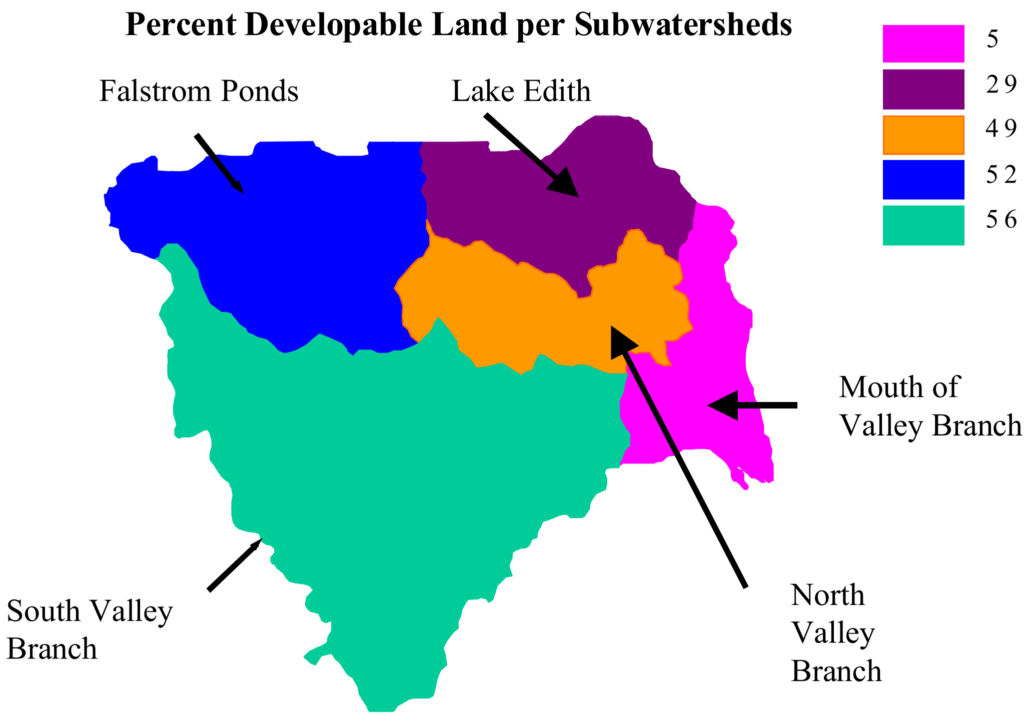
Monitoring and Modeling Valley Creek Watershed

6. Modeling the Effects of Urbanization on Surface Flows and Water Quality in the Valley Branch Watershed

Final Project Report
to the
LCMR
Legislative Commission on Minnesota Resources
30 June 1999



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Funding for this project approved by the Minnesota Legislature, ML 1997, Chapter 216, Sec. 15, Subd. 13(b) as recommended by the Legislative Commission on Minnesota Resources from the Minnesota Future Resources Fund. Funding was received by the St. Croix Watershed Research Station of the Science Museum of Minnesota, to whom the University of Minnesota was a subcontractor.

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Extended Abstract

Models are useful, and perhaps essential, tools for evaluating the impact of urbanization on runoff depth and sediment yield. They are nonetheless imperfect tools, each model having different strengths and limitations. The Soil and Water Assessment Tool (SWAT) and the Water Erosion Prediction Project (WEPP) models are used in this study. These are two widely used state-of-the-art models. The strengths of SWAT and WEPP are their representations of upland processes, especially related to agricultural practices. A limitation of the model effort is the representation of stream processes. In addition, the impact of urbanization on nutrient and pesticide loadings is not considered.

Although SWAT and WEPP were originally developed for agricultural watersheds, they use different modeling approaches for important upland processes. These differences include their representation of spatial variability within a hillslope and their algorithms for predicting infiltration and soil erosion. For the SWAT simulations, the Valley Branch Watershed was divided into subbasins. Data layers compiled with ARCVIEW were used to determine the input parameters for each subbasin. For the WEPP simulations, the Valley Branch Watershed was also divided into subbasins. In addition, the hillslopes within these subbasins were divided into segments to represent possible spatial variabilities of parameters along hillslope transects. Routines were needed to link Arc/INFO data bases with the WEPP model. These routines were successfully developed and used to determine efficiently the input parameters of WEPP.

Both models were evaluated using sensitivity analyses and by comparing the predicted values to observed data for the Valley Branch Watershed and nearby areas. The WEPP model was sensitive to changes in land use conditions. The SWAT model was relatively insensitive to several subsurface flow parameters. With the proper selection of input parameters, both models were generally able to predict reasonable runoff depths and sediment yields for the Twin Cities region. Both models, however, underpredicted the

base flow for the Valley Branch watershed. The observed base flow likely includes discharge from areas outside the watershed boundaries, and therefore accurate representation of base flow was not possible.

Five different neighborhood development scenarios were considered in the study. High density consisted of three dwelling units per acre gross and net density. This density was simulated with and without storm water management practices (ponds). Five acre gross and net density were also simulated with and without ponds. The fifth development scenario (one-third acre) was a five-acre gross density clustered at 3.3 dwelling units net density with ponds.

The impacts of urban development were first determined using detailed design scenarios compiled for Section 19. Transects were drawn through each scenario to determine parameters for flow over segments of grass and pavement and for possible concentrated flow in curb and gutters. Annual runoff depths and sediment yields were estimated from these transects using the SWAT and WEPP models. Results were adjusted to account for the impact of ponds in the design scenarios. By using the transect/pond approach, prototypical results were obtained for each development scenario. A “development soil” parameter set, corresponding to a single cover and soil type, was created to obtain the same predicted runoff depth and sediment yield as those from the prototypical representation. The impacts of urban development for other areas in the Valley Branch watershed were simulated by using the appropriate “development soil”. This greatly simplified the prediction of runoff depths and sediment yields for the urban development scenarios.

The simulation results were evaluated for five subwatersheds: (1) Section 19, (2) Lake Edith, (3) Falstrom Ponds, (4) North Valley Branch, and (5) South Valley Branch. Impacts were assessed by considering the percent change in runoff depth or sediment yield from existing conditions. Different trends were frequently predicted using the WEPP and SWAT models. The WEPP results were considered superior because of the improved representation of hillslope processes. Overall assessment of the impact of urban development was therefore based on the WEPP simulations.

The WEPP model predicted an increase in runoff depth for the high-density development scenarios (with and without ponds) for all five subwatersheds. This increase was the result of (1) the high proportion of impervious area, and (2) the presence of curb and gutters to concentrate runoff. The five-acre (with and without ponds) and the one-third acre development scenarios resulted in a decrease in runoff depth. This trend resulted from (1) the conversion of agricultural lands to grassland, (2) the low percentage of impervious area, and (3) the lack of curb and gutters to concentrate flow. The largest and smallest runoff depths were predicted for the high-density and the one-third-acre-with-ponds scenarios, respectively.

The WEPP model predicted a decrease in sediment yield for all urban development scenarios for all five subwatersheds. This decrease resulted from (1) no erosion from impervious areas, (2) the low erosion rates from grassland, and (3) effectiveness of ponds to trap sediment. In general, the greatest reduction in sediment yield was obtained for the high-density (with ponds) development scenario, and the smallest reduction with the five-acre (without) pond scenario. Even though the runoff depth is largest for the high-density scenario, this large runoff depth occurs on a non-erodible (impervious) land cover and therefore does not substantially increase the sediment yield for the scenario.

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6. Modeling the Effects of Urbanization on Surface Flows and Water Quality in the Valley Branch Watershed

D. C. Whited, E. M. Jahnke, B. N. Wilson, and D. G. Pitt

SECTION 6.1
INTRODUCTION

Urbanization can alter the hydrologic and water quality characteristics of watersheds. These potential changes are particularly important to trout streams. Pressure for urban development in Valley Creek will likely increase in the next decade. This watershed currently has a healthy trout stream. The potential impact of urbanization on this stream is unknown. The repercussions of development on the Valley Creek's trout stream should be considered in managing the watershed resources.

The impacts of urban development are difficult to determine experimentally. Because Minnesota weather is highly variable, several years of data are needed to draw conclusions about a typical response. There are also numerous possible development scenarios that could be proposed, each of which may have a different hydrologic impact. Collection of experimental data for several years for several different types of urban developments is prohibitively expensive. In addition, unacceptable developments would be difficult to remove from the watershed after the completion of the experimental project.

An alternative approach to experimental studies is to use simulation models. These models use mathematical relationships to predict the hydrologic and water quality responses of watersheds. Many years and different land use scenarios can then be easily assessed. Although powerful, models can nonetheless poorly predict the response. Good predictions require a proper match between project objectives and modeling relationships and an appropriate selection of modeling parameters.

The goal of this component of the project is to assess the impact of urbanization on Valley Creek using simulation models. Two different models, WEPP (**W**ater **E**rosion **P**rediction **P**roject) and SWAT (**S**oil and **W**ater **A**ssessment **T**ool), are used in this study to predict the runoff depth and sediment yield. A description of these models is given in Section 6.2, and an evaluation of the appropriateness of these models to represent processes in the Valley Creek watershed is discussed in Section 6.3. Five different neighborhood development scenarios were considered. The development scenarios and modeling approaches to represent them are given in Section 6.4. The results of the simulations are presented and summarized in Section 6.5.

SECTION 6.2
DESCRIPTION OF MODELS

Modeling Approaches

Models are useful tools to assess hydrologic and sedimentologic impacts of urban development. They are not, however, perfect tools. Proper use requires (1) a good match between project objectives and modeling algorithms, (2) careful selection of input parameters, and (3) assiduous interpretation of predicted values. The first condition is addressed in this section. The latter two conditions are discussed in greater detail in subsequent sections.

There are numerous models to simulate the runoff depths and sediment yields of watersheds. Reviews of these models are given by Haan et al. (1982) and Singh (1995). For this study, the Soil and Water Assessment Tool, SWAT, (Arnold et al., 1993; Arnold et al., 1997) and the Water Erosion Prediction Project, WEPP, (Flanagan and Livingston, 1995) models are used. Both are widely used state-of-the-art models for simulating runoff and erosion, but they use substantially different algorithms for representing these processes. By using these two models, the sensitivity of results with a modeling approach can be assessed.

An important difference between the SWAT and WEPP models is the representation of watersheds. In SWAT, the watershed is divided into subbasins. Average parameter values are used to simulate the response for a typical subbasin. This representation is well suited for interface with GISs, that is, many of the input parameters can be obtained from topographic, soils, and land use layers. The ability of SWAT to interface with ARCVIEW is one of the reasons that it was selected for this project. The SWAT model, however, does not directly represent parameter variability within hillslopes. This is a limitation for nonlinear processes because the average response can not be obtained using the mean parameter value.

In contrast to SWAT, the hillslope in WEPP is subdivided into overland flow elements (OFE). The parameters are allowed to vary for each OFE, and therefore the impact of varying landscape properties within hillslopes can be directly modeled. This feature is one of the reasons that WEPP was selected for this study. The WEPP model does not, however, have interface routines with the GIS databases. These routines were developed as part of the project activities.

A brief description of the hydrologic and erosion/sediment routines for WEPP and SWAT models is given in this section. Key differences in the modeling approaches are highlighted.

Modeling Hydrologic Processes

WEPP Model

The WEPP model uses a stochastic weather generator to predict mean daily precipitation, daily maximum and minimum temperatures, mean daily solar radiation and mean daily wind direction and speed. A standard two-state, first-order Markov Chain is used to determine whether a particular day has precipitation. If the average daily air temperature is below freezing, the precipitation is assumed to be snowfall. The depth of precipitation is computed from a skewed normal distribution. Rainfall duration is determined from an exponential distribution. Daily maximum and minimum temperatures and solar radiation are computed using normal distributions. The weather generator is also capable of determining the time-distribution of rainfall depths within a storm.

The WEPP model includes routines to account for snowmelt and frost depth. The snowmelt routine uses air temperature, solar radiation, vapor transfer and precipitation to determine daily snowmelt depth. Frost depth is computed using unidirectional heat flow equations. The WEPP model also includes a routine to account for snow drifting processes.

A critical difference between WEPP and SWAT models is the prediction of infiltration. Infiltration in the WEPP model is determined using the Green-Ampt-Mein-Larson model. The Green-Ampt-Mein-Larson infiltration model has two stages: infiltration prior to surface ponding and infiltration after surface ponding. A critical parameter is the effective conductivity. The WEPP model uses an innovative and dynamic method to estimate effective conductivity as a function of soil, residue, and plant conditions.

Relatively simple routines are used in the WEPP model to determine overland flow hydraulics. Broad sheet flow is assumed to estimate the peak flow rate and runoff duration. The flow is, however, divided among equally spaced rills to estimate soil detachment and transport. This approach is discussed in greater detail in the next section.

The WEPP model determines the soil moisture in the root zone by using a water balance for the profile. Important processes include evaporation, plant transpiration, and percolation. The water balance algorithm uses the daily precipitation, temperature, and solar radiation from the weather generator; the infiltration volume from the infiltration component; and the daily leaf area index, root depth, and residue cover from the plant growth component.

Plant growth and residue decomposition are also computed in the WEPP model. The plant growth component determines those plant variables that influence runoff and erosion processes. Plant variables include vegetative biomass, root growth and leaf area index. The decomposition of surface and subsurface residue and root mass is predicted in the WEPP model.

SWAT

Meteorologic variables required for SWAT simulations are precipitation, air temperature, solar radiation, wind speed and relative humidity. These variables can be entered using site specific measurements or can be computed using a weather generator. In general, the weather generator algorithms are similar to those used in WEPP. The correlation structure among temperature and radiation values is, however, maintained using a multivariate approach. The temperature and solar radiation values are also dependent on the wet or dry state of the day. Daily wind speed is estimated using a modified exponential function. Relative humidity is computed assuming a triangular distribution. The observed weather data obtained using site-specific measurements were entered into SWAT for this study.

Simple techniques are used in SWAT to compute snowmelt. It is a function of mean daily air temperature and snow pack temperature. The snow pack temperature is taken as the minimum of the temperature at the top of the snow pack and the temperature of the soil in the second layer. The temperature of the soil layers and the snow pack are estimated using simple relationships.

Surface runoff volume is computed using the Natural Resources Conservation Service's (NRCS) curve number method. Relationships are used to compute the curve number for AMC I and AMC III conditions. These relationships are used with the soil water content to adjust the curve number with soil moisture conditions. Adjustments are also used for land slope. Peak flow rate is predicted using techniques based on the rational or the NRCS TR-55 methods.

The SWAT model also determines the soil moisture using a water balance. Evaporation and plant transpiration techniques are similar to those used in WEPP. Plant growth is simulated to estimate the leaf area index and other characteristics of the vegetation. Water from the root zone can percolate to a shallow aquifer, and from the shallow aquifer to the stream or to a deep aquifer. Once water moves to the deep aquifer, it is lost from the system. The discharge from the shallow aquifer to streams is dependent on its water depth. A water balance is used to compute the daily water depth.

Impoundment routines are used to account for the effects of reservoir, farm ponds, and/or wetlands on water yield. These effects are simulated using a water balance, where evaporation is computed using potential evapotranspiration values. The surface area is estimated by using the outflow from the impoundment through surface outlets. Since the emphasis is on water yield, and not peak flow rates, simple relationships are used to represent the outflow from these outlets.

Modeling Erosion and Sediment Transport Processes

WEPP

The WEPP model predicts erosion using the rainfall intensities, the runoff rate, and the soil/vegetation/residue surface conditions. Rainfall intensities and runoff rates are computed using the hydrologic algorithms discussed in the previous section. The WEPP model allows soil parameters to vary with time and tillage practices. These changing parameters affect both the hydrology and erosion predictions. Dynamic soil parameters include random roughness, oriented roughness, bulk density, wetting-front suction, saturated conductivity, interrill and rill erodibility and critical shear stress.

Soil erosion in the WEPP model is divided into interrill and rill areas. Interrill sediment is delivered to rills or other concentrated flow channels. The sediment load in the rills is computed using a steady-state form of the conservation of sediment mass. Detachment of sediment in rills is reduced by the ratio of sediment load and transport capacity. If the sediment load is greater than the transport capacity, deposition is predicted. Deposition is therefore frequently simulated for changes in slope or in vegetation for the OFEs.

Interrill erosion and delivery is proportional to the product of the effective rainfall intensity and the interrill runoff rate. The effective rainfall intensity is defined as the average intensity corresponding to a nonzero runoff rate. Interrill erodibility is used to represent differences in detachment for different soils, vegetation, tillage, and/or residue. Sediment delivery ratio is used to compute the net mass reaching rills. This delivery ratio is a function of the surface roughness and the size of detached particles. The delivery ratio for clay particles is approximately one for all surfaces. The delivery ratio is approximately zero for sand and large aggregates for surfaces with moderate to large scale roughness.

Potential rill erosion is determined from the excess bed shear acting on soil particles. Adjustments in the potential detachment are made using the sediment load and transport capacity of the flow, where the transport capacity is determined using a transport coefficient and bed shear. Steady state conditions are assumed to determine erosion processes. The peak flow rate is used to determine steady flow conditions and the effective duration is obtained using the total runoff volume divided by the peak flow rate. Rectangular cross-sections are used to compute depth of flow, velocity, and shear stress in rills. For soil detachment, total shear is partitioned into those components acting on the soil using friction factors. Rill erodibility and critical shear are adjusted to account for soil consolidation, residue, and freeze-thaw effects.

Deposition is predicted for OFEs when the sediment load is greater than the transport capacity. The mass of deposition is computed from the surplus of load, particle settling velocity, the peak runoff rate and other factors.

SWAT

Sediment yield for each subbasin is computed using the Modified Universal Soil Loss Equation (MUSLE). With this approach, the annual rainfall erosivity parameter of the Universal Soil Loss Equation (USLE) is replaced with a storm runoff parameter. This storm runoff parameter is defined using the runoff volume and peak flow rate. The remaining parameters are as defined by USLE. The crop management factor apparently varies with time using (1) the plant growth model to compute the above ground biomass, (2) the amount of surface residue mass, and (3) the minimum value for the plant.

Sediment deposition and degradation are computed for flows in streams and channels. Deposition is computed using a delivery ratio. The delivery ratio is computed from the distance a particle will fall during the travel time in the channel reach and from the flow depth in the channel. Detachment is computed by first determining the stream power. This stream power is then used to determine the reentrainment of previously deposited sediment. Additional detachment is also computed using soil and cover parameters for the channel similar to that used in the USLE. The net loss or gain of sediment is computed by the difference between deposition and degradation.

Simple routines are used to account for the impact of impoundments on effluent concentrations. Outflow mass is computed from the outflow rate and effluent concentration. The effluent concentration is taken as the average concentration at the beginning and end of the day. For storm events, the concentration is computed from the inflow sediment mass and the remaining mass in the impoundment. Between storm events, the concentration decreases exponentially to an equilibrium concentration.

Interface with GIS Databases

WEPP

A Geographic Information System (GIS) interface was developed for the WEPP model. This greatly increased the ease of accessing GIS databases to obtain the required input data. The interface uses a menu-driven Arc/INFO interface to query the user and to compile the GIS data, and it uses a C program to transform the GIS data into WEPP input data files.

The interface generates WEPP input data using land use, soils, and elevation from a GIS database. Land use cover types include: corn with conventional tillage, corn with conservation tillage, corn with no-till, beans with conventional tillage, beans with conservation tillage, beans with no till, hay, grassland, forest, and pavement. Soil types include: silt loam, loam, sandy loam, loamy sand, and sand. Elevation is depicted by slopes ranging from 0-50%.

The Arc/INFO component queries the user for information on GIS data, hillslope width, number of years to simulate, and various output choices for the WEPP model An example screen for input information is shown in Figure 6.2.1.

