NBP-90-50

P8 Urban Catchment Model: User's Guide, Program Documentation, and Evaluation of Existing Models

109 pp + Appendices, software available upon request

Walker (IEP, Inc.)

Narragansett Bay Estuary Program

P8 URBAN CATCHMENT MODEL:
USER'S MANUAL
PROGRAM DOCUMENTATION
EVALUATION OF EXISTING MODELS, DESIGN CONCEPTS, AND HUNT-POTOWOMUT DATA INVENTORY

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#NBP-90-50

P8
URBAN CATCHMENT MODEL

USER'S MANUAL

Version 1.1

Prepared For:

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FOREWORD

The United States Congress created the National Estuary Program in 1984, citing its concern for the "health and ecological integrity" of the nation's estuaries and estuarine resources. Narragansett Bay was selected for inclusion in the National Estuary Program in 1984 , and the Narragansett Bay Project (NBP) was established in 1985. Narragansett Bay was designated an "estuary of national significance" in 1988. Under the joint sponsorship of the U.S. Environmental Protection Agency and the Rhode Island Department of Environmental Management, the NBP's mandate is to direct a program of research and planning focussed on managing Narragansett Bay and its resources for future generations.

The NBP will develop a draft Comprehensive Conservation and Management Plan (CCMP) by December, 1991, which will recommend actions to improve and protect the Bay and its natural resources.

The NBP has established the following seven priority issues for Narragansett Bay:

- management of fisheries
- nutrients and potential for eutrophication
- impacts of toxic contaminants
- health and abundance of living resources
- health risk to consumers of contaminated seafood
- land-based impacts on water quality
- recreational uses

The NBP is taking an ecosystem/watershed approach to address these problems and has funded research that will help to improve our understanding of various aspects of these priority problems. The Project is also working to expand and coordinate existing programs among federal, state and local agencies, as well as with academic researchers, in order to apply research findings to the practical needs of managing the Bay and improving the environmental quality of its watershed.

This report represents the technical results of an investigation performed for the Narragansett Bay Project. The information in this document has been funded wholly or in part by the United States Environmental Protection Agency through Cooperative Agreement #CX812768 to the Rhode Island Department of Environmental Management. It has been subject to the Agency's and the Narragansett Bay Project's peer and administrative review and has been accepted for publication as a technical report by the Management Committee of the Narragansett Bay Project. The results and conclusions contained herein are those of the author(s), and do not necessarily represent the views or recommendations of the NBP.

P8 Program Requests:

The Narragansett Bay Project (NBP) requests that individuals interested in receiving the P8 Program (for IBM-compatible systems) submit a written request and provide the NBP with a blank high-density 1.44 MB computer disk.

Please send requests to:

The Narragansett Bay Project
R.I. Dept. of Environmental Management
291 Promenade St.
Providence, RI 02908-5767

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1.0 INTRODUCTION

The Urban Catchment Model, P8, is a model for predicting the generation and transport of stormwater runoff pollutants in urban catchments. Residential and commercial developments have appeared in increasing numbers in recent years throughout the Rhode Island (RIDEM, 1988). This increase in development causes a number of impacts on the surrounding environment. In particular, as land is converted from open or forested land to developed land, the area of impervious surfaces increases dramatically, while surfaces available for infiltration of precipitation decline. These hydrologic modifications tend to increase the proportion of water which leaves a given site as surface runoff. In developed areas, pollutants which accumulate ("build up") during dry periods are "washed" off as runoff passes over the land surface. In contrast, undeveloped lands have characteristics (low imperviousness, high infiltration, vegetative cover) which reduces surface runoff and the transport of pollutants in that surface runoff. Nationally, nonpoint sources of pollution, account for about 45%, 76%, and 65% of the degradation of estuaries, lakes, and rivers, respectively (EPA, 1989). On the other hand, municipal and industrial point source discharges account for only 9 - 30% of the degradation of these water resources.

Through sound land use planning and review processes, contributions of contaminants in urban runoff can be minimized, and water, wetland, and wildlife resources protected. Therefore, under a contract with the Narragansett Bay Project, the P8 Urban Catchment Model was developed. The intent was to provide local and state land use planners and engineers with a tool for evaluating the impacts of development on water quality, with a minimum of site-specific data.

2.0 MODEL OVERVIEW

The user is referred to the P8 Program Documentation for a detailed documentation of the P8 Model including applications, limitations, reference citations, and simulation methods. Single-event or continuous simulation of rainfall events can be completed for user-defined systems consisting of a maximum of (24) watersheds, twenty-four (24) stormwater management devices (BMPs), five (5) particle size classes, and ten (10) water quality components. Simulations are driven by continuous hourly rainfall time series. Figure 1 illustrates the conceptual organization and functional components and variables simulated by the model. P8 consists primarily of algorithms derived from other tested urban runoff models (i.e., SWMM, HSPF, D3RM, TR-20). However, P8 has been designed to require a minimum of site specific data, which is expressed in terminology familiar to most local engineers and planners. Extensive user interface, including spreadsheet-like menus and on-line help documentations facilitate model use. The model will simulate a variety of treatment devices (BMPs), including swales, buffer strips, detention ponds (dry, wet, extended), flow splitters, and infiltration basins (offline and online) as illustrated in Figure 2. Initial calibration of certain water quality parameters has been completed, such that runoff concentrations correspond to values measured under the Nationwide Urban Runoff Program (NURP; Athayde et al., 1983).

FIGURE 1

P8 MASS-BALANCE SCHEMATIC

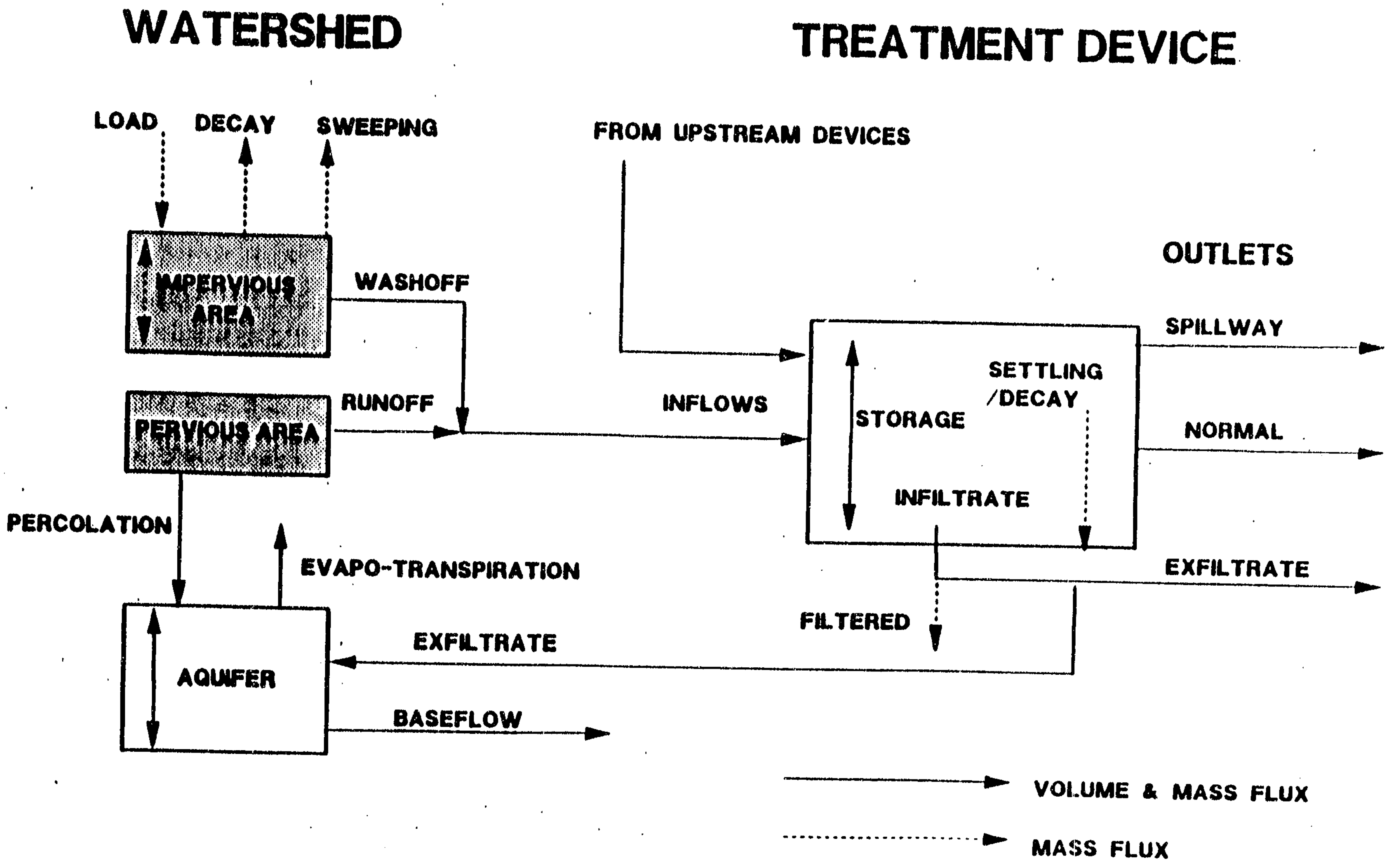
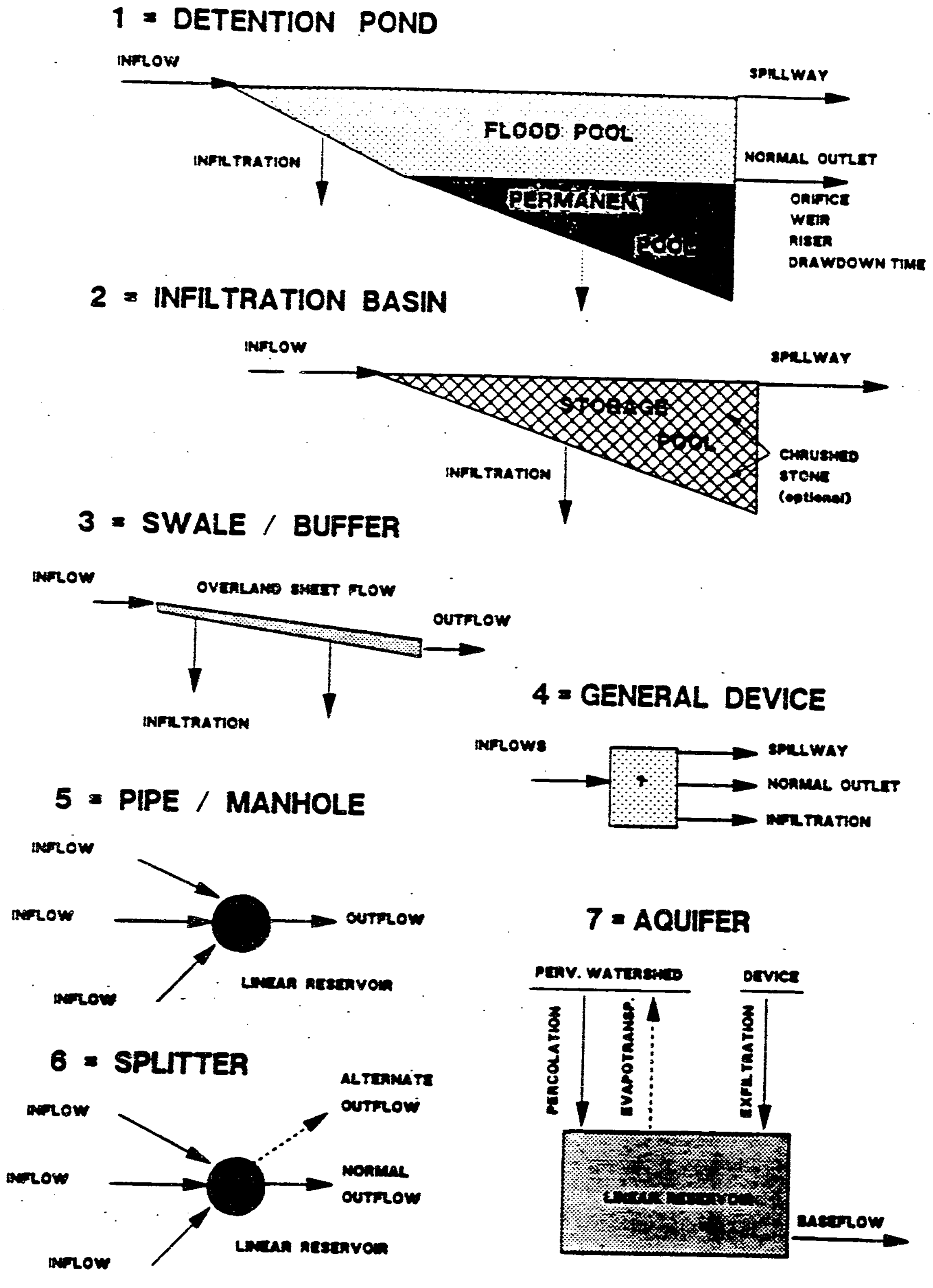


FIGURE 2

P8 DEVICE TYPES



1 = DETENTION POND

2 = INFILTRATION BASIN

3 = SWALE / BUFFER

4 = GENERAL DEVICE

5 = PIPE / MANHOLE

6 = SPLITTER

7 = AQUIFER

Because of model limitations, discussed in detail in the Program Documentation (Walker, 1990), absolute predictions of concentrations, loads, or violation frequencies are less reliable, as compared to relative predictions of removal efficiencies. Therefore, the primary intended uses of the model include:

1) Evaluating site plans for compliance with a treatment objective, expressed in terms of removal efficiency for total suspended solids, or a single particle class (e.g., 70% or 85% TSS removal, RIDEM, 1988).

2) In a design mode, selecting and sizing BMP's to achieve a given treatment objective. The program automatically scales BMP's to match user-defined watersheds, storm time series, target particle class, and target removal efficiency.

Detailed, technical documentation for the model, including simulation methods, including simulation methods and algorithms, calibration, testing, and limitations are provided in the companion document, P8 Urban Catchment Model Program Documentation (Walker, 1990). This model may also be used for watershed-scale applications. However, as with site applications, the interpretation and certainty of the model output is limited by the availability of data for calibration and verification. Without calibration, "absolute" predictions (e.g., concentration, load, flows) are less reliable than "relative predictions (e.g., comparing the relative differences (% change) between a number of different built-out scenarios). However, absolute predictions are typically of greater interest in watershed-scale applications, but the reliability of predictions will often be limited by a lack of calibration data. Therefore, the use of the model for "absolute" predictions applications are considered secondary uses of the model at this time.

3.0 DOCUMENTATION AND DISTRIBUTION

The P8 Urban Catchment Model is documented in two forms (a technical documentation and a simplified user's manual):

Walker, W.W. 1990. P8 Urban Catchment Model: Program Documentation. Version 1.1. Final Report.

IEP, Inc. 1990. P8 Urban Catchment Model (Version 1.1): User's Manual.

Both documents are suggested to operate the model and interpret the model output.

You have been provided with one MS DOS (Disk Operating System) high density 1.2 megabyte diskette that contains Version 1.1 of the P8 Urban Catchment Model. This model and its support programs and files are designed for interactive applications on the IBM PC or compatible computer system with 640k available Random Access Memory (RAM) and at least 2 megabytes of Hard Disk Storage. The program and sample input files occupy approximately 1.2 megabyte of disk space, and an additional 1 megabyte of disk space is recommended for working files. An AT (80286 processor) or higher class computer with a hard disk and numeric coprocessor are recommended to accelerate computations. The program is written in FORTRAN-77 and compiled using the Microsoft, Inc. Version 5.0 optimizing compiler (emulator library). Supporting subroutine libraries (graphics, screen control, character manipulation) include ASMUTIL 2 and BUTILE from Impulse Engineering, San Francisco.

For technical assistance or further information contact:

4.0 INSTALLATION AND DISK FILES

4.1 Installation Procedure

The following procedure is used to install P8 on your hard drive from the distribution diskette. This procedure is provided on the distribution diskette under filename 'Readme'. This file can be accessed using the >Type command in DOS.

