DEVELOPMENT OF IMPLEMENTATION METHODS OF WATER QUALTIY TRADING POLICY:

USING HYDROLOGICAL SIMULATION PROGRAM-FORTRAN (HSPF)

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The undersigned, appointed by the dean of the Graduate School, have examined the dissertation entitled

DEVELOPMENT OF IMPLEMENTATION METHODS OF
WATER QUALTIY TRADING POLICY:
USING HYDROLOGICAL SIMULATION PROGRAM-FORTRAN (HSPF)

presented by

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a candidate for the degree of doctor of philosophy in Civil and Environmental Engineering

and hereby certify that, in their opinion, it is worthy of acceptance.

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In loving memory of Dong-gil Shin

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ABSTRACT

The recently promulgated water quality trading (WQT) policy is an innovative approach for achieving water quality standards with flexibility and economic efficiency. The policy allows for the trading of point and nonpoint source pollutant discharges between different locations within a watershed, as long as water quality standards are not violated along the stream. Many pilot programs and projects have generated useful information on how to implement water quality trading, but the number of actual trades is relatively small. The difficulty in determining the equality of trading locations and the uncertainty of nonpoint source pollutant concentrations in streams hinder the implementation of the trading program.

The hydrological simulation program-fortran (HSPF) was used to estimate the hydrology and sediment loading throughout the Brush Creek, MO watershed for future land use development scenarios between upstream and downstream locations. Brush Creek does not have a proper monitoring station for calibration and validation of the watershed model. Thus, the Meramec River watershed which drains to the Meramec River near Eureka, MO station (07019000) was selected for input parameter calibration because the watershed contains the Brush Creek watershed as a subbasin.

The development scenarios considered include upstream and downstream development from agricultural, forest, and range land to urbanized development with 25, 50, and 75 percent impervious surface through manually modified land use maps. Restoration scenarios would return agricultural areas to range land in both the upstream and downstream locations. Their hydrologic and sediment impacts to the outlet of the watershed were simulated in order to provide an estimate of how this particular land use change might be incorporated into a water quality trade.

After sediment calculations for 20 different scenarios were performed in HSPF, equivalent acreages for sediment generation between upstream and downstream locations were developed as potential water quality trading units. Recommended equivalent acreages for the nonimparied and impaired stream cases were provided as references for a trading program manager in order to implement the water quality trading policy.

1 Introduction

1.1. Research background

Water is the most important element for any ecological system. In spite of the importance of clean water, more than 20,000 water bodies in America have been identified as polluted including more than 300,000 miles of rivers and shoreline and 5 million acres of lakes. Approximately 40% of U.S. waters still do not meet the water quality standards states, territories, and authorized tribes have set for them (USEPA 2000)

Because of the necessity of restoring water quality, the Clean Water Act, passed in 1972 and amended since, has placed great effort focused on regulating discharges from traditional point source facilities, such as municipal sewage plants and industrial facilities (USEPA 2009). However, it paid little attention to nonpoint sources such as runoff from streets, construction sites, and farms. With the recognition of the importance of nonpoint source pollution, regulations issued under the Clean Water Act require the establishment of total maximum daily loads (TMDL) for polluted waters by states, territories, and authorized tribes.

Even a watershed draining into a stream that is not listed as an impaired water body may still warrant some protective actions for smart growth even before development occurs. The recently promulgated water quality trading (WQT) policy is a customized policy that can be used to promote smart growth in order to maintain water quality. WQT is an innovative approach to achieve water quality goals cost effectively. The assumption of this policy is that the costs of controlling the same pollutant can be different between two locations in a watershed. For example, the Environmental Protection Agency's WQT policy allows facilities facing higher pollution control costs to meet their regulatory obligations by purchasing pollution reductions from another source at lower cost (USEPA 2003b). These economical trading efforts can achieve the same environmentally protective results with lower overall costs. However, there are problems facing its implementation. The WQT policy is not limited to the point sources facilities; thus, for the quality trading, the amount of nonpoint source pollution loads between communities within a watershed should be clearly presented before application of the WQT policy.

Recently, TMDL researchers investigating the application of TMDLs on stream segments have attempted to estimate nonpoint source pollution loads to calculate realistic loads with watershed models. Still, there is great uncertainty in predicting the amount of pollution from nonpoint sources because they are so dispersed and generally have low concentrations. Until now, WQT policy studies have been limited to point source pollutants and EPA is still looking for methods to apply to nonpoint source pollutions trading. The USEPA WQT website calls for projects to be funded for implementing the WQT policy (USEPA 2003b).

Historically, human being understood the hydrological cycle from their own accumulated experiences and used it to produce their food and protect their life styles. As the science has developed quickly, the quantification of the hydrological cycle with watershed modeling and the use of geographical information systems is getting easier and more precise than ever (Vermont_Legislature 2007). These techniques are rapidly being applied to estimate water quantity and quality by quantifying the water budget on a watershed basis.

According to Trauth and Shin (2005), smart growth principles may cause poor runoff water quality from developing communities with the increased impervious surfaces. Watershed modeling programs will be applied to predict the various watershed conditions from the present to the future in order to apply the WQT program within the watershed where development is expected.

1.2. Research goals

The final objective of this study is to establish a methodology for determining appropriate tradable units between upstream and downstream locations for nonpoint source pollutants water quality trading policy, applying HSPF watershed model.

A methodology to use watershed modeling with limited watershed monitoring data available is investigated. Using a GIS and the present characteristics of a target watershed, estimated future land cover changes will be displayed in order to develop the land use scenarios. The impact of land use development scenarios is the basis for determining trading units.

1.3. Organization of study

Chapter 2 contains a literature review relating to the WQT policy, watershed modeling, GIS, and sediment generation from land use. The limitation of the application of the trading program because of the uncertainty of nonpoint sources is discussed. The watershed modeling program which can estimate the nonpoint source pollutants is introduced, focusing on the Hydrologic Simulation Program-Fortran (HSPF). Sediment generation from the different land use was assessed through the literature.

A limitation on the implementation of the trading program is the lack of observed data to calibrate the watershed modeling program within a small local watershed. In Chapter 3, a calibration methodology for a watershed without monitoring data is introduced. The Meramec River watershed contains the much smaller Brush Creek watershed as a subbasin and the flows into the Meramec River near Eureka, MO station (07019000) which is the site of United States Geological Survey (USGS) real time monitoring, with water flow and water quality data available. The input parameters from the calibration of the Meramec River watershed applied to the HSPF model of the Brush Creek watershed are used in simulating the flow and water quality impacts of multiple land use scenarios.

In chapter 4, the land use change scenarios are developed with the modification of the current land use with future development. The flow and water quality impacts of future development scenarios between upstream and downstream locations are generated.

Chapter 5 provides the results of the hydrologic and sediment calculations after the land use changes are applied within the HSPF model. The analysis methodology to determine the trading units between upstream and downstream development scenarios is presented. Finally, the tradable equivalent acreage of each land use scenario associated the downstream development case is provided.

Chapter 6 presents the conclusions and the recommendation for future work to enhance the results of this research.

2 Literature Review

2.1. Water Quality Trading Policy

2.1.1. Overview

The Clean Water Act (CWA), passed in 1972, focused on regulating discharges from traditional "point source" facilities, such as municipal sewage plants and industrial facilities. The application of technology and water quality based requirements through the National Pollutant Discharge Elimination System (NPDES) permit program has achieved and remains critical to success in controlling point source pollution and restoring the nation's waters (USEPA 2009). Despite these accomplishments, approximately 40% of U.S. waters still do not meet the water quality standards states, territories, and authorized tribes have set for them (Ritchie 2001). These conditions are the result of the fact that the CWA and its implementing regulations paid little attention to nonpoint source pollutants such as runoff from streets, construction sites, and farms. Nutrient and sediment loadings from agriculture and storm water runoff are significant contributors to water quality problems such as hypoxia in the Gulf of Mexico and decreased fish populations in Chesapeake Bay (USEPA 2003c). Also, population growth and development has placed increasing demands on the environment, making it difficult to achieve and maintain water quality standards economically.

In early 2003, the Environmental Protection Agency (EPA) promulgated a water quality trading (WQT) policy. The policy allows for the trading, within a watershed, of point and nonpoint source pollutant discharges between different locations, as long as water quality standards are not violated along the receiving stream. The WQT is an innovative approach to achieve water quality goals more cost effectively. Trading is based on the fact that sources in a watershed can face very different costs to control the same pollutant (USEPA 2004). Trading programs allow facilities facing higher pollution control costs to meet their regulatory obligations by purchasing environmentally equivalent pollution reductions from another source at a lower cost, thus achieving the same water quality improvement at lower overall cost (Oregon_DEQ 2009).

Nishizawa (2003) introduced the potential benefits of effluent trading in various aspects: (1) with appropriate monitoring and enforcement, total pollutant loadings can be kept at or below a pre-specified level, (2) new and expanding dischargers can be accommodated, as long as they purchase credits, and (3) relocation of industrial facilities which can cause a huge impact on the local community's economy can be prevented with the purchase of effluent credits.

According to Water Quality Trading Policy Statement, the National Cost to Implement Total Maximum Daily Loads (TMDLs) Draft Report estimated that flexible approaches to improving water quality could save $900 million dollars annually compared to the least flexible approach. The purpose of this policy is to encourage states, interstate agencies and tribes to develop and implement water quality trading programs for nutrients, sediments and other pollutants where opportunities exist to achieve water quality improvements at reduced costs (USEPA 2003c).

2.1.2. Limitations

2.1.2.1 Applications to nonpoint sources pollutant

One of the difficulties noted by the EPA in the original promulgation of the WQT policy is the process of determining the equality of trading locations. Equality can be described in terms of the land areas that are associated with the trade, as well as the associated land uses/land covers. Equality is particularly difficult to establish for nonpoint-nonpoint source trades because of the inherent uncertainty, especially in the occurrence of the precipitation events that are the driving force for the generation and transport of pollutants from the land surface to a receiving stream. The difficulties of estimating nonpoint source pollution loads cause many initiative programs for WQT to be limited to point source trading (EPA 1998). A recent review showed that WQT programs are frozen at the pretrading stage of development and that very little actual trading is taking place even though plenty of new guidelines, regional trading institutions, and computer simulations of trading are being provided (King 2005).

Presently, the EPA suggests point-point source and point-nonpoint source trading to simplify the management (Figure 2-1). The trading credit can be calculated with the effluent monitoring of point sources and best management practice (BMP) efficiency ratios of nonpoint sources. However, BMP efficiency for nonpoint source pollutants is not defined easily because of the weather and geographical variables. Edge-of field monitoring and modeling with proper assumptions can reduce the uncertainty of the BMP efficiency ratio (USEPA 2003c).

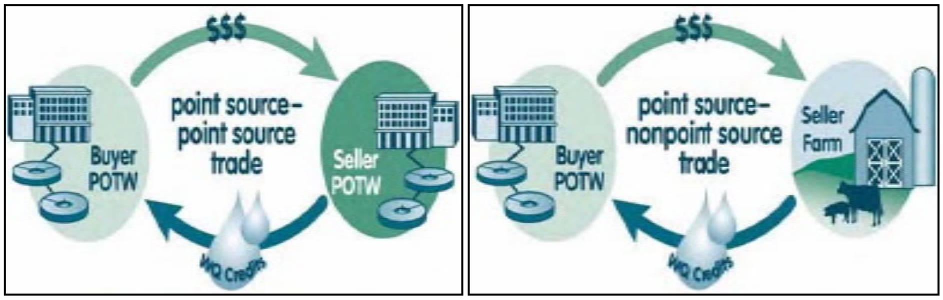


Figure 2-1. Suggestion of trading parties.
(EPA Benefits of WQT,
http://www.epa.gov/owow/watershed/trading/trading101306final.pdf)

As King (2005) noted, most of the existing trading programs deal with point-point source and point-non point source trades (Figure 2-2). The Vermont storm water discharge permit program is the only program that deals with non-point source pollutant trading among statewide trading frameworks in place. According to the Vermont statutes online (Vermont_Legislature 2007), the state authority imposes a storm water impact fee on permit applicants of $30,000.00 per acre of impervious surface. An individual discharger can reduce the storm water impact fee through compliance on the engineering feasibility analysis. The engineering feasibility analysis uses the Simple Method Model (SMM) (Schuler 1987) which is used to determine both pre-development and post-development loads from the site being evaluated. Pre-development site conditions are characterized as the natural runoff from an undeveloped field or open meadow that is not used for agricultural activity. Post-development loads will reflect the reduction in loading to be achieved through application of the treatment and control practices. The SMM can be used only for general estimates related to a small construction area, catchment or subwatershed. Also, SMM does not consider the physical geographical conditions which are very important in estimating runoff and erosion. SMM can estimate storm period pollutant loadings only because it uses an annual rainfall value. For the nonpoint sources pollutant trading program, more sophisticated watershed modeling may be needed to analyze larger and more complex watersheds.

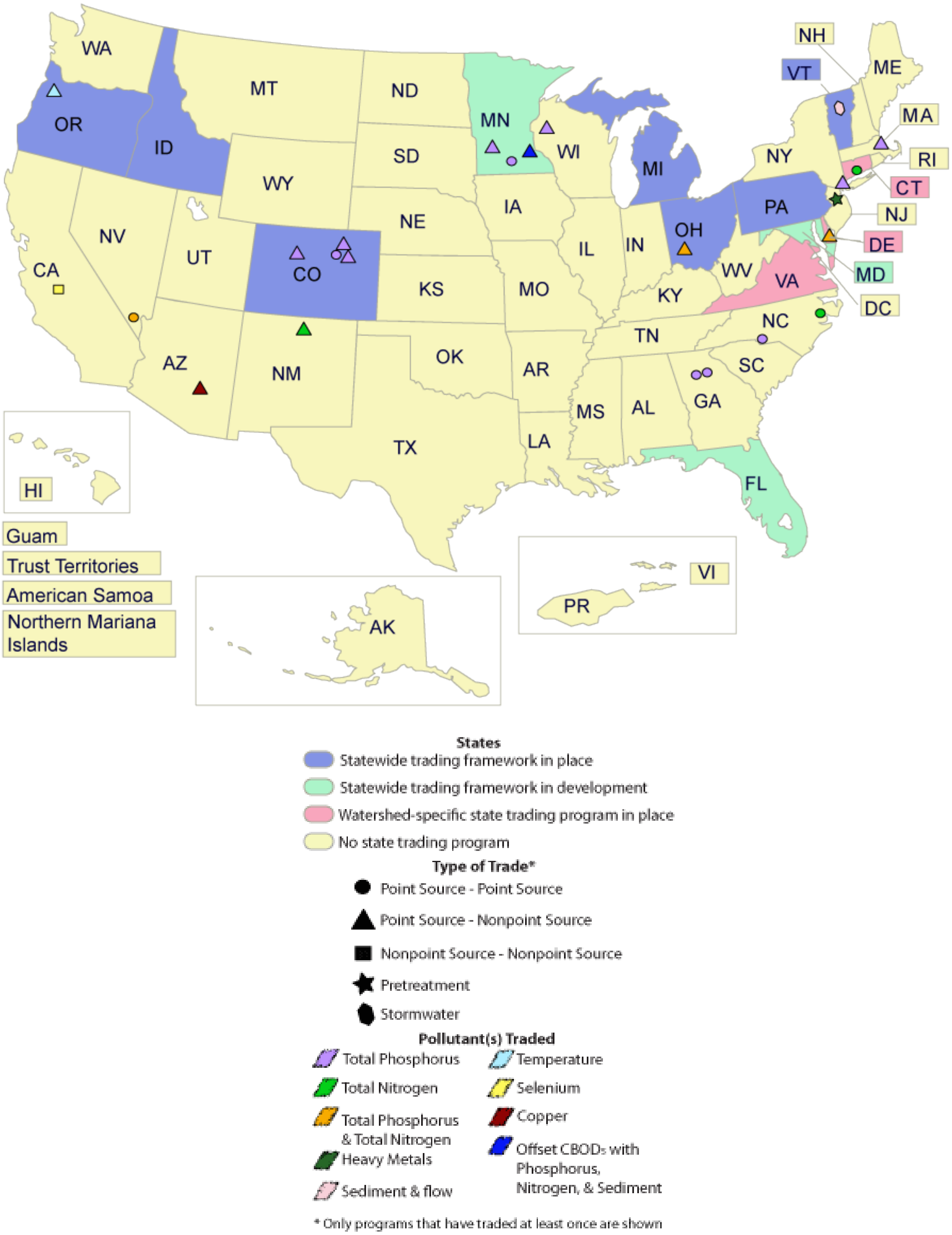


Figure 2-2. State and individual trading programs(EPA 2003).

(EPA's WQT, http//www.epa.gov/owow/watershed/trading/tradingmap.html)

2.1.2.2 Trading units

Clearly defined units of trading are necessary for trading to actually occur. Specific pollutant credits are examples of tradable units for WQT. These may be expressed in rates or mass per unit time as appropriate to be consistent with the time periods that are used to determine compliance with NPDES permit limitations or other regulatory requirements.

An example of the current implementation of trading values is a program in Montgomery County, Maryland where maximum housing density was increased from one house per five acres to one house per 25 acres (USEPA 2004(c)). No hydrologic or water quality basis is provided for this value. The twenty five-acre regulation has been established for the entire County regardless the site-specific hydrological characteristics within various locations in the County that might cause different impacts to the stream.

The timing of credit is also problematic in applying the trading program because of the uncertainty of the hydrologic cycle. For example, it is very difficult to determine the impact of pesticides to a stream even though a farmer may know the amount of pesticide that he or she applied to the crops. Thus, the trading credits should be generated and used within the same time period in order to comply with permit limits and prevent localized exceedances of water quality standards (USEPA 2003c).

A decision support system to manage a trading program properly needs to develop the process of calibrated and validated watershed modeling, education for trading parties, and compliance and enforce for the program. Above all, properly undertaken watershed modeling is the essential element for a non-point source trading program (USEPA 2007).

2.2. Watershed models

2.2.1. Hydrology

2.2.1.1 Water cycle

Water may seem to be stable and calm in our cups, bathtubs and lakes but its form and location change constantly. Water moves through the entire the earth system: the atmosphere, the lithosphere and the biosphere.

The scheme of the water cycle (Figure 2-3) of the earth is driven by energy from the sun and provides us some hints to understand hydrologic events. Water in storage in the atmosphere falls as precipitation to the land and the can move both vertically and horizontally. Vertical flow moves into the soil system as infiltration which is a function of soil moisture conditions and soil type and may continue vertically downward into groundwater storage. Other subsurface flow may move horizontally and feed streams that ultimately flow to the ocean. The original horizontal flow is surface runoff which flows to stream, being that which remains after infiltration, evaporation and evapotranspiration, and eventually reaches the ocean. The objective of a watershed model is simulation of the water cycle as realistically as possible.

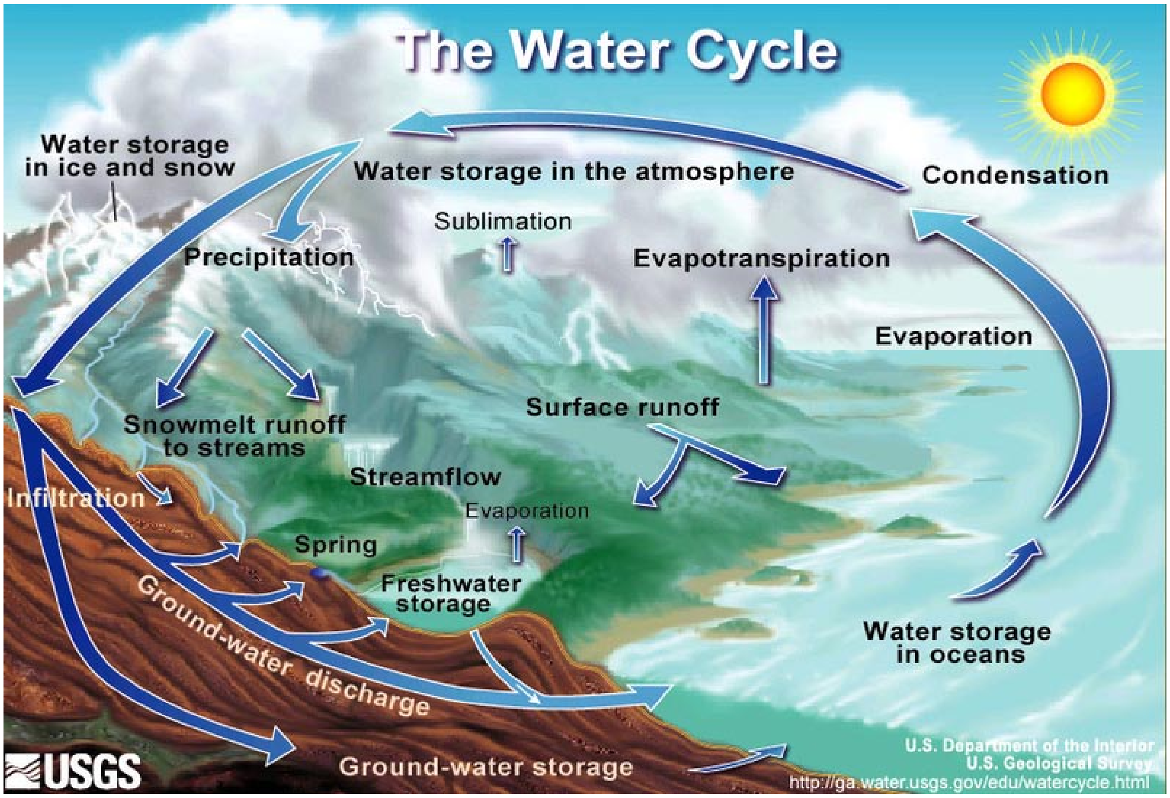


Figure 2-3. Water cycle diagram.
(USGS, http://ga.water.usgs.gov/edu/watercyclehi.html)

2.2.1.2 Development of hydrology

Hydrology is a multidisciplinary subject that deals with the occurrence, circulation, storage, and distribution of surface and ground water on the earth (Bedient 2002). Our ancestors had known about hydrologic patterns through their experiences and used them to fulfill their needs. In the nineteenth century, significant advances in groundwater hydrology occurred such as the development of Darcy’s law of flow in porous media, the Dupuit-Thiem well formula, and the Hagen-Poiseuille capillary flow equation. This information regarding groundwater systems results in the rapid development of surface flow hydrology. Moreover, the building of surface water measurement programs (U.S. Army Corps of Engineers, U.S. Geological Survey, Weather Bureau (now National Weather Service)) and precise measuring instruments enhanced the development of surface flow hydrology in the nineteenth century (Bedient 2002).

The twentieth century, as in every other modern science, saw the most rapid development in hydrologic research. The National Weather Service (NWS) has collected a tremendous amount of weather data that varies temporally and spatially and the National Resources Conservation Service (NRCS) has collected hydrology-related field data that make possible modern hydrologic analysis (Bedient 2002). Concepts such as Horton’s infiltration theory (1933) and Penman’s hydrologic losses (1948) helped to strengthen the model of the water budget in hydrological cycle and serve as the springboard for the development of the hydrologic modeling with the rapid advances being made in computer hardware and software (Lung 2001).

2.2.2. Hydrologic model development

The most certain way to evaluate equivalent trading units is with real-time monitoring. However, entire site monitoring and real-time monitoring for long periods of time are almost impossible for economic and technical reasons. Watershed models have been rapidly developing during the last several decades for the estimation of flow and water quality for areas with limited monitoring data.

Hydrological models can be classified in several ways. According to Maidment (1993), all hydrologic models can be classified according to the assumptions made about three sources of variation: time, space, and randomness.

Figure 2-4 shows the hydrologic models according to the way they treat the randomness and space and time variability of hydrologic phenomenon. Stochastic models explicitly account for randomness in model parameters but deterministic models characterize processes with specific values. Uncertainty is not considered in the processes the deterministic models characterize; therefore, the same set of input data will always give the same set of output values.

A further categorization of deterministic models involves simplifications concerning spatial variability (Chow et al. 1988). Model parameters of basins can be either lumped at the basin scale or distributed spatially through the basin. Lumped parameter models transform actual rainfall input into runoff output by conceptualizing that the subwatershed processes occur at one spatial point (Bedient 2002). Distributed parameter models are more suitable to predict the hydrologic effect of land use change because their parameters have a physical interpretation and their structure allows for a better representation of spatial variability (Nandakumar and Mein 1997). While distributed models are theoretically better at representing the hydrologic system, data have often been lacking to calibrate and validate these models (Bedient 2002). There is renewed interest in distributed hydrologic modeling with the advantages of geographic information systems, digital elevation models (DEMs), and remote sensing data.

Another way to categorize models is either as an event or a continuous model. Event models are designed to simulated runoff from single storm events. Sherman’s unit hydrograph (León et al. 2001) methods are used to generate storm hydrographs, which are then routed through a stream channel (Bedient 2002). Continuous hydrologic models are required to keep track of the changes in the hydrologic conditions of the landscape that affect rainfall-runoff responses between storm events.

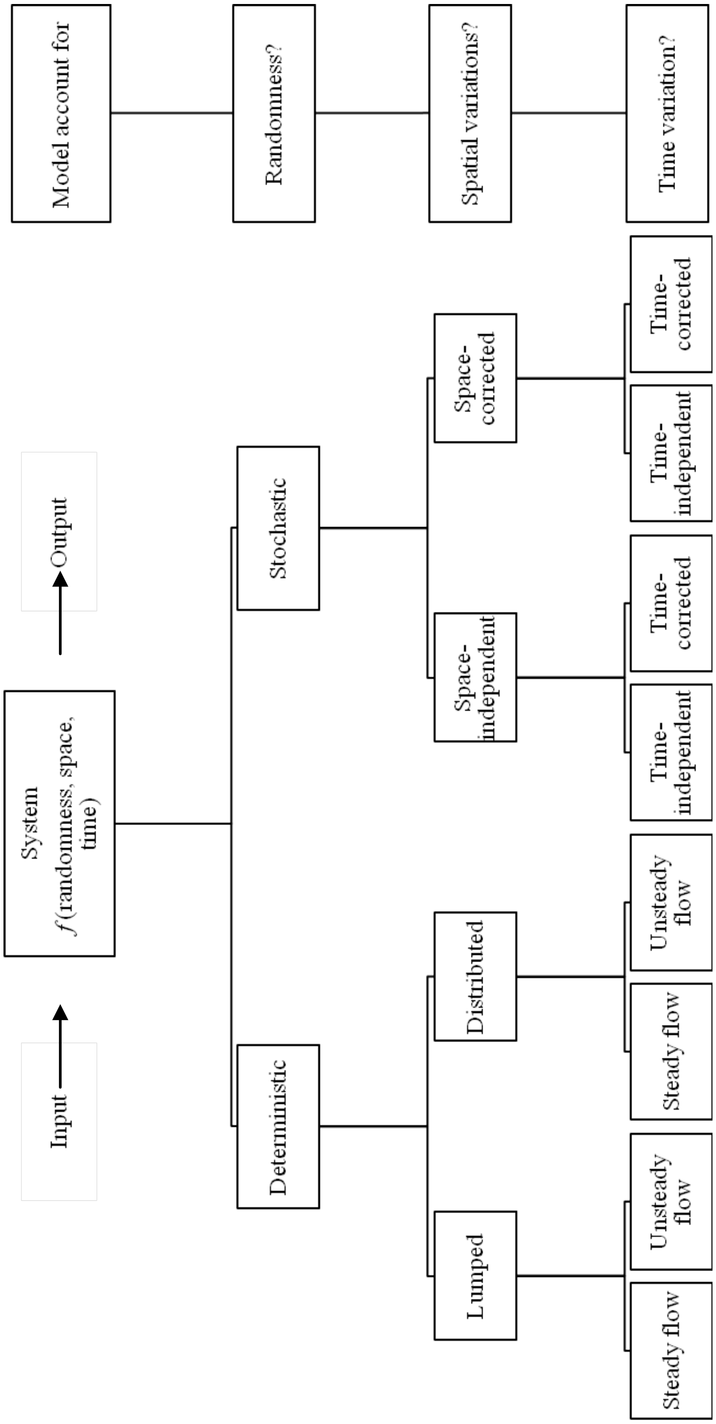


Figure 2-4. Classification of hydrologic models (Chow et al. 1988).

2.2.3. Hydrologic Simulation Program-Fortran (HSPF)

One of the first comprehensive watershed models was the Stanford Watershed Model (SWM), which was developed in the early 1960s (Crawford and Linsley 1966). SWM was enhanced by including sediment transport and water quality simulation components during the next decade. It spawned the development of the Hydrocomp Simulation Program (HSP), the Agricultural Runoff Management Model (ARM), and the Nonpoint Source Pollutant Loading Model (NPS). In 1976, the EPA commissioned Hydrocomp to develop a system of simulation modules, Hydrologic Simulation Program – Fortran (HSPF) that combined all the functions performed by the HSP, ARM, and NPS models (Engelmann et al. 2002).

HSPF is categorized in model classification as a deterministic, continuous model for simulating the water quality and quantity processes that occur in watersheds and in a river network. HSPF can be categorized as a semi-lumped-parameter model because of adapting the partitioning of the basin into sub-basins. The variability in land use changes and the resulting variation in peak discharges in the basin are significant, but may not be modeled at the outlet (Moglen and Beighley 2002).

HSPF was widely chosen to simulate the water budget in many watersheds becasuse it is used as the official model for the Chesapeake Bay Program. It can simulate a wide variety of hydrologic processes and it is particularly useful for assessing the effects of land use conversion on overall watershed behavior (Brun and Band 2000). HSPF is well suited to work with urbanizing watersheds and was developed as a tool to assess potential changes in water, sediment and pollutant movement as a result of land use change (Bicknell et al. 1997).

One of the limitations of a distributed parameter model is a lack of data for calibration and validation. HSPF adopted the use of GIS, DEM, and land cover/use data for the target watershed from EPA’s Better Assessment Science Integrating Point & Nonpoint Sources (BASINS) program. BASINS is a software package developed by the EPA that combines standard water quality and watershed models with a geographic information system containing numerous national data layers (USEPA 2004(a)). BASINS allows the user to assess water quality at selected stream sites or throughout an entire watershed. This simulation model can be run with nationwide watershed information inputs such as DEM, land use, soil characteristics, and weather data.

2.2.4. HSPF calibration

The most important step of the hydrologic model is calibration. The usefulness of the model depends on how well the model is calibrated. Thus, the calibration procedure must be conducted carefully to maximize the reliability of the model. In general, manual procedures for calibration can be extremely time-consuming and frustrating, and this has been a major factor inhibiting the use of the hydrologic models (Gupta et al. 1999). The program for automatic HSPF model calibration was developed and there are pros and cons of each method.

The Parameter Estimation (PEST) is a model-independent parameter optimization program which can communicate with any model through the model’s input and output files (USEPA 2003a). The ability to communicate with any model helps to make PEST useful with many existing computer simulation models. Many PEST applications have focused on using a single overall objective function to measure performance of the calibrated model. However the single performance measure is often inadequate to properly measure the simulation of all the complexity of a hydrologic system (Madsen 2000). From the successful multistage, automated calibration procedure of Sacramento Soil Moisture Accounting model (SAC-SMA) from the NWS, the PEST has been widely used in ground water modeling but there have been very few applications to surface water modeling (Kim et al. 2007). The limitations of automatic calibration cause many surface water modelers to hesitate and so automatic calibration has not entered into widespread use for surface water hydrologic and water quality models (Boyle et al. 2000).

As mentioned before, manual calibration is time-consuming and tedious. Furthermore, the subjectivity of the input parameter adjustment reduces confidence in the model simulation and maintaining consistency among users. In spite of the problems, it is possible to obtain good calibration using a manual approach with an experienced hydrologist (Kim et al. 2007). Manual calibration can be performed with the HSPF expert system (HSPEXP) decision support software. HSPEXP provides calibration guidance, suggesting parameter adjustments with the total volume, low flows, storm flows, and finally, seasonal flows (USGS 1994). HSPEXP calculates percent errors of the model performance based on the predefined criteria (Donigian 2002).

2.2.5. Model efficiency

Model efficiency after calibration can be assessed in order to evaluate how well it simulates water quantity and quality. Generally, statistical goodness-of-fit criteria such as the Nash-Sutcliffe coefficient of efficiency (*E*), the coefficient of determination (R^2), and deviation of runoff volumes (D_v) have been widely used for quantitative assessment of hydrologic models.

One of the simple model evaluations is the deviation of discharges (D_v), or the so-called percent difference (%).

$$D_v (\%) = (Q_{sim} – Q_{obs}) / Q_{obs} \times 100 \qquad \text{Equation 2-1}$$

Where Q_{sim} is the simulated discharge and Q_{obs} is the observed discharge. The smaller the number, the better the model results are, and D_v would equal zero for a perfect model. D_v provides an immediate complement to a visual inspection of the continuous hydrographs. Positive values mean overestimation and negative values indicate underestimation.

The coefficient of determination (R^2) is the square of the Pearson's product moment correlation coefficient between the outcomes and their predicted values. It ranges from 0 to 1.0 with higher values indicate better agreement. A perfect fit of the model to explain the variation is 1 and 0 is the value when the model does not explain the variation at all.

The Nash-Sutcliffe coefficient of efficiency (*E*) is defined as:

$$E=1 - \{ \sum (Q(t)_{sim} – Q(t)_{obs})^2 / \sum(Q(t)_{obs} – Q_{mean})^2\} \qquad \text{Equation 2-2}$$

where $Q(t)_{sim}$ is the simulated discharge, $Q(t)_{obs}$ is the observed discharge, and Q_{mean} is the mean of the observed discharges for the given period (Nash and Sutcliffe 1970). An efficiency of 1 ($E = 1$) indicates a perfect match of the simulated discharges to the observed discharges. An efficiency of 0 ($E = 0$) indicates that the model predictions are as accurate as the mean of the observed data; thus, there is no reason to use the simulated data instead of the mean observation data for discharge prediction. An efficiency less than zero ($E < 0$) occurs when the observed mean is a better predictor than the model.