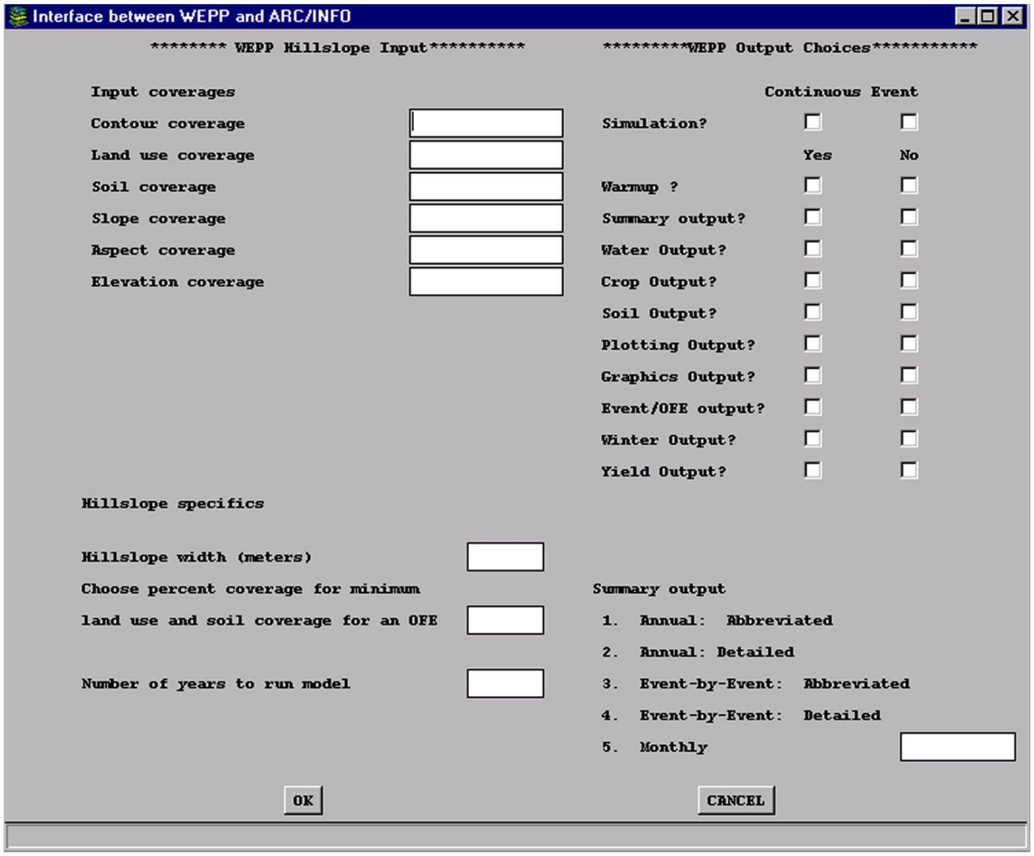

Figure 6.2.1. Arc/INFO user input screen for GIS/WEPP interface.

For a user drawn transect, the interface calculates the appropriate land use, soil, slope, and aspect. If necessary, multiple transects for different hillslopes can be used. The interface then converts the hillslope data into WEPP input.

SWAT

The ArcView/SWAT Interface (AVSI) version beta 1.01 was developed to integrate SWAT with databases obtained with ArcView. An example screen for the SWAT interface is shown in Figure 6.2.2. In an ArcView setting, the user follows a step-by-step procedure to create input files essential for running SWAT. It uses FORTRAN 90 to transform the GIS data into SWAT input data files. In addition to creating input data files, output from the SWAT simulation is returned to the interface so that it can be analyzed spatially using ArcView.

The AVSI generates SWAT input files by overlaying data files of elevation (DEM), land use, and soil cover maps. Examples of possible cover types include corn, soybean, hay, pasture, forest, urban, water and wetland. Some proposed management scenarios for agricultural lands were unavailable with our version. Possible soil types include silt loam, loam, sandy loam, loamy sand, and sand. Meteorologic inputs of maximum and minimum temperature data, precipitation data, and conversion tables are also required.

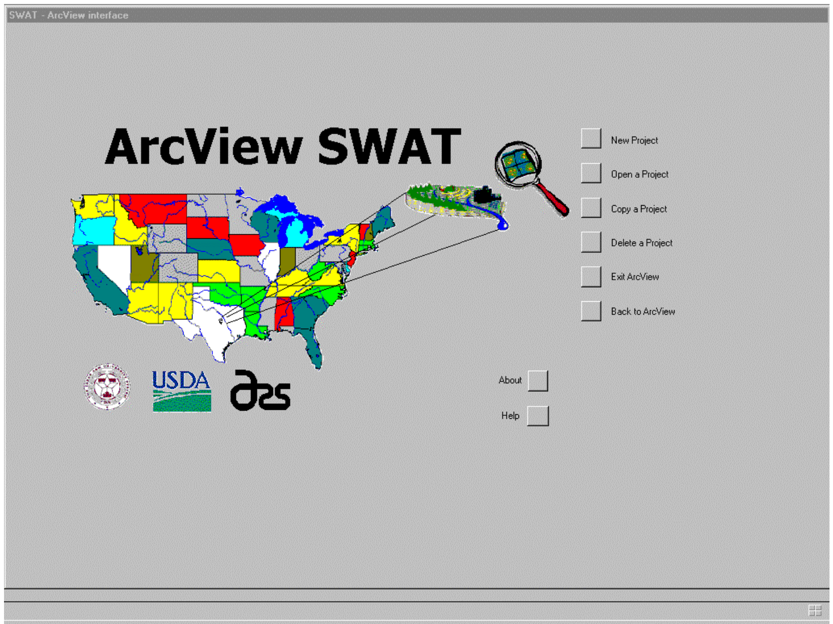

Figure 6.2.2. ArcView SWAT Interface Opening Page

Topographic related parameters are determined from a user created digital elevation map (DEM). The interface determines the overall watershed boundaries with multiple subwatersheds within these boundaries. The interface then overlays stream channel, subwatershed outlets, elevation, land use and soils. An additional feature of SWAT is the Hydrologic Response Units (HRU's), which are subareas within subwatersheds defined using land use and soil type information. Once again, the interface converts all of this information into readily usable input data files for SWAT simulations.

Summary

The Soil and Water Assessment Tool (SWAT) and the Water Erosion Prediction Project (WEPP) models are used to simulate the impact of urbanization for theValley Branch watershed. Although both are widely used models for simulating runoff and erosion, they use substantially different algorithms for representing these processes. One important difference is the representation of watersheds. The SWAT model divides the watershed into subwatersheds. The WEPP model also uses subwatersheds, but further divides them into hillslope segments called overland flow elements.

In terms of algorithms of interest in this study, the most noteworthy differences are the routines for infiltration and erosion. The SWAT model uses the curve number approach and varies the curve number with time to indirectly determine infiltration. In contrast, the WEPP model uses the Green-Ampt-Mein-Larson approach. Here infiltration is computed directly as a function of the effective conductivity and other soil properties. These infiltration parameters change with time based on plant growth and other factors. Erosion in the SWAT model is predicted using the modified universal soil loss equation where rill and interrill processes are lumped into a single relationship. For example, a single soil erodibility is used to represent rill and interrill erosion with the driving process for detachment being storm runoff volume and peak flow rate. The WEPP model considers the erosion in idealized rills and computes sediment delivery to the rills from the interrill areas. Different soil erodibilties are used for interrill and rill processes. Detachment in rills is driven by excess critical shear resulting from surface runoff; whereas detachment in interrill areas is driven by rainfall intensity.

Geographic information system (GIS) databases were used to obtain the input parameters for both the SWAT and WEPP models. These input parameters were then used to predict the runoff depth and sediment yield. The output was returned to the GIS systems for data analysis and interpretation. An ArcView interface developed by the Agricultural Research Service was used to integrate SWAT with the Valley Branch databases. An equivalent interface was unavailable for the WEPP model, and therefore a menu-driven Arc/INFO interface was developed as part of the project. This interface queries the user for input information, compiles the GIS data, and uses a C program to transform the GIS data into WEPP input data files.

SECTION 6.3
EVALUATION OF MODELS

Introduction

In this section, WEPP and SWAT are evaluated for their suitability to simulate the impact of urbanization. Models are typically evaluated by comparing predicted and observed values. Another important facet, however, is their sensitivity to input parameters and their ability to accurately represent the relative change in response caused by alternative management strategies. A sensitivity analysis is useful in selecting the most important parameters for calibration and in quantifying uncertainty in predicted values resulting from potential errors in input parameters. The ability of models to simulate the impact of management decisions is necessary in this study to represent the different urban development scenarios. The focus here is on predicting relative changes accurately, rather than absolute values.

Evaluations of the WEPP and SWAT models are given in separate sections. Since the sensitivity of many of the WEPP parameters have already been evaluated for Minnesota conditions (Oduro and Wilson, 1996; Burt and Wilson, 1997), a limited sensitivity analysis was done for this model. A more detailed sensitivity analysis for the SWAT model was performed. The data collected as part of this project proved useful in understanding the general response of Valley Creek. The record was too short, however, to be used in evaluating the predictive accuracy of WEPP and SWAT models. The accuracy of predicting long-term response was therefore assessed using nearby watersheds and regional studies.

WEPP Model

A sensitivity analysis was used to assess the predicted responses of WEPP to spatially distributed differences in land use and to the impact of cover conditions. An additional sensitivity analysis was conducted to estimate the appropriate number of hillslopes needed to adequately represent the watershed. The ability of WEPP to accurately predict annual runoff depth and sediment yield was also evaluated.

Spatial sensitivity

Spatial sensitivity analysis was used to determine whether WEPP appropriately predicts the response of spatially-varied properties along hillslopes. This variability is especially important for this study because of its use in the development scenarios. Spatial sensitivity was examined by simulating a 50 m hillslope of corn with conventional tillage without a buffer strip, with a 10 m buffer strip in the middle of the hillslope (e.g. strip cropping), and a 10 m buffer strip at the bottom of the hillslope (e.g. riparian buffer). This analysis therefore evaluated the response of two different land use covers (i.e. grassland, forest) within the buffer.

Figures 6.3.1 and 6.3.2 show the sensitivity of runoff depth and of sediment yield, respectively, to buffer strips. Runoff depth and sediment yield were both reduced with the use of buffer strips. Buffer strips located at the bottom of the hillslope performed better than those placed in the middle of the hillslope. Forested buffer strips always performed better than grass buffer strips. This is partially caused by reduced runoff and erosion from the buffer strips themselves.

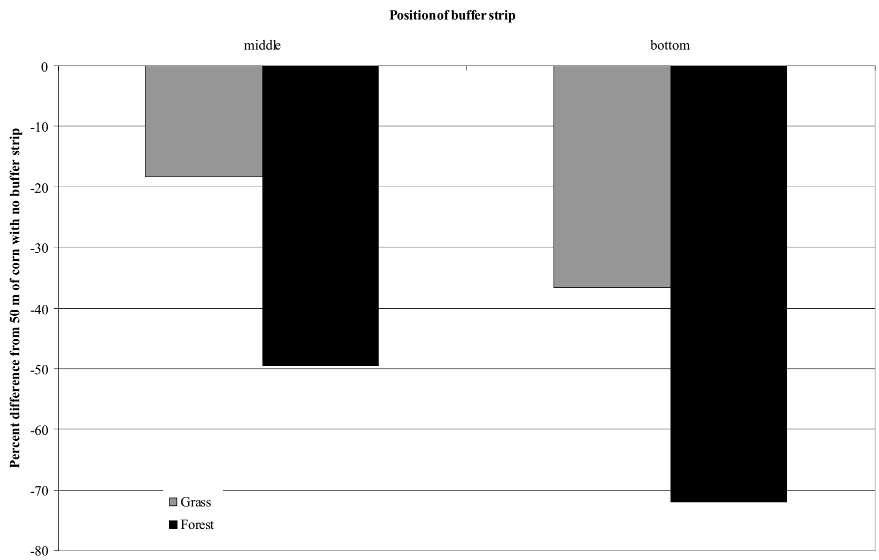

Figure 6.3.1. Runoff depth sensitivity to buffer strips (40 m corn with 10 m buffer).

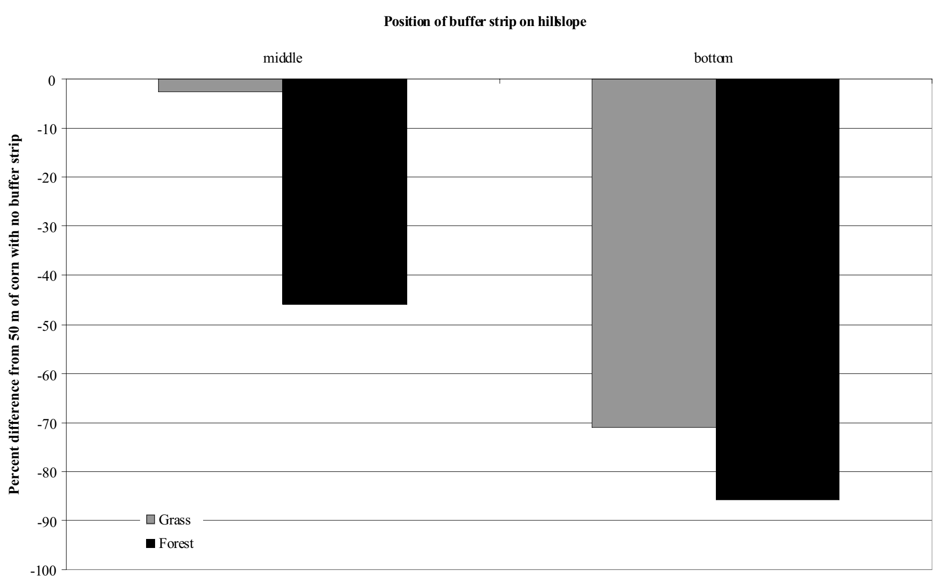

Figure 6.3.2. Sediment yield sensitivity to buffer strips (40 m corn with 10 m buffer).

Cover sensitivity

The sensitivity of WEPP to cover changes was also evaluated. A 50 m hillslope with silt loam on 2.5% slope was used to evaluate changes in runoff and sediment yield with cover condition. Four different cover types (corn with conventional tillage, grassland, forest, and urban) represent the range of cover conditions observed in Valley Creek. The analysis compared and contrasted the results from grassland, forest, and urban conditions with those obtained from corn with conventional tillage. Figure 6.3.3 shows these results. Grassland and forest cover reduced both runoff and sediment yield considerably. The urban cover increased runoff dramatically (383%), while sediment yield was reduced by 100%.

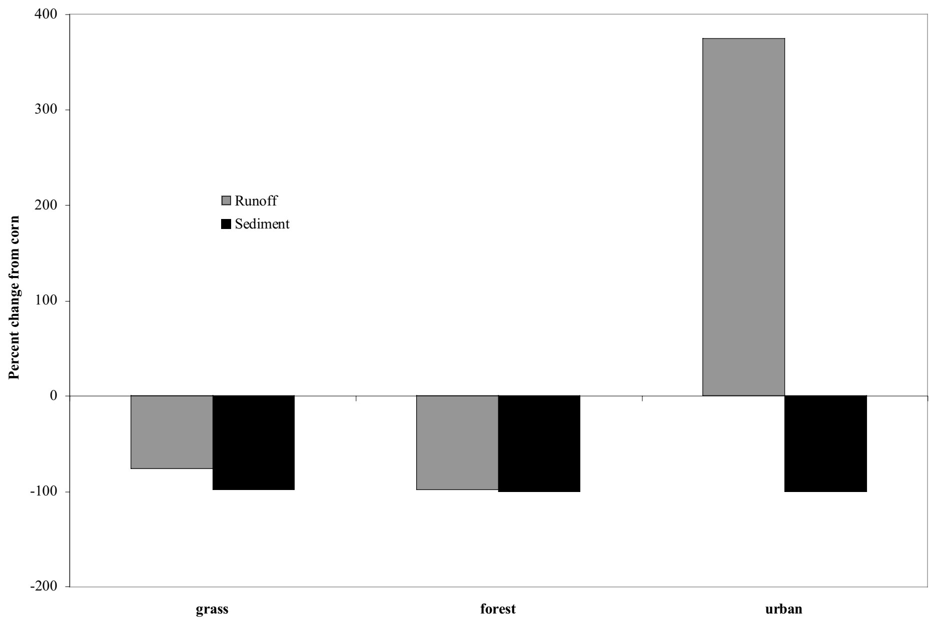

Figure 6.3.3. Runoff depth and sediment yield sensitivity to land use.

Number of hillslopes sensitivity

Unlike most hydrologic models, WEPP uses hillslopes to simulate runoff and sediment yield from fields or watersheds. Although this strategy is ideal to capture the variability along hillslopes, the proper number of hillslopes needed to accurately model a watershed is unknown, and therefore an analysis was conducted to evaluate the sensitivity of the results to this parameter. The analysis compared results obtained from four separate simulations that varied the number of hillslopes within the 450 acre Section 19 watershed (see Section 6.4 for more information about this watershed). The sensitivity analysis compared the annual runoff depth and sediment yield for 14, 7, and 5 hillslopes to those obtained using 43 different hillslopes.

The sensitivity results are shown in Figure 6.3.4. Surprisingly, the 5-hillslopes runoff depth and sediment yield were closest to those obtained using 43 hillslopes. The sediment yield from the 14-hillslope simulation was quite high. This simulation was dominated by two hillslopes consisting of corn with conventional tillage on 10% slopes. Overall, the sensitivity analysis suggests that the selection of the number of hillslopes is not trivial and should be carefully considered for each individual project.

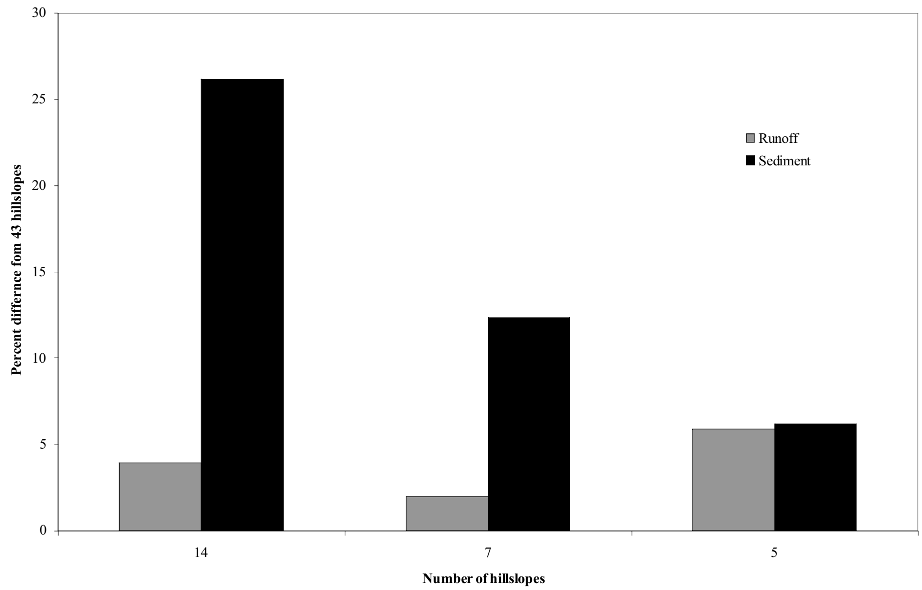

Figure 6.3.4. Sensitivity of runoff and sediment yield to the number of hillslopes.

Based on the sensitivity analysis, the watershed was reasonably represented by 5 hillslopes. Thus a ratio of one hillslope per 90 acres of watershed area was used as a criterion for defining the number of hillslopes to represent the watershed. On this basis, the entire Valley Branch watershed (17 sq. miles) was simulated with 110 hillslopes.

Accuracy of annual runoff depth

Annual runoff depths predicted by the WEPP model are shown in Figure 6.3.5 for each subwatershed of Valley Creek. These values are based on twenty-year simulations. Also shown in this figure is the long-term average runoff depth for the Valley Creek area. This value was obtained from maps of runoff depths compiled by the Minnesota Department of Natural Resources. The annual runoff depth obtained from the 18 months of data collected as part of this project is shown as well.

There are considerable differences in average annual runoff depth among subwatersheds. Runoff depths of forested areas are considerably smaller than those obtained from agricultural lands, which is consistent with established hydrologic theory. The predicted yearly average for all subwatersheds (92 mm) is, however, noticeably smaller than the long-term average for this area (DNR value = 147 mm) and is substantially smaller than the runoff depth measured for Valley Creek (300 mm).