1. Place the distribution diskette in Disk Drive A:
2. Enter the following line:
   ```
   >A:
   ```
3. To install on the hard Disk (C) in a directory called P8, enter one of the following lines depending upon the type of graphics available on your system:
   - For Computers with EGA graphics:
     ```
     > INSTALL C P8 EGA
     ```
   - For Computers with VGA graphics:
     ```
     > INSTALL C P8 VGA
     ```
   - For Computers with CGA (Standard IBM-PC) color graphics:
     ```
     > INSTALL C P8 CGA
     ```
   - For Computers with CGA monochrome graphics:
     ```
     > INSTALL C P8 MCGA
     ```
   - For Computers with other graphics:
     ```
     > INSTALL C P8 XXX
     ```
4. Add the following line to the CONFIG.SYS file in the root directory of your hard disk:
   ```
   FILES=20
   ```

5. To run P8 program, enter the following lines:

```
>C:                (to switch to hard drive)
>cd\P8             (to access P8 directory)
>P8                (to run P8)
```

Notes: The graphics resolution is poor in CGA mode and monochrome version (MCGA) is suggested. MCGA has higher resolution that CGA, but no color, and will run with either color or monochrome monitors. If installed on computers with other graphics or no graphics (XXX mode), the program will run but without plotting routines.

The program is now loaded on your hard disk, and can be accessed for future use using step 5 of the installation procedure. If you want to change driver later, enter switch XXX = EGA, VGA, CGA, etc. (see 'Readme' file for further details).

4.2 Disk Files

The P8 installation disk has 91 disk files, including sample case files and input data files. Sample case files may be used for instructional purposes or to serve as templates for building a new case file. Case files (.CAS) included on the distribution diskette include:

SIMPLE EXAMPLES/TEMPLATES:
DEFAULT.CAS - loaded automatically when program starts
WETPOND.CAS - 1 watershed with wet detention pond
DRYPOND.CAS - 1 watershed with dry detention (flood control) pond
EXTPOND.CAS - 1 watershed with extended detention pond
ONLINE.CAS - 1 watershed with on-line infiltration (retention) basin
OFFLINE.CAS - 1 watershed with offline infiltration (retention) basin
BUFFER.CAS - 1 watershed with buffer strip

MORE COMPLEX EXAMPLES/TEMPLATES:
HIGHWAY.CAS - highway/swale simulation
MYHOUSE.CAS - rooftop drainage simulation using traced devices
DYPOND.CAS - peak flow simulation, extended detention pond
PONDSWAL.CAS - pond-->swale vs. swale-->pond comparison
BASEPOND.CAS - effect of baseflow on wet pond performance
RIVBAS.CAS - simulation of runoff & baseflow using aquifer device
TEST.CAS - illustrates each device type
SENSIT.CAS - used in sensitivity analysis (see program documentation)
SWEEP.CAS - effect of street-sweeping freq. on watershed loads
IMPACT.CAS - pre-development vs. post-development analysis - runoff only
IMPACT2.CAS - same as IMPACT.CAS; includes baseflow simulation

REAL WORLD:
ESM_U.CAS - emerald square mall - upper detention facility
ESM_L.CAS - emerald square mall - lower detention facility
TRACER.CAS - one tracer lane offline infiltration basin, wet pond
HUNT.CAS - hunt/potowomut watershed (daily streamflow simulation)

The four input files for particle characteristics provided on the distribution diskette are listed below. These input data have been calibrated the Nation-wide Urban Runoff Program (NURP; Athyade et al., 1983). In NOVICE mode, one of the following particle files (.PAR) must be specified. However, if sufficient site-specific data is available, particle characteristics may be entered or edited in the ADVANCED mode using the Case Edit Particles - 'CEP' command sequence.

SIMPLE.PAR	- one particle class (NURP 10% Settling Velocity)
NURP50.PAR	- calibrated to NURP median event-mean runoff concentrations
NURP90.PAR	- calibrated to NURP 90th percentile sites
BARESOIL.PAR	- NURP50.PAR with pervious runoff concs. increased to reflect bare soil conditions (e.g., construction sites)

Several precipitation files for the Providence NOAA station are included on the distribution diskette for convenience. In addition, the UTILITIES function in the P8 MENU allows the user to convert hourly precipitation data available on diskette for any NOAA weather station or period of record. Storm files (.STM) provided on the distribution diskette include:

PROV##.STM	(record for year specified ##, including:	
	## = 65, 81	dry years
	## = 74, 76, 80	average years
	## = 79, 83	wet years
	## = 87	others
PROV6987.STM	(complete record at Providence 1969-1987)	
TYPE2.STM	(one inch, 24 hour storm with SCS Type II distribution)-to approximate long-term TSS removal efficiency in Rhode Island, use this file with PASSES > = 5	
AVERAGE.STM	(.4 inch, 6 hour, 75 hour total interval)-typical for Northeast	

5.0 PROGRAM MECHANICS

The program is operated from a MENU, has two USER MODES, and provides on-line HELP documentation.

5.1 User Modes

The program runs in either of two USER MODES (NOVICE MODE or ADVANCED MODE), selected based upon the users level of experience. The NOVICE MODE provides access to the 43 basic program functions, while restricting access to functions which are supplementary to the primary operation of the model. While, the ADVANCED MODE provides access to all 132 of the program functions and options. New users may find the NOVICE MODE, with a limited number of option choices, less difficult to follow. At startup, the program is set to NOVICE MODE. To change to ADVANCED MODE (or to return to novice mode), press <Shift> and <F1> keys simultaneously from any location in the program menu. A message will appear indicating the new mode. Press any key to continue.

5.2 Program Functions

The MENU, appearing in a blue box at the top of the computer screen, operates similar to a spreadsheet, and provides access to up to four tiers of program options or functions (Figure 3). The bottom portion of the MENU screen describes the current application or CASE. The primary menu options include:

CASE -	Enter/edit, read, list or save input data
RUN -	Execute model
LIST -	List output
PLOT -	Plot output (advanced mode only)
UTILITIES -	Supplementary functions (advanced mode only)
HELP -	Access on-line help screens
QUIT -	End session and return to DOS

Additional functions are provided in lower levels of the MENU for each of the primary options. Cursor arrows can be used to maneuver around the menu. However, a faster method is to enter the letter of the desired choice at each menu level (e.g., 'CEDI' - Case Edit Device Index). A description of the various program options are provided in Appendix A. A more detailed discussion of model input, output, and utilities is presented in section 6.0 of this document and the companion program documentation.

5.3 On-line Help Documentation

HELP SCREENS included in the program provide extensive on-line documentation for the program. These screens can be accessed by pressing the HELP KEY <F1> while in the main menu, data-entry screens, or output screens. HELP SCREENS are also accessible from the HELP selection in the main menu, or by running the independent utility 'help.exe' from DOS. These utilities permit the user to view help screens in groups, organized by topic, or to search the help file for all screens containing a user defined phase.

To view a help screen for any procedure in the main menu:
- Move the cursor to the desired procedure and press <F1>

To view a help screen for any output screen:
- Press <F1> in response to any hold screen <H> prompt which will appear in the lower left-hand corner of the screen

To view a any help screen or group of help screens from the main MENU:
- Select HELP option from top tier of MENU

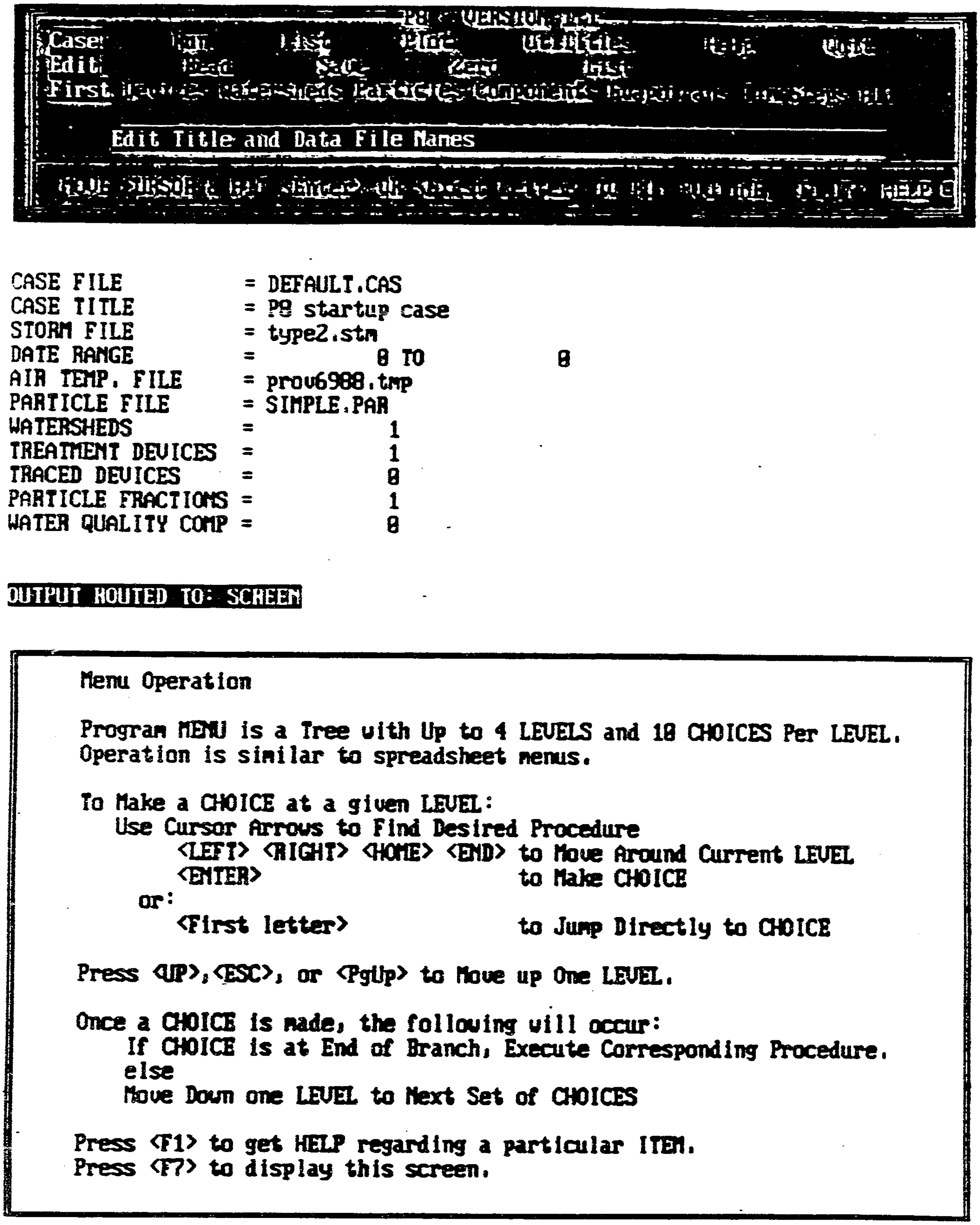
To get help from any data entry screen:

- <F1> = help for data entry screen
- <F7> = help for use of editor
- <F8> = help for current input field (cursor location)
- <F9> = help for any P8 function

To view help screens from DOS using 'help.exe':

- >help

FIGURE 3
P8 Main Menu Screen



```
Edit Title and Data File Names

CASE FILE            = DEFAULT.CAS
CASE TITLE           = P8 startup case
STORM FILE           = type2.stm
DATE RANGE           =          0 TO          0
AIR TEMP. FILE       = prov6988.tmp
PARTICLE FILE        = SIMPLE.PAR
WATERSHEDS           =          1
TREATMENT DEVICES    =          1
TRACED DEVICES       =          0
PARTICLE FRACTIONS   =          1
WATER QUALITY COMP   =          0

OUTPUT ROUTED TO: SCREEN

     Menu Operation

     Program MENU is a Tree with Up to 4 LEVELS and 10 CHOICES Per LEVEL.
     Operation is similar to spreadsheet menus.

     To Make a CHOICE at a given LEVEL:
        Use Cursor Arrows to Find Desired Procedure
             <LEFT> <RIGHT> <HOME> <END> to Move Around Current LEVEL
             <ENTER>                     to Make CHOICE
        or:
             <First letter>              to Jump Directly to CHOICE

     Press <UP>,<ESC>, or <PgUp> to Move up One LEVEL.

     Once a CHOICE is made, the following will occur:
         If CHOICE is at End of Branch, Execute Corresponding Procedure.
         else
         Move Down one LEVEL to Next Set of CHOICES

     Press <F1> to get HELP regarding a particular ITEM.
     Press <F7> to display this screen.
```

6.0 MODEL OPERATION

This section provides a brief description of the command groups utilized to enter/edit data and view output. Several demonstration cases are provided in Appendix C, illustrating frequently used commands, data entry procedures, and output formats.

6.1 Model Inputs

The first step in defining and entering a new case is to compile the necessary input data for the watershed characteristics and device design specifications. The process is facilitated by first constructing a schematic diagram of the site which illustrates the linkage of watershed and treatment devices (similar to diagrams used in TR-20 applications) as illustrated in Figure 4. Data entry worksheets are provided in Appendix B to expedite the data collection and entry process. The screens which are used to enter or edit data are illustrated in the appendices of the P8 Urban Catchment Model Program Documentation. Data entry/editing is performed using the following commands:

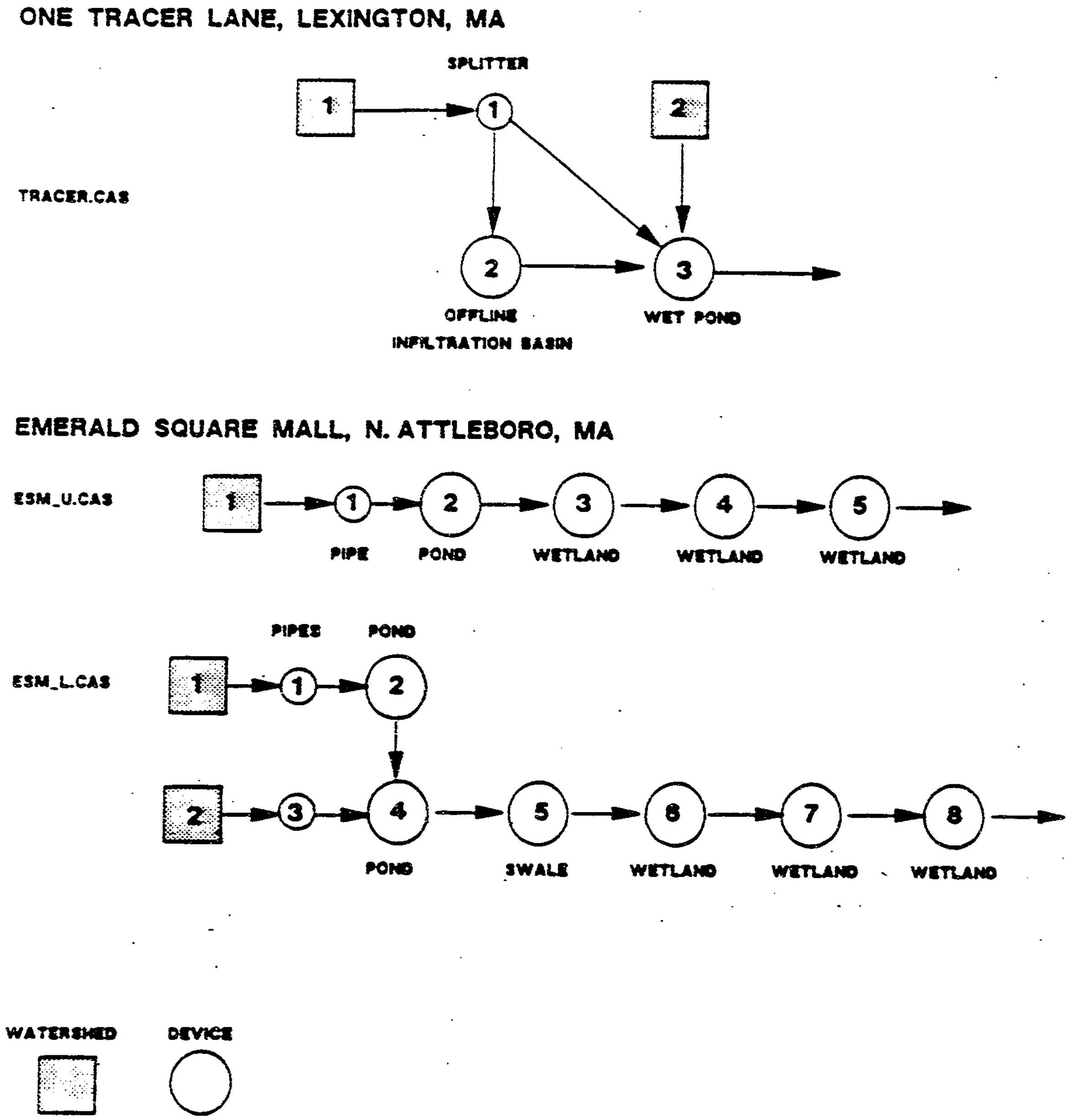
CEF	Case Title & Storm File
CEDI	Device Index
CEDD	Device Data (Separate Screen for Each Device Type)
CEWI	Watershed Index
CEWD	Watershed Data (Separate Screen for Each Watershed)
CEE	Evapotranspiration Parameters
CET	Simulation Time Steps
CRP	Read Particle Characteristics file from disk
CEP	Particle Characteristics (ADVANCED USER MODE only)
CECF	Water Quality Components (ADVANCED USER MODE only)

General help screens are accessed by pressing <F1>. More detailed help on certain data input values (e.g., infiltration rates, Curve Numbers, Manning's n) are accessed by pressing <F8> when pointing to the input field on a date-entry screen. Lookup tables for infiltration rates, curve numbers and Manning's n, provided in the on-line help screens are printed at the end of this section for easy reference. Input data can be listed using the 'CLS' (= Case List Site) command, stored in a disk file using 'CSI' (= Case Save Inputs), and subsequently retrieved using 'CRA' (= Case Read All).