2.2.6. Previous HSPF applications

HSPF is useful for the simulation of urbanized areas because of its impervious land modeling module. Many studies have investigated the impacts of urbanization on water quantity and quality. Brun and Band (2000) developed hypothetical land use scenarios from past to future conditions and simulated the runoff behavior as related to the impervious surfaces. This study showed the relationship between runoff ratio, percent impervious cover and percent soil saturation within the Gwynns Falls catchment. The HSPF modeling results are limited to stream flows rather than water quality constituents and used hypothetical land use scenarios which were not contained within the geographical information. Cho et al. (2009) report that an increase in the withdrawal and a decrease in the recharge of groundwater due to urbanization influences subsurface flow regimes using hydrological modeling results of HSPF. Many studies have investigated hydrologic impacts using HSPF model rather than water quality impacts because the water quality calibration of the model is much more complicated than the hydrologic calibration. Choi and Deal (2008) investigated the hydrological impacts of potential land use changes as estimated using land use from either the Land use Evolution and impact Assessment Model (LEAM) which estimates the general patterns of urban growth or hypothetically selected scenarios.

The HSPF model was used for agricultural runoff modeling by Moore et al. (1988) for the hydrologic, sediment, nitrogen and single pesticide simulation. The model was calibrated using experimental data collected from the watershed. The impervious surfaces were not considered because of the simulation of agricultural areas. Im et al. (2007) provide the hydrologic and water quality impacts in an urbanizing watershed using the HSPF watershed model within the Polecat Creek watershed, Virginia. This research was conducted using the observed stream flow, sediment, nitrogen and phosphorous data which were collected via an onsite monitoring program. Half and full area development scenarios were generated for assessing the impact of urbanization. Many of watersheds which want to implement the water quality trading policy do not have the onsite monitoring program. Also, the original land use categories before development were not considered in this study. Many studies of HSPF model applications related to urbanization impacts to the receiving stream have been reported. While the HSPF model has advantages for simulation of urbanization, the limited observed data on water quality and the complicated on model calibration and validation processes hinder the application of the HSPF model for water quality assessment.

2.3. Geographic Information Systems for watershed model

‘Geographic Information System is any system that captures, stores, analyzes, manages, and presents data that are linked to location’ (Berry 1993). GIS has been improving the accuracy of hydrologic modeling by increasing the number and description of spatial units. The EPA’s BASINS contains the GIS data of the target watershed in order to provide at information for the watershed models seamlessly. Whittemore and Beeve (2000) have cautioned against relying on a too simplistic approach to simulation models such as BASINS, but they judged that BASINS is an excellent beginning tool to meet complex environmental modeling needs.

From the BASINS metadata, 1:250,000 Scale Quadrangles of land use/land cover within the Geographic Information Retrieval and Analysis System (GIRAS) Spatial Data are available. The time period of the GIRAS information begins in 1977 and ends in 1980. The polygon size for the land use/land cover of urban built-up, water, confined feeding operation, agriculture, strip mines, quarries and gravel pit is 4 ha while data for the remaining areas was collected with 16 ha for the polygon size. The modification of the BASINS with spatially and timely updated land use can help to enhance the simulation ability for relatively small watersheds.

2.4. Sediment generations from land uses

The input parameter decision support system (HSPEXP) is not available for sediment and nutrient calibration, even though it is useful in the hydrologic calibration. Thus, the input parameter for each land use category should be determined based on the program guidance, the open literature and the judgment of the modeler. The source of sediment generation of each land use from the literature will help to adjust the sediment input parameters of each land use category for HSPF model calibration.

Sediment is delivered from the two broad erosion sources of sheet erosion and channel type erosion. Sheet erosion is an upland source of sediment while channel type erosion results from gully erosion, valley trenching, and streambed and streambank erosion (Roehl 1962). Nelson and Booth (2002) report that the main sources of sediment in the watershed are landslides (50%), channel-bank erosion (20%), and road-surface erosion (15%). Gravel quarries, agriculture, landfills and construction are mentioned for the remaining source of sediments. The Metropolitan Washington Council of Governments (1978) issued the report of a study titled, “Land use/runoff quality relationships in the Washington metropolitan area.” This report generated analysis of runoff characteristics based on local field data. Nonpoint pollutant loads were analyzed for several land use categories, including stabilized urban land use, transitional urban development (active construction sites), agricultural operations, and undeveloped land. Results show that urban runoff volumes were generally higher than those from nonurban land uses. Conventional tillage had the highest instantaneous concentration of total suspended solids, followed by active construction sites. Agricultural areas had higher Total Suspended Solids (TSS) than all urban land uses except the active construction sites.

Increases in impervious surfaces from urban development cause a significant impact on water quantity and quality. Several studies report that the increasing impervious cover decreases the base flow due to the decreases in infiltration and percolation (Klein 1979; Schuler and Claytor 1997). Lazaro mentioned that the increasing of impervious surfaces causes local decreases in infiltration, percolation and soil moisture storage, reductions in natural interception and depression storage and increases in runoff and flood frequency (Lazaro 1990; Pett and Foster 1985). The increasing imperviousness impacts not only water quantity but also water quality. Dunne and Leopold (1978) present that the urbanization of watersheds, involving the construction of impervious surfaces and artificial conveyance channels, as well as shifts in land cover and increasing population, have significant impacts on hydrologic processes and stream quality in urban ecosystems.

3 Model calibration with limited observed data

The Hydrological Simulation Program Fortran (HSPF) watershed model is used to estimate water quantity and quality within the Water Quality Trading (WQT) watershed. The most essential and sophisticated part of watershed modeling is the calibration and validation of simulated results with observed data. However, continuously monitored climate and surface water data which are required for calibration are limited on local streams. This chapter presents the methodology of HSPF model calibration where limited data are available.

3.1. Study area

3.1.1. General information

The city of Pacific, Missouri is located approximately 30 miles southwest of St. Louis, Missouri, which is a well-developed urban area. The community of Pacific is interested in sustainable development in order to preserve their environment from the results of development expected because of the proximity to St. Louis. As of 2009, Pacific's population was 7,209. Since 2000, it has experienced a population growth of 30.59 percent (the City of Pacific 2009). The rapidly growing small community is considered a good candidate for application of EPA’s water quality trading policy to maintain their water quality in an economical fashion. Pacific is located within the Brush Creek watershed (Figure 3-1). This watershed is part of the larger Meramec River watershed which flows to the Mississippi River. The entire drainage area of Brush Creek is approximately 6200 acres and most of the area is inside of the Franklin County, MO boundary.

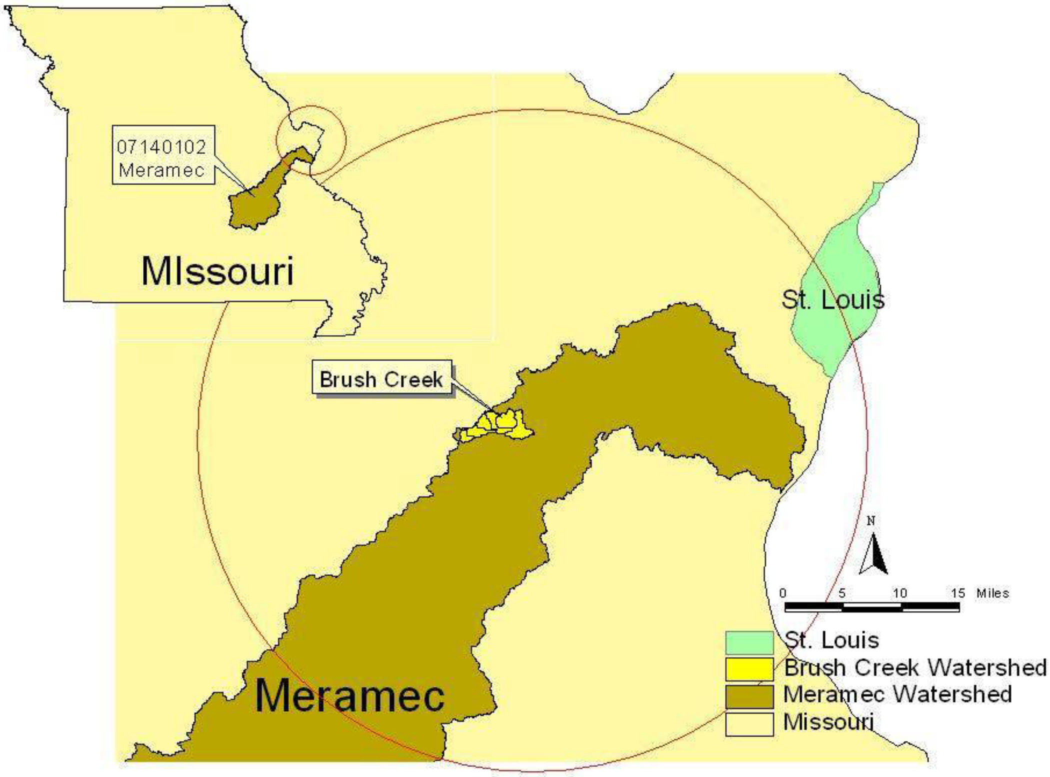


Figure 3-1. Location of Brush Creek watershed within the Meramec River watershed.

3.1.2. Meramec River Basin

Even though the target watershed is the Brush Creek watershed near Pacific, MO, the watershed model calibration must be performed for the whole Meramec River basin because the Brush Creek watershed does not have field observation monitoring data with which to calibrate a model. The Meramec River is the longest free-flowing waterway in Missouri, measuring approximately 220 miles and draining an area of 2,149 square miles.

The main stem of the Meramec River carries water from the lightly populated, forested, and agricultural upper watershed in a northeasterly direction to the heavily populated and urbanized lower watershed to enter the Mississippi River below St. Louis. Table 3-1 shows the broad land use estimates of the Meramec River basin.

Table 3-1. 1992 broad land use estimates for the Meramec River basin.

Land Use/Cover	*Thousands of Acres*	*Percent of Tota*
Cropland	70.4	4.5
Forest land	750.0	48
Pastureland	375.1	24.01
Rural transportation - roads and railroads	20.5	1.31
Urban - small and large built-up	101.1	6.47
Water	15.1	0.97
Other	230.2	14.74
Total	1,562.4	100

(Source: 1992 National Resources Inventory, USDA Natural Resources Conservation Service)

The major land use causing nonpoint source pollution of the upper and middle basin is pasture land and there is currently an increasing number of cattle and overall grazing density (Missouri Department of Conservation 2009). Most of the urban built-up area of the Meramec River basin is in the lower watershed. Sediment and pollution-laden runoff enter the lower Meramec system rapidly because of increasing impervious surfaces from development in the urban built-up area.

3.2. Methodology

3.2.1. Overview of HSPF

HSPF is a conceptual, lumped hydrological model designed to simulate various hydrological processes and associated water quality components in a watershed (Bicknell et al. 1997). The Soil Water Assessment Tool (SWAT) and HSPF are the core modeling programs of the US EPA's Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) package. The geological information system (GIS) in this package includes data covering soil characteristics, a digital elevation model (DEM), land use, and watershed information, all available to help build the target watershed delineation and provide the physical information from a watershed in order to run the model. BASINS also allows user modified data to be used when running HSPF in order to enhance the simulation performance. BASINS version 3.1 was used for the watershed delineation of Meramec River basin and the Brush Creek basin. Presently, EPA provides a web-based version BASIN 4.0 which uses an open source GIS software architecture.

HSPF consists of three modules: PERLND, IMPLND, and RCHRES. PERLND simulates the water quality and quantity processes calculating overland flow, interflow, and groundwater flow within pervious land segments. A variety of storage zones are used to represent the processes that occur on the land surface and in the soil horizons. IMPLND routes the surface runoff through the impervious parts of land segments. IMPLND includes the pollutant washoff capabilities of the commonly used urban runoff models. RCHRES simulates the processes in reaches and reservoirs including the runoff and water quality constituents simulated by PERLND and IMPLND. The processes active in land segments (PERLND, IMPLND) are connected to reaches (RCHRES) by a network that represents a watershed in its entirety.

The PERLND module has numerous functions to simulate not only hydrological processes (PWATER) but water quality such as sediment generation and removal (SEDMNT), nitrogen and phosphorous fates (NITR and PHOS), and pesticide or tracer simulation (TRACER). PWATER is a function used to simulate the water budget of pervious land segments with the estimated surface flow, interflow, and groundwater flow. Lower zone nominal storage (LZSN), upper zone nominal storage (UZSN), infiltration (INFILT), and groundwater recession rate (AGWRC) are major PWATER input parameters in order to calibrate with observed hydrologic data. In addition, interception storage capacity (CEPSC), Manning's n (NSUR), and lower zone evapotranspiration (LZETP) also perform an important role to enhance model calibration. Removal of sediment (SEDMNT) from the pervious land surface is simulated with the Universal Soil Loss Equation (USLE) which is commonly implemented in other watershed models such as the Agriculture Runoff Management (ARM) and Nonpoint Pollutant Source (NPS) models (Bicknell et al. 2001). The basic concept of calibration of sediment generation from pervious land is accomplished by manipulating the coefficients in the soil detachment equation and the coefficients in the detached sediment washoff equation based on observed data. Because there is little field data for sediment on pervious land to calibrate, common values for sediment generation from each land use from the literature and the suspended sediment data from stream monitoring are used for sediment calibration. Figure 3-2 shows the flow diagram of the sediment section (SEDMNT) of the

PERLND module. The SEDMNT module has two options for simulating sediment. The first option has the detached sediment storage (DETS) from the soil matrix of all the pervious land washed off by water to the stream. The other source of sediment is direct scour of the soil matrix by water.

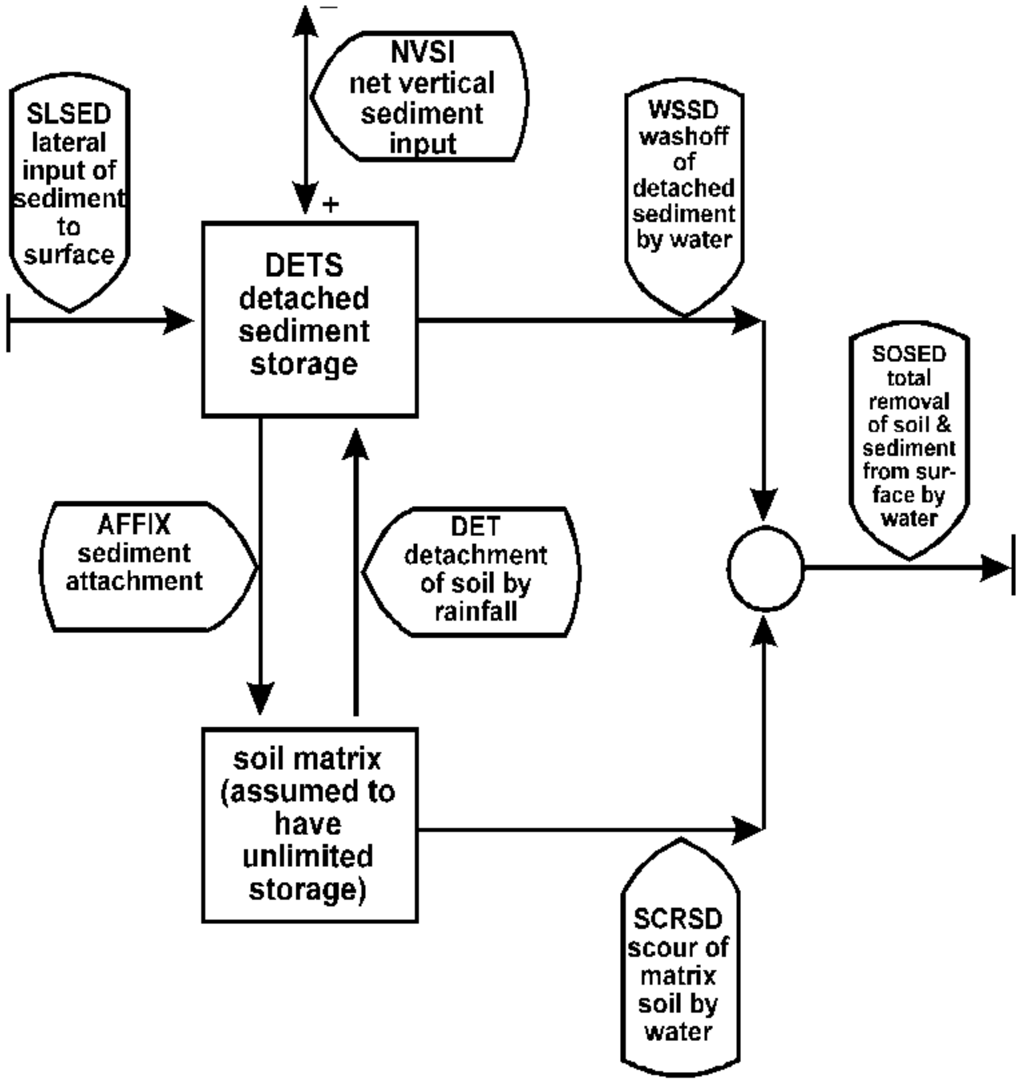


Figure 3-2. Flow diagram for SEDMNT section of PERLND (Bicknell et al. 2001).

IMPLND functions are much simpler than those of the PERLND module because IMPLND assumes that there is no infiltration or sediment detachment from the impervious surfaces. Solids accumulation and transport from impervious surfaces is calculated by adjusting the coefficient in the solids washoff equation which calculates the total washoff of solid (SOSLD). The flow diagram of the section SOLIDS in the IMPLND module explains the process of solid runoff from impervious surfaces and is shown in Figure 3-3.

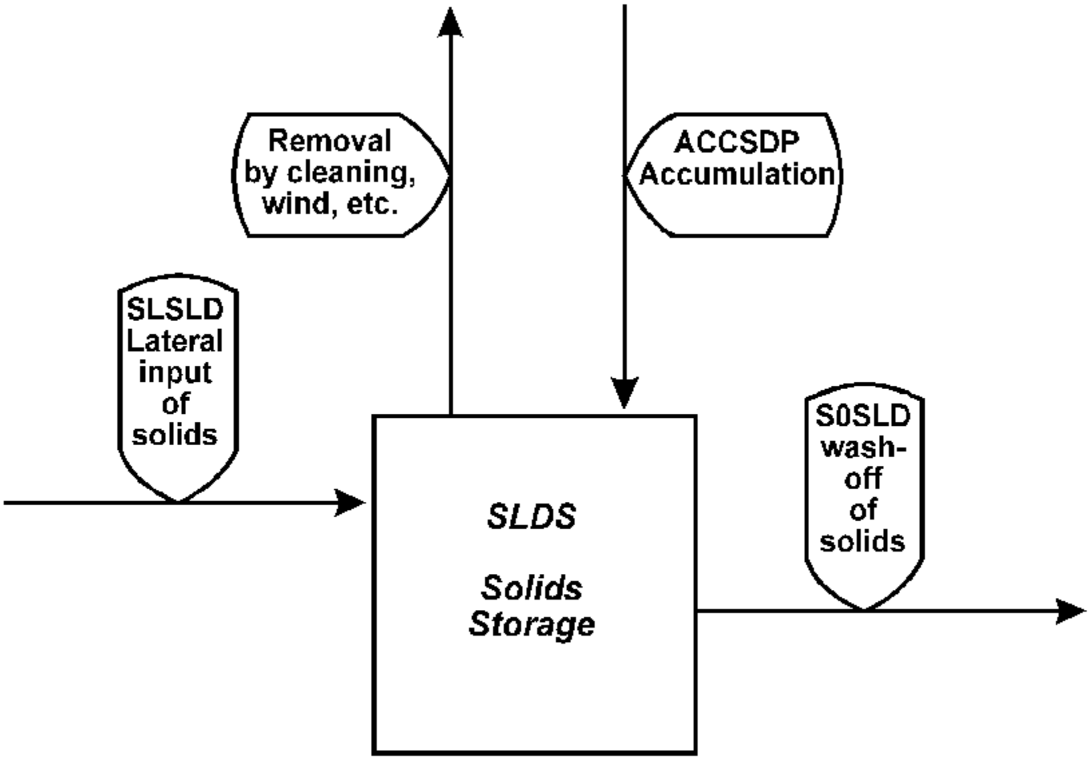


Figure 3-3. Flow diagram of the SOLIDS section of the IMPLND (Bicknell et al. 2001).

The RCHERS module has functions to calculate processes in water bodies such as hydraulic behavior, deposition/scour of sediment and nitrification. The hydraulic behavior (HYDR) in the RCHERS module is calculated using GIS data including the length of the reach (LEN), the drop in water elevation from the upstream to the downstream ends of the reach (DELTH), and channel cross section data. Transport of sediment in the reach (SEDTRN) is calibrated with the physical characteristics of sand, silt, and clay such as effective diameter of the particles (D), corresponding fall velocity (W), and density of the particles (RHO). The simulated deposition/scour (DEPSCR) and bed shear stress (TAU) is calibrated with the observed sediment data. Figure 3-4 shows the process to simulate the total amount of sediment contained in outflow (ROSED) in the RCHERS module.

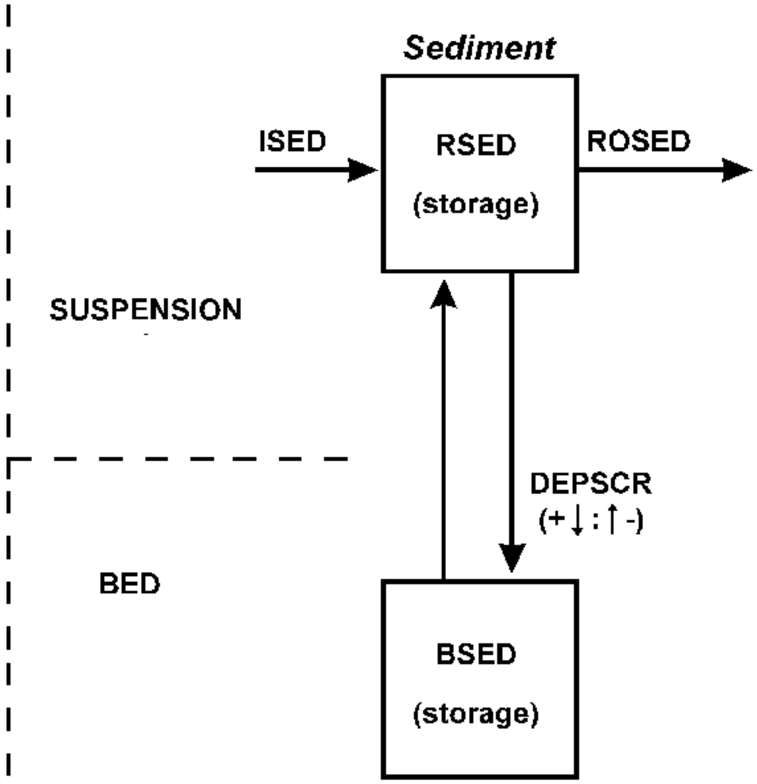


Figure 3-4. Flow diagram of the SEDTRN section of the RCHERS (Bicknell et al. 2001).

The HSPF modeling results are available with the GENeration and analysis of model simulation SCeNarios (GenScn) program. GenScn is capable of displaying results graphically and comparing the results between different scenarios.

3.2.2. Data collection

One of the useful benefits of the BASINS package for watershed modeling is the easy access to data for running HSPF. Spatially distributed data such as land use/land cover, reach file, soil characteristics, and the DEM are automatically downloadable from the BASINS system. The Geographic Information Retrieval and Analysis System (GIRAS) land use/land cover data was collected by the USGS in the early 1980s with a 1:250,000 scale. The reach file version 1 (RF1) which is the National Hydrography Dataset (NHD) produced by the U.S. Environmental Protection Agency (EPA) at a scale of 1:500,000 and the USGS 30 m resolution National Elevation Dataset (NED) can be used to delineate a watershed. Environmental monitoring data (i.e., water quality observations, weather station data, and USGS gaging station) are included in the BASINS software package for calibration.

USGS stream flow and sediment concentration data can be used to calibrate the HSPF model. USGS station 07019000 entitled Meramec River near Eureka, MO provides a record of daily discharge and precipitation data from the early 1920s to the present and was used to calibrate stream flow for the Meramec River watershed. The drainage area of the Eureka monitoring station is 3788 square miles which covers the hydrological unit codes of 07140102 Meramec, 07140103 Bourbeuse, and 07140104 Big River basins

(Figure 3-5). Suspended sediment data collected at the Eureka station was used for the sediment calibration of the Meramec River basin.

Like many other small local watersheds in the U.S., Brush Creek, the project target watershed does not have regularly monitored surface flow or climate data to calibrate watershed models. The nearest USGS National Water Information System data station is the Meramec River near Eureka, MO station (07019000). Brush Creek is one of the tributary streams of the Meramec River and the location of the Brush Creek watershed outlet is the same with the outlet of subbasin #1 of the Meramec River delineation (Figure 3-5).

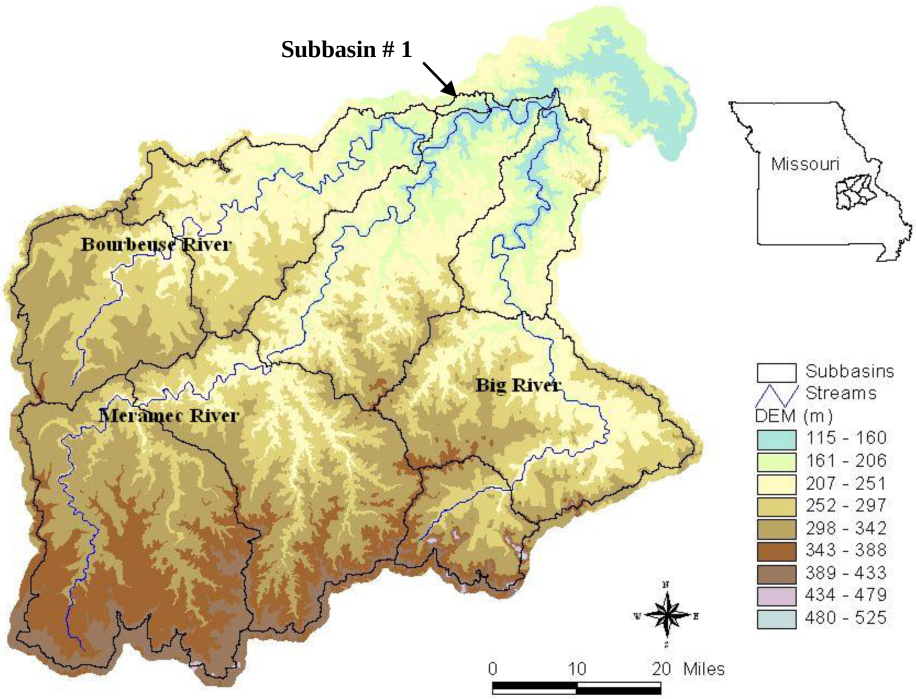


Figure 3-5. Drainage area contributing to the Eureka gauging station.

Calibrated hydrologic and sediment input parameters for subbasin # 1 within the Meramec River watershed using the Eureka monitoring station data are used as observed data for the Brush Creek only watershed delineation in the HSPF model (Figure 3-6).

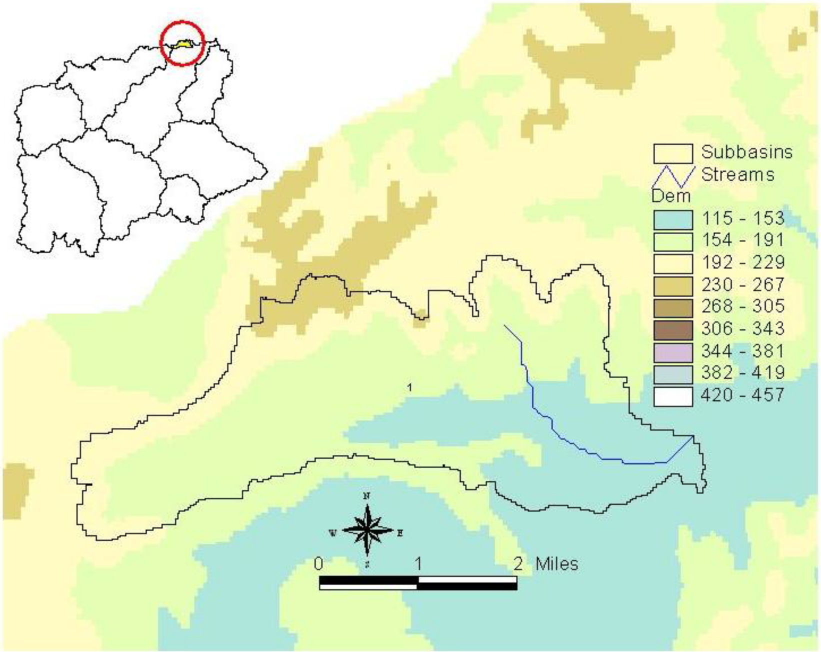


Figure 3-6. Location of the Brush Creek watershed within the Meramec River Basin.

3.2.3. Watershed delineation

The main reason for calibrating with the Meramec River basin data is to use the input parameters from the HSPF model for those of the target area model. Thus, the delineation of the Meramec River must contain the Brush Creek watershed as a subbasin within its watershed boundary. Figure 3-5 shows the entire drainage area for the Meramec River near Eureka, MO (07019000) station. The Bourbeuse River basin outlet is located at the Meramec River mile 64.0 location, and the Big River enters the Meramec at river mile 35.7. The Bourbeuse and Big River basins needed to be delineated with the Meramec River basin because the Eureka gauge station is located downstream of all three rivers.

The BASINS 3.1 software package is used for data mining, watershed delineation, and generating the HSPF model. Figure 3-7 shows the BASINS 3.1 program interface with the watershed delineation for the Meramec River near Eureka station (07019000).

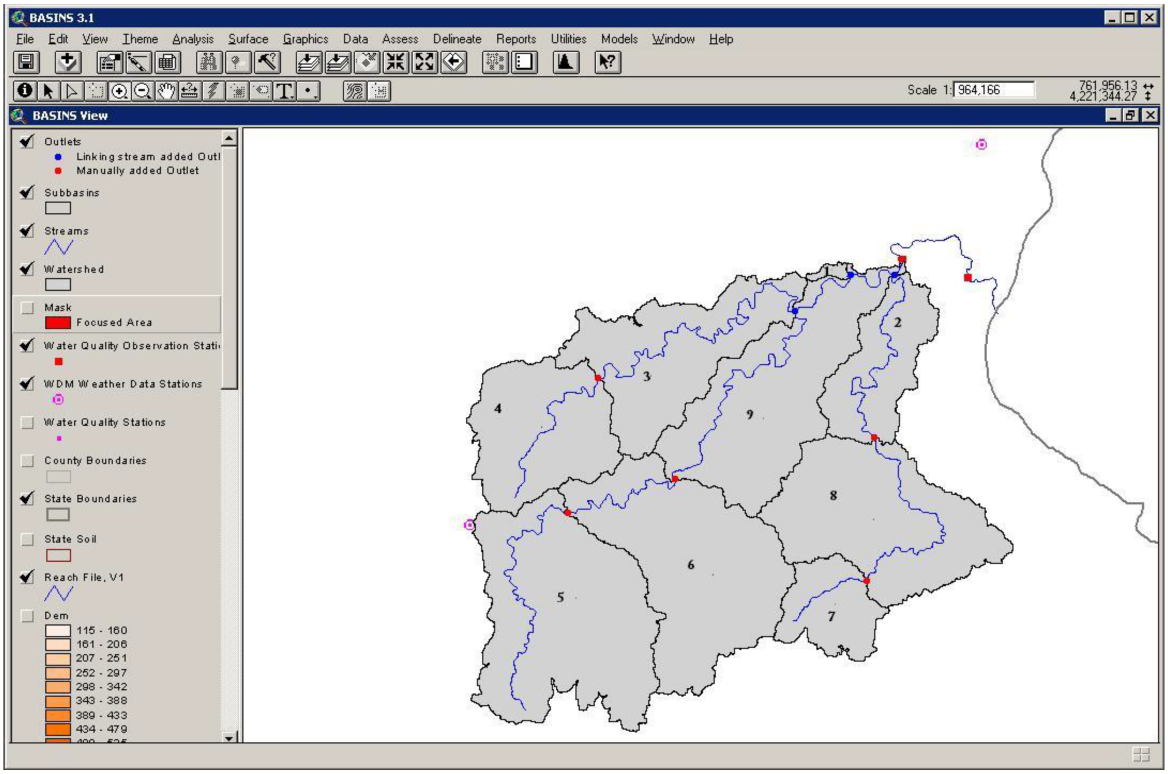


Figure 3-7. BASINS 3.1 screenshot with ArcView GIS 3.2 platform showing nine subbasins.

After extracting the core basin data for the Meramec (07140102), Bourbeuse (07140103), and Big (07140104) Rivers using the Data tab in the toolbar with the UTM

1983 and Zone 15 projection, the necessary GIS data including the DEM and land use for the basin are added to the watershed delineation. It is important to match the projections of each data type in order to add it at the same location. The automatic watershed delineation tab is used with inputs of the projected DEM grid and stream data shape file (RF1). In the stream definition section, in order to define the initial stream network and subbasin outlets, the user must define a threshold value for the upstream drainage area (in hectares) in order to define the beginning of a stream. The smaller the specified number of hectares, the more detailed the drainage network will be after delineation. A threshold of 2400 ha (approximately 5930 acres) is used to delineate the Brush Creek (6200 acres) subbasin. The Meramec River basin was delineated into nine subbasins with subbasin 1 being the Brush Creek watershed (Figure 3-4). The HSPF model for the Brush Creek watershed is generated with the BASINS watershed delineation.

3.2.4. Calibration of HSPF model

3.2.4.1 Calibration criteria

There are some criteria that can be used to evaluate the performance of continuous hydrologic models. The simulated hydrologic model needs to be compared visually using graphical plots of simulated and observed flows. The next step is a quantitative assessment which can be performed with one or more statistical goodness-of-fit criteria such as the Nash-Sutcliffe coefficient of efficiency (E), the coefficient of determination (R^2), and deviation of runoff volumes (D_v). These hydrologic evaluation tools are commonly used in hydrologic model calibration and are recommended by the

American Society of Civil Engineers (ASCE 1993). Table 3-2 is a list of the general calibration/validation tolerances of targets for the HSPF model as recommended by the program development engineers (Donigian 2002).

Table 3-2. Recommended calibration and validation percentage differences (D_v) between simulated and observed values.