The DNR value is based on observed runoff in streams in nearby watersheds that are frequently dominated by agricultural lands. Therefore the predicted annual runoff depth from agricultural subwatersheds (130 mm) is a better measure of the accuracy of WEPP, and this value is in reasonable agreement with the DNR long-term average. The observed runoff depth is based on only 18 months of data and therefore is not a reliable estimate of average annual runoff depth. Nonetheless, this value is likely a reasonable reflection of the relatively large base flow for the watershed. The base flow for Valley Creek is probably caused by subsurface flow from an area larger than the surficial watershed boundaries. Accurate simulation of base flow would therefore require different watershed boundaries for surface and subsurface processes. This level of modeling was outside of the scope of the project. Overall, the predicted average annual runoff depths of WEPP were reasonable.

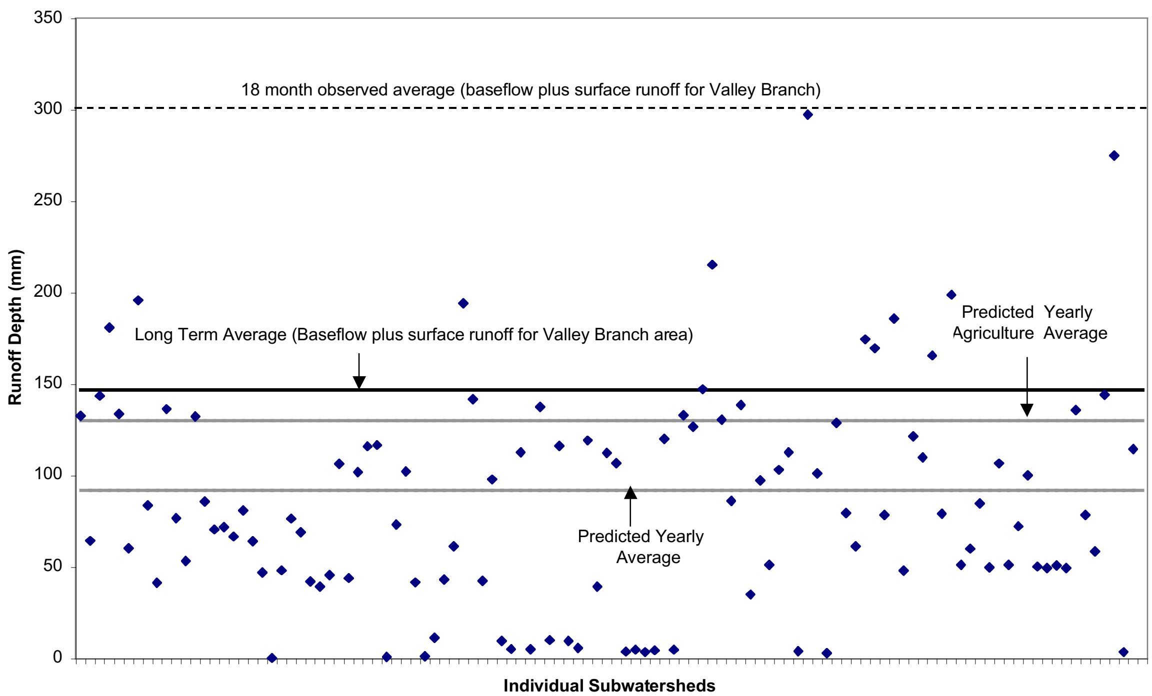

Figure 6.3.5. Evaluation of annual runoff depth predicted by WEPP.

Seasonal trends in runoff depths

The hydrologic accuracy of WEPP can also be evaluated by comparing the seasonal trends in runoff with observed values. This evaluation allows the algorithms of seasonal-dependent processes to be assessed. The seasonal trends of WEPP are compared to those observed from four nearby streams and rivers (Vermillion, Sunrise, Bevens, and Nine Mile Creek). The Vermillion River is located in central Dakota County, about 20 miles south of Valley Creek (USGS, 1998a). The Nine Mile Creek flows through Bloomington, MN, in Hennepin County (Meyer, 1999). Beven Creek is located in San Francisco Township, in Carver County, MN (Meyer, 1999). It is about 30 miles southwest of the VBC. The Sunrise River is located in central Chisago County, north of the VBC about 30 miles (USGS, 1998b).

Figure 6.3.6 shows the predicted seasonal trend of runoff for a typical agricultural hillslope and the observed trends for nearby streams. Results are presented as a ratio of monthly runoff depth to annual value. The WEPP model predicts the largest runoff depth in May and then drops considerably from June to August, followed by a slight increase in September. The Sunrise and Vermillion data have an earlier peak; whereas the Nine Mile and Bevens data have a maximum value later in the season. The zero runoff values for January and December increase the ratios of WEPP values for the other months of the year. Overall, the predicted seasonal trends reasonably approximate the observed values.

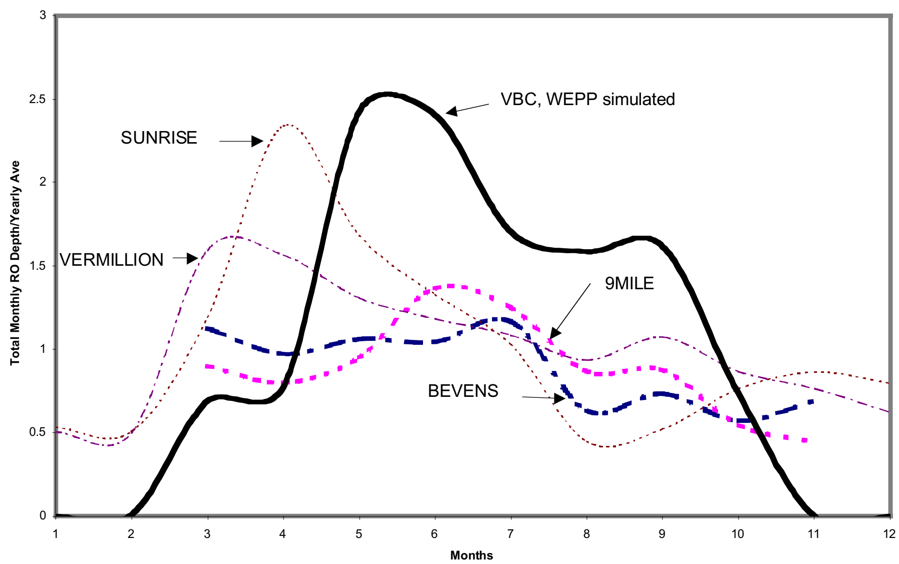

Figure 6.3.6. Predicted by WEPP and observed seasonal trends in runoff depth.

Accuracy of annual sediment yield

The WEPP model is traditionally applied to hillslope lengths of typically 25 to 50 m. However, to efficiently model the Valley Branch watershed, hillslopes were typically greater than 50 m in length. This was necessary to adequately represent the changes in cover and soils along the hillslope. Initial estimates of erosion using these lengths resulted in unreasonably large sediment yields. Therefore, if the length was longer than 50 m, the rill erodibility parameter was set to a near-zero value for that portion of the hillslope greater than 50 m. Physically, the flow would likely converge into ephemeral channels after 50 m, and the modeling approach of WEPP for rill erosion is no longer valid. Since the channels are commonly in or near the bedrock, channel erosion is likely insignificant.

Average annual sediment yields for each subwatershed are shown in Figure 6.3.7. These values are again obtained from twenty-year simulations. There is a wide range in sediment yield among subwatersheds. Relatively large values are predicted for agricultural watersheds and small values for forested watersheds. The average yield for the entire watershed is dominated by the relatively large sediment yield values.

In the previous section, the observed runoff depth for the Valley Creek area was reasonably estimated using nearby streams. This approach is more difficult for sediment yield because it is more sensitive to watershed conditions. Nonetheless, an average value for southeastern Minnesota obtained from Stall (1980) is also shown in Figure 6.3.7. This value was estimated from reservoir survey information and loading from larger rivers. Also shown in the figure is the average sediment yield obtained for the Minnesota River at Mankato, MN. The predicted yields from agricultural lands are generally larger than the observed values; whereas the predicted yields from non-agricultural lands are smaller. Overall, the estimates from WEPP appear reasonable.

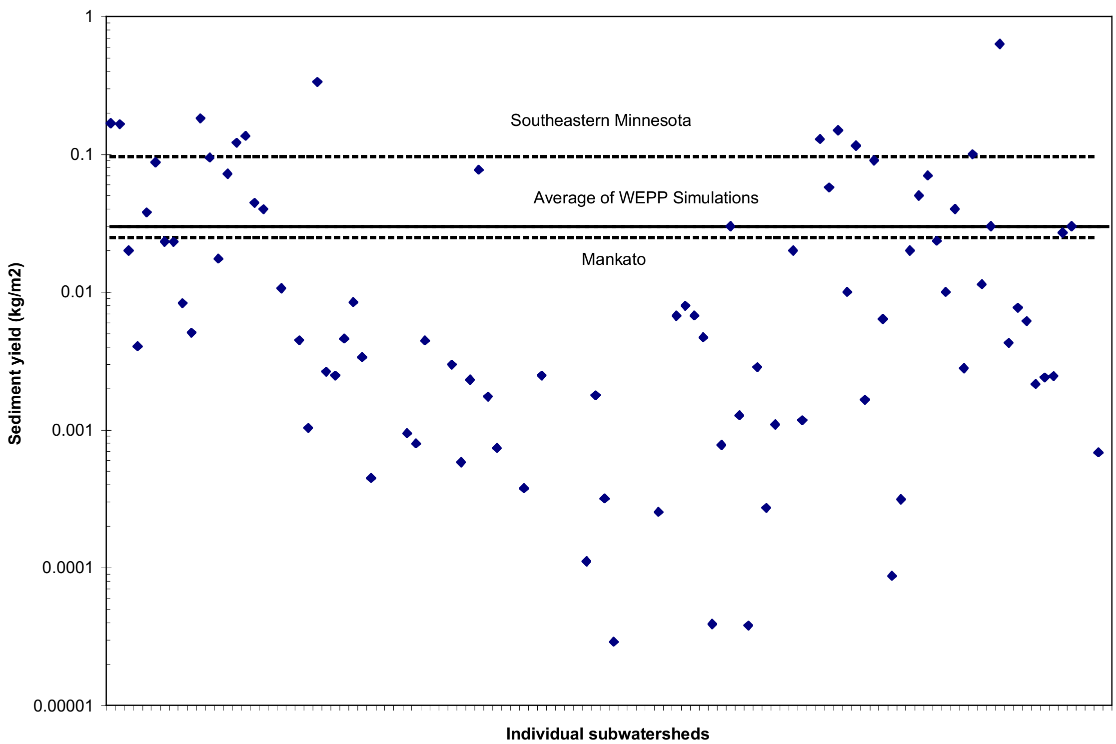

Figure 6.3.7. Evaluation of average annual sediment yields predicted by WEPP.

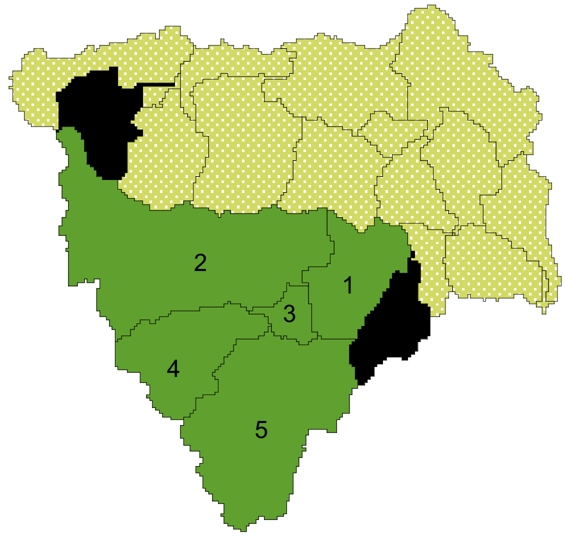

Figure 6.3.8. Southwest watershed of Valley Creek.

SWAT Model

Sensitivity analysis

A more traditional approach was taken for the sensitivity analysis of SWAT. Time constraints, however, dictated that not all of the parameters could be considered. Subwatershed one of the southwest watershed (Figure 6.3.8) was used for the sensitivity analysis. The results for years of 1995-1997 were used.

The sensitivity analysis of runoff depth divided SWAT's parameters into three major components: groundwater, lateral flow, and evapotranspiration. Within each component, parameters were examined for their impact on runoff depth. Groundwater parameters include initial groundwater height, initial groundwater flow contributing to streamflow, the alpha factor (groundwater recession factor), specific yield, revap coefficient (influencing evaporation from groundwater), fraction of root zone percolation, shallow aquifer storage, and initial deep aquifer storage. Lateral flow parameters include site moisture rating, channel length, curve number, saturated conductivity, and average slope length. Evapotranspiration parameters include the temperature lapse rate, the initial soil water content, effective hydraulic conductivity of the stream channel, and available water capacity.

Table 6.3.1 shows the components and the percentage change relative to the default value. The model was insensitive to most parameters. The curve number was the most sensitive parameter. Other parameters that changed the flow by more than 10% were the alpha factor, revap coefficient, initial soil water content, and available water capacity.

Table 6.3.1. Results of sensitivity analysis using SWAT.

GROUNDWATER COMPONENT

Parameter	Input Value	Water Yield % Change
Initial GW	1.0	0.0
HT (m)	100.0	0.0
In. GW Flow	0.5	0.0
(mm/day)	1.0	-0.2
Alpha	0.1	0.0
Factor	0.2	5.4
	0.4	10.1
	0.6	12.2
	0.8	13.3
	1.0	13.9
Specific	0.1	0.0
Yield	1.0	0.0
	100.0	0.0
Revap.	0.001	0.0
Coefficient	0.01	2.2
	0.1	14.2
	0.5	33.6
	0.7	38.2
	0.9	41.5
	1.0	40.7
Revap.	0.1	0.0
Storage(mm)	100000.0	0.0
Rootzone	0.1	0.0
Percolation	1.0	0.0
Initial Deep	0.0	0.0
Aquifer	0.1	3.2
Storage	0.3	5.8
(mm)	0.6	8.5
	0.9	10.8
	1.0	0.0
	1.5	15.2
	2.0	18.9

LATERAL FLOW COMPONENT

Parameter	Input Value	Water Yield % Change
Site	A	0.0
Moisture	B	0.0
	C	0.0
	D	0.0
Channel	4.2	0.0
Length (km)	50.0	0.0
Curve	(49,69)	0.0
Number	(51,71)	3.4
	(53,73)	7.4
	(55,75)	11.7
	(57,77)	16.4
	(59,79)	21.9
	(61,81)	28.3
	(63,83)	35.7
	(65,85)	44.1
	(67,87)	54.0
	(69,89)	65.7
	(71,91)	80.2
Ksat(mm/hr)	(37.02, 32.02)	0.0
Both soils =	10.0	0.1
Both soils =	15.0	-2.3
Both soils =	50.0	-1.7
Both soils =	150.0	2.5
Average	61.0	0.0
Slope	70.0	0.0
Length (m)	140.0	0.0

EVAPOTRANS. COMPONENT

Parameter	Input Value	Water Yield % Change
Temp.	5.0	0.0
Laps Rate	5.5	0.0
(Celsius/km)	6.0	0.0
Initial Soil	1.0	0.0
Water	0.9	-1.6
	0.7	-5.4
	0.5	-9.1
	0.3	-13.1
	0.1	-16.9
Effective	+0	0.0
Hyd.Cond.	+4	0.0
In Channel	+8	1.7
(mm/hr)	+12	3.2
(+) increase	+16	4.9
from orig.	+20	6.2
Available	+0.0	0.0
Water	+.04	-8.9
Capacity	+0.08	-12.3
(mm/mm)	+0.12	-13.9
(+) increase	+0.16	-18.0
from orig.	+0.20	-19.0
SALB,	+0.0	0.0
moist	+0.1	0.0
	+0.2	0.0
	+0.3	0.0
	+0.4	0.0
	+0.5	0.0

The sensitivity analysis for sediment yield was limited to the conservation practice (P), stream channel erodibility and cover in the stream channel. The only sensitive parameter was the conservation practice. To avoid potential errors in stream erosion, the channel erodibility was set to zero.

Accuracy of annual runoff depth

Annual runoff depths predicted by the SWAT are shown in Figure 6.3.9 for twenty-three subwatersheds of Valley Creek. In contrast to the WEPP results, the annual value for each year is given. The variability in runoff depth with time is clearly shown by this figure. For example at the main outlet, the runoff depth for 1987 is approximately four times greater than the runoff depth for 1988. Variability in runoff depths among subwatersheds is also apparent in Figure 6.3.9. The runoff depth is typically greater than 100 mm among subwatersheds.

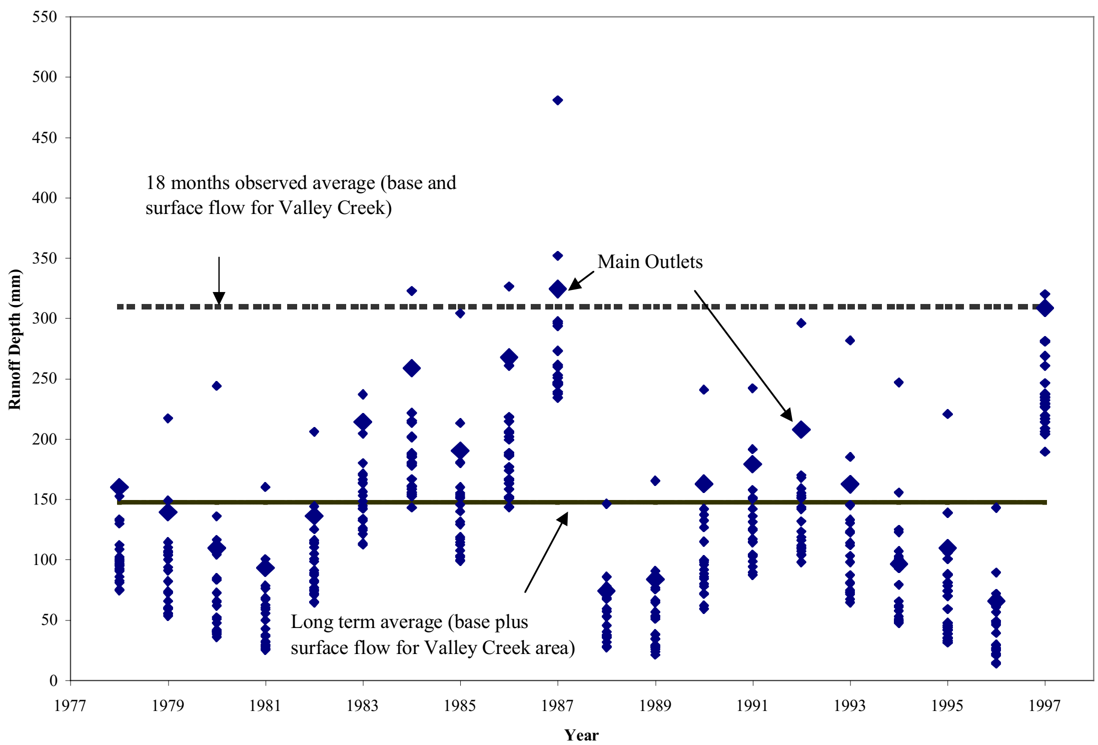

Figure 6.3.9. Evaluation of annual runoff depth predicted by SWAT.

The long-term average runoff depth for the Valley Creek area obtained from DNR data and the annual runoff depth obtained from the 18 months of observed data are also shown in Figure 6.3.9. These depths are identical to those used in the evaluation of WEPP. The accuracy of SWAT is similar to that obtained by WEPP, that is, SWAT reasonably predicts the average runoff depth for the area but drastically underpredicts the observed data gathered in the watershed. As previously discussed, the large observed runoff depth for Valley Creek is likely the result of subsurface flow from areas outside the surficial boundaries used in SWAT. Overall, SWAT adequately predicted the annual runoff depths.

Seasonal trends in runoff depths

The accuracy of SWAT is also evaluated by comparing the predicted seasonal trends in runoff with those observed. Similar to the WEPP evaluation, the predicted seasonal trends are compared to those of four nearby streams and rivers (Vermillion, Sunrise, Bevens, and Nine Mile Creek). Results are presented as a ratio of monthly runoff depth to annual value.