When the model is executed for a given set of input values and storm sequence, results are saved in a temporary disk file for subsequent use by listing and plotting routines. A "Model Executed" message appears on lower right screen. Output for a given run is available until input values are changed or a new case is read from the disk. Stored values normally include event total flows and loads for each device, particle class, and mass-balance term.

FIGURE 4

SCHEMATIC DIAGRAMS - P8 TEST CASES



INFILTRATION RATE - LOOKUP TABLE

Infiltration Rates (in/hr)

References	(a)	(b)
SOIL TEXTURE		
Sand*	4.64	8.27
Loamy Sand*	1.18	2.41
Sandy Loam*	.43	1.02
Silt Loam	.26	.27
Loam	.13	.52
Sandy Clay Loam	.06	.17
Clay Loam	.04	.09
Silty Clay Loam	.04	.06
Sandy Clay	.03	.05
Silty Clay	.02	.04
Clay	.01	.02

SCS SOIL GROUP	(a)	(c)
A	.43	.30-.45
B	.26	.15-.30
C	.13	.05-.15
D	.03	.00-.05

SCS "Soil Survey Interpretations" provide data on infiltration rate (permeability) for specific soils.

* Yousef et al., (1986) recommend using infiltration rate of ~ 1 in/hr for designing retention basins in sandy and sandy loam soils.

MANNING'S N - LOOKUP TABLE

Cover Type	Manning's N	Source
Light Turf	.20	a
Dense Turf	.35	a
Forest w/Dense Undergrowth	.80	a
Dense Growth	.40-.50	d
Pasture	.30-.40	d
Lawns	.20-.30	d
Bluegrass Sod	.20-.50	d
Shortgrass Prairie	.10-.20	d
Sparse Vegetation	.05-.03	d
Bare Clay-Loam Soil	.01-.03	d

Sources: a - McCuen (1982); b - Shaver (1986); c - Musgrave (1985); d - Bedient and Huber (1988)

RUNOFF CURVE NUMBERS - LOOKUP TABLE

LAND USE	HYDROLOGIC CONDITION	Hydrologic Soil Group A	B	C	D
Grassed Areas	Good (>75% cover)	39	61	74	88
	Fair	49	69	79	84
	Poor (<50% cover)	68	79	86	89
Meadow or Idle Land	Good	38	58	71	78
Woods	Good (thick forest)	25	55	70	77
	Fair	36	60	73	79
	Poor (thin, no mulch)	45	66	77	83
Construction Sites	Newly graded Areas	81	89	93	96

* Lawns normally assumed to be in good hydrologic condition
Source: USDA, SCS (1977)

WATERSHED IMPERVIOUS FRACTIONS - LOOKUP TABLE

Impervious Fractions vs. GIS Land Use - Hunt Potowomut Watershed

GIS LAND USE	CODE/CATEGORY	EQUIVALENT	AVERAGE	RANGE
Residential	111 High Density	>8 Units/acre	.44	.32-.60
Residential	113 Medium Dens,	1-3, 9 Units/ac	.27	.29-.38
Residential	114 Med-Low Dens.	.5-.9 Units/ac	.25	.06-.79
Residential	115 Low Density	.2-.49 Units/ac	.14	.10-.18
Residential	116 Rural Density	<.2 Units/ac	.85	.03-.06
Commercial	128		.62	.44-.92
Industrial	131 Heavy		.81	.74-.93
Industrial	132 Medium		.77	.59-1.0
Transportation	141 Roads, Interch., Service		.41	.23-.60
Institutional	188 Educ., Health, Prisons, Milit.		.47	.30-.77

Impervious Fractions vs. Land Use Classifications (USDA, 1985)

Residential Areas					
Lot Size (acres):	<=1/8	1/4	1/3	1/2	1
Impervious Fraction:	.65	.38	.38	.25	.20
Industrial Areas	.72				
Commercial & Business	.85				

6.2 Model Output

Once the input data have been entered for a given case, the model must be executed via the 'RM' (= 'Run Model') command. The sequence of storms is tracked on the screen until the simulation is completed. A red message 'MODEL EXECUTED' appears in the lower right corner of the menu screen to indicate that the simulation is complete. Simulation results are stored in disk files for later access by reporting and graphing routines. Tabular output are accessed using the following commands:

LBA	List water and mass balances by device and component
LR	List removal efficiencies by device and component
LT	List comparison of flow, loads, and concs. across devices
LV	List violation frequencies for event-mean concentrations
LP	List peak elevation and outflow ranges for each device
LS	List sediment accumulation rates by device
LM	List mean inflow or outflow concs. by device and component
LD	List detailed statistical summaries by device and component
LC	List continuity (mass-balance) check on simulation results

Tabular output may be displayed on the screen or routed to a disk file for subsequent printing or other use (see 'UO' = 'Utilities Output').

Graphic output (to screen only) is available in the following formats:

PE	Plot simulation results by event precip., flows, loads, concs., etc., in 5 formats: time series cumulative time series cumulative frequency distributions log normal frequency plots scatter plots
PM	Plot time series of monthly total precip., flows, or loads
PY	Plot time series of yearly total precip., flows, or loads
PT	Plot detailed time series of precipitation, elevation, volume, discharge, concentrations, or loads for specific devices.

Independent screen-dump utilities may be used to print screen displays. (See 'Help - Program - Printing Graphs' for a list of such utilities). Plot data may be dumped to disk in ASCII format convenient for input to spreadsheets or word processors (Press "d" when viewing graphic screen). Graphic routines have been developed primarily for use in model development and testing. They are accessible only in the ADVANCED USER MODE.

Some output procedures produce several series. In order to stop the output sequence and return to menu, press <Esc> when the <H> prompt occurs. In general, the <Esc> key (sometimes hit more than once) provides a quick route back to the program menu.

6.3 Other Functions and Utilities

Design Mode

The model can be used in a "design mode" to select and size devices appropriate for treating runoff from specified watershed(s). Step-by-step procedures for using the program in a design mode are provided in the Program Documentation and in Appendix C of this document.

One procedure ('RDL' = 'Run Design Lookup') selects and sizes a device to achieve ~70% or ~85% total suspended solids removal for one user-defined watershed. To use this routine, a valid case with at least one watershed and one device must be pre-defined. The program disk contains a catalogue of devices sized to achieve total suspended solids removal efficiencies of 70% and 85%, based upon simulation of Providence 1980 rainfall data.

The user specifies the watershed to be treated, the device prototype, and the location for the new device (overwrites any pre-defined device). This provides an "initial guess" of design requirements for a particular watershed, device type, and TSS removal objective.

Another procedure ('RDT' = 'Run Design Tune') tunes or rescales device(s) to achieve a user-defined removal efficiency for any particle class or water quality component. In order to use this procedure, the user must first define a case containing a preliminary design and execute it via the 'Run Model' command. User is prompted for list of devices to be rescaled, target particle class, and target removal efficiency. Rescaling options include areas, volumes, outlet capacities (detention ponds only). The model is run repeatedly using the specified storm sequence. Solutions are not always feasible. A maximum of 12 iterations is performed.

Trace Device

In order to save results for each time step, devices must be TRACED. Trace switches are set using the 'UT' = 'Utilities Trace' command (ADVANCED USER MODE). Tracing is not required unless plotting of within-event variation or daily-average values is desired. Since tracing consumes disk space and computer time, devices should be traced only when necessary.

Sensitivity Analysis

Another procedure ('RS' = 'Run Sensitivity') tests sensitivity of removal efficiency and device outflow concentration to each model input value. Each input value is increased by a fixed percentage (one at a time). The model is re-executed. Effects on removal efficiency and outflow concentration are tabulated. Tested inputs include watershed variables, device variables, particle parameters, and storm scale factors. The resultant percent removal and outflow concentration are reported for each variable charged during the sensitivity analysis. In addition, the relative change and percent change in both percent removal and concentration is reported for each input variable. The sensitivity coefficient is the percent increase in the output value relative to the percent change in the input variable (i.e., SENS = % increase in Y/% increase in X). This procedure is especially useful for obtaining perspectives on which model inputs have the greatest impact on model predictions, and are therefore most important to estimate accurately (Walker, 1982).

Calibration

When applying the P8 model to a large watershed application (e.g., the Hunt-Potowomut watershed), calibration of the model to predict measured daily flow time series is facilitated by the 'RC' (= 'Run Calibrate') command. This procedure compares predicted daily-mean outflow time series from a specified device with measured values contained in a disk file. The model must be executed beforehand ('RM' command), and the device used in the calibration must be traced in order to obtain daily output values ('UT' = 'Utilities Trace' command). The program merges observed and predicted daily flows by date. Moving averages are calculated at a user-defined interval. Observed and predicted time series are plotted and compared statistically. This procedure is not relevant to designing BMP's for individual developments. A detailed discussion of this function and its applications to the Hunt Potowomut watershed is provided in the P8 Urban Catchment Model Program Documentation.

To utilize this function, an AQUIFER is used to simulate baseflow, and a PIPE is used to collect surface runoff from the various watershed areas. The combined outflow from the AQUIFER and PIPE are routed to a second PIPE to obtain total outflow. Calibration is accomplished through adjusting, time of concentrations, and other scaling factors, provided for various input variables.

Batch files

Batch files may be used to execute a number of cases in sequence. This information is accessed by 'Utilities Batch'- 'UB' in the ADVANCED MODE. The user also has the option of archiving or not archiving the model output. If the noarchive option is selected results will only be stored in a temporary disk file. This model utility is particularly useful when running a large number of cases or when it is desired to run several cases for one or more years. Batch files may be created using any line editor with the case file name given in columns 0-31, and the desired storm file beginning on column 32. If no stormfile is specified, the storm file specified in the case file will be used.

Output Destination

The user may select to send the model output to the screen (default) or to a disk file. To send the output to a disk file use the 'Utilities Output File' - 'UOF' command. This option is only available in the ADVANCED mode.

View

The 'Utilities View'- 'UV' command may be used to view any DOS text/ASCII file without exiting the P8 program.

NOAA

Additional storm files can be created by the user utilizing the 'Utilities NOAA'- 'UN' command in the ADVANCED mode. This function reads hourly precipitation data which can be purchased for any first order NOAA weather station in the US.

The National Climatic Data Center in Ashville, NC can provide hourly precipitation data on diskette for NOAA weather stations in the U.S.. Call 704-259-0682 to order. The cost is ~$90/station for the period of record (~33 yrs.). Request files in RELEASE B/CONDENSED FORMAT. Each file typically contains 5 years of data.

File names specified on this screen will be read and a single storm file (.STM) will be generated for subsequent use by P8. Use a text editor to break up the .STM file into separate years or other time frames. MINIMUM INTER-EVENT TIME (MIT) - wet hours within MIT hours of each other are considered part of the same "storm" (typically 3-10 hrs.). See Bedient and Huber (1986); Huber and Dickinson (1988). The Providence files supplied with the program were generated with an MIT value of 5 hours. Storm years in input files must be between 1942 and 1999. The NOAA input file must be "normal", containing no missing or otherwise obtuse records. This is usually not a problem (based upon experience with Providence and Boston data files).

6.4 Getting Started: Step-by-Step

The following are step-by-step instructions for creating, entering, and executing a new case. The reader is referred to Appendix B for data entry worksheets and Appendix C for example case runs.

1. Assemble reference materials for site (maps, engineering reports).

2. Construct schematic diagram illustrating downstream linkage of watersheds and devices.

3. Assign a name (<=8 characters) and number (1-24) to each watershed. Write these on your schematic.

4. Tabulate basic watershed characteristics needed for model input, as indicated on worksheets in Appendix B.

5. Assign a name (<=8 characters), number (1-24), and device type code (1-7) to each device. It is often convenient (but not necessary) to assign device numbers in downstream order. Write these on your schematic.

6. Tabulate basic device characteristics needed for model input, as indicated on worksheets in Appendix B.

7. Run program. Move to program directory on hard disk and enter 'P8'.

8. Review introductory help screens (to skip these, press <ESC>).

9. Clear existing data (Procedure = 'CZ' = 'Case Zero').

10. Enter site data (Procedure - 'CEA' - 'Case Edit All'). Refer to your schematic to identify device/watershed numbers and names.

11. Load desired particle file (Procedure = 'CRP' = 'Case Read Particles'); suggest using 'SIMPLE.PAR' and 'TYPE2.STM' in preliminary runs; this will speed computations.

12. Print a copy of the watershed/device network linkage for future reference; Procedure = 'CLN' - 'Case List Network'; hit 'Print Scrn' key at <H> prompt.

13. Save input case values on disk (Procedure = 'CSI' = Case Save Inputs').

14. Run simulation (Procedure = 'RM' = 'Run Model') etc.

6.5 Watershed Scale Applications

In order to utilize the P8 Model for watershed-scale applications, a similar procedure is used to that outlined in Section 6.4, but simply focusing on a larger scale. Watershed characteristics from (i.e., infiltrations rates, impervious areas, areas, etc.) are obtained from land use/land cover and soils information available in RIGIS. A lookup table has been provided on Page 13 to convert land usage into impervious areas for watershed-scale applications. Again, each subbasin of the watershed may be modeled as separate watersheds and linked by the PIPE and AQUIFER devices (see section 6.3 Calibration for additional details on linking watersheds to the AQUIFER and PIPE devices). The number of subwatersheds modeled is selected based upon the users knowledge of the overall watershed, and the variability of characteristics within the watershed. More complex modeling on the basin or watershed level which accounts for the attenuation of pollutants in wetlands and/or buffer zones is also possible. This would require routing the watershed runoff to the specific buffers or wetland areas, and having sufficient information regarding the characteristics of buffers or wetlands to supply model inputs for these treatment areas.

Again, as mentioned in Section 2.0 without calibration, "relative" predictions (i.e. % change) are more reliable than "absolute predictions" (concentration, flow, and load). Once the user has calibrated the model using data of suitable detail and quality, the model may be used to predict absolute changes of various land use scenarios with a known degree of certainty. Without such calibration, the model should only be utilized for relative predictions.