Calibration Constituent	*Very good (%)*	*Good (%)*	Fair (%)
Hydrology / Flow	< 10	10～15	15～25
Sediment	< 20	20～30	30～45
Water temperature	<7	8～12	13～18
Water quality / Nutrients	< 15	15～25	25～35

(Utah State University WinHSPF Water Quality Calibration User's Manual p.5)

3.2.4.2 Procedure

Once an HSPF project has been created with the delineated watershed information, a user control file (UCI) is generated which is in text file format including FORTRAN language commends to run HSPF. The user needs to assign the percent of pervious land cover to each land use category. The percentage of pervious area can be assigned based upon literature values and assumptions regarding the accuracy of the land use data. Table 3-3 shows the percentage of pervious land segment in each land use category as estimated from Dunne (1978), Brun (2000), and Choi (2008).

Table 3-3. Land use categories of GIRAS land use/land cover data with the percent pervious value for the HSPF model.

Land use category	*Percent Pervious*
Forest land	100
Urban or built-up land	50
Agricultural land	100
Barren land	70
Water	100
Rangeland	100

The years from 1983 to 1986 are selected for hydrologic calibration. The time period covers wet (1983) and dry (1985) years and the time period over which the GIRAS land use/land cover data were collected. For validation purposes, the years from 1991 to 1994 are used. One of the largest floods in the basin occurred in 1993 and was used to validate the calibrated model. From the literature review, the majority of calibration and validation studies used fewer than three years of data.

Table 3-4 shows the length of calibration and validation periods of selected HSPF model projects. Therefore, the four years of each calibration and validation period of this study are acceptable.

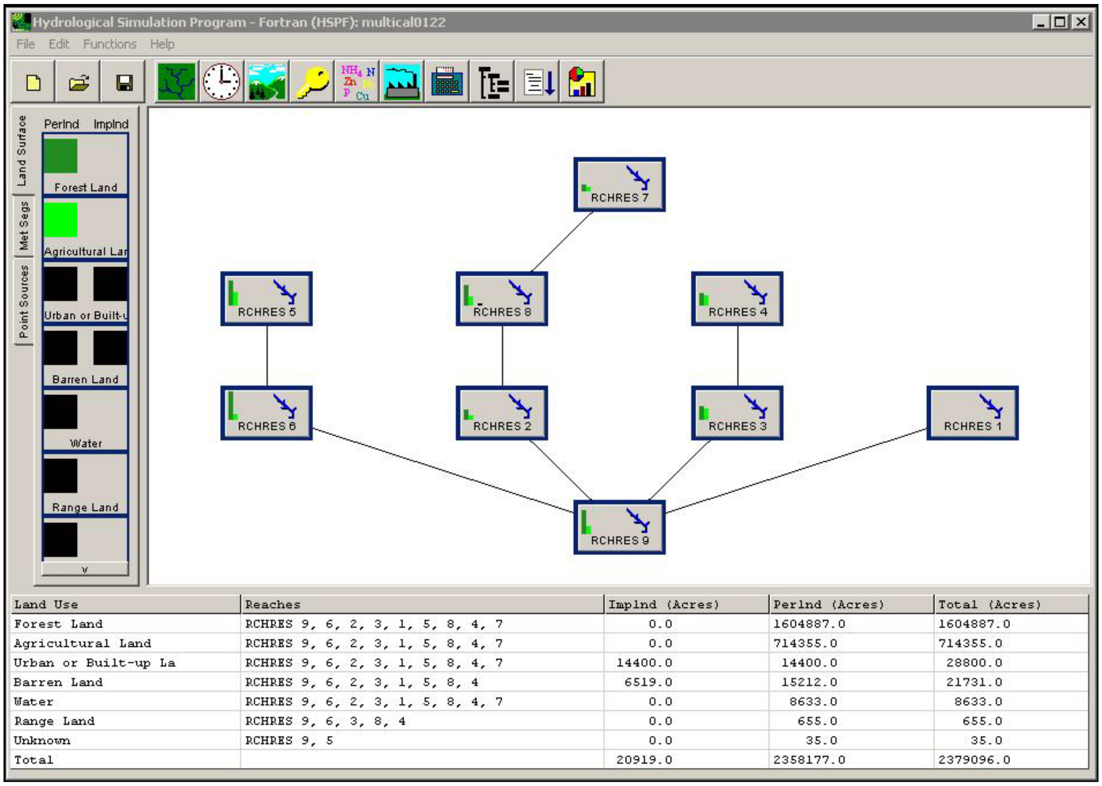
Table 3-4. The length of calibration and validation periods for selected projects.

	Length of Calibration period (months)	*Length of Validation period (months)*
Moore et al.(1988)	19	N/A (sample data)

Chew et al. (1991)	24	24
Chen et al. (1995)	72	36
Carrubba (2000)	36	36
Brun et al. (2000)	36	36
Im et al. (2007)	46	14
Choi et al. (2008)	24	24

Limited USGS water quality data results in shorter periods of time for calibration and validation for sediment generation and transport than for discharges. A one year calibration period (1983) and a one year validation period (1984) are used for sediment input parameters.

Figure 3-8 is the HSPF screenshot showing the nine subbasins of the Meramec River basin. In the Reach Editor function, the user can edit the reach file data with imported cross section data. The time tab in the functions toolbar allows the user to modify the simulation time and meteorological data. The simulation time should be at least one year earlier than the calibration period because some input parameters need time to stabilize from initial input values. For the meteorological data, there are weather data available from two stations, so each reach and land segment is assigned the nearest weather station data for the hydrological simulation.



Land Use	Reaches	Implnd (Acres)	Perlnd (Acres)	Total (Acres)
Forest Land	RCHRES 9, 6, 2, 3, 1, 5, 8, 4, 7	0.0	1604887.0	1604887.0
Agricultural Land	RCHRES 9, 6, 2, 3, 1, 5, 8, 4, 7	0.0	714355.0	714355.0
Urban or Built-up La	RCHRES 9, 6, 2, 3, 1, 5, 8, 4, 7	14400.0	14400.0	28800.0
Barren Land	RCHRES 9, 6, 2, 3, 1, 5, 8, 4	6519.0	15212.0	21731.0
Water	RCHRES 9, 6, 2, 3, 1, 5, 8, 4, 7	0.0	8633.0	8633.0
Range Land	RCHRES 9, 6, 3, 8, 4	0.0	655.0	655.0
Unknown	RCHRES 9, 5	0.0	35.0	35.0
Total		20919.0	2358177.0	2379096.0

Figure 3-8. HSPF screenshot of the Meramec River subbasins

The land use classification of the Meramec River basin using GIRAS land use/land cover data is shown in the Figure 3-8 HSPF screenshot which includes the pervious and impervious land areas calculated as percent perviousness. Table 3-1 and Table 3-5 have similar percentages of each land use classification except for the fact that Table 3-1 represents the Meramec River basin with agricultural land divided into crop land and pasture land. The reason for the difference in the total area between Table 3-1 and Table 3-5 is the fact that the HSPF land use in Table 3-5 includes the Bourbeuse and Big River basins with the Meramec River basin because they also contribute flow and sediment to the Eureka station.

Table 3-5. Land use/land cover classification from HSPF Meramec River basin.

Land use	*Impervious land (acres)*	*Pervious land (acres)*	*Total (acres)*	*Percent of total*
Forest Land	0	1604887	1604887	67.46
Agricultural Land	0	714355	714355	30.03
Urban or Built-up Land	14400	14400	28800	1.21
Barren Land	6519	15212	21731	0.91
Water	0	8633	8633	0.36
Range Land	0	655	655	0.03
Unknown	0	35	35	0
Total	20919	2358177	2379096	100

A sensitivity analysis is used to determine how sensitive a model is to changes in the values of the input parameters of the model. Parameter sensitivity was assessed through a series of test sets of different parameter values to see how a change in one parameter causes a change in the output. The main hydrologic input parameters of the PWATER functions are LZSN, UZSN, DEEPER, AGWRC, INFILT, and LZETP. They are tested with different input parameters to obtain the information for calibration. LZSN and LZETP are used to adjust overall discharge. DEEPER, AGWRC, and INTFW are used to balance the water budget between surface flow (SURO), interflow (IFWO), and ground water flow (AGWO). UZSN and INFILT are used to adjust peak flow. The hydrologic knowledge and the experience of the modeler are very important factors in watershed model calibration.

The final set of calibration input parameters are presented in Table 3-6, along with the input parameter set from other comparable studies. Noticeably, the 0.385 inch of

UZSN is lower than the typical value given (1.128 inch) by the HSPF manual because lowered UZSN helped to fitting the underestimated peak flow when the storms occur. The U.S. claypan region encompasses an area of about 4 million ha within Missouri, Illinois, and Kansas (Anderson et al. 1990). The low permeable claypan soil causes less storage of water in the near upper subsurface zone (USZN) and causes high peak flow when storms occur.

Table 3-6. Calibrated PWATER input parameters compared with those from selected studies from the literature.

Parameter	*This study*	*Im et al. (2007)*	*Chew et al. (1991)*	*Choi et al. (2008)*
LZSN (inch)	7	4.3~5.8	5~6	8
INFILT (inch/h)	0.12	0.35~1	0.05~0.16	0.11
AGWRC (d^{-1})	0.98	0.88~0.91	0.98	0.975
DEEPER (unitless)	0	0.05~0.45	N/A	0.15
UZSN (inch)	0.385	0.047~0.075	0.01~0.063	0.8
INTFW (unitless)	2	1~1.7	0.75~1	1.7
LZETP (unitless)	0.52	0.2-0.7	0.2~0.6	0.2

After the hydrologic simulation calibration is completed, the sediment calibration is undertaken with each of the sediment functions in the module. Sediment is one of the most difficult water quality constituents to model given that it incorporates an estimation of the generation via erosion for each land cover segment, delivery of the sediment to the stream, and in-stream scour and deposition processes. Erosion is primarily a function of rainfall intensity, soil erodability and physical condition such as slope degree and slope length. The Universal Soil Loss Equation (USLE) is a commonly used empirical equation to estimate the soil loss rate and has been adopted in the HSPF sediment erosion calculation. After calculation of erosion from each land segment, the eroded materials are fractioned into sand, silt, and clay. The fractioned sediment particles are transported within the stream with different power functions of the average velocity in the channel reach. Calculated sediment at the outlet should be compared with the observed suspended sediment.

The PWATER function in the PERLND module includes the sediment generation function named SEDMNT. The coefficients in the soil detachment equation (KRER and JRER) and the coefficients in the detached sediment washoff equation (KSER and JSER) are calibrated using erosion rates from the literature for each land use category. The COVER function is the fraction of land surface that is shielded from erosion by rainfall and is assigned monthly values based upon judgement (e.g., differences in vegetation between summer and winter). The IMPLND module has a much simpler equation for solids calculations. It assumes that there is no erosion of solids from impervious surfaces and calculated the solid washoff from a solids rate at which solids are placed on the land surface (ACCSDP) and the fraction of solids storage which is removed each day (REMSDP).

The in-stream sediment transport calculation (SEDTRN) in the RCHRES module focuses on the channel processes of deposition, scour, and transport. In SEDTRN, the sediment load from land surfaces is divided into sand, silt, and clay. The parameters related to sand are assigned in the SAND-PM function using the basic physical characteristics of sand. HSPF calculates the shear stress in each reach to calculate a scour or a deposition in the hydraulics (HYDR) module. With the calculated stream bed shear stress (TAU), the critical bed shear stress for deposition (TAUCD) and the critical bed shear stress for scour (TAUCS) in SILT-CLAY-PM function are assigned. Table 3-7 shows the sediment input parameters which are used in this study and the recommended value ranges for HSPF.

Table 3-7. Calibrated sediment input parameters compared with the recommended value ranges for HSPF parameters.

Parameter	*This study*	*Range of Values*
KRER (unitless)	0.45	0.15~0.45
JRER (unitless)	2.2	1.5~2.5
AFFIX (per day)	0.03	0.03~0. 1
KSER (unitless)	4	0.5~5
JSER (unitless)	1.9	1.5~2.5
ACCSDP (lb/ac-day)	0.025	0~2
REMSDP (per day)	0.05	0.03~0.2

(Source: BASINS Technical Note 8 (USEPA 2006))

3.3. Results

3.3.1. Hydrologic calibration results

Table 3-8 shows the calibration results of the Meramec River basin HSPF simulated discharges with observed discharges at Meramec River near Eureka, MO station (07019000). The deviation of runoff volumes (D_v) between observed data and simulated data is 8.07% which falls into the "very good" fit category with the HSPF hydrology modeling criteria (Table 3-2). The overall D_v for the validation period is -12.81% and falls within the "good" category in the criteria.

The coefficient of determination (R^2) of the calibration is 0.54 and that of the validation is 0.61. The Nash-Sutcliffe coefficient of efficiency (*E*) for the calibration and validation periods (Table 3-9) is 0.55. The R^2 and *E* values of this study are acceptable based upon comparison with other HSPF study results such as $E = 0.47$ from Johnson (2003) and $R^2 = 0.69$ from Brun (2000) with weekly values.

Table 3-8. Yearly calibration results for the Meramec River near Eureka, MO station.

Year	*Average observed discharge (cfs)*	*Average calibrated discharge (cfs)*	*Percent difference (D_v)*	*Coefficient of determination (R^2)*	*Nash-Sutcliffe coefficient of efficiency (E)*
1983	4689.62	5702.50	21.6	0.53	0.50
1984	4840.93	6068.79	25.36	0.46	0.35
1985	7742.61	6283.88	-18.84	0.56	0.50
1986	2987.69	3111.77	4.15	0.87	0.85
	5065.21	5291.73	8.07	0.54	0.55

Table 3-9. Yearly validation results for the Meramec River near Eureka, MO station.

Year	*Average observed discharge (cfs)*	*Average calibrated discharge (cfs)*	*Percent difference (D_v)*	*Coefficient of determination (R^2)*	*Nash-Sutcliffe coefficient of efficiency (E)*
1991	2978.01	2609.63	-12.37	0.68	0.58
1992	2516.90	2365.18	-6.03	0.50	0.50
1993	7578.71	6858.82	-9.5	0.50	0.47
1994	4671.70	3580.71	-23.35	0.75	0.64
	4436.33	3853.58	-12.81	0.61	0.55

Tables 3-10 and 3-11 indicate the monthly D_v within the calibration and validation periods. According to the HSPF model criteria (Table 3-2), an average monthly D_v of 23.22% during the calibration period falls into the hydrology/flow "fair" category. However, the validation D_v, -6.8%, is within the "very good" category.

Table 3-10. Monthly calibration results for the Meramec River near Eureka, MO station.

Month	*Average observed discharge (cfs)*	*Average calibrated discharge (cfs)*	*Percent difference (D_v)*
1	2487.73	5251.37	111.09
2	5072.29	5765.13	13.66
3	5182.76	5943.23	14.67
4	6543.03	9012.33	37.74
5	7999.32	8034.76	0.44
6	3687.92	6249.42	69.46
7	2299.83	2528.93	9.96
8	1703.17	1365.02	-19.85
9	2161.73	1390.79	-35.66
10	2445.22	4698.33	92.14
11	5668.89	6969.98	22.95
12	10335.00	6416.05	-37.92
	4632.24	5302.11	23.22

Table 3-11. Monthly validation results for the Meramec River near Eureka, MO station.

Month	*Average observed discharge (cfs)*	*Average calibrated discharge (cfs)*	*Percent difference (D_v)*
1	5854.27	4570.48	-21.93
2	3196.28	3150.8	-1.42
3	3903.71	3478.79	-10.89
4	11203.8	8767.17	-21.75
5	5519.27	5407.66	-2.02
6	2534.97	2892.25	14.09
7	2780.26	2119.48	-23.77
8	1909.51	2136.27	11.88
9	5203.92	3644.23	-29.97
10	1507.78	2063.82	36.88
11	6103.18	4142.4	-32.13
12	3632.74	3927.34	8.11
	4445.81	3858.39	-6.08

Figures 3-9 and 3-10 show how the simulated values for average monthly flow for the calibration and validation periods compare with the observed values.

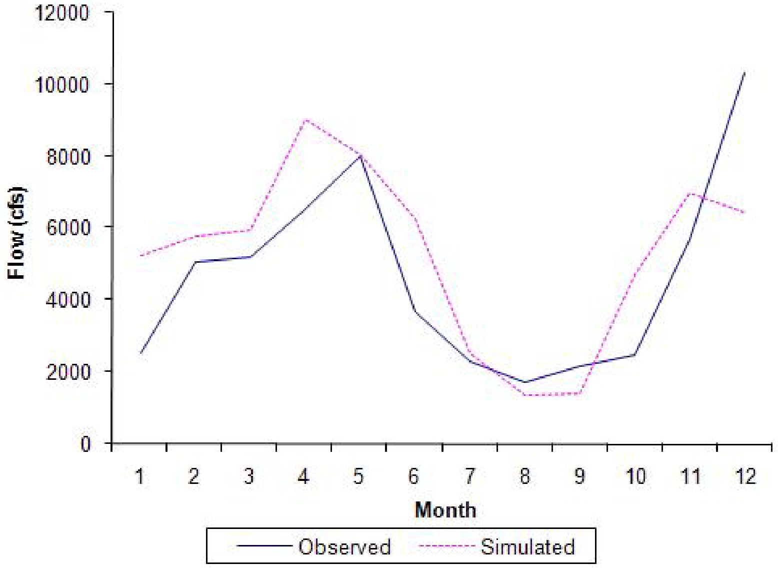


Figure 3-9. Monthly observed and simulated discharges for the calibration period.

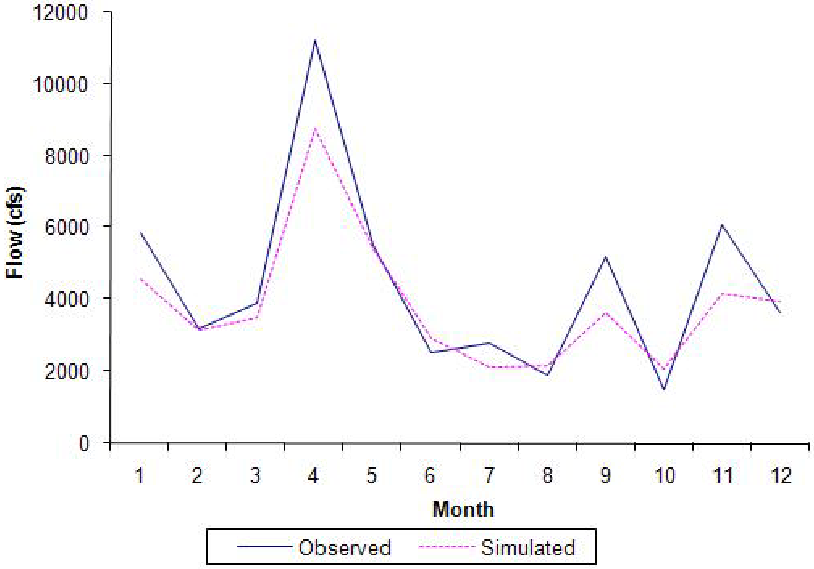


Figure 3-10. Monthly observed and simulated discharges for the validation period.

The average daily observed and simulated discharge results are shown in Figures 3-11 and 3-12 for the calibration and validation periods. The simulated discharges are not always simulating the observed peak flows and overestimate the observed base flow during the calibration and validation periods. It is common that the D_v of daily observed and simulated discharges are not as satisfactory as those of the annual or monthly periods in other studies (Choi and Deal 2008; Kim et al. 2007).

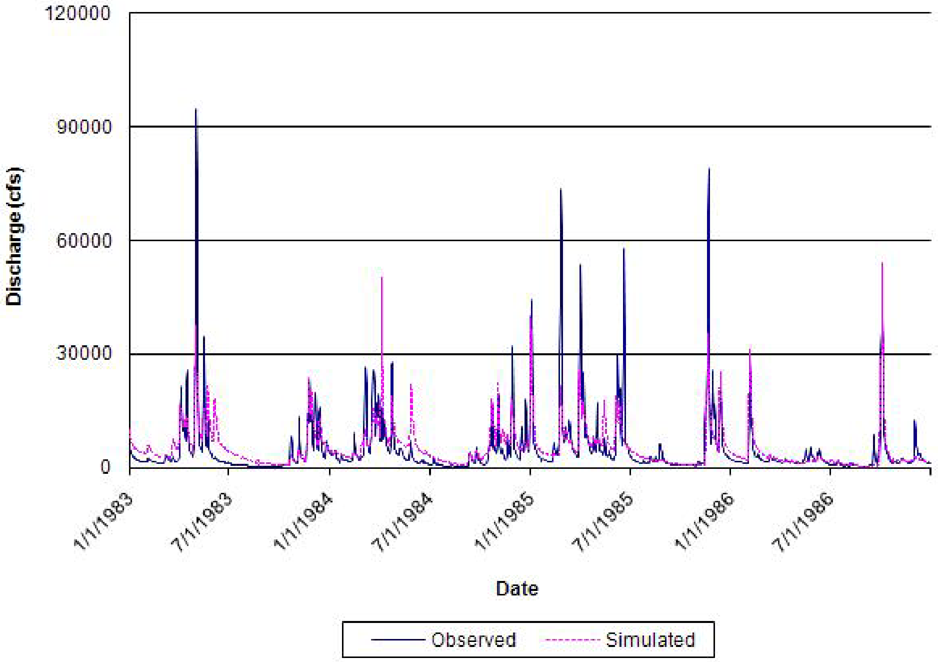


Figure 3-11. Daily observed and simulated discharges for the calibration period.

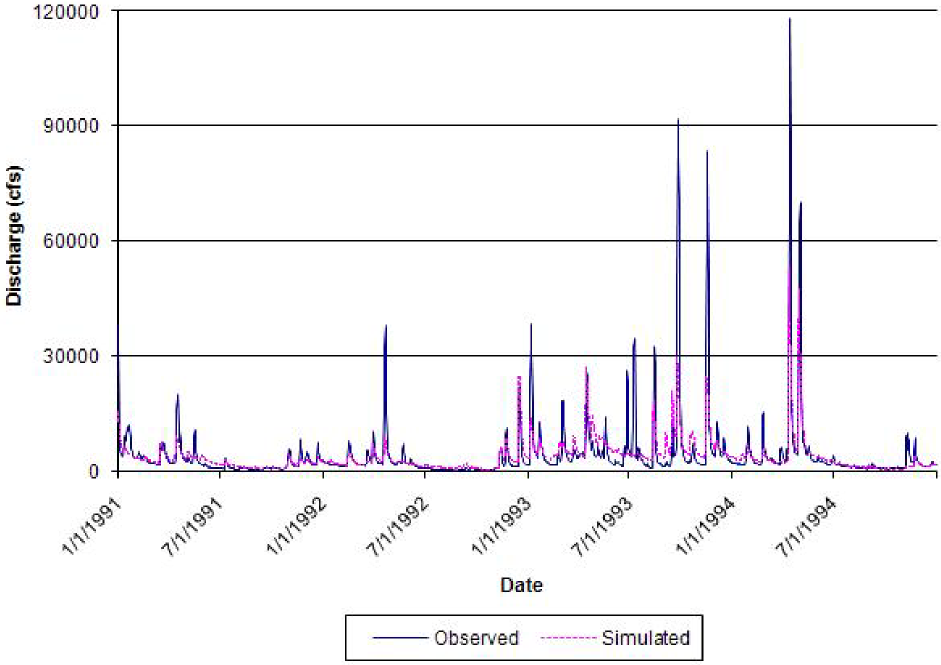


Figure 3-12. Daily observed and simulated discharges for the validation period.

The scatterplots of daily discharges on a logarithmic scale between observed and simulated output are shown in Figures 3-13 and 3-14.

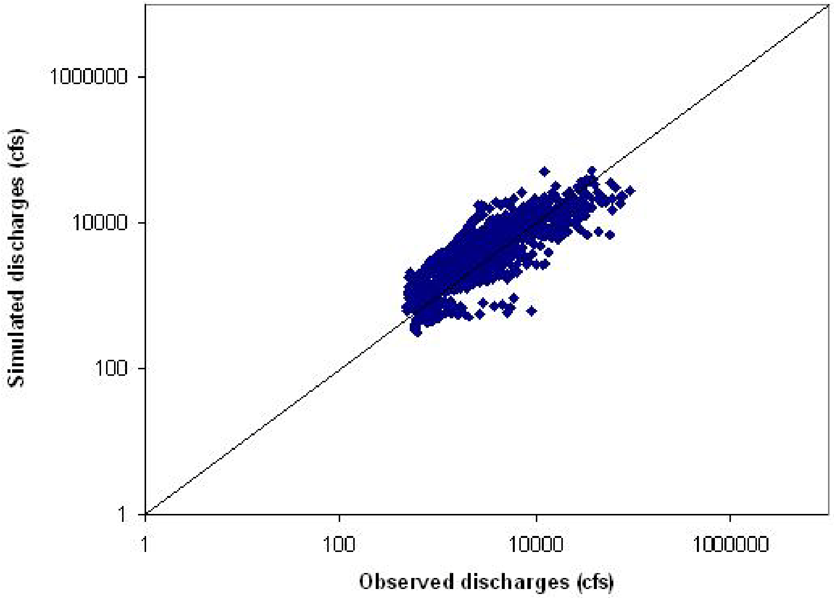


Figure 3-13. Scatterplot of observed and simulated daily discharge (cfs) for the calibration period (1983 – 1986).

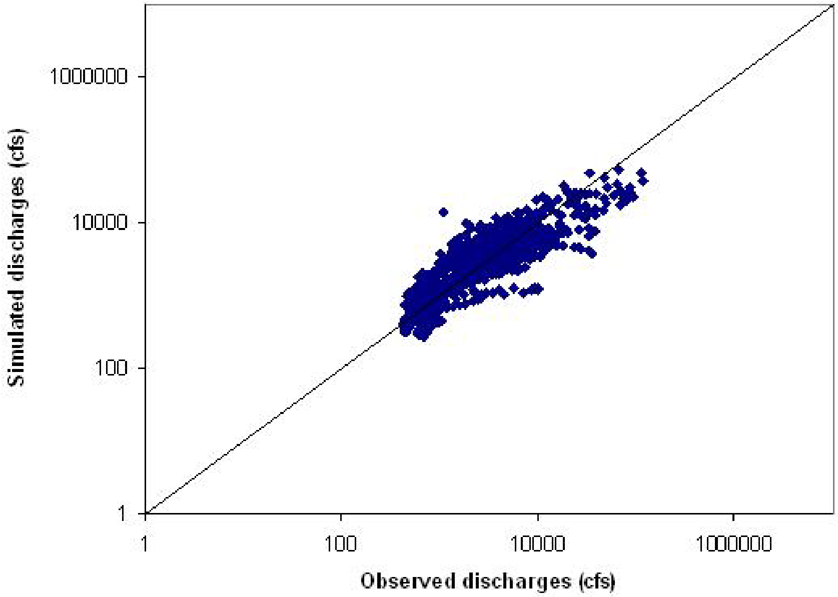


Figure 3-14. Scatterplot of observed and simulated daily discharge (cfs) for the validation period (1991 – 1994).

3.3.2. Sediment calibration results

Sediment is one of the most difficult water quality constituents to accurately represent in current watershed models because modeling sediment is very susceptible to the hydrology and other environmental impacts. Even though the observed sediment data were collected on the same day, the measured sediment results of two different samples are not the same because of sampling and measuring errors. Figure 3-15 shows the two different observed suspended sediment data which were collected at the same monitoring station. The daily observed data comes from the USGS suspended-sediment database daily values and the bi-monthly data comes from the USGS Real-Time Water Data for the Nation at the National Water Information System website. Most of the bi-monthly data is similar to daily collected data but percent differences of each data vary from 14% to 1600%. Also, the precipitation data from coarsely located weather stations throughout the Meramec River watershed make accurate sediment simulation difficult because sediment generation and transport are a function of storm size and intensity. For these reasons, the simulation of sediment is focusing on the overall annual or monthly sediment generation rather than on daily values.

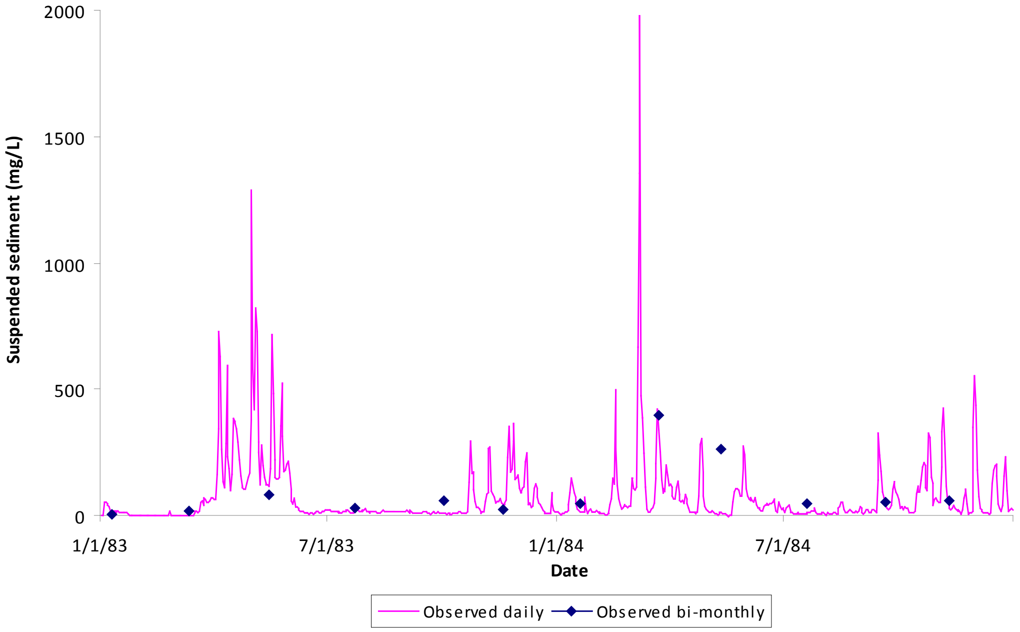


Figure 3-15. Comparison of the same day observed suspended sediment data for the Meramec River near Eureka, MO station.

The average annual concentration of simulated sediment during calibration (1983) is 69 mg/l and the difference from the observed concentration of 76.67 mg/l is - 9.97 %. The validation (1984) period has 88.57 mg/l of simulated sediment which has a 5.8 % difference from the observed annual sediment of 83.7 mg/l (Table 3-12). This result is within the "very good" category of the HSPF criteria (Table 3-2).

Table 3-12. Yearly average suspended sediment concentrations during the calibration period (1983) and validation period (1984).

Year	*Average Observed sediment (mg/l)*	*Average Calibrated sediment (mg/l)*	*Percent difference (D_v)*
1983 (calibration)	76.67	69	-9.97
1984 (validation)	83.7	88.57	5.8

Average monthly suspended sediment comparisons of the calibration (

Table 3-13) and validation periods (Table 3-14) are shown with percent differences (D_v). Overall monthly percent difference for sediment during the calibration period is 9.64 and for the validation period is -2.95. These results also fall into the “very good” category of the HSPF criteria. The simulation of sediment is a function of the rainfall which is the main cause of sediment transport. In spite of a calibration effort to raise the base flow, suspended sediment concentrations using the recommended input parameter ranges result in low concentrations. Most of the underestimations occur during the low flow situations that occur between storms. The average monthly suspended sediment concentrations during the calibration period and the validation period are plotted in Figures 3-16 and 3-17.

Table 3-13. Monthly average suspended sediment concentration during the calibration period (1983).

Month	*Average Observed sediment (mg/l)*	*Average Calibrated sediment (mg/l)*	*Percent difference (D_v)*
1	13.68	22.88	67.26
2	0.54	1.51	181.33
3	27.94	5.94	-78.73
4	306.90	158.17	-48.46
5	266.74	259.20	-2.83
6	20.40	70.49	245.52
7	19.13	1.18	-93.84
8	16.13	6.97	-56.8
9	13.47	0.90	-93.29
10	42.00	4.36	-89.62
11	129.67	229.86	77.27
12	61.39	66.23	7.89
	76.50	68.97	9.64

Table 3-14. Monthly average suspended sediment concentration during the validation period (1984).

Month	*Observed sediment (mg/l)*	*Validated sediment (mg/l)*	*Percent difference (D_v)*
1	36.19	0.77	-97.87
2	75.29	1.39	-98.15
3	269.23	66.25	-75.39
4	73.87	299.32	305.22
5	60.19	92.28	53.31
6	46.60	27.05	-41.95
7	18.03	0.54	-96.99
8	22.97	0.05	-99.78
9	74.57	35.55	-52.33
10	96.35	131.43	36.4
11	120.87	365.54	202.43
12	108.94	32.31	-70.34
	83.59	87.71	-2.95

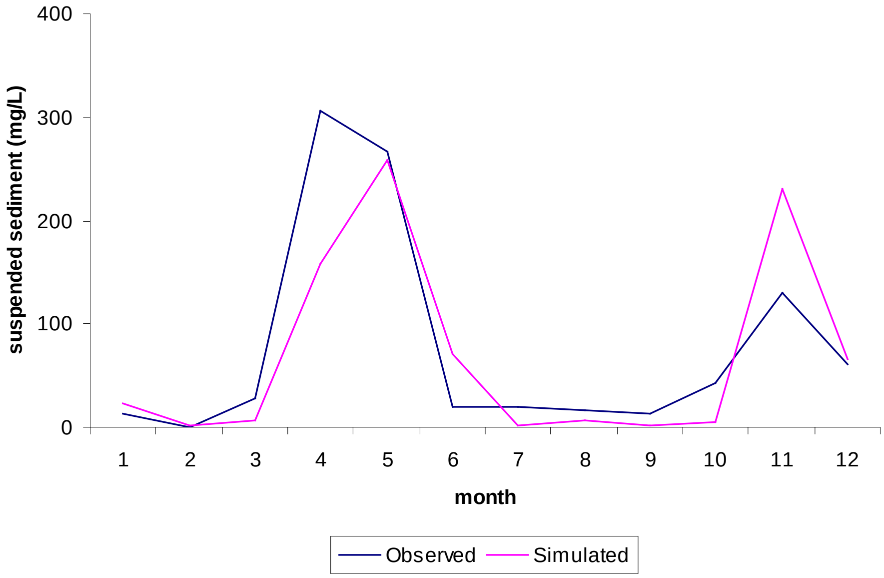


Figure 3-16. Monthly average suspended sediment concentrations during the calibration period (1983).

