Task 19 FINAL PRODUCT VMRC
FY 1993 Cum. Impacts & Carrying Capacity Creeks & Inlets

Modeling Cumulative Impacts and the Carrying Capactiy of Small Tidal Creeks and Inlets

Bruce J. Neilson
Carl Hershner
Megan Greiner

Virginia Institute of Marine Science
School of Marine Science
College of William and Mary
Gloucester Point, Virginia 23062

This report was funded, in part by the Department of Environmental Quality's Coastal Resources Management Program through Grant #NA470Z0287-01 of the National Oceanic and Atmospheric Administration, Office of Ocean and Coastal Resource Management, under the Coastal Zone Management Act of 1972, as amended.

Modeling Cumulative Impacts and the Carrying Capacity of Small Tidal Creeks and Inlets

INTRODUCTION

Estimation of water quality impacts associated with use changes on land or water is primarily dependent on knowledge of what will be added to the water as a consequence of the change in use. Understanding of the mixing and transport of substances added to water bodies is reasonably advanced, with numerous mathematical models available to generate assessments of dilution and dispersion. The accuracy of model output is constrained, however, by the accuracy of the estimates of what is being added to the water (loadings). Frequently, loading of pollutants is unknown and extremely difficult to measure.

When pollutant loading occurs as a result of point source discharge, measurement of amounts added can be determined if concentrations and flow rates are known. While not a trivial problem, it is usually possible to mount an outfall sampling program sufficient to generate the required estimate. The problem is much more intractable when dealing with nonpoint source pollution. Addition of nutrients, sediments, biological and chemical oxygen demand, fecal coliforms and other substances to water bodies from surrounding lands is generally variable in both time and space. Estimating a time and space averaged loading is a difficult undertaking requiring extensive long term sampling of all the various delivery pathways. Few studies have undertaken the comprehensive sampling necessary to generate such numbers.

Even when estimates of pollutant loadings are developed, application of the estimates to areas outside of the original sampling site entails an enormous number of assumptions about modes and rates of delivery, assumptions which are rarely documented or tested. As a consequence, prediction of water quality impacts, and particularly cumulative impacts, remains a speculative undertaking. Model output can be no better than the quality of the data used as input.

The purpose of this project was to identify pollutant loading values which might be used as input for a series of water quality models applied to small tidal creeks and inlets in Virginia's coastal plain. The intent was to identify values from literature sources which might be used in application of the models, absent better or more site specific information. Estimates of biological oxygen demand, chemical oxygen demand and fecal coliform loadings were of specific interest.

FINDINGS

Numerous studies have sought to determine pollutant loads associated with different land uses through intensive field work and long term sampling (*eg*. Clesceri et al., 1986; Beulac et al. 1982; Sonzogni, 1980). The majority of these works measure pollutant input through surface runoff following rainfall events. Runoff export coefficients are calculated as average annual pollutant loads per unit area. There are several limitations to braod application of these values. While studies have suggested that land use is the most important factor controlling pollutant loads in runoff waters (*eg*. Rast et al. 1983, Whipple et al. 1978), the net input of pollutants is understood to be a result of rainfall intensity and frequency, soil type, watershed slopes, and small scale patterns of land cover/use. Transport through groundwater pathways is also understood to be locally important and highly variable. Incorporation of all of these considerations in water quality models, while an objective of ongoing work, is not yet practical. Current models, and particularly those developed in the related work for this project, rely primarily on measures of land use and a generalized runoff coefficient.

Uttormark et al. (1974) concluded from a survey of literature that there is little justification for the delineation of land useage beyond categories of urban, agriculture, forest and pasture. Thus, most studies report values for these classes of land uses. A survey of the literature indicates loading values can vary widely, generally over one to two order of magnitude for any single pollutant and land use type.

This report provides a summary of values for both runoff coefficients (TABLE 1) and storm water runoff load estimates (TABLE 2) for total suspended solids, biological oxygen demand, coliform levels, chemical oxygen demand, total nitrogen and total phosphorus.

SPECIAL NOTE FOR FECAL COLIFORMS

Estimation of fecal coliform loadings is particularly important in efforts to evaluate projects proposing marina construction. At the present time, the number of boat slips available in a marina is used as a predictor of probable pathogen concentrations in surrounding waters. The purpose of this determination is to set shellfish harvest controls, hopefully preventing the harvest and/or marketing of shellfish which might contain unacceptably high concentrations of pathogens. The assumption that slip number is an adequate predictor of pathogen concentrations is generally viewed as grossly oversimplified, but it has served as a practical solution absent more sophisticated methods of prediction.

One of the goals of this project was generation of mathematic models which might enhance the ability of managers to assess probable pathogen loading around marinas. The models basically estimate dispersion of fecal coliforms (used as an indicator of pathogen levels) based on circulation patterns. Model output is clearly dependent on the initial loading assumption. This number is extremely difficult to estimate with any accuracy.

In 1985, the United States Environmental Protection Agency developed a Coastal Marinas Assessment Handbook. The purpose of the handbook was to provide guidance in the design and evaluation of marina projects. As part of that undertaking, the EPA contractor conducted an extensive review of available information in an effort to determine the fecal coliform loading attributable to each boat in a marina. The handbook referenced work done by Carstea et al. 1975 in identifying the assumptions necessary to develop an estimate. These assumptions include:

- average persons per boat is three;
- average per capita discharges of coliform bacteria and BOD are 2 billion and 75.6 g respectively;
- half of the people on board contribute fecal material in 24 hours;
- coliform bacteria populations do not increase;
- a boat in use spends one hour in the marina;
- 25 to 40 percent of boats present are in use and evenly distributed.

The difficulties associated with use of a number based on all these assumptions is self-evident.

The estimation of fecal coliform loading per boat in a marina is further complicated by the increased use of on-board marine sanitation devices. An even greater uncertainty derives from the potential influx of fecal coliforms from non-point sources. Schima et al. 1994 investigated the relationships between fecal coliform levels at 2,614 sampling stations and their landscape positions. They found a basic pattern of increasing fecal coliform bacteria densities with distance upstream in tidal creeks and inlets. They refered to this as a "land mass" effect, or simply the amount of land within a fixed radius of sample locations. Regression analysis of the MPN concentrations at sampling points along the Eastern Shore of Virginia indicated the following variables (in order of decreasing importance) were significant in explaining changes in the sampled MPN values:

- surface area of water in a 400 m raduius around the sampling point
- season
- tide stage during sampling
- rainfall amounts in the 2 days prior to sampling
- surface area of urban land in a 400 m radius around the sampling point

- near shore groundwater hydraulic gradient
- slinity
- proximity to nearest shoreline
- near shore soil permeability
- near shore runoff events
- surface area of agricultural land in a 400 m radius around the sampling point
- near shore Darcy velocity
- water temperature

One conclusion to be drawn from all of this is that while fecal coliform inputs from nonpoint sources on land may be very important, they are also very variable and difficult to predict, even on the basis of land use.

TABLE 1

LOADING RATES BY LAND USE (kg/ha/yr)

LANDUSE		TSS	BOD	COLIFORM	SOURCE
residential		420	35	-	Wanielista, 1978
		11-487	-	-	Bannerman et al., 1984
		360-390	-	-	Marsalek, 1978
		620-2,300	-	-	Sonzogni, 1980
		-	30-50	-	Loehr, 1974
		-	-	25,621-	Ellis, 1986
		-	-	82,500(mpn/g)	
commercial		840	87	-	Wanielista, 1978
		957	-	-	Bannerman et al., 1984
		360	-	-	Maralek, 1978
		50-830	-	-	Sonzogni, 1980
		-	-	36,900(mpn/g)	Ellis, 1986
agriculture	mean	450	18	-	Wanielista, 1978
	range	180-4,200	4-31	-	
pasture	mean	343	11.5	-	Wanielista, 1978
	range	10-840	6-17	-	
forest	mean	85	5	-	Wanielista, 1978
	range	15-132	2-7	-	

TABLE 1 (continued)

LOADING RATES BY LANDUSE (kg/ha/yr)

LANDUSE		TN	TP	SOURCE
residential		5.0-7.3	-	Sonzogni, 1980
		9-11.2	1.6-3.4	Marsalek, 1978
		5.4-18.0	1.00-2.47	EPA, 1983
		6.6	1.8	Wanielista,1978
		-	1.2-8.0	Whipple et al., 1978
commercial		1.9-11	-	Sonzogni, 1980
		11.2	3.4	Marsalek, 1978
		16.3	2.22	EPA, 1983
		14.5	2.7	Wanielista, 1978
pasture	mean	6.2	0.5	Wanielista, 1978
	range	2.0-12.0	0.1-2.1	
		4.94	0.74	Beulac & Reckhow, 1982
		-	0.34-0.56	Mackiernan, 1985
agriculture		8.89	2.22	Beulac & Reckhow, 1982
	mean	26.0	1.05	Wanielista, 1978
	range	15.0-37.0	0.18-1.62	
		-	1.68-5.6	Mackiernan, 1985
		-	0.06-2.9	Loehr, 1974

TABLE 1 (continued)

LOADING RATES BY LANDUSE (kg/ha/yr)

LANDUSE		TN	TP	SOURCE
forest	mean	3.0	0.10	Wanielista, 1978
	range	2.0-5.1	0.01-0.86	
		2.47	0.25	Beulac & Reckhow, 1982
		-	0.06-0.11	Mackiernan, 1985
		-	0.03-0.9	Loehr, 1974

TABLE 2

STORM WATER RUNOFF ESTIMATES (mg/l)

POLLUTANT				SOURCE
TSS			141-224	EPA, 1983
			1,401-2,909	Wanielista, 1978
	urban		227	Carstea et al., 1975
	Durham, NC	mean	1,440	Colston, 1974
		range	194-8,620	
	agricultural		90-5,000	Dornbush et al., 1974
	watershed		180-6,000	
	cultivated		1,021	
	pasture		38	
BOD	urban area		12-160	Loehr, 1974
			17	Carstea et al., 1975
	Cincinnati, OH	mean	19	Weibel et al., 1964
		range	2-84	
	agricultural		7	Loehr, 1974
	watershed		5-30	Dornbush et al., 1974
			3-15	
COLIFORM			1,000-21,000 MPN/100ml	EPA, 1983
			> 2,000 MPN/100ml	Olivieri et al,. 1977
	Washington, DC		76,100	Wanielista, 1978
	Durham, NC	mean	23,000	Colston, 1974
		range	100-200,000	

TABLE 2 (continued)

STORM WATER RUNOFF ESTIMATES (mg/l)

POLLUTANT				SOURCE
COD	Durham, NC	mean	170	Colston, 1974
		range	20-1042	
	Cincinatti, OH	mean	99	Weibel et al., 1964
		range	20-610	
	agricultural		50-360	Dornbush et al., 1974
	watershed		70-780	
	pasture		49	
TN			5.6-7.1	EPA, 1983
	urban area	mean	3.1	Weibel et al., 1966
		range	0.3-75	
			3.1	Carstea et al., 1975
	forested		0.3-1.8	Loehr, 1974
	agriculture		9.0	Loehr, 1974
TP			0.4-0.5	EPA, 1983
	agriculture		0.04-2.4	Dornbrush et al., 1974
	forested		0.01-0.11	Loehr, 1974
	agriculture		0.02-1.7	Loehr, 1974
	urban area		0.2-1.1	Loehr, 1974
			1.1	Carstea et al., 1975

REFERENCES

Bannerman, R., K. Baun, M. bohm. P.E. Hughes and D.A. Graczyk. 1984. Evaluation of Urban Nonpoint Source Pollution Management in Milwaukee County, Wisconsin. Report No. PB84-114164. Chicago, Ill. EPA Region V.

Beulac, M.N. and K.H. Reckhow. 1982. An examination of landuse nutrient export relationships. Water Resources Bulletin. 18:1013-1023.

Carstea, D., A. Binder, R. Strieter, L. Boberschmidt, L. Thomas and J. Golden. 1975. Guidelines for the environmental impact assessment of small structures and related activities in coastal bodies of water. Prepared by MITRE Corporation for U. S. Army Corps of Engineers, New York District.

Clesceri, N.L. S.J. Curran, and R.I. Sedlak. 1986. Nutrient Loads to Wisconsin Lakes: Part I: Nitrogen and Phosphorus export coefficients. Water Res. Bull. 22(6):983-1000.

Colston, N.V. Jr. Characterization and treatment of urban land runoff. Environ. Protection Technol. Series. EPA 670/2-74-096. 1974.

D'Elia, F. 1987. Nutrient Enrichment of the Chesapeake Bay: Too much of a good thing? Env. 29:6-33.

Dornbush, J.N., J.R. Anderson, L.L. Harms. 1974. Quantification of pollutants in agricultural runoff. EPA-660/2-74-005. US EPA. Washington, D.C.

Ellis, J.B. 1986. Pollutional aspects of urban runoff. pp.1-38 in H.C. Torna, J. Marsalek, and M.Desbordes, ed. Urban Runoff Pollution. Springer-Verlag, NY, Inc.

Loehr, R.C. 1974. Characteristics and comparative magnitude of non-point sources. Journal WPCF 46(8):1849-1872.

Mackiernan, G.B., D.A. Flemer, Nehlsen, W. V.K. Tippie and R.B. Biggs. 1985. Chesapeake Bay: A profile of environmental change. EPA, Annapolis, MD. Chesapeake Bay Program.

Marsalek, J. 1978. Pollution Due to Urban Runoff: Unit Loads and Abatement Measures. Windsor, Canada: Pollution by Land Use Activities Reference Group of the International Joint Commission.

Nagnien, R.E., R.M. Summers and K.G. Sellner. 1992. External Nutrient Sources, Internal Nutrient Pools, and Phytoplankton Production in Chesapeake Bay. Estuaries 15(4):497-516.

Olivieri, V., C. Kruse, K. Kawata, and J. Smith. 1977. Microorganisms in Urban Stormwater. Report No. EPA 600/2-77-087. Cincinnati, OH: EPA Municipal Environmental Research Laboratory.

Overton, D.E. and M.E. Meadows. 1976. Stormwater Modeling. NY Academic Press.

Rast, W. and G.F. Lee. 1983. Nutrient Loading Estimates for Lakes. J.Env. Engineering. ASCE 109(2):502-517.

Schima, F.J., W.G. Reay, D.L. Gallagher, G. M. Simmons, Jr., J.L. Waldon and K.K. Reay. 1994. Groundwater transport of fecal coliform bacteria to open coastal waters of Virginia's coastal plain: A GIS approach. Final Report to Virginia's Coastal Resource

Sonzogni, W.C. 1980. Pollution from land runoff. Environ. Sci. and Tech. 14:148-153.

United States Environmental Protection Agency. 1985. Coastal Marina Assessment Handbook. USEPA 904/6-85-132. Region 4, Atlanta, Georgia.

United States Environmental Protection Agency. 1983. Results of the Nationwide Urban Runoff Program: Volume 1. USEPA, Washington, D.C.

Uttormark, P.D., J.D. Chapin and K.M. Green. 1974. Estimating Nutrient Loading of Lakes from non-point sources. US EPA 600/3-74-020. US EPA. Corvallis, OR.

Wanielista, M.P. 1978 Stormwater Management: Quantity and Quality. Ann Arbor Science Publishers.

Weibel, S.R. et al. 1964. Urban land runoff as a factor in stream pollution. J. WPCF. 36(7):914-924.

Weibel, S.R. et al. 1966. Pesticides and Other Contaminants from Raingall and Runoff as Observed in Ohio. Jour. Amer. Water Works Assn. 58:1075-1084.

Whipple, W. Jr. J.V. Hunter, and S.L. Yu. 1978. Runoff pollution from multiple family housing. Water Res. Bull. 14:288-301.

Coastal Screening Model
User Manual

Version 0.95

Developed for:
Virginia Marine Resource Commission

Virginia Polytechnic Institute and State University
Division of Environmental Engineering and Sciences
Department of Civil Engineering

Mary Ann Parcher
Research Assistant

Dr. Daniel Gallagher
Associate Professor

June 20, 1995

This brochure was reprinted by the Department of Environmental Quality's Coastal Resource Management Program through Grant #NA37OZ0360-01 of the National Oceanic and Atmospheric Administration, Office of Ocean and Coastal Resource Management, under the Coastal Zone Management Act of 1972, as amended.

Table of Contents

List of Tables

Table of Figures

1. Introduction

Significant demand exists for housing and marina development along tidal creeks and inlets around the Chesapeake Bay. These changes in land use have the potential to adversely impact the water quality of Virginia's waterways. Existing water quality models can predict these water quality changes, but existing models require extensive field data, model calibration, and expertise to use. The Virginia Marine Resource Commission (VMRC) issues permits for most coastal development and does not have the necessary resources to apply such models on a routine basis. The Coastal Screening (CS) Model was developed to provide the VMRC with a tool for a preliminary evaluation of development applications and to identify those projects with relatively insignificant water quality impacts.

As the name implies, the CS Model is a screening-level model. The unavailability of measured field values requires that the model contain many assumptions to reduce the amount of required input. As model complexity and site-specific information is reduced, the uncertainty of the predicted values increases. Therefore, the goal of the CS Model is not to predict a specific water quality concentration, but only to identify those projects that can be permitted without further in-depth analysis. A proposed project passing the screening model would indicate no major impacts with a fair degree of uncertainty. Projects with greater impacts or with high degrees of uncertainty would require additional analysis and modeling effort.

1.1 Model Overview

The Coastal Screening Model is a PC-based computer model that operates in the Windows environment. The components of the CS Model are several water quality models, a land use model, a few utility codes, and a model selection advisor.

The model selection advisor is designed to aid the user in determining which model is most applicable for the current assessment. The advisor contains a checklist of various water quality parameters and model options that the user can select for each modeling effort. Based on the options selected by the user, the advisor determines the appropriate model(s). A description of model characteristics and parameters and a brief discussion of required inputs is provided for each model to further aid the user in the selection process. A complete discussion of the model selection advisor and all its components is provided in Chapter 2.

The Watershed Model is a lumped parameter, watershed-scale land use model. It is based on empirical equations for runoff, erosion, and sediment yields. The model will estimate stream flow, runoff, sediment yield, total and dissolved nitrogen, and total and dissolved phosphorus at the watershed outlet. It can be used to estimate potential pollutant loads entering coastal waters as a result of land use changes. A comprehensive discussion of the Watershed Model and its required inputs is provided in Chapter 3.

The Marina Water Quality Model is a steady-state, two-dimensional model that can be used to estimate coliform bacteria concentration, carbonaceous biochemical oxygen demand (CBOD), and nitrogenous biochemical oxygen demand (NBOD). It is based on three analytical mixing and transport models that describe the physical processes in wide channels, narrow channels, or semi-enclosed bays. A comprehensive discussion of the Marina Water Quality Model and its required inputs is provided in Chapter 4.

The Tidal Prism Model is a dynamic, one-dimensional, segmented water quality model that considers the tidal effects in estuaries and rivers. It can be used to estimate coliform bacteria concentration, CBOD, or other contaminants subject to a first order decay. Each contaminant must be simulated separately. A comprehensive discussion of the Tidal Prism Model and its required inputs is provided in Chapter 5.

