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AN INTEGRATED IMPACT ASSESSMENT MODEL FOR URBAN WATERSHED PLANNING

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ABSTRACT

An integrated assessment model was developed to evaluate the impact of urban development on stormwater runoff and water quality as well as the effectiveness of the best management practices (BMPs) on stormwater runoff reduction and water quality improvement. The model consists of the following major components: (1) a hydrologic site loading module simulating the runoff and water quality from urban development sites; (2) a BMP module simulating the effectiveness of various types of best management practices; (3) a net-working component linking the loading module to the BMP module and computing the compounding flow network effects; (4) the pre- and post-processors facilitating the data input/output processes. All of the components are integrated into a Windows application allowing the user to apply the model in an intuitive and user-friendly environment. The integrated model is capable of both single storm event and continuous simulation, and can serves as a powerful tool in urban watershed assessment and planning. This paper describes the development of the integrated model and provides example simulations demonstrating its potential use and capability.

INTRODUCTION

The use of best management practices (BMPs) as stormwater pollution control system has gained great attention in recent years. Many state and local governments have provided BMP guidelines and design criteria for developers to minimize the impact of urban development on the receiving water bodies. Pollutant removal efficiency data for different types of BMPs are also widely available (U.S. EPA, 1986). However, the use of these data on evaluating a specific BMP is severely limited as most of these data are collected without regard to the site specific geophysical information and unrelated the hydrologic and pollutant removal mechanisms. To address this deficiency, we developed a site assessment model incorporating hydrologic and pollutant removal mechanisms and the site specific information to evaluate the efficiency of a BMP. The model provides the user the following capabilities:

- Evaluate the effects of various BMPs (structural and non-structural) on runoff flow and pollutant reduction.
- Allow the user to input data without worrying data format.
- Provide default input data related to different land uses and soil types.
- Visualize land and BMP units and their compounding flow pattern.
- Display the output results graphically without using external software packages.

MODEL DEVELOPMENT

The SAM model consists of two core modules, the site hydrologic loading module (SHLM) and the BMP evaluation module (BMPEM). The SHLM module simulates the runoff flow and pollutant loads from a site while the BMPEM module determines the removal of runoff and pollutants in the BMP. Both modules are deterministic and based on various hydrologic and physical, chemical, and biological processes. In addition to the two core modules, the model has three auxiliary modules include the network connection module and the pre- and post-processors. The auxiliary modules are necessary to make the model user-friendly, which is essential for this model because the potential users are regulators and developers who may have limited computer experience. The model components and the flow chart are shown in Table 1 and Figure 1 respectively.

Site Hydrologic Loading Module (SHLM)

This module determines the runoff and pollutant loads from land units. The runoff depends upon various factors including the intensity and duration of the storm, the initial abstraction, initial soil moisture content, soil infiltration capacity, flow length and slope of the land unit. These factors also affect the pollutant loads, which are a function of the physical and chemical properties of the soil. Currently there are a number of computer models which can be potentially used as the SHLM module. These models include the Storm Water Management Model (Huber and Dickonson, 1992), The Urban Stormwater Runoff Model (U.S. Army Corps of Engineers, 1974), and the Hydrological Simulation Program - FORTRAN (HSPF) model (Bicknell et al. 1993), among others. We choose the HSPF model as it is the most comprehensive and powerful single hydrologic model available at the current time. The HSPF model consists of three main components: PERLND, IMPLND and RECHRES, standing for pervious land, impervious land, and reach respectively. The SAM model incorporates the PERLND and IMLND modules, which can simulate the stormwater runoff and pollutant loads from a variety of pervious and impervious lands. Water quality constituents that can be simulated include BOD_5, total suspended solids (TSS), total nitrogen (TN), total phosphorus (TP),

Table 1. Function of different modules in the SAM model.

