pollutant i through underdrain (0-1)
c Where i = 1 to N (N = Number of QUAL from card 705)
c
c BMPSITE QUALPCTREM1 QUALPCTREM2... QUALPCTREMN
6 0
c--
c775 Sediment General Parameters (required if pollutant type is sediment in card 705)
c
c BMPSITE = BMP site identifier in card 715
c BEDWID = Bed width (ft) - this is constant for the entire simulation period
c BEDDEP = Initial bed depth (ft)
c BEDPOR = Bed sediment porosity
c
c BMPSITE BEDWID BEDDEP BEDPOR
c--
c780 Sand Transport Parameters (required if pollutant type is sediment in card 705)
c
c BMPSITE = BMP site identifier in card 715
c D = Effective diameter of the transported sand particles (in)
c W = The corresponding fall velocity in still water (in/sec)
c RHO = The density of the sand particles (lb/ft3)
c KSAND = The coefficient in the sandload power function formula
c EXPSND = The exponent in the sandload power function formula
c
c BMPSITE D W RHO KSAND EXPSND
c--
c785 Silt Transport Parameters (required if pollutant type is sediment in card 705)
c
c BMPSITE = BMP site identifier in card 715
c D = Effective diameter of the transported silt particles (in)
c W = The corresponding fall velocity in still water (in/sec)
c RHO = The density of the silt particles (lb/ft3)
c TAUCD = The critical bed shear stress for deposition (lb/ft2)
c TAUCS = The critical bed shear stress for scour (lb/ft2)
c M = The erodibility coefficient of the silt particles (lb/ft2/day)
c
c BMPSITE D W RHO TAUCD TAUCS M
c--
c786 Clay Transport Parameters (required if pollutant type is sediment in card 705)
c
c BMPSITE = BMP site identifier in card 715
c D = Effective diameter of the transported clay particles (in)
c W = The corresponding fall velocity in still water (in/sec)
c RHO = The density of the silt/clay particles (lb/ft3)
c TAUCD = The critical bed shear stress for deposition (lb/ft2)
c TAUCS = The critical bed shear stress for scour (lb/ft2)
c M = The erodibility coefficient of the clay particles (lb/ft2/day)
c
c BMPSITE D W RHO TAUCD TAUCS M
c--
c790 LAND TO BMP ROUTING NETWORK (required for external land simulation control in card 700)
c
c UniqueID = Identifies an instance of LANDTYPE in SCHEMATIC
c LANDTYPE = Corresponds to LANDTYPE in c710
c AREA = Area of LANDTYPE in ACRES
c DS = UNIQUE ID of DS BMP (0 - no BMP, add to end)
c
c UniqueID LANDTYPE AREA DS
1 1 20 6
2 2 20 6
3 3 60 6
4 7 100 6
5 8 100 3
6 9 100 5
c--
c795 BMP Site ROUTING NETWORK
c

```
c BMPSITE          = BMPSITE identifier in card 715
c OUTLET_TYPE      = Outlet type (1-total, 2-weir, 3-orifice or channel, 4-underdrain)
c DS               = Downstrem BMP site identifier in card 715 (0 - no BMP, add to end)
c
c BMPSITE   OUTLET_TYPE   DS
1          1          2
2          1          3
3          1          4
4          1          5
6          1          3
c-------------------------------------------------------------------------------------------
c800 Optimization Controls
c
c Technique -- Optimization Techniques
c    0 = no optimization
c    1 = Scatter Search
c    2 = NSGAII
c Option -- Optimization options
c    0 = no optimization
c    1 = specific control target and minimize cost
c    2 = generate cost effectiveness curve
c StopDelta -- Criteria for stopping the optimization iteration
c          in dollars($), meaning if the cost not improved by this criteria, stop the search (for Option 1)
c MaxRuns -- Maximum number of iterations
c NumBest -- Number of best solutions for output (for Option 1)
c
c Technique   Option   StopDelta   MaxRuns   NumBest
2          2          0          100        2
c-------------------------------------------------------------------------------------------
c805 BMP Cost Functions
c Cost ($) = ((LinearCost)*Length^(LengthExp) + (AreaCost)*Area^(AreaExp) + (TotalVolumeCost)*TotalVolume^(TotalVolExp)
c         + (MediaVolumeCost)*SoilMediaVolume^(MediaVolExp) + (UnderDrainVolumeCost)*UnderDrainVolume^(UDVolExp)
c         + (ConstantCost)) * (1+PercentCost/100)
c
c BMPSITE                    = BMP site identifier in card 715
c LinearCost                 = Cost per unit length of the BMP structure ($/ft)
c AreaCost                   = Cost per unit area of the BMP structure ($/ft^2)
c TotalVolumeCost            = Cost per unit total volume of the BMP structure ($/ft^3)
c MediaVolumeCost            = Cost per unit volume of the soil media ($/ft^3)
c UnderDrainVolumeCost       = Cost per unit volume of the under drain structure ($/ft^3)
c ConstantCost               = Constant cost ($)
c PercentCost                = Cost in percentage of all other cost (%)
c LengthExp                  = Exponent for linear unit
c AreaExp                    = Exponent for area unit
c TotalVolExp                = Exponent for total volume unit
c MediaVolExp                = Exponent for soil media volume unit
c UDVolExp                   = Exponent for underdrain volume unit
c
c BMPSITE   LinearCost   AreaCost   TotalVolumeCost   MediaVolumeCost   UnderDrainVolumeCost   ConstantCost   PercentCost
c LengthExp   AreaExp   TotalVolExp   MediaVolExp   UDVolExp
6          0          18.25      4.78       0          0          0          0          1          1          1          1      1
c-------------------------------------------------------------------------------------------
c810 BMP SITE Adjustable Parameters
c
c BMPSITE          = BMP site identifier in card 715
c VARIABLE         = Variable name (must use the exact same keyword)
c                    LENGTH --- BMP length,
c                    NUMUNIT --- number of units,
c                    WEIRH --- weir height,
c                    SDEPTH --- soil media depth,
c                    DCIA --- directly connected impervious area for area BMP type,
c                    MAXDEPTH --- maximum surface storage depth for swale,
c                    CECURVE --- cost-effectiveness curve for Tier-1 solution
c FROM             = From value in the range
c TO               = To value in the range
c STEP             = Increment step
c
c BMPSITE   VARIABLE   FROM   TO   STEP
6          NUMUNIT          0          1000       10
c-------------------------------------------------------------------------------------------
```

c814 Predeveloped Timeseries at Assessment Point for Flow Duration Curve

```
c
c BMPSITE        = BMP site identifier in card 715 if it is an assessment point
c NumBins        = Number of bins for flow duration curve
c PreDevFlag     = Pre-developed timeseries option (1-internal,2-external)
c PreDevFile     = Pre-developed timeseries file path for external option
c                  The timeseries file format (AssessmentPoint_ID  Year  Month  Day  Hour  Minute  Flow_cfs)
c                  The first line is skipped (comment line) and data start from the second line in the required format.
c
c BMPSITE   NumBins   PreDevFlag   PreDevFile
5  20000  1
c-----------------------------------------------------------------------------------------
```