The Finite Section Model is a steady-state, one-dimensional, segmented water quality model that does not consider tidal effects in the stream channel. It can be used to estimate coliform bacteria concentration, DO, CBOD, and NBOD from point or known nonpoint sources. A comprehensive discussion of the Finite Section Model and its required inputs is provided in Chapter 6.

The Spill Model is a dynamic, one-dimensional water quality model that can be used to estimate the concentration of a pollutant "spilled" into a river or creek. The contaminant is assumed to be completely mixed vertically and axially and decrease over time through first order decay. A detailed discussion of the Spill Model and its required inputs is provided in Chapter 7.

The CS Model also includes several utility models to aid the user with quick, simple calculations. Currently, there are utility models for determining dispersion coefficient estimation, DO saturation, and Manning's open channel flow. A complete discussion of these models is provided in Chapter 8.

1.2 Notation Review

The following conventions are used throughout the user manual.

- Keyboard strokes, menu choices, command buttons, and anything you are asked to type are printed in **boldface.**

- Keyboard strokes are surrounded by < >. For example, the "Enter" key is denoted as **<Enter>**.

- Command buttons are surrounded by [ ]. For example, a "Close" command button is denoted as **[Close]**.

- The terms "click on" and "select" refer to a specified mouse action. When you are told to click on or select an item, locate the mouse cursor over the selected item and press the left mouse button. If you prefer to use the keyboard instead of the mouse, you can navigate the model by using **<Alt>** and the underlined letter of the desired menu or command option.

This manual uses standard Windows terminology. For users who are not familiar with the Windows environment, some common elements of a window are described below.

Title Bar: The title bar displays the window title. The window title displayed in the CS Model corresponds to the currently selected modeling option, however, when a component model is minimized, the title bar returns to the general Coastal Screening Model title.

Menu Bar: The menu bar at the top of each window displays the commands available for that window. The main menu bar of the CS Model provides access to the individual models. When a component model is selected, its menu bar becomes active. Menu bars for individual models provide file and printer access.

Minimize Button: This is the button with the down arrow on the right side of the title bar. When this button is selected, the window is reduced to its icon. The window can be maximized (returned to its original size) by double-clicking on the icon. The CS Model and all its component models have minimize buttons and can be reduced to an icon.

Dialog Boxes: A dialog box requests or provides information, but does not have a menu bar. For example, a dialog box will appear when the **File/Open** menu option is selected in any of the models.

List Boxes: A list box provides a list of available choices from which you must make a selection. To select an item from the list, move the mouse pointer to the desired item and click the left mouse button, or access the list boxes by pressing the **<Tab>** key until the desired list box gains the focus and then use the arrow keys until the desired item is highlighted. When space is limited, a "drop-down" list box may be used. A drop-down list box displays only one entry. To access all of the available items, click on the down arrow button next to the displayed list item. A list box will appear beneath the originally displayed item. Items in a drop-down list box are selected in the same manner as a regular list box.

Scroll Bars: Some dialog and list boxes may contain more information than can be viewed in the allocated area, so scroll bars will be added to allow the user to access all of the information. Scroll bars contain an up and a down arrow as well as a scroll button. To scroll information line by line, click repeatedly on one of the scroll arrows until the desired information comes into view. To page through the list quickly, click the scroll bar above or below the scroll button, or drag the scroll button up or down the scroll bar.

Command Buttons: A command button performs a command or action when chosen by a user. When selected, a command button not only carries out the appropriate action, but appears as if it's being pushed in and released.

Option Buttons: Option buttons allow the user to select **one** option from the group. An option button is activated by clicking on it or its description.

Check Boxes: Check boxes allow the user to decide whether or not some action should be taken. A check box is activated by clicking on it or its description. If a check box is selected, then its value is true and the action it describes will occur. Unlike option buttons, check boxes operate independently of each other and more than one can be selected within a group.

Text Boxes: A text box displays text that can be edited by the user. To change information in a text box, click on the text box and type the new information. Text boxes can also be accessed by pressing the **<Tab>** key until the desired text box gains the focus. In the CS Model, text boxes are used to allow user input for model parameter values and can usually be distinguished by their white background.

Spin Buttons: Spin buttons are a set of up and down arrows associated with a text box. Clicking on either of the spin buttons will incrementally change the value in the text box.

Notebook: The component models utilize a notebook format to enter data and display model results. Each page of the notebook can be accessed by clicking on the corresponding tab or pressing <Alt> plus the underlined letter of the tab header.

1.3 System Requirements

You will need an IBM or IBM-compatible personal computer and a monitor that are capable of running MicroSoft Windows (version 3.1 or higher). The minimum system requirements include:

- A 386-33 CPU
- 4 mega bytes (MB) of random access memory (RAM)
- 5 MB of free hard disk space
- A VGA monitor with 16 colors

A 386-based system is technically sufficient, but depending on which component model is selected, the processing time could be quite slow, particularly since the models are designed to run in an interactive rather than a batch mode. The recommended system requirements are:

- A 486-33 DX or 486-66 DX CPU
- 8 MB of RAM
- 5 MB of free hard disk space
- A VGA monitor with 256 colors

A monitor operating in 256 color mode increases the clarity of map and picture displays.

A mouse or other type of tracking device is not strictly required by the program, but will greatly improve the ease with which the models can be accessed and used.

1.4 Installation Procedures

The current setup process requires two steps. The first install the CS model itself. Insert Disk 1 into your disk drive. From the **File** menu of the Program Manager or File Manager, choose **Run**. Type <**a: setup**> (or b: if you are using the b drive). The set-up routine will prompt you for the path where you want to install the program files. (Follow the set-up instructions on the screen). The second step installs the ancillary data files and maps. Insert the Ancillary Disk 1 and run the setup.bat file. You will be asked for the path where you installed the CS model.

1.5 Getting Started

To access the Coastal Screening Model, click on the Coastal icon from your Windows program manager. The title bar and menu bar for the Coastal Screening Model will appear. The model selection advisor or any of the component models can be accessed from **Models** on the menu bar.

2. Model Selection Advisor

The model selection advisor is designed to aid the user in determining which model is most applicable for the current assessment. The advisor divides the component models into two types: (1) water quality models and (2) land use models. Since this version of the CS Model contains only one land use model, the model selection advisor is most appropriate for selecting among the water quality models. If a land use model is desired, the advisor can be used to view a brief description of the Watershed Model or to activate the model, however, the Watershed Model can be activated directly from the menu bar.

The advisor contains a checklist of various water quality parameters and model options that the user can select for each modeling effort. Based on the options selected by the user, the advisor determines the appropriate model(s). If only one model fits the selected criteria, a screen containing a brief model description appears. The user then has the option to perform another search or activate the selected model. If the advisor selects more than one model, a model choice screen will appear, and the user can view a description for each of the selected models. The user then has the option to perform another search or activate one of the selected models.

Section 2.1 contains a detailed discussion of modeling and types of models. Section 2.2 discusses how to access and navigate through the advisor. A description of all the water quality parameter options available within the advisor is provided in Section 2.3. Criteria for final model selection are discussed in Section 2.4.

2.1 Model Types

The CS Model is composed of both a land use model and several water quality models. These model types are explained in greater detail in the following subsections. While all of these models are available, none of them are linked together. Each component model operates seperately.

Models are a conceptualization of how the "real" world operates. No model completely reflects reality, but models can be useful improving our understanding of natural systems and in assessing anthropogenic impacts on these systems. Models can be defined in a variety of ways.

Empirical models are commonly termed "black box" models. These models use equations that are derived from measured data, but do not attempt to describe all of the physical properties that are involved in assessing the data. For example, tide charts have been developed based on the measured tidal cycles. The use of these values does not require a complete understanding of how tides are generated. It just important to know under what conditions the charts are valid. Empirical equations explain the measured data for the given conditions. As conditions vary from the ones applied during the equation development, the validity of the empirical equation is reduced. With greater number of measured values and testing conditions, the applicability of the equations increases.

Many models use equations that attempt to reflect the processes involved. The factors in the equations are based on real world processes. The advective-dispersive transport equation applied in many water quality models is an example of a process model.

2.1.1 Land Use Models

Land use models evaluate the loadings of some constituent from the upland areas to a water body. Typically modeled parameters include sediment and nutrients. Most land use models examine the loadings from an entire watershed, are a commonly termed watershed models.

Watershed models can be either lumped or distributed parameter models. A lumped parameter model will assess the loadings from each land use without considering the spacial variations or stream routing. Each designated land use is assumed to be uniform and have constant soil and cover properties. A distributed parameter model allows for spatial variation. Typically, the watershed is divided into a grid of cells, where each cell has defined land use, topography, and soil properties. The overland flow is routed from cell to cell or to a defined stream channel. A distributed parameter model provides loadings throughout the watershed, not just at the watershed outlet. It also allows for upstream land uses to impact downstream land use.

2.1.2 Water Quality Models

Water quality models evaluate the water quality constituents in the water column of a stream or river. The complexity of the model will depend on the number of stream dimensions that are being modeled, whether temporal variations are being considered, and whether the solution is analytical or numerical.

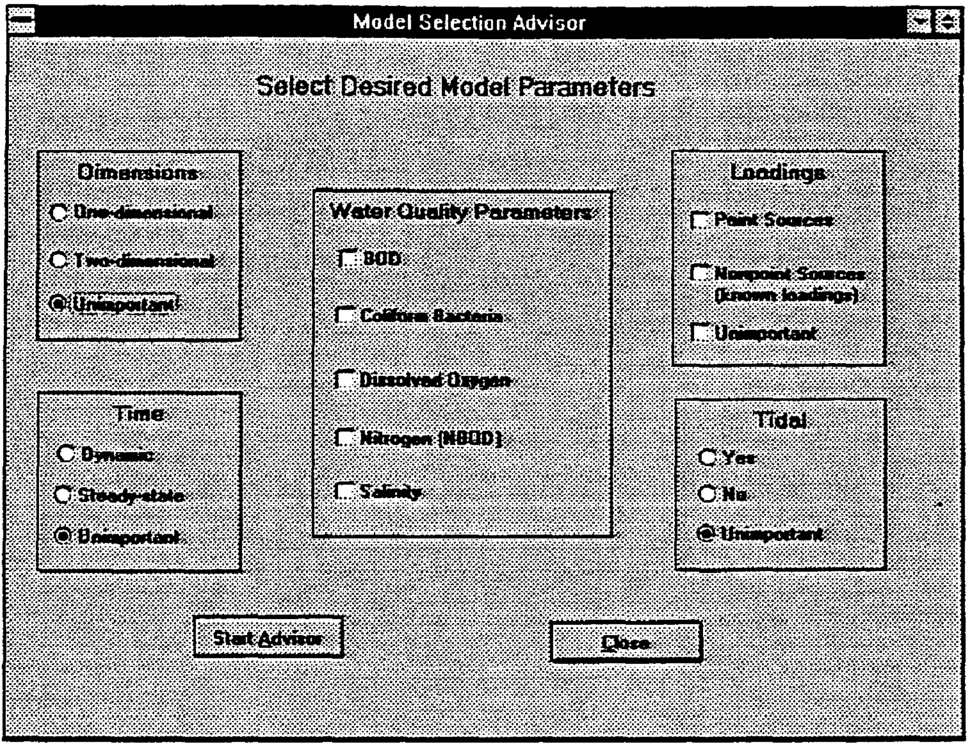
Most water quality models are based on the principle of the conservation of mass. All system outputs must equal system inputs. The mass balance calculation is performed for specified volumes of water over a given time period. Material balances typically involve dissolved or suspend substances, such as organic carbon, nitrogen, phosphorus, suspended sediment, and dissolved oxygen. This principle can be applied to any substance whose transformation kinetics are known (McCutcheon and French, ?).

2.2 Operating the Advisor

To access the model selection advisor, select **Models/Advisor** from the main menu. The advisor prompts you to select the type of model desired.

To select a land use model, click on the corresponding option button or enter <Alt L>. A screen displaying the description of the Watershed Model will appear. The model can be activated by selecting [**Run Model**]. If you do not wish to run the model at this time, choose [**Close**] to return to the main advisor screen.

To select a water quality model, click on the corresponding option button or enter <**Alt** W>. A screen displaying all the parameter options will appear (Figure 2-1). The various model options are grouped by parameter type. Each of these parameter options is explained in Section 2.3. Select the desired options by clicking on the appropriate option buttons or check boxes. The parameter option groups can also be accessed by using the <**Tab**> key. Once the focus is on the desired parameter option group, individual options can be selected using the up and down arrow keys.



Select Desired Model Parameters

Dimensions
○ One-dimensional
○ Two-dimensional
● Unimportant

Time
○ Dynamic
○ Steady-state
● Unimportant

Water Quality Parameters
☐ BOD
☐ Coliform Bacteria
☐ Dissolved Oxygen
☐ Nitrogen (NBOD)
☐ Salinity

Loadings
☐ Point Sources
☐ Nonpoint Sources (known loadings)
☐ Unimportant

Tidal
○ Yes
○ No
● Unimportant

Figure 2-1. Model selection advisor parameter options.

After all the desired parameter options are selected, choose the [**Start Advisor**] button by either clicking on it or pressing <Alt A>. The advisor will determine which models best match the desired criteria. If only one water quality model matches the selected parameter options, a screen will appear that provides a brief description of the model. You can either choose [**Run Model**] to activate the selected model or [**Close**] to return to the parameter options screen. If more than one model meets the desired criteria, a model choice screen will appear. The names of the water quality models that best match the selected options are displayed on command buttons. To learn more about a particular model or to activate a model, click on the command button displaying its name or press <Alt> and the underlined letter in its name. A screen will appear that provides a brief description of the model. Choose [**Run Model**] to activate the selected model, [**Return**] to return to the model choice screen to evaluate other model options, or [**Close**] to return to parameter options screen.

2.3 Water Quality Parameters

The parameter options for water quality models are divided into five categories. Each of these categories and the possible options are discussed in detail in the following subsections. Several of the categories contain an [**Unimportant**] option. If this option is selected in any of the categories, then that category is not used by the advisor during the model selection process. The water quality parameters option group does not contain an [**Unimportant**] option. It is assumed that the user will always be trying to model for at least one of these parameters.

To select the desired water quality parameters simple click on the appropriate option button or check box. The various frames housing the options can be accessed using the <Tab> key. Once the desired frame has gained the focus, use the arrow keys to select the desired option(s).

2.3.1 Dimensions

Water quality models are classified based on the importance of longitudinal, lateral, and vertical variations in the water quality constitutents. As more aspects of the stream are considered, the complexity of the equations required to describe the variations increase. While water quality models can be zero-, one-, two-, or three-dimensional, the component models included with the CS Model are only one- or two-dimensional.

A one-dimensional model considers only the longitudinal variations in describing stream water qualiy. It is assumed that "mixing processes will provide complete mixing both laterally and vertically, such that the concentrations gradients are only along the axis of the river" (Thomann and Mueller, 1987).

A two-dimensional model will consider the water quality variations in two directions. Most two-dimensional water quality models describe variations in the longitudinal and lateral direction and assume complete vertical integration.

The selection screen includes a branching one dimensional model option which will be implemented in future versions.

2.3.2 Time

This option addresses how water quality models address temporal variations. A model is classified as being either steady-state or dynamic. A steady-state model provides an analysis for a specific set of input conditions for some point or period of time (Basta and Moreau, 1982). A steady-state model can also consider two or more time periods that are seperated by some number of time periods if there is no analysis of these intervening time periods. In contrast, a dynamic model will examine successive time periods, where the inputs from the first time period will affect the inputs into the second time period. The analysis is much more complex than for models utilizing steady-state conditions.

2.3.3 Loadings

Point sources provide a constant input to the stream from a specified location along the channel. Typical point sources include wastewater treatment plants and processing plants. Nonpoint source discharges are generated by overland flow and do not originate from one fixed location. Nopoint source loadings are typically calculated by the use of a watershed model. However, some models can consider a known nonpoint source load as an additional input.

2.3.4 Tidal

This option allows the user to decide if the effects of tidal variations should be explicitly considered. Most water quality models address average tidal responses in the dispersion coefficient.

2.3.5 Water Quality Parameters

The water quality parameters are the constituents that one of the component water quality models will be evaluating. Except for salinity, these parameters are typically selected as indicators of stream health and water contamination. Salinity is typically modeled to establish dispersion coefficients.

Carbonaceous Biochemical Oxygen Demand (CBOD): CBOD is an indicator of organic pollution measured in terms of the oxygen demand that can develop as the organics are degraded. Units are commonly in mg/L.

Nitrogenous Oxygen Demand (NBOD): NBOD is the equivalent measure of the organic nitrogen and ammonia that will consume oxygen as they are converted to nitrite and nitrate. Units are commonly in mg/L.

Dissolved Oxygen (DO): A direct measure of the amount of oxygen dissolved within the water. Units are commonly in mg/L.

Coliforms: Coliforms are bacteria in the *Enterobacteriaceae* family and are commonly use as an indicator of fecal contamination. The coliform group includes *Escherichia coli*, *Enterobacter aerogenes*, and *Klebsiella pneumoniae*. These organisms make up approximately 10 percent of the intestinal microorganisms found in humans and other animals. Coliforms are used as an indicator species because they lose viability in water at slower rates than most of the major intestinal bacterial pathogens (Prescott et al., 1990). Water quality and potability is commonly evaluated by testing for the presence of coliform bacteria. Units are usually measured in the number of organisms/L.

Salinity: Salinity is a measurement of the salt concentrations in the water column. It is commonly used to calibrate a finite section model for dispersion. It is treated as a conservative material. Usually, the only loads for salinity arise at the mouth of the estuary or river.

2.4 Model Selection

The model selection advisor counts the total number of options selected by the user and compares this value to the number of these options that apply to each of the water quality models. The model that matches the greatest number of options is selected. Under this scheme, each option has equal value. This assumption may not reflect the needs of the user. The user may want one of the criteria to be more significant than the others and this is not possible with the current equal weighting scheme. If there is a critical option, the user can run the advisor with only that option selected and the other parameters set to **[Unimportant]**.

The model selection advisor can be a useful tool for model selection, especially when the user is first becoming familiar with the various component models, however, there is no substitute for good professional judgment. The user should become familiar with the characteristics, assumptions, and limitations of all the component models to be able to accurately estimate input parameters and to assess the model results.

3. Watershed Model

The Watershed Model is based on the Generalized Watershed Loading Functions model developed by Haith et al. (1992) at Cornell University. The model predicts monthly and annual sediment, nitrogen, and phosphorus loadings from complex watersheds. The Soil Conservation Service (SCS) Curve Number Equation and the Universal Soil Loss Equation are used to predict runoff and erosion, respectively. Individual land uses, point sources, and septic systems are evaluated. The Watershed model is a lumped parameter model, and therefore, land use is considered uniform with respect to soil and cover.