7.0 APPENDICES

APPENDIX A
Menu Structure

APPENDIX A
P8 Menu Structure

PROCEDURE	DESCRIPTION	HELP	MODE
Case	Define Case	180	0
Edit	Edit Case Variables	180	0
First	Edit Title, Data File Names, Storm File Names, Storm Dates	5	0
Devices	Edit Device Index or Data	70	0
Index	Edit Device Index (Device Labels & Types)	9	0
Data	Edit Device Data (Dimensions, Infiltration Rates, Slopes, etc.)	10	0
Watersheds	Edit Watershed Index or Data	40	0
Index	Edit Watershed Index (Watershed Labels & Outflow Devices)	7	0
Data	Edit Watershed Data (Area, Imperv. Frac., Curve Number, etc.)	8	0
Particles	Edit Particle Data (Runoff Conc., Settling Veloc., etc.)	4	1
Components	Edit Water Quality Components & Criteria	17	1
First	Edit First Group (Components 1 - 5)	17	1
Second	Edit Second Group (Components 6 - 10)	17	1
Evapotrans	Edit Evapotranspiration Factors	98	1
TimeSteps	Edit Time Step Lengths & Continuity Error Limit	18	1
All	Edit All Site Input Data Groups	19	0
Read	Read Input Data File	20	0
All	Read All Input Data Groups from a Disk File	20	0
Particles	Read Particle/Component Input Data Groups from Disk File	20	0
Save	Save Input Data File	22	0
Inputs	Save all Input Data Groups in a Disk File	22	0
Particles	Save Particle/Component Input Groups in a Disk File	22	1
Archive	Save All Input Data Groups and Output Files	22	1
Zero	Erase All Case Input Values	24	0
List	List Input Values for Current Case	1	0
Site	List Watershed & Device Input Data	1	0
Network	List Watershed / Device Network	1	0
Tables	List Device Morphometry & Outflow vs. Elevation Tables	33	0
Parameters	List Particle & Water Quality Component Input Data	1	0
Run	Run Model or Size Devices	180	0
Model	Run Model for Current Watershed/Device Network	25	0
Design	Select / Size Devices for Defined Watershed(s)	77	0
Lookup	Retrieve Preliminary Designs for One Device	78	0
70%	Retrieve a Device to Achieve TSS Removal = 70%	78	0
85%	Retrieve a Device to Achieve TSS Removal = 85%	78	0
Tune	Rescale Device(s) to Achieve Target Removal Efficiency	79	0
One	Target Removal Efficiency for One Device	79	0
All	Target Removal Efficiency for Entire Device Network	79	0
Sensitivity	Run Sensitivity Analysis on Model Input Variables	89	1
Watersheds	Run Sensitivity Analysis on Watershed Input Variables	89	1
Devices	Run Sensitivity Analysis on Device Input Variables	89	1
Both	Run Sensitivity Analysis on Watershed & Device Inputs	89	1
Particles	Run Sensitivity Analysis on Particle Parameters	89	1
All	Run Sensitivity Analysis on All Input Variables	89	1
Calibrate	Run Flow Calibration - Compare Observed & Predicted Flows	97	1
List	List Model Output (Must Run Model First)	23	0
Balances	Water & Mass Balances by Device & Component	27	0
All	Water & Mass Balances for All Storms	27	0
Each	Water & Mass Balances for Each Storm Separately	27	1
Removals	List Removal Efficiencies (%) by Device & Component	29	0
Terms	List/Plot Flow & Mass-Balance Terms by Device & Component	90	0
Outflow	List/Plot Device Total Outflows (Infilt.+Normal+Spillway)	90	0
Surface	List/Plot Device Surface Outflows (Normal + Spillway)	90	0
Inflow	List/Plot Device Total Inflows	90	0
Any	List/Plot Any Mass-Balance Term	90	0
Violations	Violation Frequencies for Event-Mean Concentrations	28	1
Outflow	Violation Frequencies for Total Outflow Concentrations	28	1
Surface	Violation Frequencies for Surface Outflow Concentrations	28	1
Inflow	Violation Frequencies for Total Inflow Concentrations	28	1
Any	Violation Frequencies for Any Mass-Balance Term	28	1
Peaks	List Maximum Elevations, Outflows, and Velocities by Device	81	0
Sedim	List Sediment Accumulation Rates by Device	37	0
Means	List Flow-Weighted-Mean Concentrations Device & Component	21	1
Inflow	List Flow-Weighted-Mean Inflow Concentrations	21	1
Outflow	List Flow-Weighted-Mean Total Outflow Concentrations	21	1
Surface	List Flow-Weighted-Mean Surface Outflow Concentrations	21	1
Any	List Flow-Weighted-Mean Concs for Any Mass-Balance Term	21	1

P8 Menu Structure (ct.)

PROCEDURE	DESCRIPTION	HELP	MODE
Detail	Detailed Statistical Summaries of Simulation Results	30	1
Flows	Summarize Event-Total Flows (acre-ft)	30	1
Loads	Summarize Event-Mean Loads (lbs)	30	1
Concs	Summarize Event-Mean Concentrations (ppm)	30	1
Precip	Summarize Event-Mean Precipitation (inches)	30	1
Traced	Detailed Output Statistics by Time Step for Traced Devices	31	1
Continuity	List Continuity (Water-Balance & Mass-Balance) Errors	32	1
Plot	Plot Simulation Results (Must Run Model First)	188	1
Events	Plot Event Summary Values	71	1
Timeser	Plot Event Time Series	71	1
Volumes	Plot Event Total Flow Volume (ac-ft) vs. Time (Julian Day)	71	1
Loads	Plot Event Total Loads (lbs) vs. Time (Julian Day)	71	1
Concs	Plot Event Mean Concentrations (ppm) vs. Time (Julian Day)	71	1
Precip	Plot Event Total Precipitation (inches) vs. Time (Julian Day)	71	1
Elev	Plot Event Maximum Elevations (ft) vs. Time (Julian Day)	71	1
Flows	Plot Event Maximum Flows (cfs) vs. Time (Julian Day)	71	1
Other	Plot Other Storm Values vs. Time (Julian Day)	71	1
Cumulatives	Plot Event Cumulative Totals vs. Time (Julian Day)	72	1
Flows	Plot Cumulative Flows (ac-ft) vs. Time (Julian Day)	72	1
Loads	Plot Cumulative Loads (lbs) vs. Time (Julian Day)	72	1
Precip	Plot Cumulative Precip. (inches) vs. Time (Julian Day)	72	1
Frequency	Plot Cumulative Frequency Distributions of Event Values	73	1
LogNormal	Plot Frequency Distributions of Event Values - Lognormal Scale	74	1
Scatter	Scatter Plots for Event-Mean Values	75	1
1CvsQ	Plot Event-Mean Concentration (ppm) vs. Event-Mean Flow (cfs)	75	1
2CvsP	Plot Event-Mean Concentration (ppm) vs. Event Total Precip (in)	75	1
3CvsI	Plot Event-Mean Concentration (ppm) vs. Precip Intens (in/hr)	75	1
4Other	Scatter Plot of Other Variables	75	1
Yearly	Plot Yearly Total Flows, Loads, or Precip. vs. Year	99	1
Flows	Plot Yearly Total Flows (ac-ft) vs. Year	99	1
Loads	Plot Yearly Total Loads (lbs) vs. Year	99	1
Precip	Plot Yearly Total Precipitation (inches) vs. Year	99	1
Monthly	Plot Monthly Total Flows, Loads, or Precip. vs. Date	99	1
Flows	Plot Monthly Total Flows (ac-ft) vs. Date	99	1
Loads	Plot Monthly Total Loads (lbs) vs. Date	99	1
Precip	Plot Monthly Total Precipitation (inches) vs. Date	99	1
Daily	Plot Daily-Average Time Series - for Traced Devices Only	34	1
Precip	Plot Daily Avg. Precipitation Intensity (in/hr) vs. Julian Day	34	1
Elevations	Plot Daily Avg. Device Elevations (ft) vs. Julian Day	34	1
Volumes	Plot Daily Avg. Storage Volumes (ac-ft) vs. Julian Day	34	1
Flows	Plot Daily Average Surface Outflows (cfs) vs. Julian Day	34	1
Traced	Plot Time-Step Results for Traced Devices	36	1
Precip	Plot Precipitation Intensity (in/hr) vs. Julian Hours	36	1
Elevations	Plot Device Elevations (ft) vs. Julian Hours	36	1
Volumes	Plot Device Storage Volumes (ac-ft) vs. Julian Hours	36	1
Flows	Plot Device Surface Outflows (cfs) vs. Julian Hours	36	1
Concs	Plot Surface Outflow Concentrations (ppm) vs. Julian Hours	36	1
Loads	Plot Surface Outflow Loads (lbs/hr) vs. Julian Hours	36	1
Utilities	Program Utilities	180	1
Output	Select Destination for Program Output	194	1
Screen	Send Output to Screen (Default)	194	1
File	Send Output to Disk File	194	1
Trace	Select Devices to be Traced - Save Time-Step Results	38	1
Some	Trace Simulation Results for Specific Devices	38	1
None	Do Not Trace Results (Default)	38	1
All	Trace All Devices (Careful !! - Ample Disk Space Required)	38	1
View	View any DOS Text/ASCII File	186	1
NOAA	Translate NOAA/NCDC Hourly Precipitation File	43	1
Batch	Batch Processing - Run Model for List of Cases	76	1
NoArchive	Batch - Do Not Archive Results	76	1
Archive	Batch - Archive Results - Save Output for Future Analysis	76	1
Help	View Supplementary Help Screens	195	0
Quit	End Session	180	0

USER MODES <SHIFT><F1>: 0=NOVICE, 1=ADVANCED, HELP: Screen Numbers Listed in Appendix D

APPENDIX B
Data Entry Worksheets

P8 URBAN CATCHMENT MODEL
DATA ENTRY WORKSHEET

Notes:

1) Data inputs denoted with an "*" are user defined inputs (labels, notes, filenames)
2) Data inputs denoted with a "$" should be available from drainage plan (hydrologic sequence, watershed and device characteristics)
3) Data inputs denoted with "@" should be taken from look up tables provided on the model help screens or from other available sources
4) Data inputs denoted by a number in parentheses (#) are selected from available computer disk files.
5) Data inputs denoted by "+" Use default values unless more detailed site-specific information is available.

CASE EDIT FIRST (title, file names, user reference notes)

Case Title (Label): ______________________________ *
Case Data File (Filename.cas): ____________________ *
Storm Data File (Filename.stm): ____________________(1)

Notes (User reference about case): __________________ *

Site Schematic Diagram:

CASE EDIT DEVICE INDEX (define list of treatment devices for simulation)

NO.	LABEL*	TYPE$	NO.	LABEL*	TYPE$	NO.	LABEL*	TYPE$
1			9			17		
2			10			18		
3			11			19		
4			12			20		
5			13			21		
6			14			22		
7			15			23		
8			16			24		

1=detention pond 2=infiltration basin 3=swale/buffer 4=general
5=pipe/manhole 6=splitter 7=aquifer

P8 URBAN CATCHMENT MODEL
DATA ENTRY WORKSHEET

CASE EDIT WATERSHEDS INDEX (define list of watersheds for simulation; 8 character watershed label, and downstream discharge location)

NO.	LABEL*	OUTFLOW DEVICE$	NO.	LABEL*	OUTFLOW DEVICE$	NO.	LABEL*	OUTFLOW DEVICE$
1			9			17		
2			10			18		
3			11			19		
4			12			20		
5			13			21		
6			14			22		
7			15			23		
8			16			24		

CASE EDIT WATERSHEDS DATA **(specify watershed specific data)**

Watershed Number (as specified in watershed index): ____*
Watershed Label (as specified in watershed index): ________*

Outflow device number (downstream surface water device sequence): ______$
Aquifer Device Number (down gradient movement to aquifer): ______$

Total Area (acres): ______$
Impervious Fraction (impervious area/total area): _____$

Depression Storage (inches): _____@
Sweeping Frequency (times/week, if applicable): ___$

Pervious Curve Number (based on hydrologic soils group): _____@

Scale Factor for Pollutant Load (default value = 1): ___+

P8 URBAN CATCHMENT MODEL
DATA ENTRY WORKSHEET

CASE EDIT DEVICE DATA - DETENTION POND

Device No. (specified in device index): ____*
Label (specified in device index): _________*
Bottom Elevation (feet; for reference only): ________$

	Area (acres)	Volume (ac-ft)
Pond Bottom	__________	____________$
Permanent Pool	__________	____________$
Flood Pool	__________	____________$

Infiltration Rate (in/hr; flood pool only): ______@

Normal Outlet (specify only one)$:

Flood Pool Drawdown Time (hours): ______

Outlet orifice diameter (inches): ______

Outlet weir length (feet): ______

Riser Height (feet): _____ Holes (#): ____ Hole diameter (inches): ____

Outlet Device Numbers (downstream flow direction):$
Normal Outlet: ______
Spillway: _____
Infiltration: _______

To direct flow out of system set device number to "0" or to other device number listed in device index.

P8 URBAN CATCHMENT MODEL
DATA ENTRY WORKSHEET

CASE EDIT DEVICE DATA - GENERALIZED DEVICE

-Defines elevation, area, discharge table for device with up to three outlets; similar input is required for hydrologic models (i.e., TR-20)

Device No. (specified in device index): __________*
Label (specified in device index): ______________*

	INFILTR.	NORMAL OUTLET	SPILLWAY
OUTFLOW DEVICE NUMBERS	_______	______	________$

ELEVATION feet$	AREA acres$	OUTFLOW RATES cfs$		
________	____	________	________	________
________	____	________	________	________
________	____	________	________	________
________	____	________	________	________
________	____	________	________	________
________	____	________	________	________
________	____	________	________	________
________	____	________	________	________
________	____	________	________	________
________	____	________	________	________
________	____	________	________	________
________	____	________	________	________

To direct **flow out of system** set device number to "0" or to other device number listed in device index.

P8 URBAN CATCHMENT MODEL
DATA ENTRY WORKSHEET

CASE EDIT DEVICE DATA - INFILTRATION BASIN

Device Number (specified in Device index): __*
Device Label (specified in device index): __*

Bottom Elevation (feet): _______$
Bottom Area (acres): _______$
Storage Pool Area (acres): _______$
Storage Pool Volume (acre-ft): ________$

Void Volume Percent (%; default = 100): _____+

Infiltration Rate (inches/hour): ________@

Outflow Device Numbers:
Overflow: _____$
Exfiltrate: _____$

CASE EDIT DEVICE DATA - SWALE/BUFFER STRIP

Device Number: ____*
Device Label: _____*

Bottom Elevation (feet): _______$
Flow Path Length (feet): _______$
Flow Path Slope (%): _______$

Bottom Width (feet): _______$
Side Slopes (ft-h/ft-v): _______$

Maximum Depth (feet): ______$
Manning's N: ______@
Infiltration Rate (in/hr): _____@

Outflow Device Numbers:
Overflow: _________$
Exfiltrate: _____$

To direct flow out of system set device number to "0" or to other device number listed in device index.

P8 URBAN CATCHMENT MODEL
DATA ENTRY WORKSHEET

CASE EDIT DEVICE DATA - PIPE/MANHOLE

Device Number: ____*
Device Label: ________*

Time of Concentration (hrs; default = 0): ____________+

Outflow Device Number: _____$

CASE EDIT DEVICE DATA - FLOW SPLITTER

Device Number: ____*
Device Label: ________*

Outflow to Device: _________$ If Surface Elev. < ________ Feet

Otherwise, outflow to alternative device: ________

Time of Concentration (hrs; default = 0): ____________+

CASE EDIT DEVICE DATA - AQUIFER

Device Number: ____*
Device Label: ________*

Outflow Device Number: _____$

Time of Concentration (hrs; default = 0): ____________+

To direct flow out of system set device number to "0" or to other device number listed in device index.

APPENDIX C
Example Case Applications

This appendix provides several demonstration examples illustrating typical model applications. General instructions for running sample cases, entering new cases, and designing Site BMPs is provided in Appendix E of the Program Documentation (Walker, 1990). A case scenario and command sequence is provided for each example, followed by the MENU screen, data entry screens, and model output. The example scenarios include:

CASE 1) Running a sample case (one device-one watershed)
CASE 2) Evaluate proposed BMP design for residential development
CASE 3) Lookup an extended wetpond design for a given watershed

CASE 1: RUNNING A SAMPLE CASE

Scenario: This example illustrates the basic model functions (CASE, RUN, LIST) using the BUFFER.CAS sample case file provided on the distribution diskette.