c815 Assessment Point and Evaluation Factor

```
c
c BMPSITE -- BMP site identifier in card 715 if it is an assessment point
c FactorGroup -- Flow or pollutant related evaluation factor group
c   -1 = flow related evaluation factor
c    # = pollutant ID in card 705
c FactorType -- Evaluation Factor Type (negative number for flow related and positive number for pollutant related)
c   -1 = AAFV Annual Average Flow Volume (ft3/yr)
c   -2 = PDF  Peak Discharge Flow (cfs)
c   -3 = FEF  Flow Exceeding frequency  (#times/year)
c   -4 = FDC  Flow Duration Curve (sum of sorted flow difference with pre-developed condition, cfs)
c    1 = AAL  Annual Average Load (lb/yr)
c    2 = AAC  Annual Average Concentration (mg/L)
c    3 = MAC  Maximum #days Average Concentraion (mg/L)
c FactorVal1 -- if FactorType = 3 (MAC): Maximum #Days;
c          -- if FactorType = -3 (FEF): Threshold (cfs)
c          -- if FactorType = -4 (FDC): Low flow limit (cfs)
c          -- all other FactorType : -99
c FactorVal2 -- if FactorType = -3 (FEF): Minimum inter-exceedance time (hr)
c                                  if =  0 then daily running average flow exceeding frequency
c                                  if = -1 then daily average flow exceeding frequency
c                                  otherwise minimum inter-exceedance time for simulation interval
c          -- if FactorType = -4 (FDC): High flow limit (cfs)
c          -- all other FactorType : -99
c CalcMode -- Evaluation Factor Calculation Mode
c   -99 for Option 0 (card 800): no optimizaiton
c    1 = % percent of value under existing condition (0-100)
c    2 = S scale between pre-develop and existing condition (0-1)
c    3 = V  absolute value in the unit as shown in FactorType (third block in this card)
c TargetVal1 -- Target value for evaluation factor calculation mode
c    -99 for Option 0 (card 800): no optimizaiton
c    Target value for minimize cost Option 1 (card 800)
c    Lower limit of target value for cost-effective curve Option 2 (card 800)
c TargetVal2 -- Target value for evaluation factor calculation mode
c    -99 for Option 0 (card 800): no optimizaiton
c    -99 for Option 1 (card 800): minimize cost
c    Upper limit of target value for cost-effective curve Option 2 (card 800)
c Factor_Name -- Evaluation factor name (user specified without any space), e.g. FlowVolume or SEDIMENT
c
c BMPSITE   FactorGroup   FactorType   FactorVal1   FactorVal2   CalcMode   TargetVal1   TargetVal2   FactorName
5           -1            -4           0.23         16           1          0            100          FDC_%
c-----------------------------------------------------------------------------------------
```

Tier2_optimization.inp

```
c------------------------------------------------------------------------------------------
c
c SUSTAIN: System for Urban Stormwater Treatment and Analysis INtegration
c Version 1.2 - May 2013
c
c Designed and maintained by:
c       Tetra Tech, Inc.
c       10306 Eaton Place, Suite 340
c       Fairfax, VA 22030
c       (703) 385-6000
c
c NOTE:  The line starting with the letter c and followed by space or - is a comment line.
C       There must be no comment line in between the data lines
C       The input text field must be a continuous string without any space in between the characters
c
c------------------------------------------------------------------------------------------
c700 Model Controls
c
c LINE1 = Land simulation control (0-external,1-internal),
c       Land output directory (containing land output timeseries),
c       external land timeseries data must be in this order;  flow (in./timestep), groundwater recharge (in./timestep), pollutant 1
c       (lb/acre/timestep), pollutant2, ...
c       Mixed land use output file name (for internal control),
c       PreDeveloped land use output file name (for internal control)
c LINE2 = Start date of simulation (Year Month Day)
c LINE3 = End date of simulation (Year Month Day)
c LINE4 = Land Timeseries timestep (Min),
c       BMP simulation timestep (Min),
c       CRRAT = The ratio of max velocity to mean velocity under typical flow conditions (value of 1.0 or greater)
c       Model output control (0-the same timestep as land timeseries; 1-hourly),
c       Model output directory
c LINE5 = ET Flag (0-constant monthly ET,1-daily ET from the timeseries,2-calculate daily ET from the daily temperature data),
c       Climate timeseries file path (required if ET flag is 1 or 2),
c       Latitude (Decimal degrees) required if ET flag is 2
c LINE6 = Monthly ET rate (in/day) if ET flag is 0   OR
c       Monthly pan coefficient (multiplier to ET value) if ET flag is 1   OR
c       Monthly variable coefficient to calculate ET values
c
0       C:\SUSTAIN\DATA\WRIA9\TS_130414\
1999    10      1
2009    9       30
60      5       1.5     1       C:\SUSTAIN\DATA\WRIA9\Tier2_Output
0
0.017081  0.020101382  0.030222  0.057060215  0.093066  0.121471  0.152994  0.143218  0.106247  0.06039  0.035044  0.024387
c------------------------------------------------------------------------------------------
c705 Pollutant Definition
c
c POLLUT_ID       = Unique pollutant identifier (Sequence number same as in land output timeseries)
c POLLUT_NAME     = Unique pollutant name
c MULTIPLIER      = Multiplying factor used to convert the pollutant load to lbs (external control)
c SED_FLAG        = The sediment flag (0-not sediment,1-sand,2-silt,3-clay,4-total sediment)
c                   if = 4 SEDIMENT will be splitted into sand, silt,and clay based on the fractions defined in card 710.
c SED_QUAL        = The sediment-associated pollutant flag (0-no, 1-yes)
c                   if = 1 then SEDIMENT is required in the pollutant list
c SAND_QFRAC      = The sediment-associated qual-fraction on sand (0-1), only required if SED_QUAL = 1
c SILT_QFRAC      = The sediment-associated qual-fraction on silt (0-1), only required if SED_QUAL = 1
c CLAY_QFRAC      = The sediment-associated qual-fraction on clay (0-1), only required if SED_QUAL = 1
c
c POLLUT_ID   POLLUT_NAME   MULTIPLIER   SED_FLAG   SED_QUAL   SAND_QFRAC   SILT_QFRAC   CLAY_QFRAC
1       TSS     1       0       0       0       0       0
c------------------------------------------------------------------------------------------
c710 LAND USE DEFINITION (required if land simulation control is external)
c
c LANDTYPE         = Unique land use definition identifier
c LANDNAME         = land use name
c IMPERVIOUS       = Distinguishes pervious/impervious land unit (0-pervious; 1-impervious)
c TIMESERIESFILE   = File name containing input timeseries
c SAND_FRAC        = The fraction of total sediment from the land which is sand (0-1)
c SILT_FRAC        = The fraction of total sediment from the land which is silt (0-1)
```

c CLAY_FRAC = The fraction of total sediment from the land which is clay (0-1)
c
c LANDTYPE LANDNAME IMPERVIOUS TIMESERIESFILE SAND_FRAC SILT_FRAC CLAY_FRAC

1	EIA_Roads	1	HRU153sro.plt	0	0	0
2	EIA_Low_Den_Residential	1	HRU150sro.plt	0	0	0
3	EIA_High_Den_Residential	1	HRU151sro.plt	0	0	0
4	EIA_Commercial	1	HRU152sro.plt	0	0	0
5	TILL_Forest_FLAT	0	HRU61sro.plt	0	0	0
6	TILL_Forest_FLAT	0	HRU61gw.plt	0	0	0
7	TILL_HDGrass_FLAT	0	HRU21sro.plt	0	0	0
8	TILL_HDGrass_FLAT	0	HRU21gw.plt	0	0	0
9	TILL_Forest_FLAT	0	HRU61.plt	0	0	0

c---
c712 Aquifer INFORMATION
c
c AquiferID = Unique Aquifer identifier
c AquiferNAME = Aquifer name
c Initial Storage = Initial Storage (ac-ft)
c RecessionCoef = Recession Coefficient (1/hr)
c SeepageCoef = Seepage Coefficient (1/hr)
c
c AquiferID AquiferNAME InitialStorage RecessionCoef SeepageCoef