3.1 Modeling Approach

The Watershed model features a simple, daily time step hydrologic budget as depicted in Figure 3-1. The daily unsaturated and shallow saturated zone water budget for day t in cm is

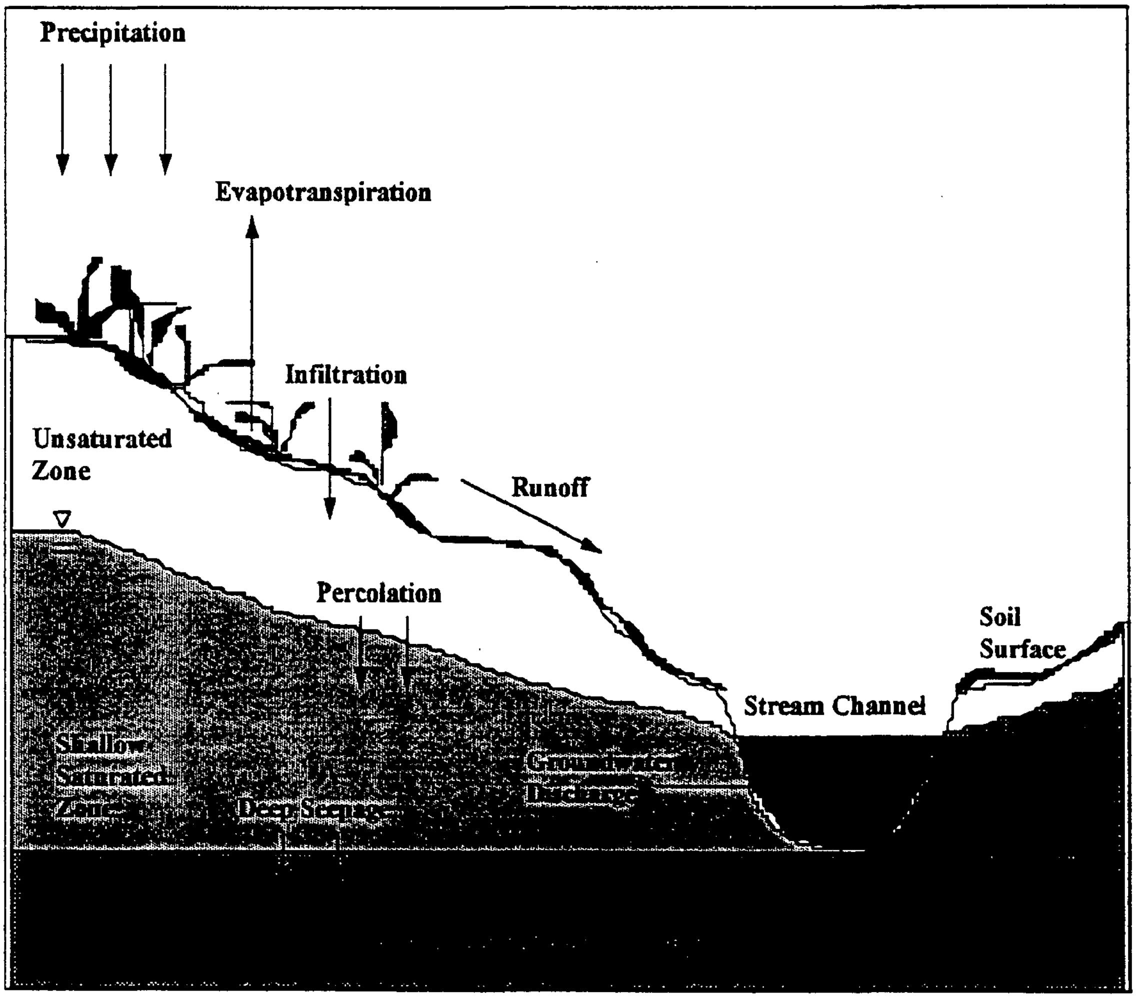


Figure 3-1. Conceptual model of a watershed, adapted from Haith et al., 1992.

$$U_{t+1} = U_t + R_t + M_t - Q_t - E_t - PC_t$$

$$S_{t+1} = S_t + PC_t - G_t - D_t$$

where U_t = unsaturated zone soil moisture
S_t = shallow saturated zone soil moisture
R_t = rainfall
M_t = snowmelt
Q_t = watershed runoff Q_{kt}, for all land uses k
E_t = evapotranspiration
PC_t = percolation into the shallow saturated zone
G_t = groundwater flow into the stream
D_t = deep seepage flow into the deep saturated zone

Values for rainfall and snowmelt are provided by the included weather files. Watershed runoff is calculated by the SCS Curve Number Equation as

$$Q_{kt} = \frac{\left(R_t + M_t - 0.2DS_{kt}\right)^2}{R_t + M_t + 0.8DS_{kt}}$$

where DS_{kt} is the storage detention parameter. A more detailed discussion of curve numbers and how the storage detention parameter is calculate is provided in Subsection 3.5.1.

Evapotranspiration is limited by the available moisture in the unsaturated zone and is the minimum of either (CV_t PE_t) or ($U_t + R_t + M_t - Q_t$), where CV_t is a cover coefficient and PE_t is the potential evapotranspiration. Hamon (1961) described the potential evapotranspiration as

$$PE_t = \frac{0.021H_t^2 e_t}{T_t + 273}$$

where H_t is the number of daylight hours per day during the month containing day t, e_t is the saturated water vapor pressure in millibars on day t, and T_t is the temperature on day t in °C. When $T_t \le 0$, then PE_t is set to zero. Bosen (1960) approximated the saturate vapor pressure as

$$e_t = 33.8639\left[\left(0.00738T_t + 0.8072\right)^8 - 0.000019\left(1.8T_t + 48\right) + 0.001316\right], \text{ for Tt} \ge 0$$

Percolation occurs when unsaturated zone water exceeds the available soil water capacity (U*) and is the maximum of either zero or ($U_t + R_t + M_t - Q_t - E_t - U^*$).

The groundwater discharge and deep seepage are modeled as a simple linear reservoir as described by Haan (1972) by the following equations:

$$G_t = r\ S_t$$

$$D_t = s\ S_t$$

where r is the groundwater recession coefficient and s is the seepage coefficient. These coefficients are described in Section 3.4.

3.1.1 Septic Systems

The septic system option in the Watershed Model is based on research presented by Mandel (1993). The model will calculate the dissolved nutrient loads from septic systems under four conditions: normal, short-circuited, ponded, and direct discharge. These loads are determined from the per capita daily effluent loads and the monthly population being served by septic systems in each condition.

Normal Systems: These septic systems conform with guidelines and standards suggested by the USEPA and are in compliance with state regulations. The effluent from these systems infiltrates into the shallow saturated zone. Nitrogen in the effluent is considered to be either removed by plant uptake or converted to nitrate and transported to the stream by ground water discharge. While normal systems contribute to dissolved nitrogen, the model does not consider phosphorus inputs. It is assumed that any phosphorus from the effluent becomes adsorbed to soil particles, and hence, does not leave the system. Since normal septic systems are operating properly, they are generally located away from streams. This means that as the dissolved nitrogen from the effluent move through the shallow saturated zone, it is diluted by other groundwater sources. Thus, the Watershed Model makes the monthly dissolved nitrogen load proportional to the groundwater discharge to the stream.

Short-Circuited Systems: These septic systems have been placed in an inappropriate location, and the effluent is not being properly treated by the septic field. These systems are located too close to surface waters, and therefore, negligible adsorption of phosphorus occurs. The only mechanism for nutrient removal is plant uptake. The Watershed Model computes dissolved loads for both nitrogen and phosphorus.

Ponded Systems: Ponded septic systems are the result of hydraulic overload or hydraulic failure. The effluent from these systems "ponds" over the adsorption field. If the temperature is below freezing, than the ponded effluent is assumed to freeze and nutrients can accumulate. Monthly nutrient loads from these systems consider whether or not nutrients have accumulated due to frozen conditions.

Direct Discharge: These systems are illegal and discharge effluent directly to surface waters. The nutrient loads from these systems are based solely on the per capita tank effluent and the population served. Removal by plant uptake is not considered. These systems contribute to dissolved loads of both nitrogen and phosphorus.

3.2 Model Format

The Watershed Model utilizes a notebook format to enter data and display model results. The first eight notebook pages provide screens for input data and the last two notebook pages are used to present tabular and graphical model results, respectively. Each page of the notebook can be accessed by clicking on the corresponding tab or pressing <Alt> plus the underlined letter of the tab header. Comprehensive discussions regarding model input and parameter estimation are provided in Section 3.3 to Section 3.9. Each of these sections corresponds to an individual notebook page in the Watershed Model. Simulation results and model output are discussed in Section 3.10.

For each notebook page used to enter data, there is an example data set. This data set can be used as a tutorial for the Watershed Model. To access this data click on the [**Example Data**] buttons on each notebook page. There is data available to meet all model options. The example weather file must also be selected from the weather file list box. These data can be used to become familiar with how to navigate through the model and it provides an example of typical input and model results.

The first notebook page, Project Info, serves as the Watershed Model's introductory screen. This notebook page can be used for record keeping purposes. There are text boxes available to enter in the project title, project number, date, and the names of the individuals involved with the model run. This notebook page may be omitted if desired.

The menu bar on the Watershed Model provides the user with file access, editing capability, and help information. Selecting **File** will display a drop-down menu list with the following items: **New**, **Open**, **Save**, **Save As**, **Print**, and **Exit**. **New** deletes the current data set. A message box will ask for verification prior to deleting current values. **Open** calls up the Open File dialog box to select an existing data set. **Save** will save the current data set using the existing file name. If a file name has not been defined, the Save As File dialog box will appear prompting the user to enter a file name. **Save As** opens the Save As File dialog box to allow the current data set to be saved with a new file name. Selecting **Print** will call up the Print File dialog box. The user can select to print the input data and/or any of the tabular output displays. Note that graphs are not printed from this menu item. The graphs are printed directly from the Graphical Output notebook page using the **[Print Graph]** command button. **Exit** closes the Watershed Model and returns the user to the main CS Model window. If the current data set has not been saved, it will be lost. Selecting **Edit** will display a drop-down menu list with **Cut**, **Copy**, and **Paste**. These menu items can be used to edit input data. **Cut** will remove the selected text and move it to the windows clipboard. **Copy** will place a duplicate of the selected text on the clipboard, but not remove the original text. **Paste** can be used to put text placed on the clipboard back onto one of the input screens. **Help** will provide information pertaining to the Watershed Model.

3.3 Program Options

The Watershed Model will simulate stream flow, sediment yields, nutrient loads, and septic system inputs. Click on the desired model option or press the **<Tab>** key to gain access to the option group and use the arrow keys to select the desired model option. The required input parameters will vary depending on the model option selected. Any notebook pages that contain unnecessary input information for the selected model option will have "greyed" tabs. These tabs are disabled, which means that the user no longer has access to these pages. This feature aids the user in determining what information is required to run the model.

3.3.1 Hydrologic Unit Data

Regardless of which model option is selected, land use data must be entered. If the land uses of the watershed being modeled are not known, land use values can be retrieved from the Hydrologic Unit Database (HUD). Hydrologic units define watershed boundaries and the HUD contains land use information for each hydrologic unit in Virginia. The database information was provided by the Virginia Department of Conservation and Recreation, Division of Soil and Water Conservation. Acreage values were supplied for 13 land uses: cropland, hay, orchard, idle farmland, Agricultural Stabilization and Conservation Service (ASCS) set aside, Conservation Reserve Program (CRP) land, pastureland, forest, urban residential, urban industrial, urban other, waterbodies, and Christmas trees. This data was restructured to provide the VMRC with more manageable land use categories and to meet the input requirements of the Watershed Model. Data for waterbodies were discarded because they are not applicable to the Watershed Model. Acreage values for orchards and Christmas trees were combined into one land use category since these two land uses would have similar model input values. Farmland that is enrolled in the CRP or has been designated as an ASCS set aside is not in production. These land uses are likely to have model input values which are similar to idle farmland, and therefore, their acreage values were combined with the acreage values for idle farmland in each hydrologic unit. This restructuring of the database information yielded nine land use categories in the HUD. Upon completion of the database restructuring, the acreage values for these nine land uses were converted to hectares to meet the model input requirements.

To access the HUD, select the [Yes] option under "**Use Hydrologic Unit data?**". A frame will appear that contains a drop-down list box for selecting the appropriate hydrologic unit. If the appropriate hydrologic unit is not known, it can be determined by using the map viewer. The map viewer list box contains the names of all the counties in tidewater Virginia. Select the name of the county where the watershed currently being modeled is located and choose the [**View**] command button. A picture box containing a map of the selected county will be displayed. The map defines all of the hydrologic units within the county. Various parts of the map can be viewed by selecting one of the command buttons beneath the picture box or using the horizontal and vertical scroll bars. Once the appropriate hydrologic unit has been determined, select that value from the hydrologic unit list box and choose [**Close**] to exit the map viewer. The types of land uses and their corresponding areas will automatically be entered into the Land Uses notebook page.

Because land use information changes over time, the Virginia Department of Conservation and Recreation, Division of Soil and Water Conservation should be periodically contacted to obtain the most recent data.

3.3.2 Climate Data

The Watershed Model requires temperature and precipitation data. This data is provided for nine locations in Virginia. Table 3-1 contains a detailed description of the location where the climate data was collected and can be used to select the most appropriate weather file for the area being modeled. A tenth weather file provides climate data that corresponds to the example data set. Use the scroll bar to view all the available weather files and select the desired weather file by clicking on it.

The weather files are organized by month. The first entry is the number of days in the month and subsequent entries are daily temperature (°C) and precipitation (cm) values. The weather files are arranged to correspond to the assumptions of the model. "Both the groundwater and sediment portions of the model require that simulated years begin at a time when soil moisture conditions are known and runoff events have flushed the watershed of the previous year's accumulated sediment" (Haith et al., 1992). In Virginia, this corresponds to early spring, and therefore, the weather files provided with the model are arranged in April to March weather years.

The climate data was provided by the USGS and converted to the format required by the model. Daily maximum and minimum temperatures were averaged and then converted from Fahrenheit to Celsius. Daily precipitation values were converted from inches to centimeters. Some of the weather files contained data gaps. For a missing daily temperature measurement, the temperatures from the day prior to and after the missing measurement were averaged. For a missing daily precipitation measurement, the value was set to zero. If there were numerous missing measurement points or consecutive missing measurement points, then the data for the entire year was discarded.

After a weather file has been selected, the length (number of years) of the climate record will be displayed in the simulation time text box. The simulation length cannot exceed this value, but a shorter simulation time may be entered. To enter a value in the text box, move the mouse cursor to the text box and click the left mouse button to set the focus to the text box and then type the desired simulation length.

Table 3-1. Weather File Locations and Record Lengths

Location	Station No.	Lat	Long	Dates
Blackstone FAA Airport (Nottoway County)	773	N37:05:00	W077:57:00	April 1949 - March 1972 (23 years)
Corbin (Caroline County)	2009	N38:12:00	W077:22:00	April 1959 to March 1992 (33 years)
Louisa (Louisa County)	5050	N38:02:00	W078:00:00	April 1949 to March 1992 (minus 1968, incomplete) (42 years)
Nassawadox (Northampton county)	5931	N37:28:00	W075:52:00	April 1957 to March 1976 (19 years)
Onley 1 S (Accomack County)	6362	N37:41:00	W075:43:00	April 1930 to March 1955 (25 years)
Richmond WSO Airport (Henrico County)	7201	N37:30:00	W077:20:00	April 1942 to March 1992 (minus 1951, incomplete) (42 years)
Wallops Island WSSF (Accomack County)	8849	N37:56:00	W075:28:00	April 1967 to March 1980 (13 years)
Warsaw 2 N (Richmond County)	8894	N37:59:00	W076:46:00	April 1951 to March 1992 (minus 1970, incomplete) (40 years)
Washington WB Chantilly (Loudon County)	8903	N38:57:00	W077:27:00	April 1963 to March 1992 (29 years)

3.4 Initial Conditions

The values for the initial conditions can be entered directly into each text box by clicking on it and then entering the desired value from the keyboard. The text boxes may also be accessed using the <Tab> key. As each text box becomes active, its corresponding label will turn blue.

Unsaturated Available Water Capacity (U*): The available unsaturated zone soil moisture capacity is used to estimate percolation to the groundwater, which occurs when the unsaturated zone water exceeds the available soil water capacity (Haith et al., 1992). "In principle, U* is equivalent to a mean watershed maximum rooting depth multiplied by a mean volumetric soil available water capacity. The latter also requires determination of a mean unsaturated zone depth, and this is impractical for most watershed studies. A default value of 10 cm can be assumed for pervious areas, corresponding to a 100 cm rooting depth and a 0.1 cm/cm volumetric available water capacity" (Haith et al., 1992). Selecting the **[Default]** button will assign a value of 10 cm to U*.

Sediment Delivery Ratio: The sediment delivery ratio is the ratio between the amount of sediment yield and the gross erosion in a watershed (Gottschalk, 1964).

Table 3-2 shows the effect of drainage basin size on the sediment delivery ratio. Figure 3-2 provides a commonly used area-based relationship from Vanoni (1975) that can be used to estimate the sediment delivery ratio based on the area of the watershed being modeled. Since the sediment delivery ratio is very site specific, selecting the [Default] button will not provide a value for this parameter.

Table 3-2. Sediment Delivery Ratio Based on Watershed Size

Drainage Area (km^2)	Sediment Delivery Ratio (percent)
0.1	53.0
0.5	39.0
1.0	35.0
5.0	27.0
10.0	24.0
50.0	15.0
100.0	13.0
200.0	11.0
500.0	8.5
26,000	4.9

Source: Robinson, 1979.

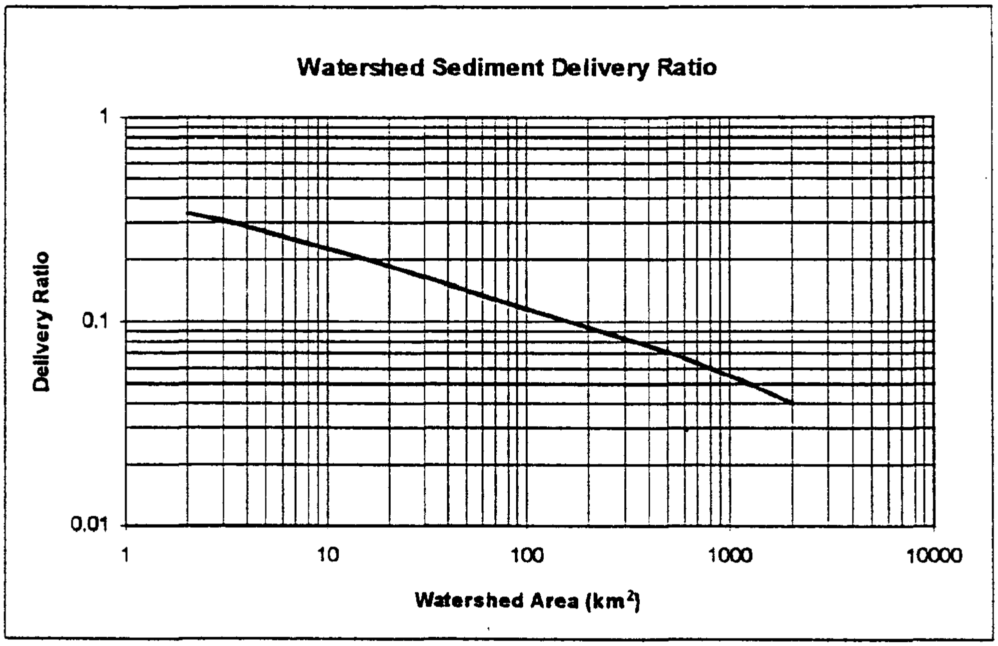


Figure 3-2. Watershed sediment delivery ratio, adapted from Vanoni, 1975.