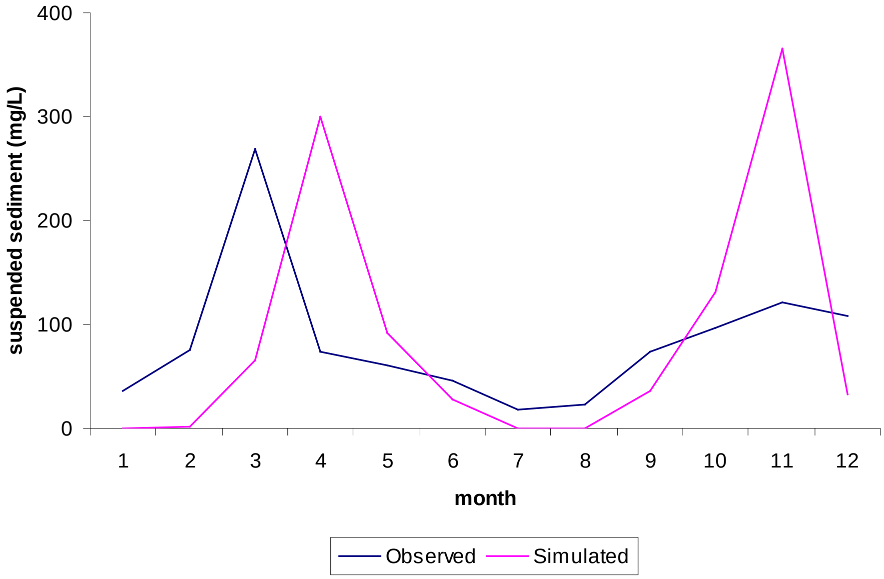


Figure 3-17. Monthly average suspended sediment concentrations during the validation period (1984).

These very good monthly sediment simulations represent only two years worth of simulations and the flow results of the simulated years (1983 and 1984) are overestimated by approximately 20 % (Table 3-8). However, the lack of continuous observed data prevented calibration and validation from being conducted over the same time period as the flow calculations. Figure 3-18 shows the discrete observed data on top of the daily simulated sediment concentrations helping to highlight the differences between observed and simulated values.

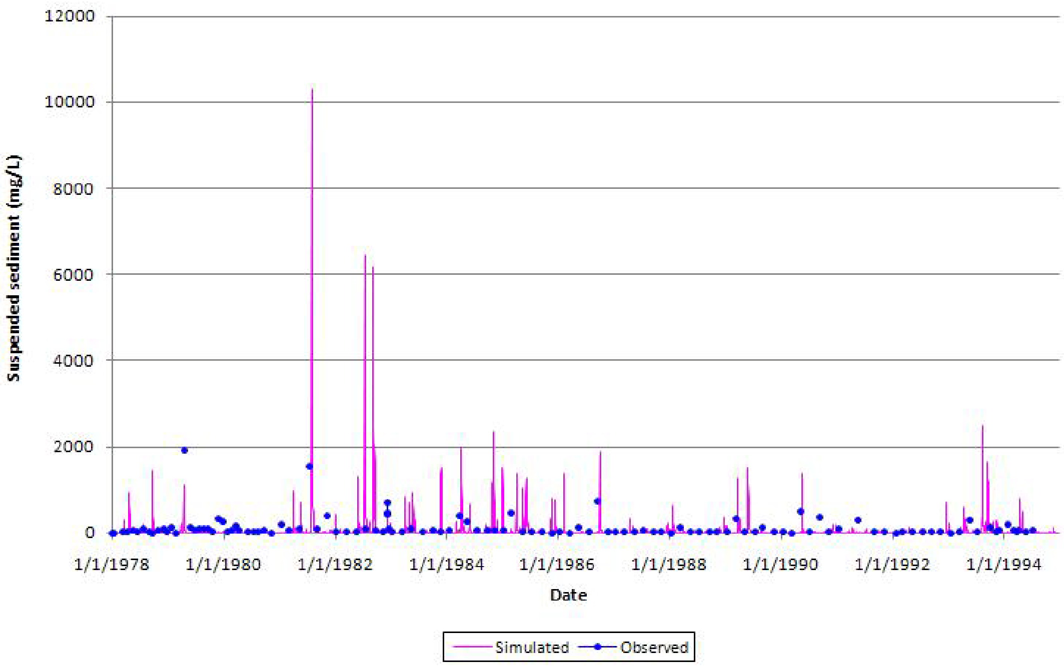


Figure 3-18. Observed sediment concentration plot superimposed on the simulated sediment values.

The daily observed and simulated suspended sediment data are shown in Figures 3-19 and 3-20 along with the observed precipitation data from the St. Louis MO 7455 station on a secondary vertical axis. The simulated sediment represents the sequential effect of suspended sediment lagging after the precipitation event, but the observed data do not show this trend very well. The observed hydrology and sediment data are impacted by weather conditions throughout the whole watershed but the simulated data at the watershed outlet are calculated with the precipitation data from the St. Louis weather station which is located near the outlet of the Meramec River basin.

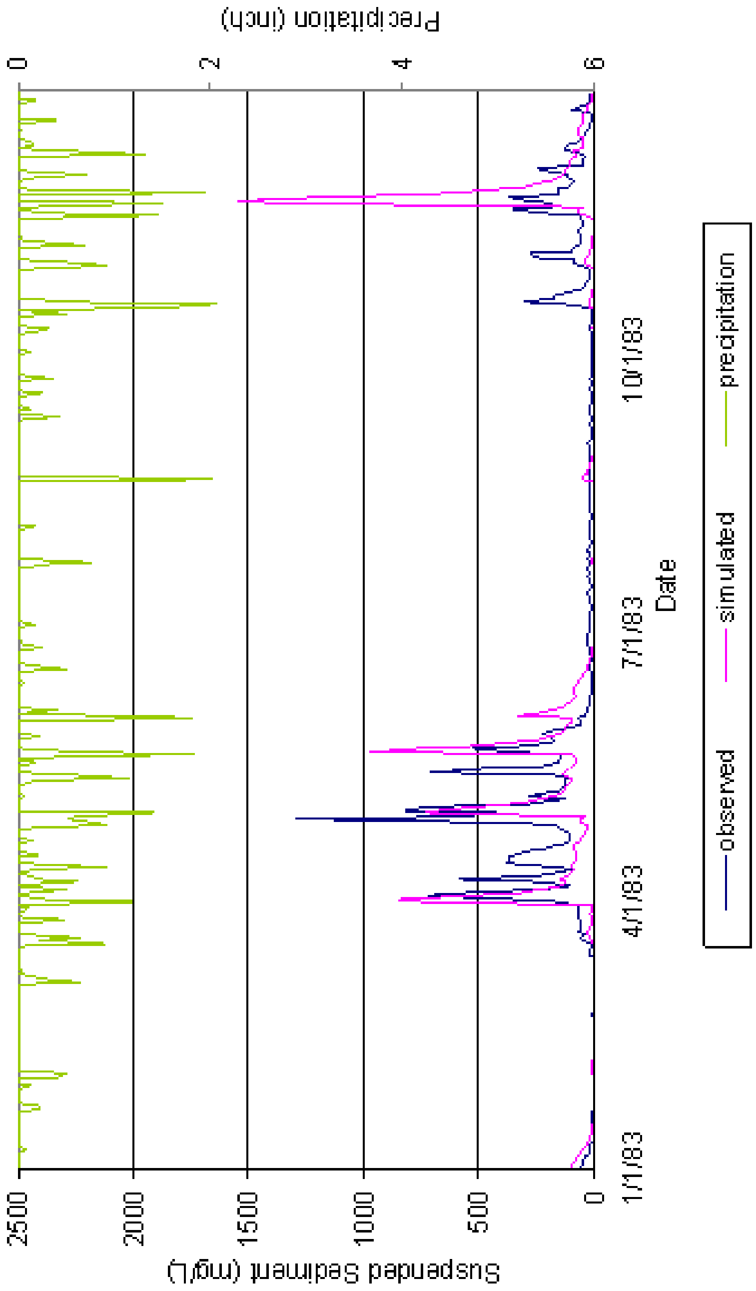


Figure 3-19. Daily observed and simulated suspended sediment during the calibration period with observed precipitation data at the St. Louis, MO 7455 station.

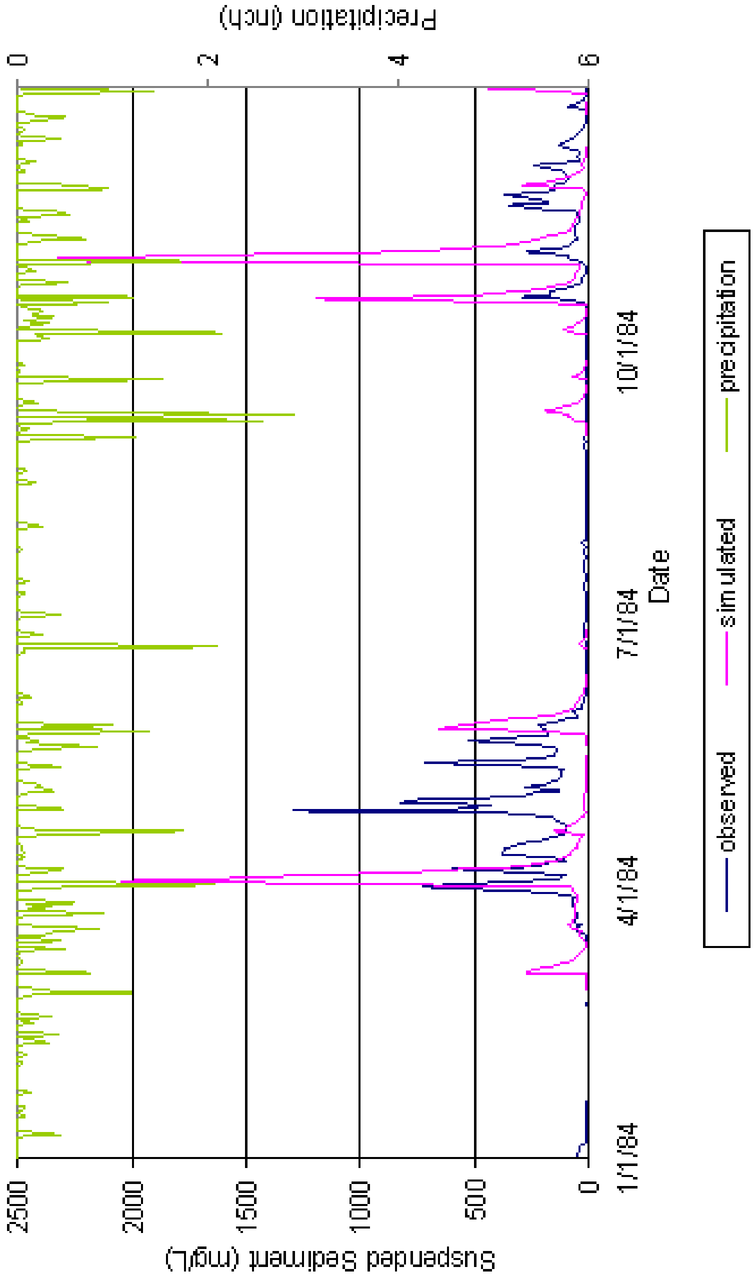


Figure 3-20. Daily observed and simulated suspended sediment during the validation period with observed precipitation data at the St. Louis MO 7455 station.

3.4. Conclusion

The target watershed for testing WQT policy implementation does not have complete local weather, water quantity, or water quality monitoring data, as is the case for many other small watersheds that are confronted with the pressures of development. The HSPF watershed modeling program that can estimate non-point sources pollutant loadings is calibrated with Meramec River basin observed data. The calibrated Meramec River basin input parameters for subbasin # 1 can be applied to modeling the target watershed which is being used as a test for the development of WQT policy trading policy units.

The specific procedure for watershed modeling is described and the calibration results are shown in section 3.3. From the result that the flow and sediment simulations are considered to range from very good to fair within HSPF criteria, the input parameters from calibration can be accepted for further calibration of the target watershed.

The Brush Creek suspended sediment is one of the nonpoint pollutants of concern that can be simulated throughout different weather conditions and land uses with the calibrated HSPF model input parameters in Chapter 4.

4 Land use impact to water quality between tradable locations

4.1. Introduction

Land use change in urbanizing watersheds has significant impacts on hydraulic processes and stream quality because a development with increasing impervious surface causes increasing surface runoff (Brun and Band 2000) and the nonpoint source pollutant loading which is generated and transported within the surface runoff is also expected to increase with the increasing impervious surfaces. The impacts of increased runoff and pollutant loadings will be different in accordance with the characteristics of the watershed. The calibrated input parameters of the HSPF model for the Meramec River basin are applied to the Brush Creek HSPF model to examine the hydrological processes and sediment concentration impacts of urbanization in specific locations. Scenarios of development with different intensities are analyzed using HSPF and the modeling results can be used to determine water quality trading units between two locations within one watershed.

The hydrologic and sediment impacts at a watershed outlet are calculated for various development scenarios and compared. The scenarios represent various combinations of original land use with different magnitudes of impervious surface and will help to plan for smart growth with reasonable development intensities.

4.1.1. General description of the study area

The city of Pacific, Missouri is located in the Brush Creek watershed (shown in purple in Figure 4-1) and has experienced an abrupt increase of population of around 30 percent within the last 10 years. This increase is expected to have occurred because of the proximity of St. Louis, MO and Interstate 44 which has allowed for movement between Pacific and St. Louis. An increase in population increases urbanization with rapidly increasing impervious surfaces near the Brush Creek downstream location. The drainage area of Brush Creek is approximately 6200 acres and most of the area is located inside of the Franklin County, MO boundary.

The impact of the development in downstream locations of the Brush Creek can be modeled in advance of actual development and the estimated potential future environmental impacts can be used to calculate the trading units for implementing EPA's Water Quality Trading policy to maintain the water quality even after development.

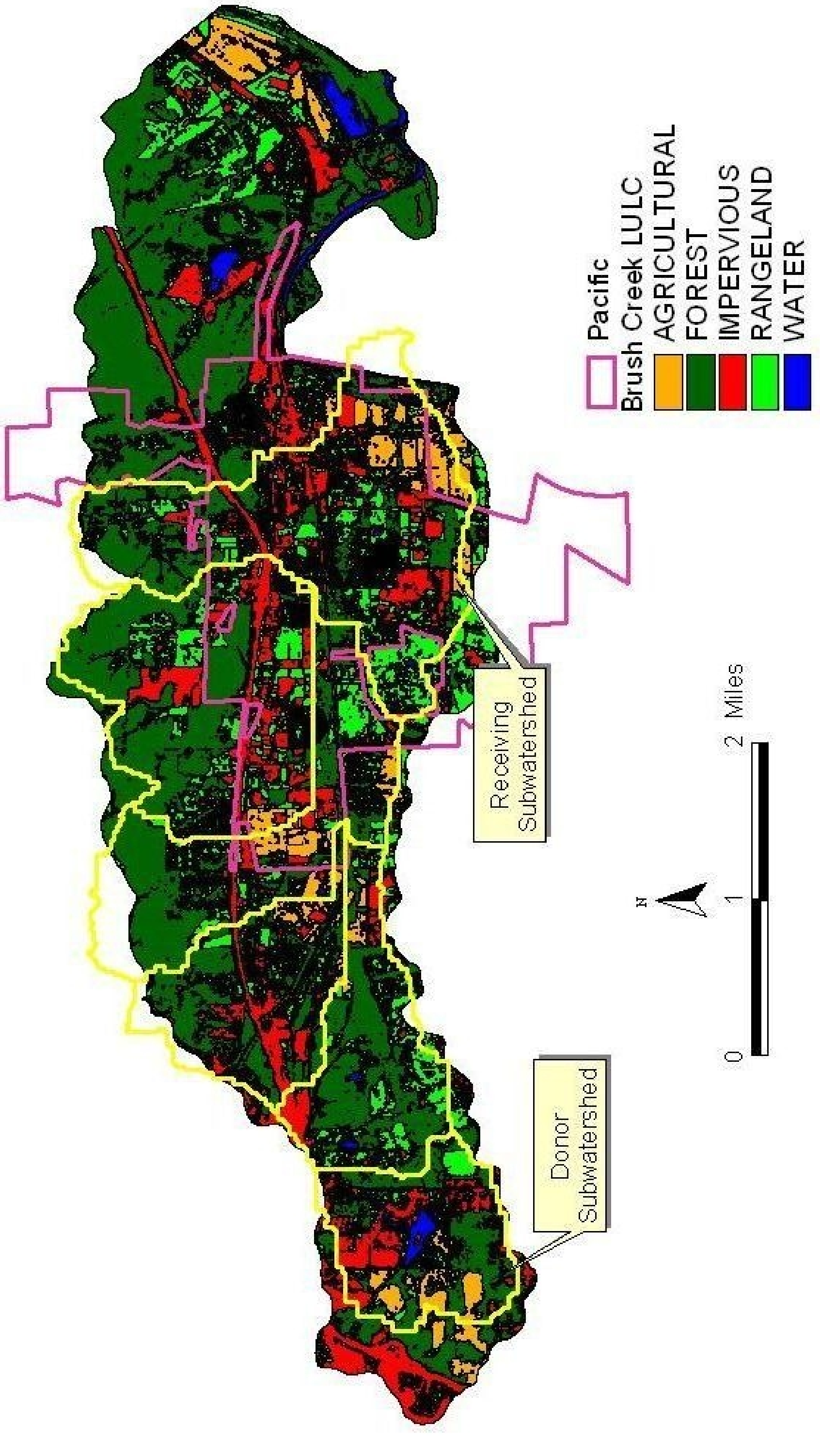


Figure 4-1. The city of Pacific and the Brush Creek watershed with subbasins superimposed upon a land cover map.

4.2. HSPF Model adjustment for the Brush Creek

4.2.1. Watershed delineation

The overall Brush Creek watershed is the same area as the Meramec River subbasin #1 discussed previously. The delineated Brush Creek watershed is further divided into several subbasions because this study is concerned with the comparisons of the hydrologic and sediment impacts between upper and lower watershed areas which are potential trading locations. The new watershed delineation includes four different subbasins within the Brush Creek watershed. The city of Pacific is located within the downstream subbasin and is one of the fast growing cities in the vicinity of the St. Louis metropolitan area. The downstream subbasin (receiving subwatershed in Figure 4-1) is a potential area for receiving trading credits because heavy development is expected in this area. The upstream subbasin is considered as a potential donor area for trading credits that would be associated with limiting its development or restoring current land uses to previous uses. Figure 4-1 indicates the donor subwatershed and the receiving subwatershed in the Brush Creek watershed with subbasins superimposed upon a land cover map.

Within the BASINS 3.1 ArcView interface, the automatic delineation method is used, based on the stream information from the National Hydrography Dataset (NHD). The NHD is a comprehensive set of digital spatial data representing the surface waters of the United States using common features such as lakes, ponds, streams, rivers, canals, and oceans. These detailed surface water data were collected for every stream longer than one mile (approximately 1.6 kilometers). The resolution of the NHD data set is appropriate for delineating the Brush Creek watershed which has 7.2 miles of stream traveling through four different subbasins. The Meramec River watershed shapefile is used as a mask area for the Brush Creek delineation to obtain the same size delineation to the extent possible.

4.2.2. Application of the latest land cover data

The Geographic Information Retrieval and Analysis System (GIRAS) land use/land cover data which is used for the HSPF modeling within the Meramec River basin is too coarse to define the specific land cover within the upper and lower subbasins. GIRAS has a 4 ha polygon size for the land use/land covers of urban built-up, water, confined feeding operation, agriculture, strip mines, quarries and gravel pit. The remaining areas are collected with a 16 ha polygon size. Rather than the coarse GIRAS land use data, the Brush Creek watershed HSPF model uses a land cover map that is derived from QuickBird satellite imagery from Digital Globe, Inc. with a 2.4 meter pixel resolution through an image classification scheme. The QuickBird land cover map was generated with several QuickBird satellite images representing both leaf on and leaf off conditions (Aslan 2009). The dates of the images are October 17, 2003; March 19, 2004; December 4, 2004; July 24, 2006; and August 16, 2006. The land cover map consists of seven classes (i.e., forest, shrubs, cropland, grassland, barren land, impervious, and water). The differences between the land use/land cover resolutions of GIRAS and the satellite imagery can be seen in Figure 4-2. The finer resolution of the land cover map can help to generate more realistic development scenarios within each land use category.

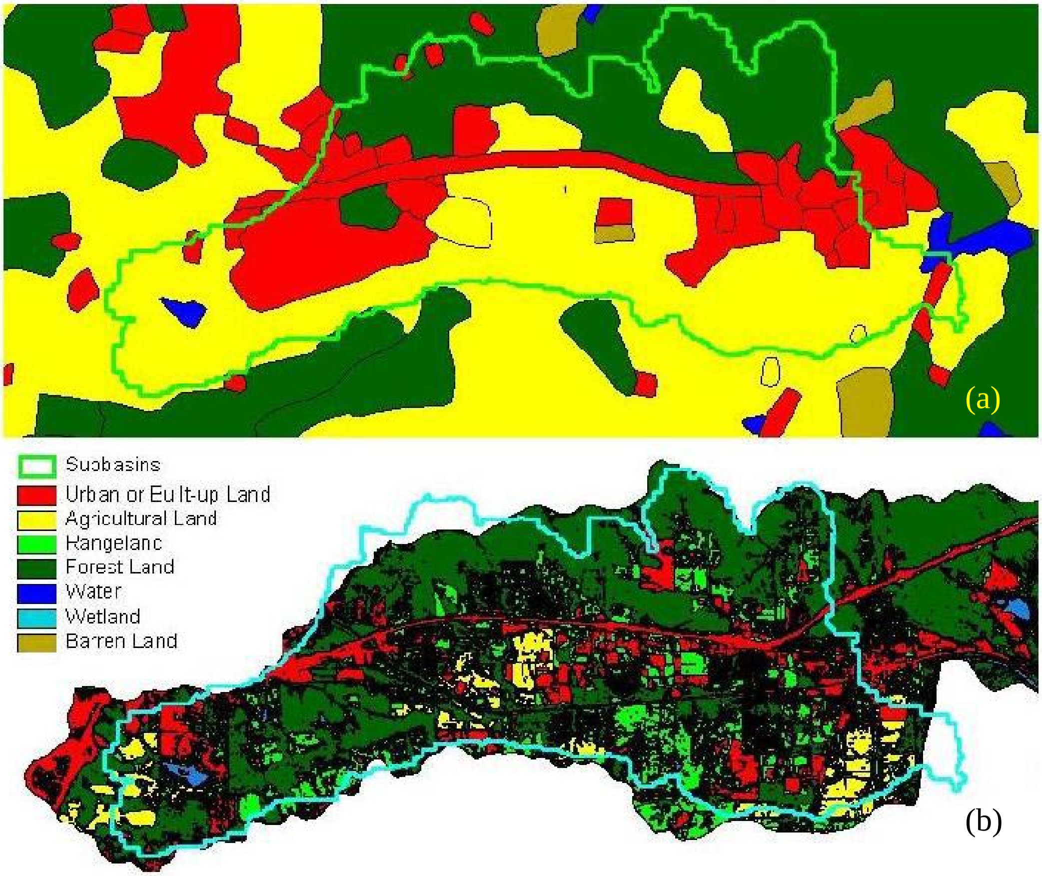


Figure 4-2. The GIRAS land use/land cover (a) versus QuickBird land cover (b) within the Brush Creek watershed.

As one can see in the GIRAS land use image ((a) in Figure 4-2), the urban built-up area shown with red polygons in the map was aggregated with all the urban components such as residential, commercial, industrial and transport area; thus, the percent pervious was assumed as 50% in the Meramec River watershed HSPF model. The impervious land cover from QuickBird is assigned as 5% in the HSPF model generation because the QuickBird imagery impervious land cover precisely represents only the impervious areas within the urban areas.

Table 4-1 shows the estimated percent impervious values from the literature (Dunne and Leopold 1978);(Klein 1979). From Table 4-1, the urban built-up percent impervious is assigned as 50% within the GIRAS land use/land cover map and the agricultural area is assigned 5% impervious area. The final assumptions of percent pervious for each land use category for the Brush Creek HSPF model are provided in

Table 4-2.

Table 4-1. Percent impervious surface for each land use category in the literature.

Land use/land cover category	*Percent impervious*
Residential	25
Open land	5
Forest land	0
Commercial	70
Agricultural	5

(estimation from Dunne et al. (1978) and Klein (1979))

Table 4-2. Land use categories from QuickBird land cover with percent impervious values for the Brush Creek HSPF model.

Land use/land cover category	*Percent impervious*
Impervious	95
Agricultural land	5
Forest land	0
Range land	0
Water	0

With the assigned percent imperviousness, the Brush Creek watershed land use/land cover is assessed and is displayed in Table 4-3. Also, the HSPF calculation of percent impervious land area using the Meramec River watershed subbasin #1 with GIRAS land use is shown in Table 4-4.

From Tables 4-3 and 4-4, the impervious land classified using QuickBird imagery from the Brush Creek is 1435 acres; while the urban or built-up land of the GIRAS land use indicates 1580 acres. Even though the GIRAS land use has a larger acreage of urban area, the impervious land of the Brush Creek watershed is more than that from GIRAS land use. Here, the percent of total impervious land of the Brush Creek watershed and subbasin #1 of the Meramec River watershed are 21.46 and 12.39, respectively.

Table 4-3. Land use/land cover within the Brush Creek watershed as generated by HSPF.

Land use/land cover	*Impervious land (acres)*	*Pervious Land (acres)*	*Total (acres)*	*Percent of total*
Impervious	1363	72	1435	22.2
Agricultural	24	461	485	7.5
Water	0	31	31	0.48
Forest	0	2613	2613	40.43
Range land	0	1899	1899	29.38
Total	1387	5076	6463	100
Percent of total	21.46	78.54	100	

Table 4-4. Land use/land cover within subbasin #1 of the Meramec River watershed generated by HSPF.

Land use/land cover	*Impervious land (acres)*	*Pervious Land (acres)*	*Total (acres)*	*Percent of total*
Urban or Built-up land	790	790	1580	24.56
Agricultural	0	3183	3183	49.47
Water	0	27	27	0.42
Forest	0	1621	1621	25.19
Range land	0	0	0	0.00
Barrenland	7	16	23	0.36
Total	797	5637	6434	100
Percent of total	12.39	87.61	100	

The HSPF modeling results with the QuickBird land cover are expected to generate higher surface runoff and suspended sediment than the results of the Meramec subbasin #1 modeling because the QuickBird land cover represents more recent land use than GIRAS land use which is collected from the late 1970s to the early 1980s. When the QuickBird land cover is applied to the Brush Creek watershed, the 9.07% increase in impervious surfaces might cause an increase in flow and sediment transport representing the current status of the watershed.

4.3. Development of land use scenarios

It is assumed that the HSPF hydrologic and sediment simulation results using the QuickBird land cover map represent the present status of the Brush Creek watershed. The estimation of the impacts of the urban development to the watershed outlet even before the development occurs is possible through watershed modeling. The generation of various development scenarios within the upper and lower subbasins with manually updated land uses representing possible development is presented. In addition, a restoration scenario can be applied to this model to estimate the improvement in water quality when agricultural areas return to range land.

4.3.1. Urban development scenarios

4.3.1.1 Downstream development scenarios

Urbanization scenarios can be generated by manually estimating or using a model such as the Land use Evolution and impact Assessment Model (LEAM). The LEAM was designed to project the general patterns of urban growth and does not predict exactly where development will take place (Choi and Deal 2008). For the generation of land use scenarios, the manually updated land cover using expected development area is applied because the LEAM is not able to incorporate urbanization in specific areas.

Figure 4-3 has two different land cover maps of the same location. The first picture (a) shows the Brush Creek downstream subbasin with the actual QuickBird land cover map. The second picture (b) is the same location but with the land cover modified by manually changing agricultural land to developed land. The red circles indicate that all yellow agricultural land uses inside of the subbasin (yellow subbasin polygon) have been changed to the gray development land uses category. This manual update of land cover/land use was completed using the ArcGIS 9.1 software and selecting the downstream agricultural locations and editing the attributes to the developed land use theme. With the same methodology, the forest land and range land inside of the downstream subbasin are selected and changed to development area to generate the expected development land cover maps for the HSPF scenario runs.

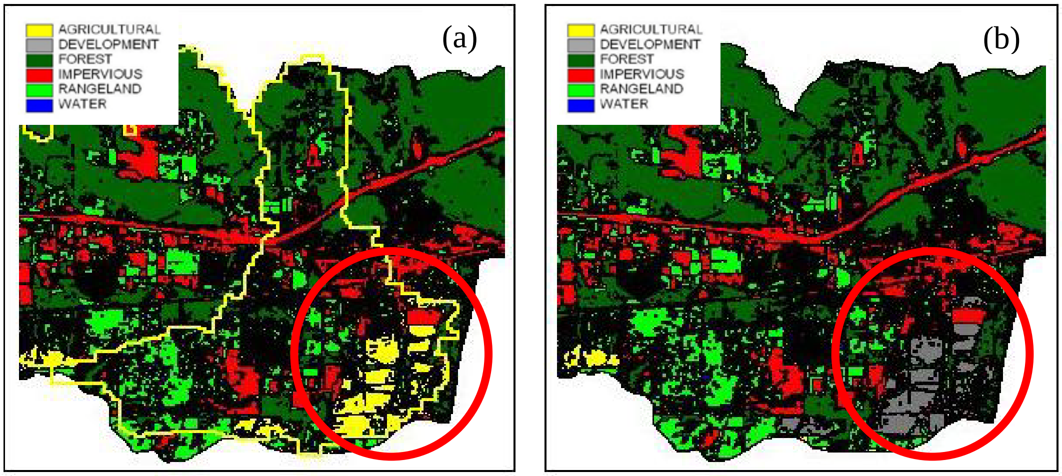


Figure 4-3. An example of downstream development scenario with agricultural land becoming developed.

Figure 4-4 shows the 3 different land use themes of the BASINS model for the downstream development scenarios. The grey areas of each theme show the estimated future development areas which are modified from agricultural (a), forest land (b), and range land (c).

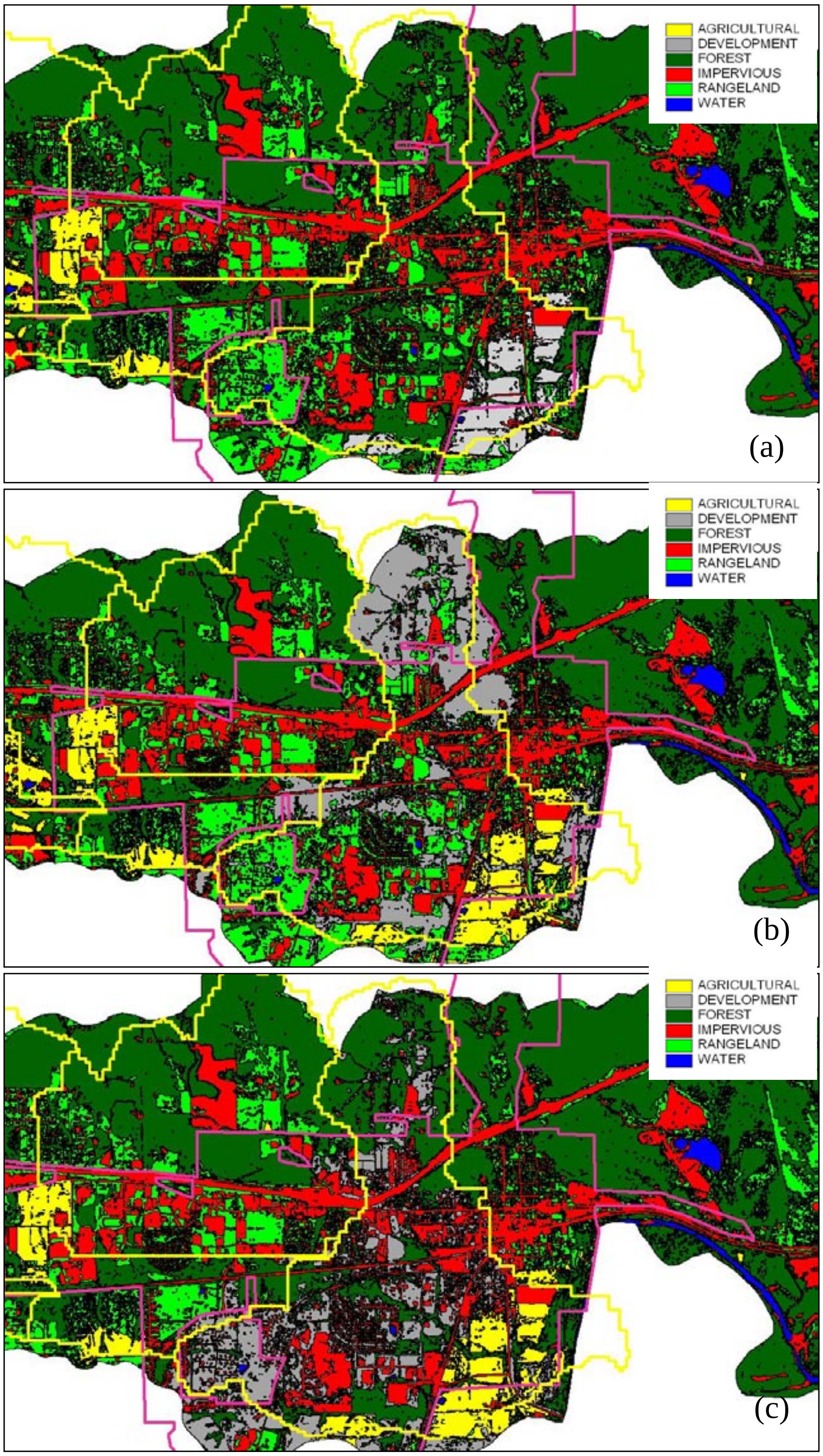


Figure 4-4. BASINS land use themes modified to developed (grey area) from agricultural (a), forest land (b), and range land (c) in the downstream subwatershed.