Module	Function
Site hydrologic loading module (SHLM)	Determine the runoff and pollutant loads from land units from storm events
BMP evaluation module (BMPEM)	Use the output from SHLM as input and determine the runoff flow and pollutant reduction in the BMP unit
Network connection module	Allow the usér to specify flow patterns and calculate the compounding effects.
Pre-processor	Provide a user friendly and intuitive data entry environment. Also allow the user to select input data from default input databases
Post-processor	Present the output results graphically and or export the them to other software

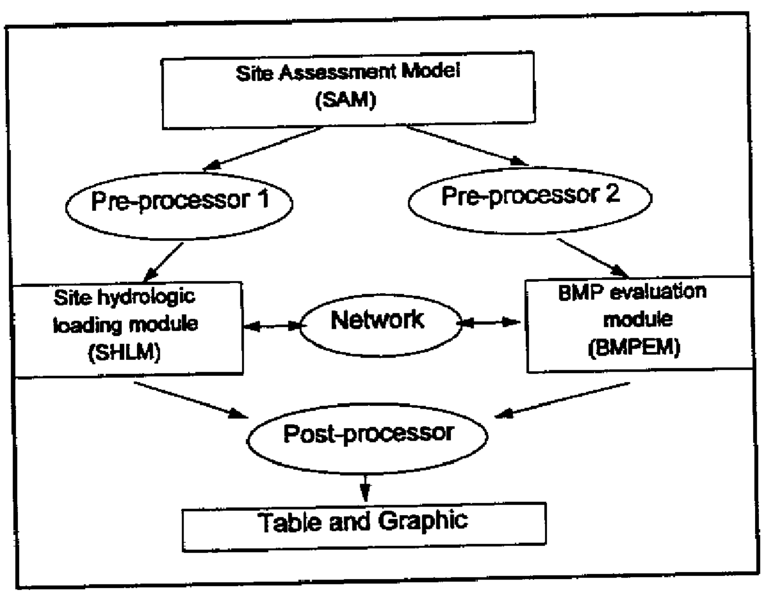

Figure 1. Flow chart of the site assessment model.

pesticide, metal, and tracer. Modeling mechanisms in the HSPF model are fully documented by Huber and Dickonson (1993).

BMP Evaluation Module (BMPEM)

The BMPEM module evaluates the effectiveness of different types of BMPs on the reduction of runoff and pollutant loads. Urban BMPs can be generally categorized into the following four types (Woodward-Clyde Consultants 1990):

(1) Detention Basins - runoff is temporarily stored or detained and subsequently discharged to a surface water, including dry ponds, wet ponds, and extended detention dry ponds;

(2) Retention Devices - runoff is permanently captured by infiltration so that it never discharges directly to a surface water, including infiltration basins, infiltration trenches and dry wells, porous pavement;

(3) Vegetative Controls - runoff is contacted with vegetated areas so that pollutant concentration are reduced by a combination of filtration, sedimentation and biological uptake, including basin landscaping, wetlands, grassed swales, and filter strips; and

(4) Source Controls - runoff, discharge and source pollutants are reduced by regulations, including education, regulation, and guidance.

The first three types are structural BMPs as they are related to some kind of physical facilities, while type four is a non-structural BMP as it focuses on source reduction and elimination and is not related to physical structures. We developed the BMPEM module so that it can simulate the structural BMPs described above. Non-structural BMPs can also be simulated in the SHLM module, using the HSPF's "special actions" function.

The BMPEM module is a deterministic numerical code employing various hydrologic and pollutant removal mechanisms to simulate the water movement and pollutant reduction. Runoff and pollutant removal mechanisms used includes evapotranspiration, water storage and infiltration; settling of total suspended solids; biodecay, adsorption, and plant uptake of various pollutants. Figure 2 provides an overview of the hydrologic and pollutant removal processes in a generalized BMP. We are unable to discussed the detail of the processes and the equations we used due to space limitation. The module provides options to turn on and off various mechanisms, allowing the user to tailor the simulation for different types of BMPs and specific activities.

Pre- and Post-processors *and Network Connection Module*

The pre- and post-processors allow the user to prepare an input data file with minimal efforts and to directly view the simulation results in graphics and tables. The SHLM and BMPEM modules have their own pre-processors to handle the data input