Recession Coefficient (r): The baseflow recession coefficient is used to determine ground water discharge to stream flow. Standard hydrograph separation techniques can be used to estimate the recession coefficient from stream flow records.

Recession coefficients are measured for a number of hydrographs and an average value is used for the simulations. Typical values range from 0.01 to 0.2. The **[Default]** button supplies an arbitrary value of 0.1.

Seepage Coefficient (s): The rate constant for deep seepage loss is used during the calculation of the groundwater discharge to stream flow. The seepage coefficient is multiplied by the daily shallow saturated zone soil moisture to determine the amount entering into the deep saturated zone, and thereby leaving the watershed. There are no standard techniques available for estimating the seepage coefficient. If the coefficient cannot be determined by calibration, then a conservative approach is to assume that all precipitation exits the watershed by either evapotranspiration or stream flow, and therefore deep seepage equals zero. Selecting the **[Default]** button will set s to zero.

Unsaturated Storage - The initial unsaturated soil zone moisture in cm.
Saturated Storage - The initial shallow saturated soil zone moisture in cm.
Snowmelt Water - The amount of snow melt water in cm at the beginning of the simulation.
Antecedent Rain and Melt - The amount of rain and snow melt for the five previous days.

The preceding four parameters are difficult to characterize, but they will not affect simulation results beyond the first several months. To ameliorate this problem, assign arbitrary values to these initial conditions and discard the results from the first year of the simulation. A common approach is to assign the value of the unsaturated available water capacity (U*) to the unsaturated storage and zero to the remaining variables. The **[Default]** button will assign a value of zero to all the following variables, except for unsaturated storage, which is assigned 10 cm.

Selecting the **[Example Data]** button will provide initial conditions data for the example watershed. To provide reasonable output data, this data should be used in conjunction with the example data provided for the other input parameters and the example weather file.

The **[Cancel]** button will clear all values from the initial conditions text boxes. If this button is selected, a message box will appear asking for verification prior to deleting current values.

3.5 Land Use Information

A minimum of one land use with a non-zero area (in hectares) must be specified prior to beginning any simulation. A land use without a corresponding area value is not allowed. To model land use changes over time, a run must be performed with the initial land use cover and then a second run must be performed with the modified land uses.

Land uses are divided into two categories: rural and urban. This separation is required because of model formulation. The Watershed Model uses a modification of the Universal Soil Loss Equation (USLE) to determine erosion from rural sources. The USLE was not developed for urban land uses, and is therefore not applied to these areas. In addition, the model will calculate both a dissolved and a solid phase nutrient load from rural sources, but urban nutrient loads are modeled as being entirely a solid phase.

To enter land use values into either the Rural Land Use or the Urban Land Use spreadsheet simply click on the desired cell. The spreadsheets can also be accessed using the **<Tab>** key. Once the desired spreadsheet has gained the focus, use the arrow keys to move from cell to cell. For each land use in the watershed, enter its name and area in hectares. If the land use name you wish to enter is two words, enter the name without a hyphen. When the model graphs the results, it will use the first two letters from each word in the name for the graph label if the name consists of two discrete words. For example, the land use "Impervious Residential" would have a graph label of "Im-Re", but a land use designated as "Impervious-Residential" would have a graph label of "Imper".

Rows may be removed or added to either the Rural or the Urban Land Uses spreadsheets by clicking on the **[Delete Row]** or **[Insert Row]** buttons. When either of these command buttons are selected, the active row in the spreadsheet will be altered accordingly.

Selecting the **[Example Data]** button will provide land use data for the example watershed. To provide reasonable output data, this land use data should be used in conjunction with the example data provided for the other input parameters and the example weather file.

The **[Cancel]** button will clear all values from both the Rural and the Urban Land Uses spreadsheets. If this button is selected, a message box will appear asking for verification prior to deleting all cell values.

3.5.1 Runoff Curve Numbers

For each rural and urban land use entered in the spreadsheet, a runoff curve number (CN) must be assigned. Curve numbers represent a relationship between precipitation and runoff volume. The Soil Conservation Service developed a method to estimate excess rain volume (runoff) based on the precipitation volume and the volume of total storage. The storage parameter (DS) in centimeters is obtained from the equation

$$DS = \frac{2540}{CN} - 25.4$$

Curve numbers exist for three antecedent moisture conditions: (1) $CN1_k$ is for below-average (dry) moisture conditions; (2) $CN2_k$ is for average moisture conditions; and (3) $CN3_k$ is for above-average (wet) moisture conditions. The Watershed Model requires $CN2_k$ to be input. The model computes the values for $CN1_k$ and $CN3_k$ from $CN2_k$. During simulations, the model will evaluate the current moisture conditions and supply the appropriate curve number. Table 3-3 to Table 3-5 contain suggested curve numbers for average antecedent moisture conditions ($CN2_k$) for a variety of land uses and are based on soil hydrologic groups. A description of the four soil hydrologic groups, for both undisturbed and disturbed soils, is provided in Table 3-6. Disturbed soils are characterized by a major alteration of the soil profile, as would occur from construction or development.

Table 3-3. Runoff Curve Numbers for Cultivated Agricultural Land

Land Use/Cover[a]		Hydrologic Condition[b]	Soil Hydrologic Group			
			A	B	C	D
Fallow Bare Soil		N/A	77	86	91	94
Crop Residue Cover		Poor	76	85	90	93
		Good	74	83	88	90
Row Crops	SR	Poor	72	81	88	91
		Good	67	78	85	89
	SR + CR	Poor	71	80	87	90
		Good	64	75	82	85
	C	Poor	70	79	84	88
		Good	65	75	82	86
	C + CR	Poor	69	78	83	87
		Good	64	74	81	85
	C&T	Poor	66	74	80	82
		Good	62	71	78	81
	C&T + CR	Poor	65	73	79	81
		Good	61	70	77	80
Small Grains	SR	Poor	65	76	84	88
		Good	63	75	83	87
	SR + CR	Poor	64	75	83	86
		Good	60	72	80	84
	C	Poor	63	74	82	85
		Good	61	73	81	84
	C + CR	Poor	62	73	81	84
		Good	60	72	80	83
	C&T	Poor	61	72	79	82
		Good	59	70	78	81
	C&T + CR	Poor	60	71	78	81
		Good	58	69	77	80
Close-seeded or Broadcast Legumes or Rotation Meadow	SR	Poor	66	77	85	89
		Good	58	72	81	85
	C	Poor	64	75	83	85
		Good	55	69	78	83
	C&T	Poor	63	73	80	83
		Good	51	67	76	80

Source: Soil Conservation Service, 1986.

[a] CR = Crop Residue; SR = Straight Row; C = Contoured; C&T = Contoured and Terraced

[b] Hydrologic condition is based on a combination of factors that affect infiltration and runoff, including: (1) density and canopy of vegetative areas, (2) amount of year-round cover, (3) amount of close-seeded legumes in rotations, (4) percent of residue cover on the land surface (good ≥ 20%), and (5) degree of surface roughness.

Table 3-4. Runoff Curve Numbers for Other Rural Land

Land Use/Cover	Hydrologic Condition	Soil Hydrologic Group			
		A	B	C	D
Pasture, grassland or range - continuous forage for grazing[a]	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow - continuous grass, protected from grazing, generally mowed for hay	N/A	30	58	71	78
Brush - brush/weeds/grass mixture with brush the major element[b]	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30	48	65	73
Woods/grass combination (orchard or tree farm)[c]	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods[d]	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30	55	70	77
Farmsteads	N/A	59	74	82	86

Source: Soil Conservation Service, 1986.

[a] **Poor:** <50% ground cover or heavily grazed with no mulch; **Fair:** 50-70% ground cover and not heavily grazed; **Good:** >75% ground cover and lightly or only occasionally grazed.

[b] **Poor:** <50% ground cover; **Fair:** 50-70% ground cover; **Good:** >75% ground cover.

[c] Estimated as 50% woods and 50% pasture.

[d] **Poor:** forest litter, small trees and brush are destroyed by heavy grazing or regular burning; **Fair:** woods are grazed but not burned and some forest litter covers the soils; **Good:** woods are protected from grazing and litter and brush adequately cover the soil.

Table 3-5. Runoff Curve Numbers for Urban Areas

Land Use/Cover		Soil Hydrologic Group			
		A	B	C	D
Open space (lawns, parks, golf courses, cemeteries, etc.):					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50-75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Paved parking lots, driveways, roofs, etc.		98	98	98	98
Streets and roads:					
Paved with curbs and storm sewers		98	98	98	98
Paved with open ditches		83	89	92	93
Gravel		76	85	89	91
Dirt		72	82	87	89
	Average Imperviousness[a] (%)				
Residential average lot size[b]					
0.05 ha (1/8 acre)	65	77	85	90	92
0.10 ha (1/4 acre)	38	61	75	83	87
0.15 ha (1/3 acre)	30	57	72	81	86
0.20 ha (1/2 acre)	25	54	70	80	85
0.4 ha (1 acre)	20	51	68	79	84
Commercial and business	85 (average)	89	92	94	95
Industrial districts	72	81	88	91	93

Source : Novotny and Olem, 1994 and the Soil Conservation Service, 1986.

[a] The remaining pervious areas (lawns) are considered to be in good pasture condition for these curve numbers.

[b] Curve numbers are computed assuming the runoff from the house and driveway is directed toward the street with a minimum of roof water directed to lawns where additional infiltration could occur.

Table 3-6. Description of Soil Hydrologic Groups

Soil Group	Description
	Undisturbed Soils
A	Low runoff potential and high infiltration rates even when thoroughly wetted. Chiefly deep, well to excessively drained sands or gravels. High rate of water transmission (>0.75 cm/hr).
B	Moderate infiltration rates when thoroughly wetted. Chiefly moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. Moderate rate of water transmission (0.40-0.75 cm/hr).
C	Low infiltration rates when thoroughly wetted. Chiefly soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture. Low rate of water transmission (0.15-0,40 cm/hr).
D	High runoff potential. Very low infiltration rates when thoroughly wetted. Chiefly clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, or shallow soils over nearly impervious material. Very low rate of water transmission (0-0.15 cm/hr).
	Disturbed Soils
A	Sand, loamy sand, sandy loam
B	Silt loam, loam
C	Sandy clay loam
D	Clay loam, silty clay loam, sandy clay, silty clay, clay

Source: Soil Conservation Service, 1986.

3.5.2 Universal Soil Loss Equation Factors

The Universal Soil Loss Equation (USLE) is the most widely accepted estimator of soil loss caused by upland erosion (Novotny and Chesters, 1981; Schwab and Frevert, 1985; Wischmeier and Smith, 1978). The USLE is an empirical equation that was developed through statistical analysis of more than 40 years of measured soil losses from many small, experimental plot studies. The Agricultural Research Service of the USDA established soil erosion experiment stations at different geographic locations throughout the country that represented a wide range of soil and climatic conditions. The USLE was developed by Walt Wischmeier and Dwight Smith from the data collected at these experiment stations and other available information from a network of state and federal research units (Browning, 1979; Sandels, 1986). The USLE was originally developed to provide a reliable means of selecting adequate erosion control practices for farm fields and construction areas. More recently, the USLE has been used to predict sediment losses for pollution control programs or as an erosion estimator in land use models.

Variables influencing upland erosion are: climate, soil properties, vegetation, topography, and human activities (Novotny and Chesters, 1981). The USLE accounts for these erosion variables by estimating average annual soil loss by the following six major factors:

$$A = RKLSCP$$

where,

A = average annual soil loss in tons per acre (t/a),

R = rainfall and runoff factor, which is the number of rainfall erosion index units plus a factor for runoff from snowmelt or applied water where such runoff is significant,

K = soil-erodibility factor in t/a, which is the average soil loss per unit of erosion index for a soil in cultivated continuous fallow with a slope length of 72.6 ft and slope of 9 percent,

L = slope-length factor, which is the ratio of soil loss from the field slope length to that from a 72.6 ft length under identical conditions,

S = slope-steepness factor, which is the ratio of soil loss from the field slope gradient to that from a 9 percent slope under otherwise identical conditions,

C = cover and management factor, which is the ratio of soil loss for given conditions to that from cultivated continuous fallow, and

P = conservation practice factor, which is the ratio of soil loss for a given practice to that for straight row farming up and down the slope.

The Watershed Model uses a modification of the USLE to calculate erosion from rural sources. Since the USLE is an empirical equation which was derived from data for agricultural and rural land uses, applying it to urban land areas is not appropriate. For each rural land use, an "erosion product" must be specified. This is the product of KLSCP. The Watershed Model uses this erosion product to calculate the erosion from each source area k on day t in Mg as

$$X_{kt} = 0.132\ RE_t\ [K_k\ (LS)_k\ C_k\ P_k]\ AR_k$$

where, AR_k is the area of source area k and RE_t is the rainfall erosivity on day t. Unlike all it's other inputs, the Watershed Model expects that the value of K will be in English units. The model converts the erosion product to metric units with the factor 0.132.

The Watershed Model estimates rainfall erosivity by the empirical equation developed by Richardson et al. (1983) as

$$RE_t = 64.6\ a_t\ R_t^{1.81}$$

where, a_t is the rainfall erosivity coefficient and R_t is the rainfall on day t. The rainfall erosivity coefficient is input on the Evapotranspiration Conditions notebook page and the model uses the values in the weather file for rainfall values.

Estimating the USLE Factors

A brief description of each of the factors and a means to estimate them is provided. This is only an abbreviated overview of using the USLE. A comprehensive discussion of the equation's derivation, factors and their estimation, applications, and limitations can be obtained in Wischmeier and Smith (1978).

Soil Erodibility Factor (K): This is a measure of the potential erodibility of the soil. It is based on soil properties. Values for K have been experimentally determined. Table 3-7 contains values of K based on soil texture and organic matter content. Representative values of K for most soils types and texture classes can be obtained from SCS offices. Site-specific values of K can also be calculated using soil erodibility nomograph techniques.

Table 3-7. Values of Soil Erodibility Factor (K) in t/a

Texture	Organic Matter Content (%)		
	< 0.5	2	4
Sand	0.05	0.03	0.02
Fine sand	0.16	0.14	0.10
Very fine sand	0.42	0.36	0.28
Loamy sand	0.12	0.10	0.08
Loamy fine sand	0.24	0.20	0.16
Loamy very fine sand	0.44	0.38	0.30
Sandy loam	0.27	0.24	0.19
Fine sandy loam	0.35	0.30	0.24
Very fine sandy loam	0.47	0.41	0.33
Loam	0.38	0.34	0.29
Silt loam	0.48	0.42	0.33
Silt	0.60	0.52	0.42
Sandy clay loam	0.27	0.25	0.21
Clay loam	0.28	0.25	0.21
Silty clay loam	0.37	0.32	0.26
Sandy clay	0.14	0.13	0.12
Silty clay	0.25	0.23	0.19
Clay	-	0.13-0.29	-

Source: Stewart et al., 1975.

Topographic Factor (LS): The effects of slope-length and slope-steepness have been research separately and represent individual factors in the USLE, but they are commonly combined into a single topographic factor for application purposes. Table 3-8 provides LS values for some common slope lengths and percent slopes. Other combinations of length and gradient can be determined by interpolating between the values in Table 3-8. The values in Table 3-8 were calculated by

$$LS = (\lambda/72.6)^m\ (65.41 \sin^2\theta + 4.56 \sin\theta + 0.065)$$

where, λ is the slope length in feet, θ is the angle of slope, and m is the slope-length exponent based on percent slope. For slopes of 5 percent or greater, m equals 0.5. For slopes of 3.5 to 4.5 percent, m equals 0.4. On slopes of 1 to 3 percent, m equals 0.3, and on uniform gradients of less than 1 percent, m equals 0.2

Cover and Management Factor (C): Also called the cropping management factor and the vegetative cover factor, C "estimates the effect of ground cover conditions, soil conditions, and general management practices on erosion rate" (Novotny and Chesters, 1981). The C Factor reflects the amount of protection against raindrop impact and the subsequent soil particle displacement. C is a dimensionless factor with values ranging between 0 and 1. A cover and management factor of 1 represents continuous fallow tilled up and down the slope. This condition would potentially yield the greatest amount of erosion. As the value of C approaches zero, the vegetative cover or management efforts have reduced the potential for erosion. Table 3-9 provides some common values for C for agricultural land uses. The cover and management factor can also be applied to construction sites. Table 3-10 contains C Factor values and slope-length limits for construction sites. Factor C is usually provided in terms of an average annual value for a particular combination of crop systems and management (Wischmeier and Smith, 1978).

Table 3-8. Values for the Topographic Factor (LS)

Percent	Slope Length (feet)											
Slope	**25**	**50**	**75**	**100**	**150**	**200**	**300**	**400**	**500**	**600**	**800**	**1000**
0.2	.060	.069	.075	.080	.086	.092	.099	.105	.110	.114	.121	.126
0.5	.073	.083	.090	.096	.104	.110	.119	.126	.132	.137	.145	.152
0.8	.086	.098	.107	.113	.123	.130	.141	.149	.156	.162	.171	.179
2	.133	.163	.185	.201	.227	.248	.280	.305	.326	.344	.376	.402
3	.190	.233	.264	.287	.325	.354	.400	.437	.466	.492	.536	.573
4	.230	.303	.357	.400	.471	.528	.621	.697	.762	.820	.920	1.01
5	.268	.379	.464	.536	.656	.758	.928	1.07	1.20	1.31	1.52	1.69
6	.336	.476	.583	.673	.824	.952	1.17	1.35	1.50	1.65	1.90	2.13
8	.496	.701	.859	.992	1.21	1.41	1.72	1.98	2.22	2.43	2.81	3.14
10	.685	.968	1.19	1.37	1.68	1.94	2.37	2.74	3.06	3.36	3.87	4.33
12	.903	1.28	1.56	1.80	2.21	2.55	3.13	3.61	4.04	4.42	5.14	5.71
14	1.15	1.62	1.99	2.30	2.81	3.25	3.98	4.59	5.13	5.62	6.49	7.26
16	1.42	2.01	2.46	2.84	3.48	4.01	4.92	5.68	6.35	6.95	8.03	8.98
18	1.72	2.43	2.97	3.43	4.21	3.86	5.95	6.87	7.68	8.41	9.71	10.9
20	2.04	2.88	3.53	4.08	5.00	5.77	7.07	8.16	9.12	10.0	11.5	12.9

Source: Wischmeier and Smith, 1978.