1	Aq1	0	1	0
2	AqBMP	10	0.0001	0

c---
c713 Aquifer Pollutant Background Concentration
c
c AquiferID = Unique Aquifer identifier as in c712
c Ci = Background concentration for pollutant i (mg/l)
c Where i = 1 to N (N = Number of QUAL from card 705)
c
c AQUIFER_ID QUALC1 QUALC2 ... QUALCN
1 0
2 0
c---
c714 Ftable for BMP Class A, B, and C
c
c FTABLE_ID = Unique Ftable identifier (continuous string)
c FLOW_LENGTH = Flow length (ft)
c BED_SLOPE = Longitudinal bed slope (ft/ft)
c NUM_RECORD = Number of layers in the Ftable
c
c DEPTH = Water depth (ft)
c SURFACE_AREA = Water surface area at the given depth (acre)
c VOLUME = Storage volume at the given depth (ac-ft)
c FLOW_WEIR = Overflow or weir outflow rate at the given depth (cfs)
c FLOW_ORIFICE = Channel flow or orifice outflow rate at the given depth (cfs)
c
c FTABLE_ID FLOW_LENGTH BED_SLOPE NUM_RECORD
c DEPTH SURFACE_AREA VOLUME FLOW_WEIR FLOW_ORIFICE
Ftable1 100 0.001 92

0.0000	0.122	0.000	0.000	0.000
0.0556	0.122	0.006	0.000	0.000
0.1111	0.122	0.013	0.000	0.000
0.1667	0.122	0.020	0.000	0.000
0.2222	0.122	0.027	0.000	0.000
0.2778	0.122	0.034	0.000	0.000
0.3333	0.122	0.040	0.000	0.000
0.3889	0.122	0.047	0.000	0.000
0.4444	0.122	0.054	0.000	0.000
0.5000	0.122	0.061	0.000	0.000
0.5556	0.122	0.068	0.000	0.000
0.6111	0.122	0.074	0.000	0.000
0.6667	0.122	0.081	0.000	0.000
0.7222	0.122	0.088	0.000	0.000
0.7778	0.122	0.095	0.000	0.000
0.8333	0.122	0.102	0.000	0.000
0.8889	0.122	0.108	0.020	0.000
0.9444	0.122	0.115	0.020	0.000
1.0000	0.122	0.122	0.021	0.000