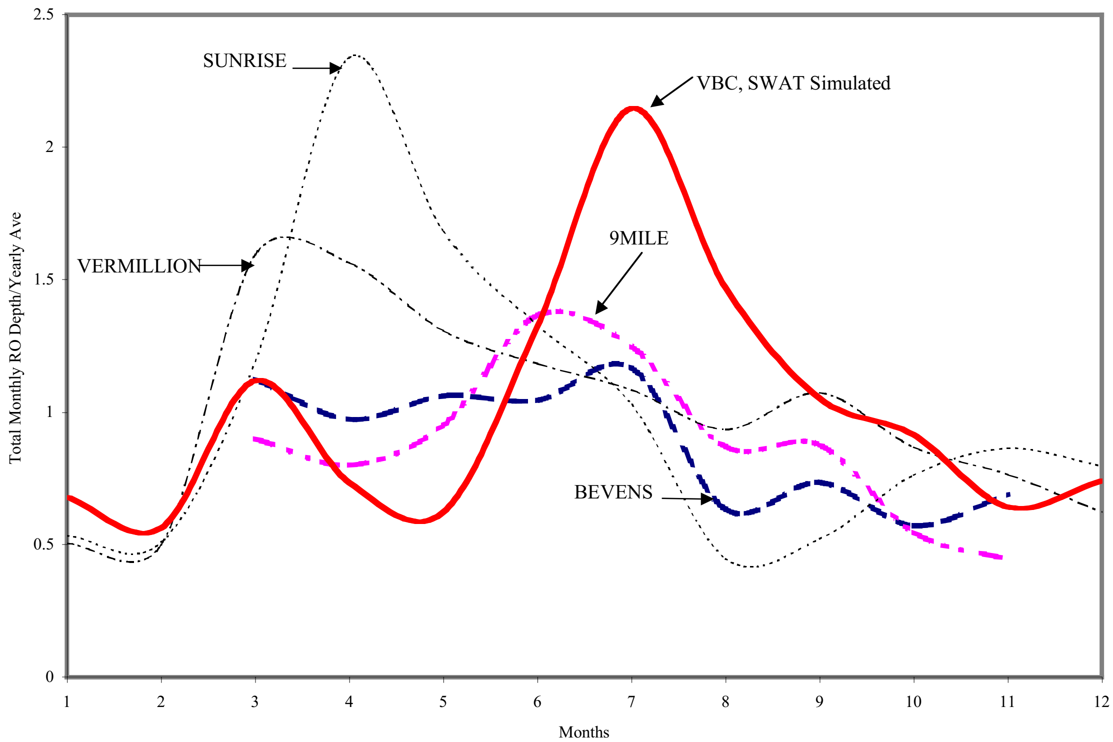

Figure 6.3.10. Predicted by SWAT and observed seasonal trends.

Figure 6.3.10 shows the seasonal trend predicted by SWAT and that observed for the four nearby watersheds. The month with the greatest runoff depth for SWAT is July, which corresponds to the Bevens creek results. The predicted runoff in the winter and spring months is considerably less for SWAT than that observed for Vermillion and Sunrise watersheds. This suggests that snowmelt was unpredicted by SWAT. Overall, SWAT did not predict the seasonal trends for the non-winter months as well as WEPP.

Accuracy of annual sediment yield

Predicted annual sediment yields by SWAT for the subwatersheds of Valley Creek are shown in Figure 6.3.11. These values were obtained from twenty-year simulations. The previously discussed sediment yields for the Minnesota River at

Mankato and for southeast Minnesota are also shown in Figure 6.3.7. There is again a wide range in sediment yield among subwatersheds corresponding to erosion from agricultural and forested conditions. The average yield for the entire watershed is also dominated by the relatively large sediment yield values.

The predicted yields from agricultural lands are generally larger than those observed values; whereas the predicted yields from non-agricultural lands are smaller. The average of the SWAT simulations is greater than that obtained from the WEPP model. It is likely that the SWAT model is overpredicting the sediment yield values.

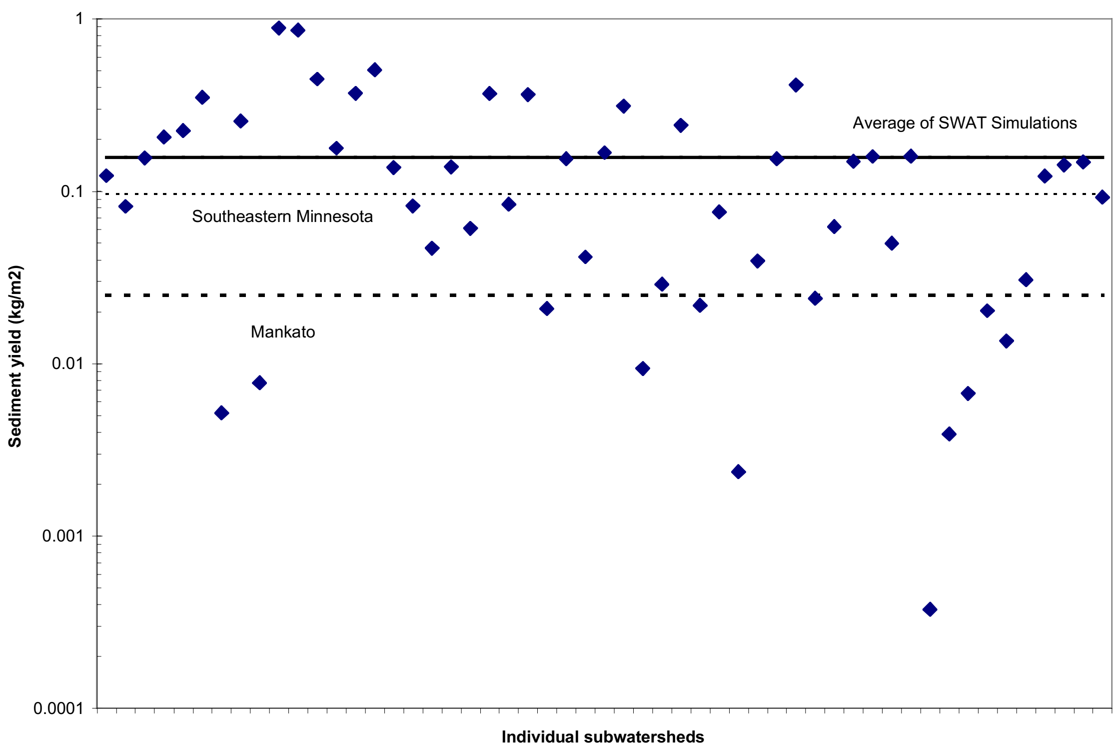

Figure 6.3.11. Evaluation of average annual sediment yields predicted by SWAT.

Summary

The appropriateness of WEPP and SWAT models to simulate the runoff depths and sediment yields for Valley Creek was evaluated by considering the sensitivity of predicted results to input parameters and by comparing predicted to observed values. The sensitivity analysis is used to quantify the uncertainty in predicted values caused by uncertainty in input parameters and to assess the capabilities to simulate the impact of alternative management decisions. Although observed values for Valley Creek were useful in understanding the overall response of the watershed, the limited data was inadequate for evaluating prediction accuracy. Data from nearby watersheds and regional studies were used to evaluate the accuracy of predicted values.

The WEPP model was appropriately sensitive to land use changes and to the spatial distribution to cover conditions along hillslopes. The number of hillslopes needs to be selected carefully to obtain consistent results. This study used one hillslope per 90 acres. The WEPP model adequately represented the annual runoff depth for the Valley Creek region. Although errors were apparent in its prediction for winter month events, WEPP reasonably represented the seasonal distribution of runoff for the other months. The predicted sediment yields were within expected ranges of values for the Valley Creek region. Overall, the WEPP model adequately represented the response of Valley Creek and appears to be well suited to represent land use changes of urban development scenarios.

Parameters for the sensitivity analysis of SWAT were divided into those influencing groundwater, lateral flow, evapotranspiration, and erosion. The curve number was the most sensitive parameter for predicting runoff depth and the conservation practice was the most important parameter for predicting sediment yield. Annual runoff depth was also adequately modeled by SWAT. In comparison to WEPP, SWAT appeared to more accurately predict the seasonal trend of flow for the winter months and to less accurately predict the trend for the summer months. The annual sediment yield was likely overpredicted by SWAT. Overall, the use of SWAT to evaluate urban development scenarios appears to be a reasonable alternative to the modeling approach of WEPP.

SECTION 6.4
SIMULATION APPROACH FOR URBAN DEVELOPMENT

Introduction

This portion of the report describes the procedures used in developing the alternative urbanization scenarios, and it presents maps illustrating them.

The development of the urbanization scenarios proceeded at two geographic scales. A watershed-wide development policy was conceived to guide the distribution of future urbanization throughout the watershed. Following implementation of this smaller scale policy, a series of larger scale site design policies were created to simulate alternative patterns of neighborhood development within the watershed development strategy.

Watershed Development Scenario

Projecting existing development policies into the future simulated the distribution of future patterns of urbanization within the watershed. Existing development policies for the watershed fall into two categories: zoning plans and overlay district regulations. The prospect of land that can be developed based on existing zoning plans and overlay district regulations is moderated by the size and ownership status of existing parcels.

Existing zoning plans

The Atlas of Physiography, Hydrology and Land Use for the Valley Branch Watershed contains a map entitled Existing Zoning Plans. This map displays the current zoning plans for the three political jurisdictions within the Valley Branch watershed. The portion of West Lakeland Township contained within the watershed is currently zoned for residential development at a density of 2-1/2 acres per dwelling unit.

As of the preparation of this report, the City of Woodbury was considering adoption of a revised comprehensive land use plan. If adopted, this plan would provide a mixture of land uses and residential densities for that portion of the city contained within the watershed. The plan also calls for a system of development rights transfers that encourage developers to maintain a greenway plan throughout this area. The section of land on the western side of Manning Trail will be zoned for retail commercial and commercial office space uses. In the far northwestern corner of the watershed, Woodbury's plan would establish a high-density residential district having a targeted gross density of 12 dwelling units per acre. Immediately to the south of the commercial districts, Woodbury's plan would establish a mixed residential district. This area would contain a mixture of detached and attached single family homes at a targeted gross density of three dwelling units per acre. Developers of land within this district who agree to keep the designated greenways free of development and who agree to build a mixture of attached and detached housing units will be able to increase densities on land actually developed up to 5.5 dwelling units per acre. Similarly, developers of land within the commercial district would be allowed to transfer development rights that would otherwise be exercised in the designated greenways onto adjacent commercial land holdings if they agree not to develop the commercial greenways.

The Metropolitan Council designated that portion of the watershed contained within Afton as part of the Rural Preserve on the Metropolitan Area's East Side. The Council encouraged Afton to main a gross density within this area of one dwelling unit per ten acres. Afton's response was to adopt a land use plan that permits densities of five acres per dwelling unit in rural residential districts of the watershed, three dwelling units per 40 acres of land in agriculture districts and one dwelling unit per 40 acres in agricultural preservation districts. The overall intent of Afton's plan is to comply with the Metropolitan Council's preferred policy. Landowners within the Agricultural Land Preservation Districts have voluntarily enrolled their land in a preserve for an eight-year period of time. During this period, owners are prohibited by easement stipulations from developing their holdings at densities exceeding the prescribed density of one dwelling unit per forty acres. Upon termination of the easement's contract period, owners may apply for rezoning to the Agricultural District density (i.e. three dwelling units per 40 acres). The Afton City Council has generally been granted such requests. The Existing Zoning Plan map in the Atlas of Physiography, Hydrology and Land Use in the Valley Branch Watershed illustrates the spatial extent of these zoning districts.

Overlay district regulations

The largest single political jurisdiction within the Valley Branch watershed is the City of Afton. The policies of this jurisdiction were therefore used as a basis for determining land that may be developed under existing public policy. In addition to its Euclidean zoning districts wherein certain land uses and densities are prescribed by zoning regulation, Afton also has a series of "overlay districts" within its zoning ordinance. The regulations of an overlay district become applicable whenever, land meeting a set of defined criteria is proposed for development. In the Atlas of Physiography, Hydrology and Land Use in the Valley Branch Watershed, the locations of these overlay districts are illustrated by the map entitled Undevelopable Land Under Existing Public Policy. The overlay districts address the following issues:

Slopes: The Afton Zoning Ordinance specifies that development occurring in accordance with allowable densities within Agricultural Districts or in Agricultural Preservation Districts must occur of slopes of 13% or less. Development on slopes exceeding 12% requires approval from the Washington County Soil and Water Conservation District. For purposes of defining slopes capable of being developed in this atlas, a criterion of 12% was used. This criterion will likely subsume another requirement that development be setback a minimum of 40 feet from point on a hillside where the slope begins to exceed 18%.

Shoreland and Riparian Setbacks. The Shoreland Zoning Ordinance requires a minimum building setback of 200 feet from the ordinary high water mark of all Natural Environment and Recreational Lakes as well as all trout streams.

Wetlands. Alteration of public water areas in Afton require public water use permits from the Minnesota Department of Natural Resources and the US Army Corps of Engineers and a grading permit from the city. For purposes of defining land that cannot be developed, it was assumed that wetlands would not be disturbed.

Floodplains. New single family homes may be constructed within the 100-year floodplain if their finished floor elevations are above the specified flood elevation and if they are properly flood proofed. However, for purposes of defining land capable of being developed, it was assumed that floodplains would not be disturbed by future development.

In developing a scenario that extends existing public policy for development, the overlay district restrictions on development were presumed to continue into the future.

Existing patterns of land ownership

The map entitled Land Parcel Size and Development Prospect in the Atlas of Physiography, Hydrology and Land Use in the Valley Branch Watershed illustrates that a large majority of the land parcels within the watershed remain in holdings that exceed 20 acres in size. Assuming the presence of willing land sellers, it is likely that future development in the watershed will occur on the parcels larger than 20 acres. The economies of scale afforded to developers seeking to purchase land for development purposes are greater on larger parcels of land. Parcels under 20 acres in size, and especially those under 10 acres, can be considered as being already committed to development.

Some of the parcels exceeding 20 acres in size are in an ownership status that will most likely preclude exercising development options in the near future. For example, the Science Museum of Minnesota owns approximately 127 acres just west of Lake Edith. It is unlikely that this land will be available in the near future for development. Similarly, the State of Minnesota has numerous land holdings throughout the watershed. Land holdings having an ownership status that is unlikely to result in development in the near future are identified on the Land Parcel Size and Development Prospect map via a blue stippled pattern.

The definition of land possessing development potential based on land ownership was presumed to remain constant. Land in a protected ownership status was presumed to not become available for development in the future, and land parcels of less than 20 acres were presumed to be already committed to development. Thus, the land parcels greater than 20 acres in size that were not constrained by any of the overlay development criteria were all presumed to be available for development. The pattern of these parcels within the watershed is illustrated by Figure 6.4.1 entitled Land Development Potential.

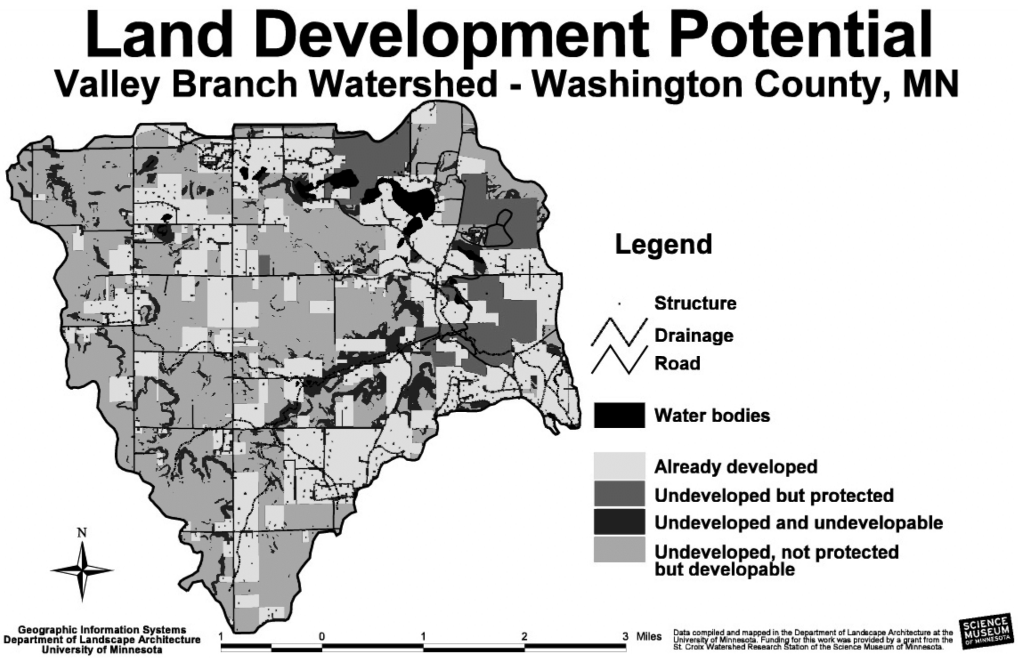

Figure 6.4.1. Land Development Potential, Valley Branch Watershed.

Neighborhood Development Scenarios

The Valley Branch watershed has a somewhat divided set of policies regarding neighborhood development patterns. The division centers on Manning Trail, a human created political boundary that separates what would otherwise be a continuous landscape pattern. On the west side of Manning Trail sits the City of Woodbury preparing to develop the far upper end of the Valley Branch watershed for commercial uses and residential neighborhoods of between 3 and 12 dwelling units per acres. On the east side of Manning Trail sits the City of Afton seeking to maintain a gross density and net density of absolutely not more intensive than of one dwelling unit per five acres. On opposite sides of the same street, there are two jurisdictions having completely different notions of how neighborhood is defined. Furthermore, throughout Washington County, there is considerable debate about the idea of cluster development. In the implementation of cluster development strategies, overall gross densities are maintained at a constant level. However, net density is allowed to rise to a higher level. Within the context of Afton's Rural Residential District, for example, a 50-acre parcel might be developed with 10 homes. However, rather than distributing the 10 homes across the entire 50 acres providing 5 acres of privately owned land for each homeowner, the 10 houses might be clustered on three acres at a net density of 3.3 dwelling units per acre. The remaining 47 acres is then reserved as open space.

Since each of these three ideas of neighborhood is a viable design concept in the context of existing conditions in the watershed, they were selected as alternative neighborhood designs to be simulated in the Valley Branch watershed. The three neighborhood design concepts (i.e. 3 dwelling units per acre gross and net density, 1 dwelling unit per five acre net and gross densities, and 1 dwelling unit per five acre gross density clustered at a net density of 3.3 dwelling units per acre) were simulated in the context of extending existing watershed development policies. Both the three dwelling units per acre gross and net density concept and the one dwelling unit per five acres gross and net density concept were simulated as they would exist with and without application of conventional storm water management technologies. The 3.3 dwelling unit net density clusters having a gross density of 5 acres per dwelling unit were simulated only with the implementation of storm water management strategies.

The five patterns of neighborhood development were simulated throughout the watershed regardless of current densities as allowed by existing zoning plans. This strategy of simulation provides an opportunity to examine the hydrologic and water quality implications of the developable portions of the watershed becoming transformed into development patterns containing 3 dwelling units per acre gross and net densities, 5 acres per dwelling unit gross and net density, and 5 acres per dwelling unit gross density with 3.3 net density clusters.

Detailed designs for each of the five neighborhood scenarios were created in a prototypical first order watershed located in section 19 of the City of Afton (see Figure 6.4.2). The prototypical designs were created to gather land cover information that was used when each of the neighborhood scenarios was simulated in other parts of the Valley Branch watershed.