Table 3-9. Values of C for Cropland, Pasture, and Woodland

Land Use	C
Continuous fallow tilled up and down slope	1.0
Shortly after seeding or harvesting	0.3 - 0.8
For crops during main part of growing season	
Corn	0.1 - 0.3
Wheat	0.05 - 0.15
Cotton	0.4
Soybeans	0.2 - 0.3
Meadow	0.01 - 0.02
For permanent pasture, idle land, unmanaged woodland	
Ground cover 95 - 100% as grass	0.003
Ground cover 95 - 100% as weeds	0.01
Ground cover 80% as grass	0.01
Ground cover 80% as weeds	0.04
Ground cover 60% as grass	0.04
Ground cover 60% as weeds	0.09
For managed woodland	
Tree canopy of 75 -100%	0.001
Tree canopy of 40 - 75%	0.002 - 0.004
Tree canopy of 20 - 40%	0.003 - 0.01

Source: Novotny and Chesters, 1981

Table 3-10. C Factor Values and Slope-Length (LS) Limits for Construction Sites

Mulch Type	Application (tonnes/ha)	Slope (%)	C	LS
No mulch or seeding		All	1.0	
Straw or hay tied down by anchoring and tracking equipment used on slope	2.25	<5	0.2	60
	2.25	6-10	0.2	30
	3.4	<5	0.12	90
	3.4	6-10	0.12	45
	4.5	<5	0.06	100
	4.5	6-10	0.06	60
	4.5	11-15	0.07	45
	4.5	16-20	0.11	30
	4.5	21-25	0.14	23
Crushed stone	300	<15	0.05	60
	300	16-20	0.05	45
	300	21-33	0.05	30
	540	<20	0.02	90
	540	21-35	0.02	60
Wood chips	15	<15	0.08	23
	15	16-20	0.08	15
	27	<15	0.05	45
	27	16-20	0.05	23
	56	<15	0.02	60
	56	16-20	0.02	45
	56	21-33	0.02	30
Asphalt emulsion 12 m^3/ha			0.03	

		C - During first 6 weeks of growth	C - After the 6th week of growth
Temporary seeding with grain or fast-growing grass with:			
No mulch		0.70	0.10
Straw	2.25	0.20	0.07
	3.4	0.12	0.05
Stone	300	0.05	0.05
	540	0.02	0.02
Wood chips	15	0.08	0.05
	27	0.05	0.02
	56	0.02	0.02
Sod		0.01	0.01

Source: Novotny and Olem, 1994.

Conservation Practice Factor (P): The conservation practice factor accounts for management activities which slows runoff water and thus reduces sediment transport capacity, thereby retaining detached soil particles near their sources. This includes contouring, compacting, strip cropping, and establishing sediment basins. P is a dimensionless factor with values ranging between 0 and 1. The P Factor has a value of 1 when no management activities are applied. Table 3-11 and Table 3-12 provide values for the conservation practice factor.

Table 3-11. Values of P for Agricultural Lands

		Strip Cropping and Terracing	
Slope (percent)	**Contouring**	**Alternate Meadows**	**Closegrown**
0 - 2.0	0.6	0.3	0.45
2.1 - 7.0	0.5	0.25	0.40
7.1 - 12.0	0.6	0.30	0.45
12.1 - 18.0	0.8	0.40	0.60
18.1 - 24.0	0.9	0.45	0.70
> 24	1.0	1.0	1.0

Source: Novotny and Olem, 1994.

Table 3-12. Values of P for Construction Sites

Erosion Control Practice	P
Surface Condition with No Cover	
Compact, smooth, scraped with bulldozer or scraper up and down hill	1.30
Same as above, except raked with bulldozer or scraper up and down hill	1.20
Compact, smooth, scraped with bulldozer or scraper across slope	1.20
Same as above, except raked with bulldozer or scraper across slope	0.90
Loose as a disked plow layer	1.00
Rough irregular surface, equipment tracks in all directions	0.90
Loose with rough surface > 0.3 m depth	0.80
Loose with smooth surface < 0.3 m depth	0.90
Structures	
Small sediment basins - 0.09 ha basin/ha	0.50
Small sediment basins - 0.13 ha basin/ha	0.30
Downstream sediment basin with chemical flocculants	0.10
Downstream sediment basin without chemical flocculants	0.20
Erosion control structures - normal rate usage	0.50
Erosion control structures - high rate usage	0.40
Strip building	0.75

Source: Novotny and Olem, 1994.

Estimation of KLSCP for the Hydrologic Unit Database: The following is a rough estimate of USLE factor values to use for the land uses in the HUD. These values are for the tidewater area of Virginia and are based on the following assumptions:

- Fairly permeable sandy to sandy loamy soils
- Fairly level terrain with a percent slope of 5 percent

- A slope length of 500 feet
- No support practices are being applied

When evaluating a potential source of pollution, the worst case scenario is often used to ensure that any water quality impacts would be detected. This rationale was applied during the selection of the slope-length factor and the conservation practice factor. As slope length increases, the potential for soil detachment and transport also increases, therefore a slope length of 500 feet was selected as a conservative value. By using a large value for the slope length, a greater potential for erosion exists. Although Table 3-8 contains data extrapolated to 1000 feet, these values have not been validated with field measurements, and could increase the uncertainty of model calculations. A conservation practice factor of 1 was selected, since this implies that nothing is being done to minimize erosion on any of the land uses.

Selection of the soil erodibility factor is somewhat arbitrary. This factor should be estimated based on the average of known soil types for each land use. A constant value was selected for all land uses and is based on general property values of the Coastal Plain area.

A percent slope value of 5 percent was selected as an average value for the tidewater area. As slopes steepen, soil loss increases much more rapidly than runoff and a large slope value could have tremendous impact on model results. There are certainly slopes in the tidewater area that are steeper than 5 percent, but to use the maximum value for this factor would present a very unlikely scenario for a watershed.

Values selected for the cover and management factor are average values for each land use and have been selected from the literature values.

The estimates contained in Table 3-13 are an educated best guess, and could be inaccurate if the area being modeled does not match the assumptions. It is always best to use the most site-specific information whenever possible.

Table 3-13. Estimated Values for Land Uses in the Hydrologic Unit Database

Land Use	K	LS	C	P	KLSCP
Cropland	0.24	1.20	0.35	1.0	0.1008
Forest	0.24	1.20	0.005	1.0	0.0014
Hay	0.24	1.20	0.02	1.0	0.0058
Idle Farmland	0.24	1.20	0.1	1.0	0.0288
Orchards/Christmas Trees	0.24	1.20	0.1	1.0	0.0288
Pasture	0.24	1.20	0.08	1.0	0.0230

Limitations

The USLE estimates gross erosion from sheet and rill erosional processes. It does not consider gully or channel erosion, which can be a significant source of erosion in some watersheds. Also, the USLE does not address soil loss by wind erosion.

"The USLE is designed to predict longtime-average soil losses for specified conditions" (Wischmeier and Smith, 1978). It is not recommended for trying to predict soil losses from a specific storm event.

The USLE estimates only erosion potential. It does not estimate transport or deposition, and therefore it does not provide a direct estimate of sediment yield. To estimate the sediment yield, the USLE must be multiplied by a delivery ratio for the watershed.

"Soil losses computed with the USLE are best available estimates, not absolutes. They will generally be most accurate for medium-textured soils, slope lengths of less than 400 feet, gradients of 3 to 18 percent, and consistent cropping and management systems that have been represented in the erosion plot studies. The farther these limits are exceeded, the greater will be the probability of significant extrapolation error" (Wischmeier and Smith, 1978).

3.6 Nutrient Input

The Nutrient Info notebook page contains two spreadsheets: one for rural land uses and one for urban land uses. The land use category names entered into the land uses spreadsheets on the Land Uses notebook page will be automatically transferred to the nutrient spreadsheets. For the rural land uses, the dissolved nitrogen and phosphorus concentrations in mg/L must be entered. Table 3-14 contains flow weighted nutrient concentrations measured by Dornbush et al. (1974) for several agricultural land uses. For urban land uses, the nutrient build-up in kg/ha-day must be entered. Table 3-15 provides nutrient accumulation rates for urban areas around northern Virginia as measured by Kuo et al. (1988).

The Watershed Model requires groundwater concentration values for nitrogen and phosphorus in mg/L. These values should be computed from area weighted averages for land use type. According to Reay (1994), typical ground water nitrogen concentrations as NO_3-N are < 1 mg/L for forest, 2 mg/L for pasture and residential areas, and 10 mg/L for agriculture. Typical phosphorus concentrations are 0.15 mg/L for all mentioned land uses.

Soil nutrient levels must be entered in mg/kg for both nitrogen and phosphorus. These values should be computed from area weighted averages for land use type.

The values for the groundwater and soil nutrient parameters may be entered by selecting the appropriate text box with the mouse or using the <Tab> key until the desired text box gains the focus. As each text box gains the focus, it's label will turn blue for easy identification.

Selecting the [**Example Data**] button will provide nutrient concentration and loading data for the example watershed. To provide reasonable output data, this data should be used in conjunction with the example data provided for the other input parameters and the example weather file.

The [**Cancel**] button will clear all values from the nutrient information text boxes and spreadsheets. If this button is selected, a message box will appear asking for verification prior to deleting current values.

Table 3-14. Dissolved Nutrients in Agricultural Runoff

Land Use	Nitrogen (mg/L)	Phosphorus (mg/L)
Fallow	2.6	0.10
Corn	2.9	0.26
Small grains	1.8	0.30
Hay	2.8	0.15
Pasture	3.0	0.25

Source: Dornbush et al., 1974.

Table 3-15. Nutrient Accumulation Rates for Northern Virginia Urban Areas

Land Use	Total Nitrogen (kg/ha-day)	Total Phosphorus (kg/ha-day)
Impervious Surfaces		
Single family residential		
Low density (units/ha < 1.2)	0.045	0.0045
Medium density (units/ha ≥ 1.2)	0.090	0.0112
Townhouses and apartments	0.090	0.0112
High rise residential	0.056	0.0067
Institutional	0.056	0.0067
Industrial	0.101	0.0112
Suburban shopping center	0.056	0.0067
Central business district	0.101	0.0112
Pervious Surfaces		
Single family residential		
Low density (units/ha < 1.2)	0.012	0.0016
Medium density (units/ha ≥ 1.2)	0.022	0.0039
Townhouses and apartments	0.045	0.0078
High rise residential	0.012	0.0019
Institutional	0.012	0.0019
Industrial	0.012	0.0019
Suburban shopping center	0.012	0.0019
Central business district	0.012	0.0019

Source: Kuo et al., 1988.

3.7 Point Sources

The Watershed Model can account for nitrogen and phosphorus loadings from continuous point source discharges. If there are known continuous point source discharges into the watershed, they should be modeled to provide the most accurate picture of watershed nutrient loadings.

To enter nutrient loads into the Point Sources spreadsheet, click on the spreadsheet or use the <**Tab**> key until the spreadsheet gains the focus. The monthly loadings should be entered in kilograms.

Selecting the [**Example Data**] button will provide point source data for the example watershed. To provide reasonable output data, this data should be used in conjunction with the example data provided for the other input parameters and the example weather file.

The **[Cancel]** button will clear all values from the point sources spreadsheet. If this button is selected, a message box will appear asking for verification prior to deleting current values.

3.8 Evapotranspiration Conditions

The parameters on the Evapotranspiration Conditions notebook page are used to determine the water balance in the Watershed Model. Default values for all of the monthly ET parameters have been provided. They are based on Virginia's geographic location and typical growing season.

Evapotranspiration Cover Coefficient (CV_t): The amount of daily evapotranspiration is determined by multiplying the potential ET by the cover coefficient. This parameter can be difficult to estimate, but Haith et al. (1992) has developed a simplified procedure:

1. Cover Coefficients should vary between 0 and 1, in principle.
2. Cover coefficients will approach their maximum value when plants have developed full foliage.
3. Because evapotranspiration measures both transpiration and evaporation of soil water, the lower limit for cover coefficients will be greater than zero. This lower limit essentially represents a situation without any plant cover.
4. The protection of soil by impervious surfaces prevents evapotranspiration.

Cover coefficients for forests reach minimum values of 0.2 to 0.3 as leaf area indices approach zero. Similarly, cover coefficients for farmland with annual crops can fall to 0.3 prior to planting and after harvesting. Cover coefficients for perennial crops and conifers tend towards 1.0. "This suggests that monthly cover coefficients can be given the value 0.3 when foliage is absent and 1.0 otherwise" (Haith et al., 1992). For urban areas, a constant value of 1.0 can be assigned to pervious surfaces and 0.0 to impervious surfaces. The monthly values for the cover coefficient should reflect the area weighted average for the various land use types in the watershed. Assuming that the amount of impervious surfaces is small in relation to the watershed extent, default values have been selected based on seasonal foliage development in Virginia. The values can be displayed by selecting the **[Default]** button. If the watershed being modeled contains substantial urban development or unusual conditions, the default cover coefficients might not be applicable.

Daylight Hours: This value represents the mean daylight hours for each month. This parameter is fairly constant for most of Virginia. The mean daylight hours for 38° latitude are used as default values (USEPA, 1984). Selecting the **[Default]** button will display these values in the Evapotranspiration spreadsheet.

Growing Season: The monthly value is classified as either dormant or growing and is represented by either a 0 or a 1, respectively. The growing season parameter determines the breakpoints between antecedent moisture conditions. For months in the dormant season, AM1 = 1.3 cm and AM2 = 2.8 cm. For months in the growing seasons, AM1 = 3.6 cm and AM2 = 5.3 cm. The growing season for Virginia is considered to be April to October. Selecting the **[Default]** button will display the growing season values in the Evapotranspiration spreadsheet.

Rainfall Erosivity Coefficient (a_t): The rainfall erosivity coefficient is used to determine rainfall erosivity and contributes to the calculation of erosion by the USLE. The coefficient varies with season and geographic location, but can be estimated by using the methods developed by Selker et al. (1990). According to the rainfall erosivity zones defined by Wischmeier and Smith (1978), all of tidewater Virginia is located in Zone 30. For this zone, Selker et al. has defined the cool season (October to

March) value to be 0.12 and the warm season (April to September) value to be 0.30. Selecting the **[Default]** button will display these values in the Evapotranspiration spreadsheet.

Selecting the [**Example Data**] button will provide evapotranspiration data for the example watershed. To provide reasonable output data, this data should be used in conjunction with the example data provided for the other input parameters and the example weather file.

The [**Cancel**] button will clear all values from the evapotranspiration spreadsheet. If this button is selected, a message box will appear asking for verification prior to deleting current values.

3.9 Septic Systems

The per capita nutrient load must be specified for both nitrogen and phosphorus. The USEPA (1980) reports loadings of 10.4 g/day of total nitrogen and 3.5 g/day of phosphorus. Loading values can also be determined from representative septic tank wastewater flow and effluent concentrations. The USEPA (1980) indicates that a typical on-site wastewater disposal system will discharge 170 L/day per person. Mean nitrogen concentrations in septic tank effluent were measured as 73 mg/L, while mean phosphorus concentrations were 14 mg/L when phosphate detergents were being used and only 7.9 mg/L when non-phosphate detergents were used (Alhajjar et al., 1989). These values yield a per capita septic tank effluent of 12.0 g/day for nitrogen, 2.5 g/day for phosphorus if phosphate detergent is used, and 1.5 g/day if non-phosphate detergent is used.

The per capita growing season nutrient uptake in g/day must also be specified. This refers to the uptake of nutrients from septic tank effluent by the ground cover (usually grasses) over the septic field. There has not been much research in this area. Haith et al. (1992) provided estimates of 1.6 g/day for nitrogen and 0.4 g/day for phosphorus, but these are speculative values. The most conservative approach is to assume that plant uptake is minimal and enter a value of zero. If predicted nutrient loadings from septic systems are within acceptable limits when nutrient uptake by plants is *not* considered, then the septic systems are probably not contributing nonpoint nutrient loadings.

The values for these parameters may be entered by selecting the appropriate text box with the mouse or using the <**Tab**> key until the desired text box gains the focus. As each text box gains the focus, it's label will turn blue for easy identification.

The number of individuals served per month by the four different conditions of septic systems should be entered into the Septic Systems spreadsheet. These four conditions are described in Section 3.1. The number of individuals served by each system can be obtained by performing surveys or by contacting local public health officials. To input data, click on the desired spreadsheet cell or use the <**Tab**> key until the spreadsheet gains the focus, and then use the arrow keys to move around in the spreadsheet.

Selecting the [**Example Data**] button will provide septic system data for the example watershed. To provide reasonable output data, this data should be used in conjunction with the example data provided for the other input parameters and the example weather file.

The [**Cancel**] button will clear all values from the septic system text boxes and spreadsheet. If this button is selected, a message box will appear asking for verification prior to deleting current values.

3.10 Model Results

Simulation results from the Watershed Model can be examined as either tabular or graphical output. To view the tabular results, click on the Tabular Output notebook tab or press <Alt T>. A compete description of this notebook page is provided in subsection 3.10.1. To view the results in a graphical format, click on the Graphical Output notebook tab or press <Alt G>. A complete description of this notebook page is provided in subsection 3.10.2. Selecting the Graphical Output notebook page will run the Watershed Model. If simulation results have not been previously calculated or if any of the input parameters have been altered since the simulation results were generated, the Watershed Model will begin a new simulation. The time required to complete the simulation will depend on the number of years being modeled and the processing power of your computer. The mouse pointer will change to an hourglass while the simulation is being processed.

3.10.1 Tabular Output

The simulation results can be viewed in the following five ways:

1. Summary by Month
2. Summary by Source (land use category)
3. Annual Results
4. Annual Results by Source (land use category)
5. Monthly Results

Selecting *Summary by Month* will provide the average monthly values for precipitation, ET, groundwater flow, stream flow, runoff, erosion, sediment yield, dissolved and total nitrogen, and dissolved and total phosphorus. These are the average values for the entire simulation period. The average annual value for each parameter is also provided in this summary.

Selecting *Summary by Source* will provide average parameter values for each land use category. Results include runoff, erosion per hectare, dissolved and total nitrogen, and dissolved and total phosphorus. The area of each land use is also provided. In addition to the designated land uses, dissolved nutrient loadings are also provide for the groundwater discharge, as well as point sources and septic systems if either has been modeled.

Annual Results provides the average annual values for precipitation, ET, groundwater flow, stream flow, runoff, erosion, sediment yield, dissolved and total nitrogen, and dissolved and total phosphorus for each year in the simulation period.

Annual Results by Source provides the same information as *Summary by Source*, but instead of values averaged over the entire simulation period, the values are presented for each year of the simulation. For large simulation periods, output for the entire simulation may not be desired. To give the user the flexibility to view only selected output years, an input dialog box appears when this display option is selected. Enter the desired beginning and ending years of the output you wish to view and then [Close] the input box.

Selecting *Monthly Results* provides the same information as *Summary by Month*, but instead of monthly values averaged over the entire simulation period, the monthly values are presented for each year of the simulation. For large simulation periods, output for the entire simulation may not be desired. To give the user the flexibility to view only selected output years, an input dialog box appears when this display option is selected. Enter the desired beginning and ending years of the output you wish to view and then **[Close]** the input box.

The default option is *Summary by Month*. To select a different option, use the mouse or press the **<Tab>** key. After the desired display option has been selected, click on **[Show Output]**. If simulation results have not been previously calculated or if any of the input parameters have been altered since the simulation results were generated, the Watershed Model will begin a new simulation. The time required to complete the simulation will depend on the number of years being modeled and the processing power of your computer. The mouse pointer will change to an hourglass while the simulation is being processed. The results will be displayed in a noninteractive spreadsheet.

Any of the simulation results spreadsheets can be printed by selecting **File/Print** from the menu bar. A Print dialog box will appear with check boxes for all the output options. Select as many output options as desired by using the mouse or by pressing <Alt> and the underscored letter in the option name. Once all desired options have been selected, choose the **[OK]** command button. This will send the selected files to the designated windows printer. The output spreadsheets will print in color if a color printer is designated. Select the **[Cancel]** button when the print option is no longer desired.