1.0556	0.122	0.129	0.022	0.000
1.1111	0.122	0.136	0.022	0.000
1.1667	0.122	0.142	0.023	0.000
1.2222	0.122	0.149	0.023	0.000
1.2778	0.122	0.156	0.024	0.000
1.3333	0.122	0.163	0.024	0.000
1.3889	0.122	0.170	0.025	0.000
1.4444	0.122	0.176	0.025	0.000
1.5000	0.122	0.183	0.026	0.000
1.5556	0.122	0.190	0.026	0.000
1.6111	0.122	0.197	0.027	0.000
1.6667	0.122	0.204	0.027	0.000
1.7222	0.122	0.210	0.028	0.000
1.7778	0.122	0.217	0.028	0.000
1.8333	0.122	0.224	0.029	0.000
1.8889	0.122	0.231	0.029	0.000
1.9444	0.122	0.238	0.029	0.000
2.0000	0.122	0.244	0.030	0.000
2.0556	0.122	0.251	0.030	0.000
2.1111	0.122	0.258	0.031	0.000
2.1667	0.122	0.265	0.032	0.000
2.2222	0.122	0.272	0.034	0.000
2.2778	0.122	0.278	0.036	0.000
2.3333	0.122	0.285	0.038	0.000
2.3889	0.122	0.292	0.040	0.000
2.4444	0.122	0.299	0.043	0.000
2.5000	0.122	0.306	0.045	0.000
2.5556	0.122	0.312	0.048	0.000
2.6111	0.122	0.319	0.051	0.000
2.6667	0.122	0.326	0.054	0.000
2.7222	0.122	0.333	0.057	0.000
2.7778	0.122	0.340	0.060	0.000
2.8333	0.122	0.346	0.063	0.000
2.8889	0.122	0.353	0.066	0.000
2.9444	0.122	0.360	0.069	0.000
3.0000	0.122	0.367	0.072	0.000
3.0556	0.122	0.374	0.075	0.000
3.1111	0.122	0.380	0.079	0.000
3.1667	0.122	0.387	0.082	0.000
3.2222	0.122	0.394	0.086	0.000
3.2778	0.122	0.401	0.090	0.000
3.3333	0.122	0.408	0.094	0.000
3.3889	0.122	0.414	0.098	0.000
3.4444	0.122	0.421	0.102	0.000
3.5000	0.122	0.428	0.125	0.000
3.5556	0.122	0.435	0.130	0.000
3.6111	0.122	0.442	0.136	0.000
3.6667	0.122	0.448	0.142	0.000
3.7222	0.122	0.455	0.147	0.000
3.7778	0.122	0.462	0.153	0.000
3.8333	0.122	0.469	0.159	0.000
3.8889	0.122	0.476	0.165	0.000
3.9444	0.122	0.482	0.171	0.000
4.0000	0.122	0.489	0.177	0.000
4.0556	0.122	0.496	0.369	0.000
4.1111	0.122	0.503	0.719	0.000
4.1667	0.122	0.510	1.172	0.000
4.2222	0.122	0.516	1.709	0.000
4.2778	0.122	0.523	2.317	0.000
4.3333	0.122	0.530	2.990	0.000
4.3889	0.122	0.537	3.722	0.000
4.4444	0.122	0.544	4.508	0.000
4.5000	0.122	0.550	5.345	0.000
4.5556	0.122	0.557	6.229	0.000
4.6111	0.122	0.564	7.159	0.000
4.6667	0.122	0.571	8.132	0.000
4.7222	0.122	0.578	9.147	0.000
4.7778	0.122	0.584	10.20	0.000
4.8333	0.122	0.591	11.29	0.000
4.8889	0.122	0.598	12.42	0.000

```
4.9444    0.122    0.605    13.59    0.000
5.0000    0.122    0.612    14.79    0.000
5.0556    0.122    0.618    16.02    0.000
c-----------------------------------------------------------------------------------------
c715 BMP SITE INFORMATION
c
c BMPSITE          = Unique BMP site identifier
c BMPNAME          = BMP template name or site name
c BMPTYPE          = Unique BMP Types (must use the exact same keyword)
c                     (BIORETENTION, WETPOND, CISTERN, DRYPOND, INFILTRATIONTRENCH, GREENROOF,
c                      POROUSPAVEMENT, RAINBARREL, REGULATOR, SWALE, CONDUIT, BUFFERSTRIP,
c                      AREABMP)
c DArea            = Total Drainage Area in acre
c NUMUNIT          = Number of BMP structures
c DDAREA           = Design drainage area of the BMP structure (acre)
c PreLUType        = Predeveloped land use type (for external land simulation option)
c AquiferID        = Unique Aquifer ID, 0 --- no aquifer (for external land simulation option)
c FtableFLG        = Ftable flag, 0 = no, 1 = yes (for BMP Class A, B, and C)
c FTABLE_ID        = Unique Ftable identifier (continuous string) as in card 714
c
c BMPSITE   BMPNAME   BMPTYPE   DArea   NUMUNIT   DDAREA   PreLUType   AquiferID   FtableFLG   FTABLE_ID
1           J1        JUNCTION    200     1         0        9           1           0
2           C2        CONDUIT     0       1         0        9           1           0
3           J3        JUNCTION    0       1         0        9           1           0
4           C4        CONDUIT     0       1         0        9           2           0
5           J5        JUNCTION    100     1         0        9           1           0
6           WP1       WETPOND     0       0         0        9           2           1           Ftable1
c-----------------------------------------------------------------------------------------
c720 Point Source Definition
c
c point source timeseries data must be in this order;  flow (in.-acre/timestep), pollutant 1 (lbs/timestep), pollutant2, ...
c
c POINTSOURCE      = Unique point source identifier
c DESCRIPTION      = Point source description (a continuous string without any space)
c BMPSITE          = BMP site identifier in card 715
c MULTIPLIER       = Multiplier applied to the timeseries file (flow and pollutants). It will be in addition to the pollutant multiplier
c                    in card 705
c TIMESERIESFILE   = File name containing input timeseries
c SAND_FRAC        = The fraction of total sediment which is sand (0-1)
c SILT_FRAC        = The fraction of total sediment which is silt (0-1)
c CLAY_FRAC        = The fraction of total sediment which is clay (0-1)
c
c POINTSOURCE   DESCRIPTION   BMPSITE   MULTIPLIER   TIMESERIESFILE   SAND_FRAC  SILT_FRAC  CLAY_FRAC
c-----------------------------------------------------------------------------------------
c721 Tier-1 Watershed Outlets Definition
c
c BMPSITE          = BMP site (watershed outlet) identifier in card 715
c NUMBREAKS        = Number of break points on the cost-effectiveness curve
c CECurveFile      = CECurve_Solutions file for the project cost (sorted cost value) of each break point
c
c BMPSITE   NUMBREAKS   CECurveFile
1           5           C:\SUSTAIN\DATA\WRIA9\Tier1_till_output\CECurve_Solutions.out
3           5           C:\SUSTAIN\DATA\WRIA9\Tier1_outwash_output\CECurve_Solutions.out
c-----------------------------------------------------------------------------------------
c722 Tier-1 Watershed Timeseries Definition
c
c BMPSITE          = BMP site (watershed outlet) identifier in card 721
c BREAKPOINTID     = Unique break point id on cost-effectiveness curve
c                    (0 for initial, -1 for PreDev, and -2 for PostDev condition)
c MULTIPLIER       = Multiplier applied to the timeseries file
c TIMESERIESFILE   = Timeseries output file corresponding to the breakpoint id
c
c  BMPSITE   BREAKPOINTID   MULTIPLIER   TIMESERIESFILE
1           -2          0.5         C:\SUSTAIN\DATA\WRIA9\Tier1_till_output\PostDev_Junction_1.out
1           -1          0.5         C:\SUSTAIN\DATA\WRIA9\Tier1_till_output\PreDev_Junction_1.out
1           0           0.5         C:\SUSTAIN\DATA\WRIA9\Tier1_till_output\Init_Junction_1.out
1           1           0.5         C:\SUSTAIN\DATA\WRIA9\Tier1_till_output\BestPop1_Junction_1.out
1           2           0.5         C:\SUSTAIN\DATA\WRIA9\Tier1_till_output\BestPop9_Junction_1.out
1           3           0.5         C:\SUSTAIN\DATA\WRIA9\Tier1_till_output\BestPop11_Junction_1.out
1           4           0.5         C:\SUSTAIN\DATA\WRIA9\Tier1_till_output\BestPop12_Junction_1.out
```

```
1    5    0.5    C:\SUSTAIN\DATA\WRIA9\Tier1_till_output\BestPop10_Junction_1.out
3    -2   0.5    C:\SUSTAIN\DATA\WRIA9\Tier1_outwash_output\PostDev_Junction_1.out
3    -1   0.5    C:\SUSTAIN\DATA\WRIA9\Tier1_outwash_output\PreDev_Junction_1.out
3    0    0.5    C:\SUSTAIN\DATA\WRIA9\Tier1_outwash_output\Init_Junction_1.out
3    1    0.5    C:\SUSTAIN\DATA\WRIA9\Tier1_outwash_output\BestPop20_Junction_1.out
3    2    0.5    C:\SUSTAIN\DATA\WRIA9\Tier1_outwash_output\BestPop5_Junction_1.out
3    3    0.5    C:\SUSTAIN\DATA\WRIA9\Tier1_outwash_output\BestPop10_Junction_1.out
3    4    0.5    C:\SUSTAIN\DATA\WRIA9\Tier1_outwash_output\BestPop12_Junction_1.out
3    5    0.5    C:\SUSTAIN\DATA\WRIA9\Tier1_outwash_output\BestPop3_Junction_1.out
c------------------------------------------------------------------------------------------
c723 Pump Curve (applies if PUMP_FLG is ON in card 725)
c
c PUMP_CURVE     = The unique name of pump curve (continuous string without space)
c NUM_RECORD     = Number of points on the curve
c
c DEPTH          = Depth (ft)
c FLOW           = Pumping flow rate (cfs)
c
c PUMP_CURVE   NUM_RECORD
c DEPTH   FLOW
c------------------------------------------------------------------------------------------
c725 CLASS-A BMP Site Parameters (required if BMPSITE is CLASS-A in card 715)
c
c BMPSITE        = Class A BMP dimension group identifier in card 715
c WIDTH          = Basin bottom width (ft)
c LENGTH         = Basin bottom length (ft) / diameter (ft) for rain barrel or cistern
c OHEIGHT        = Orifice Height (ft)
c DIAM           = Orifice Diameter (in)
c EXTP           = Exit Type (1 for C=1,2 for C=0.61, 3 for C=0.61, 4 for C=0.5)
c RELTP          = Release Type (1-Cistern, 2-Rain barrel, 3-others)
c PEOPLE         = Number of persons (Cistern Option)
c DDAYS          = Number of dry days (Rain Barrel Option)
c WEIRTP         = Weir Type (1-Rectangular,2-Triangular)
c WEIRH          = Weir Height (ft)
c WEIRW          = (weir type 1) Weir width  (ft)
c THETA          = (weir type 2) Weir angle  (degrees)
c ET_MULT        = multiplier to PET
c PUMP_FLG       = pump option (0-OFF, 1-ON)
c DEPTH_ON       = water Depth (ft) at which the pump is started
c DEPTH_OFF      = water Depth (ft) at which the pump is stopped
c PUMP_CURVE     = The unique name of pump curve (continuous string without space)
c
c BMPSITE   WIDTH   LENGTH   OHEIGHT   DIAM   EXITYPE   RELEASETYPE   PEOPLE   DDAYS   WEIRTYPE   WEIRH
c WEIRW   THETA   ET_MULT   PUMP_FLG   DEPTH_ON   DEPTH_OFF   PUMP_CURVE
6    103.27   51.63   0    0.9   1    3    0    0    1    5    4.4   0
     1        0       0    0
c------------------------------------------------------------------------------------------
c730  Cistern Control Water Release Curve (applies if release type is cistern in card 725)
c
c BMPSITE        = Class A BMP dimension group identifier in card 715
c Flow           = Hourly water release per capita from the Cistern Control (ft3/hr/capita)
c
c BMPSITE   FLOW
6    0    0    0    0    0    0    0    0    0    0    0    0
     0    0    0    0    0    0    0    0    0    0    0    0
c------------------------------------------------------------------------------------------
c735 CLASS B BMP Site DIMENSION GROUPS
c
c BMPSITE        = BMP Site identifier in card 715
c WIDTH          = basin bottom width (ft)
c LENGTH         = basin bottom Length (ft)
c MAXDEPTH       = Maximum depth of channel (ft)
c SLOPE1         = Side slope 1 (ft/ft)
c SLOPE2         = Side slope 2 (ft/ft)   (1-4)
c SLOPE3         = Side slope 3 (ft/ft)
c MANN_N         = Manning  's roughness coefficient
c ET_MULT        = multiplier to PET
c
c BMPSITE   WIDTH   LENGTH   MAXDEPTH   SLOPE1   SLOPE2   SLOPE3   MANN_N   ET_MULT
c------------------------------------------------------------------------------------------
```