Command Sequence:

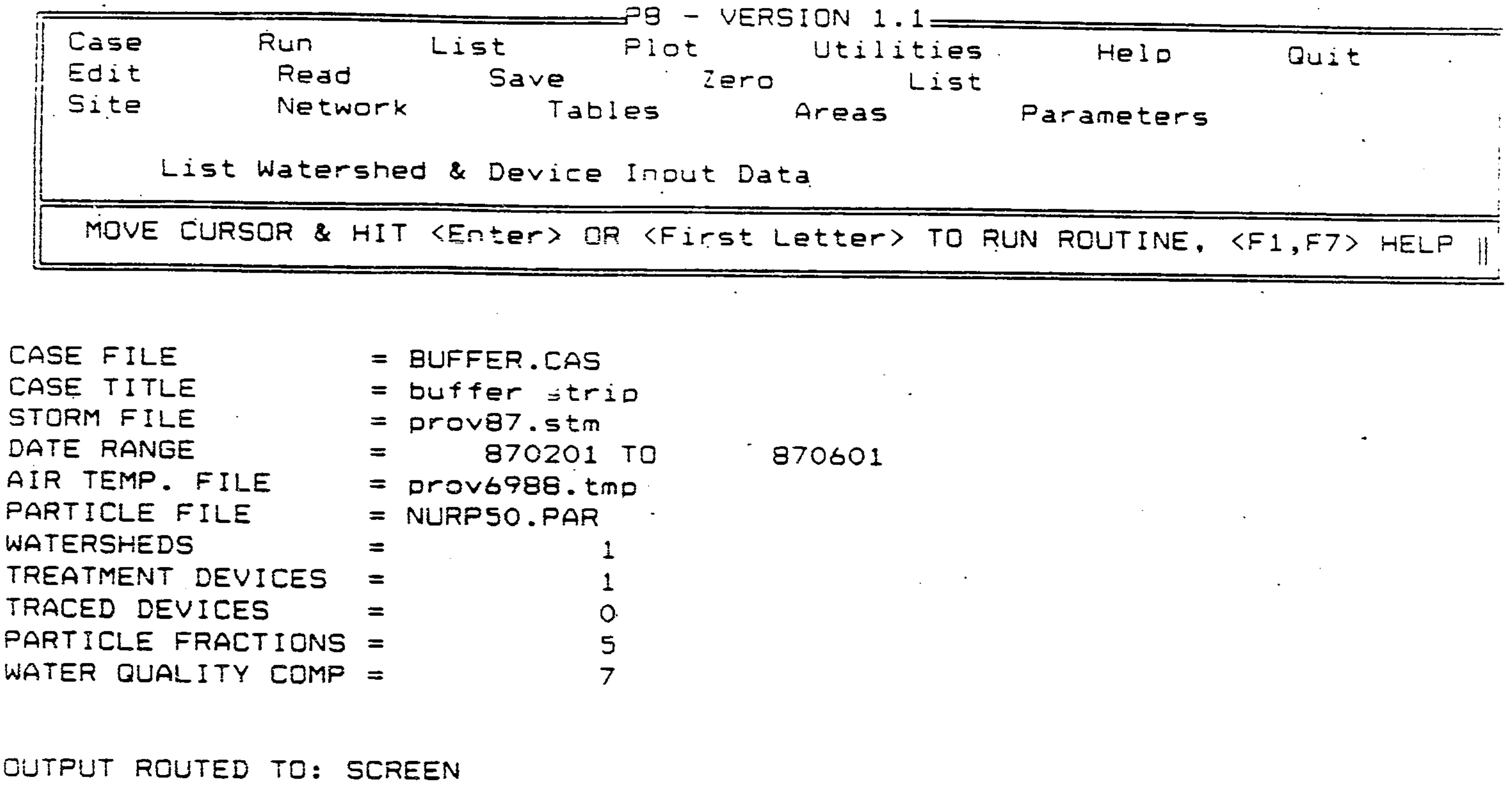
1) Load Case File:
   - Select 'Case Read All'- CRA **
   - Press return for listing of disk case files (use cursor arrows to select file, press return) or Press <ESC> to enter filename and path directly.
   - The Hold Screen prompt <H> will appear when file is loaded; press any key to continue or <F1> for help.

2) View the input data:
   - Select 'Case List Site' - CLS
   - Press any key to view next screen at <H>; program will return to MENU after passing through all screens; press escape to go back to main MENU at any point.

3) Execute model:
   - Select 'Run Model' - RM (WAIT - will flash in the upper right corner of the screen while model is running)
   - Press any key at <H> to return to MENU

4) List percent pollutant removal:
   - Select 'List Removals' - LR

** This procedure may be used to read any case file from the disk



```
P8 - VERSION 1.1
 Case       Run        List       Plot       Utilities       Help       Quit
 Edit        Read        Save        Zero        List
 Site        Network        Tables        Areas        Parameters

      List Watershed & Device Input Data

  MOVE CURSOR & HIT <Enter> OR <First Letter> TO RUN ROUTINE, <F1,F7> HELP ||


CASE FILE              = BUFFER.CAS
CASE TITLE             = buffer strip
STORM FILE             = prov87.stm
DATE RANGE             =     870201 TO      870601
AIR TEMP. FILE         = prov6988.tmp
PARTICLE FILE          = NURP50.PAR
WATERSHEDS             =           1
TREATMENT DEVICES      =           1
TRACED DEVICES         =           0
PARTICLE FRACTIONS     =           5
WATER QUALITY COMP     =           7

OUTPUT ROUTED TO: SCREEN
```

```
watershed          =  1  watershd
surface runoff device =  1  buffer
percolation device     =  0

watershed area                        acres      =    100.000
impervious fraction                              =       .250
impervious depression storage        inches     =       .020
scs curve number (pervious portion)              =     74.000
sweeping frequency                 times/week    =       .000
water quality load factor                -       =      1.000
```

```
device =  1  buffer  .   type   =  3  buffer

bottom elevation          feet     =        .000
length of flow path       feet     =     294.248
slope of flow path         %       =       2.000
bottom width              feet     =     500.000
side slope             ft-h/ft-v   =       1.000
maximum flow depth        feet     =        .100
infiltration rate        in/hr     =     .500000
mannings n                 -       =        .400
particle removal scale factor =            1.000

exfiltrate routed to device          0  OUT
normal outlet routed to device       0  OUT
```

<H>

```
removal efficiencies (%) vs. device and particle class
                      1        2        3        4        5
device               P0%      P10%     P30%     P50%     P80%
 1 buffer            49.4     68.7     86.5     95.3     99.4
25 OVERALL           49.4     68.7     86.5     95.3     99.4

removal efficiencies (%) vs. device and water quality component
  device             tss      tp       tkn       cu       pb       zn       hc
 1 buffer            89.9     70.9     67.3     67.3     84.5     67.3     84.5
25 OVERALL           89.9     70.9     67.3     67.3     84.5     67.3     84.5
```

```
<H>
```

```
SELECT PARTICLE CLASSES / WQ COMPONENTS

                        VARIABLE
                        P0%
                        P10%
                        P30%
                        P50%
                        P80%
                      * tss
                        tp
                        tkn
                        cu
                        pb
                        zn
                        hc

     PRESS <SPACE> TO SELECT(*) OR NO( ), <ENTER>=DONE, <a>= ALL, <n>=NONE
```

```
number of storms =           31
interval =  2864. hrs. storm duration =   319. hrs.  precip =  14.72 inches
device =  1 buffer   ,  type = buffer   .  variable = tss
                                 flow          load          conc
mass-balance term              acre-ft          lbs           ppm
01 watershed inflows             38.71       7746.24       73.6215
03 infiltrate                    20.87        762.66       13.4440
04 exfiltrate                    20.87           .00         .0000
05 filtered                        .00        762.66         .0000
06 normal outlet                 13.84        522.99       13.8987
07 spillway outlet                3.76        261.79       25.6404
08 sedimen + decay                 .00       6197.47         .0000

09 total inflow                  38.71       7746.24       73.6215
10 surface outflow               17.60        784.78       16.4046
11 groundw outflow               20.87           .00         .0000
12 total outflow                 38.47        784.78        7.5050
13 total trapped                   .00       6960.12
14 storage increase                .00          1.33
15 mass balance check              .24           .00

load removal efficiency    =  89.85 %.  adjusted =  89.85 %
continuity errors:  volume =    .62 %.  load     =     .00 %
<H>
```

CASE 2: SITE PLAN/BMP EVALUATION

Scenario: A residential development is proposed adjacent to a recreational lake. You have been provided with a site plan and preliminary design specifications for wet pond to treat the stormwater runoff leaving the site. Approximately 235 acres of the parcel drain to the lake via 4 existing drainage swales. The dominant hydrologic soil group on the site is Class B with grass cover in fair condition. The 235 acre parcel has been divided into four subcatchment areas, each with a wet pond designed to with a capacity equal to the volume of runoff from the mean storm of 0.4 inches. The following table has been provided by the site engineer:

			BASIN	
Subcatchment #	**Drainage Area (ac)**	**Imperv. Area (ac)**	**Volume (ac-ft)**	**Area (ac)**
1	32.7	10.3	0.46	0.23
2	54.8	14.3	0.64	0.32
3	71.0	22.5	1.41	0.40
4	76.8	17.8	1.10	0.31

You would like to evaluate the preliminary pond sizing for each subcatchment to determine if the 85% removal criteria for Total Suspended Solids (TSS) will be met.

Command Sequence:

1) Compile case data:
   - Draw Schematic diagram of the system
   - Complete data entry worksheets as necessary

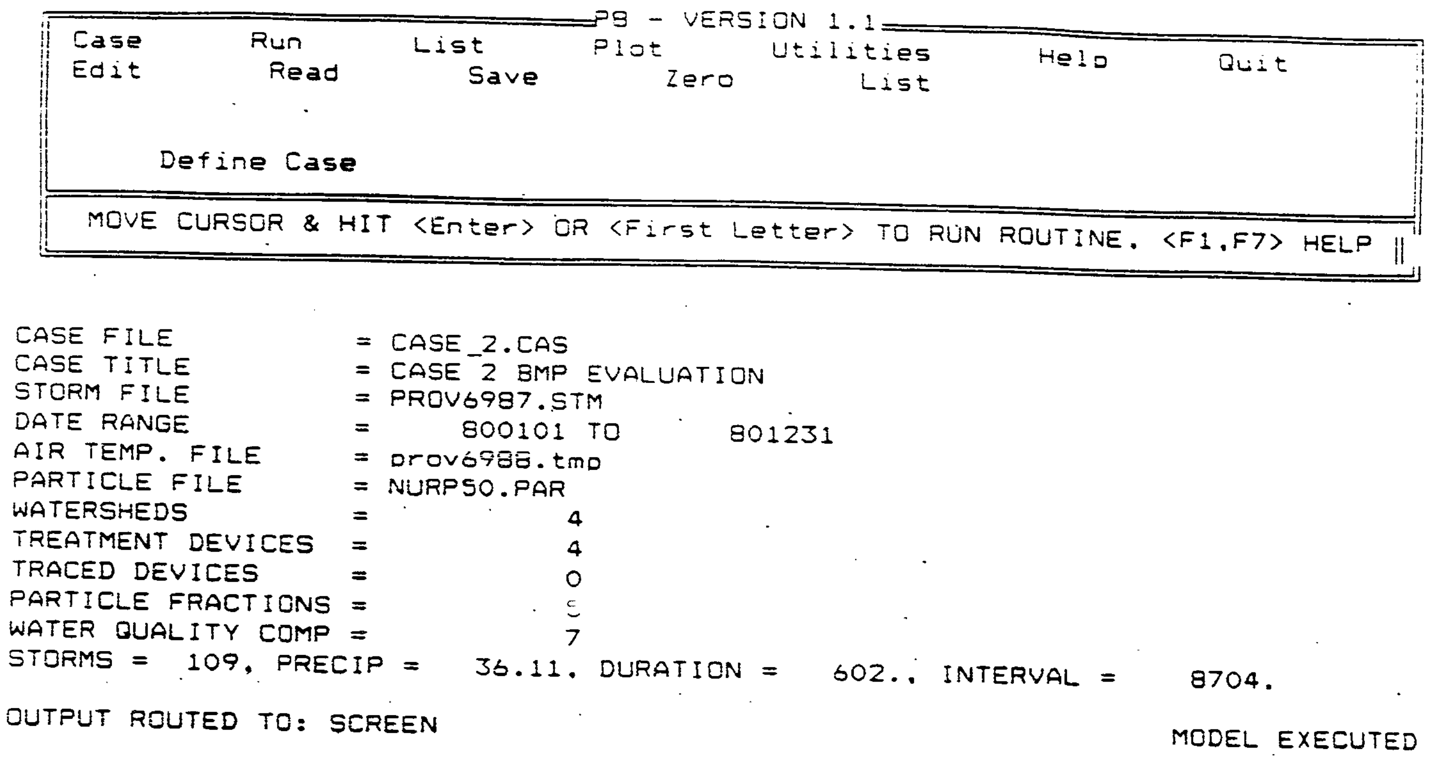
2) Create new case file:
   - 'Case Edit All' - CEA (enter data for all data entry screens)
   - 'Case Read Particles' - CRP (read desired particle characteristic file)

3) Save input data:
   - 'Case Save Input' - CSI (saves input data to disk file name specified in first data entry screen)

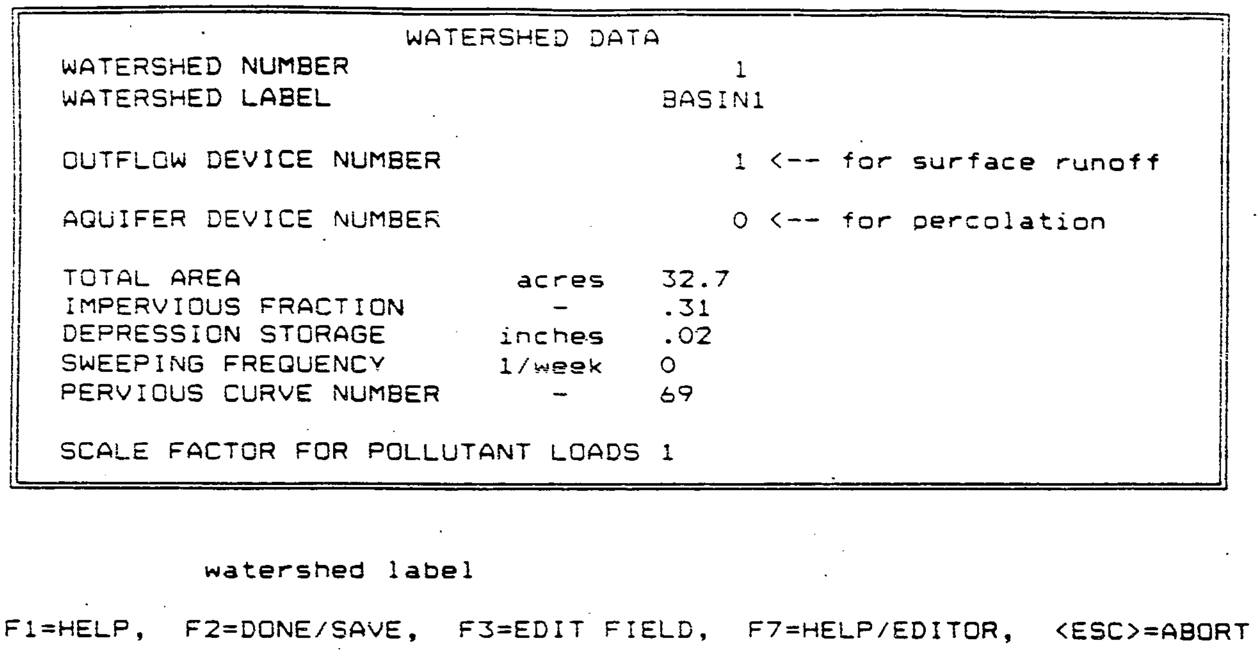
4) Execute **Model:**
   - **'Run Model' - RM**