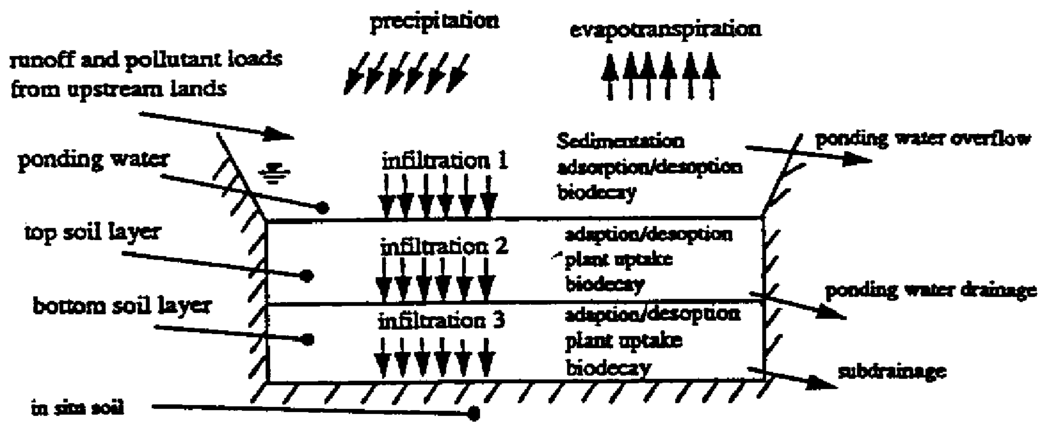

Figure 2. Runoff and pollutant removal mechanisms for a generalized BMP.

processes, while a post-processor is provided to display the outputs from both modules. The pre-processors are Windows-based and include standard menus, dialog boxes, check boxes and radio buttons. In SHLM module, the pre-processor also provides default data for a number of input parameters based on different land use types. In the BMPEM pre-processor, the user can select soil property data from a SCS classified soil types. The post-processor displays the simulation results of user-selected land or BMP units (up to four units can be selected and displayed in the same graph.). Three types of graphs are available: 3D bar chart, 2D bar chart, and line graph. The user can select three time intervals (hourly, daily, or monthly) and specify the starting and ending time. In addition to displaying results in graphics, the post-processor can also generate tables and export ASCII files for subsequent use.

The network connection module provides a tool for the user to specify flow direction and linkage between land and BMP units. The user can use the mouse on the screen to draw an arrow between two units, indicating the direction of the runoff flow. The module automatically determines the compounding effects based on the screen connection. Working with the pre-processors of the SHLM and BMPEM modules, the network module allows the user to set up a complex network with the point and click of the mouse. The users can freely change the flow direction on the screen and rerun the model to evaluate the effects of different network connections. Figure 3 shows some screens of the pre- and post-processor and the network connection module.

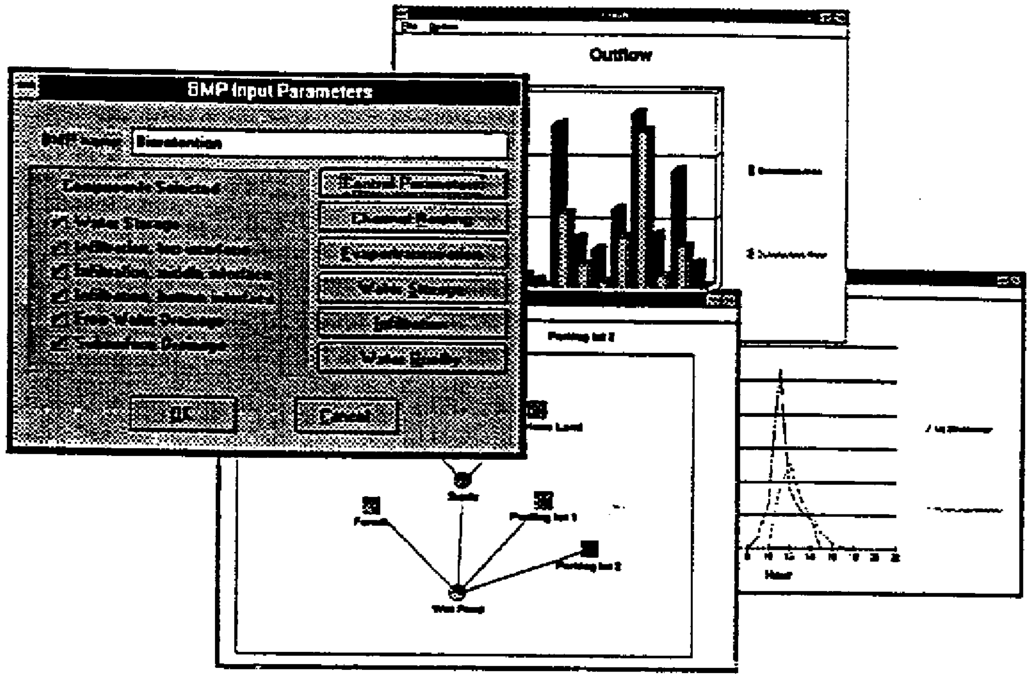

Figure 3. Sample screens of the pre- and post-processor and network connection module

EXAMPLE MODEL APPLICATIONS

We presents two example simulations to demonstrate how to apply the model to evaluate the effectiveness of BMPs. The main purpose of the these simulations is to show the model's capability and to evaluate the output response to various input data. To successfully apply the SAM model to a specific site, substantial efforts must be made to calibrate the model and obtain site specific input data.