Nine downstream development scenarios are generated through the combination of three land uses and three different percentages of impervious surface. The downstream development scenarios of the modified land uses and the percent imperviousness are presented in Table 4-5.

In Table 4-5, **A25D** represents that all of the **A**gricultural land in the **D**ownstream subwatershed is developed with **25**% impervious surfaces. While the other land use categories maintained the original imperviousness, as introduced in Figure 4-2, the percent impervious of the developed land was assigned as either 25, 50, or 75% for the HSPF model runs. The different percent imperviousness of the development is designed to indicate the level of future development intensity.

Table 4-5. Downstream development scenarios.

Land use Changes	*Scenarios*		
	25% Impervious	*50% Impervious*	*75% Impervious*
Agricultural area to Developed area	A25D	A50D	A75D
Forest land to Developed area	F25D	F50D	F75D
Range land to Developed area	R25D	R50D	R75D

4.3.1.2 Upstream development scenarios

The water quantity and quality impacts of the upstream development cannot be assumed to be the same as those of the downstream development because of the potential in-stream effects that should be a part of the upstream development results. For example, the upstream suspended sediment impacts to the Brush Creek watershed outlet could be decreased if sediment deposition occurs in the stream bed, or sediment could increase if sediment is scoured from the stream bed and banks. These in-stream effects can be simulated with the upstream development scenarios, where the scenarios are shown in Table 4-6. As is the case with the downstream development scenarios, the nine different upstream development scenarios were generated from combinations of three land use changes and three magnitudes of percent imperviousness.

The A25U represents that all the Agricultural lands of Upstream area are expected development with 25% impervious surfaces.

Table 4-6. Upstream development scenarios.

Land use changes	*Scenarios*		
	25% Impervious	*50% Impervious*	*75% Impervious*
Agricultural area to Developed area	A25U	A50U	A75U
Forest land to Developed area	F25U	F50U	F75U
Range land to Developed area	R25U	R50U	R75U

Figure 4-5 shows the upstream development land use from agricultural (a), forest land (b), and range land (c). The three different land use themes of the BASINS model of the upstream development scenarios are generated from modifications to the QuickBird imagery using GIS software.

4.3.2. Agricultural restoration scenarios

The upstream and downstream development scenarios are generated to investigate the equivalent trading credits between two locations. Thus, the equivalent amount of trading credit from upstream locations to pair with the development of downstream locations will be limited based on the undeveloped area upstream and potential stream effects. Alternatively, and as a modification to the expected implementation of EPA's Water Quality Trading policy, the restoration of the upstream and downstream land use may be used to generate trading credits for the downstream development scenarios. This unconventional method of trading may be of interest when there are limited tradable areas at the upstream locations. The restoration from urban built up areas and agricultural area to range land or forest land can be considered as restorations. However, the restoration of already built up land use to range land is not a realistic option. Thus, the restoration from agricultural land to range land is chosen for the restoration scenario and the upstream and downstream restoration scenarios are shown in Table 4-7.

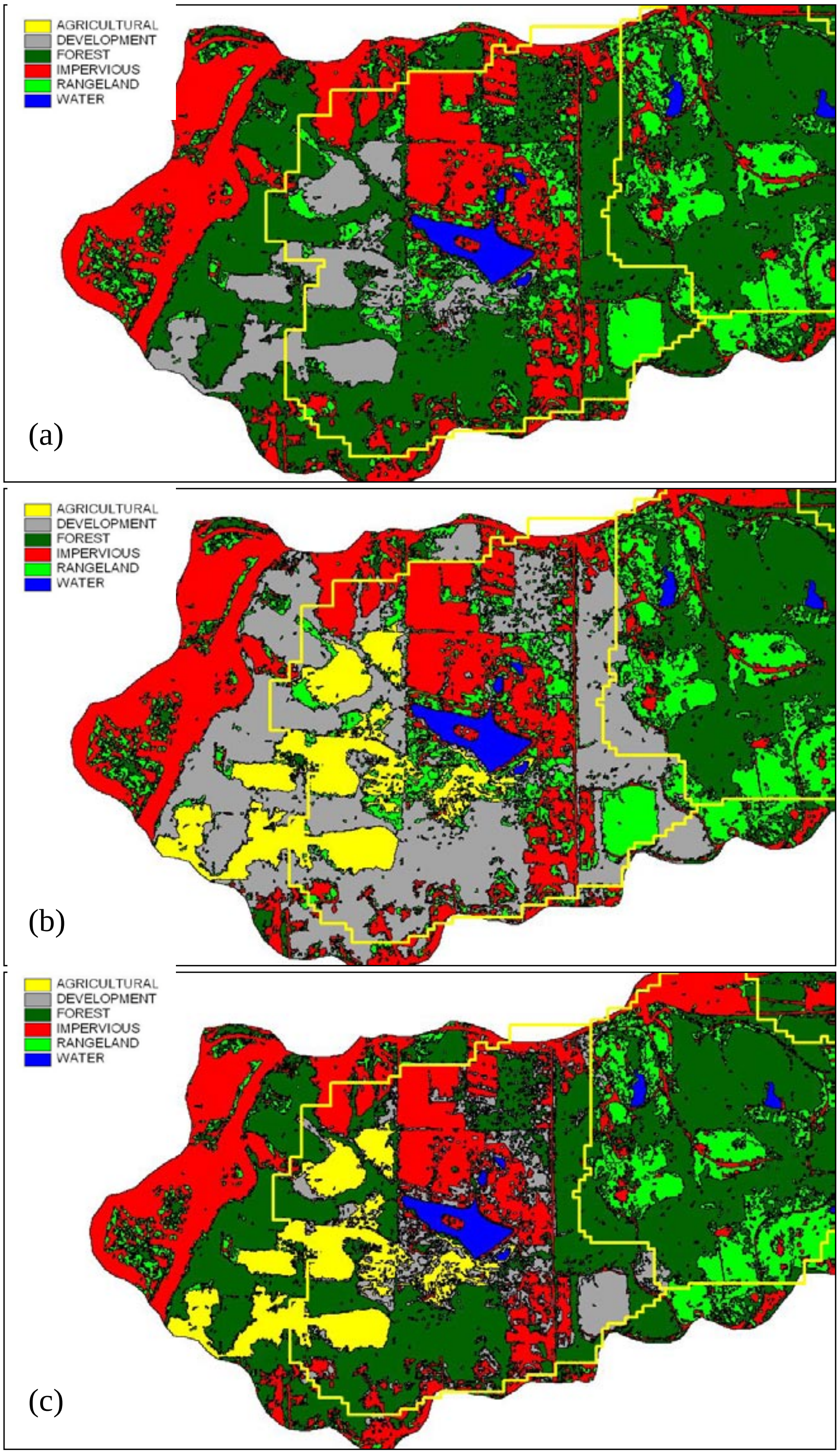


Figure 4-5. BASINS land use themes modified to developed (grey area) from agricultural (a), forest land (b), and range land (c) in the upstream subwatershed.

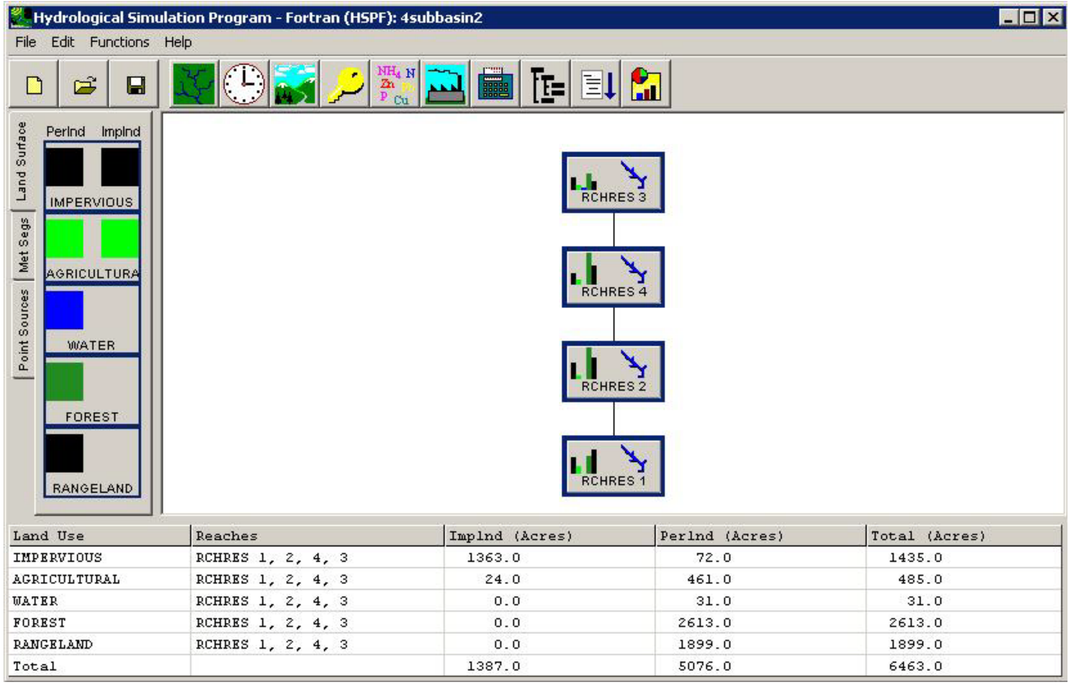
Table 4-7. Restoration scenarios from agricultural land to range land.

Land use changes	*Upstream restore scenario*	*downstream restore scenario*
Agricultural land to Range land	ARU	ARD

4.4. HSPF modeling

The HSPF model combines a GIS map of the watershed with runoff and in-stream hydraulic information to generate the flow rate, sediment load, and nutrient and pesticide concentrations. The flow rate and sediment load at the outlet of the watershed are chosen to represent the water quantity and quality impacts of the land use scenarios. The HSPF model is run with the final set of input parameters developed from the model calibration with the observed flows and sediment data from the Meramec River watershed, as discussed in Chapter 3.

Figure 4-6 is a screenshot of the HSPF model of the current scenario which is displayed after combining watershed delineation, land use and weather files. After application of input data editing with the calibrated input parameters and output management via the function tab, the model is run for the simulation.

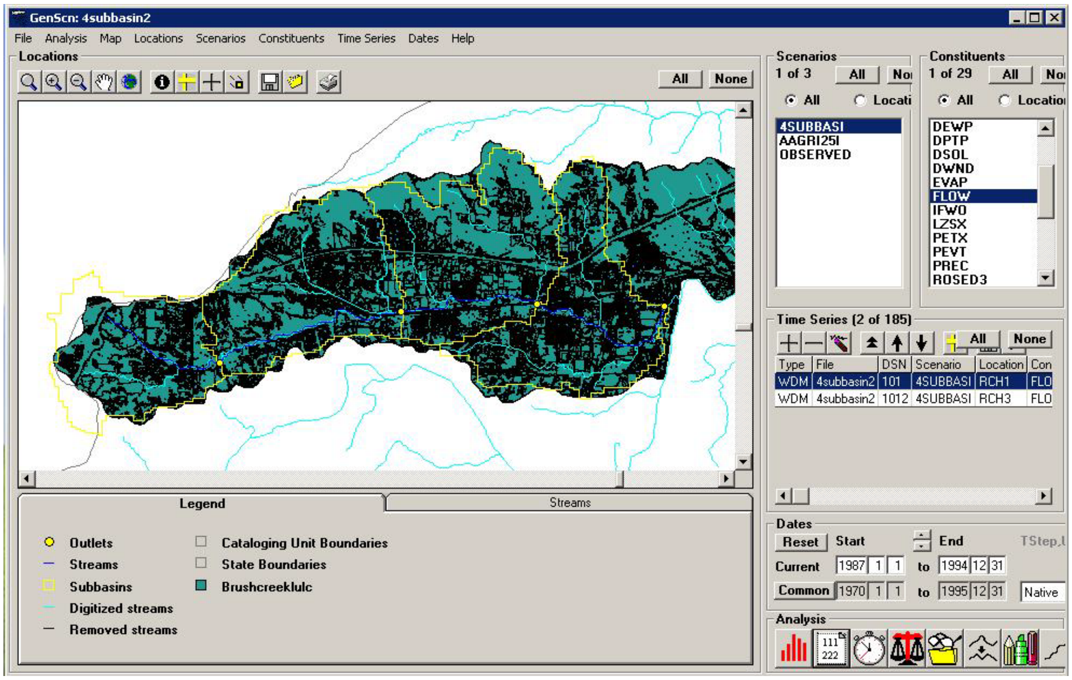


Land Use	Reaches	Implnd (Acres)	Perlnd (Acres)	Total (Acres)
IMPERVIOUS	RCHRES 1, 2, 4, 3	1363.0	72.0	1435.0
AGRICULTURAL	RCHRES 1, 2, 4, 3	24.0	461.0	485.0
WATER	RCHRES 1, 2, 4, 3	0.0	31.0	31.0
FOREST	RCHRES 1, 2, 4, 3	0.0	2613.0	2613.0
RANGELAND	RCHRES 1, 2, 4, 3	0.0	1899.0	1899.0
Total		1387.0	5076.0	6463.0

Figure 4-6. HSPF screenshot of the current scenario.

Applied input parameters are shown in Chapter 3 (Tables 3-6 3-7). The HSPF data input file (*, uci) of the current scenario of the Brush Creek watershed is attached as Appendix D for reference.

The simulated results can be presented using the GENeration and analysis of model simulation SCeNarios (GenScn) program which was developed to create simulation scenarios, analyze results of the scenarios, and compare scenarios. Figure 4-7 is the screenshot of the GenScn program with the current scenario’s map, scenarios, and constituents from 1987 to 1994 displayed. The list or graph of the simulated results can be displayed though the dates and analysis tab on the bottom right of the GenScn screen shot.



Scenarios:
4SUBBASI
AAGRI25I
OBSERVED

Constituents:
DEWP
DPTP
DSOL
DWND
EVAP
FLOW
IFWO
LZSX
PETX
PEVT
PREC
ROSED3

Type	File	DSN	Scenario	Location	Con
WDM	4subbasin2	101	4SUBBASI	RCH1	FLO
WDM	4subbasin2	1012	4SUBBASI	RCH3	FLO

Current 1987 1 1 to 1994 12 31

Common 1970 1 1 to 1995 12 31 Native

Figure 4-7. GenScn program screenshot of the current scenario.

4.5. Scenario results and analysis

4.5.1. Water quality and quantity results

4.5.1.1 Water quantity results

The HSPF model runs with land use scenarios provides the simulated stream flow (cfs) and sediment concentrations (mg/l) for this research. The stream discharge changes at the outlet of the Brush Creek watershed because of the land use change scenarios will be shown in Chapter 5.

The annual flow changes are calculated by averaging the daily average discharges for each year from 1987 to 1994. Floods and droughts are important features of most running water ecosystems, therefore, the high flow and low flow condition changes after the implementation of the land use scenarios are checked. The statistical low flow estimation Q95 which is the flow equaled or exceeded 95% of the time, is widely used because of its relevance for multiple topics of water resources management (Laaha and Blöschl 2006). In this research, the average of the Q95 low flows using daily discharge of each year is calculated to express the general trend of low flows caused by the land use scenarios. Also, the high flows are calculated with the same methodology from the top 5% of high flows.

4.5.1.2 Sediment

Sediment concentration within the HSPF model is simulated via three steps. First, soil erosion is calculated using the Universal Soil Loss Equation (USLE) from the pervious land segment. At the same time, the washoff of the stored solid on the impervious surfaces is assessed. Finally, the soil and solid of the pervious and impervious land segments are joined at a stream and travel to the outlet location of the watershed when a storm occurs. The in-stream inorganic sediment generated from land segments are fractioned into sand, silt, and clay and can be routed by estimation of the deposition or scour of sediments through the channel system. The sediment yield at the watershed outlet is displayed using GenScn as an average daily concentration (mg/l). The daily sediment generation (kg/day) is calculated using the average daily sediment concentration (mg/l) and the average daily flow (cfs).

4.5.2. Water quality impact caused by land use changes

Sediment generation from the land use scenarios represents the direct impact of land use changes to the stream caused by urbanization and the intensity of that development. The impact of the land use changes can be quantified through the sediment differences between current and land use scenarios. To compare the sediment differences between scenarios, the sediment differences per acre of the land use change are calculated. Through the calculated sediment differences per acre of land use change, the equivalent sediment trading units between upstream and downstream locations are determined.

4.5.3. Determination of trading units

The determination of trading units between upstream and downstream locations is a very sensitive issue because the decision has an influence on the environment, individual property rights, and the economics of a community and could raise even environmental justice problems. Thus, a reasonable decision support system is necessary in order to treat all land owners in an equitable fashion. Watershed modeling is one of those technologies. The sediment generation differences of future development scenario will help to determine the water quality trading units and identify an equivalent area to restore to previous conditions or limit the development of for maintaining the overall water quality in the stream.

In addition, because of the great variability in sediment generation, as through rainfall intensity and the impacts of wet and dry years options should be considered in order to make the decision support effort more robust.

5 Results and analysis for trading units

5.1. Application of the remotely sensed land cover map to the calibrated HSPF model

More recently collected remotely sensed land cover information, with its greater resolution, represents recent increases in impervious surface that have taken place within the Brush Creek watershed (see Table 5-1). Thus, the application of this remotely sensed land cover map results in increased average flows and sediment concentrations.

Table 5-1. Land covers from GIRAS and QuickBird.

	Impervious (acres)	*Pervious (acres)*	*Total (acres)*
Meramec subbasin #1 with GIRAS Land use (1977~1980)	797	5637	6434
Brush Creek watershed with QuickBird land use (2003~2006)	1387	5076	6463

The impervious land within subbasin #1 of the Meramec River watershed was 797 acres, as reported in GIRAS, which is 12.4% of the total subbasin #1 area. QuickBird produces a calculated impervious land value of 1387 acres or 21.5% of the total Brush Creek watershed area. The 9.1% increase in impervious surface caused an 11.37 % increase in the average of annual discharges over eight years (Table 5-2). In addition, a 56.1% increase in average of annual suspended sediment concentrations calculated after the QuickBird land cover map was applied (Table 5-3). The annual average discharges and sediment concentrations for each year are plotted in Figure 5-1 and Figure 5-2. The monthly discharge and sediment impacts of the increased impervious surface are shown in Table 5-4 and 5-5 and plotted in Figure 5-3 and 5-4).

Table 5-2. Average annual discharge and percent differences between the GIRAS land use and the QuickBird land use.

Year	*Meramec subbasin #1 with GIRAS land use (cfs)*	*Brush Creek with QuickBird land use (cfs)*	*Difference (%)*
1987	8.63	10.10	17.12
1988	10.45	11.44	9.44
1989	8.52	9.18	7.73
1990	10.06	11.74	16.75
1991	8.55	9.56	11.79
1992	8.10	9.26	14.39
1993	20.57	21.86	6.26
1994	11.16	12.00	7.48
Average	10.76	11.89	11.37

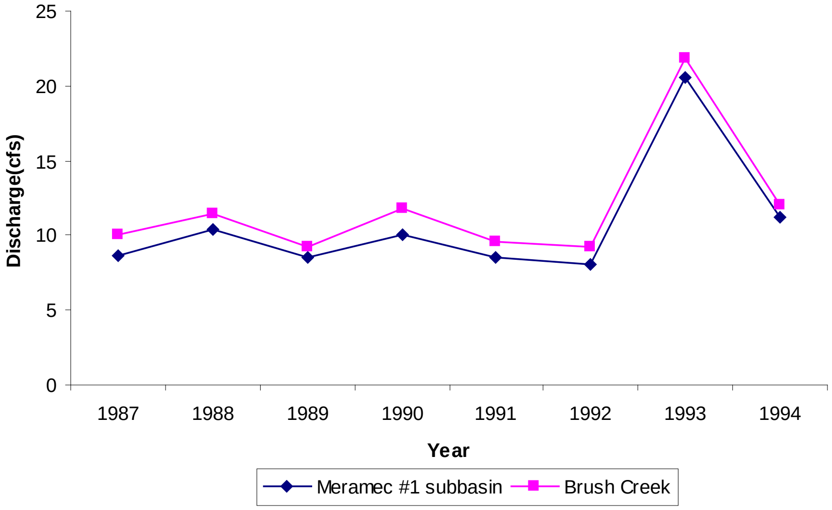


Figure 5-1. Annual average discharge at the Brush Creek watershed outlet comparing Meramec #1 subbasin with GIRAS land use and the Brush Creek watershed with QuickBird land cover.

Table 5-3. Average annual suspended sediment concentrations and percent differences between the GIRAS land use and the QuickBird land use.

Year	*Meramec subbasin #1 with GIRAS land use (mg/l)*	*Brush Creek with QuickBird land use (mg/l)*	*Difference (%)*
1987	4.93	8.11	64.64
1988	4.49	7.44	65.66
1989	3.03	5.60	84.70
1990	6.73	8.40	24.85
1991	3.62	6.69	84.59
1992	5.38	7.36	36.80
1993	7.33	11.06	50.92
1994	5.94	8.11	36.49
Average	5.18	7.85	56.08

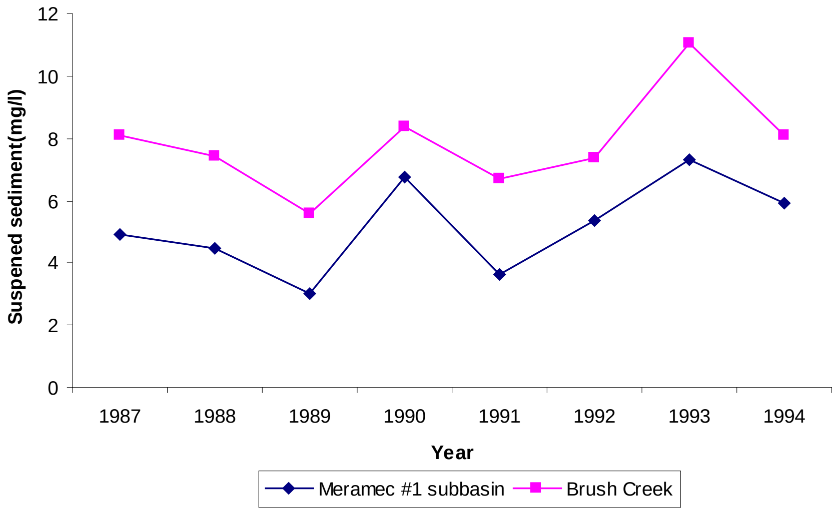


Figure 5-2. Annual average suspended sediment concentrations at the Brush Creek watershed outlet comparing Meramec #1 subbasin with GIRAS land use and the Brush Creek watershed with QuickBird land use.

Table 5-4. Monthly average of discharges at the Brush Creek watershed outlet comparing the different land cover impacts.

Month	*Meramec subbasin #1 with GIRAS land use (cfs)*	*Brush Creek with QuickBird land use (cfs)*	*Difference (%)*
1	13.78	14.87	7.98
2	13.51	14.62	8.16
3	10.04	12.08	20.36
4	10.42	12.42	19.17
5	10.11	12.18	20.45
6	9.25	11.66	26.11
7	9.36	11.92	27.38
8	9.59	12.09	26.05
9	10.44	12.68	21.52
10	5.84	11.53	97.60
11	15.87	16.76	5.61
12	17.79	17.72	-0.40
Average	11.33	13.38	23.33

Table 5-5. Monthly averages of suspended sediment concentration at the Brush Creek watershed outlet comparing the different land cover impacts.

Month	*Meramec subbasin #1 with GIRAS land use (mg/l)*	*Brush Creek with QuickBird land use (mg/l)*	*Difference (%)*
1	5.65	8.28	46.51
2	5.73	8.38	46.08
3	5.18	7.87	51.90
4	5.78	8.36	44.51
5	5.63	8.29	47.04
6	5.14	7.92	54.02
7	5.43	8.33	53.41
8	5.51	8.74	58.64
9	5.56	8.49	52.76
10	5.25	8.31	58.28
11	7.75	10.40	34.12
12	7.48	9.77	30.70
Average	5.84	8.59	48.17

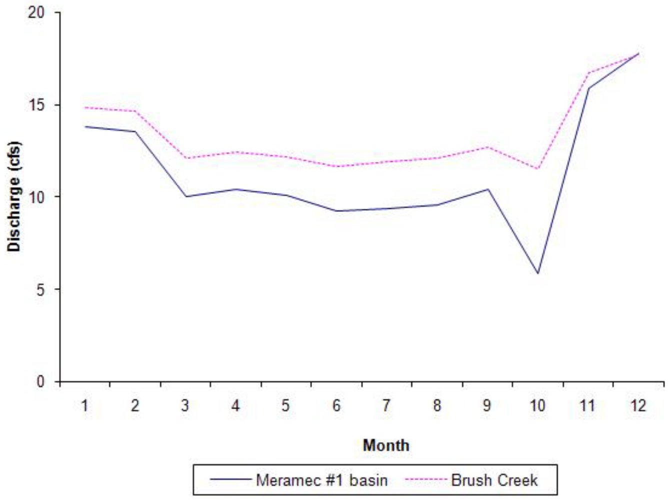


Figure 5-3. Comparison of monthly average of discharges between Meramec #1 subbasin with GIRAS land use and the Brush Creek watershed with QuickBird land cover from 1987 to 1994.

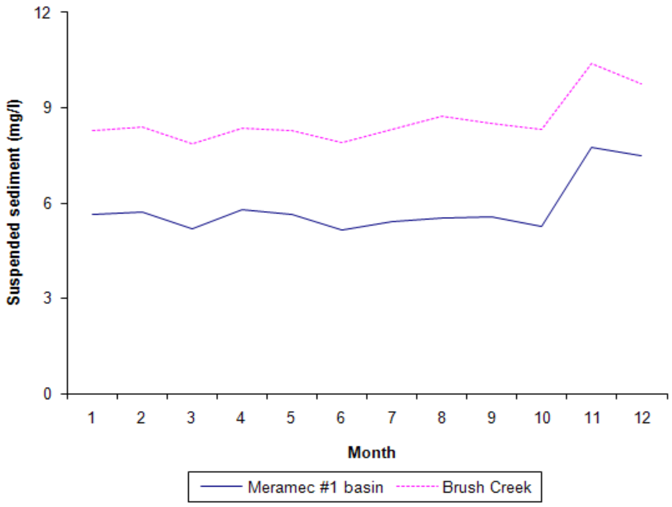


Figure 5-4. Comparisons of monthly average of suspended sediment concentrations between Meramec #1 subbasin with GIRAS land use and the Brush Creek watershed with QuickBird land cover from 1987 to 1994.

According to Band (2000), a 20 percent increase in impervious cover between non-urbanized and urbanized is a threshold for a watershed and any further increase in urbanization causes a dramatic increase in the runoff at any percent soil saturation. The 21.5% impervious surface in the Brush Creek watershed explains the increase in both discharges and sediment concentrations from the HSPF modeling result using the GIRAS land use. This methodology assumes that the current HSPF model run with the QuickBird land use represents the current conditions of land cover/land use in the Brush Creek watershed.

5.2. Water quality and quantity simulation results of the current conditions

The discharges and sediment concentrations from the current scenarios are discussed in section 5.2 and compared with the same information from different land use scenarios in section 5.3 in order to determine the trading units between upstream and downstream locations.

5.2.1. Stream flow with the current land use

The stream flows associated with the current land use and recorded precipitation were calculated with the HSPF model and the results are statistically quantified as to low flow and high flow conditions, which are most critical to the environment. Annual average stream flows, Q95 low flows, and Q5 high flows at the outlet of the Brush Creek watershed are simulated with current land use and shown in Table 5-6 from 1987 to 1994. Q95 is a widely used term in hydrology to represent the low flow conditions which can be calculated as the discharge that is exceeded on 95% of all days of the measurement period. Likewise, the Q5 high flow condition represents the top 5% of total peak discharges in the stream.

Table 5-6. Annual average of stream flows, low flows, and high flows at the outlet of the Brush Creek watershed.

Year	*Stream flow (cfs)*	*Q95 Low flow (cfs)*	*Q5 High flow (cfs)*
1987	10.1	1.04	79.66
1988	11.5	0.46	79.19
1989	9.2	0.35	69.26
1990	11.7	0.22	91.03
1991	9.6	0.80	55.86
1992	9.2	0.92	72.12
1993	21.9	6.40	112.72
1994	12	0.72	99.99
Average	11.9	1.36	82.48

5.2.2. Sediment generation with the current land use

The yearly sediment generation is the summation of all the sediment generation from the entire watershed due to precipitation. The HSPF model was run with the current land use Table 5-7 shows the yearly differences in sediment generations from 1987 to 1994 along with the annual precipitation. The sediment and precipitation are plotted in Figure 5-5.

Table 5-7. Total sediment generation (kg/ac·yr) per year at the Brush Creek watershed outlet.

Year	*Sediment(kg/ac·yr)*	*precipitation (in/yr)*
1987	85.28	38.38
1988	84.49	33.93
1989	98.30	28.60
1990	144.08	45.09
1991	64.04	33.48
1992	76.17	33.49
1993	227.72	54.76
1994	120.91	34.70
Average	112.62	37.80

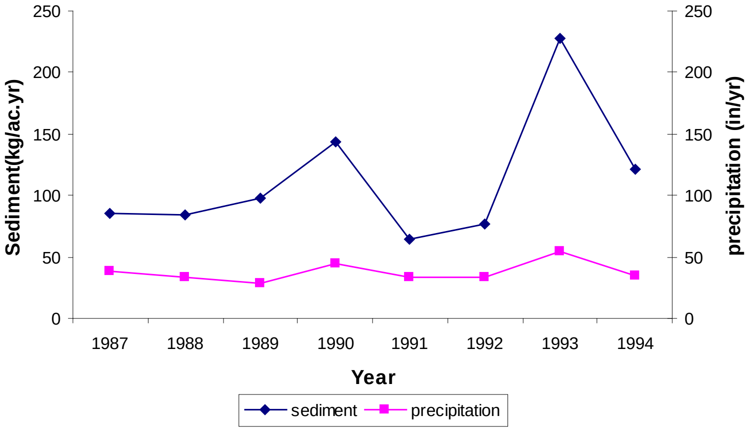


Figure 5-5. Annual total sediment generation with precipitation.

5.3. Water quantity and quality simulation results from the various land use scenarios

There are 20 scenarios representing various land use changes. Each scenario has the same input parameters as the current scenario except for the land use. The classifications of QuickBird land cover/land use are impervious, agricultural, water, forest land, and range land. A new classification named ‘Development’ was generated manually and associated with agricultural, forest land and range land being built upon to represent the future development scenarios. The ‘Development’ land uses are assigned 25%, 50%, or 75% impervious surface when each HSPF scenario is generated.

Table 5-8. Land use change scenarios.

Locations Impervious Scenarios	*Upstream land changes*			*Downstream land changes*		
	25%	*50%*	*75%*	*25%*	*50%*	*75%*
Agricultural to development area	A25U	A50U	A75U	A25D	A50D	A75D
Forest land to development area	F25U	F50U	F75U	F25D	F50D	F75D
Range land to development area	R25U	R50U,	R75U	R25D	R50D	R75D
Range land to Agricultural	ARU			ARD		

All of the 20 scenarios are shown in Table 5-8. The first letter of the scenario name indicates the current land use before land use change to development or restore to range land. The number in the middle of the scenario name is the percent imperviousness. The last letter shows the location of the land use changes whether in the Upstream or Downstream subbasin.

5.3.1. Stream flow with the land use scenarios

5.3.1.1 Urban development scenarios

The development scenarios consist of nine downstream development scenarios and nine upstream development scenarios. The downstream basin of the Brush Creek watershed is co-located with the city of Pacific and may be expected to be developed and considered as a possible receiving subbasin of trading credits. The nine downstream scenarios classifications which are manually modified from agricultural, forest land, and range land with 25, 50, and 75 percent of impervious surfaces. The upstream subbasin of the watershed is a possible donor subbasin and has the same development scenarios with the downstream subbasin. The upstream development scenario results from HSPF show the impact on water quantity and quality at the outlet of the downstream of the Brush Creek watershed from upstream development including the impact o any in-stream erosion or deposition.

5.3.1.1.1 Downstream development scenarios

The increase in impervious surface as a result of the development scenarios causes a corresponding increase in the discharges at the watershed outlet which is critical to the ecology of the stream. The water quantity impacts to the stream can be quantified through the differences of the average of low flows and high flows of the simulated discharges with the downstream development scenarios.

Figures 5-6, 5-7, and 5-8 plot eight years of daily flow data versus with the percent of time that the indicated discharge was equaled or exceeded. The 2923 days of average daily flow are sorted and plotted with the percent exceedance using the XY scatter chart in Excel in order to illustrate the dry weather and wet weather extremes.

Figure 5-6 contains the results for the current condition and agricultural development scenarios with 25, 50, and 75 % impervious surfaces. Figure 5-7 contains the same information for forest land development scenarios, while Figure 5-8 contains the information for range land development scenarios. The current scenario is the lowest discharge in comparison with the development scenarios except the section of the percent of time lower than 85 % in flow exceedance graphs. In figures, the percent of time in section between 85% to 100% is not easy to differentiate the each scenarios result but the over 85 % of the percent of time which is representing low flow discharge condition shows the current condition has the highest discharge than development scenarios. The development scenarios from agricultural, forest land, and range land to development result in higher discharges than current condition and the larger the percentages of impervious surface the wider the differences in the discharges from the current conditions. In these figures, It is difficult to compare the each land use impact between agricultural, forest land, and range land because the acres of newly generated development areas from those original land use classifications are not the same.