3.10.2 Graphical Output

There are four types of graphs:

1. Annual Mean by Source (land use category)
2. Monthly Mean
3. Annual
4. Monthly

When you select the desired graph option, a parameter option box will appear with the applicable parameter types. When a parameter type is selected, the corresponding graph will be displayed. This graph can be sent to the printer by clicking on the **[Print Graph]** button. *Annual Mean by Source* and *Monthly Mean* graphs are bar graphs. *Annual* and *Monthly* graphs are line graphs. When the *Monthly* graph option is selected, an input dialog box will appear requesting the yearly range over which to graph the data. Since data for all months is displayed for each specified year, the *Monthly* graph option is more applicable for viewing simulations with short time periods or smaller portions of simulations with large time periods.

4. Marina Water Quality Model

The Marina Water Quality (MWQ) Model is an analytical model for steady-state, two-dimensional contaminant transport from a continuous shoreline source. The model is based on the work of Hamrick and Neilson (1989). A marina was designated as the continuous shoreline contaminant source. The model is applicable to marinas located along the shoreline of a wide channel. Hamrick and Neilson define a *wide* channel as being typically wider than 100m and having "measurable net fresh water discharge in addition to tidal driven flow". The MWQ Model considers advection, dispersion, and first order decay.

Two analytical solutions are included in the MWQ Model: an infinite channel solution and a finite channel solution. These solutions are designated, respectively, by selecting either the *neglect channel end effects* or the *consider channel end effects* option on the Options notebook page. Both solutions assume constant water depth, decay coefficient, longitudinal and transverse dispersion coefficients, and longitudinal velocity. The solutions are based on depth and tidal cycle average conditions. Therefore, the contaminant concentration is constant with depth. In addition, the MWQ Model assumes that the tidal range is significantly less than the water depth. The contaminant is assumed to be uniformly mixed over the water depth at time T_z,

$$T_z = 120\frac{h}{q_m}$$

where, h is the mean water depth and q_m is the maximum tidal velocity magnitude (Hamrick and Neilson, 1989). If Tz is less than or equal to the inverse of the decay coefficient and to the semi-diurnal tidal period, than the vertical uniformity condition is satisfied.

The infinite channel solution is based on the assumption that any contaminant will decay before it reaches the boundaries. Advective transport is limited to the longitudinal direction. This solution is

$$C = \frac{M}{\pi h\sqrt{D_x D_y}}\exp\left[\frac{u}{\sqrt{4K_d D_x}}\sqrt{\frac{K_d}{D_x}}x\right]\sum_{i=-\infty}^{\infty} K_o\left[\sqrt{\left(1+\frac{u^2}{4K_d D_x}\right)}\sqrt{\frac{K_{dx^2}}{D_x}+\frac{K_d}{D_y}(y+2iB)^2}\right]$$

where, C = depth and tidal cycle averaged contaminant concentration
M = mass of the contaminant
D_x = longitudinal dispersion
D_y = transverse dispersion
u = tidally averaged mean discharge velocity
K_d = the decay coefficient
x = the current value along the channel
y = the current value across the channel
K_o = the modified Bessel function of the second kind of order zero
B = channel width

The finite channel solution is for a stream with a no flow (closed) upstream boundary and a downstream boundary open to another water body. The downstream boundary is infinitely diluted. Because of the no flow upstream boundary, longitudinal advective transport is assumed to be negligible. This solution is

$$C=\frac{M}{\pi h_o\sqrt{D_x D_y}}\left(\sum_{i=-\infty}^{\infty}\sum_{j=-\infty}^{\infty}(-1)^j K_o\sqrt{\frac{K_d}{D_x}(x+2L_u+jL_d)^2+\frac{K_d}{D_y}\left(y^2 iB\right)^2}+(-1)^j K_o\sqrt{\frac{K_d}{D_x}(x+2jL_d)^2+\frac{K_d}{D_y}(y+2iB)^2}\right)$$

where, L_u is the upstream boundary location and L_d is the downstream boundary location.

The major weakness of the MWQ Model is the use of idealized stream geometry, topography, and flow fields. This allows for the use of analytical solutions, but site-specific data cannot be used, even if it is known.

4.1 Model Format

The Marina Water Quality Model utilizes a notebook format to enter data and display model results. The first three notebook pages provide screens for input data and the last two notebook pages are used to present tabular and graphical model results. Each page of the notebook can be accessed by clicking on the corresponding tab or pressing **<Alt>** plus the underlined letter of the tab header. Discussions regarding model input and parameter estimation are provided in Sections 4.2 and 4.3. Both of these sections corresponds to an individual notebook page in the MWQ Model. Simulation results and model output are discussed in Section 4.4.

The first notebook page, Project Info, serves as the MWQ Model's introductory screen. This notebook page can be used for record keeping purposes. There are text boxes available to enter in the project title, date, and the names of the individuals involved with the model run. This notebook page may be omitted if desired.

On the Parameters notebook page, there is an example data set. This data set can be used as a tutorial for the MWQ Model. To access this data click on the [**Test Data Set**] button. This data can be used to become familiar with how to navigate through the model and it provides an example of typical input and model results. There is data available to meet all model options.

The menu bar on the MWQ Model provides the user with file access, editing capability, and help information. Selecting **File** will display a drop-down menu list with the following items: **New**, **Open**, **Save**, **Save As**, **Print**, and **Exit**. **New** deletes the current data set. A message box will ask for verification prior to deleting current values. **Open** calls up the Open File dialog box to select an existing data set. **Save** will save the current data set using the existing file name. If a file name has not been defined, the Save As File dialog box will appear prompting the user to enter a file name. **Save As** opens the Save As File dialog box to allow the current data set to be saved with a new file name. Selecting **Print** will send the current model data and results to the default Windows printer. **Exit** closes the MWQ Model and returns the user to the main CS Model window. If the current data set has not been saved, it will be lost. Selecting **Edit** will display a drop-down menu list with **Cut**, **Copy**, and **Paste**. These menu items can be used to edit input data. **Cut** will remove the selected text and move it to the windows clipboard. **Copy** will place a duplicate of the selected text on the clipboard, but not remove the original text. **Paste** can be used to put text placed on the clipboard back onto one of the input screens. **Help** will provide information pertaining to the MWQ Model.

4.2 Parameters

The hydraulic and contaminant parameters and the region to be modeled must de defined. The values for these parameters can be entered directly into each text box by clicking on it and then entering the desired value from the keyboard. The text boxes may also be accessed using the <Tab> key. As each text box becomes active, its corresponding label will turn blue. Clicking on the label for the various input parameters will display a pop-up message box with help information.

The [Cancel] button will clear all values from the parameter text boxes. If this button is selected, a message box will appear asking for verification prior to deleting current values.

4.2.1 Hydraulic Parameters

Mean Water Depth: This is the water depth averaged over the area to be modeled. The depth is assumed to be constant.

Maximum Tidal Velocity: The magnitude of maximum tidal velocity. Units are meters per second.

Mean Discharge Velocity: Tidally averaged mean discharge velocity. A conservative estimate can be obtained by setting this value to zero.

Channel Width: The width of the channel is assumed to be constant over the region being modeled. This value should be entered in meters.

Tidal Period: The tidal period is usually 12.4 hours.

Distance Downstream to Open End: This is the distance downstream to the open end of the channel, and it must be greater than or equal to the downstream distance to be modeled.

Distance Upstream to Closed End: This is the distance upstream to the closed end of the channel, and it must be greater than or equal to the upstream distance to be modeled.

4.2.2 Contaminant Parameters

The MWQ Model will predict results for coliforms, CBOD, and NBOD. Subsection 2.3.5 contains a detailed discussion of these parameters. Check boxes allow for the selection of the contaminants to model. More than one contaminant can be modeled simultaneously. Both a loading and a first order decay rate must be specified for each parameter that will be modeled. Loadings for all parameters are considered to be continuous and steady-state, and the contaminant is introduced into the water body at a point along the shoreline. Required units for loading of CBOD and NBOD are kg/day. Coliform loadings are in organisms per second. Decay rates for all parameters should be per day.

4.2.3 Region to be Modeled

Distance Downstream: Distance downstream from the contaminant source being modeled.

Distance Upstream: Distance upstream from the contaminant source being modeled.

Width Across Channel: The distance across the channel to be modeled. This distance must be less than or equal to the actual channel width.

Display Length: This value will control the interval used to display the distance *along* the channel in the tabular display of the MWQ Model's results on the Tabular Output notebook page. Units are in meters. A value can be entered directly into the text box or the spin buttons can be used to select the desired interval.

Display Width: This value will control the interval used to display the distance *across* the channel in the tabular display of the MWQ Model's results on the Tabular Output notebook page. Units are in meters. A value can be entered directly into the text box or the spin buttons can be used to select the desired interval.

4.3 Options

Selecting the Options notebook page will provide a preliminary assessment of the initial data. The longitudinal and transverse dispersion coefficients are calculated and the model assumptions are evaluated. If you do not want to use the calculated dispersion coefficients, select the check box and enter the desired values in the user selected text boxes. Model assumptions are evaluated based on the chosen selection option to consider or neglect channel end effects. If the displayed values are much greater than 1, than the given assumption is valid. If any of the assumptions are not valid, different parameter values should be entered prior to starting a simulation.

4.4 Model Results

Selecting the Tabular Output notebook page will run the MWQ Model. The mouse pointer will change to an hourglass while the simulation is being processed. Results from the MWQ Model can be examined as either concentrations plots or in a tabular format. To run the model and view the tabular results, click on the Tabular Output notebook tab or press <Alt T>. A compete description of this notebook page is provided in Subsection 4.4.1. To view the results in a graphical format, click on the Transects notebook tab. A complete description of this notebook page is provided in Subsection 4.4.2.

4.4.1 Tabular Output

The MWQ Model displays the results in a spreadsheet format. The distance along the channel, as specified on the Parameter notebook page, is displayed in the first column. The values are for the specified interval in both the upstream and downstream direction. The first row of the spreadsheet displays the distance across the channel, as specified on the Parameter notebook page. The rest of the matrix contains the values for the modeled water quality variable. There is a set of options buttons to the right of the spreadsheet that can be used to change which water quality parameter is being displayed. All values are displayed in exponential notation.

4.4.2 Transects

For each of the water quality variables, the longitudinal concentration can viewed for the transects across the channel. The distance upstream and downstream from the discharge point is set on the x-axis and the parameter concentration is placed along the y-axis. To change which transect is being displayed, click on one of the scroll arrows. The new transect value will be displayed in the text box. The transect value will correspond to the display width value selected on the Parameter notebook page. Once the desired transect value is selected, click on the **[Redraw]** button to refresh the graphical display.

5. Tidal Prism Model

The Tidal Prism Model was developed by Jason Luettinger as a part of his master's degree research. The model description contained in this section is provided from his thesis with his permission.

The Tidal Prism Model is a one-dimensional tidal flushing model capable of predicting the longitudinal distribution of contaminant concentrations at high tide intervals. The algorithm was first proposed by Ketchum in 1951 and later modified by Kuo and Neilson in 1988. The model differs from traditional finite segment models in that the segmentation of a water body is based upon the geometry and hydrodynamic flow characteristics of the water body rather than a manual segmentation process. Instead of solving a large set of simultaneous equations as is necessary for typical finite segment models, the Tidal Prism Model successively solves one mass balance equation progressively from the mouth to the upstream boundary segment for each tidal cycle increment. Concentrations are initialized after each tidal cycle such that the model uses the previous tidal cycle concentrations as the initial conditions for the next time step. This iterative process continues until a specified time period has elapsed or the system reaches a steady-state condition.

Ketchum's original Tidal Prism Model was proven to be fundamentally sound in theory, but some minor flaws were shown to exist in later revisions of the model. Ketchum's model based the segmentation of a water body on the fact that the upstream river flow was a non-zero parameter. Segmentation was proposed to begin at the upstream limit of tidal current reversal and continue downstream to the mouth of the water body. Because a non-zero flow was required in Ketchum's proposed model, it was not applicable to tidal embayments or dammed tidal rivers were an inflow may not always exist. Ketchum demonstrated that the Tidal Prism Model could accurately predict salinity distributions in three very different estuaries including the Raritan River and Bay, Alberni Inlet, and Great Pond (Ketchum, 1951).

Three major revisions have been proposed to Ketchum's original model. Dyer and Taylor (1973) first corrected a fundamental error in the model's mass balance equation and also proposed a fitting parameter associated with the mixing. This unnamed parameter is referred to in later articles as the "return flow factor" or the "returning ratio", and was identified as a relatively important parameter in fitting the model (Sanford et al., 1992). Wood (1978) further expanded this concept by proposing an alternative to the "inter-segment exchange" in terms of an average dispersion coefficient. This dispersion coefficient was included to account for the relative mixing which occurs between the neighboring segments of a water body. Wood's proposed model was calibrated to Ketchum's data on the Raritan Estuary for comparison of fit. It was shown that there was no single dispersion index which could provide an accurate representation of the salinity profile, but that a combination of low dispersion near the freshwater source and high dispersion near the seaward boundary produced a fairly accurate fit.

Wood's model combined the basic ideas proposed by Ketchum (1951) and Dyer and Taylor (1973), but still required that the flow be a non-zero parameter for segmentation of the water body. Kuo and Neilson (1988) later expanded the model such that it became applicable to cases where the water body is branched and/or the freshwater discharge is negligibly small. Kuo and Neilson proposed a fundamental change in the segmentation of the water body in order to allow for the zero flow case. In this version of the model, the segmentation begins at the mouth of the water body and continues upstream until a cutoff point is reached. This cutoff may be a physical barrier such as a dam or embayment, or a hydraulic barrier such as the point where current reversal stops and pure advective flow begins in a tidal river. Kuo and Neilson's final modification of the Tidal Prism Model is capable of simulating point and non-point discharges and can handle both conservative and non-conservative substances. The application of the model is relatively simple as it requires a minimal amount of physical data including depth, surface area and tidal range.

The Tidal Prism Model has been demonstrated to be successful in predicting water quality in many small coastal embayments in Virginia, including the Lynnhaven Bay system on the lower Chesapeake Bay (Kuo and Neilson, 1988).

5.1 Modeling Approach

As the surface of the river rises during flood tide, this increase in water volume must be accounted for from some source. In a tidal river, this increase in volume is accounted for from both the landward river flow and the seaward flooding tide. This increase in water volume is referred to as the "tidal prism" of the river. For every given flow volume in a river, there exists an imaginary boundary in the river where the entire volume change during the rise in tide can be equated to the volume of river flow during that same time period. In other words, there exists a boundary where the prism volume is exactly equal to the river flow (P(x) = R(x)). The entire river landward of this boundary, where P(x) = R(x), can be considered a purely advective river because there is no flow reversal, and therefore no influence from the flooding waters from downstream. The portion of the river downstream of this boundary experiences flow reversal and tidal mixing. This part of the river is truly under tidal influence, and therefore experiences much different hydraulic mixing conditions. The Tidal Prism Model was developed to model this portion of the river. Note that when there is negligible flow, the entire river is influenced by this type of tidal mixing.

The feature that makes the Tidal Prism Model unique when compared to other finite section tidal models is in the process by which the water body is segmented. During flood tide, large amounts of sea water pass through the mouth of the water body and mix with the inland fresh water. Because this water mixes with the freshwater during high tide, a portion of the contaminant is flushed out during ebb tide. This process is known as "tidal flushing". Rather than hypothetically dividing the estuary into finite segments, the tidal prism model assures complete mixing within each segment throughout a tidal cycle by segmenting the water body according to its physical characteristics, i.e. tidal oscillation, upstream flow and topography.

Segmentation begins at the mouth of the water body. The segment length is defined as the distance a particle of water may travel upstream during one flood tide. Longitudinal segmentation is achieved by continuing upstream from the mouth placing segment transects at lengths according to the flooding distance. Because the segment length is always equal to or less than the distance water will travel during a flooding cycle, complete mixing is assured throughout the water body. The Tidal Prism Model is a mathematical simulation of this tidal flushing process. The model is capable of predicting the longitudinal distribution of contaminants within a body of water and is therefore well suited for long coastal embayments or tidal rivers (Kuo and Neilson, 1988). The Tidal Prism Model is considered a dynamic model because it is able to predict the distribution of contaminants at any given point in time, and is therefore not restricted to the steady-state condition.

The Tidal Prism Mass Balance Equation

The Tidal Prism Model mass balance equation is based upon the exchange of mass between segments over an entire ebb to flood tide cycle. This equation is solved from the mouth (segment 1) toward the landward segments, successively solving for the high tide concentration in each segment. The equation requires only the upstream and downstream boundary concentrations and the initial concentrations existing in the water body. The equation begins at cycle 1, using the initial concentration fields that are entered for the first time period, and solves successively upstream for the final concentrations in each segment. These calculated concentrations in each segment then become the new starting point for the second cycle and the process continues. The cycling process continues at intervals equal to one tidal cycle until the desired period of time has elapsed or a steady-state condition is reached. Figure 5-1 is an elevation view of a hypothetical water body. This figure illustrates the exchanges which take place between each segment. During flood tide, a volume of water equal to the prism volume minus the river flow (P(n)-R(n)) moves into the landward segments from the downstream segments. Because the model assumes that complete mixing takes place within each segment, this water that has flooded from the downstream segments mixes completely with the water in the adjacent landward segments. During ebb tide, a volume of water equal to the prism volume plus the river flow (P(n)+R(n)) moves seaward from each segment. This exchange of volume between the ebb and flood tides creates what is referred to as tidal flushing. Mass is slowly transported out of the water body by the constant dilution of the sea water which floods into the coastal embayments or tidal rivers, mixes with the ambient "contaminated" water, and is once again removed during ebb tide.

The returning ratio or "alpha" is incorporated into the flood tide transport portion of the mass balance equation. This parameter accounts for the volume of water which moves out of a segment during ebb tide and then returns at the same concentration in the following flood tide. Alpha therefore represents the relative mixing which occurs between segments. Low values of alpha signify less water exchange and therefore less mixing and vise versa. Sanford et al. (1992) discuss in detail the different hydrodynamic properties of a water body which influence the value of this returning ratio at the seaward boundary. In general, it was shown that the differences in current direction and magnitude at the intersection of the embayment with the receiving water will influence the amount of contaminant that is "returned" to the embayment upon flood tide.

5.2 Model Format

The Tidal Prism Model utilizes a notebook format to enter data and display model results. The first five notebook pages provide screens for input data and the last notebook page is used to present tabular and graphical model results. Each page of the notebook can be accessed by clicking on the corresponding tab or pressing <Alt> plus the underlined letter of the tab header. Comprehensive discussions regarding model input and parameter estimation are provided in Section 5.3 to Section 5.6. Each of these sections corresponds to an individual notebook page in the Tidal Prism Model. Simulation results and model output are discussed in Section 5.7.

For each notebook page used to enter data, there is an example data set. This data set can be used as a tutorial for the Tidal Prism Model. To access this data click on the **[Example Data]** buttons on each notebook page. There is data available to meet all model options. These data can be used to become familiar with how to navigate through the model and it provides an example of typical input and model results.

The first notebook page, Project Info, serves as the Tidal Prism Model's introductory screen. This notebook page can be used for record keeping purposes. There are text boxes available to enter in the project title, date, and the names of the individuals involved with the model run. This notebook page may be omitted if desired.