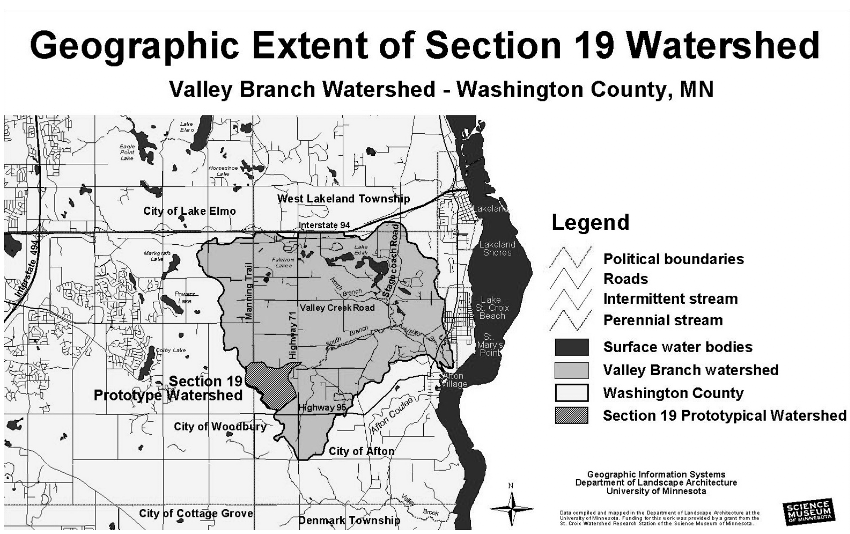

Figure 6.4.2. Geographic Extent of Section 19 Watershed.

Throughout the remainder of this report, the five neighborhood development scenarios are referred to using the following terms:

- Three dwelling units per acre gross and net density without storm water management practices = **high density without ponds.**

- Three dwelling units per acre gross and net density with storm water management practices = **high density with ponds.**

- Five acre gross and net density without storm water management practices = **five acre without ponds.**

- Five acre gross and net density with storm water management practices = **five acre with ponds.**

- Five acre gross density clustered at 3.3 dwelling units net density with storm water management practices = **one-third acre with ponds.**

The five prototypical neighborhood design scenarios as they were created in the section 19 watershed are illustrated in Figures 6.4.3 through 6.4.7, respectively.

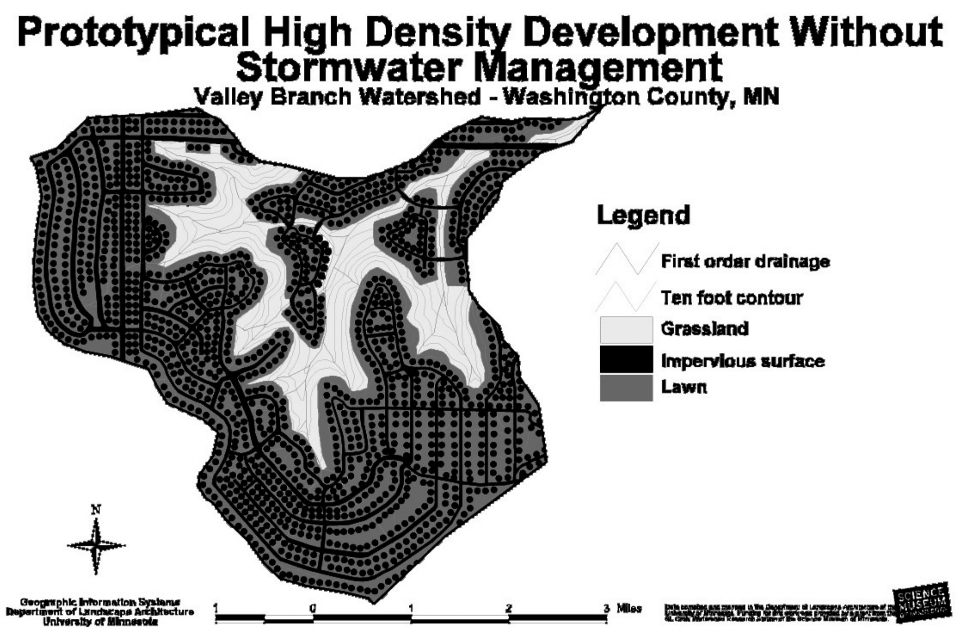

Figure 6.4.3. Prototypical high density development without storm water management.

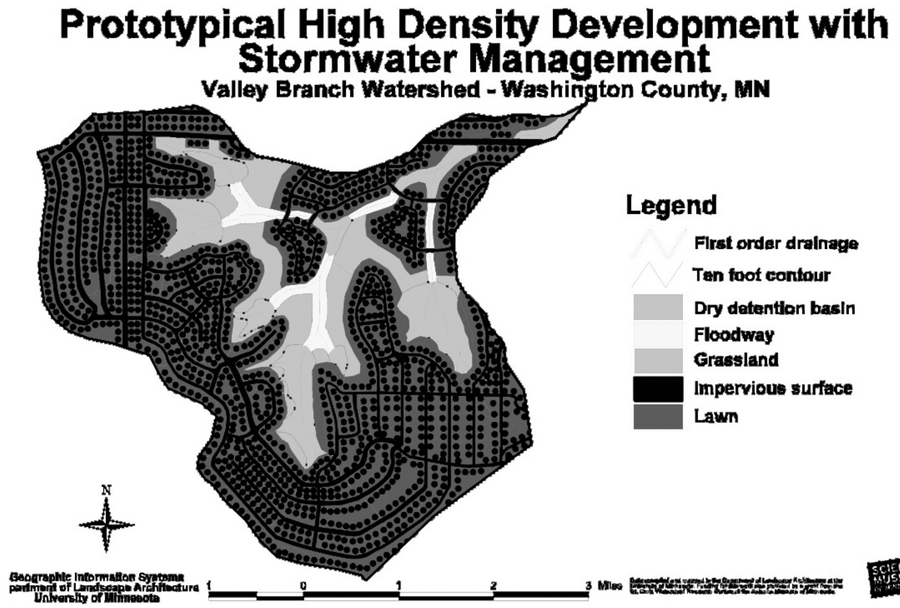

Figure 6.4.4. Prototypical high density development with storm water management**.**

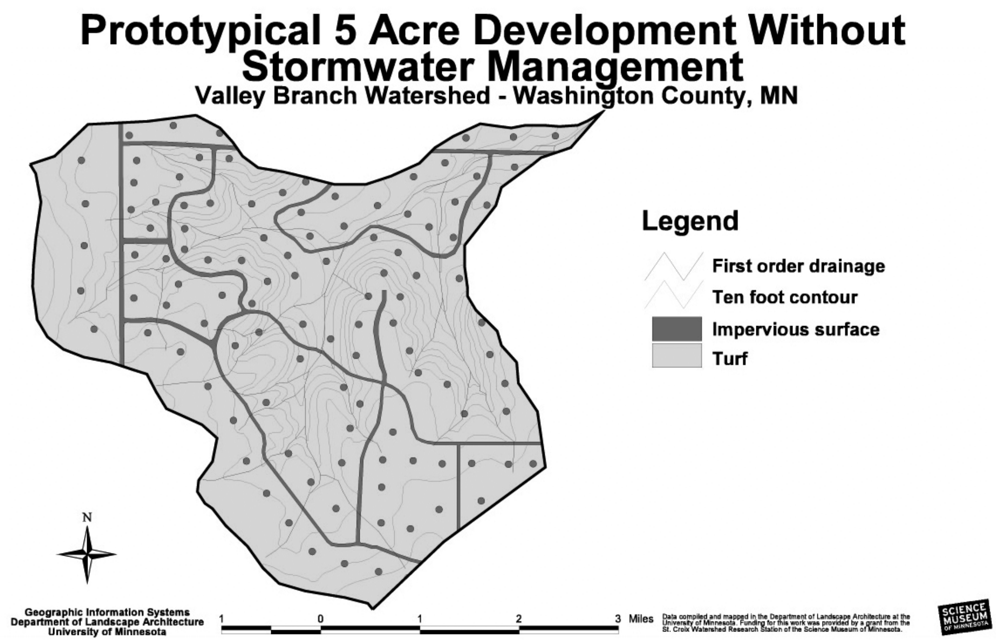

Figure 6.4.5. Prototypical 5 acre development without storm water management.

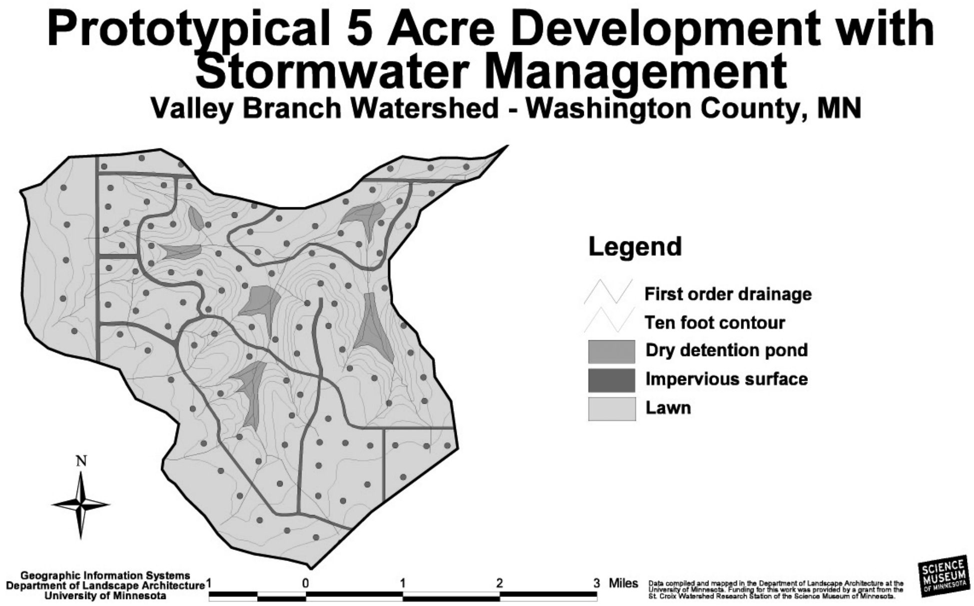

Figure 6.4.6. Prototypical 5 acre development with storm water management.

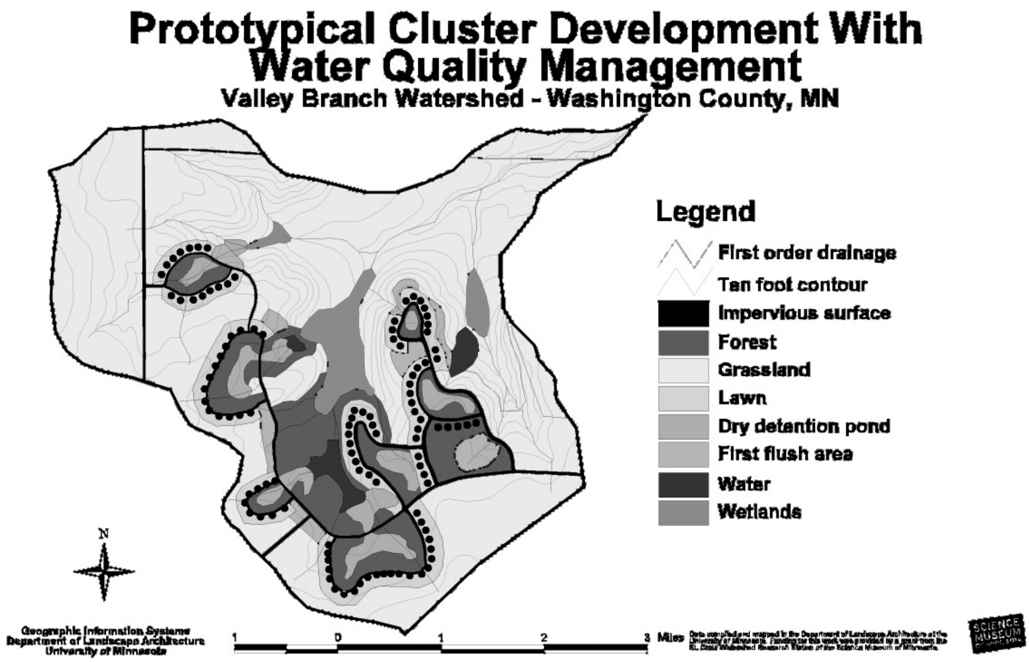

Figure 6.4.7. Prototypical one-third acre cluster development with water quality management.

Simulation of Ponds

Pond evaporation

Evaporation will reduce the annual runoff depth for those developments using ponds. The hillslope version of the WEPP model does not account for this evaporation, and it is difficult to incorporate pond evaporation using Minnesota conditions into SWAT. A simple algorithm was therefore used to account for pond evaporation on the runoff depth. As discussed in the next section, the values for the curve number (for SWAT) and the effective conductivity (for WEPP) were adjusted using this simple algorithm.

The average annual lake evaporation depth for Valley Creek was first determined from maps prepared by the Minnesota Department of Natural Resources. Since the surface area of the ponds vary during the year, the effective area was assumed to be one-half the maximum area. The runoff depth for urban scenarios with ponds can then be computed as

$$RO_p = RO - \frac{E_L A_{\max} / 2}{A_{wtsd}}$$

where RO_p is the runoff depth with ponds, RO is the runoff depth without ponds, E_L is the average annual lake evaporation depth, which for Valley Creek was estimated as 36 inches, A_{max} is the maximum surface area of all ponds in the urban development scenarios, and A_{wstd} is the watershed area.

Trap efficiency of ponds

Ponds will also reduce the sediment load from watersheds. This reduction is simulated in the study by using the BASIN model with watershed inputs from the WEPP model as described by Burt and Wilson (1997). Twenty-years of simulated runoff and erosion data were used as input into the BASIN model to assess the trap efficiency of the detention ponds. The water elevation was assumed to be 3 inches below the pond outlet. The three-inch value assumes roughly 10 days between runoff events. To account for the eventual discharge of fine material suspended in the permanent pool, a fictitious pipe was placed near the bottom to discharge the permanent pool in 48 hours.

The results of the BASIN simulations are shown in Table 6.4.1, where the mass-weighted average values are used in Section 6.5 for each of the scenarios. The relatively high trap efficiencies for the 1/3-acre and 5-acre designs are attributed to the large-sized sediment reaching the detention pond. The low trap efficiencies for the high-density designs is the result of only small sized particles reaching the pond. Erosion here is dominated by interrill erosion capable of only transporting clay-sized material to the ponds.

Table 6.4.1. Average trap efficiencies of detention ponds.

Scenario	Numerical Average	Mass Average
1/3 acre	87%	85%
5 acre	87%	85%
High Density	12%	7%

Representation of Prototypical Watershed – WEPP Model

Development of pavement soils

The development scenarios for the Section 19 watershed have different impervious densities. Percentages of impervious areas are 24% for the 1/3-acre scenario, 30% for the 5-acre scenario, and 65% for the high-density scenario. Having been developed originally for agricultural watersheds, WEPP currently has no direct mechanism for estimating hydrologic performance and sediment yield for impervious surfaces. To simulate impervious conditions, pavement management and soil files were created by manipulating the soil and management files within WEPP. The "pavement management" file consists of a cover crop that resembles a barren landscape with sparse vegetative cover. The "pavement soil" file consists of a clay soil with very low saturated hydraulic conductivity and erodibility values of zero for rill or interill detachment.

Using the detailed design scenarios compiled for Section 19, 130-m transects were drawn through each development scenario to represent flow over pavement and grass segments. The same transect locations were used for all scenarios. Two transects used for the 5-acre scenario are shown in Figure 6.4.8. Annual runoff depth and sediment yield were estimated for a detailed transect (top figure). The parameters for the prototypical transect (bottom figure) were selected to match these values. Development hillslopes were therefore defined by a single unique cover and soil type that produced the same runoff depth and sediment yield as those obtained from the detailed transects of impervious and grass segments. Additional details of this procedure are given in the next two subsections.

The approach illustrated in Figure 6.4.8 was repeated for each development scenario for Section 19. These prototypical development hillslopes were then applied throughout the watershed. The high-density development scenarios were portrayed as having curb and gutter to simulate concentrated flow throughout the development. However the 5- and 1/3-acre scenarios lacked an equivalent curb-and-gutter system, and concentrated flow was not simulated for these developments.

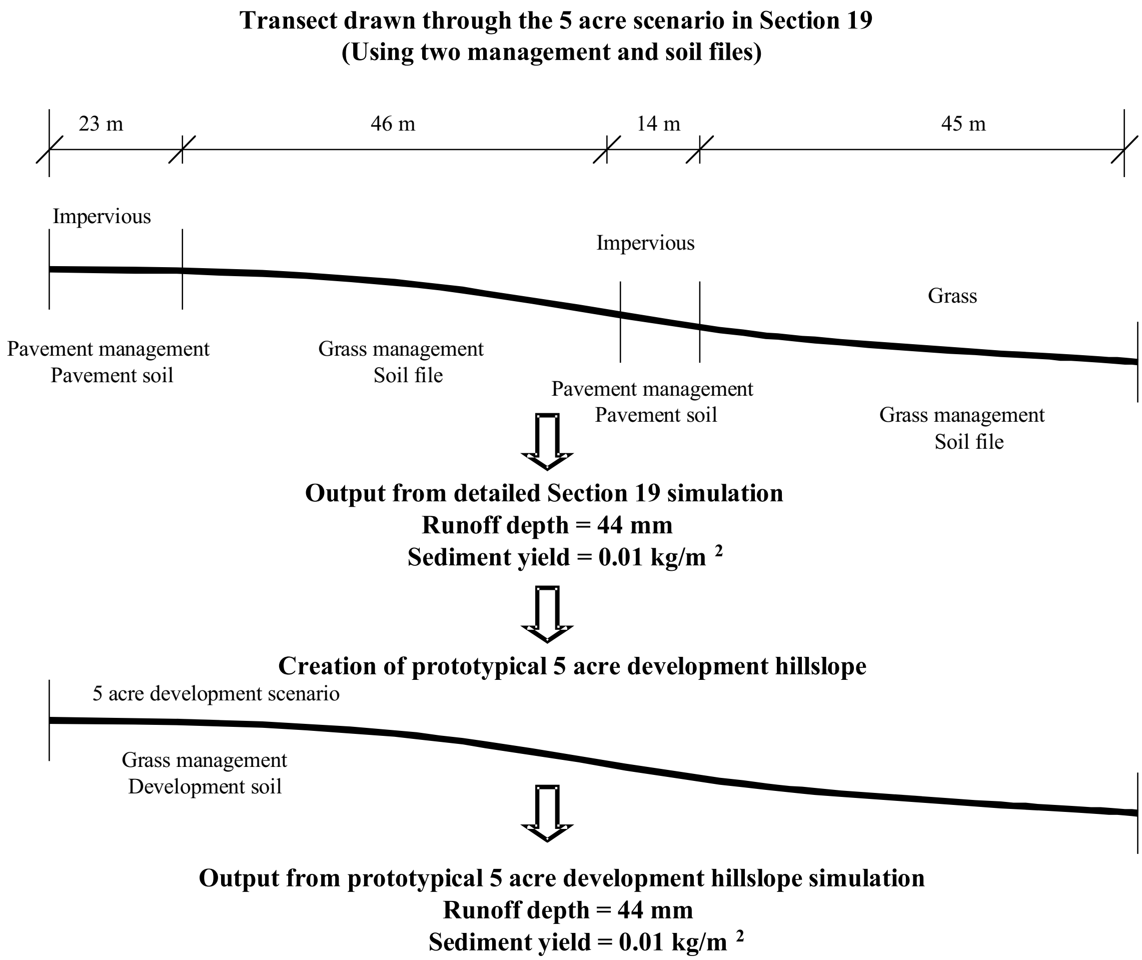

Figure 6.4.8. Illustration of approach used to create pavement files.

Runoff

For annual runoff depth, the saturated hydraulic conductivity parameter was adjusted for the "development soils" to predict the same runoff depth as obtained from the detailed transects. The results are shown in Figure 6.4.9. The process of defining "development soils" was twofold. First, annual runoff depth was plotted against saturated hydraulic conductivity to define a runoff curve. Second, the runoff depth value for each development scenario was used to determine the equivalent saturated hydraulic conductivity for each development scenario. A grass management file was used to define the runoff curve for the 5-acre and 1/3-acre scenarios. A pavement management file was use for the high-density developments.