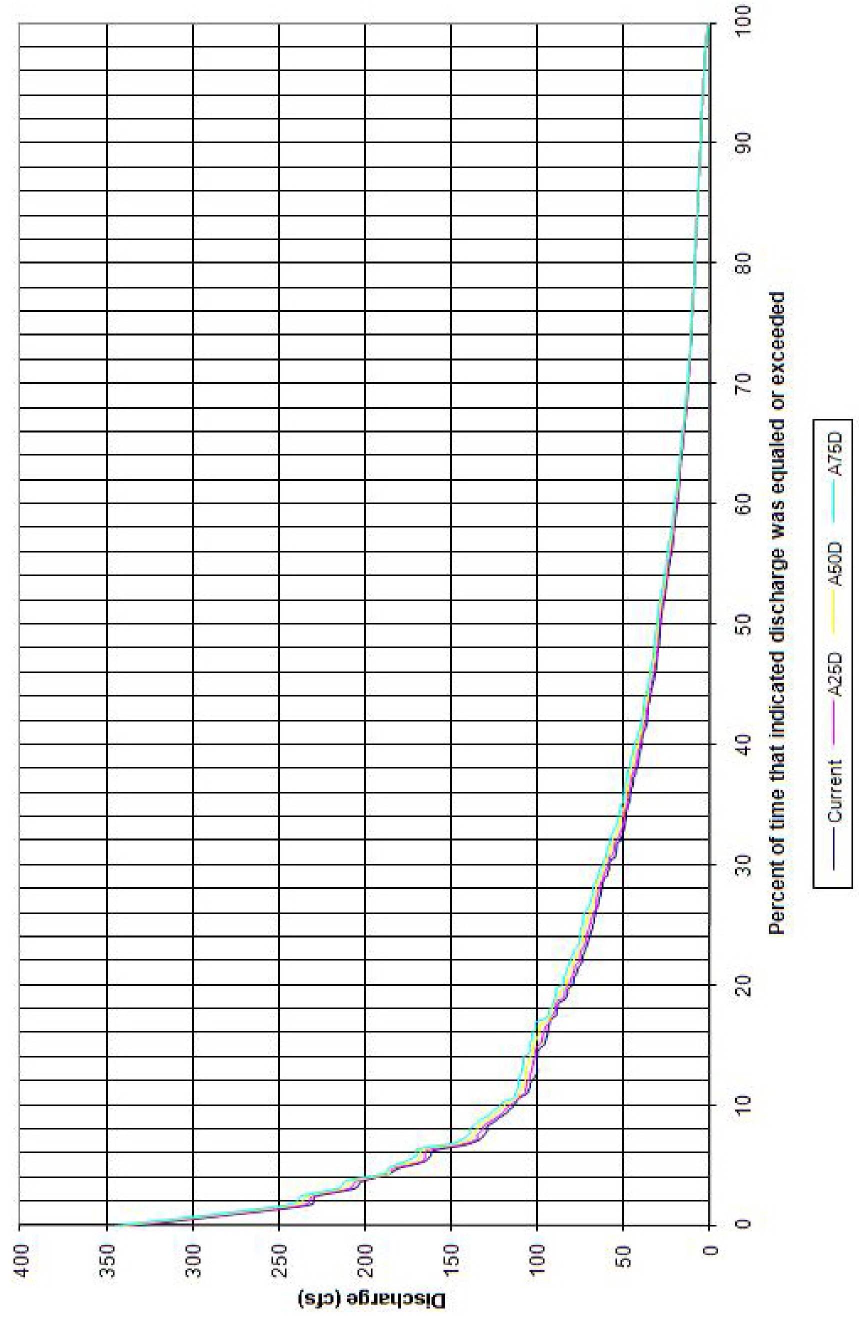


Figure 5-6. Flow exceedance curves for scenarios A25D, A50D, and A75D.

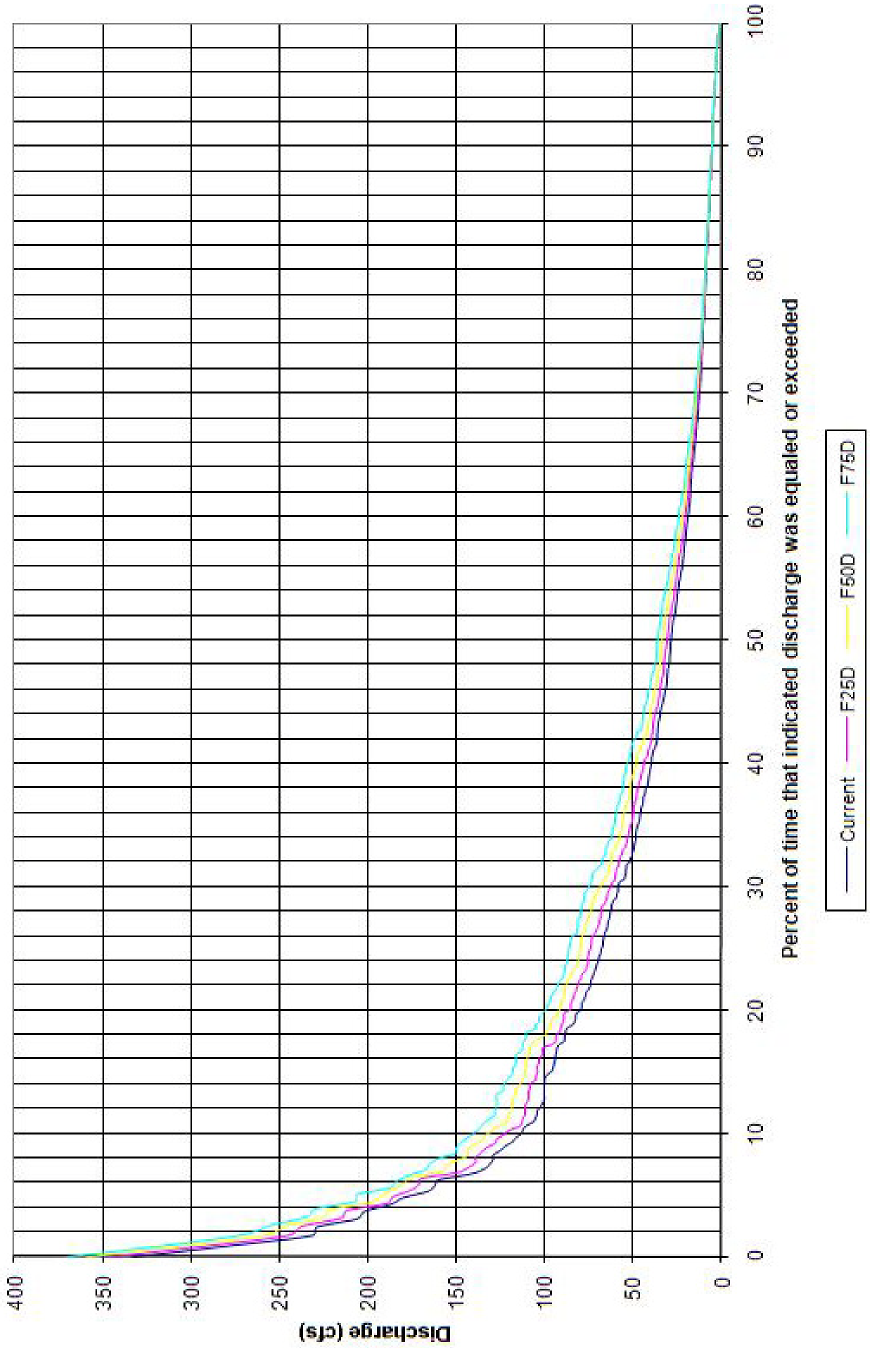


Figure 5-7. Flow exceedance curves for scenarios F25D, F50D, and F75D.

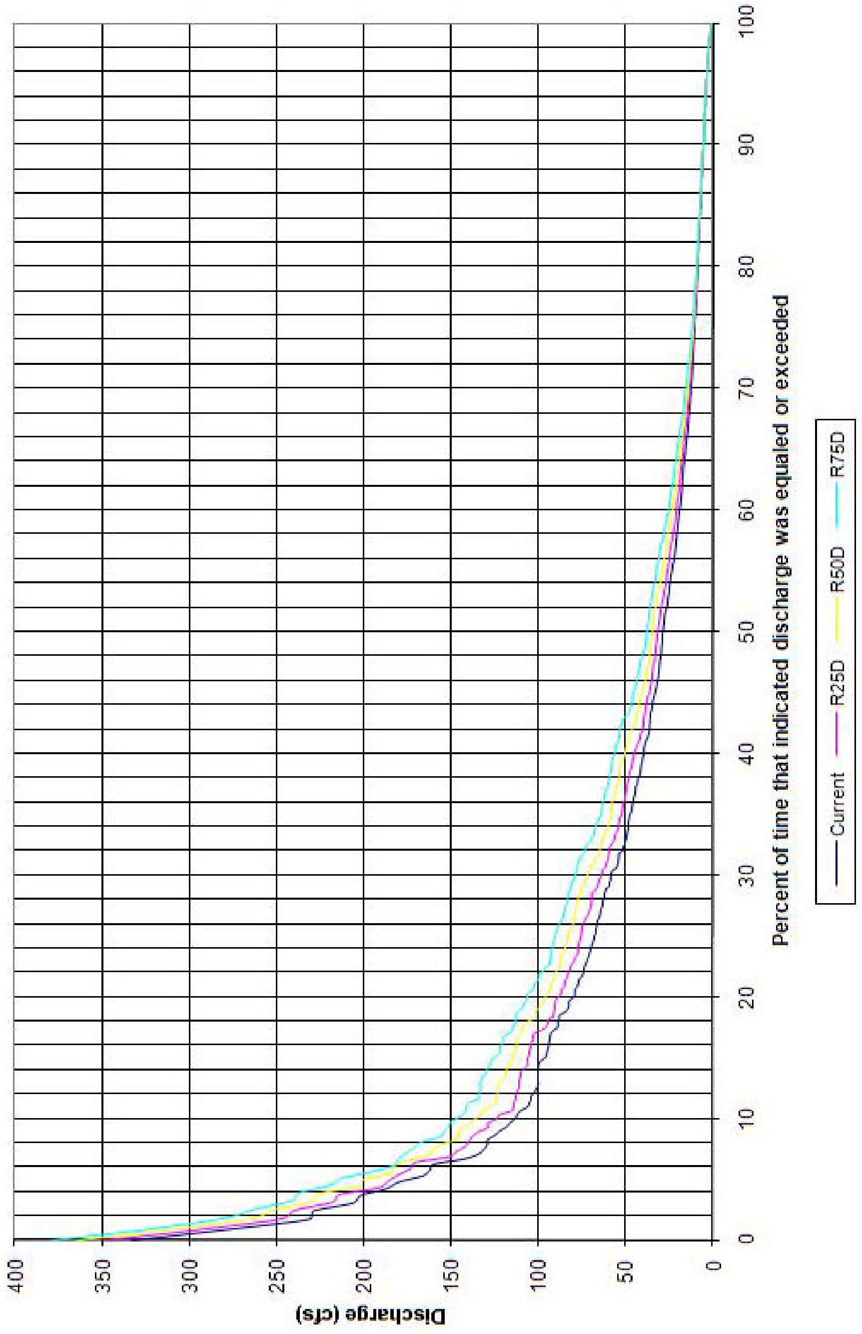


Figure 5-8. Flow exceedance curves for scenarios R25D, R50D, and R75D.

Table 5-9 shows the annual average stream flow with the current scenario and the nine different downstream development scenarios to represent average flow changes after application of land use scenarios.

Table 5-9. Annual average of the stream flows (cfs) with the current and the downstream development scenarios.

	CUR	*A25D*	*A50D*	*A75D*	*F25D*	*F50D*	*F75D*	*R25D*	*R50D*	*R75D*
1987	10.10	10.20	10.32	10.45	10.45	10.79	11.14	10.54	10.97	11.40
1988	11.44	11.50	11.59	11.68	11.69	11.93	12.17	11.74	12.04	12.35
1989	9.18	9.23	9.30	9.36	9.37	9.54	9.73	9.41	9.64	9.87
1990	11.74	11.85	11.99	12.14	12.15	12.55	12.95	12.25	12.75	13.26
1991	9.56	9.63	9.72	9.81	9.81	10.05	10.30	9.87	10.17	10.48
1992	9.26	9.34	9.42	9.52	9.53	9.78	10.05	9.59	9.92	10.26
1993	21.86	21.95	22.06	22.17	22.18	22.49	22.81	22.26	22.65	23.04
1994	12.00	12.06	12.13	12.21	12.22	12.43	12.64	12.27	12.53	12.80
Average	11.89	11.97	12.07	12.17	12.17	12.44	12.72	12.24	12.59	12.93

Table 5-10 is average annual of high flows of the current and downstream development scenarios. The high flows were calculated as the average highest 5% high flow each year in order to compare the impacts between current and development scenarios when measured precipitation occur.

Table 5-10. Annual average of the high flows, Q5 (cfs) with the current and the downstream development scenarios.

	CUR	*A25D*	*A50D*	*A75D*	*F25D*	*F50D*	*F75D*	*R25D*	*R50D*	*R75D*
1987	79.7	81.4	83.4	85.6	85.7	91.6	97.9	87.1	94.8	102.6
1988	79.2	78.4	80.3	82.1	82.2	87.4	92.4	83.4	89.8	96.3
1989	69.3	70.3	71.7	73.1	73.2	77.1	81.2	74.2	79.1	84.3
1990	91.0	92.4	94.2	96.0	96.2	101.1	106.4	97.4	103.8	110.5
1991	55.9	57.1	58.6	60.2	60.3	64.6	69.1	61.4	66.9	72.5
1992	72.1	73.3	74.9	76.4	76.5	80.9	85.8	77.6	83.5	89.5
1993	112.7	114.2	115.8	117.8	117.9	123.2	128.6	119.2	125.9	132.7
1994	100.0	100.8	101.8	102.9	103.1	106.1	109.4	103.8	107.7	111.7
Average	82.5	83.5	85.1	86.7	86.9	91.5	96.4	88.0	93.9	100.0

The low flow condition of the stream which is important to stream ecology was calculated from the daily discharges with each scenario averaging the lowest 5% of the flows during each year and the results are shown in Table 5-11. The low flow averages from the development scenarios are lower than current scenario's low flows. The reductions of low flow conditions are inversely proportional to the percent of imperviousness of development scenarios because more of the precipitation is seen as surface runoff than as surface generated baseline.

Table 5-11. Annual average of the low flows, Q95 (cfs) with the current and the downstream development scenarios.

	CUR	*A25D*	*A50D*	*A75D*	*F25D*	*F50D*	*F75D*	*R25D*	*R50D*	*R75D*
1987	1.04	1.04	1.03	1.04	1.04	1.04	0.95	1.04	0.96	0.94
1988	0.46	0.46	0.45	0.45	0.45	0.44	0.45	0.45	0.44	0.38
1989	0.35	0.35	0.35	0.34	0.34	0.34	0.34	0.34	0.34	0.29
1990	0.22	0.22	0.21	0.20	0.20	0.20	0.19	0.20	0.20	0.18
1991	0.80	0.79	0.79	0.79	0.79	0.73	0.72	0.78	0.73	0.71
1992	0.92	0.92	0.90	0.89	0.89	0.86	0.82	0.90	0.87	0.82
1993	6.40	6.32	6.29	6.23	6.23	6.06	5.93	6.21	5.95	5.78
1994	0.72	0.72	0.72	0.71	0.71	0.70	0.64	0.71	0.65	0.63
Average	1.36	1.35	1.34	1.33	1.33	1.30	1.26	1.33	1.27	1.21

The percent differences of the annual average flow, low flow, and high flow conditions between the current scenario and development scenarios are shown in Figure 5-9 and Table 5-12. The results can be explained as the fact that there is reduced infiltration caused by the increase in impervious surface, which leads to a decline in the base flow of the streams (Brun and Band 2000; Cho et al. 2009) .

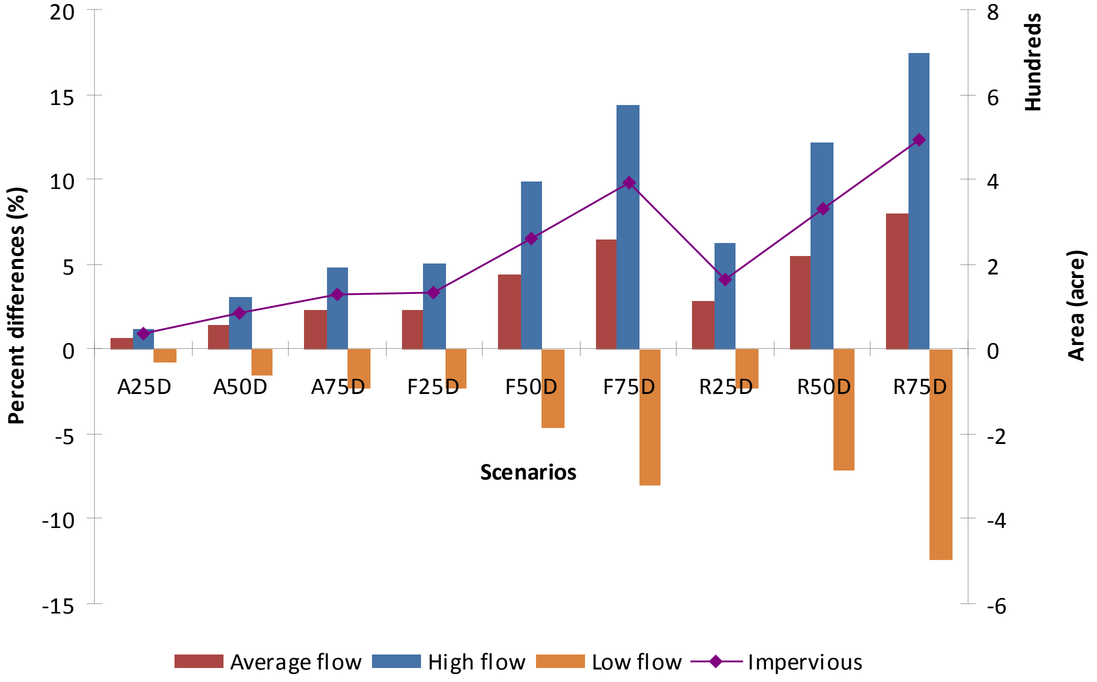


Figure 5-9. Percent differences of average, high, and low flows between current conditions and the development scenarios with the changes in impervious area between current and development scenarios.

Table 5-12. Percent differences between the annual average flow, high flow (Q5), and low flow (Q95), between the current and development scenarios.

Averages of	*A25D*	*A50D*	*A75D*	*F25D*	*F50D*	*F75D*	*R25D*	*R50D*	*R75D*
Flow	0.67	1.49	2.30	2.30	4.42	6.53	2.86	5.56	8.04
High flow (Q5)	1.21	3.06	4.91	5.05	9.86	14.40	6.26	12.19	17.53
Low flow (Q95)	-0.74	-1.49	-2.26	-2.26	-4.62	-7.94	-2.26	-7.09	-12.40

5.3.1.1.2 Upstream development scenarios

The upstream development scenarios are analyzed with the same methods as the downstream development scenarios. The reason to investigate the upstream development scenarios is to demonstrate the impacts of upstream development on the downstream outlet.

Tables 5-13, 5-14, and 5-15 display the average annual streamflow, high flow, and low flow with the current conditions and the development scenarios. The flows from the upstream development scenarios have the same trends as the downstream development scenarios except that the differences between current and development scenarios are less than those of the downstream development scenarios. The impacts of the upstream development were attenuated by the phenomenon of stream routing when it flows down to the downstream outlet locations.

Table 5-13. Annual average of stream flows (cfs) with the current condition and the upstream development scenarios.

	CUR	*A25U*	*A50U*	*A75U*	*F25U*	*F50U*	*F75U*	*R25U*	*R50U*	*R75U*
1987	10.10	10.17	10.26	10.34	10.36	10.63	10.9	10.21	10.31	10.41
1988	11.44	11.49	11.54	11.61	11.62	11.81	12.0	11.52	11.58	11.65
1989	9.18	9.22	9.26	9.31	9.32	9.46	9.6	9.23	9.29	9.35
1990	11.74	11.82	11.92	12.02	12.05	12.34	12.7	11.86	11.98	12.10
1991	9.56	9.61	9.67	9.73	9.75	9.93	10.1	9.63	9.71	9.78
1992	9.26	9.31	9.38	9.44	9.46	9.66	9.9	9.34	9.42	9.50
1993	21.86	21.93	22.00	22.08	22.10	22.34	22.6	21.95	22.06	22.14
1994	12.00	12.04	12.09	12.14	12.16	12.32	12.5	12.06	12.13	12.19
Average	11.89	11.95	12.02	12.08	12.10	12.31	12.52	11.98	12.06	12.14

Table 5-14. Annual average of the high flows, Q5 (cfs) with the current and the upstream development scenarios.

	CUR	*A25U*	*A50U*	*A75U*	*F25U*	*F50U*	*F75U*	*R25U*	*R50U*	*R75U*
1987	79.7	80.8	82.1	83.3	83.7	87.8	92.2	81.3	82.9	84.5
1988	79.2	78.0	79.2	80.5	80.8	84.7	88.3	78.6	80.1	81.6
1989	69.3	70.0	70.9	71.9	72.2	75.1	78.1	72.4	71.6	72.7
1990	91.0	92.0	93.3	94.5	94.9	98.5	102.4	92.6	94.0	95.5
1991	55.9	56.7	57.7	58.8	59.0	62.2	65.3	57.1	58.4	59.7
1992	72.1	73.0	74.0	75.1	75.3	78.7	82.1	73.4	74.7	76.0
1993	112.7	113.9	115.2	116.5	116.9	120.9	125.3	114.4	116.1	117.6
1994	100.0	100.6	101.3	102.0	102.4	104.6	107.0	100.8	101.9	102.8
Average	82.5	83.1	84.2	85.3	85.7	89.1	92.6	83.9	85.0	86.3

Table 5-15. Annual average of the low flows, Q95 (cfs) with the current and the upstream development scenarios.

	CUR	*A25U*	*A50U*	*A75U*	*F25U*	*F50U*	*F75U*	*R25U*	*R50U*	*R75U*
1987	1.04	1.04	1.04	1.03	1.03	1.04	1.04	1.04	1.04	1.04
1988	0.46	0.46	0.46	0.45	0.45	0.45	0.45	0.46	0.45	0.45
1989	0.35	0.35	0.35	0.35	0.35	0.34	0.34	0.35	0.35	0.35
1990	0.22	0.22	0.22	0.22	0.22	0.20	0.20	0.22	0.22	0.22
1991	0.80	0.79	0.79	0.79	0.79	0.79	0.78	0.79	0.79	0.79
1992	0.92	0.92	0.91	0.90	0.90	0.90	0.88	0.92	0.91	0.89
1993	6.40	6.40	6.33	6.31	6.31	6.15	6.06	6.31	6.30	6.21
1994	0.72	0.72	0.72	0.72	0.72	0.71	0.71	0.72	0.72	0.72
Average	1.36	1.36	1.35	1.35	1.35	1.32	1.31	1.35	1.35	1.33

5.3.1.2 Agricultural restoration scenarios

Some mediation of the development impacts to the stream could be brought about by land use changes from developed areas or agricultural areas to range land or forest land. Practically, the restoration of agricultural areas to range land is a reasonable case to consider in water quality trading. Agricultural areas in the downstream portions of the watershed were restored to range land for the scenario ARD, while the restoration scenario at the upstream location is called ARU.

5.3.1.2.1 Downstream restoration scenarios

Table 5-16 shows the annual averages of stream flows with the current condition and downstream restoration scenarios. Unlike the development scenarios, the simulated hydrologic results of the restoration scenario are lower than for the current scenario, as would be expected.

Table 5-16. Annual averages of stream flows (cfs) of the current and the downstream agricultural areas restored to range land scenario (ARD).

Year	*CUR(cfs)*	*ARD(cfs)*
1987	10.10	10.05
1988	11.44	11.45
1989	9.18	9.16
1990	11.74	11.71
1991	9.56	9.56
1992	9.26	9.23
1993	21.86	21.84
1994	12.00	11.98
Average	11.89	11.87

The annual averages of the high flows with ARD are lower than the current scenario and the averages of the low flows are slightly higher than current scenario as shown in Table 5-17. While the development scenarios increased the impervious areas over the current scenario, the impervious area of the restoration scenarios decreased from the impervious area of the current scenario. The reduction of impervious surfaces causes the lower average stream flows, the lower average high flows and the higher average low flows. The increase of the average low flow of each year is too small to show the difference in Table 5-17 but the daily data indicate either the same or increased discharges within the low flow conditions. Because very little impervious area is associated with agriculture, the small impervious area reductions from the current scenario led to small differences in annual average flows between the current and restoration scenarios.

Table 5-17. Annual averages of high flows and low flows (cfs) of the downstream agricultural areas restored to range land scenario (ARD).

	High flows		*Low flows*	
	CUR (cfs)	*ARD (cfs)*	*CUR (cfs)*	*ARD (cfs)*
1987	79.66	79.29	1.04	1.04
1988	79.19	76.72	0.46	0.46
1989	69.26	68.94	0.35	0.35
1990	91.03	90.64	0.22	0.22
1991	55.86	55.53	0.80	0.80
1992	72.12	71.83	0.92	0.92
1993	112.72	112.38	6.40	6.41
1994	99.99	99.77	0.72	0.72
average	82.48	81.89	1.36	1.36

5.3.1.2.2 Upstream restoration scenarios

The manually modified land use reverting from agricultural area to range land at the upstream locations is applied to the HSPF model and called the upstream restoration scenario (ARU). Table 5-18 lists the annual average stream flows of the current and upstream restoration scenarios. The average stream flow for ARU is 11.88 cfs and falls in the middle of the average stream flows of the current and the downstream restoration scenario.

Table 5-18. Annual averages of stream flows (cfs) of the upstream agricultural areas restored to range land scenario (ARU).

Year	*CUR(cfs)*	*ARU(cfs)*
1987	10.10	10.06
1988	11.44	11.45
1989	9.18	9.17
1990	11.74	11.72
1991	9.56	9.56
1992	9.26	9.23
1993	21.86	21.85
1994	12.00	11.99
Average	11.89	11.88

The annual averages of high and low flows are shown in Table 5-19 and the value of average high flows of ARU falls between the average high flows of the current and ARD scenarios. The ARU low flows are too small to differentiate from current scenarios but ARU has slightly higher low flow conditions than the current scenario.

Table 5-19. Annual averages of high flows and low flows (cfs) of the upstream agricultural areas restored to range land scenario (ARU).

	High flows		*Low flows*	
	CUR(cfs)	*ARU(cfs)*	*CUR(cfs)*	*ARU(cfs)*
1987	79.66	79.46	1.04	1.04
1988	79.19	76.84	0.46	0.46
1989	69.26	69.12	0.35	0.35
1990	91.03	90.83	0.22	0.22
1991	55.86	55.68	0.80	0.80
1992	72.12	71.90	0.92	0.92
1993	112.72	112.64	6.40	6.41
1994	99.99	99.92	0.72	0.72
average	82.48	82.05	1.36	1.36

5.3.2. Sediment generation from various land use scenarios

The twenty scenarios of land use changes were developed with the same methods as the stream flow scenarios. The simulated sediment generation (kg/ac·day) was calculated from the average daily sediment concentration (mg/l) and the average daily stream flow (cfs). The calculated mass of sediment generation from each scenario is shown in the following tables. The trading unit for sediment generation between upstream and down stream subwatersheds will be quantified through the examination of land use scenarios.

5.3.2.1 Urban development scenarios

The impact analysis of sediment generation for development near the city of Pacific is one of the main objectives of this research. The watershed scenarios with downstream development simulate the anticipated nonpoint source sediment generations of future development in Pacific, which is near the outlet of the Brush Creek.

5.3.2.1.1 Downstream development scenarios

The annual summation of the daily sediment generation per acre is shown in Table 5-20. The sediment increases when each land use was developed, with the increase in impervious surface. Sediment generation comparisons between agricultural, forest, and range land were not performed because there are different acreages for agricultural, forest, and range land in the different subwatersheds.

Table 5-20. Annual sum of sediment generation per acre (kg/ac·yr) with the current and the downstream development scenarios.

	CUR	*A25D*	*A50D*	*A75D*	*F25D*	*F50D*	*F75D*	*R25D*	*R50D*	*R75D*
1987	85.3	87.3	89.9	92.6	92.7	100.0	107.8	94.6	104.3	114.5
1988	84.5	86.1	88.2	90.4	90.6	96.6	102.8	92.0	99.7	108.4
1989	98.3	99.2	100.6	102.0	102.7	107.3	110.7	103.9	109.1	113.7
1990	144.1	145.5	148.0	151.0	152.1	160.3	169.7	154.2	165.4	178.5
1991	64.0	65.9	68.2	70.6	70.6	77.9	85.0	72.5	81.7	90.5
1992	76.2	79.1	79.1	80.5	80.7	85.0	90.1	81.7	87.7	94.6
1993	227.7	229.8	232.4	235.8	236.2	245.4	255.1	238.4	250.4	262.9
1994	120.9	121.9	123.0	124.1	126.1	129.2	133.2	128.5	132.9	138.2
Average	112.6	114.4	116.2	118.4	119.0	125.2	131.8	120.7	128.9	137.7

5.3.2.1.2 Upstream development scenarios

An upstream subwatershed can be a potential donor of trading credits in water quality trading. The sediment generation from upstream development scenarios are greater than the sediment generation of the current scenario. The same is true with the downstream development scenarios where the increase in impervious surface leads to an increase of sediment generation. Beside the sediment generations at the upstream area, the in-stream process of erosion from the cannel is added to the outlet of the watershed in the upstream development scenarios. The annual summation of the daily sediment generation per acre is shown in Table 5-21.

Table 5-21. Annual sum of sediment generation per acre (kg/ac·yr) with the current and the upstream development scenarios.

	CUR	*A25U*	*A50U*	*A75U*	*F25U*	*F50U*	*F75U*	*R25U*	*R50U*	*R75U*
1987	85.3	87.3	89.7	92.1	92.7	100.5	108.4	88.3	91.2	94.2
1988	84.5	86.4	88.9	91.2	91.8	98.5	105.4	92.0	99.7	108.4
1989	98.3	99.1	100.0	101.1	104.0	106.4	109.2	101.8	101.6	102.7
1990	144.1	146.0	148.7	151.4	153.1	161.5	170.9	147.4	150.7	154.2
1991	64.0	66.0	68.2	70.5	71.1	77.6	84.0	66.8	69.7	72.4
1992	76.2	77.5	79.2	81.1	81.4	87.0	92.7	78.2	80.3	82.5
1993	227.7	229.7	232.0	234.6	236.2	243.9	252.5	231.9	234.1	236.9
1994	120.9	122.1	123.3	124.6	127.8	132.2	136.8	130.1	126.1	127.9
Average	112.6	114.3	116.3	118.3	119.8	126.0	132.5	117.1	119.2	122.4

5.3.2.2 Agricultural restoration scenarios

The restoration scenarios from agricultural to range land at the upstream and downstream locations were performed to quantify the sediment reductions at the outlet of the watershed (Table 5-22).

Table 5-22. Annual sum of sediment generations per acre (kg/ac·yr) of the upstream and downstream restoration scenarios at the watershed outlet.

	CUR (kg/yr·ac)	*ARU (kg/yr·ac)*	*ARD (kg/yr·ac)*
1987	85.28	84.89	69.08
1988	84.49	84.10	70.04
1989	98.30	97.48	86.95
1990	144.08	143.28	123.55
1991	64.04	63.73	51.56
1992	76.17	75.83	63.84
1993	227.72	227.36	202.79
1994	120.91	119.24	105.33
Average	112.62	111.99	96.64

The percent differences between the current and the ARU and ARD scenarios were 0.6% and 14.2%, respectively. ARD causes a large reduction in sediment generation because sediment generation from agricultural land is much more than that of range land. The sediment restoration of the ARU scenario does not have much impact on the outlet of the watershed because the in-stream sediment generation is large enough to conceal the sediment reductions.

5.4. Analysis

5.4.1. Sediment generation differences caused by land use scenarios

The land use scenarios can be divided as development and restoration scenarios. Development scenarios are associated with the conversion of land use from the agriculture, forest land, and range land to urban areas with differing percentages of impervious surface. The restoration scenario only includes agricultural areas to range land because the restoration from the urban development land to range land is a less realistic possibility.

All the data of the sediment generations with the land use scenarios for 8 years were collected and averaged based storm days. The storm day average was selected for trading units because there is no sediment generation without precipitation in the HSPF model.

The top 5 percent of sediment generation storm days were identified through the percent ranks methods in an Excel spreadsheet and averaged. The other percent averages (i.e., 10, 20, 30, 50, and 80) were calculated with the same methodology.

5.4.1.1 Urban development scenarios

The simulated sediment generation increased when land use development was applied to the HSPF model. The amount of sediment increase from the development scenario as compared to the current scenario was divided by the area that led to the increase in sediment and the values are shown in following tables. The values from each scenario will be used to compare the trading credits between upstream and downstream locations.

5.4.1.1.1 Downstream development scenarios

Table 5-23 provides the additional sediment generation after the land use changes at the downstream of the watershed. For instance, the 0.44 kg/acre for the storm day average in the A25D column means that development of 1 acre of downstream agricultural area to an urbanized area with 25% impervious surface causes 0.44 kg greater sediment generation than the current scenario without development for each storm day. The top 5%, 10%, 20%, 30%, 50%, and between 20 and 80 % average sediment generation in comparison with the storm day average were calculated through a sediment ranking from largest to smallest. The top 5% of sediment generation event over the 8 years of calculations can represent possible maximum sediment generation with each scenario. The other percentages of sediment generations (i.e., 10, 20, 30, 50, and 80) were calculated to help the determination of trading units.

Table 5-23. Average sediment differences from the current scenario per acre of change from agricultural, forest, or range land to development at the downstream of the watershed.

(kg/ acre of change)

Scenario	*A25D*	*A50D*	*A75D*	*F25D*	*F50D*	*F75D*	*R25D*	*R50D*	*R75D*
Average	0.44	1.03	1.65	0.64	1.27	1.94	0.65	1.31	2.02
Top 5%	4.46	10.80	17.87	7.43	14.57	22.11	7.67	15.22	23.41
Top 10%	3.24	7.73	12.59	5.01	9.92	15.13	5.15	10.30	15.89
Top 20%	1.97	4.67	7.55	2.95	5.86	8.95	3.02	6.06	9.37
Top 30%	1.41	3.33	5.37	2.09	4.14	6.31	2.13	4.27	6.59
Top 50%	0.87	2.05	3.30	1.28	2.54	3.87	1.31	2.62	4.04
Between 20% and 80%	0.07	0.16	0.25	0.09	0.17	0.26	0.09	0.17	0.25

5.4.1.1.2 Upstream development scenarios

The average of sediment generations from the upstream development scenarios was determined with the same methods as with the downstream development scenarios and will be used to find the equivalent areas for the trading credits to offset the sediment generation from downstream development scenarios.