c740 BMP Site BOTTOM SOIL/VEGITATION CHARACTERISTICS

```
c
c BMPSITE        = BMPSITE identifier in c715
c INFILTM        = Infiltration Method (0-Green Ampt, 1-Horton, 2-Holtan)
c POLROTM        = Pollutant Routing Method (1-Completely mixed, >1-number of CSTRs in series)
c POLREMM        = Pollutant Removal Method (0-1st order decay, 1-kadlec and knight method )
c SDEPTH         = Soil Depth (ft)
c POROSITY       = Soil Porosity (0-1)
c FCAPACITY      = Soil Field Capacity (ft/ft)
c WPOINT         = Soil Wilting Point (ft/ft)
c AVEG           = Vegetative Parameter A (0.1-1.0) (Empirical), only required for Holtan infiltration method
c FINFILT        = Soil layer infiltration rate (in/hr)
c UNDSWITCH      = Consider underdrain (1), Do not consider underdrain (0)
c UNDDEPTH       = Depth of storage media below underdrain (ft)
c UNDVOID        = Fraction of underdrain storage depth that is void space (0-1)
c UNDINFILT      = Background infiltration rate, below underdrain (in/hr)
c SUCTION        = Average value of soil capillary suction along the wetting front, value must be greater than zero (in), only
c                  required for Green-Ampt infiltration method
c IMDMAX         = Difference between soil porosity and initial moisture content, value must be greater than or equal to zero (a
c                  fraction), only required for Green-Ampt infiltration method
c MAXINFILT      = Maximum rate on the Horton infiltration curve (in/hr), only required for Horton infiltration method
c DECAYCONS      = Decay constant for the Horton infiltration curve (1/hr), only required for Horton infiltration method
c DRYTIME        = Time for a fully staurated soil to completely dry (day), only required for Horton infiltration method
c MAXVOLUME      = Maximum infiltration volume possible (in), only required for Horton infiltration method
c
c BMPSITE   INFILTM   POLROTM   POLREMM   SDEPTH   POROSITY   FCAPACITY   WPOINT   AVEG   FINFILT
c UNDSWITCH   UNDDEPTH   UNDVOID   UNDINFILT   SUCTION   IMDMAX   MAXINFILT   DECAYCONS   DRYTIME
c MAXVOLUME
6      2      1      0      1      0.35   0.25   0.1    1      1      0      0      0
       1      3      0.3    3      4      7      0
c-------------------------------------------------------------------------------------------
```

c745 BMP Site HOLTAN GROWTH INDEX

```
c
c HOLTAN EQUATION:    F = GI * AVEG * (Computed Available Soil Storage)^1.4 + FINFILT
c
c BMPSITE        = BMPSITE identifier in card 715
c GIi            = 12 monthly values for GI in HOLTAN equation
c                  Where i = jan, feb, mar ... dec
c
c BMPSITE   jan   feb   mar   apr   may   jun   jul   aug   sep   oct   nov   dec
6      0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00
c-------------------------------------------------------------------------------------------
```

c747 BMP Site Initial Moisture Content

```
c
c BMPSITE        = BMP Site identifier in card 715
c WATDEP_i       = initial surface water depth (ft)
c THETA_i        = initial soil moisture (ft/ft)
c
c BMPSITE   WATDEP_i   THETA_i
6      0      0
c-------------------------------------------------------------------------------------------
```

c750 Class-C Conduit Parameters (required if BMPSITE is CLASS-C in card 715)

```
c
c BMPSITE        = BMP site identifier in card 715
c INLET_NODE     = BMP Id at the entrance of the conduit
c OUTLET_NODE    = BMP Id at the exit of the conduit
c LENGTH         = Conduit length (ft)
c MANNING_N      = Manning's roughness coefficient
c INLET_IEL      = Invert Elevation at the entrance of the conduit (ft)
c OUTLET_IEL     = Invert Elevation at the exit of the conduit (ft)
c INIT_FLOW      = Initial flow in the conduit (cfs)
c INLET_HL       = Head loss coefficient at the entrance of the conduit
c OUTLET_HL      = Head loss coefficient at the exit of the conduit
c AVERAGE_HL     = Head loss coefficient along the length of the conduit
c
c BMPSITE   INLET_NODE   OUTLET_NODE   LENGTH   MANNING_N   INLET_IEL   OUTLET_IEL   INIT_FLOW
c INLET_HL   OUTLET_HL   AVERAGE_HL
2      1      3      3364.1   0.14   0      0      0      0      0      0
4      3      6      3364.1   0.14   0      0      0      0      0      0
c-------------------------------------------------------------------------------------------
```

c755 Class C Conduit Cross Sections
c
c LINK = BMP site identifier in card 715
c TYPE = Conduit Type (rectangular, circular...)
c GEOM1 = Geometric cross-sectional property of the conduit
c GEOM2 = Geometric cross-sectional property of the conduit
c GEOM3 = Geometric cross-sectional property of the conduit
c GEOM4 = Geometric cross-sectional property of the conduit
c BARRELS = Number of Barrels in the conduit
c

c LINK	TYPE	GEOM1	GEOM2	GEOM3	GEOM4	BARRELS
2	DUMMY	0	0	0	0	0
4	DUMMY	0	0	0	0	0

c--
c760 Irregular Cross Sections
c
c Format of transect data follows:
c NC nLeft nRight nChannel
c X1 name nSta xLeftBank xRightBank 0 0 0 xFactor yFactor
c GR Elevation Station ...
c--
c761 BufferStrip BMP Parameters (required if BMPTYPE is BUFFERSTRIP in card 715)
c
c BMPSITE = BMP site identifier in card 715
c Width = BMP width (ft)
c FLength = Flow length (ft)
c DStorage = Surface depression storage (in)
c SLOPE = Overland slope (ft / ft)
c MANNING_N = Overland Manning's roughness coefficient
c POLREMM = Pollutant Removal Method (0-1st order decay, 1-kadlec and knight method)
c ET_MULT = Multiplier to PET
c
c BMPSITE Width FLength DStorage SLOPE MANNING_N POLREMM ET_MULT
c--
c762 Area BMP Parameters (required if BMPTYPE is AREABMP in card 715)
c
c BMPSITE = BMP site identifier in card 715
c Area = BMP area (ft2)
c FLength = flow length (ft) note: area width = area / flow length
c DStorage = Surface depression storage (in)
c SLOPE = Overland slope (ft / ft)
c MANNING_N = Overland Manning's roughness coefficient
c SAT_INFILT = Saturated infiltration rate (in/hr)
c POLREMM = Pollutant Removal Method (0-1st order decay, 1-kadlec and knight method)
c DCIA = Percentage of Directly Connected Impervious Area (0-100)
c TOTAL_IMP_DA = Total Impervious Drainage Area (acre)
c
c BMPSITE Area FLength DStorage SLOPE MANNING_N SAT_INFILT POLREMM DCIA TOTAL_IMP_DA
c--
c765 BMP SITE Pollutant Decay/Loss rates
c
c BMPSITE = BMP site identifier in card 715
c QUALDECAYi = First-order decay rate for pollutant i (hr^-1)
c Where i = 1 to N (N = Number of QUAL from card 705)
c

c BMPSITE	QUALDECAY1 QUALDECAY2... QUALDECAYN
6	0.02
2	0
4	0

c--
c766 Pollutant K' values (applies when pollutant removal method is kadlec and knight method in card 740)
c
c BMPSITE = BMP site identifier in card 715
c K 'i = Constant rate for pollutant i (ft/yr)
c Where i = 1 to N (N = Number of QUAL from card 705)
c