5) View Results:
   - 'List Removal' - LR (lists percent removal for each subcatchment device)

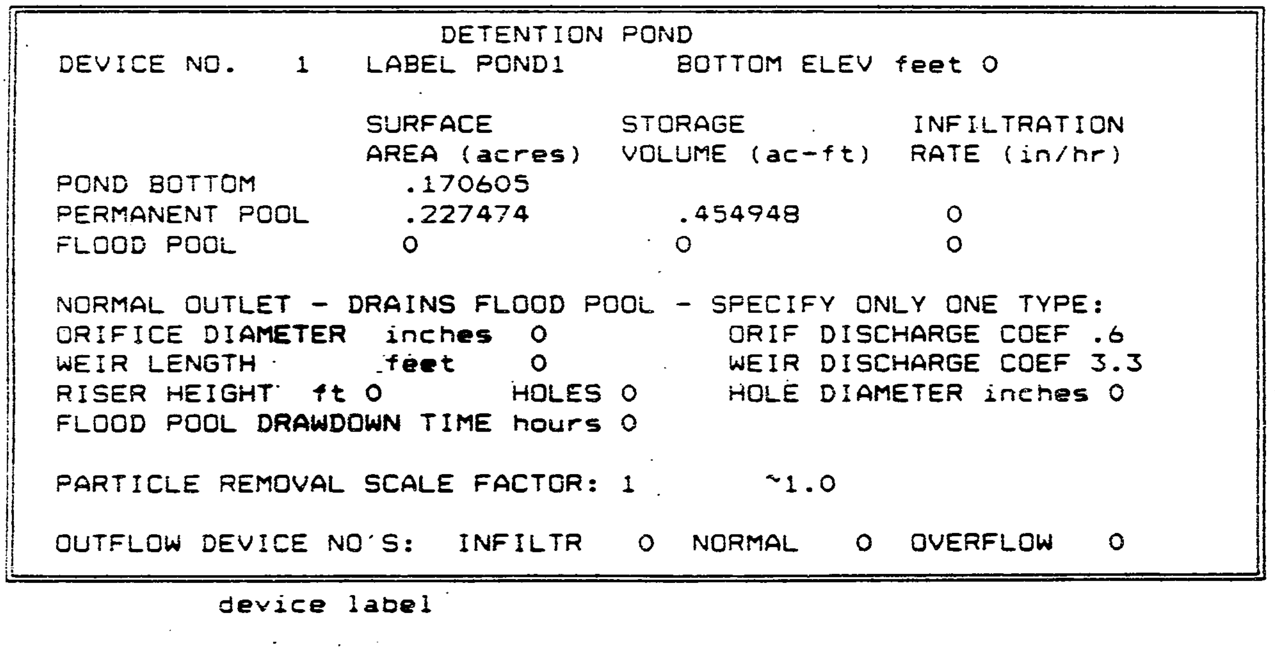
   Note: 85% TSS Removal criteria not met; request proponent to redesign or resizing of treatment systems to achieve removal target. The 'Run Design Tune' - RDT function of P8 may be used to provide an initial re-scaling to the pond area and volume or the outlet configuration necessary to meet the 85% TSS removal (The Type 2 or Average storm file should be used for this operation).



```
     Define Case

  MOVE CURSOR & HIT <Enter> OR <First Letter> TO RUN ROUTINE. <F1,F7> HELP

CASE FILE           = CASE_2.CAS
CASE TITLE          = CASE 2 BMP EVALUATION
STORM FILE          = PROV6987.STM
DATE RANGE          =     800101 TO     801231
AIR TEMP. FILE      = prov6988.tmp
PARTICLE FILE       = NURP50.PAR
WATERSHEDS          =            4
TREATMENT DEVICES   =            4
TRACED DEVICES      =            0
PARTICLE FRACTIONS  =            5
WATER QUALITY COMP  =            7
STORMS =   109, PRECIP =   36.11, DURATION =   602., INTERVAL =    8704.

OUTPUT ROUTED TO: SCREEN                                          MODEL EXECUTED
```



```
                         WATERSHED DATA
  WATERSHED NUMBER                              1
  WATERSHED LABEL                           BASIN1

  OUTFLOW DEVICE NUMBER                         1 <-- for surface runoff

  AQUIFER DEVICE NUMBER                         0 <-- for percolation

  TOTAL AREA                    acres   32.7
  IMPERVIOUS FRACTION             -     .31
  DEPRESSION STORAGE           inches   .02
  SWEEPING FREQUENCY           1/week   0
  PERVIOUS CURVE NUMBER           -     69

  SCALE FACTOR FOR POLLUTANT LOADS 1


          watershed label

F1=HELP,  F2=DONE/SAVE,  F3=EDIT FIELD,  F7=HELP/EDITOR,  <ESC>=ABORT
```



```
                         DETENTION POND
  DEVICE NO.   1     LABEL POND1       BOTTOM ELEV  feet 0

                     SURFACE          STORAGE          INFILTRATION
                     AREA (acres)   VOLUME (ac-ft)   RATE (in/hr)
  POND BOTTOM          .170605
  PERMANENT POOL       .227474          .454948          0
  FLOOD POOL           0                0                0

  NORMAL OUTLET - DRAINS FLOOD POOL - SPECIFY ONLY ONE TYPE:
  ORIFICE DIAMETER  inches  0          ORIF DISCHARGE COEF .6
  WEIR LENGTH        feet   0          WEIR DISCHARGE COEF 3.3
  RISER HEIGHT  ft 0      HOLES 0      HOLE DIAMETER inches 0
  FLOOD POOL DRAWDOWN TIME hours 0

  PARTICLE REMOVAL SCALE FACTOR: 1       ~1.0

  OUTFLOW DEVICE NO'S:  INFILTR   0  NORMAL   0  OVERFLOW   0
          device label

F1=HELP,  F2=DONE/SAVE,  F3=EDIT FIELD,  F7=HELP/EDITOR,  <ESC>=ABORT
```

```
removal efficiencies (%) vs. device and particle class
                        1         2         3         4         5
device                P0%      P10%      P30%      P50%      P80%
 1 POND1               .0      39.0      56.4      75.0      95.1
 2 POND2               .0      38.0      55.1      73.7      94.7
 3 POND3               .0      40.7      58.9      74.2      94.2
 4 POND4               .0      38.7      56.3      71.6      93.1
25 OVERALL             .0      39.3      56.9      73.5      94.1

removal efficiencies (%) vs. device and water quality component
  device             tss        tp       tkn        cu        pb        zn        hc
 1 POND1            72.1      40.4      34.8      34.8      65.3      34.8      65.3
 2 POND2            71.2      39.4      33.9      33.9      64.4      33.9      64.4
 3 POND3            72.4      41.3      35.6      35.6      65.6      35.6      65.6
 4 POND4            70.6      39.2      33.7      33.7      63.7      33.7      63.7
25 OVERALL          71.6      40.2      34.6      34.6      64.7      34.6      64.7
```

```
<H>
```

```
number of storms =          109
interval =  8704. hrs, storm duration =    602. hrs,  precip =  36.11 inches
device =  1 POND1    ,  type = pond      ,  variable = tss
                                          flow            load            conc
mass-balance term                       acre-ft            lbs             ppm
01 watershed inflows                      33.68        9691.54        105.8604
07 spillway outlet                        33.68        2698.00         29.4702
08 sedimen + decay                          .00        6988.07           .0000

09 total inflow                           33.68        9691.54        105.8604
10 surface outflow                        33.68        2698.00         29.4702
12 total outflow                          33.68        2698.00         29.4702
13 total trapped                            .00        6988.07
14 storage increase                         .00           5.45
15 mass balance check                       .00            .00

load removal efficiency     =  72.10 %,  adjusted =  72.10 %
continuity errors:  volume =    .00 %,  load     =    .00 %
```

```
<H>
```

CASE 3: DESIGN BMP FOR A SITE

Scenario: You have a residential development planned on a 100 acre parcel. The down gradient site boundary follows a small Class A stream. The predominant hydrologic soil group falls into Class C, with good condition grass cover. The proposed development will result in an impervious area of 25 acres. You would like to design an extended detention pond to treat the storm water runoff. Because the stream is of high quality (Class A), you would like to achieve a minimum of 85% percent removal of suspended solids under worst case conditions.

Command Sequence:

1) Enter case file information:
   - 'Case Edit First' - CEF
     Storm File: TYPE2.STM
     Passes: 5
   - 'Case Read Particle' - CRP
     Particle File: NURP90.PAR

2) Enter watershed data:
   - 'Case Edit Watershed Data' - CEWD
     Total Area: 100 acres
     Impervious Fraction: 0.25
     Depression Storage: 0.02
     SCS Curve Number: 74

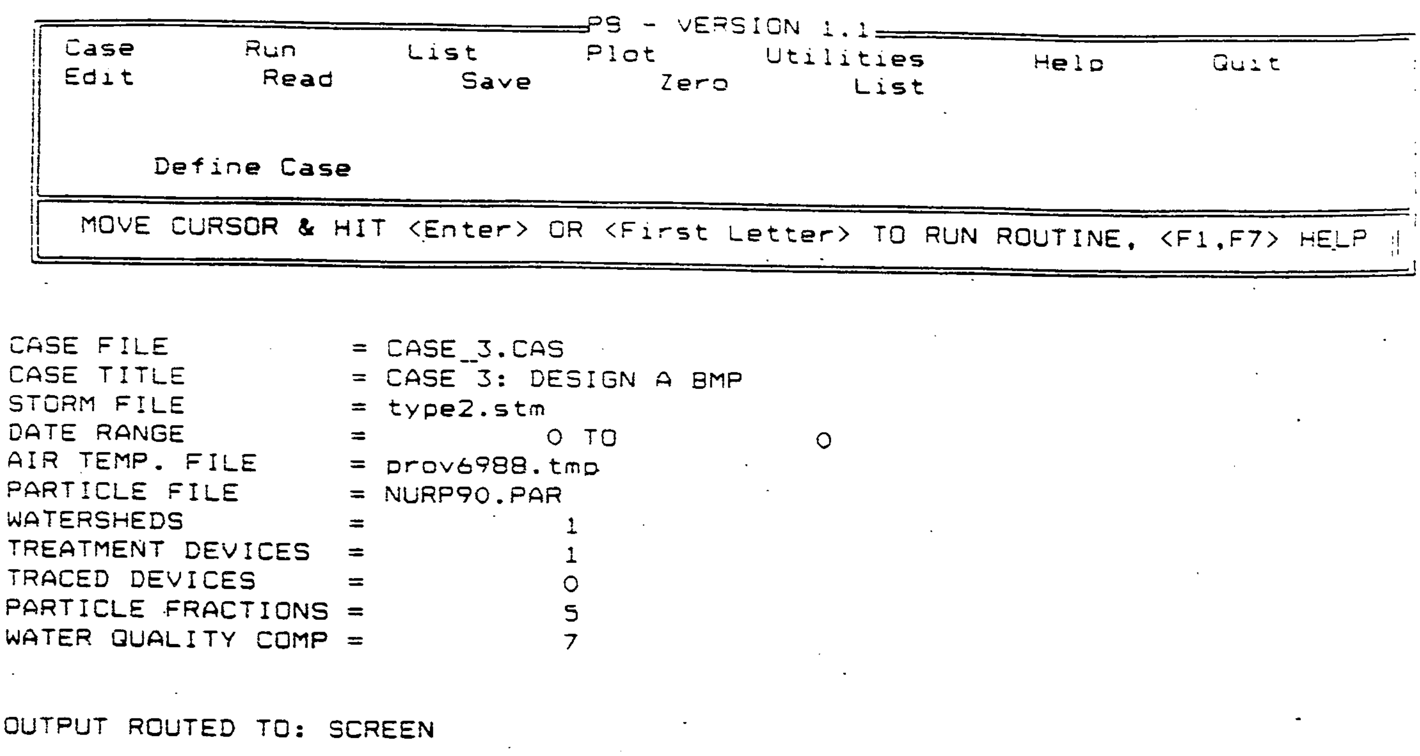
3) Look up a design:
   - 'Run Design Lookup 85%' - RDL8 (select a dry pond with a 48 hour drawdown time, 3.5 ft depth).