Simulation 1 --Evaluate the storm event and long term effects of the bioretention area on runoff and pollutant load reduction

Bioretention is a BMP commonly used in Prince George's as an innovative method to control the stormwater. It uses the natural processes such as infiltration, adsorption, biodecay, and plant uptake to remove access storm runoff and pollutants. We apply the SAM model to evaluate the effectiveness of the bioreteintion for a 6070 m^2 residential area. The area is divided into two parts: pervious land of 3380 m^2 including lawns, gardens and other pervious areas; impervious land of 2690 m^2 including roofs, drive ways, paved parking areas. The area of the bioretention unit is 182 m^2, which is 3% of the drainage area. The storage depth of the unit is 0.15 meter and the thickness of the planting soil and bottom sand layer is 1.22 and one 0.3 meter respectively..The infiltration rate of the in-situ soil is assumed to be 1.0 cm/hr. The runoff from the pervious and impervious areas is routed to the bioretention area, which is an innovative BMP commonly used in the Prince George's County. For storm event simulation, we used a two-year frequency and six-hour duration storm, which is approximately 6.4 cm in Prince George County area based on data published by National Weather Service (Frederick et. al., 1977). Rainfall distribution within the six-hour period is calculated by the SCS method (US Department of Agriculture, 1986). We apply the SAM model to simulate the instantaneous water flow and nutrient loads from the pervious and impervious areas as well as the bioretention, then evaluate the effects of the bioretention area by comparing the hydrographs and pollutographs of total nitrogen (TN) before and after the bioretention unit. For long term simulation, we used the hourly precipitation data for the year of 1984, obtained in the Baltimore International Airport. The runoff volume before and after the bioretention area is summarized monthly for comparison.

The hydrographs and the pollutographs of TN before and after the bioretention unit are shown in figures 4 to 5. The results show a significant reduction and delay of peak runoff flow and nutrient loads. The peak runoff flow after the bioretention area

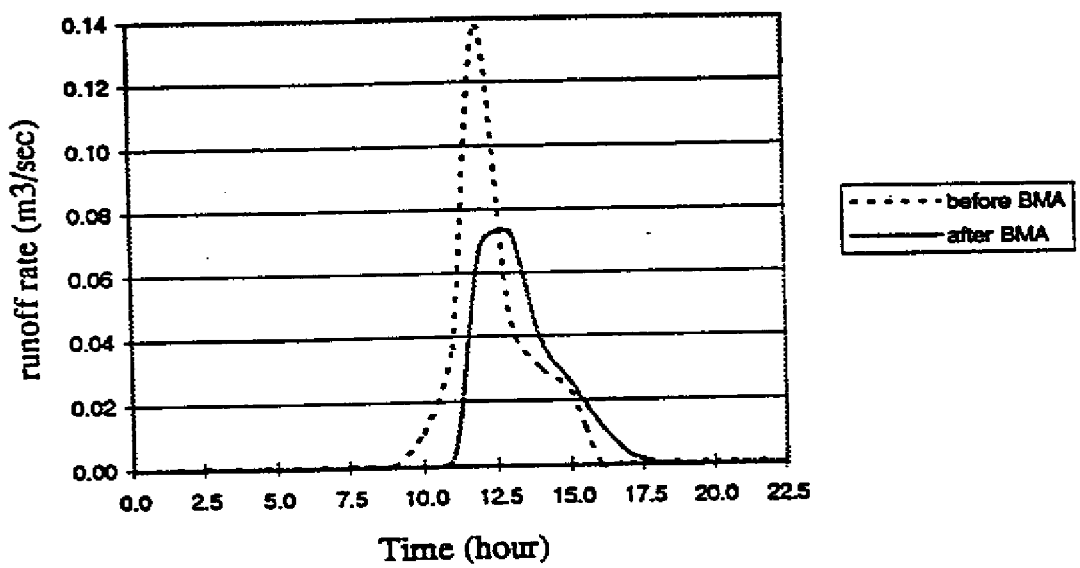

Figure 4. Hydrographs before and after the bioretention area.