c BMPSITE	QUALK'1 QUALK'2... QUALK'N
6	3280
2	0
4	0

```
c-------------------------------------------------------------------------------------------
c767 Pollutant C* values (applies when pollutant removal method is kadlec and knight method in card 740)
c
c BMPSITE        = BMP site identifier in card 715
c C*i            = Background concentration for pollutant i (mg/l)
c                   Where i = 1 to N (N = Number of QUAL from card 705)
c
c BMPSITE   QUALC*1   QUALC*2... QUALC*N
6       12
2       0
4       0
c-------------------------------------------------------------------------------------------
c770 BMP Underdrain Pollutant Percent Removal (applies when underdrain is on in card 740)
c
c BMPSITE        = BMPSITE identifier in card 715
c QUALPCTREMi    = Perecent Removal for pollutant i through underdrain (0-1)
c                   Where i = 1 to N (N = Number of QUAL from card 705)
c
c BMPSITE   QUALPCTREM1   QUALPCTREM2... QUALPCTREMN
6       0
c-------------------------------------------------------------------------------------------
c775 Sediment General Parameters (required if pollutant type is sediment in card 705)
c
c BMPSITE        = BMP site identifier in card 715
c BEDWID         = Bed width (ft) - this is constant for the entire simulation period
c BEDDEP         = Initial bed depth (ft)
c BEDPOR         = Bed sediment porosity
c
c BMPSITE   BEDWID   BEDDEP   BEDPOR
c------------------------------------------------------------------------------------------------------------------------
c780 Sand Transport Parameters (required if pollutant type is sediment in card 705)
c
c BMPSITE        = BMP site identifier in card 715
c D              = Effective diameter of the transported sand particles (in)
c W              = The corresponding fall velocity in still water (in/sec)
c RHO            = The density of the sand particles (lb/ft3)
c KSAND          = The coefficient in the sandload power function formula
c EXPSND         = The exponent in the sandload power function formula
c
c BMPSITE   D   W   RHO   KSAND   EXPSND
c------------------------------------------------------------------------------------------------------------------------
c785 Silt Transport Parameters (required if pollutant type is sediment in card 705)
c
c BMPSITE        = BMP site identifier in card 715
c D              = Effective diameter of the transported silt particles (in)
c W              = The corresponding fall velocity in still water (in/sec)
c RHO            = The density of the silt particles (lb/ft3)
c TAUCD          = The critical bed shear stress for deposition (lb/ft2)
c TAUCS          = The critical bed shear stress for scour (lb/ft2)
c M              = The erodibility coefficient of the silt particles (lb/ft2/day)
c
c BMPSITE   D   W   RHO   TAUCD   TAUCS   M
c------------------------------------------------------------------------------------------------------------------------
c786 Clay Transport Parameters (required if pollutant type is sediment in card 705)
c
c BMPSITE        = BMP site identifier in card 715
c D              = Effective diameter of the transported clay particles (in)
c W              = The corresponding fall velocity in still water (in/sec)
c RHO            = The density of the silt/clay particles (lb/ft3)
c TAUCD          = The critical bed shear stress for deposition (lb/ft2)
c TAUCS          = The critical bed shear stress for scour (lb/ft2)
c M              = The erodibility coefficient of the clay particles (lb/ft2/day)
c
c BMPSITE   D   W   RHO   TAUCD   TAUCS   M
c------------------------------------------------------------------------------------------------------------------------
c790 LAND TO BMP ROUTING NETWORK (required for external land simulation control in card 700)
c
c UniqueID       = Identifies an instance of LANDTYPE in SCHEMATIC
c LANDTYPE       = Corresponds to LANDTYPE in c710
c AREA           = Area of LANDTYPE in ACRES
```

```
c DS                    = UNIQUE ID of DS BMP (0 - no BMP, add to end)
c
c UniqueID   LANDTYPE   AREA   DS
1           1           20        6
2           2           20        6
3           3           60        6
4           7           100       6
5           8           100       3
6           9           100       5
c-------------------------------------------------------------------------------------------
c795 BMP Site ROUTING NETWORK
c
c BMPSITE               = BMPSITE identifier in card 715
c OUTLET_TYPE           = Outlet type (1-total, 2-weir, 3-orifice or channel, 4-underdrain)
c DS                    = Downstrem BMP site identifier in card 715 (0 - no BMP, add to end)
c
c BMPSITE   OUTLET_TYPE   DS
1           1           2
2           1           3
3           1           4
4           1           5
6           1           3
c-------------------------------------------------------------------------------------------
c800 Optimization Controls
c
c Technique -- Optimization Techniques
c    0 = no optimization
c    1 = Scatter Search
c    2 = NSGAII
c Option -- Optimization options
c    0 = no optimization
c    1 = specific control target and minimize cost
c    2 = generate cost effectiveness curve
c StopDelta -- Criteria for stopping the optimization iteration
c           in dollars($), meaning if the cost not improved by this criteria, stop the search (for Option 1)
c MaxRuns -- Maximum number of iterations
c NumBest -- Number of best solutions for output (for Option 1)
c
c Technique   Option   StopDelta   MaxRuns   NumBest
2           2           0           100         2
c-------------------------------------------------------------------------------------------
c805 BMP Cost Functions
c Cost ($) = ((LinearCost)*Length^(LengthExp) + (AreaCost)*Area^(AreaExp) + (TotalVolumeCost)*TotalVolume^(TotalVolExp)
c         + (MediaVolumeCost)*SoilMediaVolume^(MediaVolExp) + (UnderDrainVolumeCost)*UnderDrainVolume^(UDVolExp)
c         + (ConstantCost)) * (1+PercentCost/100)
c
c BMPSITE                    = BMP site identifier in card 715
c LinearCost                 = Cost per unit length of the BMP structure ($/ft)
c AreaCost                   = Cost per unit area of the BMP structure ($/ft^2)
c TotalVolumeCost            = Cost per unit total volume of the BMP structure ($/ft^3)
c MediaVolumeCost            = Cost per unit volume of the soil media ($/ft^3)
c UnderDrainVolumeCost       = Cost per unit volume of the under drain structure ($/ft^3)
c ConstantCost               = Constant cost ($)
c PercentCost                = Cost in percentage of all other cost (%)
c LengthExp                  = Exponent for linear unit
c AreaExp                    = Exponent for area unit
c TotalVolExp                = Exponent for total volume unit
c MediaVolExp                = Exponent for soil media volume unit
c UDVolExp                   = Exponent for underdrain volume unit
c
c BMPSITE   LinearCost   AreaCost   TotalVolumeCost   MediaVolumeCost   UnderDrainVolumeCost   ConstantCost   PercentCost
c LengthExp   AreaExp   TotalVolExp   MediaVolExp   UDVolExp
6           0           18.25       4.78        0           0           0           0           1           1           1           1       1
c-------------------------------------------------------------------------------------------
c810 BMP SITE Adjustable Parameters
c
c BMPSITE               = BMP site identifier in card 715
c VARIABLE              = Variable name (must use the exact same keyword)
c                         LENGTH --- BMP length,
c                         NUMUNIT --- number of units,
```

```
c                         WEIRH --- weir height,
c                         SDEPTH --- soil media depth,
c                         DCIA --- directly connected impervious area for area BMP type,
c                         MAXDEPTH --- maximum surface storage depth for swale,
c                         CECURVE --- cost-effectiveness curve for Tier-1 solution
c FROM              = From value in the range
c TO                = To value in the range
c STEP              = Increment step
c
c BMPSITE   VARIABLE   FROM   TO   STEP
6          NUMUNIT          0          200        5
1          CECurve          0          5          1
3          CECurve          0          5          1
c-------------------------------------------------------------------------------------------
```

c814 Predeveloped Timeseries at Assessment Point for Flow Duration Curve

```
c
c BMPSITE           = BMP site identifier in card 715 if it is an assessment point
c NumBins           = Number of bins for flow duration curve
c PreDevFlag        = Pre-developed timeseries option (1-internal,2-external)
c PreDevFile        = Pre-developed timeseries file path for external option
c                     The timeseries file format (AssessmentPoint_ID   Year   Month   Day   Hour   Minute   Flow_cfs)
c                     The first line is skipped (comment line) and data start from the second line in the required format.
c
c BMPSITE   NumBins   PreDevFlag   PreDevFile
5   20000   1
c-------------------------------------------------------------------------------------------
```