As an example, the annual runoff depth of 460 mm that was obtained from the detailed transect simulations for the 5-acre development corresponds to an equivalent saturated hydraulic conductivity of 0.2 $m \cdot s^{-1}$. Saturated hydraulic conductivity values were further adjusted to account for the reduction in runoff depth by the evaporation from detention ponds as previously discussed. This adjustment is also shown in Figure 6.4.9.

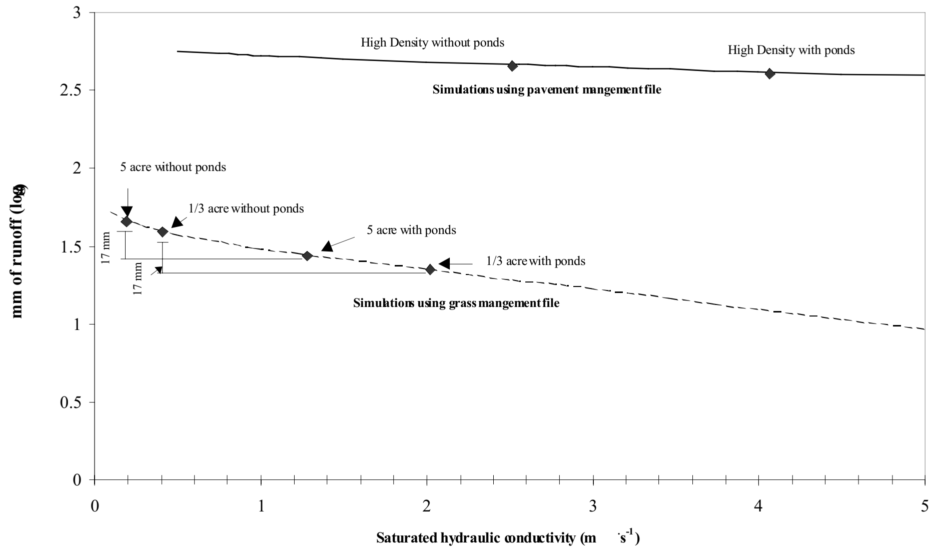

Figure 6.4.9. Saturated hydraulic conductivity for the pavement management file.

Sediment yield

The rill and interrill erodibilities are possible parameters that can be adjusted to match the sediment yield obtained from the detailed simulations. However, the equivalent rill erodibility for the high-density scenario needed to be set equal to zero to obtain the small predicted values of the detailed simulations. Although a nonzero value was used for the 1/3-acre and 5-acre simulations, it was possible to match the sediment yield by simply varying the interrill erodibility.

The procedure of the previous section was also used to define the equivalent interrill erodibility value. Sediment yield was plotted against interrill erodibility to define a sediment yield curve. The sediment yield for each development scenario was located on this curve to determine the pavement's interrill erodibility. The interrill erodibility was also adjusted to account for deposition in detention ponds as previously discussed. The results are shown in Figure 6.4.10.

Representation of Prototypical Watershed – SWAT Model

Creating a watershed with urban land uses

The modeling of development scenarios by SWAT used a similar approach to that taken for WEPP. A prototypical watershed was defined for each scenario by conducting a detailed analysis of Section 19. The parameters for the prototypical watersheds were defined to match the runoff depth and sediment yield of the detailed analysis.

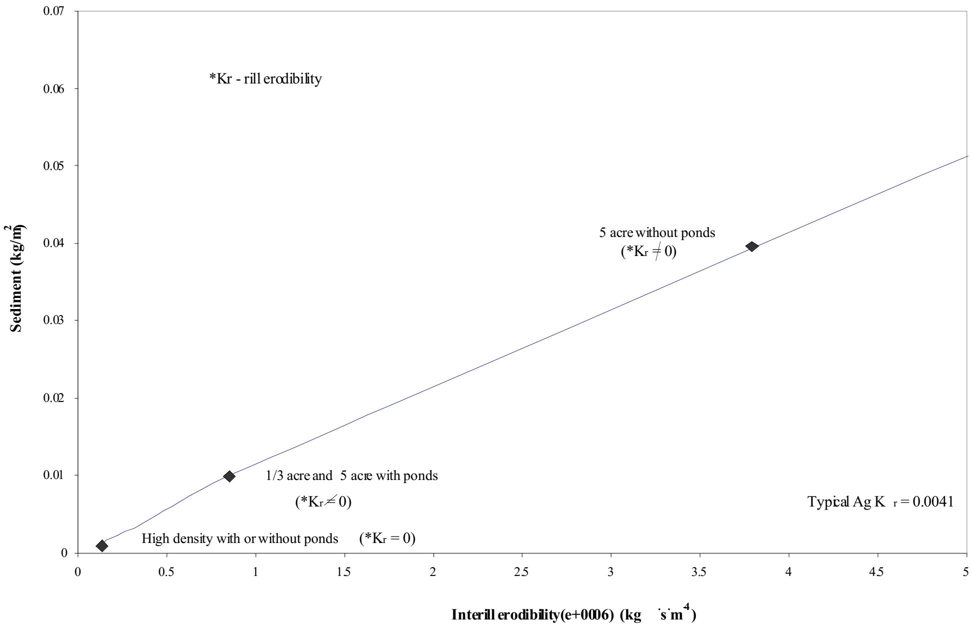

Figure 6.4.10. Sediment yield as a function of interrill erodibility.

Section 19 was divided into six watersheds. The existing condition contained four watersheds dominated by corn, one dominated by hay, and another one dominated by soybeans. The high-density scenario had all watersheds dominated by urban land uses. The five-acre scenario contained two watersheds dominated by pasture land use and three by an urban condition. The one-third acre scenario contains three watersheds dominated by pasture, two in urban and one in forest.

Runoff

The curve number was used to match the runoff depths. The curve number of urban areas (not containing ponds) was computed using (Haan et al., 1994)

$$CN_c = CN_p + \left(\frac{P_{imp}}{100}\right)\left(98 - CN_p\right)$$

where CN_c is the urban curve number, CN_p is the pervious curve number, and P_{imp} is the percent impervious.

The adjustment in curve number to account for the evaporation from ponds is shown in Figure 6.4.11. The runoff curve for a given curve number is given with the runoff with and without ponds. The runoff with ponds is reduced for evaporation as previously discussed. The reduced curve number is then used to simulate the impact of ponds in the development scenarios.

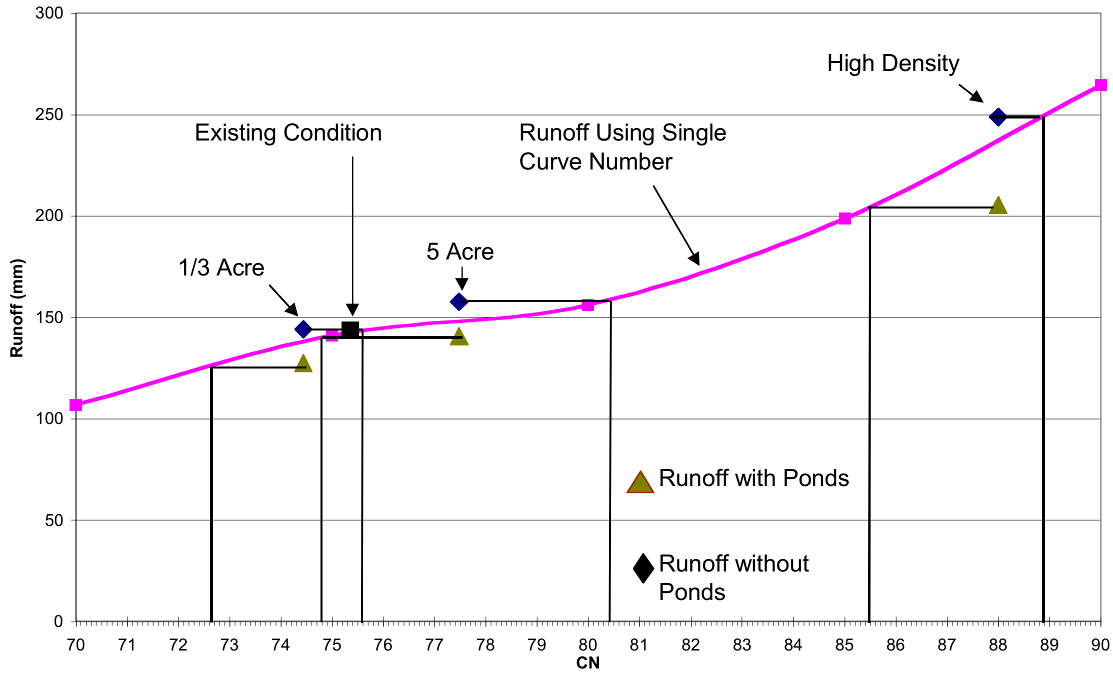

Figure 6.4.11. Selection of curve number for prototypical watersheds.

Sediment yield

To adjust sediment yield, the following equation was used with the C and P factors from the Universal Soil Loss Equation.

$$P_{SWAT} = \frac{C_i P_i}{\overline{C}_{SWAT}} \frac{A_i}{A_T} + \frac{C_i P_i}{\overline{C}_{SWAT}} \frac{A_i}{A_T} + \frac{C_n P_n}{\overline{C}_{SWAT}} \frac{A_n}{A_T}$$

where P_{swat} is the adjusted SWAT value, C_I is the C factor for "i" land use, P_I is the P factor for "i" land use, C_{swat} is the minimum C factor of dominant land use used in the SWAT model, A_I is the area of "i" land use, and A_T is the total area of subwatershed.

When land uses dominated by agriculture (such as corn or soybean) and had an average slope larger than 10%, the following equation was used

$$\overline{CP} = C_1 P_1 \frac{L_1^{m+1}}{L_T^{m+1}} \frac{S_1}{\overline{S}} + C_2 P_2 \frac{L_2^{m+1} - L_1^{m+1}}{L_T^{m+1}} \frac{S_2}{\overline{S}} + C_3 P_3 \frac{L_T^{m+1} - L_2^{m+1}}{L_T^{m+1}} \frac{S_3}{\overline{S}}$$

where $\overline{CP}$ is the combined cover factor and conservation practice factor, L_i is the length of slopes, L_T is the total length of slopes, S_I is the USLE factor for slope on particular land use, and $\overline{S}$ is the average USLE factor for slope of all land uses. The P_{SWAT} is defined as

$$P_{SWAT} = \frac{(CP)_{Landuse}}{\overline{C}_{Landuse}}$$

where is the $(CP)_{Landuse}$ is the combined cover factor and conservation practice factor, and $\overline{C}_{Landuse}$ is the average C factor land use.

Application to Valley Creek

The urbanization scenarios were applied to the developable areas of the watershed. In WEPP, 110 subwatersheds, each with one hillslope, were used to simulate the entire Valley Creek watershed. The development soil and management files were used on the portion of the hillslope corresponding to the developable fraction of the watershed. For example, if 80% of subwatershed X was allocated for potential development, then 80% of the hillslope was converted to a given development scenario (e.g., high density). The remaining portion of the hillslope was left in the existing conditions. For the 110 watersheds, two were classified as 100% developable, and nineteen were classified as having no development potential. The average development potential for all subwatersheds was 41%.

For SWAT, an image was created showing areas of potential development. Watersheds were then created that matched (as close as possible) the developable areas. These development watersheds were then simulated using the procedures discussed in the previous section.

Summary

Urbanization developments were defined using existing zoning plans and by overlaying district regulations. Five neighborhood scenarios were developed using gross and net densities. These scenarios were high density with and without ponds, 5 acre with and without ponds, and 1/3 acre with ponds. Detailed plans were developed for Section 19 of the watershed. Simulations of ponds were done indirectly using annual lake evaporation for Valley Creek and using the results obtained from the BASIN model.

It was impractical to rigorously apply the urbanization scenarios to all of the potentially developable areas of Valley Creek. Instead, detailed analyses were done for Section 19, which was the prototypical watershed for this study. These analyses include comprehensive urban designs, detailed breakdown of land use, development of corresponding input parameters, and the simulation of runoff depth and sediment yield. To use the WEPP model, development soil and management files were defined so that the runoff and sediment yield matched those obtained from the detailed analysis. Different files were developed for each scenario. A similar approach was used for SWAT. These results were then applied to the entire watershed.

SECTION 6.5
RESULTS AND DISCUSSION

Introduction

The simulation results of WEPP and SWAT are presented in this section. The Valley Branch Watershed Plan has divided the watershed into five major subwatersheds as shown in Figure 6.5.1. The percent developable for each of the subwatersheds is also shown in this figure. Analyses of runoff depth and sediment yield are presented for the Section 19 subwatershed and for four of the five major subwatersheds as defined by the Valley Branch Watershed Plan (Lake Edith, Falstrom Ponds, North Valley Branch, and South Valley Branch). The Mouth of the Valley Branch subwatershed was excluded from the analysis because of the minimal land area classified as developable (5%).

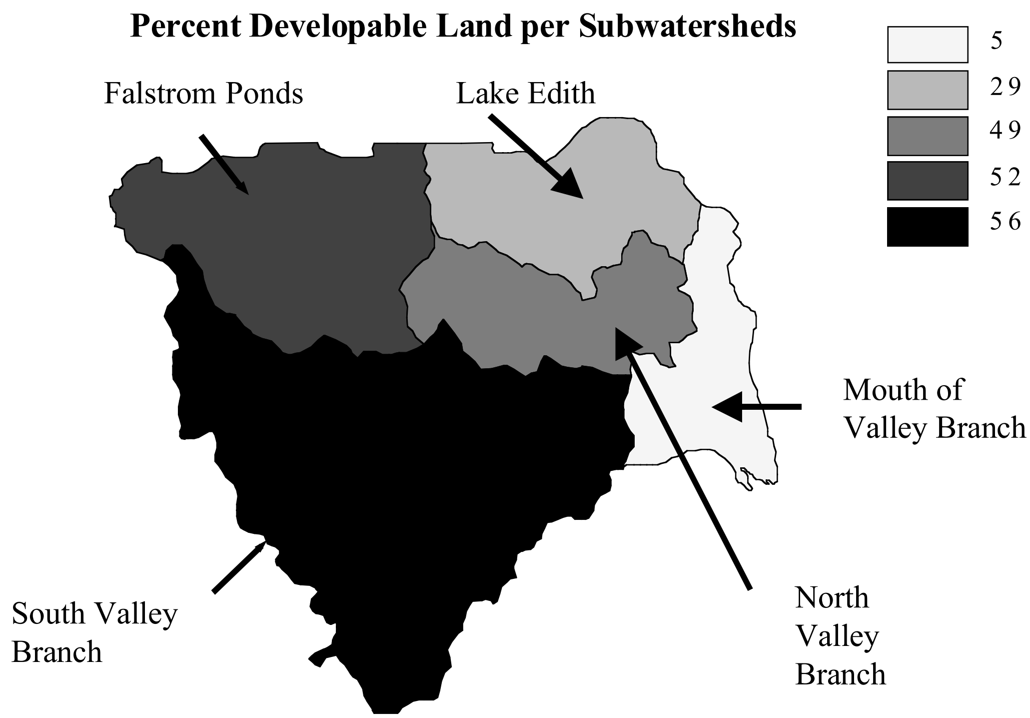

Figure 6.5.1. The five major subwatersheds used in the analysis.

All results are presented as a percent change from existing conditions. If the existing condition is a small value, then a small absolute change can correspond to a large percent change. Analyses are given separately for the WEPP and SWAT models. A brief description of the existing land uses is given in the next section.

Results of WEPP Model

Prototypical watershed - Section 19

Section 19 is a 450-acre subwatershed located in the southwestern portion of the City of Afton. Land use is predominately agriculture (80%) interspersed with small patches of grassland and forest. Drainage is classified as ephemeral throughout the watershed. Approximately 80% of the Section 19 subwatershed was allocated for development.

Percent changes in annual runoff depth for the development scenarios are shown in Figure 6.5.2. The high-density simulations increased runoff depth by 338% without ponds and 289% with ponds. The 5- and 1/3-acre simulations all reduced runoff depths. The 1/3-acre scenario with ponds reduced runoff depth by 73%, while the 5-acre with ponds reduced runoff by 68%. The 5-acre without ponds reduced runoff by 55%.

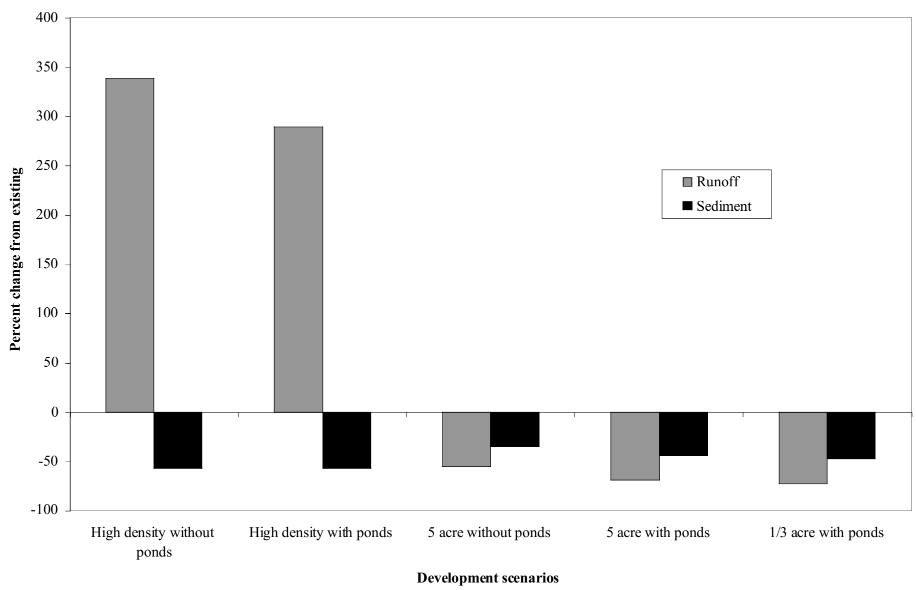

Figure 6.5.2. Percent changes in runoff depth and sediment yield predicted by WEPP for Section 19.

Percent changes in sediment yield are also shown in Figure 6.5.2. All development scenarios reduced annual sediment yield. The greatest reduction was with the high-density scenarios with and without ponds (57%), followed by the 1/3-acre with ponds (48%), 5-acre with ponds (44%), and 5-acre without ponds (36%).

Lake Edith

The Lake Edith region is a 1400-acre subwatershed located in the northeastern section of the Valley Branch watershed. The land use is a mixture of forest (41%), grassland (29%) and water bodies (10%). Twenty-nine percent of the Lake Edith subwatershed was classified as developable.

Percent changes in annual runoff depth are shown in Figure 6.5.3. The high-density simulations increased runoff depth by 51% without ponds and 30% with ponds. Similar to the results of Section 19, the 5- and 1/3-acre simulations all reduced runoff depths. The 1/3-acre scenario with ponds reduced runoff depth by 72%, while the 5-acre with ponds reduced runoff by 71%. The 5-acre without ponds reduced runoff by 66%.

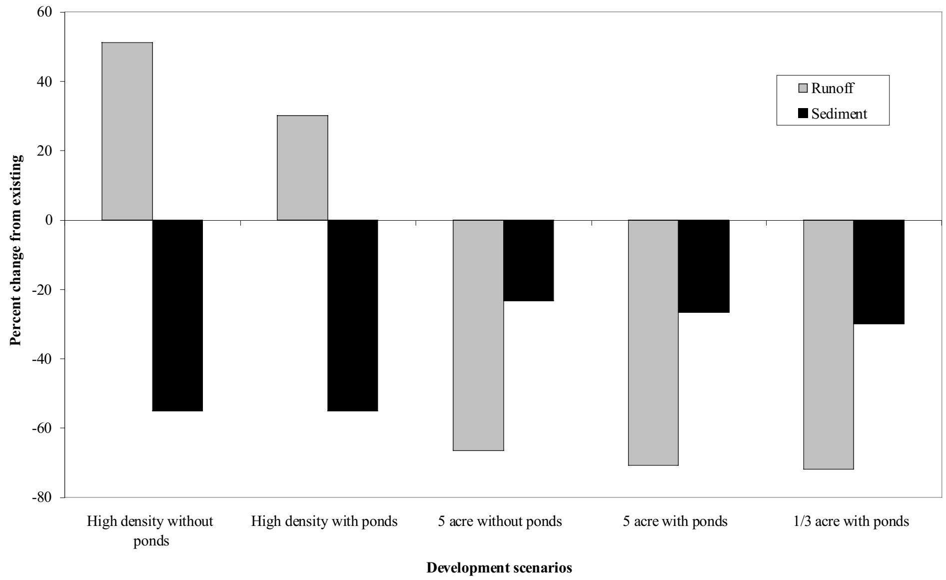

Figure 6.5.3. Percent changes in runoff depth and sediment yield predicted by WEPP for Lake Edith.