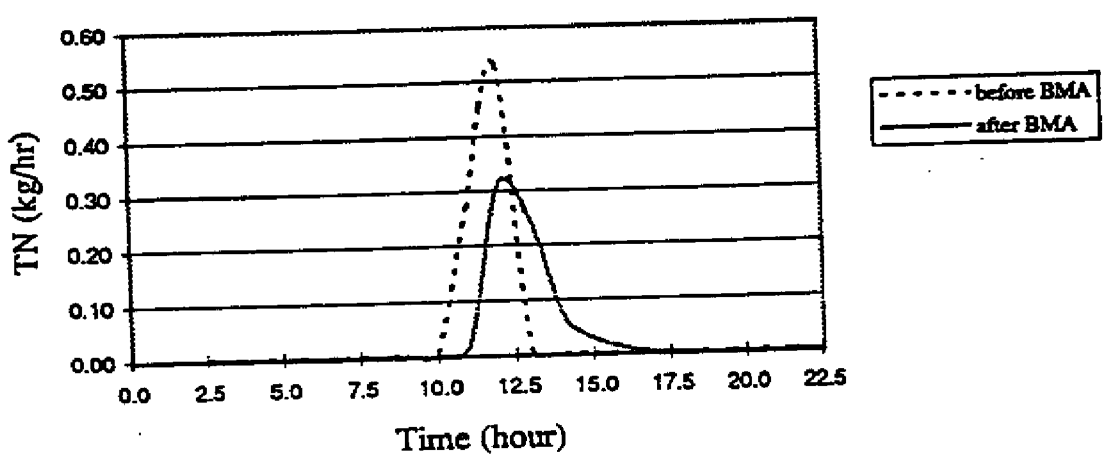

Figure 5. Pollutographs of TN before and after the bioretention area.

drops from 0.14 m^3/sec to 0.71 m^3/sec, a 50% reduction, while the peak TN load achieves a 41 % reduction. We also calculate the total reduction of runoff volume and TN amount by comparing the areas under the respective hydrographs and pollutographs. Results of numerical integration of these areas show a 20% reduction for total runoff volume and 15% for TN.

The monthly runoff volume before and after the bioretention is shown in Figure 6. While the reduction percentage varies from month to month, an annual runoff volume reduction of 45% is achieved (runoff volume reduced from 11280 m^3 to 6176 m^3).

Simulation 2 – Evaluate the Effect of in-situ soil infiltration on runoff volume reduction

The infiltration rate of the in-situ soil plays an important role for the performance of the bioretention area. When the infiltration rate is high, the BMA allows large amount of water percolating to the groundwater, results in significant reduction of peak flow and total stormwater runoff volume. The infiltration rate also has an impact on whether and how long ponding water exists in BMA. In this simulation, we fix the BMA area to 5% of total drainage area and 0.15 meter of storage depth, then apply the SAM model using infiltration rates from 0 to 5 cm/hr. The same storm event and input parameters applied in simulation one are used.