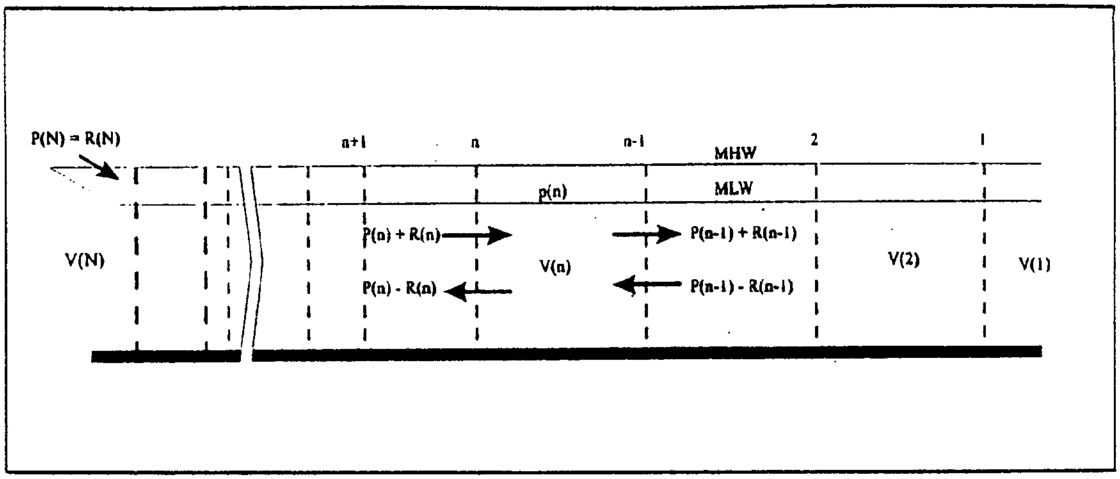


Figure 5-1. Elevation view of a hypothetical river illustrating the volumes of water exchanges between adjacent segments during a complete tidal cycle.

The menu bar on the Tidal Prism Model provides the user with file access, editing capability, and help information. Selecting **File** will display a drop-down menu list with the following items: **New**, **Open**, **Save**, **Save As**, **Print**, and **Exit**. **New** deletes the current data set. A message box will ask for verification prior to deleting current values. **Open** calls up the Open File dialog box to select an existing data set. **Save** will save the current data set using the existing file name. If a file name has not been defined, the Save As File dialog box will appear prompting the user to enter a file name. **Save As** opens the Save As File dialog box to allow the current data set to be saved with a new file name. Selecting **Print** will send the current model data and results, including the graph to the default Windows printer. **Exit** closes the Tidal Prism Model and returns the user to the main CS Model window. If the current data set has not been saved, it will be lost. Selecting **Edit** will display a drop-down menu list with **Cut**, **Copy**, and **Paste**. These menu items can be used to edit input data. **Cut** will remove the selected text and move it to the windows clipboard. **Copy** will place a duplicate of the selected text on the clipboard, but not remove the original text. **Paste** can be used to put text placed on the clipboard back onto one of the input screens. **Help** will provide information pertaining to the Tidal Prism Model.

5.3 Parameters

The Parameters notebook page prompts the user to enter a series of stream parameters necessary to run the Tidal Prism Model. The screen is divided into two portions: (1) the upper portion, which consists of a series of text boxes that are used for numeric input data entered from the keyboard, and (2) the bottom portion, which consists of two radio option buttons that allow the user to choose the duration of time over which stream concentrations will be calculated.

The following numeric stream parameters must be entered in the upper text box portion of this notebook page.

Number of Stream Divisions: In order to simulate the changing cross-sections of a body of water, the Tidal Prism Model allows the user to divide the water body into a number of divisions. Each division will consist of a given length of the water body with an approximately constant cross-section and flow volume. This text box prompts the user to enter the number of divisions in the water body being studied.

Upstream River Flow: The upstream river flow parameter is considered the flow volume in m^3/day which enters the upstream boundary segment of the water body.

Ambient River Concentration: The background concentration of the contaminant of interest present in the upstream river flow is considered the ambient river concentration. The user is prompted to enter this concentration in mg/L.

Mouth Concentration: The model requires that a mouth boundary concentration be entered at the downstream limit of the water body. For calculation purposes, this concentration will remain constant with time. The user should include stream divisions far enough downstream to allow for this constant boundary condition.

Delta X: The delta X parameter refers to the calculation interval that is used for segmenting the water body. The model will iterate upstream from the mouth at intervals equal to delta X in this calculation. Small delta X values correspond to a more accurate segmentation of the water body, but also require more computer time for the calculation. A delta X of 1 meter is recommended.

Minimum Segment Length: The minimum segment length is the minimum distance between segment transects that is allowed before the segmentation routine ceases. Because the segment lengths decrease as one moves towards the upstream boundary of a water body, the upstream limit of the model's segmentation will directly depend upon the minimum segment length in most cases.

The bottom portion of the parameters screen consists of the Desired Stream Concentration panel. In this panel the user is given the choice of having the model compute concentrations after a finite number of tidal cycles or at a steady-state condition. A steady-state condition is assumed to be reached when the segment concentrations change less than 0.0001 percent between tidal cycles. The steady-state option will usually require slightly more computer time due to the increased number of tidal cycles which must be run through before this condition is reached. If the alternative option is chosen, the user may enter the desired number of tidal cycles with the spin button at the bottom of the screen. The Tidal Prism Model will calculate final concentrations after any number of tidal cycles have passed. This option is useful when the user desires information about the time varying changes which may occur in a stream after a spill or a slug discharge of finite duration has occurred. In this case, the number of tidal cycles can be increased at a set increment between runs and the dispersion of the plume can be visualized over time.

5.4 Stream Geometry

This screen allows the user to enter the stream geometry cross-section and flow data for each division of the water body. Six variables are required to describe the cross-section of a stream, which is estimated as a trapezoidal polygon. These include the following:

Slope 1 and Slope 2: These two slope variables refer to the "run to rise" ratio of the stream bank. In other words, the side slopes are the ratio of the distance traveled horizontally divided by the distance traveled vertically from the water surface to the bottom the channel. These variables are entered as single decimal values.

Base Width: The base width is the width across the "bottom" of the channel.

High Depth: The high depth is the mean depth of the stream division at peak high tide.

Low Depth: The low depth is the mean depth of the stream division at low tide.

Length: The length refers to the length of the individual stream division.

In addition to the stream geometry parameters, the user may also enter a value for the additional flow into a division. This additional flow is assumed to begin at the upstream limit of the division and is added to the total upstream flow in the river. This variable was incorporated into the model to account for a tributary flow or a significant discharge into the water body. A significant flow is considered to be one in which the river flow is significantly increased downstream of the point. When the river flow is significantly increased, this change in flow must be included in the calculation of the segment transect locations for an accurate representation of the real world condition.

5.5 Segmentation

The segmentation notebook page consists of a noninteractive spreadsheet display of the Tidal Prism Model's segmentation of the water body. The segmentation spreadsheet displays seven parameters associated with each segment. These seven parameters include the following:

Segment Number:	Numbering begins at the mouth and continues upstream.
Location:	This value is the distance from the mouth (considered to be at 0 meters) to the upstream transect of the segment.
Length:	This is the length between the upstream and downstream transects of a segment.
Low Volume:	This is the volume of the segment at low tide.
High Volume:	This is the volume of the segment at high tide.
Prism Volume:	The prism volume of a segment is the total volume of the tidal prism upstream of a segment.
River Flow:	The river flow is the total volume of water entering a segment from upstream.

5.6 Loading Data

The user may enter all relevant discharge loading parameters in the Loading Data notebook page. Mass and volume data are entered into the Discharge Parameters spreadsheet. A loading source is represented by both the volume per day that is discharged and the mass of the contaminant that is carried within that volume. The user may enter a discharge volume (m^3/day) and the mass of contaminant discharged (gm/day) at any given point in the water body. Segment numbers and locations are given in the first two columns to aid the user in locating the point of discharge.

At the bottom of the screen, two panels have been included which define the loading characteristics and the value of the returning ratio to be used in the calculation of final concentrations. The user may define any given type of contaminant discharge. For instance, a continuous discharge may be chosen for a treatment plant flow or an industrial waste in which discharge is constant over time. For circumstances where flow is not constant over time, such as runoff events or a one time slug discharge, the finite discharge option button may be chosen. With this option, the user may indicate the duration of the discharge using the spin button located at the bottom of the screen. For example, a spill of some contaminant lasting two days would be represented by a finite discharge of a four tidal cycle duration.

The returning ratio can be defined as a constant value throughout the water body, or may be varied linearly from the upstream boundary to the mouth. The linear gradient alpha value is represented by the ratio of the total number of segments minus the segment number divided by the total number of segments. This simple linear formula will vary alpha from zero at the upstream boundary segment (total number of segments = segment number), to a value close to one at the first segment (segment number two). For situations where the user desires to define alpha as a constant value, the spin button at the bottom of the panel may be used to increment alpha between zero and one.

5.7 Table Results

The Table Results notebook page is divided into two halves. On the left hand side of the screen is the noninteractive concentration output spreadsheet. This spreadsheet displays the tabular results of the concentration routine. Concentrations are given in mg/L for each of the water body's segments. On the right half of the screen is the graphical output of the concentration data. This graph consists of a plot of the segment concentrations versus their corresponding distance from the mouth. For each model run, the concentration at half of the total cycles are plotted in addition to the final concentration in each segment. The plot of the concentrations at half of the total cycles was included to give the user an idea of the general trend that the concentrations were moving in. For example, in an instantaneous spill one would expect that the contaminant plume would disperse over time due to the dilution effects in the water body. In this case, the concentration at half of the total cycles would be higher than the final concentration in each segment. Alternatively, for cases where the discharge is continuous, the final concentrations would be higher in each segment due to the constant input of the contaminant. This difference would continue until a steady-state condition is reached at which time the two plots would overlap exactly. The graphical output therefore gives the user information about both the final concentrations in each segment and the general trend of the concentrations in the system.

6. Finite Section Model

The Finite Section Model (FINSEC) is a one-dimensional, steady-state water quality model that can be used to determine the concentrations of water quality variables in a river. It is based on dividing the river or estuary into a number of approximately homogeneous regions or sections where the concentration gradient is not significant within each reach. A mass balance is constructed around each section for each water quality variable to be modeled. The model does not consider tidal effects.

6.1 Modeling Approach

The river is divided into segments of varying lengths, where the segment length is selected based on the principle concentration gradients of the substance being modeled. If segments of equal length are applied, the area of each segment will typically increase as the river begins to widen near the mouth or downstream boundary. The average river depth would also typically increase. An assumption in the FINSEC Model is that velocity gradients and dispersion will provide complete mixing both laterally (across the river) and vertically such that the concentrations gradients are only along the axis of the river (Thomann and Mueller, 1987). Figure 3-2 illustrates a possible segmentation of a river reach. Segments are numbered from 1 to n.

The concentration of substance S in any segment i is calculated using a basic mass balance equation. Thomann and Mueller (1987) have outlined the following components of the mass balance equation:

1. transport of S due to advective flow
2. mass transport due to tidal dispersion and density mixing
3. loss of mass due to decay, and
4. any external sources or sinks of S.

This concept is graphically displayed in Figure 6-2. The subscript i refers to the value in segment i. The subscripts i-1, i and i, i+1 refer to the value at the interface between segment i and the upstream and downstream segments, respectively. The FINSEC Model solves for the concentrations of substance S at these interfaces. There are several different methods that can be applied to solve the

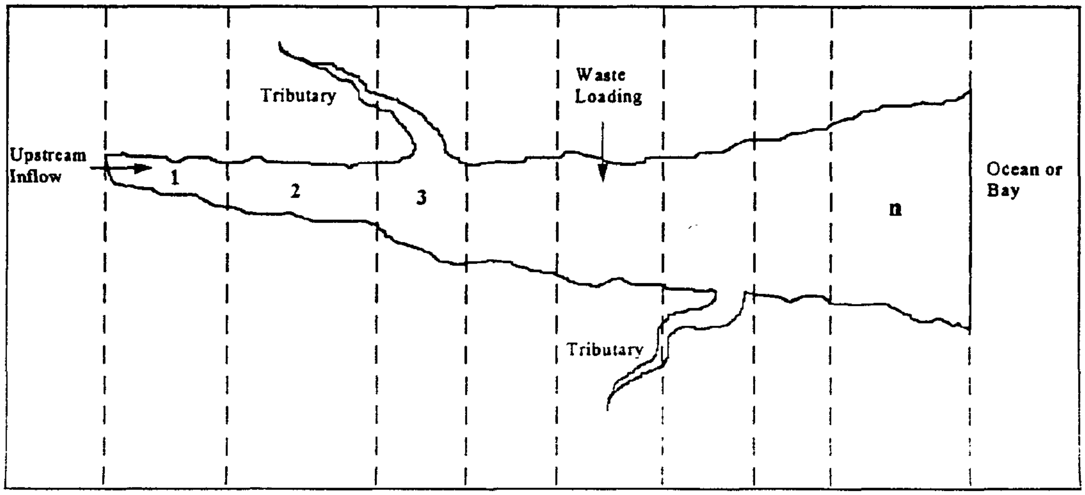


Figure 6-1. Finite Section Conceptualization.

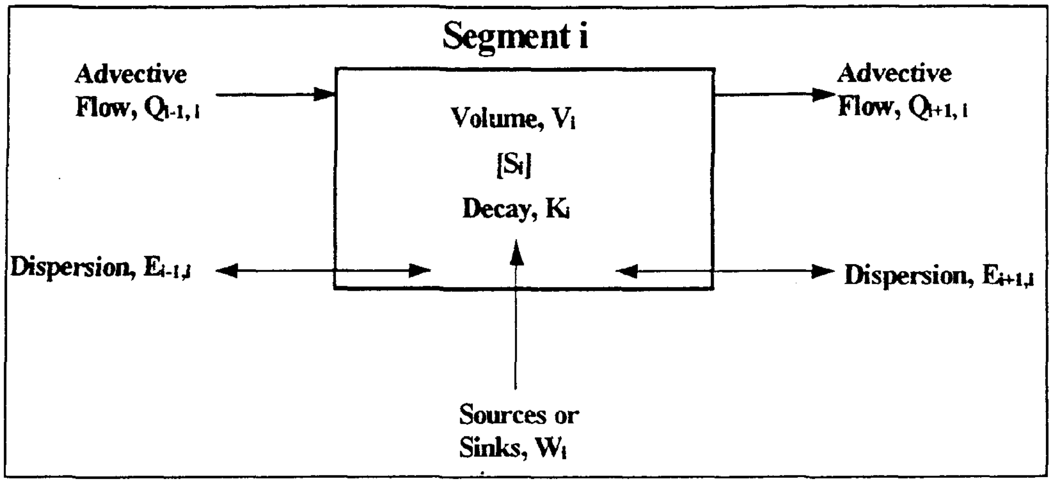


Figure 6-2. Components of mass balance equation, adapted from Thomann and Mueller (1987).

interface concentration: central, backward, or length dependent differencing options. These options are discussed in greater detail in subsection 6.3.3.

Applying a backward differencing option, the numerical approximation of the mass balance equation can be written as

$$V_i \frac{dS_i}{dt} = Q_{i-1,i}S_{i-1} - Q_{i,i+1}S_i + E_{i-1,i}(S_{i-1} - S_i) + E_{i+1,i}(S_{i+1} - S_i) - K_i V_i S_i \pm W_i$$

The FINSEC Model utilizes the steady-state condition, which assumes that all inputs, flow, exchanges, and reaction rates are constant over time. This reduces the numerical mass balance equation to a simple linear algebraic equation because $V_i \frac{dS_i}{dt} = 0$. There will an algebraic equation for each defined segment. This set of simultaneous algebraic equations is solved using a matrix inversion.

6.2 Model Format

The FINSEC Model utilizes a notebook format to enter data and display model results. The first three notebook pages provide screens for input data and the last two notebook pages are used to present tabular and graphical model results, respectively. Each page of the notebook can be accessed by clicking on the corresponding tab or pressing <Alt> plus the underlined letter of the tab header. Discussions regarding model input and parameter estimation are provided in Sections 6.3 and 6.4. Both of these sections corresponds to an individual notebook page in the FINSEC Model. Simulation results and model output are discussed in Sections 6.5 and 6.6.

The first notebook page, Project Info, serves as the FINSEC Model's introductory screen. This notebook page can be used for record keeping purposes. There are text boxes available to enter in the project title, date, and the names of the individuals involved with the model run. This notebook page may be omitted if desired.

On the Input Data notebook page, there is an example data set. This data set can be used as a tutorial for the FINSEC Model. To access this data click on the [**Example Data**] button. This data can be used to become familiar with how to navigate through the model and it provides an example of typical input and model results. There is data available to meet all model options.

The menu bar on the Finite Section Model provides the user with file access, editing capability, and help information. Selecting **File** will display a drop-down menu list with the following items: **New**, **Open**, **Save**, **Save As**, **Print**, and **Exit**. **New** deletes the current data set. A message box will ask for verification prior to deleting current values. **Open** calls up the Open File dialog box to select an existing data set. **Save** will save the current data set using the existing file name. If a file name has not been defined, the Save As File dialog box will appear prompting the user to enter a file name. **Save As** opens the Save As File dialog box to allow the current data set to be saved with a new file name. Selecting **Print** will send the current model data and results to the default Windows printer. Note that graphs are not printed from this menu item. The graphs are printed directly from the Graph notebook page using the [**Print Graph**] command button. **Exit** closes the FINSEC Model and returns the user to the main CS Model window. If the current data set has not been saved, it will be lost. Selecting **Edit** will display a drop-down menu list with **Cut**, **Copy**, and **Paste**. These menu items can be used to edit input data. **Cut** will remove the selected text and move it to the windows clipboard. **Copy** will place a duplicate of the selected text on the clipboard, but not remove the original text. **Paste** can be used to put text placed on the clipboard back onto one of the input screens. **Help** will provide information pertaining to the FINSEC Model.

6.3 Options

The Options notebook page is used to set the basic options for the model. These are the water quality variables, boundary conditions, and differencing options. Each of these options is explained in the following subsections.

6.3.1 Water Quality Variables

The concentrations of the water quality variables in the river are what the FINSEC Model is being used to determine. The model will currently estimate concentrations for five water quality variables. A brief description of each variable is provided below, but a more detailed description is available in Subsection 2.3.5 The default variable is salinity. Any or all of these variables may be selected for a model simulation.

Carbonaceous Biochemical Oxygen Demand (CBOD): CBOD is an indicator of organic pollution measured in terms of the oxygen demand that can develop as the organics are degraded. Units are mg/L.

Nitrogenous Oxygen Demand (NBOD): NBOD is the equivalent measure of the organic nitrogen and ammonia that will consume oxygen as they are converted to nitrite and nitrate. Units are mg/L.

Dissolved Oxygen (DO): A direct measure of the amount of oxygen dissolved within the water column. Units are mg/L.

Coliforms: Coliforms are bacteria in the *Enterobacteriaceae* family and are commonly used as an indicator of fecal contamination. Units are organisms/L.

Salinity: Salinity is commonly used to calibrate a finite section model for dispersion. It is treated as a conservative material. Usually, the only loads for salinity arise at the mouth of the estuary or river.