Percent changes in annual sediment yield are also shown in Figure 6.5.3. All development scenarios reduced sediment yield. The high-density scenarios had the greatest reduction in sediment yield by 55%, followed by the 1/3 acre with ponds (33%), 5-acre with ponds (26%), and 5 acre without ponds (23%).

Falstrom Ponds

The Falstrom Ponds area is a 2300-acre subwatershed located in the northwest portion of Valley Creek. The Falstrom Ponds subwatershed lies within the cities Woodbury and Afton. This subwatershed is essentially land-locked. Drainage flows north towards I-94 and enters a pipe carrying it under I-94. Once the drainage passes the highway it joins a surface drainage system that carries water to the St. Croix River. Land use is typified by agriculture (39%) and grassland (35%) with forest patches (17%) interspersed throughout the area. Fifty-two percent of the Falstrom Ponds subwatershed was classified as having the potential to be developed.

Percent changes in annual runoff depth for the development scenarios are shown in Figure 6.5.4. The high-density simulations increased runoff depth by 320% (without ponds) and 283% (with ponds). The 5 and 1/3 acre simulations all reduced runoff depths. The 1/3 acre scenario with ponds reduced runoff depth by 41%, while the 5 acre with ponds reduced runoff by 38%. The five acre without ponds reduced runoff by 25%.

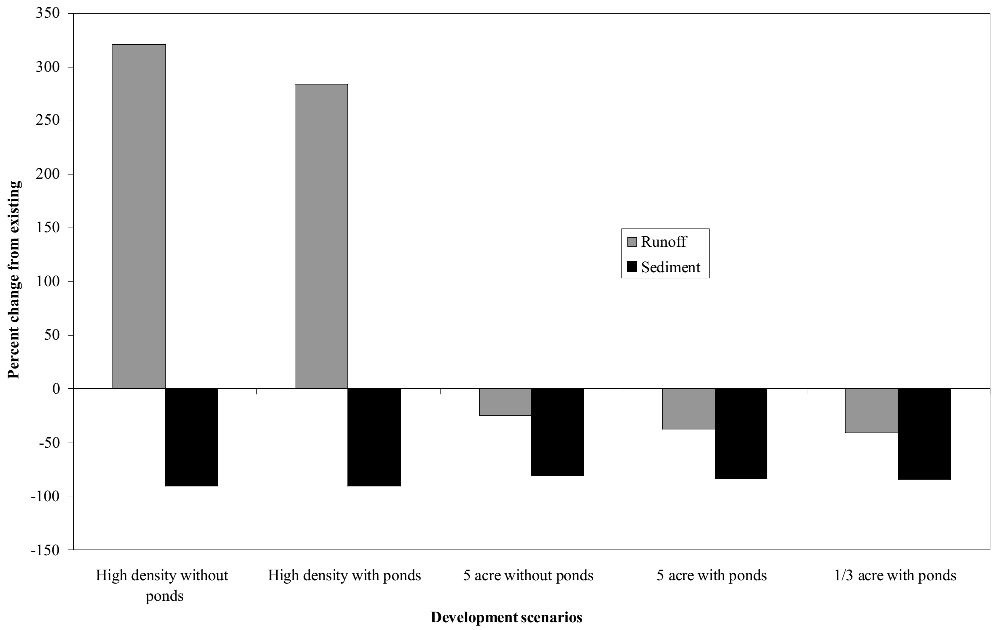

Figure 6.5.4. Percent changes in runoff depth and sediment yield predicted by WEPP for Falstrom Ponds.

Percent changes in annual sediment yield are also shown in Figure 6.5.4. All development scenarios reduced sediment yield. The high-density scenarios reduced sediment yield by 90%, followed by the 1/3 acre with ponds (86%), 5 acre with ponds (83%), and 5 acre without ponds (80%).

North Valley Branch

The North Valley Branch subwatershed consists of 1300 acres of predominately undisturbed cover (41% forested and 28% grassland) with the remaining area in agriculture. The North Valley Branch subwatershed is located south of Lake Edith and north of the South Branch. Both intermittent and perennial drainage exists in the subwatershed, with the perennial drainage joining the south branch just east of Point Douglas Road. Forty-nine percent of the North Valley Branch subwatershed was classified as developable.

Percent changes in annual runoff depth for the North Valley Branch are shown in Figure 6.5.5. The high-density simulations increased runoff depth by 73% without ponds and 55% with ponds. The 5- and 1/3-acre simulations all reduced runoff depths. The 1/3-acre scenario with ponds reduced runoff depth by 60%, while the 5 acre with ponds reduced runoff by 59%. The 5 acre without ponds reduced runoff by 54%.

Percent changes in annual sediment yield are also shown in Figure 6.5.5. All development scenarios reduced sediment yield. The high-density scenarios reduced sediment yield the greatest (86%), followed by the 1/3 acre with ponds (82%), 5 acre with ponds (80%), and 5 acre without ponds (78%).

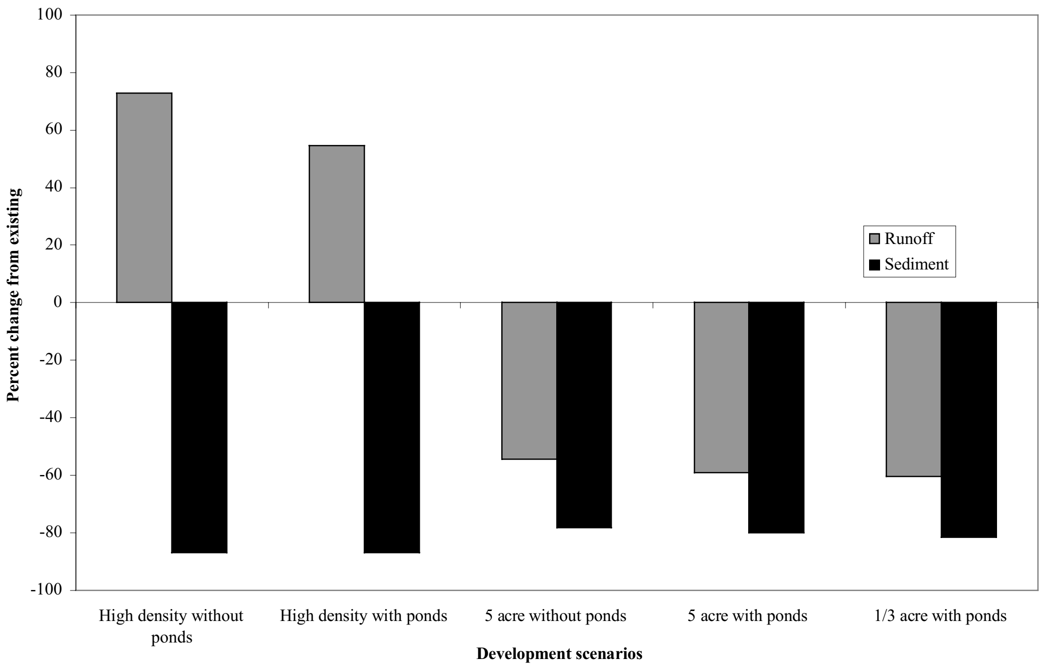

Figure 6.5.5. Percent changes in runoff depth and sediment yield predicted by WEPP for North Valley Branch.

South Valley Branch

The South Valley Branch watershed consists of 5000 acres located in the southern portion of Valley Branch watershed. Land use consists of a mixture of agriculture (45%), grassland (27%), and forested land (24%). Perennial drainage starts within section 17 and flows eastward toward the St. Croix River. Fifty-six percent of the South Valley Branch watershed was classified as having the potential to be developed.

Percent changes in annual runoff depth are shown in Figure 6.5.6. The high-density simulations increased runoff depth by 194% without ponds and 158% with ponds. The 5- and 1/3-acre simulations all reduced runoff depths. The 1/3-acre scenario with ponds reduced runoff depth by 55%, while the 5 acre with ponds reduced runoff by 52%. The five acre without ponds reduced runoff by 44%.

All development scenarios reduced sediment yield as shown in Figure 6.5.6. The high-density scenarios reduced sediment yield by 54%, the 1/3 acre with ponds by 52%, 5 acre with ponds by 50%, and 5 acre without ponds by 45%.

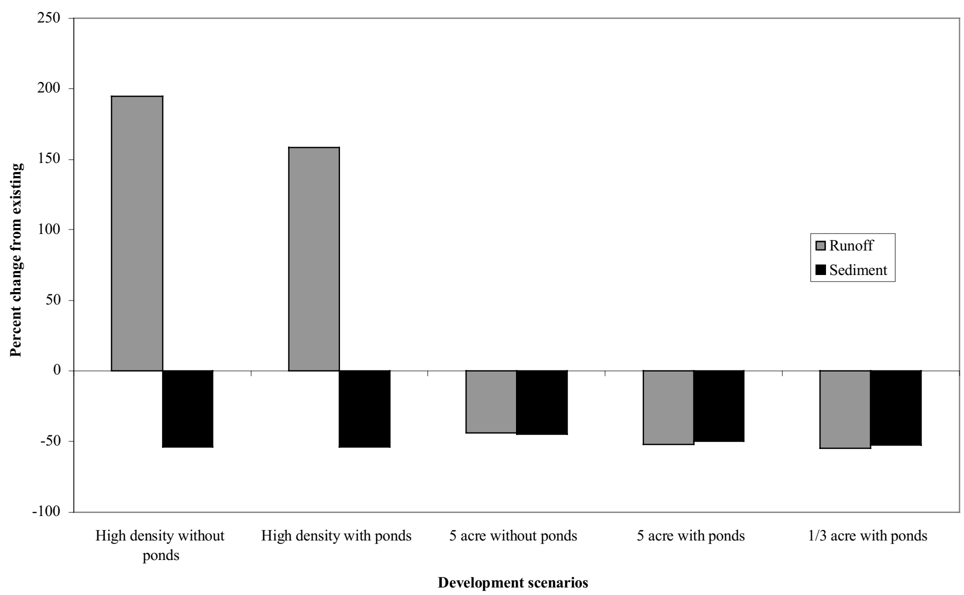

Figure 6.5.6. Percent changes in runoff depth and sediment yield predicted by WEPP for South Valley Branch.

Discussion of WEPP Results

Runoff

A summary of the changes in annual runoff depth is given in Table 6.5.1. For all subwatersheds, the high-density developments increased the annual runoff depth. The largest increase was predicted for the Falstrom Pond subwatershed (320% increase for high-density simulation without ponds). The other urbanization scenarios reduced the annual runoff depth. The 1/3-acre simulation with ponds resulted in the greatest reduction in runoff depth. The use of ponds always reduced runoff depth. In comparison among subwatersheds, the greatest reduction in runoff depth was for the Lake Edith subwatershed (72% decrease in 1/3 acre with ponds scenario), followed by the North and South Valley Branches.

The larger runoff depth from the high-density simulations can be attributed to (1) the conversion of agriculture to grassland, (2) the high proportion of area that was simulated as impervious (65%) in the developable areas, and (3) the presence of curb and gutters to collect and concentrate the runoff. The contrary trends for the 5- and 1/3-acre simulations (where runoff depth was reduced) can be explained by the (1) the low percentage of imperviousness in the developable areas (30% and 24% for respective scenarios) and (2) the lack of curb of gutters to collect and concentrate flow.

Table 6.5.1. Summary of changes in annual runoff depths.

	Section 19	Falstrom Ponds	Lake Edith	N. Valley Branch	S. Valley Branch
Percent developed	80	52	29	49	56
	Runoff				
High density without ponds	338	321	51	73	194
High density with ponds	290	283	30	55	158
5 acre without ponds	-55	- 25	-67	-54	-44
5 acre with ponds	-68	-37	-71	-59	-52
1/3 acre with ponds	-73	-41	-72	-60	-55

Annual runoff depths in this study include both surface and subsurface lateral flows predicted by WEPP. The inclusion of subsurface lateral flow is important in understanding the trends in this table, such as the apparently inconsistent change in runoff depth with the development percentage. For example, a 56% development potential in the South Valley Branch resulted in a 55% decrease in runoff depth for the 1/3-acre scenario; whereas only a 29% development potential in the Lake Edith produced a 71% decrease in runoff depth for the same scenario. In addition, the South Valley Branch subwatershed, which is predominately agriculture on silt loams, had a smaller predicted runoff depth for existing conditions than that for the Lake Edith subwatershed, which is forested/grassland land use on sandy loams and sands.

For subwatersheds with forest/grass cover and sandy soils (such as Lake Edith and North Valley Branch), high infiltration and percolation rates are predicted by WEPP. These high rates result in large subsurface lateral flows, and therefore, larger annual runoff depths than predicted for agricultural lands with silt loam soils. When the development scenarios were simulated, the “development soils” were used to estimate runoff response rather than using the actual sandy loam soils. Since the “development soils” were developed using a silt loam soil, percolation was negligible. Therefore, when development occurred in areas where the soil was either sandy loams or sands (in existing conditions), the runoff depth attributable to percolation was substantially decreased, resulting in a relatively large change in runoff percentage.

The use of ponds did not substantially decrease the runoff depth for the 5- and 1/3-acre simulations. Runoff depths from these scenarios were small, approximately 44 mm. In contrast, runoff depths from high-density scenarios were approximately 460 mm. Consequently, the runoff depth from the development areas was small compared to the runoff depth obtained from the undeveloped portions of the watershed. Further reductions in runoff by ponds were inconsequential because it was a small fraction of the total.

Sediment yield

A summary of the changes in annual sediment yield depth is given in Table 6.5.2. The WEPP model predicted a reduction in sediment yield for all subwatersheds for all development scenarios. Falstrom Ponds had the largest reduction in sediment yield (≈90% reduction for high density), followed by the North and South Valley Branch subwatersheds. The Lake Edith subwatershed had the smallest reduction in sediment yield (≈23% reduction for1/3-acre simulations). The high-density simulations resulted in the greatest reduction in sediment yield; where as the 5-acre-without-ponds scenario had the least reduction. This trend was consistent for all subwatersheds.

Table 6.5.2. Summary of percent changes in annual sediment yields.

	Section 19	Falstrom Ponds	Lake Edith	N. Valley Branch	S. Valley Branch
Percent developed	80	52	29	49	56
	Sediment Yields				
High density without ponds	-56.7	-90.5	-55.0	-86.8	-55.5
High density with ponds	-56.7	-90.5	-55.0	-86.8	-55.5
5 acre without ponds	-35.6	-80.5	-23.3	-78.3	-45.0
5 acre with ponds	-44.4	-83.3	-26.7	-80.0	-50.0
1/3 acre with ponds	-47.8	-84.5	-30.0	-81.7	-52.5

With the exception of high-density simulations, the use of ponds reduced the sediment yield. These reductions were the result of the trap efficiency values given in Section 6.4. Negligible changes in sediment yield for high-density simulations are caused by the small trap efficiencies for this development. As previously discussed, the sediment yield here is dominated by interrill erosion. The transport of large particles is unlikely for these shallow flows, and therefore only clay-sized sediment is reaching the ponds. Since the clay particles are very small and mobile they are not likely to be trapped in the ponds. Although ponds reduced the sediment yield for the 5 and 1/3-acre scenarios, the reduction was less than might be expected from the trap efficiency values reported in Section 6.4. Similar to the discussion of runoff depth, the sediment yield from urban developments is usually small compared to the undisturbed portions of the watershed, and therefore represents a relatively small fraction of the total load. The reduction in sediment yield by ponds is therefore only influencing a small fraction of the total yield.

Impacts of ponds on runoff depth and sediment yield are more readily assessed for a hillslope that is 100% developable. With the addition of ponds in the 5-acre simulations, runoff depth and sediment yield are reduced by 38% and 37%, respectively. This example illustrates the benefits of ponds in reducing runoff depth and sediment yield in developable areas.

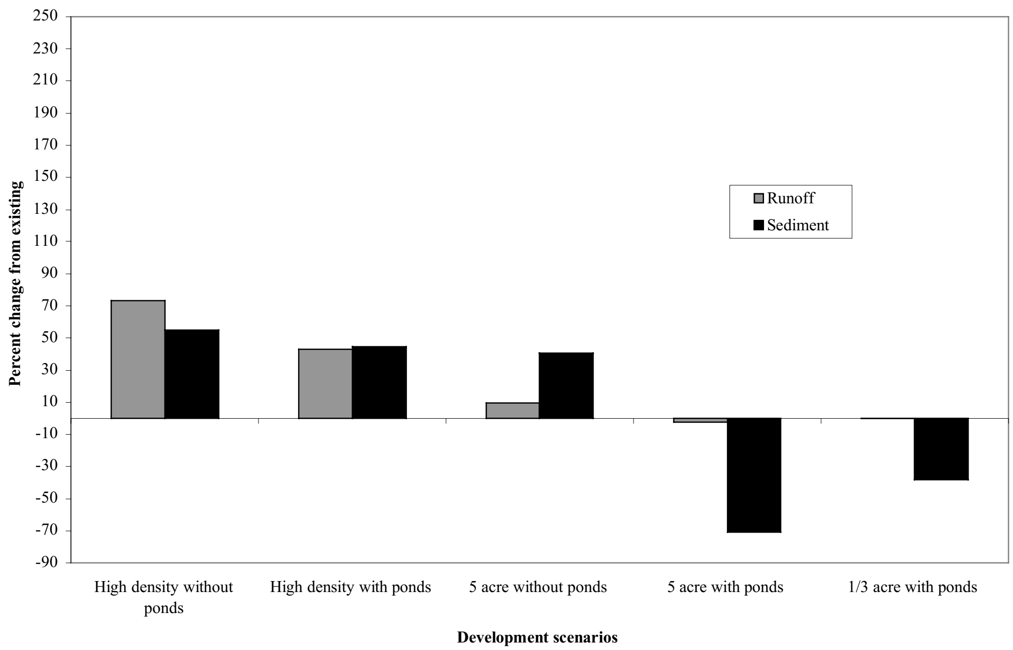

Figure 6.5.7. Predicted change in runoff depth and sediment yield by SWAT for Section 19.

Results of SWAT Model

Prototypical watershed – Section 19

Percent changes in annual runoff depths predicted by SWAT are shown in Figure 6.5.7**.** The high-density simulations increased runoff depth by 73% without ponds and by 43% with ponds. The 5-acre (without ponds) and 1/3-acre (with ponds) simulations both increased runoff depths as well. The 5 acre scenario without ponds increased runoff depth by 10%, while the 1/3 acre with ponds increased runoff by 0.3%. The only scenario that decreased runoff was the 5-acre-with-ponds design, which reduced runoff by only 2%.

Percent changes in annual sediment yield predicted by SWAT are also shown in Figure 6.5.7**.** Both high-density and the 5-acre-without-ponds scenarios increased sediment yield. The high-density scenario with ponds increase yield by 55%, high density without ponds by 45%, and the 5 acre without ponds by 41%. A decrease was found in both the 5-acre-with-ponds (71%) and the 1/3-acre-with-ponds (38%) scenarios.

Lake Edith

Percent changes in annual runoff depth are shown in Figure 6.5.8 for each development scenario. All of the simulations increased runoff depth. The largest increase was found for the high density without ponds, which had an increase of 35%. It was followed by high density with ponds at 26%, 5 acre without ponds at 17%, 5 acre with ponds at 9% and the 1/3 acre with ponds by 7%.