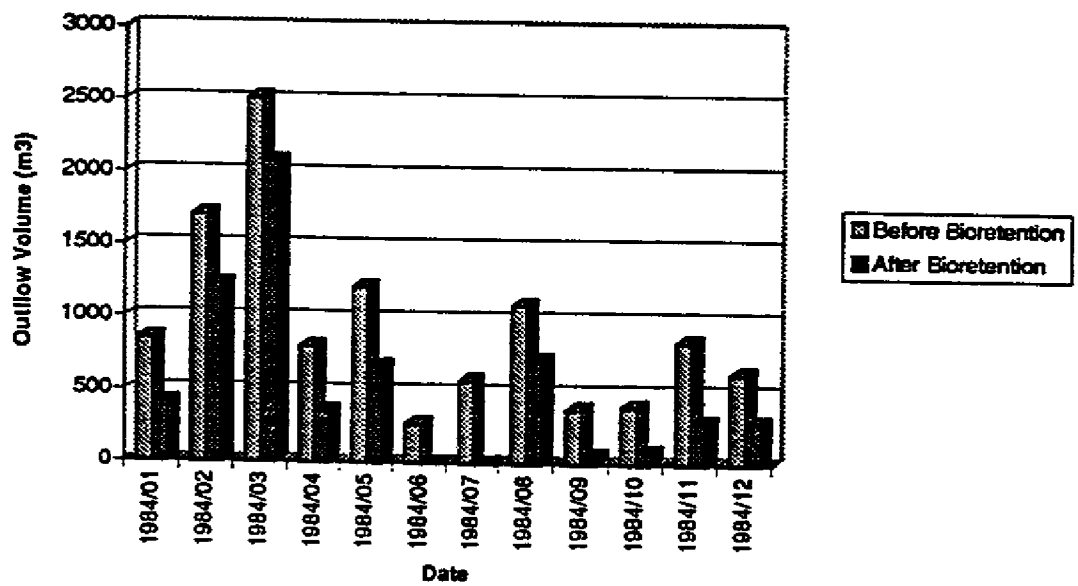

Figure 6. Monthly runoff volume before and after the bioretention area

The reduction runoff volume at different infiltration rates is plotted in figure 7. The results show that when the infiltration rate is less than 1.3 cm/hr, the reduction of runoff volume is sensitive to the infiltration rate of the in-situ soil. As the infiltration rate increases, its effect becomes smaller. The reduction of runoff volume increases from 0 to 29 percent as infiltration rate increases from 0 to 1.3 cm/hr. However, as the infiltration rate increases beyond 1.3 cm/hr, the runoff reduction curve becomes flat. This may be attributed to the fact that as infiltration rate of the in-situ soil increases, the limiting factor controlling the overall infiltration process gradually shifts to the upper soil layer having the smallest infiltration rate (most likely the planting soil layer if the bottom layer is sand). In this situation, only selecting more permeable planting soil can improve the overall infiltration process.

CONCLUSION

An integrated model was developed for impact assessment of urban development and watershed planning. The model can be used to simulate hydrologic and pollutant loads from different land uses and to evaluate the effectiveness of various types of BMPs. We plan to further calibrate the model using data collected from a low impact development site in Prince George's County. The model will serves as an evaluation tool for the County and the developers to evaluate the environmental impact of urban development. Simulation results from the model will also be used to establish design criteria for different BMP facilities.

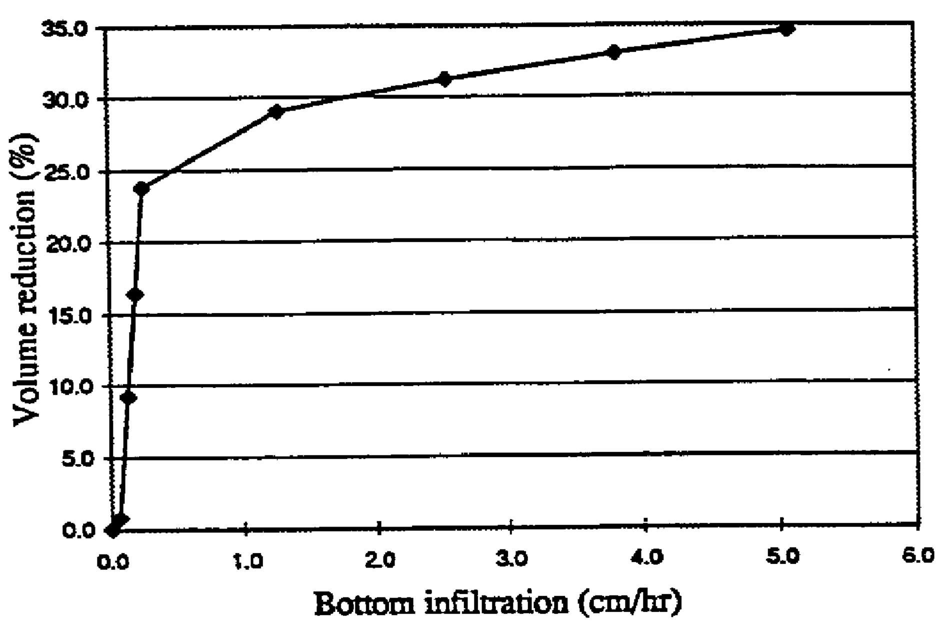

Figure 7. Effect of in-situ soil infiltration rate on runoff reduction

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