     Note: Model will overwrite any existing design specification

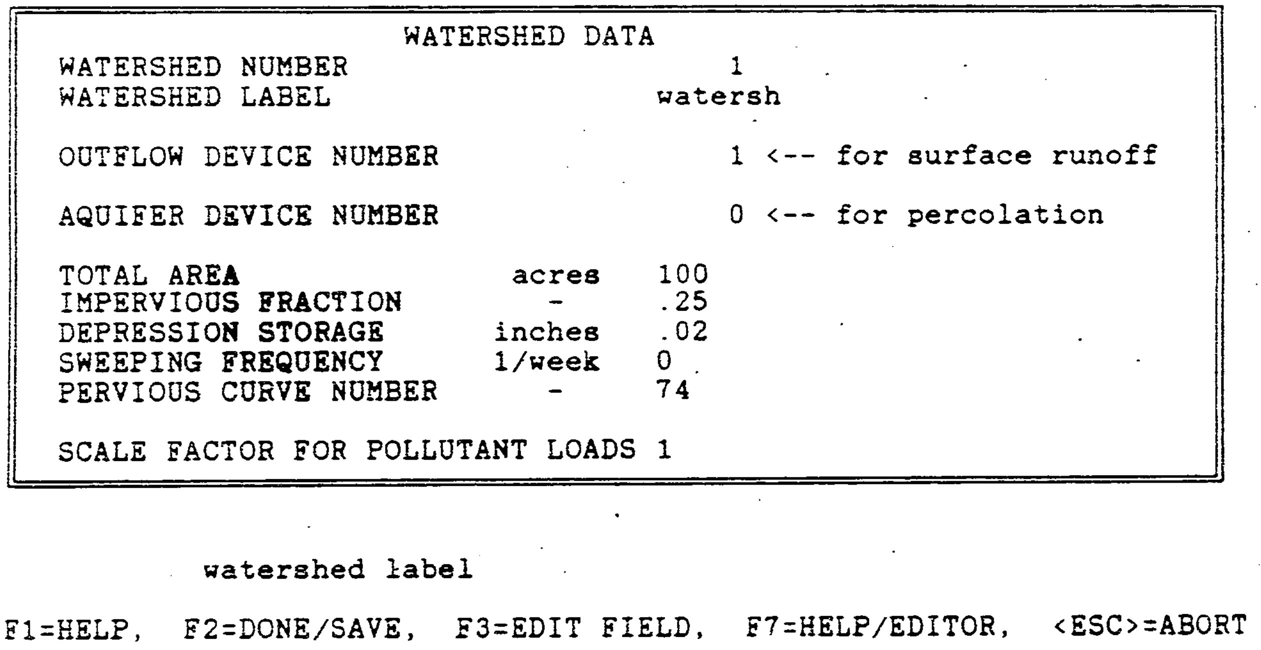
4) Execute Model
   - 'Run Model' - RM

5) View results:
   - 'List Removal' - LR

6) Verify **removal** efficiency using continuous storm series:
   - '**Case Edit First**' - CEF (Change to design storm file: PROV80.STM)
   - '**Run Model**' - RM
   - 'List **Removals**' - LR



```
CASE FILE            = CASE_3.CAS
CASE TITLE           = CASE 3: DESIGN A BMP
STORM FILE           = type2.stm
DATE RANGE           =            0 TO             0
AIR TEMP. FILE       = prov6988.tmp
PARTICLE FILE        = NURP90.PAR
WATERSHEDS           =             1
TREATMENT DEVICES    =             1
TRACED DEVICES       =             0
PARTICLE FRACTIONS   =             5
WATER QUALITY COMP   =             7

OUTPUT ROUTED TO: SCREEN
```



```
                           WATERSHED DATA
  WATERSHED NUMBER                               1
  WATERSHED LABEL                           watersh

  OUTFLOW DEVICE NUMBER                          1 <-- for surface runoff

  AQUIFER DEVICE NUMBER                          0 <-- for percolation

  TOTAL AREA                 acres    100
  IMPERVIOUS FRACTION          -      .25
  DEPRESSION STORAGE        inches    .02
  SWEEPING FREQUENCY        1/week    0
  PERVIOUS CURVE NUMBER        -      74

  SCALE FACTOR FOR POLLUTANT LOADS 1


          watershed label

F1=HELP,  F2=DONE/SAVE,  F3=EDIT FIELD,  F7=HELP/EDITOR,  <ESC>=ABORT
```

```
PRESS <ESC> TO STOP SIMULATION
CASE TITLE = CASE 3: DESIGN A BMP
CASE FILE  = CASE_3.CAS
STORM FILE = type2.stm                                    DEVICES    =  1
KEEP STORM DATES:          0  --->       0                WATERSHEDS =  1

PASS    =   5/  5  STORM    =         1  DATE      =   690101
PRECIP  =    1.00  DURATION =        24  INTERVAL  =       75
KEEP    =       1
```

```
RUN TIME =        .055 MINUTES.  =      6.424 MINUTES/DEVICE/YEAR
calculating totals over all storms...
<H>
```

```
  removal efficiencies (%) vs. device and particle class
                          1       2       3       4       5
 device                  P0%    P10%    P30%    P50%    P80%
  1 dry pond              .0    42.5    86.9    97.6    99.8
 25 OVERALL               .0    42.5    86.9    97.6    99.8

 removal efficiencies (%) vs. device and water quality component
   device                tss      tp     tkn      cu      pb      zn      hc
  1 dry pond            85.3    49.3    41.3    41.3    74.9    41.3    74.9
 25 OVERALL             85.3    49.3    41.3    41.3    74.9    41.3    74.9
```

```
<H>
```

```
PRESS <ESC> TO STOP SIMULATION
CASE TITLE = CASE 3: DESIGN A BMP
CASE FILE  = CASE_3.CAS                            DEVICES.    =  1
STORM FILE = PROV6987.STM                          WATERSHEDS  =  1
KEEP STORM DATES:  800101  --->  801231

PASS    =  1/  1  STORM     =     109  DATE      =  801229
PRECIP  =     .45  DURATION  =      11  INTERVAL  =      75
KEEP    =       1

warning: device overflow:  1 dry pond, storm =   16









RUN TIME =      3.229 MINUTES.  =      3.212 MINUTES/DEVICE/YEAR
calculating totals over all storms...
<H>








removal efficiencies (%) vs. device and particle class
                     1       2       3       4       5
device              P0%    P10%    P30%    P50%    P80%
 1 dry pond          .0    46.8    84.1    95.3    99.4
25 OVERALL           .0    46.8    84.1    95.3    99.4

removal efficiencies (%) vs. device and water quality component
  device            tss      tp     tkn      cu      pb      zn      hc
 1 dry pond        85.0    53.3    45.9    45.9    76.8    45.9    76.8
25 OVERALL         85.0    53.3    45.9    45.9    76.8    45.9    76.8











<H>
```

APPENDIX D
Limitations/Uses Summary

P8 Urban Catchment Model
Limitations/Uses Summary

The following provides a summary of the existing model limitations, suggested future expansions or enhancements of the model, and guidelines for future monitoring efforts.

Model Limitations

1) Without calibration of the model to site specific , regional, or other nation-wide data sets, absolute predictions (e.g., concentrations, flows, loads) are less reliable than relative predictions (e.g., percent removal, percent change in load pre- and post-development).

2) The model does not directly account for chemical or biological pollutant removal mechanisms within treatment devices.

3) The model does not directly account for pollutant loads associated with individual sewage disposal systems (ISDS).

4) The model does not simulate pollutant loads from agricultural land uses.

5) The default particle parameters may have to be re-calibrated to predict NURP median runoff concentrations in regions outside of Rhode Island.

6) The model does not account for snowfall or snowmelt, but rather assumes all precipitation is in the form of rainfall.

7) The model does not provide ability to account for water import/export (i.e., withdrawls for irrigation or water supply, point source discharges, etc.) to or from a watershed.

8) The model does not simulate backwater effects or particle resuspension in treatment devices.

9) The model does not warn if BMP designs do not meet standard accepted design practices.

10) The model is not intended for use in flood control (water quantity) planning.

11) The model does not simulate thermal impacts of detention ponds.

12) Runoff predictions using the SCS Curve number for pervious areas and the SWMM method for impervious areas may underestimate the runoff from pervious areas, and over-estimate the runoff from impervious areas. While this makes the model predictions less "realistic", predictions are more conservative, and pollutant removal efficiencies in treatment devices are not affected.

Intended Uses

Given the above described limitations, the recommended uses of the P8 Urban Catchment Model (Version 1.1) are:

1) Evaluating site plans for compliance with treatment objectives, expressed in terms of removal efficiency for total suspended solids (e.g., 70%, 85% TSS removal, RIDEM 1988) or a single particle class.

2) In design mode, selecting and sizing BMP's to achieve a given treatment objective. The program automatically scales BMP;'s to user-defined watersheds, storm time series, target particle class, and targeted removal efficiency.

3) Comparing the relative (%) change pollutant loads under various build-out scenarios.

Use of the model to predict absolute changes in concentrations, flows or pollutant loads, for either site or watershed-scale level applications is not recommended without calibration of the model to site-specific or regional data. If such data is not available for calibration, the user should make conservative assumptions (e.g., indicative of a worse-case scenario) in input data requirements. Extreme caution must be used in interpreting absolute predictions from the uncalibrated model.

Future Model Enhancement/Expansion

Based upon the the above described limitations, and comments received during the review of the model and its documentation, the following expansions and enhancements of the P8 Urban Catchment Model are recommended for future versions for the model:

1) Incorporate modified procedures for computing pervious and impervious runoff as an option. The SCS method of predicting runoff from pervious areas may under-predict runoff from these areas, and the SWMM method may over-predict runoff from impervious areas. The computational modifications will increase input data requirements, require input data which are less familiar to users, provide less conservative BMP designs, and depart from conventional procedures.

2) Modify the model to permit specification of multiple particle/component matrices.

3) Modify the model to account for backwater effects in treatment devices, or at a minimum to issue a warning to the model user if backwater effects occur during the course of the simulation.

4) Investigate and possibly modify the device simulation methods to account for particle resuspension to improve simulation of dry ponds and swales.

5) Investigate alternative methods for simulating particle and contaminant behavior in devices, particularly using second-order kinetics.

6) Develop a software link between GIS and the P8 model to facilitate usage of the model in watershed-scale applications.

7) Calibrate/test the model against measured flow and water quality data from small urban watersheds in the region; Test stimulations of within-event and among-event variations in runoff volume and load above, and below treatment devices; Measure particle size distributions and settling velocities in runoff samples.

8) Expand the model to provide a mechanism to account for water import and export for watershed-scale applications.

9) Add check lists of engineering guidelines for BMP design to the help screens; develop an applications handbook to demonstrate how the P8 model can be used in combination with engineering guidelines to design treatment facilities.

10) Modify pervious watershed load simulations to include the Universal Soil Loss Equation.

11) Add flood routing capability, testing against TR-20 or other existing flood routing models.

12) Modify the model to simulate winter conditions in watershed and device simulations, including frozen ground, snowfall,and snowmelt.

Monitoring for Model Calibration

It is typically cost-prohibitive to collect sufficient water quality and discharge data for site-specific calibration of the model. In addition, in calibrating the model to predict future (post-development) conditions, it is not possible to sample post-development conditions prior to development of a specific site. Therefore, a regional calibration approach may be desirable. The following are guidelines are recommended for consideration in developing a regional calibration data set:

1) Data collection efforts would include pre- and post- development monitoring at various sites throughout the region; or monitoring of a sufficient number of existing developed sites (with and without stormwater management systems) with varying land use and soils characteristics.

2) Several storm events, of varying intensity and duration, should be monitored.

3) Monitoring should include continuous flow (discharge) measurements throughout the duration of each storm event.

4) Samples for water quality analysis should be collected at discrete time intervals throughout the duration of the storm, including first flush.

5) Water samples should be analyzed for total suspended solids and other water quality constituents of interest. Samples should also be analyzed for particle distribution, particle settling velocities, and contaminant distribution among the various particle fractions. Ideally, analyses should be performed on discrete samples to document within event variability. However, flow-weighted composite samples would also provide valuable information.

6) Monitoring locations should be included above, within, and below treatment devices.

P8
URBAN CATCHMENT MODEL
Program Documentation
Version 1.1

prepared for

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and

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October 1990

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P8

URBAN CATCHMENT MODEL

Program for Predicting Polluting Particle Passage
Thru Pits, Puddles, & Ponds

ABSTRACT

P8 is a model for predicting the generation and transport of stormwater runoff pollutants in urban watersheds. Continuous water-balance and mass-balance calculations are performed on a user-defined system consisting of the following elements:

- WATERSHEDS	(nonpoint source areas)
- DEVICES	(runoff storage/treatment areas, BMP's)
- PARTICLE CLASSES	
- WATER QUALITY COMPONENTS	

Simulations are driven by continuous hourly rainfall and daily air temperature time series. The model has been developed for use by engineers and planners in designing and evaluating runoff treatment schemes for existing or proposed urban developments. The model is initially calibrated to predict runoff quality typical of that measured under the EPA's Nationwide Urban Runoff Program (Athayede et al., 1983) for Rhode Island rainfall patterns. Predicted water quality components include suspended solids (five size fractions), total phosphorus, total Kjeldahl nitrogen, copper, lead, zinc, and total hydrocarbons.

Primary applications include site BMP design to achieve total suspended solids removal efficiencies (70% or 85%) recommended by the Rhode Island Department of Environmental Management (1988). Simulated BMP types include detention ponds (wet, dry, extended), infiltration basins, swales, and buffer strips. Hydrologic components of the program are calibrated and tested against six years of daily streamflow data from the 15,000-acre Hunt-Potowomut watershed, Rhode Island. The model is used to examine the water quality implications of alternative treatment objectives.

Inputs are structured in terms which should be familiar to planners and engineers involved in hydrologic evaluation. Several tabular and graphic output formats are provided. The computer program runs on IBM-PC compatible microcomputers. This report documents the structure, calibration, testing, potential uses, and limitations of the program. A companion report (P8 Urban Catchment Model - User's Manual, IEP Inc., 1990) provides an overview and several example applications.

1.0 INTRODUCTION

1.1 Overview

P8 is a model for predicting the generation and transport of stormwater runoff pollutants in urban catchments. Continuous water-balance and mass-balance calculations are performed on a user-defined system consisting of the following elements:

- **WATERSHEDS** (nonpoint source areas)
- **DEVICES** (runoff storage/treatment areas, BMP's)
- **PARTICLE CLASSES**
- **WATER QUALITY COMPONENTS**

Simulations are driven by continuous hourly rainfall and daily air temperature time series. The model has been developed for use by engineers and planners in designing and evaluating runoff treatment schemes for existing or proposed urban developments. This report documents the structure, calibration, testing, potential uses, and limitations of the program.

P8 is short for "Program for Predicting Polluting Particle Passage through Pits, Puddles & Ponds". It consists primarily of algorithms derived from other urban runoff models (e.g., SWMM, STORM, HSPF, D3RM, TR-20). Unique features include:

(1) minimal requirements for site-specific input data, typically available from drainage plans, soil surveys, and other local sources;

(2) expression of input data in terms which should be familiar to local engineers and planners who normally deal with hydrologic aspects of urban developments;

(3) initial calibration of certain water-quality parameters (particle settling velocities, particle buildup/washoff parameters, particle contaminant contents) so that predicted runoff concentrations correspond to median (50th percentile) or extreme (90th percentile) values measured under the EPA's Nationwide Urban Runoff Program (NURP, Athayede et al., 1983); these parameters may be modified by the model users with alternative bases for calibration;

(4) capability for simulating a variety of treatment devices, including swales, buffer strips, detention ponds (dry, wet, extended), flow splitters, infiltration basins (offline, online);

(5) extensive user interface, including interactive operation, spreadsheet-like menus, help screens, and high-resolution color graphics.

The program runs on IBM-PC-compatible microcomputers. Computers equipped with 80286 processors (AT-class or higher) and numeric coprocessors are recommended.

1.2 Limitations of P8 and Other Urban Runoff Models

Results of the Nationwide Urban Runoff Program indicate that runoff quality is highly variable from site-to-site and from storm-to-storm at a given site (Athayede et al., 1983). The availability of calibration data limits the accuracy and use of urban runoff water quality models (Huber, 1986). Site-specific runoff quality data sufficient for model calibration purposes are generally not available to the engineer/planner, particularly when dealing with future developments. By relying upon generalized data sources for calibration of certain key parameters, this model does not "solve" data availability problems, but it does provide a reasonable starting point for calibration and a consistent frame of reference for evaluating proposed developments with respect to compliance with local treatment guidelines.

One important concept is that runoff model predictions are more accurate in a **relative** sense than in an **absolute** sense (Huber, 1986). For example, because it is independent of assumed runoff concentrations, prediction of suspended solids removal efficiency in a detention pond is likely to be more accurate than predictions of inflow or outflow concentrations of suspended solids or other water quality components. Removal efficiency depends upon the distribution of particle settling velocities (as estimated from NURP studies; Driscoll, 1983; USEPA, 1986) in relation to the hydraulic characteristics of the treatment device (area, depth, overflow rate, hydraulic residence time). These relationships are simulated by the physically-based model. Predicted removal efficiencies are independent of assumed inflow concentrations, which are highly variable from site-to-site.

Predictions of total suspended solids (TSS) removal efficiency are useful for evaluating the adequacy of urban runoff water quality controls proposed for a given development. For example, the Rhode Island Department of Environmental Management (1988) has proposed that BMP's in new urban developments be designed to provide average TSS removal efficiencies of 85% in "sensitive" areas (e.g., watersheds of water supply reservoirs, coastal ponds) and 70% in "non-sensitive" areas. P8 is designed for evaluating site compliance with these guidelines or others expressed in terms of a target removal efficiency for a specific particle class or water quality component.

Because of data limitations and site-to-site variations in the factors controlling runoff quality, absolute predictions generated by the model (inflow and outflow concentrations, loadings, violation frequencies) are more likely to deviate from actual conditions at a given site than are relative predictions of removal efficiency. Conservative input values (e.g., NURP 90th percentile concentrations) can be used to generate worst-case projections of contaminant concentrations and loadings, but these values should be interpreted cautiously because they may considerably over-estimate contaminant levels at specific sites.

The difficulties and potential errors associated with predicting absolute values at a given site may not be large a problem in a planning context, because it is generally impossible to evaluate the downstream water quality implications of over-predicting or under-predicting contaminant loadings from a specific development. Over a large number of sites, absolute predictions based upon the NURP 50th percentiles are expected to provide more accurate assessments, although significant regional biases in absolute predictions may still exist. Calibration of model parameters to regional runoff monitoring data should help to reduce local biases.

Another limitation of this and other urban runoff models is that water quality predictions are developed by assigning contaminant contents (mg/kg) to particle fractions. The only removal mechanisms directly simulated by the model are sedimentation and filtration. Filtration occurs when water infiltrates into the soil. Biological and/or chemical mechanisms for contaminant removal in treatment devices are not directly considered. Given adequate data, however, such mechanisms could be considered to the extent that they can be represented by the kinetics formulations included in the model (filtration, first-order settling, first-order decay, second-order decay).

1.3 Intended Uses

Based upon the above considerations, the model is intended primarily for making "relative" predictions:

(1) Evaluating site plans for compliance with treatment objective, expressed in terms of removal efficiency for total suspended solids or a single particle class. (e.g.,70%, 85% TSS removal, RIDEM, 1988);

(2) In a design mode, selecting and sizing BMP's to achieve a given treatment objective. The program automatically scales BMP's to match user-defined watersheds, storm time series, target particle class, and target removal efficiency.

These applications are insensitive to errors associated with predicting untreated runoff water quality and are therefore more accurate than predictions of concentrations or loads. Note that a treatment objective (removal efficiency and particle class) must be defined by the user. Section 8.0 discusses treatment objectives.