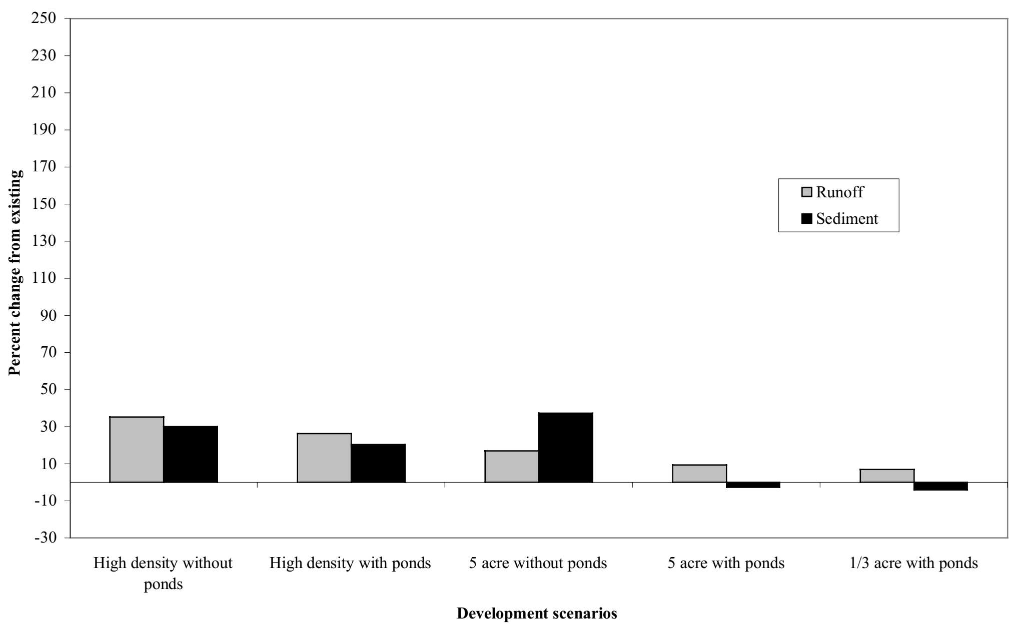

Figure 6.5.8. Predicted change in runoff depth and sediment yield by SWAT for Lake Edith.

Percent changes in annual sediment yield are also shown in Figure 6.5.8. Annual sediment yield increased for each of the high-density and the 5-acre-without-ponds scenarios. The high-density scenario with ponds increased by 30%, high density without ponds by 20%, and the 5 acre without ponds by the largest amount of 38%.

The largest decrease in sediment yield came from the 1/3 acre with ponds, which had a decrease of 4%. This was followed by the 5-acre-with-ponds scenario (3%).

Falstrom Ponds

Percent changes in annual runoff depth for Falstrom Ponds are shown in Figure 6.5.9**.** All of the simulations increased runoff depth. The largest increase was found for the high density without ponds (101%). This scenario was followed by high density with ponds (69%), 5 acre without ponds (36%), 5 acre with ponds (10%), and the 1/3 acre with ponds (3%).

The percent changes in annual sediment yield for each development scenario are also shown in Figure 6.5.9. Similar to the previous subwatersheds, both high-density and the 5-acre-without-ponds scenarios increased the sediment yield. The high-density scenario with ponds increased sediment yield by 224%, high density without ponds by 139%, and the 5 acre without ponds by 226%. The largest decrease in sediment yield came from the 1/3 acre with ponds, which had a decrease of 46%. This was followed by the 44% decrease of 5-acre-with-ponds scenario.

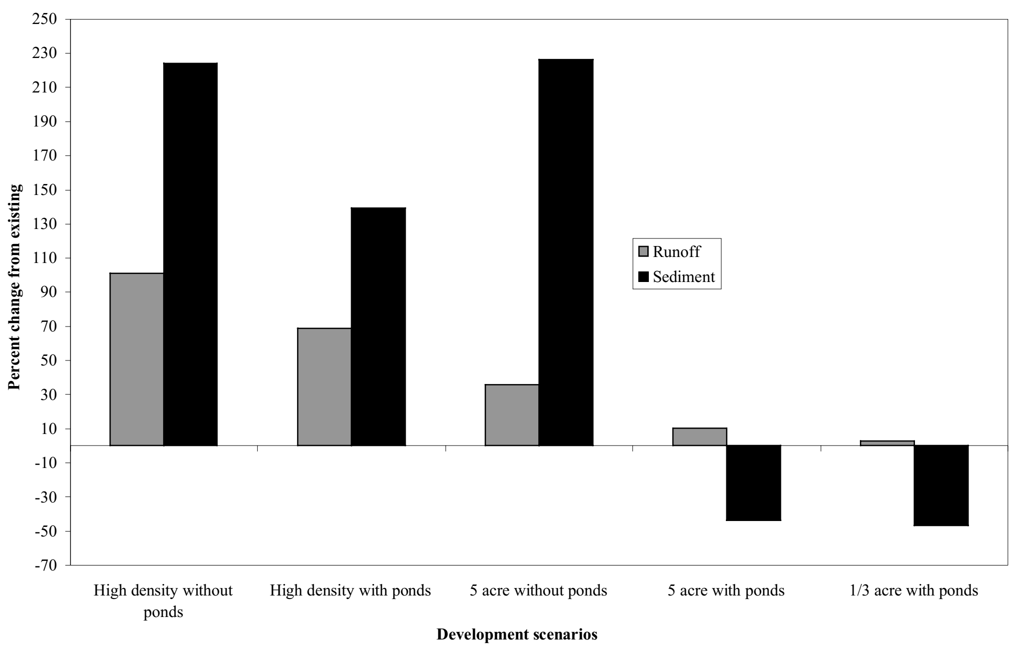

Figure 6.5.9. Predicted change in runoff depth and sediment yield by SWAT for Falstrom Ponds.

North Valley Branch

Percent changes in annual runoff depth for the North Valley Branch subwatershed are shown in Figure 6.5.10. The high-density simulations increased runoff depth by 73%

(without ponds) and 43% (with ponds). The 5 acre (without ponds) increased runoff depths by 10%. Both the 5 acre with ponds and the 1/3 acre with ponds decreased runoff. The 5-acre scenario decreased it by 4% and the 1/3 acre with ponds decreased runoff depth by 10%.

Percent changes in annual sediment yield are also shown in Figure 6.5.10. Three scenarios increased sediment yield; whereas the other two scenarios decreased it. The high-density-without-ponds scenario increased sediment yield by 10%, the high density with ponds by 11%, and the 5 acre without pond by 41%. A reduction in sediment yield was obtained for the 5 acre with ponds (57%), and the 1/3 acre with ponds (59%).

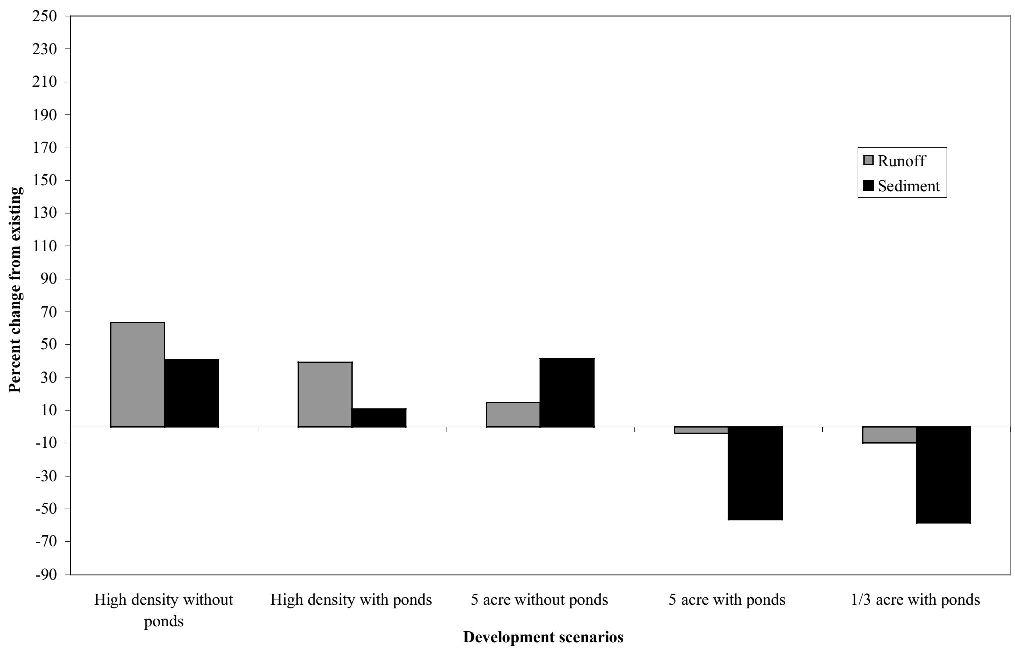

Figure 6.5.10. Predicted change in runoff depth and sediment yield by SWAT for North Valley Branch.

South Valley Branch

The South Valley Branch subwatershed had a constructed detention pond located on its main stream. The sediment load for this watershed was reduced using Brune's curve (Haan et al., 1994). This curve only requires an estimate of the pond volume relative to the runoff volume.

Percent changes in annual runoff depth for the South Valley Branch subwatershed are shown in Figure 6.5.11 for each of the development scenarios. All of the simulations increased runoff depth. The largest increase of 84% was obtained for the high-density-without-ponds simulation. This development was followed by an increase for high density with ponds of 39%, 5 acre without ponds of 15%, 5 acre with ponds of 11%, and the 1/3 acre with ponds of 5%.

Percent changes in annual sediment yield for each of the development scenarios are also shown in Figure 6.5.11. Both high-density and the 5-acre-without-ponds scenarios increased sediment yield. The largest increase (191%) was for the high-density-without-ponds scenario. The high-density-without-ponds development increased sediment yield by 119% and the 5-acre-without-ponds development increased yield by 180%. The largest decrease in sediment yield came from the 1/3 acre with ponds (34%). This was followed by a 26% decreased for the 5-acre-with-ponds scenario.

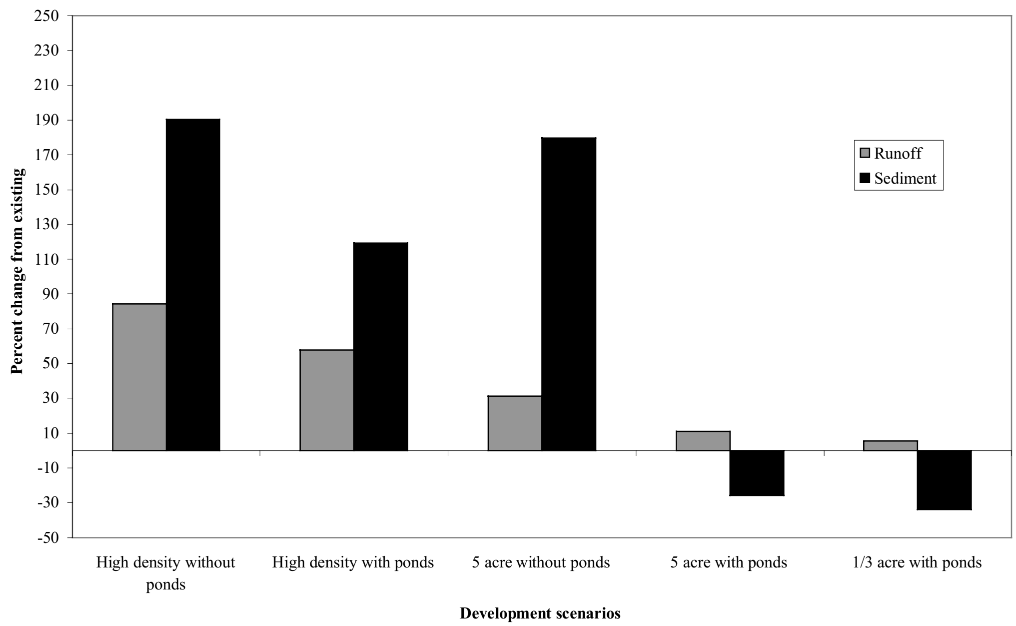

Figure 6.5.11. Predicted change in runoff depth and sediment yield by SWAT for South Valley Branch.

Discussion of SWAT Results

Runoff

A summary of the predicted changes in runoff depth by SWAT for the different developments for each subwatershed is given in Table 6.5.3. Similar to the results obtained with WEPP, the runoff depth increased for all subwatersheds for the high-density simulations. This increase varied between 26% and 101%. Although smaller in magnitude, the 5-acre-without-ponds simulation also increased the runoff depth for all subwaterheds. The change in the predicted runoff depths for the 5-acre-with-ponds and the 1/3-acre-with-ponds was relatively minor, generally within 10% of the existing conditions. Some subwatersheds had an increase in runoff depth for these scenarios; whereas other had a decrease in predicted runoff depth. The range of increase or decrease in runoff depth was smaller for the SWAT simulations than those obtained with WEPP.

As expected, the SWAT model predicted greater runoff depths with an increase in the percentage of impervious surfaces. By using the approach previously discussed, the largest curve number was obtained for the high-density-without-ponds scenario: the smallest for the 1/3 acre with ponds. This corresponds to the expected inverse relationship between runoff depth and curve number. The use of ponds decreased the runoff depths for all development scenarios.

Table 6.5.3. Summary of percent changes in annual runoff depth predicted by SWAT.

	Section 19	Falstrom Ponds	Lake Edith	N. Valley Branch	S. Valley Branch
Percent developed	80	52	29	49	56
	Runoff				
High density without ponds	73	101	35	63	84
High density with ponds	43	69	26	39	58
5 acre without ponds	10	36	17	15	31
5 acre with ponds	-2	10	9	-4	11
1/3 acre with ponds	0.3	3	7	-10	5

Sediment yield

A summary of predicted changes in annual sediment yield by SWAT is given in Table 6.5.4. An increase in sediment yield for all subwatersheds was predicted for both high-density and the 5-acre-without-ponds scenarios. A decrease in sediment yield was predicted for the other two scenarios. The greatest change in the sediment yield was generally obtained for the Falstrom Ponds subwatershed.

The use of ponds decreased the sediment yield. Similar to the results obtained for WEPP, the ponds were less effective in removing sediment for the high-density simulations because of the low trap efficiencies for this scenario. The particle size distribution used to evaluate trap efficiency was obtained from the WEPP simulation. As previously discussed for these simulations, only clay-sized particles were transported to the pond resulting in small trap efficiencies.

Table 6.5.4. Summary of percent changes in annual sediment yield predicted by SWAT.

	Section 19	Falstrom Ponds	Lake Edith	N. Valley Branch	S. Valley Branch
Percent developed	80	52	29	49	56
	Sediment Yield				
High density without ponds	55	224	30	41	191
High density with ponds	45	139	20	11	119
5 acre without ponds	41	226	38	41	180
5 acre with ponds	-71	-44	- 3	-57	-26
1/3 acre with ponds	-38	-47	-4	-59	-34

Summary and Conclusions

The impact of urbanization on annual runoff depth and sediment yield was evaluated for five subwatersheds of Valley Creek: Section 19, Falstrom Ponds, Lake Edith, North Valley Branch and South Valley Branch. Section 19 had the greatest percentage that was developable (80%); where Lake Edith had the least developable area (29%). Both WEPP and SWAT models were used to simulate the response. Different trends were sometimes obtained from the results of the two models. This makes definitive conclusions more difficult and requires greater use of professional judgement (which can be more subjective) in deciding which of the modeling techniques are better suited for the analyses.

Both WEPP and SWAT predicted an *increase* in annual runoff depth for the high-density scenarios. Although WEPP generally supports a greater increase than SWAT, the increase in runoff depth is consistent. The range of increase predicted by WEPP was 30% to more than 300%, depending on the existing land use and the percentage of developable area.

The WEPP model predicted a *decrease* in sediment yield for the high-density scenarios; whereas the SWAT model predicted an *increase* in sediment yield. Physically, the high-density scenarios are increasing the runoff depth corresponding to more erosive flows. On the other hand, these scenarios use surface covers of nearly zero erodibility for impervious areas and low erosion rates from lawns and other grassed areas. In WEPP, erosive flows are conveyed in non-erosive curb-and-gutter systems. Because of its superior representation, the results from WEPP are more likely to be representative of sediment yield trends for the high-density scenarios.

The WEPP model predicted a *decrease* in runoff depth for the 5-acre and 1/3-acre scenarios for all subwatersheds; whereas, the SWAT model predicted a *modest increase or decrease* depending on the subwatershed and the use of ponds. The development plans for these scenarios allowed runoff from impervious areas to flow over relatively high infiltration areas of grass cover. The total runoff depth would then be reduced (generally) by the sequence of flow paths. This runon process is well represented by WEPP. SWAT, however, lumps infiltration for complex pathways into a single parameter. The results of WEPP are therefore generally preferred. Care, however, is needed for the interpretation of the results for Lake Edith and North Valley Branch. Here highly permeable soils were replaced with "pavement soils" of low permeability. The subsurface lateral flows are therefore likely underpredicted by WEPP, and consequently, the predicted percent reduction is likely too large.

The WEPP model predicted a *decrease* in sediment yield for the 5-acre and 1/3-acre scenerios for all subwatersheds. The SWAT model predicted a *decrease* in sediment yield for the scenarios with ponds and an *increase* in sediment yield for the 5-acre-without-ponds scenario for all subwatersheds. For the developable portions of the watershed, the runoff is likely to decrease for the 5-acre and 1/3-acre developments (as previously discussed), and the existing surfaces are likely to be replaced with non-erodible impervious areas or minimal erosion cover corresponding to lawns or other grassed areas. These processes support a decrease in sediment yield. Less confidence, however, should be placed on the results from WEPP for subwatersheds dominated by subsurface flow because of the previously discussed limitation used to define pavement files.

REFERENCES

Arnold, J.G., J.R. Williams, R. Srinivasan, K.W. King, and S. Dagitz. 1997. SWAT User Manual. USDA-ARS, Temple, TX. In: http://www.brc.tamus.edu/swat/swatdoc.html#old

Arnold, J. G., P.M. Allen, and G. Bernhardt. 1993. A Comprehensive Surface-Groundwater Flow Model. J. Hydrol. 142:47-69.

Burt, E.A. and B.N. Wilson. 1997. Impact of Surface Tile Inlets on Quantity and Quality of Water Flows. *In* 1997 ASAE Annual International Meeting, Minneapolis Convention Center, Minneapolis, MN, August 10-14, 1997. Paper No. 97-2153. ASAE, St. Joseph, MI.

Flanagan, D.C. and S.J. Livingston (eds). 1995. WEPP User Summary. NSERL Report NO. 11. West Lafayette.

Foster, G.R. and L.J. Lane. 1987. User Requirements: USDA-Water Erosion Prediction Project (WEPP). NSERL Report No. 1, USDA-ARS National Soil Erosion Research Laboratory, West Lafayette, IN. pp 43.

Haan, C.T. H.P. Johnson, and D.L. Brakensiek. 1982. *Hydrologic Modeling of Small Watersheds*. ASAE Monograph #5, 2950 Niles Road, St. Joseph, MI.

Haan, C.T., B.J. Barfield, and J.C. Hayes. 1994. *Design Hydrology and Sedimentology for Small Catchments*. Academic Press. San Diego, CA, USA.

Hydrologic Investigation Atlas HA-490. 1974. "Water Resources of the Lower St. Croix River Watershed, East-Central Minnesota." U.S. Geological Survey.

Meyers, M. 1999. Researcher for the Metropolitan Council of the Twin Cities. Personal Communication. February and March, 1999.

Oduro, P. and B.N. Wilson. 1997. An evaluation of the water erosion prediction project model. ASAE Paper 972231, Presented at the 1997 ASAE Annual International Meeting, ASAE, 2950 Niles Road, St. Joseph, MI.

Singh, V.P. 1995. *Computer Models of Watershed Hydrology*. Water Resources Publications, Highlands Ranch, CO.

Stall, J.B. 1980. Estimating Reservoir Sedimentation Rates in the Midwest. *In* Proceedings of the Symposium on Surface Water Impoundments ASCE, June 2-5, 1980, Minneapolis, MN. Paper No. 7-7. 8 pp.

U.S. Geological Survey. 1998a. Vermillion River near Empire, MN, St. 05345000, 1977- 1984. Website: waterdata.usgs.gov/nwis-w/MN/?statnum=05345000.

U.S. Geological Survey. 1998b. Sunrise River near Linstrom, MN, St. 05340050, 1965-1985. Web: waterdata.usgs.gov/nwis/MN/data.components/hist.cgi?statnum=05340050.