6.3.2 Boundary Conditions

The FINSEC Model simulates a river or a portion of a river reach. The simulated area will have boundaries on both the upstream and downstream ends. As with all models based on differential equations, boundary conditions must be applied to obtain a solution. There are two type of boundary conditions available in the FINSEC Model: fixed or linear gradient.

A fixed boundary condition requires a known concentration at the boundary. This concentration does not vary regardless of any changes in loading or kinetics that occur within the modeled reaches. If this option is selected, you will need to specify the boundary concentration for section 0 in the predicted column of the Input Data spreadsheet.

A linear gradient boundary condition assumes that the trend in the two adjacent interior sections is linear and can be extrapolated out to the boundary section. The boundary concentration is a function of what occurs within the modeled region.

Boundary conditions must be applied to *both* the upstream and downstream sections. However, it is perfectly allowable to mix boundary condition types. For example, a gradient upstream boundary and a fixed downstream boundary is permitted.

If fixed boundaries are appropriate, they are generally easier to work with than gradient boundary conditions. Gradient boundaries are more difficult to apply, but are more appropriate where little is known about the boundary concentrations. However, gradient boundaries should not be used when there are significant loadings to sections near the boundary because the trend will no longer be linear and extrapolation to the boundary is not valid.

6.3.3 Differencing Options

The FINSEC Model solves the mass balance differential equation numerically by applying a finite difference scheme. The concentration of substance S at the interface between segment i and segment i-1 must be determined for all segments. Differencing options provide the choice of how to solve for the concentrations at the interfaces. There are three options: central, backward, and length dependent.

In almost all cases, the central difference option is the most appropriate. This assumes that the concentration of S at the interface is equally influenced by the concentrations in both segment i and segment i-1. This option is applicable when dispersive transport predominates. It is the most accurate numerically, and exhibits the least numerical dispersion, however, it may yield negative predicted concentrations if the section lengths are too large. To ensure that all predicted concentrations will be positive, all segment lengths should be less than or equal to 2E/V.

The backward difference option is most appropriate when advection predominates dispersion. This option assumes that the concentration of S at the interface is completely dependent on the upstream concentration in segment i-1. It is easier to program and guarantees that the predicted concentrations will be positive regardless of the section lengths. However, it is subject to high numerical dispersion. Numerical dispersion is an increase in the dispersion of substance S as a result of the discretization process. The concentration gradient of S is more spread out than the analytical solution would predict.

The length dependent approach is most appropriate when section lengths differ significantly. This option will interpolate the concentration of S at the interface using similar triangles to compare slopes. It is included for more advanced users.

6.4 Input Data

The Input Data notebook page is where the necessary hydraulic and chemical properties are entered for the FINSEC Model. The appearance of this notebook page will vary depending on the modeling options selected. The user should first set the number of sections to be modeled, including the two boundary sections. This number can be entered by either clicking on the text box and typing the number from the keyboard or by clicking on the spin buttons until the desired number appears. The data entry spreadsheet itself consists of one row for each section that will be modeled. The boundary sections are highlighted in blue. If the number of sections is increased, blank rows are added to the bottom of the spreadsheet. If the number of rows is decreased, the bottom row is removed from the spreadsheet and any data in that row are lost.

The number of columns requiring data input will vary depending on which water quality variables are selected. The length, cross-sectional area, flow, and dispersion coefficient for each segment must always be entered. If the substance being modeled degrades in the natural environment than a decay coefficient should be entered. Any known loadings of the modeled substances should also be entered for each applicable segment.

The river reach being modeled can be divided into any number of sections. As the number of sections increase, the number of simultaneous equations to solve increases and simulation time will also increase. Segment length should be based on stream geometry, points of discharge, and the selected differencing option. Thomann and Mueller (1987) state that a section length of 1-2 miles (1.6-3.2 km) will generally provide a good representation of the actual river. Segment lengths should be smaller around waste loading (discharge) points. If larger segments are used at discharge points than dilution could produce predicted concentrations that would be less than an observed value. The selected differencing option could affect either the positivity of predicted values or the amount of numerical dispersion generated by the model. If the central differencing option is selected, numerical dispersion in not a problem, but positivity could be. Refer to Subsection 6.3.3. If the backward differencing option is selected than the effects of numerical dispersion should be considered when selecting segment length. Smaller segments will yield less numerical dispersion.

If dissolved oxygen is being modeled, entry boxes for the temperature and salinity are shown. These are used to calculate the dissolved oxygen saturation concentration. For the Coastal Screening Model, sea level is always used for the elevation. If salinity is being modeled, the saturation calculation uses the modeled salinity concentration in each section and ignores the mean value.

6.5 Model Results

Selecting the Graph or Tables notebook page will run the FINSEC Model. The mouse pointer will change to an hourglass while the simulation is being processed. Results from the FINSEC Model can be examined as either concentrations plots or in a tabular format. To view the results in a graphical format, click on the Graph notebook tab or press <Alt G>. A complete description of this notebook page is provided in Subsection 6.5.1. To view the tabular results, click on the Tables notebook tab or press <Alt T>. A compete description of this notebook page is provided in Subsection 6.5.2.

6.5.1 Graph Output

The results from the FINSEC Model can be viewed as concentration or loading plots versus distance. To display the model results, select the desired water quality variable and statistic option. The graphs can be sent to a printer by clicking on the [**Print Graph**] button or pressing <**Alt P**>.

6.5.2 Table Output

Selecting the Tables notebook page displays a noninteractive spreadsheet containing the model results. The row number corresponds to the segment number. The number of columns will vary depending on the number of water quality variables selected. The input values for flow and dispersion in each segment and for the water quality variables are reiterated. The volume of each segment has been calculated from the segment length and cross-sectional area and is displayed in the spreadsheet. The predicted concentrations in each segment for each modeled water quality variable is also displayed in the spreadsheet.

7. Spill Model

The Spill Model solves the advective diffusive equation for an *instantaneous* spill of a material into a river or a stream. Instantaneous is the name applied to the assumption that the material is completely mixed vertically and axailly immediately following the spill. The model provides an analytical solution. The equation is established for one dimension, and therefore, the concentration of the material is only a function of the distance downstream and the time elapsed since the spill occurred. The initial pulse of material will move downstream with time because of advection. As time increases, the pulse will spread out because of dispersion and the total mass of the material will decrease through first order decay.

The Spill Model is based on the following mass balance equation:

$$\frac{\partial s}{\partial t} = -u\,\frac{\partial s}{\partial x} + E\,\frac{\partial s^{2}}{\partial^{2} x} - k s$$

where s = solvent concentration
t = elapsed time since spill occurred
x = distance downstream from spill location
E = dispersion coefficient
u = average velocity
k = first order decay rate

7.1 Model Format

The Spill Model utilizes a notebook format to enter data and display model results. The first two notebook pages provide screens for input data, the next two notebook pages present tabular and graphical model results, and the final notebook page allows for model calibration. Each page of the notebook can be accessed by clicking on the corresponding tab or pressing **<Alt>** plus the underlined letter of the tab header. Section 7.2 provides information regarding model input and parameter estimation. Simulation results and model output are discussed in Section 7.3. Model calibration is explained in Section 7.4.

An example data set is included with the Spill Model and can be used as a tutorial. To access this data click on the [**Example Data**] buttons on the Parameter notebook page. These data can be used to become familiar with how to navigate through the model and it provides an example of typical input and model results.

The first notebook page, Project Info, serves as the Spill Model's introductory screen. This notebook page can be used for record keeping purposes. There are text boxes available to enter in the project title, date, and the names of the individuals involved with the model run. This notebook page may be omitted if desired.

The menu bar on the Spill Model provides the user with file access, editing capability, and help information. Selecting **File** will display a drop-down menu list with the following items: **New**, **Open**, **Save**, **Save As**, **Print**, and **Exit**. **New** deletes the current data set. A message box will ask for verification prior to deleting current values. **Open** calls up the Open File dialog box to select an existing data set. **Save** will save the current data set using the existing file name. If a file name has not been defined, the Save As File dialog box will appear prompting the user to enter a file name. **Save As** opens the Save As File dialog box to allow the current data set to be saved with a new file name. Selecting **Print** will send the current model data and results, including the graph to the default Windows printer. **Exit** closes the Spill Model and returns the user to the main CS Model window. If the current data set has not been saved, it will be lost. Selecting **Edit** will display a drop-down menu list with **Cut, Copy,** and **Paste**. These menu items can be used to edit input data. **Cut** will remove the selected text and move it to the windows clipboard. **Copy** will place a duplicate of the selected text on the clipboard, but not remove the original text. **Paste** can be used to put text placed on the clipboard back onto one of the input screens. **Help** will provide information pertaining to the Spill Model.

7.2 Parameters

This notebook page allows the user to enter the required model data and decide how the simulation results will be displayed. The values for these parameters can be entered directly into each text box by clicking on it and then entering the desired value from the keyboard. The text boxes may also be accessed using the **<Tab>** key. As each text box in the Model Data frame becomes active, its corresponding label will turn blue. Clicking on the label for the various input parameters will display a pop-up message box with help information.

Flow: The average flow of the river in m^3/second.

Dispersion: The dispersion coefficient of the river allows for tidal effects and diffusion from concentration gradients. Units are square kilometers per day. A typical dispersion coefficient is

0.03 - 0.3 km^2/day.

Area: This is the average cross-sectional area of the river in square meters.

Spill Mass: The total mass of the contaminant spilled into the river in kilograms.

Decay Rate: The first order decay rate of the contaminant determines the rate at which the contaminant disappears. The higher the decay rate, the faster the contaminant will disappear. Units are 1/day.

The display results frame allows the user to specify how the model will display the simulation results. The beginning and ending distances are from the point of the spill. Negative (upstream) distances are permissible. The upstream concentration values could be important in systems where dispersion predominates flow. The distance interval is entered in the text box beneath the Every header. The beginning and ending time in days must also be specified. Time zero is when the spill occurred. Selection of time should reflect the decay rate of the contaminant.

The **[Clear]** button will delete all values from the parameter text boxes. If this button is selected, a message box will appear asking for verification prior to removing current values.

7.3 Model Results

Selecting either the Graph Results or the Table Results notebook page will begin the model simulation. The mouse pointer will change to an hourglass while the simulation is being processed. Results from the Spill Model can be examined as either concentrations plots or in a tabular format. To view the results in a graphical format, click on the Graph Results notebook tab or press **<Alt G>**. A complete description of this notebook page is provided in Subsection 7.3.1. To view the tabular results, click on the Table Results notebook tab or press <**Alt** T>. A compete description of this notebook page is provided in Subsection 7.3.2.

7.3.1 Graph Results

The predicted concentrations can be viewed versus distance or time. The concentration plot versus distance is automatically displayed when the Graph Results notebook page is activated. There will be a concentration plot for each specified time period. Each of these plots is in a different color. To change to the concentration versus time plots, select the time option button below the plot area. The graph will change accordingly. There will be a concentration plot for each specified distance interval.

7.3.2 Table Results

The model results are presented in a spreadsheet format. The first column is distance along the river from the point of the contaminant spill. The second column is the time from when the contaminant was spilled. The time series will reflect the values selected on the Parameter notebook page. The time series will be repeated for each distance interval. Third column contains the contaminant concentration in mg/L at the specified distance and time.

7.4 Calibration

This notebook page allows the user to calibrate the Spill Model to observed data if it is available. To enter the observed values, click on the [**Observed Data**] button. A new form will fill the notebook page. Enter the observed concentrations in the spreadsheet and give their appropriate time and distance from the spill. If needed, an entire row can be deleted from the spreadsheet by clicking on the [**Delete Row**] button. The [**Example Data**] button will provide a sample data set. The [**Clear**] button will delete all values from the spreadsheet. If this button is selected, a message box will appear asking for verification prior to removing current values. When you have entered all observed values, select the [**Close**] button to return to Calibration notebook page.

The Spill Model Calibration allows the user to change one of the input parameters and quickly assess the results through the concentration plots, residual plots, or the calibration statistics. To change one or more parameters, click on the appropriate spin button or enter the desired value directly into the appropriate text box. To evaluate the effect that the new parameter value has on the predicted concentrations, select the [**Run Model**] option button. The graphical display and calibration statistics will be automatically updated.

If the *predictions* option is selected in the plot type frame, then the user can view the concentrations plots as either points or curves. There are also option buttons for selecting either distance or time as the x-axis label. The default plot is predicted contaminant concentration versus distance. When the *residuals* option is selected, the other two option frames disappear. The residual plot of the observed versus the predicted concentrations will appear in the graph window. Viewing the residuals can help improve the calibration effort if the residuals indicate a trend.

The calibration statistics are shown in the shaded box to the right of the parameter text boxes. The Spill Model supplies both the sum of the squared deviations (SSR) and the sum of the absolute deviations (MAD).

After a calibration run has been performed, if the exact predicted values or residuals are desired, select the **[Observed Data]** button to view the spreadsheet. The predicted values and the residuals will be in the fourth and fifth columns, respectively.

8. Utility Models

The utility models option has not been completely developed for this version of the CS Model. Utility models are designed to aid the user with quick, simple calculations. Currently, there is a utility model for estimating dispersion coefficients, for determining DO saturation, and for Manning's open channel flow.

9. References

Alhajjar, B.J., J.H. Harkin, and G. Chesters. 1989. Detergent formula and characteristics of wastewater in spetic tanks. *Journal of the Water Pollution Control Federation*, 61(5): 605-613.

Basta, D.J, and Moreau. 1982. Introduction to analyzing natural systems. *Analyzing Natural Systems*, Chapter 2, D.J. Basta and B.T. Bower, (eds.), Resources for the Future, Washington, D.C.

Bosen, J.F. 1960. A formula for approximation of saturated vapor pressure over water. *Monthly Weather Reviews*, 88(8): 275-276.

Browning, G.M. 1979. Development for and of the Universal Soil Loss Equation. *Universal Soil Loss Equation: Past, Present, and Future*. SSSA Special Publication Number 8. Soil Science Society of America, Madison, Wisconsin.

Dornbush, J.N., J.R. Anderson, and L.L. Harms. 1974. *Quantification of Pollutants in Agricultural Runoff.* EPA-660/2-74-005. U.S. Environmental Protection Agency, Washington, D.C.

Dyer, K.R., and P.A. Taylor. 1973. A simple, segmented, prism model of tidal mixing in well-mixed estuaries. *Estuarine and Coastal Marine Science*, 1: 411-418.

Gottschalk, L.C. 1964. Sedimentation. In: V.T. Chow (ed.). *Handbook of Applied Hydrology*. MacGraw-Hill, New York, NY.

Haan, C.T. 1972. A water yield model for small watersheds. *Water Resources Research*, 8(1): 58-69.

Haith, D.A., R. Mandel, and R.S. Wu. 1992. *Generalized Watershed Loading Functions , Version 2.0, User's Manual.* Department of Agricultural and Biological Engineering, Cornell University, Ithaca, New York.

Hamon, W.R. 1961. Estimating potential evapotranspiration. *Proceedings of the American Society of Civil Engineers, Journal of the Hydraulics Division*, 87(HY3): 107-120.

Hamrick, J.M., and B.J. Neilson. 1989. *Determination of Marina Buffer Zones Using Simple Mixing and Transport Models*. Virginia Institute of Marine Science.

Ketchum, B.H. 1951. The exchange of fresh and salt waters in tidal estuaries. *Journal of Marine Research*, 10(1): 18-37.

Kuo, A.Y., and B.J. Neilson. 1988. A modified tidal prism model for water quality in small coastal embayments. *Water Science and Technology*, 20(6): 133-142.

Kuo, C.Y., K.A. Cave, and G.V. Loganathan. 1988. Planning urban best management practices. *Water Resources Bulletin*, 24(1): 125-132.

Luettinger, J.C. 1995. *A Tidal Prism Analysis of the Soluble Copper Mixing Zone around the Occoquan Water Treatment Plant.* Master's thesis submitted to the faculty of Virginia Polytechnic Institute and State University.

Mandel, R. 1993. The Impact of Septic Systems on Surface Water Quality. M.S. dissertation submitted to the School of Civil and Environmental Engineering, Cornell University, Ithaca, N.Y.

McCutcheon, S.C., and R.H. French. ??. *Water Quality Modeling, Volume I: Transport and Surface Exchange in Rivers.* CRC Press, Boca Raton, Florida.

Novotny, V. and G. Chesters. 1981. *Handbook of Nonpoint Pollution.* Van Nostrand Reinhold Company, New York, N.Y.

Novotny, V. and H. Olem. 1994. *Water Quality: Prevention, Identification, and Management of Diffuse Pollution.* Van Nostrand Reinhold Company, New York, N.Y.

Prescott, L.M., J.P. Harley, and D.A. Klein. 1990. *Microbiology.* Wm. C. Brown Publishers

Reay, W. 1994. Personal communication. Virigina Polytechnic Institute and State University.

Richardson, C.W., G.R. Foster, and D.A. Wright. 1983. Estimation of erosion index from daily rainfall amount. *Transactions of the American Society of Agricultural Engineers*, 26(1): 153-157,160.

Robinson, A.R. 1979. Sediment yield as a function of upstream erosion. *Universal Soil Loss Equation: Past, Present, and Future.* SSSA Special Publication Number 8. Soil Science Society of America, Madison, Wisconsin.

Sandels, Mark. 1986. *Studying Soil Erosion with the Universal Soil Loss Equation.* Oxford Polytechnic, Discussion paper in Geography No. 24.

Sandford, L.P., W.C. Boicourt, and S.R. Rives. 1992. Model for estimating tidal flushing of small embayments. *Journal of Waterway, Port, Coastal and Ocean Engineering,* 118: 635-654. ASCE.

Schwab, G.O., and R.K. Frevert. 1985. *Elementary Soil and Water Engineering (3rd edition).* John Wiley & Sons, Inc.

Selker, J.S., D.A. Haith, and J.E. Reynolds. 1990. Calibration and testing of daily rainfall erosivity model. *Transactions of the American Society of Agricultural Engineers*, 33(5): 1612-1618.

Soil Conservation Service. 1986. *Technical Release No. 55 (2nd edition).* U.S. Department of Agriculture, Washington, D.C.

Stewart, B.A., D.A. Woolhiser, W.H. Wischmeier, J.H. Caro, and M.H. Frere. 1975. *Control of Water Pollution from Cropland. Volume I: A Manual for Guideline Development.* EPA-600/2-75-026a. U.S. Environmental Protection Agency, Washington, D.C.

Thomann, R.V., and J.A. Mueller. 1987. *Principles of Surface Water Quality Modeling and Control.* HarperCollins Publishers, Inc.

USEPA. 1980. *Design Manual: Onsite Wastewater Treatment and Disposal Systems.* EPA-625/1-80-012. U.S. Environmental Protection Agency, Washington, D.C.

USEPA. 1984. *User Manual for the Pesticide Root Zone Model (PRZM).* EPA 600/3-84-109. U.S. Environmental Protection Agency.

Vanoni, V.A. (ed.). 1975. *Sediment Engineering.* American Society of Civil Engineers, New York, NY.

Wischmeier, W.H., and D.D. Smith. 1978. *Predicting Rainfall Erosion Losses: A Guide to Conservation Planning.* Agricultural Handbook 537. U.S. Department of Agriculture, Washington, D.C.

Wood, T. 1977. A modification of existing simple segmented tidal prism models of mixing in estuaries. *Estuarine and Coastal Marine Science*, 8: 339-347.