c815 Assessment Point and Evaluation Factor

```
c
c BMPSITE -- BMP site identifier in card 715 if it is an assessment point
c FactorGroup -- Flow or pollutant related evaluation factor group
c    -1 = flow related evaluation factor
c     # = pollutant ID in card 705
c FactorType -- Evaluation Factor Type (negative number for flow related and positive number for pollutant related)
c    -1 = AAFV Annual Average Flow Volume (ft3/yr)
c    -2 = PDF  Peak Discharge Flow (cfs)
c    -3 = FEF  Flow Exceeding frequency  (#times/year)
c    -4 = FDC  Flow Duration Curve (sum of sorted flow difference with pre-developed condition, cfs)
c     1 = AAL  Annual Average Load (lb/yr)
c     2 = AAC  Annual Average Concentration (mg/L)
c     3 = MAC  Maximum #days Average Concentraion (mg/L)
c FactorVal1 -- if FactorType = 3 (MAC): Maximum #Days;
c           -- if FactorType = -3 (FEF): Threshold (cfs)
c           -- if FactorType = -4 (FDC): Low flow limit (cfs)
c           -- all other FactorType : -99
c FactorVal2 -- if FactorType = -3 (FEF): Minimum inter-exceedance time (hr)
c                                   if =  0 then daily running average flow exceeding frequency
c                                   if = -1 then daily average flow exceeding frequency
c                                   otherwise minimum inter-exceedance time for simulation interval
c           -- if FactorType = -4 (FDC): High flow limit (cfs)
c           -- all other FactorType : -99
c CalcMode -- Evaluation Factor Calculation Mode
c   -99 for Option 0 (card 800): no optimizaiton
c     1 = % percent of value under existing condition (0-100)
c     2 = S scale between pre-develop and existing condition (0-1)
c     3 = V  absolute value in the unit as shown in FactorType (third block in this card)
c TargetVal1 -- Target value for evaluation factor calculation mode
c     -99 for Option 0 (card 800): no optimizaiton
c     Target value for minimize cost Option 1 (card 800)
c     Lower limit of target value for cost-effective curve Option 2 (card 800)
c TargetVal2 -- Target value for evaluation factor calculation mode
c     -99 for Option 0 (card 800): no optimizaiton
c     -99 for Option 1 (card 800): minimize cost
c     Upper limit of target value for cost-effective curve Option 2 (card 800)
c Factor_Name -- Evaluation factor name (user specified without any space), e.g. FlowVolume or SEDIMENT
c
c BMPSITE   FactorGroup   FactorType   FactorVal1   FactorVal2   CalcMode   TargetVal1   TargetVal2   FactorName
5          -1          -4          1.025       50          1          0          100         FDC_%
```

Appendix B - Input File Card Dependencies Mapping

Users can make changes to a *SUSTAIN* input text file without having to go through the ArcGIS interface. Changes to certain model components have dependencies that span multiple input cards. This appendix provides an index of dependent input cards for nine common changes that can be made to input files. Table B lists common changes made to *SUSTAIN* input files. Some of the dependency changes are required, while others are optional, meaning that they are only required if the relevant object, feature, or option is being used in the project. For example, Table B1 shows that adding a new pollutant in the text file (card 705) will require modifying card 713 only if any aquifer object is defined in the project, while the referenced steps noted for cards 705, 710, 765 and 770 must be performed. In each table, optional dependencies are italicized.

Table B. Index of tables and desired input file modification

Table Number	Desired Input File Change (Adding or Removing)
B1	A new pollutant to an input text file
B2	A new land use category for runoff boundary conditions
B3	An aquifer
B4	A retention or detention BMP (i.e. bioretention, wet pond, rain barrel, etc.)
B5	A swale BMP
B6	A conduit
B7	A buffer strip
B8	Adding/removing BMP (Disconnected Impervious Area)
B9	A junction

Table B1. Dependency cards for adding a pollutant in the input text file

Card #	Definition	Option	Remarks
705	Pollutant	Required	Add a row and define the parameters for this pollutant.
710	Land Use	Required	The land output timeseries should have the loading rate for this pollutant.
713	*Aquifer*	*Optional*	*Add a column in the predefined Aquifers for the background concentration of this pollutant.*
720	*Point Source*	*Optional*	*The point source timeseries should have the loading rate for this pollutant.*
765	Decay Rate	Required	Add a column in the existing row for the 1st order decay rate of this pollutant.
766	*K' values*	*Optional*	*Add a column in the existing rows for this pollutant if the pollutant removal method is kadlec and knight in card 740.*
767	*C* values*	*Optional*	*Add a column in the existing rows for this pollutant if the pollutant removal method is kadlec and knight in card 740.*
770	Removal Rate	Required	Add a column in the existing row for the underdrain removal rate of this pollutant.
775	*Sediment*	*Optional*	*Add this card if the pollutant type is sediment in card 705.*
780	*Sand*	*Optional*	*Add this card if the pollutant type is sediment in card 705.*
785	*Silt*	*Optional*	*Add this card if the pollutant type is sediment in card 705.*
786	*Clay*	*Optional*	*Add this card if the pollutant type is sediment in card 705.*

Table B2. Dependency cards for adding a land use in the input text file

Card #	Definition	Option	Remarks
710	Land Use	Required	Add a row and assign an external timeseries file for this land use.
790	Land to BMP/Junction Routing	Required	Add a row and define the downstream BMP/Junction identifier as given in card 715.

Table B3. Dependency cards for adding an aquifer in the input text file

Card #	Definition	Option	Remarks
712	Aquifer	Required	Add a row and define the parameters for this aquifer.
713	Pollutant Conc.	Required	Add a row and define the pollutant background concentration for this aquifer.
715	*BMP*	*Optional*	*Modify the existing BMP-Aquifer assignment if needed.*

Table B4. Dependency cards for adding a BMP (Bioretention, Wet Pond, Cistern, Dry Pond, Infiltration Trench, Green Roof, Porous Pavement, Rain Barrel, and Regulator) in the input text file

Card #	Definition	Option	Remarks
715	BMP	Required	Add a row and define the parameters for this BMP.
714	*F-table*	*Optional*	*Define a functional table for the stage, volume, and discharge relationship for this BMP.*
720	*Point Source*	*Optional*	*Add a row and assign a point source timeseries file for this BMP.*
723	*Pump Curve*	*Optional*	*Define a pump curve for stage discharge relationship for this BMP.*
725	BMP Dimensions	Required	Add a row and define the parameters for this BMP.
730	*Cistern Hourly Release Rate*	*Optional*	*Add a row and define the hourly release rate for this BMP if the orifice release type is Cistern in card 725.*
740	Soil Properties	Required	Add a row and define the parameters for this BMP.
745	*Holtan Growth Index*	*Optional*	*Add a row and define the monthly growth index for this BMP if the infiltration method is Holtan in card 740.*
747	Initial Moisture	Required	Add a row and define the parameters for this BMP.
765	Decay Rate	Required	Add a row for this BMP if the pollutant removal method is 1st order decay in card 740.
766	*K' values*	*Optional*	*Add a row for this BMP if the pollutant removal method is kadlec and knight in card 740.*
767	*C* values*	*Optional*	*Add a row for this BMP if the pollutant removal method is kadlec and knight in card 740.*
770	Removal Rate	Required	Add a row for this BMP for the underdrain pollutant removal rates.
775	*Sediment*	*Optional*	*Add a row for this BMP if any pollutant type is sediment in card 705.*
780	*Sand*	*Optional*	*Add a row for this BMP if any pollutant type is sediment in card 705.*
785	*Silt*	*Optional*	*Add a row for this BMP if any pollutant type is sediment in card 705.*
786	*Clay*	*Optional*	*Add a row for this BMP if any pollutant type is sediment in card 705.*
795	BMP to	Required	Add a row and define the downstream BMP/Junction