Table 5-24 displays sediment generation associated with the upstream development scenario.

The Sediment generations are increased with the increases of the impervious surfaces. However, sediment of the top 5% of upstream range land development scenario (R25U) is higher than the R50U scenario. The top 5% of sediment generations are representing the sediment generations of extremely high precipitation cases. The intense and long period of precipitations causes the higher sediment generations on pervious surfaces which has unlimited soil matrix to be washed off because the solids of impervious surfaces are washed off at the early stages of storm and needs more time to build the solids on the impervious surfaces. The other land uses has the same trends at the same precipitation cases but the impacts are small to be seen in tables because the total acreages of land use changes are less than range land.

Table 5-24. Average sediment generation differences from current scenario per acre of change from agricultural, forest, or range land to development at the upstream of the watershed.

(kg/ acre of change)

Scenario	*A25U*	*A50U*	*A75U*	*F25U*	*F50U*	*F75U*	*R25U*	*R50U*	*R75U*
Average	0.68	1.51	2.36	0.96	1.80	2.68	1.31	1.82	2.65
Top 5%	5.03	11.10	17.57	8.77	15.00	22.13	15.99	15.52	21.82
Top 10%	4.27	9.46	14.88	6.53	11.78	17.46	10.10	12.04	17.33
Top 20%	2.96	6.56	10.27	4.27	7.86	11.68	6.04	8.03	11.64
Top 30%	2.18	4.82	7.55	3.10	5.75	8.56	4.28	5.85	8.51
Top 50%	1.36	3.01	4.71	1.92	3.58	5.34	2.63	3.64	5.30
Between 20% and 80%	0.15	0.33	0.52	0.19	0.38	0.59	0.18	0.37	0.56

5.4.1.2 Agricultural restoration scenarios

The restoration scenario is one of the means by which to generate sediment trading credits to sell because the reduced sediment generation from the restoration scenario at the outlet of the watershed can compensate for the increased sediment generation of development. Table 5-25 presents the decreases in sediment generation from the restoration scenario in terms of the various categories of the decreases.

Table 5-25. Average sediment generation differences from current scenario per acre of change from agricultural to range land in the upstream (ARU) and downstream (ARD) subbains of the watershed.

(kg/ acre of change)

Scenario	*ARU*	*ARD*
Average	-0.26	-4.61
Top 5%	-3.32	-45.36
Top 10%	-2.04	-31.78
Top 20%	-1.21	-20.13
Top 30%	-0.86	-14.62
Top 50%	-0.53	-9.18
Between 20% and 80%	-0.04	-1.00

5.4.2. Wet and dry year comparisons

Annual rainfall data for St. Louis, MO from the National Weather Service Weather Forecast Office is available for the 135 years from 1870 to 2005. The wettest year on record was 1993 and 1989 was the 17th driest year on record. Sediment generation comparisons between the driest (1989) and wettest (1993) years within the target 8 year period of analysis can be used to determine appropriate trading units. Table 5-26 indicates the rank of annual rainfall from driest to wettest of 135 records.

Table 5-26. Annual rainfall rank from driest to wettest for the 8 years of analysis in St. Louis, MO with yearly sediment generation.

Year	*Annual rainfall (inch/yr)*	*Rank*	*Simulated sediment generations(kg/ac·yr)*
1987	38.38	81	85.28
1988	33.93	43	84.49
1989	28.6	17	98.30
1990	45.09	118	144.08
1991	33.48	37	64.04
1992	33.49	38	76.17
1993	54.76	135	227.72
1994	34.7	50	120.91

The percent difference between the driest (1989) and wettest (1993) years of the target 8 year period is 47.77 for precipitation and 56.83 for sediment generation (Table 5-27).

Table 5-27. Percent difference in annual rainfall and simulated sediment generation between 1989 and 1993.

	Annual rainfall (inch/yr)	*Simulated sediment generations (kg/ac·yr)*
1989	28.60	98.30
1993	54.76	227.72
Percent difference	47.77	56.83

The percent difference between lowest sediment generation year (1987) and highest sediment generation year (1993) of the simulated 8 year period is 29.91 for precipitation and 62.55 for sediment generation (Table 5-28).

Table 5-28. Percent difference in annual rainfall and simulated sediment generation between 1987 and 1993.

	Annual rainfall (inch/yr)	*Simulated sediment generations (kg/ac·yr)*
1987	38.38	85.28
1993	54.76	227.72
Percent difference	29.91	62.55

Figure 5-10 shows the simulated sediment generation with the increasing order of precipitation graph. Generally the sediment generation has a proportional relationship with precipitation depth. The year 1989 was the driest year of the target period of analysis and has relatively higher sediment generation than 1987 that has a relatively lower rate of sediment generation. The summation of daily sediment generation on March 20th and May 28th of 1989 was 374 tons that comprise 58 % of the total yearly sediment generation of 635 ton/yr. The daily precipitations of those days are 2.02 and 1.95 inches respectively, and represent the first and second highest precipitation in 1989. Those two days result in the relatively higher sediment generation in the drier year of 1989. This result indicates there is another important factor in function of sediment generations in addition to total precipitation.

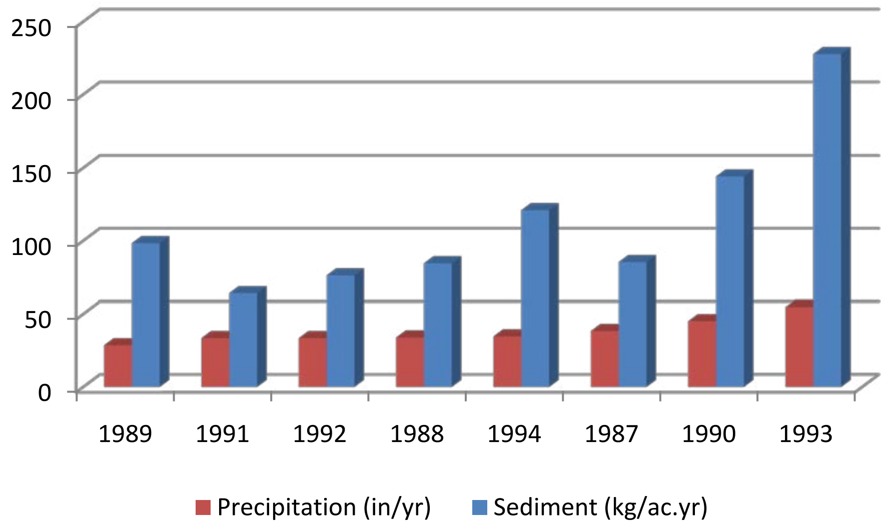


Figure 5-10. Simulated sediment generations compared with the increasing order of precipitations.

5.4.3. Rainfall intensity differences

Rainfall intensity is as important of a factor for the generation of sediment as is precipitation. There are several cases of huge differences in sediment generation caused by the rainfall intensity between similar total daily precipitations. One of the cases is shown in Figure 5-11.

The total precipitations of the storms on 6/6/1988 and 5/12/1990 were 1.26 and 1.47 inches, respectively. The only difference of those storms is the hourly rainfall intensity which is shown in Figure 5-11 (a). The 6/6/1988 storm lasted only 5 hours and the highest precipitation intensity was 1.14 inch/hr. However, the 5/12/1990 storm lasted 26 hours with 10 hours of the lull in the rainfall and the highest precipitation intensity was 0.27inch/hr. The intense storm 6/6/1988 generated 51.2 tons of sediments at the outlet of watershed while the mild pattern storm 5/12/1990 generated 21.6 tons of sediment. The intense storm generated 30 tons more than the mild pattern storm even though the total depth of precipitation for the mild pattern storm was 14% higher than the precipitation of intense storm (Figure 5-11 (b)).

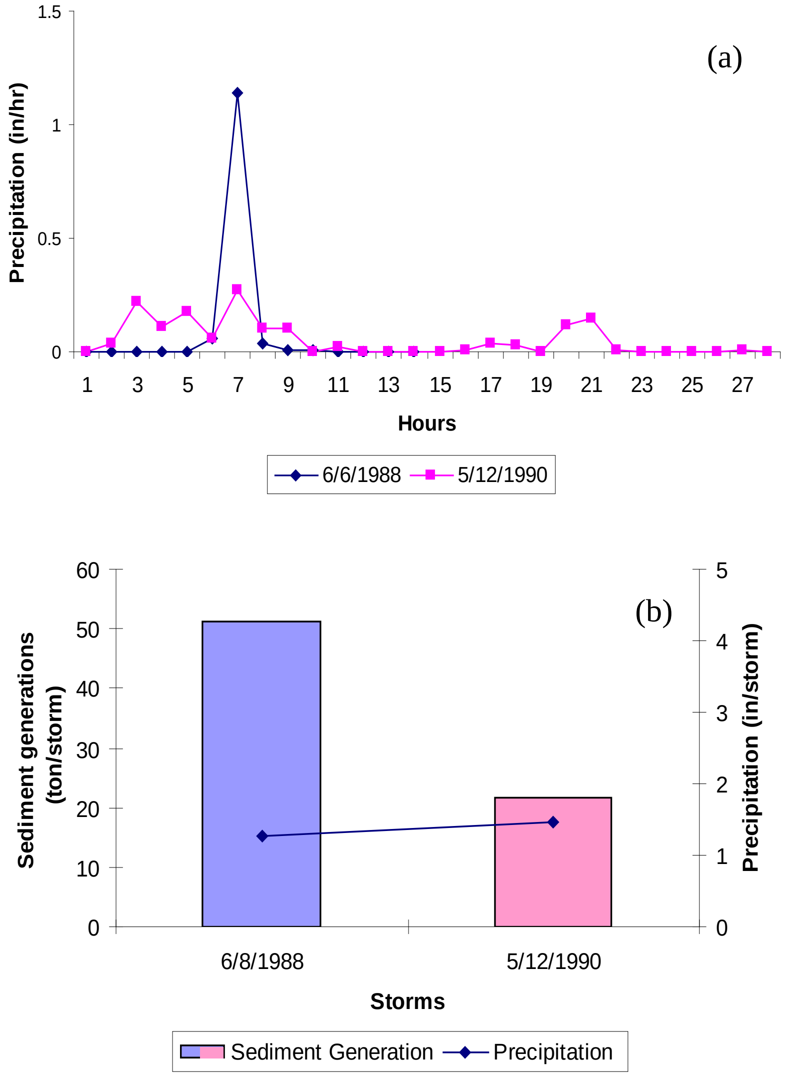


Figure 5-11. Precipitation patterns (a) and sediment generation (b) comparisons between two similar precipitation events.

5.5. Determination of trading units

5.5.1. Limited upstream developments for downstream intense developments

Most of local streams that are not impaired do not have water quality regulations. The basic assumption of these local watersheds is that all the upstream and downstream land owners have the right to develop their land with regular percent impervious surfaces (i.e. 25% impervious). More and more communities are putting limits on that right to develop, as is a cap of no more than 25% impervious surfaces in new development. However, in many instances, a special effort needed within the community to maintain, or improve, water quality and to do so while still allowing for smart growth. The water quality trading program can be an effective and economic solution for a watershed expecting future urban development to maintain water quality.

The average sediment generation of all twenty scenarios (Table 5-23 through 5-25) indicates that sediment at the downstream location may increase or decrease from the land use scenarios compared with the baseline (current condition) depending upon the scenario. The unit of sediment generation is represented by kilogram of sediment per acre of change, per storm day. The following tables indicate the tradable land use when the specific location development plan occurs. Table 5-29 shows the equivalent acreage of a land use scenario with the same sediment generation as that of one acre of downstream agricultural area developed with 50% impervious surface. For example, a downstream developer may be able to develop to 25% impervious surface under an existing storm water ordinance. However, development to 50% impervious surface might not ordinarily be allowed, and additional water quality protection measures may need to be taken. He or she might need to buy the development rights for 0.65 acres (sediment of A50D minus Sediment of A25D) of upstream agricultural area, 0.46 acres of forest, or 0.34 acres of range land in order to match the pollutant generation of the more intense development.

Table 5-29. The equivalent acreage of land for the excess sediment generation resulting from 50% imp. rather than 25% imp. for one acre of downstream agricultural development.

(Acres)

Scenario	*A25U*	*F25U*	*R25U*
Average	0.87	0.61	0.45
Top 5%	1.26	0.72	0.40
Top 10%	1.05	0.69	0.44
Top 20%	0.91	0.63	0.45
Top 30%	0.88	0.62	0.45
Top 50%	0.87	0.61	0.45
Between 20% and 80%	0.60	0.47	0.50

Table 5-30. The equivalent acreage of land for the excess sediment generation resulting from 50% imp. rather than 25% imp. for one acre of downstream forest development.

(Acres)

Scenario	*A25U*	*F25U*	*R25U*
Average	0.93	0.66	0.48
Top 5%	1.42	0.81	0.45
Top 10%	1.15	0.75	0.49
Top 20%	0.98	0.68	0.48
Top 30%	0.94	0.66	0.48
Top 50%	0.93	0.66	0.48
Between 20% and 80%	0.53	0.42	0.44

Table 5-31. The equivalent acreage of land for the excess sediment generation resulting from 50% imp. rather than 25% imp. for one acre of downstream range land development.

(Acres)

Scenario	*A25U*	*F25U*	*R25U*
Average	0.97	0.69	0.50
Top 5%	1.50	0.86	0.47
Top 10%	1.21	0.79	0.51
Top 20%	1.03	0.71	0.50
Top 30%	0.98	0.69	0.50
Top 50%	0.96	0.68	0.50
Between 20% and 80%	0.53	0.42	0.44

The trading program manager can refer those recommended equivalent acreages of land use for the downstream intense development cases. The downstream developer can choose the right land use for trading with considerations of the equivalent acreages of land use and the cost of development rights of each land use.

The following tables indicate the 75% impervious surface development cases at the downstream location rather than regular development (25% impervious surfaces).

Table 5-32. The equivalent acreage of land for the excess sediment generation resulting from 75% imp. rather than 25% imp. for one acre of downstream agricultural development.

(Acres)

Scenario	*A25U*	*F25U*	*R25U*
Average	1.78	1.26	0.92
Top 5%	2.67	1.53	0.84
Top 10%	2.19	1.43	0.93
Top 20%	1.89	1.31	0.92
Top 30%	1.82	1.28	0.93
Top 50%	1.79	1.27	0.92
Between 20% and 80%	1.20	0.95	1.00

Table 5-33. The equivalent acreage of land for the excess sediment generation resulting from 75% imp. rather than 25% imp. for one acre of downstream forest development.

(Acres)

Scenario	*A25U*	*F25U*	*R25U*
Average	1.91	1.35	0.99
Top 5%	2.92	1.67	0.92
Top 10%	2.37	1.55	1.00
Top 20%	2.03	1.41	0.99
Top 30%	1.94	1.36	0.99
Top 50%	1.90	1.35	0.98
Between 20% and 80%	1.13	0.89	0.94

Table 5-34. The equivalent acreage of land for the excess sediment generation resulting from 50% imp. rather than 25% imp. for one acre of downstream range land development.

(Acres)

Scenario	*A25U*	*F25U*	*R25U*
Average	2.01	1.43	1.05
Top 5%	3.13	1.79	0.98
Top 10%	2.52	1.64	1.06
Top 20%	2.15	1.49	1.05
Top 30%	2.05	1.44	1.04
Top 50%	2.01	1.42	1.04
Between 20% and 80%	1.07	0.84	0.89

5.5.2. Restoration method to maintain the water quality

The restoration method is a more aggressive trading program than the limited upstream development method intended to prevent stream degradation. Instead of simply limiting upstream development, the restoration scenario would return agricultural land to range land. This change would cause a decrease in the sediment generation to below that of the baseline. The decreased sediment generation upstream could compensate for the sediment generation of downstream development plan in order to maintain the water quality. The following tables show the equivalent acreages of land restoration required in order to maintain the water quality after implementation of the downstream development plan. The downstream restoration (ARD) scenario has large benefit in that the restoration of one acre of downstream agricultural usage can be tradable with 10 acres of downstream development at 25% impervious surface because the agricultural usage generates more sediment than urban development (Metropolitan Washington Council of Governments 1978) and the in-stream sediment processes are not added to the ARD scenario. However, there is more pressure for agricultural areas within downstream location to be developed rather than restored to range land because of the location of the city of Pacific. The upstream agricultural restoration scenario (ARU) requires an average of 1.69 acres of agricultural land being restored acre of downstream development at 25% impervious surface. This trading methodology could be implemented when a stream is impaired and a TMDL has been developed in order to actually cause improvement in water quality.

Table 5-35. The equivalent acreages of upstream agricultural land required to compensate for the sediment generation from one acre of downstream agricultural land to 25% impervious surface development (A25D).

(Acres)

Scenario	*ARU*	*ARD*
Average	1.69	0.10
Top 5%	1.34	0.10
Top 10%	1.59	0.10
Top 20%	1.63	0.10
Top 30%	1.64	0.10
Top 50%	1.64	0.09
Between 20% and 80%	1.75	0.07

Table 5-36. The equivalent acreages of upstream agricultural land required to compensate for the sediment generation from one acre of downstream forest to 25% impervious surface development (F25D).

(Acres)

Scenario	*ARU*	*ARD*
Average	2.46	0.14
Top 5%	2.24	0.16
Top 10%	2.46	0.16
Top 20%	2.44	0.15
Top 30%	2.43	0.14
Top 50%	2.42	0.14
Between 20% and 80%	2.25	0.09

Table 5-37. The equivalent acreages of upstream agricultural land required to compensate for the sediment generation from one acre of downstream range land to 25% impervious surface development (R25D).

(Acres)

Scenario	*ARU*	*ARD*
Average	2.50	0.14
Top 5%	2.31	0.17
Top 10%	2.52	0.16
Top 20%	2.50	0.15
Top 30%	2.48	0.15
Top 50%	2.47	0.14
Between 20% and 80%	2.25	0.09

The equivalent acreages of restorations with intense downstream developments (50% and 75 % impervious surfaces development) are available in Appendices B and C.

6 Conclusions and recommendations

6.1. Conclusion

EPA’s Water Quality Trading Policy published in 2003 is an innovative approach for achieving water quality standards with flexibility and economic efficiency. The policy allows for the trading of point and nonpoint source pollutant discharges between different locations within a watershed, as long as water quality standards are not violated along the stream (USEPA 2007). Many pilot programs and projects have generated useful information on how to implement water quality trading, but the number of actual trades is relatively small. One of the hindrances of the trading program is the uncertainty of the pollutant reactions in the stream. The impact of that pollutant at the downstream of the watershed cannot be easily assessed because of the in-stream reactions of the pollutant.

Watershed modeling can be a good answer to estimate the pollutant loading throughout the watershed and inform stakeholders when the trading program may be applicable and useful. However, watershed models need to be calibrated with the observed weather, hydrologic, and water quality data which may not be available for many small local watersheds.

The calibration methodology for the local watershed that is lacking monitoring data was introduced in Chapter 3. The Meramec River watershed which drains to the Meramec River near Eureka, MO station (07019000) was selected for input parameter calibration because the watershed contains the Brush Creek watershed as a subbasin. Four years of calibration and four years of validation of hydrologic simulation were conducted and the calibrated annual deviation of runoff volumes (D_v) between observed data and simulated data 8.07% and the D_v of validation is -12.82%. The coefficient of determination (R^2) of the calibration is 0.54 and that of the validation is 0.61. The percent difference of the sediment during the calibration period is -9.97 and that of the validation period is 5.8. Those results are acceptable within the HSPF hydrology modeling criteria provided with the HSPF model.

The city of Pacific is expecting continued and accelerating development because of its proximity to the city of St. Louis, MO. The city of Pacific within the Brush Creek watershed may be an appropriate location for the application of the water quality trading to support sustainable development. The calibrated input parameters and the recently classified land use generated from remote sensing imagery were applied to the Brush Creek watershed HSPF model to simulate the baseline (current condition scenario). Through the manually modified land use map, representing future development or restoration, in upstream and downstream development or restoration scenarios were developed and simulate the hydrologic and sediment impact to the outlet of the watershed.

Chapter 5 shows the results of the hydrologic and sediment estimations after the land use changes are applied in the HSPF model. There are nine downstream development scenarios including development from agricultural, forest, and range land to urbanized development with 25, 50, and 75 percent impervious surface. Also, the nine upstream development scenarios were generated using the same method as with the downstream development scenarios. The restoration scenarios would return agricultural areas to range land in both the upstream and downstream locations. Their impacts were simulated in order to provide an estimate of how this particular land use change might be incorporated into a water quality trade. After the sediments calculations for the 20 different scenarios were performed in HSPF, equivalent acreage for sediment generation between upstream and downstream locations was developed as a potential water quality trading units.

Most of local streams which are not impaired have the right to develop with a typical percent impervious surfaces (e.g., 25% impervious). However, the downstream developer who wants intense development with 50 or 75% impervious surfaces need to buy the equivalent acre of upstream development right with the additional sediment generations. A municipal official asked to approve a development with a percent impervious surface greater than normally allowed could refer to the equivalent acreage for sediment generation between upstream and downstream land use scenarios in order to approved a water quality trade that would compensate for the additional nonpoint source pollutants for the implementing the trading program. In case of the impaired stream, the development at the downstream location can be allowed only when the equivalent acreages of agricultural area are restored to the range land. The equivalent acreages of each land use scenario are provided in chapter 5.

6.2. Future research directions

This study generated the hydrologic and sediment simulation within the Brush Creek watershed in order to estimate the water quantity and quality impacts from the land use changes. There are additional nonpoint source pollutants that should be considered in a trading program such as nitrogen, phosphorous, heavy metals, and pesticides. These non-point sources can be simulated with the HSPF model after calibration with observed data.

The overall annual and monthly calibration of the Meramec River watershed was performed and falls into the acceptable ranges of the HSPF hydrology modeling criteria. However, the daily hydrologic simulation tends to overestimate the baseline and underestimate the peak discharges. Those simulation errors can be lower if the physical stream information which is already available from BASINS can be adjusted with the field survey cross-section data.

The restoration scenarios in the upstream and downstream locations were simulated to provide the compensation areas for sediment generated from the downstream development scenarios. However, the restoration is limited to agricultural lands which are not always available for trading with a downstream development plan. Thus, the development of best management practices (BMPs) within the watershed can be another compensation method for the downstream development plan. The HSPF model provides the BMP editor function which helps to add the BMPs within the watershed and simulate the water quality results containing the BMPs effects. This capability should be incorporated into a trading program.

7 References

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Appendices

A. Annual Rainfall Total (St. Louis, MO)

Table A - 1. Ranked driest to wettest years (1870 ~2005)

RANK	YEAR	AMOUNT	RANK	YEAR	AMOUNT	RANK	YEAR	AMOUNT
1	1953	20.69	**46**	1956	34.43	**91**	1975	40.21
2	1930	23.23	**47**	1962	34.63	**92**	1884	40.64
3	1871	23.38	**48**	1880	34.66	**93**	1919	40.79
4	1976	23.46	**49**	1899	34.69	**94**	1878	40.83
5	1940	24.73	**50**	1994	34.70	**95**	2002	40.95
6	1901	24.80	**51**	1933	34.77	**96**	1921	41.10
7	1917	25.00	**52**	1986	34.88	**97**	1888	41.17
8	1952	25.67	**53**	1944	34.90	**98**	1961	41.20
9	1879	25.70	**54**	2001	35.29	**99**	1967	41.30
10	1936	25.74	**55**	1887	35.30	**100**	1907	41.39
11	1870	27.08	**56**	1906	35.52	**101**	1877	41.43
12	1894	27.44	**57**	1914	35.63	**102**	1892	41.62
13	1980	27.48	**58**	1947	35.78	**103**	1942	41.64
14	1954	27.61	**59**	1918	35.91	**104**	1995	41.68
15	1965	28.26	**60**	1911	36.13	**105**	1923	41.69
16	1959	28.31	**61**	1970	36.20	**106**	1916	41.80
17	*1989*	*28.60*	**62**	1951	36.37	**107**	1948	42.26
18	1963	28.62	**63**	1924	36.51	**108**	2004	42.27
19	1979	29.48	**64**	1939	36.56	**109**	1875	43.00
20	1900	29.51	**65**	1974	36.83	**110**	1882	43.15
21	1934	30.22	**66**	1937	36.85	**111**	1977	43.41
22	1872	30.47	**67**	1910	37.31	**112**	1998	43.62
23	1891	30.53	**68**	2000	37.37	**113**	1996	43.67
24	1895	31.20	**69**	1881	37.37	**114**	1969	43.72
25	1997	31.23	**70**	1958	37.38	**115**	1886	44.35
26	1955	31.33	**71**	1931	37.39	**116**	1912	44.59
27	1941	31.37	**72**	1938	37.49	**117**	1983	44.80
28	1920	31.53	**73**	1943	37.53	***118***	*1990*	*45.09*
29	1960	31.78	**74**	1896	37.55	**119**	1873	45.50
30	1964	32.16	**75**	1950	37.63	**120**	1981	45.52
31	1925	32.23	**76**	1890	37.69	**121**	1885	45.59
32	1966	32.34	**77**	1978	37.71	**122**	1949	45.76
33	1922	32.34	**78**	2005	37.85	**123**	2003	46.06
34	1968	32.49	**79**	1874	37.88	**124**	1929	46.30
35	1889	33.16	**80**	1932	38.01	**125**	1957	47.16
36	1926	33.35	**81**	1987	38.38	**126**	1909	47.50
37	1991	33.48	**82**	1905	38.54	**127**	1945	47.55
38	1992	33.49	**83**	1928	38.61	**128**	1876	48.46
39	1904	33.71	**84**	1902	38.63	**129**	1898	49.20
40	1971	33.73	**85**	1913	38.68	**130**	1915	49.28
41	1972	33.74	**86**	1893	39.28	**131**	1946	50.31
42	1903	33.81	**87**	1935	39.36	**132**	1985	50.73
43	1988	33.93	**88**	1973	39.82	**133**	1927	50.83
44	1999	34.06	**89**	1883	40.10	**134**	1984	51.65
45	1908	34.19	**90**	1897	40.17	***135***	*1993*	*54.76*

http://www.crh.noaa.gov/lsx/climate/STL/ranked_annual_rainfall_a.php

B. The equivalent acreages of upstream to the downstream 50% impervious surface development

Table A - 2. The equivalent acreages of upstream agricultural land required to compensate for the sediment generation from one acre of downstream agricultural land to 50% impervious surface development (A50D).

(Acres)

Scenario	*ARU*	*ARD*
Average	3.96	0.22
Top 5%	3.25	0.24
Top 10%	3.79	0.24
Top 20%	3.86	0.23
Top 30%	3.87	0.23
Top 50%	3.87	0.22
Between 20% and 80%	4.00	0.16

Table A - 3. The equivalent acreages of upstream agricultural land required to compensate for the sediment generation from one acre of downstream forest to 50% impervious surface development (F50D).

(Acres)

Scenario	*ARU*	*ARD*
Average	4.88	0.28
Top 5%	4.39	0.32
Top 10%	4.86	0.31
Top 20%	4.84	0.29
Top 30%	4.81	0.28
Top 50%	4.79	0.28
Between 20% and 80%	4.25	0.17

Table A - 4. The equivalent acreages of upstream agricultural land required to compensate for the sediment generation from one acre of downstream range land to 50% impervious surface development (R50D).

(Acres)

Scenario	*ARU*	*ARD*
Average	5.04	0.28
Top 5%	4.58	0.34
Top 10%	5.05	0.32
Top 20%	5.01	0.30
Top 30%	4.97	0.29
Top 50%	4.94	0.29
Between 20% and 80%	4.25	0.17

C. The equivalent acreages of upstream to the downstream 75% impervious surface development

Table A - 5. The equivalent acreages of upstream agricultural land required to compensate for the sediment generation from one acre of downstream agricultural land to 75% impervious surface development (A75D).

(Acres)

Scenario	*ARU*	*ARD*
Average	6.35	0.36
Top 5%	5.38	0.39
Top 10%	6.17	0.40
Top 20%	6.24	0.38
Top 30%	6.24	0.37
Top 50%	6.23	0.36
Between 20% and 80%	6.25	0.25

Table A - 6. The equivalent acreages of upstream agricultural land required to compensate for the sediment generation from one acre of downstream forest to 75% impervious surface development (F75D).

(Acres)

Scenario	*ARU*	*ARD*
Average	7.46	0.42
Top 5%	6.66	0.49
Top 10%	7.42	0.48
Top 20%	7.40	0.44
Top 30%	7.34	0.43
Top 50%	7.30	0.42
Between 20% and 80%	6.50	0.26

Table A - 7. The equivalent acreages of upstream agricultural land required to compensate for the sediment generation from one acre of downstream range land to 25% impervious surface development (R75D).

(Acres)

Scenario	*ARU*	*ARD*
Average	7.77	0.44
Top 5%	7.05	0.52
Top 10%	7.79	0.50
Top 20%	7.74	0.47
Top 30%	7.66	0.45
Top 50%	7.62	0.44
Between 20% and 80%	6.25	0.25