Card #	Definition	Option	Remarks
	BMP/Junction Routing		identifier as given in card 715.
805	BMP Cost	Required	Add a row and define the cost parameters for this BMP.
810	*Decision Variables*	*Optional*	*Define decision variables if this BMP specifications (size, unit, etc.) need to be optimized.*
815	*Assessment Point*	*Optional*	*Add a row and define evaluation factors if this BMP location is an assessment point.*

Table B5. Dependency cards for adding a BMP (Swale) in the input text file

Card #	Definition	Option	Remarks
715	BMP	Required	Add a row and define the parameters for this BMP.
714	*F-table*	*Optional*	*Define a functional table for the stage, volume, and discharge relationship for this BMP.*
720	*Point Source*	*Optional*	*Add a row and assign a point source timeseries file for this BMP.*
735	BMP Dimensions	Required	Add a row and define the parameters for this BMP.
740	Soil Properties	Required	Add a row and define the parameters for this BMP.
745	*Holtan Growth Index*	*Optional*	*Add a row and define the monthly growth index for this BMP if the infiltration method is Holtan in card 740.*
747	Initial Moisture	Required	Add a row and define the parameters for this BMP.
765	Decay Rate	Required	Add a row for this BMP if the pollutant removal method is 1st order decay in card 740.
766	*K' values*	*Optional*	*Add a row for this BMP if the pollutant removal method is kadlec and knight in card 740.*
767	*C* values*	*Optional*	*Add a row for this BMP if the pollutant removal method is kadlec and knight in card 740.*
770	Removal Rate	Required	Add a row for this BMP for the underdrain pollutant removal rates.
775	*Sediment*	*Optional*	*Add a row for this BMP if any pollutant type is sediment in card 705.*
780	*Sand*	*Optional*	*Add a row for this BMP if any pollutant type is sediment in card 705.*
785	*Silt*	*Optional*	*Add a row for this BMP if any pollutant type is sediment in card 705.*
786	*Clay*	*Optional*	*Add a row for this BMP if any pollutant type is sediment in card 705.*
795	BMP to BMP/Junction Routing	Required	Add a row and define the downstream BMP/Junction identifier as given in card 715.
805	BMP Cost	Required	Add a row and define the cost parameters for this BMP.
810	*Decision Variables*	*Optional*	*Define decision variables if this BMP specifications (size, unit, etc.) need to be optimized.*
815	*Assessment Point*	*Optional*	*Add a row and define evaluation factors if this BMP location is an assessment point.*

Table B6. Dependency cards for adding a Conduit in the input text file

Card #	Definition	Option	Remarks
715	BMP/Conduit	Required	Add a row and define the parameters for this Conduit.
714	*F-table*	*Optional*	*Define a functional table for the stage, volume, and discharge relationship for this Conduit.*
720	*Point Source*	*Optional*	*Add a row and assign a point source timeseries file for this Conduit.*
750	Conduit Dimensions	Required	Add a row and define the parameters for this Conduit.
755	Conduit Geometry	Required	Add a row and define the geometric cross-sectional properties of this Conduit.
760	*Irregular Cross-section*	*Optional*	*Define the transect parameters if the conduit geometry type is irregular in card 755.*
765	Decay Rate	Required	Add a row for this Conduit if the pollutant removal method is 1st order decay in card 740.
766	*K' values*	*Optional*	*Add a row for this Conduit if the pollutant removal method is kadlec and knight in card 740.*
767	*C* values*	*Optional*	*Add a row for this Conduit if the pollutant removal method is kadlec and knight in card 740.*
775	*Sediment*	*Optional*	*Add a row for this Conduit if any pollutant type is sediment in card 705.*
780	*Sand*	*Optional*	*Add a row for this Conduit if any pollutant type is sediment in card 705.*
785	*Silt*	*Optional*	*Add a row for this Conduit if any pollutant type is sediment in card 705.*
786	*Clay*	*Optional*	*Add a row for this Conduit if any pollutant type is sediment in card 705.*
795	Conduit to BMP/Junction Routing	Required	Add a row and define the downstream BMP/Junction identifier as given in card 715.

Table B7. Dependency cards for adding a BMP (Bufferstrip) in the input text file

Card #	Definition	Option	Remarks
715	BMP	Required	Add a row and define the parameters for this BMP.
761	BMP Dimensions	Required	Add a row and define the parameters for this BMP.
765	Decay Rate	Required	Add a row for this BMP if the pollutant removal method is 1st order decay in card 761.
766	*K' values*	*Optional*	*Add a row for this BMP if the pollutant removal method is kadlec and knight in card 761.*
767	*C* values*	*Optional*	*Add a row for this BMP if the pollutant removal method is kadlec and knight in card 761.*
775	*Sediment*	*Optional*	*Add a row for this BMP if any pollutant type is sediment in card 705.*
780	*Sand*	*Optional*	*Add a row for this BMP if any pollutant type is sediment in card 705.*
785	*Silt*	*Optional*	*Add a row for this BMP if any pollutant type is sediment in card 705.*
786	*Clay*	*Optional*	*Add a row for this BMP if any pollutant type is sediment in card 705.*
795	BMP to BMP/Junction	Required	Add a row and define the downstream BMP/Junction identifier as given in card 715.

Card #	Definition	Option	Remarks
	Routing		
805	BMP Cost	Required	Add a row and define the cost parameters for this BMP.
810	*Decision Variables*	*Optional*	*Define decision variables if this BMP specifications (size, unit, etc.) need to be optimized.*
815	*Assessment Point*	*Optional*	*Add a row and define evaluation factors if this BMP location is an assessment point.*

Table B8. Dependency cards for adding a BMP (Disconnected Impervious Area) in the input text file

Card #	Definition	Option	Remarks
715	BMP	Required	Add a row and define the parameters for this BMP.
762	BMP Dimensions	Required	Add a row and define the parameters for this BMP.
765	Decay Rate	Required	Add a row for this BMP if the pollutant removal method is 1st order decay in card 762.
766	*K' values*	*Optional*	*Add a row for this BMP if the pollutant removal method is kadlec and knight in card 762.*
767	*C* values*	*Optional*	*Add a row for this BMP if the pollutant removal method is kadlec and knight in card 762.*
775	*Sediment*	*Optional*	*Add a row for this BMP if any pollutant type is sediment in card 705.*
780	*Sand*	*Optional*	*Add a row for this BMP if any pollutant type is sediment in card 705.*
785	*Silt*	*Optional*	*Add a row for this BMP if any pollutant type is sediment in card 705.*
786	*Clay*	*Optional*	*Add a row for this BMP if any pollutant type is sediment in card 705.*
795	BMP to BMP/Junction Routing	Required	Add a row and define the downstream BMP/Junction identifier as given in card 715.
805	BMP Cost	Required	Add a row and define the cost parameters for this BMP.
810	*Decision Variables*	*Optional*	*Define decision variables if this BMP specification (DCIA) needs to be optimized.*
815	*Assessment Point*	*Optional*	*Add a row and define evaluation factors if this BMP location is an assessment point.*

Table B9. Dependency cards for adding a Junction in the input text file

Card #	Definition	Option	Remarks
715	BMP/Junction	Required	Add a row and define the parameters for this Junction.
721	*Tier-1 Outlet*	*Optional*	*Only required for Tier-2 linkage*
722	*Tier-1 Timeseries*	*Optional*	*Only required for Tier-2 linkage*
795	Junction to BMP/Junction Routing	Required	Add a row and define the downstream BMP/Junction identifier as given in card 715.
814	*Predeveloped Timeseries*	*Optional*	*Only required if the evaluation factor at the assessment point is Flow Duration Curve in card 815.*
815	*Assessment Point*	*Optional*	*Add a row and define evaluation factors if this Junction is an assessment point.*