D. The HSPF input file (UCI file) – The Meramec River Watershed

```
RUN

GLOBAL
  UCI Created by WinHSPF for multical0122
  START       1970/01/01 00:00  END    1994/12/31 24:00
  RUN INTERP OUTPT LEVELS    1    0
  RESUME     0 RUN     1                         UNITS    1
END GLOBAL

FILES
<FILE>  <UN#>***<----FILE NAME------------------------------------------------->
MESSU      24   multical0122.ech
           91   multical0122.out
WDM1       25   multical0122.wdm
WDM2       26   ..\..\data\met_data\mo.wdm
BINO       92   multical0122.hbn
END FILES

OPN SEQUENCE
    INGRP              INDELT 01:00
      PERLND     101
      PERLND     102
      PERLND     103
      PERLND     104
      PERLND     105
      PERLND     106
      PERLND     107
      IMPLND     101
      IMPLND     102
      RCHRES       1
      RCHRES       7
      RCHRES       4
      RCHRES       3
      RCHRES       5
      RCHRES       8
      RCHRES       2
      RCHRES       6
      RCHRES       9
      COPY         1
      COPY         2
    END INGRP
END OPN SEQUENCE

PERLND
  ACTIVITY
*** <PLS >               Active Sections                              ***
*** x -  x ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC ***
  101  107    0    0    1    1    0    0    0    0    0    0    0    0
  END ACTIVITY
```

```
 PRINT-INFO
*** < PLS>              Print-flags                   PIVL  PYR
*** x  - x ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC
 101  107    4    4    4    4    4    4    4    4    4    4    4    4    1    9
 END PRINT-INFO

 BINARY-INFO
*** < PLS>           Binary Output Flags                 PIVL  PYR
*** x  - x ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC
 101  107    4    4    4    4    4    4    4    4    4    4    4    4    1    9
 END BINARY-INFO

 GEN-INFO
***          Name              Unit-systems   Printer BinaryOut
*** <PLS >                      t-series Engl Metr Engl Metr
*** x -  x                       in  out
 101     Forest Land                 1    1    0    0   92    0
 102     Agricultural Land           1    1    0    0   92    0
 103     Urban or Built-up La        1    1    0    0   92    0
 104     Barren Land                 1    1    0    0   92    0
 105     Water                       1    1    0    0   92    0
 106     Range Land                  1    1    0    0   92    0
 107     Unknown                     1    1    0    0   92    0
 END GEN-INFO

 PWAT-PARM1
*** <PLS >             Flags
*** x -  x CSNO RTOP UZFG  VCS  VUZ  VNN VIFW VIRC  VLE IFFC  HWT IRRG IFRD
 101  107    0    1    1    1    1    0    0    0    1    1    0    0    0
 END PWAT-PARM1

 PWAT-PARM2
*** < PLS>    FOREST      LZSN    INFILT      LSUR     SLSUR     KVARY     AGWRC
*** x  - x              (in)   (in/hr)      (ft)             (1/in)   (1/day)
 101             1.        7.      0.12      300.    0.0406        0.      0.98
 102  105        0.        7.      0.12      300.    0.0406        0.      0.98
 106             0.        7.      0.12      300.    0.0306        0.      0.98
 107             0.        7.      0.12      300.    0.0318        0.      0.98
 END PWAT-PARM2

 PWAT-PARM3
*** < PLS>    PETMAX    PETMIN    INFEXP    INFILD    DEEPFR    BASETP    AGWETP
*** x  - x   (deg F)   (deg F)
 101  107       40.       35.        2.        2.        0.        0.      0.01
 END PWAT-PARM3

 PWAT-PARM4
*** <PLS >     CEPSC      UZSN      NSUR     INTFW       IRC     LZETP
*** x -  x      (in)      (in)                         (1/day)
 101  107       0.1      1.12       0.3        2.       0.7       0.1
 END PWAT-PARM4

 PWAT-STATE1
```

```
*** < PLS>  PWATER state variables (in)
*** x  - x      CEPS      SURS       UZS      IFWS       LZS      AGWS      GWVS
  101  107      0.01      0.01       0.3      0.01       1.5      0.01      0.01
  END PWAT-STATE1

  MON-INTERCEP
*** <PLS >  Interception storage capacity at start of each month (in)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  101  107  0.2 0.05  0.2  0.2 0.05 0.08 0.45  0.3  0.3  0.2 0.25 0.05
  END MON-INTERCEP

  MON-UZSN
*** <PLS >  Upper zone storage at start of each month  (inches)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  101  107 0.02 0.05 0.07 0.07 0.03  0.4  2.6  1.2 0.05 0.07 0.03 0.03
  END MON-UZSN

  MON-MANNING
*** <PLS >  Manning's n at start of each month
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  101  107  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3
  END MON-MANNING

  MON-LZETPARM
*** <PLS >  Lower zone evapotransp   parm at start of each month
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  101  107  0.3  0.3  0.4  0.5  0.2  0.3  0.7  0.5  0.9  0.7  0.9  0.5
  END MON-LZETPARM

  SED-PARM1
*** <PLS >  Sediment parameters 1
*** x -  x  CRV VSIV SDOP
  101  107    1    0    1
  END SED-PARM1

  SED-PARM2
*** <PLS >      SMPF      KRER      JRER     AFFIX     COVER      NVSI
*** x -  x                          (/day)          lb/ac-day
  101  107        1.      0.45       2.2      0.03      0.88        1.
  END SED-PARM2

  SED-PARM3
*** <PLS >  Sediment parameter 3
*** x -  x      KSER      JSER      KGER      JGER
  101  107        4.       1.9        0.        1.
  END SED-PARM3

  MON-COVER
*** <PLS >  Monthly values for erosion related cover
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  101       0.4  0.4  0.4 0.85 0.95 0.95 0.55 0.55  0.9 0.98   1.  0.7
  102       0.3  0.3  0.4 0.75 0.88 0.88 0.55 0.55  0.9  0.9   1. 0.45
  103       0.6  0.6  0.6  0.8 0.85 0.85 0.55 0.55  0.9  0.9   1.  0.8
```

```
  104       0.5  0.5 0.55 0.75 0.85 0.85  0.6  0.6   1.  0.9   1. 0.75
  105      0.98 0.98 0.98 0.98 0.98 0.98 0.98 0.98 0.98 0.98 0.98 0.98
  106       0.5  0.5  0.6 0.92 0.98  0.9  0.6  0.6  0.9  0.9   1. 0.85
  107      0.55 0.55  0.7  0.8 0.93  0.9 0.65 0.65   1.  0.9  0.9 0.55
  END MON-COVER

  SED-STOR
*** <PLS >  Detached sediment storage (tons/acre)
*** x -  x      DETS
  101  107       0.2
  END SED-STOR

END PERLND

IMPLND
  ACTIVITY
*** <ILS >               Active Sections
*** x -  x ATMP SNOW IWAT  SLD  IWG IQAL
  101  102    0    0    1    1    0    0
  END ACTIVITY

  PRINT-INFO
*** <ILS > ******** Print-flags ******** PIVL  PYR
*** x -  x ATMP SNOW IWAT  SLD  IWG IQAL *********
  101  102    4    4    4    4    4    4    1    9
  END PRINT-INFO

  BINARY-INFO
*** <ILS > **** Binary-Output-flags **** PIVL  PYR
*** x -  x ATMP SNOW IWAT  SLD  IWG IQAL *********
  101  102    4    4    4    4    4    4    1    9
  END BINARY-INFO

  GEN-INFO
***             Name             Unit-systems   Printer BinaryOut
*** <ILS >                        t-series Engl Metr Engl Metr
*** x -  x                         in  out
  101     Urban or Built-up La        1    1    0    0   92    0
  102     Barren Land                 1    1    0    0   92    0
  END GEN-INFO

  IWAT-PARM1
*** <ILS >        Flags
*** x -  x CSNO RTOP  VRS  VNN RTLI
  101  102    0    0    0    0    0
  END IWAT-PARM1

  IWAT-PARM2
*** <ILS >      LSUR     SLSUR      NSUR     RETSC
*** x -  x      (ft)                          (in)
  101  102      300.    0.0406      0.05       0.1
  END IWAT-PARM2
```

```
  IWAT-PARM3
*** <ILS >    PETMAX    PETMIN
*** x -  x   (deg F)   (deg F)
  101  102       40.       35.
  END IWAT-PARM3

  IWAT-STATE1
*** <ILS >  IWATER state variables (inches)
*** x -  x      RETS      SURS
  101  102      0.01      0.01
  END IWAT-STATE1

  SLD-PARM1
*** <ILS >     Flags
*** x -  x VASD VRSD SDOP
  101  102    0    0    1
  END SLD-PARM1

  SLD-PARM2
***            KEIM      JEIM    ACCSDP    REMSDP
*** <ILS >                        tons/      /day
*** x -  x                       ac.day
  101  102       0.1        2.     0.025      0.05
  END SLD-PARM2

  SLD-STOR
*** <ILS >  Solids storage (tons/acre)
*** x -  x
  101  102       0.5
  END SLD-STOR

END IMPLND

RCHRES
  ACTIVITY
*** RCHRES  Active sections
*** x -  x HYFG ADFG CNFG HTFG SDFG GQFG OXFG NUFG PKFG PHFG
    1    9    1    1    0    0    1    0    0    0    0    0
  END ACTIVITY

  PRINT-INFO
*** RCHRES  Printout level flags
*** x -  x HYDR ADCA CONS HEAT  SED  GQL OXRX NUTR PLNK PHCB PIVL  PYR
    1    9    4    4    4    4    4    4    4    4    4    4    1    9
  END PRINT-INFO

  BINARY-INFO
*** RCHRES  Binary Output level flags
*** x -  x HYDR ADCA CONS HEAT  SED  GQL OXRX NUTR PLNK PHCB PIVL  PYR
    1    9    4    4    4    4    4    4    4    4    4    4    1    9
  END BINARY-INFO

  GEN-INFO
```

```
***             Name        Nexits   Unit Systems   Printer
*** RCHRES                          t-series  Engl Metr LKFG
*** x -  x                         in  out
   1    9                    1        1    1   91    0    0   92    0
  END GEN-INFO

  HYDR-PARM1
***        Flags for HYDR section
***RC HRES  VC A1 A2 A3  ODFVFG for each *** ODGTFG for each     FUNCT  for each
*** x  - x  FG FG FG FG  possible   exit *** possible   exit     possible   exit
   1    9   0  1  1  1    4  0  0  0  0      0  0  0  0  0      1  1  1  1  1
  END HYDR-PARM1

  HYDR-PARM2
*** RCHRES FTBW FTBU       LEN     DELTH     STCOR        KS      DB50
*** x -  x           (miles)      (ft)      (ft)              (in)
   1       0.   1.      0.66       13.        0.       0.5     0.014
   2       0.   2.     47.38      177.         0.       0.5     0.014
   3       0.   3.     70.54      262.         0.       0.5     0.014
   4       0.   4.     32.43      246.         0.       0.5     0.014
   5       0.   5.      54.8      423.        0.       0.5     0.014
   6       0.   6.     28.48      151.         0.       0.5     0.014
   7       0.   7.     14.92      253.         0.       0.5     0.014
   8       0.   8.     42.94      213.         0.       0.5     0.014
   9       0.   9.     78.71      253.         0.       0.5     0.014
  END HYDR-PARM2

  HYDR-INIT
***        Initial conditions for HYDR section
***RC HRES       VOL  CAT Initial value  of COLIND     initial  value  of OUTDGT
*** x  - x     ac-ft      for each possible   exit  for each possible exit,ft3
   1    9      0.01       4.2  4.5  4.5  4.5  4.2       2.1  1.2  0.5  1.2  1.8
  END HYDR-INIT

  SANDFG
*** RCHRES
*** x -  x SNDFG
   1    9    3
  END SANDFG

  SED-GENPARM
*** RCHRES    BEDWID    BEDWRN       POR
*** x -  x      (ft)      (ft)
   1    9       100        12       0.4
  END SED-GENPARM

  SAND-PM
*** RCHRES        D         W       RHO     KSAND    EXPSND
*** x -  x      (in)  (in/sec)  (gm/cm3)
   1    9     0.014       1.5      2.65        0.        0.
  END SAND-PM

  SILT-CLAY-PM
```

```
*** RCHRES        D        W       RHO     TAUCD     TAUCS         M
*** x -  x      (in)  (in/sec)    gm/cm3    lb/ft2    lb/ft2  lb/ft2.d
    1        0.0006     0.003       2.2      0.06       0.2      0.05
    2    3    0.0006     0.003       2.2      0.06      0.14      0.05
    4        0.0006     0.003       2.2      0.12      0.25      0.05
    5        0.0006     0.003       2.2      0.06      0.14      0.05
    6    7    0.0006     0.003       2.2      0.12      0.55      0.05
    8    9    0.0006     0.003       2.2      0.08      0.18      0.05
  END SILT-CLAY-PM

  SILT-CLAY-PM
*** RCHRES        D        W       RHO     TAUCD     TAUCS         M
*** x -  x      (in)  (in/sec)    gm/cm3    lb/ft2    lb/ft2  lb/ft2.d
    1      0.000055  0.000022        2.      0.06       0.2     0.065
    2    3  0.000055  0.000022        2.      0.06      0.14     0.065
    4      0.000055  0.000022        2.      0.12      0.25     0.065
    5      0.000055  0.000022        2.      0.06      0.14     0.065
    6    7  0.000055  0.000022        2.      0.12      0.55     0.065
    8    9  0.000055  0.000022        2.      0.08      0.18     0.065
  END SILT-CLAY-PM

  SSED-INIT
*** RCHRES     Suspended sed concs (mg/l)
*** x -  x      Sand      Silt      Clay
    1    9        0.       16.       24.
  END SSED-INIT

  BED-INIT
*** RCHRES    BEDDEP  Initial bed composition
*** x -  x      (ft)      Sand      Silt      Clay
    1    9        1.       0.5      0.25      0.25
  END BED-INIT

END RCHRES

FTABLES

  FTABLE      1
 rows cols                              ***
    8    4
     depth      area    volume  outflow1 ***
        0.      2.14        0.        0.
      0.16      2.17      0.34      2.24
      1.57      2.39      3.56    103.17
      1.96      2.45      4.51    149.59
      2.45      7.39       8.1    194.39
      2.94      7.55     11.77    356.73
     50.55     22.78    733.66 160842.08
     98.15       38.   2180.37 696951.13
  END FTABLE  1

  FTABLE      7
 rows cols                              ***
```

```
   8    4
    depth      area    volume  outflow1 ***
       0.    279.21        0.        0.
     0.49    280.98    136.87     78.96
     4.89    296.89   1407.58   3648.52
     6.11    301.31   1772.97   5287.83
     7.64    906.14   3148.25   6690.27
     9.16    917.19    4540.4  12207.02
   157.29    1988.8 219762.75  4517015.
   305.41   3060.42  593716.5 17574000.
 END FTABLE  7

 FTABLE      4
rows cols                               ***
   8    4
    depth      area    volume  outflow1 ***
       0.    988.67        0.        0.
     0.67    993.95    666.49    146.65
     6.72   1041.53   6824.86   6779.58
      8.4   1054.75   8586.61    9825.9
    10.51   3170.85  15214.06  12368.07
    12.61   3203.89  21910.93  22542.76
   216.41   6408.781001448.81 8015840.5
   420.21   9613.662634146.25 30321182.
 END FTABLE  4

 FTABLE      3
rows cols                               ***
   8    4
    depth      area    volume  outflow1 ***
       0.   3444.77        0.        0.
     0.92   3460.43   3162.14    274.24
     9.16   3601.38  32266.91  12683.61
    11.45   3640.53  40557.67  18383.53
    14.31  10941.18  71732.36  23041.11
    17.17  11039.07  103187.2   41959.5
    294.8  20533.89  4485897. 14436251.
   572.42  30028.72 11504600. 53224824.
 END FTABLE  3

 FTABLE      5
rows cols                               ***
   8    4
    depth      area    volume  outflow1 ***
       0.   9593.93        0.        0.
     1.67   9625.84  16068.17   1742.63
    16.72   9912.99 163082.36  80660.17
     20.9   9992.76 204686.77 116922.25
    26.13  30018.08 361014.81 145576.13
    31.35   30217.5 518384.75 264752.28
   538.19  49560.62 20735738. 86597144.
  1045.03  68903.73 50756948.305399872.
 END FTABLE  5
```

```
 FTABLE      8
rows cols                               ***
   8    4
     depth      area    volume  outflow1 ***
        0.    1872.1        0.        0.
      1.11   1879.78   2088.48    610.79
     11.13   1948.97  21269.94  28256.51
     13.92   1968.19   26721.1   40956.2
      17.4   5914.18  47213.25  51210.99
     20.87   5962.23  67872.56  93214.27
    358.34  10622.792866332.75 31490688.
    695.81  15283.36  7237585.114345424.
 END FTABLE  8

 FTABLE      2
rows cols                               ***
   8    4
     depth      area    volume  outflow1 ***
        0.   2554.65        0.        0.
      0.98   2565.88   2502.67    339.94
      9.78   2666.92  25520.57  15723.63
     12.22   2694.98  32072.11  22789.96
     15.27   8098.99  56704.91   28540.6
     18.33   8169.15  81552.05  51965.89
    314.63  14975.27 3510472.5 17766798.
    610.94   21781.4  8956091. 65166488.
 END FTABLE  2

 FTABLE      6
rows cols                               ***
   8    4
     depth      area    volume  outflow1 ***
        0.   1935.91        0.        0.
      0.87   1944.96   1686.44    268.85
      8.69   2026.38   17218.2  12433.26
     10.86     2049.  21645.65  18020.66
     13.58    6158.3   38294.5  22601.64
      16.3   6214.84  55096.92  41164.86
    279.74  11699.38  2414814. 14237096.
    543.19  17183.93  6219412. 52713128.
 END FTABLE  6

 FTABLE      9
rows cols                               ***
   8    4
     depth      area    volume  outflow1 ***
        0.    988.67        0.        0.
      0.67    993.95    666.49    146.65
      6.72   1041.53   6824.86   6779.58
       8.4   1054.75   8586.61    9825.9
     10.51   3170.85  15214.06  12368.07
     12.61   3203.89  21910.93  22542.76
```

```
   216.41   6408.781001448.88  8015841.
   420.21   9613.66 2634146.5 30321186.
  END FTABLE  9
END FTABLES

COPY
  TIMESERIES
  Copy-opn***
*** x -  x  NPT  NMN
    1    2    0    7
  END TIMESERIES

END COPY

EXT SOURCES
<-Volume-> <Member> SsysSgap<--Mult-->Tran <-Target vols> <-Grp> <-Member-> ***
<Name>   x <Name> x tem strg<-factor->strg <Name>   x   x       <Name> x x ***
*** Met Seg MO007455
WDM2   111 PREC     ENGLZERO          SAME PERLND 101 107 EXTNL  PREC
WDM2   113 ATEM     ENGL              SAME PERLND 101 107 EXTNL  GATMP
WDM2   117 DEWP     ENGL              SAME PERLND 101 107 EXTNL  DTMPG
WDM2   114 WIND     ENGL              SAME PERLND 101 107 EXTNL  WINMOV
WDM2   115 SOLR     ENGL              SAME PERLND 101 107 EXTNL  SOLRAD
WDM2   116 PEVT     ENGL              SAME PERLND 101 107 EXTNL  PETINP
*** Met Seg MO007455
WDM2   111 PREC     ENGLZERO          SAME IMPLND 101 102 EXTNL  PREC
WDM2   113 ATEM     ENGL              SAME IMPLND 101 102 EXTNL  GATMP
WDM2   117 DEWP     ENGL              SAME IMPLND 101 102 EXTNL  DTMPG
WDM2   114 WIND     ENGL              SAME IMPLND 101 102 EXTNL  WINMOV
WDM2   115 SOLR     ENGL              SAME IMPLND 101 102 EXTNL  SOLRAD
WDM2   116 PEVT     ENGL              SAME IMPLND 101 102 EXTNL  PETINP
*** Met Seg MO007455
WDM2   111 PREC     ENGLZERO          SAME RCHRES   1   3 EXTNL  PREC
WDM2   113 ATEM     ENGL              SAME RCHRES   1   3 EXTNL  GATMP
WDM2   117 DEWP     ENGL              SAME RCHRES   1   3 EXTNL  DEWTMP
WDM2   114 WIND     ENGL              SAME RCHRES   1   3 EXTNL  WIND
WDM2   115 SOLR     ENGL              SAME RCHRES   1   3 EXTNL  SOLRAD
WDM2   118 CLOU     ENGL              SAME RCHRES   1   3 EXTNL  CLOUD
WDM2   112 EVAP     ENGL              SAME RCHRES   1   3 EXTNL  POTEV
*** Met Seg MO007455
WDM2   111 PREC     ENGLZERO          SAME RCHRES   7   9 EXTNL  PREC
WDM2   113 ATEM     ENGL              SAME RCHRES   7   9 EXTNL  GATMP
WDM2   117 DEWP     ENGL              SAME RCHRES   7   9 EXTNL  DEWTMP
WDM2   114 WIND     ENGL              SAME RCHRES   7   9 EXTNL  WIND
WDM2   115 SOLR     ENGL              SAME RCHRES   7   9 EXTNL  SOLRAD
WDM2   118 CLOU     ENGL              SAME RCHRES   7   9 EXTNL  CLOUD
WDM2   112 EVAP     ENGL              SAME RCHRES   7   9 EXTNL  POTEV
*** Met Seg MO007263
WDM2    91 PREC     ENGL              SAME RCHRES   4   6 EXTNL  PREC
WDM2    93 ATEM     ENGL              SAME RCHRES   4   6 EXTNL  GATMP
WDM2    97 DEWP     ENGL              SAME RCHRES   4   6 EXTNL  DEWTMP
WDM2    94 WIND     ENGL              SAME RCHRES   4   6 EXTNL  WIND
WDM2    95 SOLR     ENGL              SAME RCHRES   4   6 EXTNL  SOLRAD
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```
WDM2    98 CLOU     ENGL             SAME RCHRES   4   6 EXTNL  CLOUD
WDM2    92 EVAP     ENGL             SAME RCHRES   4   6 EXTNL  POTEV
END EXT SOURCES

SCHEMATIC
<-Volume->              <--Area-->    <-Volume->  <ML#> ***       <sb>
<Name>   x              <-factor->    <Name>   x        ***        x x
PERLND 101                  1621     RCHRES   1      2
PERLND 102                  3183     RCHRES   1      2
PERLND 103                   790     RCHRES   1      2
IMPLND 101                   790     RCHRES   1      1
PERLND 104                    16     RCHRES   1      2
IMPLND 102                     7     RCHRES   1      1
PERLND 105                    27     RCHRES   1      2
PERLND 101                 66420     RCHRES   7      2
PERLND 102                 43101     RCHRES   7      2
PERLND 105                    77     RCHRES   7      2
PERLND 103                   132     RCHRES   7      2
IMPLND 101                   132     RCHRES   7      1
PERLND 101                133302     RCHRES   4      2
PERLND 102                107003     RCHRES   4      2
PERLND 103                  1419     RCHRES   4      2
IMPLND 101                  1419     RCHRES   4      1
PERLND 106                    19     RCHRES   4      2
PERLND 105                   543     RCHRES   4      2
PERLND 104                   176     RCHRES   4      2
IMPLND 102                    75     RCHRES   4      1
PERLND 102                125189     RCHRES   3      2
PERLND 101                153715     RCHRES   3      2
PERLND 103                  2050     RCHRES   3      2
IMPLND 101                  2050     RCHRES   3      1
PERLND 104                   467     RCHRES   3      2
IMPLND 102                   200     RCHRES   3      1
PERLND 105                   523     RCHRES   3      2
PERLND 106                   216     RCHRES   3      2
RCHRES   4                           RCHRES   3      3
PERLND 101                286698     RCHRES   5      2
PERLND 102                158092     RCHRES   5      2
PERLND 103                  2418     RCHRES   5      2
IMPLND 101                  2418     RCHRES   5      1
PERLND 105                   308     RCHRES   5      2
PERLND 104                   980     RCHRES   5      2
IMPLND 102                   420     RCHRES   5      1
PERLND 107                     5     RCHRES   5      2
PERLND 101                230690     RCHRES   8      2
PERLND 102                100793     RCHRES   8      2
PERLND 104                  9418     RCHRES   8      2
IMPLND 102                  4036     RCHRES   8      1
PERLND 105                  2146     RCHRES   8      2
PERLND 103                  3192     RCHRES   8      2
IMPLND 101                  3192     RCHRES   8      1
PERLND 106                   104     RCHRES   8      2
RCHRES   7                           RCHRES   8      3
```

```
PERLND 101          113012   RCHRES  2    2
PERLND 102           39269   RCHRES  2    2
PERLND 103            1608   RCHRES  2    2
IMPLND 101            1608   RCHRES  2    1
PERLND 105             752   RCHRES  2    2
PERLND 104            1451   RCHRES  2    2
IMPLND 102             622   RCHRES  2    1
RCHRES   8                   RCHRES  2    3
PERLND 101          345752   RCHRES  6    2
PERLND 102           57457   RCHRES  6    2
PERLND 103             963   RCHRES  6    2
IMPLND 101             963   RCHRES  6    1
PERLND 106             123   RCHRES  6    2
PERLND 105            3247   RCHRES  6    2
PERLND 104             481   RCHRES  6    2
IMPLND 102             206   RCHRES  6    1
RCHRES   5                   RCHRES  6    3
PERLND 101          273677   RCHRES  9    2
PERLND 102           80268   RCHRES  9    2
PERLND 103            1828   RCHRES  9    2
IMPLND 101            1828   RCHRES  9    1
PERLND 104            2223   RCHRES  9    2
IMPLND 102             953   RCHRES  9    1
PERLND 105            1010   RCHRES  9    2
PERLND 107              30   RCHRES  9    2
PERLND 106             193   RCHRES  9    2
RCHRES   1                   RCHRES  9    3
RCHRES   3                   RCHRES  9    3
RCHRES   2                   RCHRES  9    3
RCHRES   6                   RCHRES  9    3
PERLND 101         1604887   COPY    1   90
PERLND 102          714355   COPY    1   90
PERLND 103           14400   COPY    1   90
IMPLND 101           14400   COPY    1   91
PERLND 104           15212   COPY    1   90
IMPLND 102            6519   COPY    1   91
PERLND 105            8633   COPY    1   90
PERLND 107              35   COPY    1   90
PERLND 106             655   COPY    1   90
PERLND 101            1621   COPY    2   90
PERLND 102            3183   COPY    2   90
PERLND 103             790   COPY    2   90
IMPLND 101             790   COPY    2   91
PERLND 104              16   COPY    2   90
IMPLND 102               7   COPY    2   91
PERLND 105              27   COPY    2   90
END SCHEMATIC

EXT TARGETS
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Volume-> <Member> Tsys Aggr Amd ***
<Name>   x        <Name> x x<-factor->strg <Name>   x <Name>qf  tem strg strg***
PERLND 101 SEDMNT SOSED  1 1          SUM  WDM1  1018 SOSED  1 ENGL AGGR REPL
PERLND 101 SEDMNT DET    1 1          AVER WDM1  1027 DET    1 ENGL AGGR REPL
```

```
PERLND 102 SEDMNT SOSED  1 1          SUM  WDM1  1019 SOSED  1 ENGL AGGR REPL
PERLND 102 SEDMNT DET    1 1         AVER WDM1  1028 DET    1 ENGL AGGR REPL
PERLND 103 SEDMNT SOSED  1 1          SUM  WDM1  1020 SOSED  1 ENGL AGGR REPL
PERLND 103 SEDMNT DET    1 1         AVER WDM1  1029 DET    1 ENGL AGGR REPL
PERLND 104 SEDMNT SOSED  1 1          SUM  WDM1  1021 SOSED  1 ENGL AGGR REPL
PERLND 104 SEDMNT DET    1 1         AVER WDM1  1030 DET    1 ENGL AGGR REPL
PERLND 105 SEDMNT SOSED  1 1          SUM  WDM1  1022 SOSED  1 ENGL AGGR REPL
PERLND 105 SEDMNT DET    1 1         AVER WDM1  1031 DET    1 ENGL AGGR REPL
PERLND 106 SEDMNT SOSED  1 1          SUM  WDM1  1023 SOSED  1 ENGL AGGR REPL
PERLND 106 SEDMNT DET    1 1         AVER WDM1  1032 DET    1 ENGL AGGR REPL
PERLND 107 SEDMNT SOSED  1 1          SUM  WDM1  1024 SOSED  1 ENGL AGGR REPL
PERLND 107 SEDMNT DET    1 1         AVER WDM1  1033 DET    1 ENGL AGGR REPL
IMPLND 101 SOLIDS SOSLD  1 1          SUM  WDM1  1025 SOSLD  1 ENGL AGGR REPL
IMPLND 101 SOLIDS SLDS   1 1         AVER WDM1  1034 SLDS   1 ENGL AGGR REPL
IMPLND 102 SOLIDS SOSLD  1 1          SUM  WDM1  1026 SOSLD  1 ENGL AGGR REPL
IMPLND 102 SOLIDS SLDS   1 1         AVER WDM1  1035 SLDS   1 ENGL AGGR REPL
RCHRES   1 ROFLOW ROVOL  1 1 0.0018651     WDM   1009 SIMQ   1 ENGL AGGR REPL
RCHRES   1 HYDR   RO     1 1         AVER WDM1  1017 FLOW   1 ENGL AGGR REPL
RCHRES   1 HYDR   TAU    1 1         MAX  WDM1  1036 TAU    1 ENGL AGGR REPL
RCHRES   1 SEDTRN SSED   4 1         AVER WDM1  1037 SSED4  1 ENGL AGGR REPL
RCHRES   1 SEDTRN DEPSCR 4 1          SUM  WDM1  1038 DEPSCR 1 ENGL AGGR REPL
RCHRES   7 HYDR   TAU    1 1         MAX  WDM1  1039 TAU    1 ENGL AGGR REPL
RCHRES   7 SEDTRN SSED   4 1         AVER WDM1  1040 SSED4  1 ENGL AGGR REPL
RCHRES   7 SEDTRN DEPSCR 4 1          SUM  WDM1  1041 DEPSCR 1 ENGL AGGR REPL
RCHRES   4 HYDR   TAU    1 1         MAX  WDM1  1042 TAU    1 ENGL AGGR REPL
RCHRES   4 SEDTRN SSED   4 1         AVER WDM1  1043 SSED4  1 ENGL AGGR REPL
RCHRES   4 SEDTRN DEPSCR 4 1          SUM  WDM1  1044 DEPSCR 1 ENGL AGGR REPL
RCHRES   3 HYDR   TAU    1 1         MAX  WDM1  1045 TAU    1 ENGL AGGR REPL
RCHRES   3 SEDTRN SSED   4 1         AVER WDM1  1046 SSED4  1 ENGL AGGR REPL
RCHRES   3 SEDTRN DEPSCR 4 1          SUM  WDM1  1047 DEPSCR 1 ENGL AGGR REPL
RCHRES   5 HYDR   TAU    1 1         MAX  WDM1  1048 TAU    1 ENGL AGGR REPL
RCHRES   5 SEDTRN SSED   4 1         AVER WDM1  1049 SSED4  1 ENGL AGGR REPL
RCHRES   5 SEDTRN DEPSCR 4 1          SUM  WDM1  1050 DEPSCR 1 ENGL AGGR REPL
RCHRES   8 HYDR   TAU    1 1         MAX  WDM1  1051 TAU    1 ENGL AGGR REPL
RCHRES   8 SEDTRN SSED   4 1         AVER WDM1  1052 SSED4  1 ENGL AGGR REPL
RCHRES   8 SEDTRN DEPSCR 4 1          SUM  WDM1  1053 DEPSCR 1 ENGL AGGR REPL
RCHRES   2 HYDR   TAU    1 1         MAX  WDM1  1054 TAU    1 ENGL AGGR REPL
RCHRES   2 SEDTRN DEPSCR 4 1          SUM  WDM1  1055 DEPSCR 1 ENGL AGGR REPL
RCHRES   2 SEDTRN SSED   4 1         AVER WDM1  1056 SSED4  1 ENGL AGGR REPL
RCHRES   6 HYDR   TAU    1 1         MAX  WDM1  1057 TAU    1 ENGL AGGR REPL
RCHRES   6 SEDTRN SSED   4 1         AVER WDM1  1058 SSED4  1 ENGL AGGR REPL
RCHRES   6 SEDTRN DEPSCR 4 1          SUM  WDM1  1059 DEPSCR 1 ENGL AGGR REPL
RCHRES   9 HYDR   RO     1 1         AVER WDM1   101 FLOW   1 ENGL AGGR REPL
RCHRES   9 ROFLOW ROVOL  1 1 5.0439e-6     WDM   1001 SIMQ   1 ENGL AGGR REPL
RCHRES   9 HYDR   TAU    1 1         MAX  WDM1  1060 TAU    1 ENGL AGGR REPL
RCHRES   9 SEDTRN SSED   4 1         AVER WDM1  1061 SSED4  1 ENGL AGGR REPL
RCHRES   9 SEDTRN DEPSCR 4 1          SUM  WDM1  1062 DEPSCR 1 ENGL AGGR REPL
COPY     1 OUTPUT MEAN   1 1 4.2033e-7SUM  WDM   1002 SURO   1 ENGL AGGR REPL
COPY     1 OUTPUT MEAN   2 1 4.2033e-7SUM  WDM   1003 IFWO   1 ENGL AGGR REPL
COPY     1 OUTPUT MEAN   3 1 4.2033e-7SUM  WDM   1004 AGWO   1 ENGL AGGR REPL
COPY     1 OUTPUT MEAN   4 1 4.2033e-7     WDM   1005 PETX   1 ENGL AGGR REPL
COPY     1 OUTPUT MEAN   5 1 4.2033e-7     WDM   1006 SAET   1 ENGL AGGR REPL
COPY     1 OUTPUT MEAN   6 1 4.2033e-7AVER WDM   1007 UZSX   1 ENGL AGGR REPL
```

```
COPY    1 OUTPUT MEAN   7 1 4.2033e-7AVER WDM   1008 LZSX   1 ENGL AGGR REPL
COPY    2 OUTPUT MEAN   1 1 1.5542e-4SUM  WDM   1010 SURO   1 ENGL AGGR REPL
COPY    2 OUTPUT MEAN   2 1 1.5542e-4SUM  WDM   1011 IFWO   1 ENGL AGGR REPL
COPY    2 OUTPUT MEAN   3 1 1.5542e-4SUM  WDM   1012 AGWO   1 ENGL AGGR REPL
COPY    2 OUTPUT MEAN   4 1 1.5542e-4     WDM   1013 PETX   1 ENGL AGGR REPL
COPY    2 OUTPUT MEAN   5 1 1.5542e-4     WDM   1014 SAET   1 ENGL AGGR REPL
COPY    2 OUTPUT MEAN   6 1 1.5542e-4AVER WDM   1015 UZSX   1 ENGL AGGR REPL
COPY    2 OUTPUT MEAN   7 1 1.5542e-4AVER WDM   1016 LZSX   1 ENGL AGGR REPL
END EXT TARGETS

MASS-LINK

  MASS-LINK        2
<-Volume-> <-Grp> <-Member-><--Mult-->     <-Target vols> <-Grp> <-Member->  ***
<Name>            <Name> x x<-factor->     <Name>                <Name> x x  ***
PERLND     PWATER PERO       0.0833333     RCHRES          INFLOW IVOL
PERLND     PWTGAS PODOXM                   RCHRES          INFLOW OXIF   1
PERLND     PWTGAS POHT                     RCHRES          INFLOW IHEAT  1
PERLND     PEST   POPST  1                 RCHRES          INFLOW IDQAL  1
PERLND     PEST   SOSDPS 1                 RCHRES          INFLOW ISQAL  1 1
PERLND     PEST   SOSDPS 1                 RCHRES          INFLOW ISQAL  2 1
PERLND     PEST   SOSDPS 1                 RCHRES          INFLOW ISQAL  3 1
PERLND     SEDMNT SOSED  1       0.05      RCHRES          INFLOW ISED   1
PERLND     SEDMNT SOSED  1       0.55      RCHRES          INFLOW ISED   2
PERLND     SEDMNT SOSED  1        0.4      RCHRES          INFLOW ISED   3
  END MASS-LINK    2

  MASS-LINK        1
<-Volume-> <-Grp> <-Member-><--Mult-->     <-Target vols> <-Grp> <-Member->  ***
<Name>            <Name> x x<-factor->     <Name>                <Name> x x  ***
IMPLND     IWATER SURO       0.0833333     RCHRES          INFLOW IVOL
IMPLND     IWTGAS SODOXM                   RCHRES          INFLOW OXIF   1
IMPLND     IWTGAS SOHT                     RCHRES          INFLOW IHEAT  1
IMPLND     SOLIDS SOSLD  1       0.05      RCHRES          INFLOW ISED   1
IMPLND     SOLIDS SOSLD  1       0.55      RCHRES          INFLOW ISED   2
IMPLND     SOLIDS SOSLD  1        0.4      RCHRES          INFLOW ISED   3
  END MASS-LINK    1

  MASS-LINK        3
<-Volume-> <-Grp> <-Member-><--Mult-->     <-Target vols> <-Grp> <-Member->  ***
<Name>            <Name> x x<-factor->     <Name>                <Name> x x  ***
RCHRES     ROFLOW                          RCHRES          INFLOW
  END MASS-LINK    3

  MASS-LINK       90
<-Volume-> <-Grp> <-Member-><--Mult-->     <-Target vols> <-Grp> <-Member->  ***
<Name>            <Name> x x<-factor->     <Name>                <Name> x x  ***
PERLND     PWATER SURO                     COPY            INPUT  MEAN   1
PERLND     PWATER IFWO                     COPY            INPUT  MEAN   2
PERLND     PWATER AGWO                     COPY            INPUT  MEAN   3
PERLND     PWATER PET                      COPY            INPUT  MEAN   4
PERLND     PWATER TAET                     COPY            INPUT  MEAN   5
PERLND     PWATER UZS                      COPY            INPUT  MEAN   6
```

```
PERLND     PWATER LZS                      COPY          INPUT  MEAN   7
  END MASS-LINK   90

  MASS-LINK       91
<-Volume-> <-Grp> <-Member-><--Mult-->     <-Target vols> <-Grp> <-Member->  ***
<Name>            <Name> x x<-factor->     <Name>               <Name> x x  ***
IMPLND     IWATER SURO                     COPY          INPUT  MEAN   1
IMPLND     IWATER PET                      COPY          INPUT  MEAN   4
IMPLND     IWATER IMPEV                    COPY          INPUT  MEAN   5
  END MASS-LINK   91
END MASS-LINK

END RUN
```

VITA

Yee Sook Shin was born on September 7, 1974 in Seoul, Korea. She had a Bachelor of Science degree in chemistry and Master's degree in civil and environmental engineering in Seoul, Korea. After her marriage to Hanbaek Lee, she came to the U.S. and started her PhD education in the Department of Civil and Environmental Engineering, at the University of Missouri in 2002. She received the GIS certificate from the University of Missouri in 2004. She has two precious ones, Yebon and Doreen born in 2005 and 2009, respectively