Secondary uses of the model are for making "absolute" predictions of the following types:

(1) Predicting runoff water quality, loads, violation frequencies;

(2) Predicting water quality impacts due to proposed developments (e.g., upstream vs. downstream changes, existing vs. future changes);

(3) Generating loads for driving receiving water quality models;

(4) Watershed-scale or basin-scale landuse planning (e.g., zoning issues).

These applications are subject to greater error because of the high degree of site-to-site and storm-to-storm variability associated with urban runoff quality. Local calibration may reduce absolute prediction error, but is rarely feasible.

2.0 PROGRAM MECHANICS

P8 runs on an IBM-PC or compatible microcomputer with 640K memory, hard disk, and MS-DOS operating system. To speed computations, an AT (80286 processor) or higher class with a numeric coprocessor is recommended. The program and sample input files occupy approximately 1.2 megabytes of disk space. An additional 1 megabyte of disk space is recommended for working files (more for long simulations). Typical run times are on the order of .4 to 3 minutes per device per year of storms simulated for AT or higher class machines with numeric coprocessors. The program is written in FORTRAN-77 and compiled using the Microsoft, Inc. Version 5.0 optimizing compiler (emulator library). Supporting subroutine libraries (graphics, screen control, character manipulation) include ASMUTIL2 and BUTILE from Impulse Engineering, San Francisco.

The structure and capabilities of the program are summarized in the Appendices to this report:

APPENDIX A - **Menu Structure**
APPENDIX B - **Data Entry Screens**
APPENDIX C - **Output Screens**
APPENDIX D - **Help Screen Index**

Appendix E contains step-by-step procedures for installing the program, running sample problems or "CASES", entering new cases, and using the program for designing BMP's.

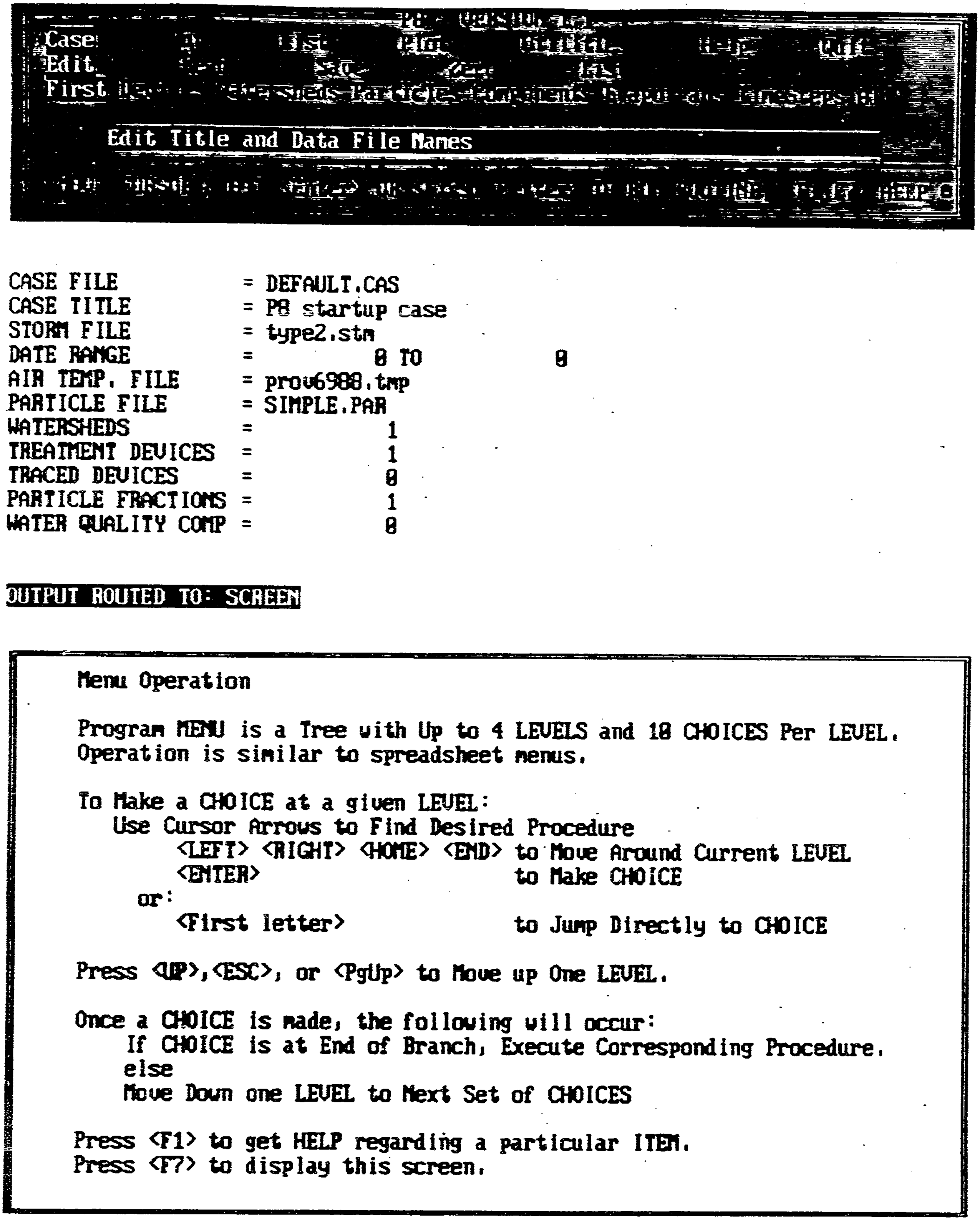
The program is operated from a MENU, which occurs in a blue box at the top of the screen, as illustrated in Figure 1. The bottom portion of the menu screen describes the current case. The menu provides access to ~120 program functions, as outlined in Appendix A. Major menu headings include:

'Case' - Enter, Edit, Read, List, or Save Input Data
'Run' - Execute Model
'List' - List Output (Several Formats)
'Plot' - Plot Output (Several Formats)
'Utilities' - Supplementary Functions
'Help' - View Help Screens
'Quit' - End Session and Return to DOS

Operation is similar to a spreadsheet. Cursor arrows can be used to maneuver around the menu. A faster method is to enter the first letter associated with the desired choice at each menu level (e.g., 'CEDI' - 'Case Edit Device Index'). Press <F7> to get help on menu operation.

HELP SCREENS provide online documentation for the program. These are accessed by pressing the HELP KEY <F1> from the main menu, edit screens, or data-entry screens. To view a help screen for any procedure in the

Figure 1
P8 Main Menu Screen



```
CASE FILE           = DEFAULT.CAS
CASE TITLE          = P8 startup case
STORM FILE          = type2.stm
DATE RANGE          =         0 TO          0
AIR TEMP. FILE      = prov6988.tmp
PARTICLE FILE       = SIMPLE.PAR
WATERSHEDS          =         1
TREATMENT DEVICES   =         1
TRACED DEVICES      =         0
PARTICLE FRACTIONS  =         1
WATER QUALITY COMP  =         0

OUTPUT ROUTED TO: SCREEN
```

```
Menu Operation

Program MENU is a Tree with Up to 4 LEVELS and 10 CHOICES Per LEVEL.
Operation is similar to spreadsheet menus.

To Make a CHOICE at a given LEVEL:
   Use Cursor Arrows to Find Desired Procedure
        <LEFT> <RIGHT> <HOME> <END> to Move Around Current LEVEL
        <ENTER>                     to Make CHOICE
    or:
        <First letter>              to Jump Directly to CHOICE

Press <UP>,<ESC>, or <PgUp> to Move up One LEVEL.

Once a CHOICE is made, the following will occur:
    If CHOICE is at End of Branch, Execute Corresponding Procedure.
    else
    Move Down one LEVEL to Next Set of CHOICES

Press <F1> to get HELP regarding a particular ITEM.
Press <F7> to display this screen.
```

main menu, move the cursor to that procedure and press <F1>. To view a help screen for any output screen, press <F1> in response to screen hold <H> prompt in lower left-hand corner. In addition, help screens are accessed from the 'Help' selection on the menu, or by running the independent utility 'HELP.EXE' from DOS. These utilities permit the user to view help screens in groups, organized by topic, or to search the help file for all screens containing a user-defined phrase.

The program runs in either of two USER MODES, depending upon the user's level of experience:

NOVICE MODE
ADVANCED MODE

The NOVICE MODE (default) provides access to basic program functions but prevents access to supplementary functions which new users may find relatively difficult to follow. The number of choices available from the program menu is limited. The ADVANCED MODE provides access to all functions and options. At startup, the program is set to NOVICE MODE. To change to ADVANCED MODE (or vice-versa), press <SHIFT><F1> keys simultaneously from any location in the program menu. A message will appear indicating the new mode. Press any key to continue. A symbol in the lower right hand corner of the menu box indicates the user mode (☺ = NOVICE MODE, ● = ADVANCED MODE). Appendix A indicates procedures which are available in each mode.

3.0 MODEL INPUTS

Input data for each model application or "**CASE**" are specified on input screens described in Appendix B. Each CASE has the following maximum dimensions:

24 WATERSHEDS
24 DEVICES
5 PARTICLE CLASSES
10 WATER QUALITY COMPONENTS

General features of these input groups are described below.

3.1 Watershed and Device Characteristics

WATERSHEDS are the sources of flow and particles simulated by the program. They are defined based upon factors controlling runoff and particle export (total area, impervious fraction, depression storage, SCS curve number for pervious areas, street-sweeping frequency). The model simulates runoff from pervious and impervious surfaces and particle buildup/washoff from impervious surfaces. Watershed runoff and percolation can be routed to specified DEVICES.

DEVICES provide collection, storage, and/or treatment of watershed discharges. Devices are defined based upon factors controlling hydraulic response and particle removal efficiency (elevation/area table and elevation/discharge tables for up to three outlets (1 = infiltration, 2 =

normal outlet, 3 = overflow/spillway). Specific inputs vary with device types, as illustrated in Figure 2:

1 = **Detention Pond (Wet, Dry, Extended)**
2 = **Infiltration Basin (Online, Offline)**
3 = **Swale/Buffer (Overland Flow Area)**
4 = **General (User-Defined Elev/Area/Outflow Table)**
5 = **Pipe/Manhole (Collector with One Outlet)**
6 = **Splitter (Collector with Two Outlets)**
7 = **Aquifer (Approx. Groundwater Budget, Baseflow Calc.)**

Routing from one device to another is accomplished by specifying downstream device numbers for each outlet. A downstream device number of 0 is used to route flow and loads out of the system (to receiving waters). The linkage of watersheds and devices is illustrated in Figure 3. The program keeps track of volume and mass fluxes into and out of each device, as well as changes in storage. Program output formats (tables, graphs) summarize this information in various ways.

3.2 Particle and Water Quality Component Characteristics

PARTICLE CLASSES are defined based upon factors controlling watershed export (accumulation/washoff parameters for impervious areas, fixed runoff concentrations for pervious and/or impervious areas, street-sweeping efficiency) and behavior in treatment devices (settling velocity, decay rates, filtration efficiency).

WATER QUALITY COMPONENTS are defined based upon their weight distributions across particle classes (mg/kg). Three standards or criteria may be specified for each water quality component. These can be used to estimate violation frequencies, based upon comparison with the frequency distributions of event-mean outflow concentration for any device and storm sequence.

Default values for PARTICLE CLASSES and WATER QUALITY COMPONENTS are provided, based upon calibration to "typical urban runoff" values measured under the EPA's Nationwide Urban Runoff Program (Athayede et al, 1983). The following WATER QUALITY COMPONENTS are considered in the default calibrations: total suspended solids, total phosphorus, total Kjeldahl nitrogen, lead, copper, zinc, hydrocarbons. Section 6.0 of this report describes the default calibrations. They may be modified by the user to reflect site-specific measurements and/or alternative modeling assumptions.

To load a particle/component input file from the main menu, type 'CRP' (Case Read Particles) and press <Enter>. A list of available particle files will appear. Use the cursor arrows or space bar to point to desired file name, and press <Enter>. The following sample input files containing particle and water quality component parameters are provided:

NURP50.PAR
distribution of particle settling velocities derived from NURP studies (USEPA, 1986); component concentration calibrated to NURP 50th percentile (median) sites (Athayede et al, 1983).

Figure 2

P8 DEVICE TYPES

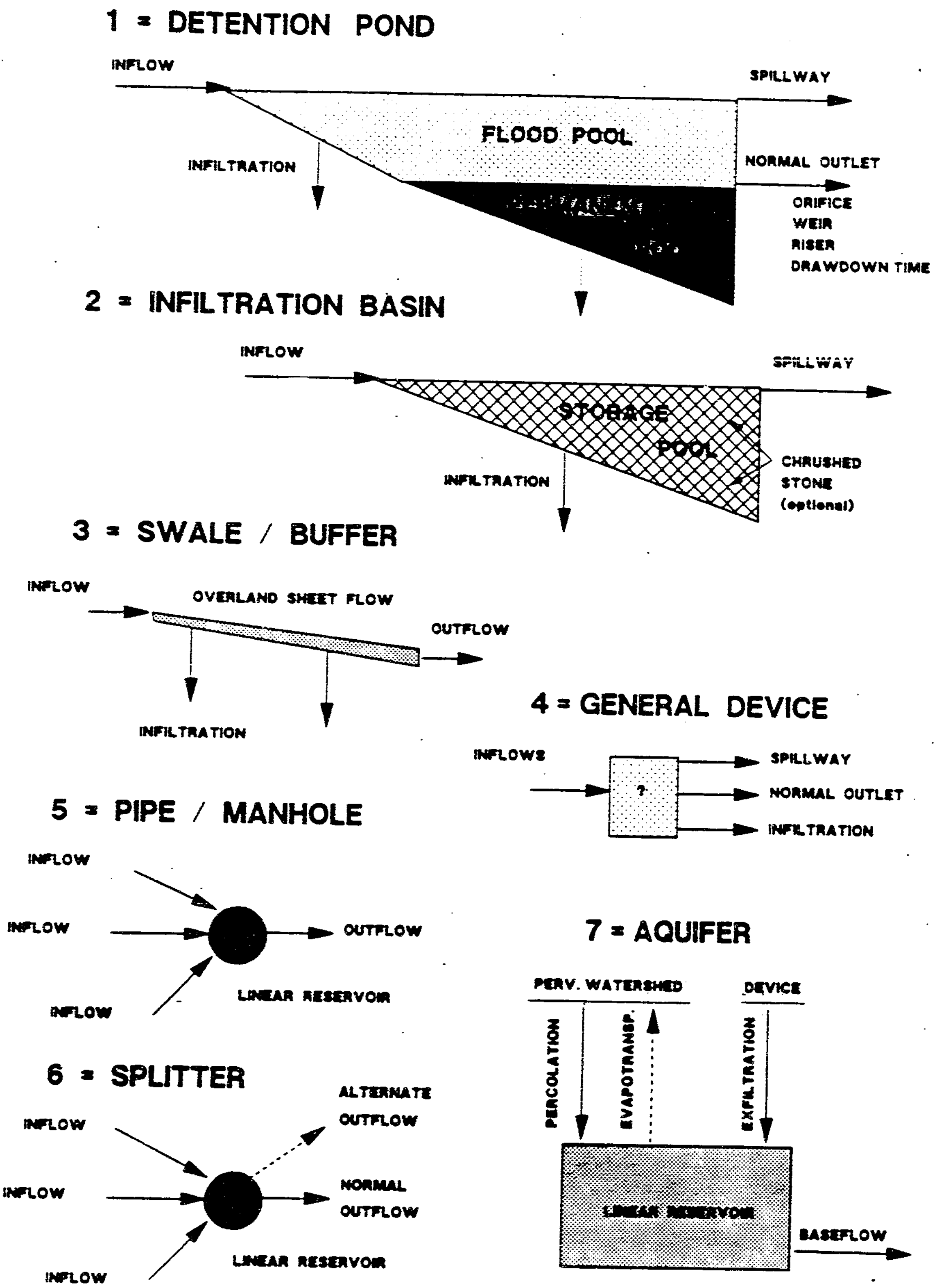
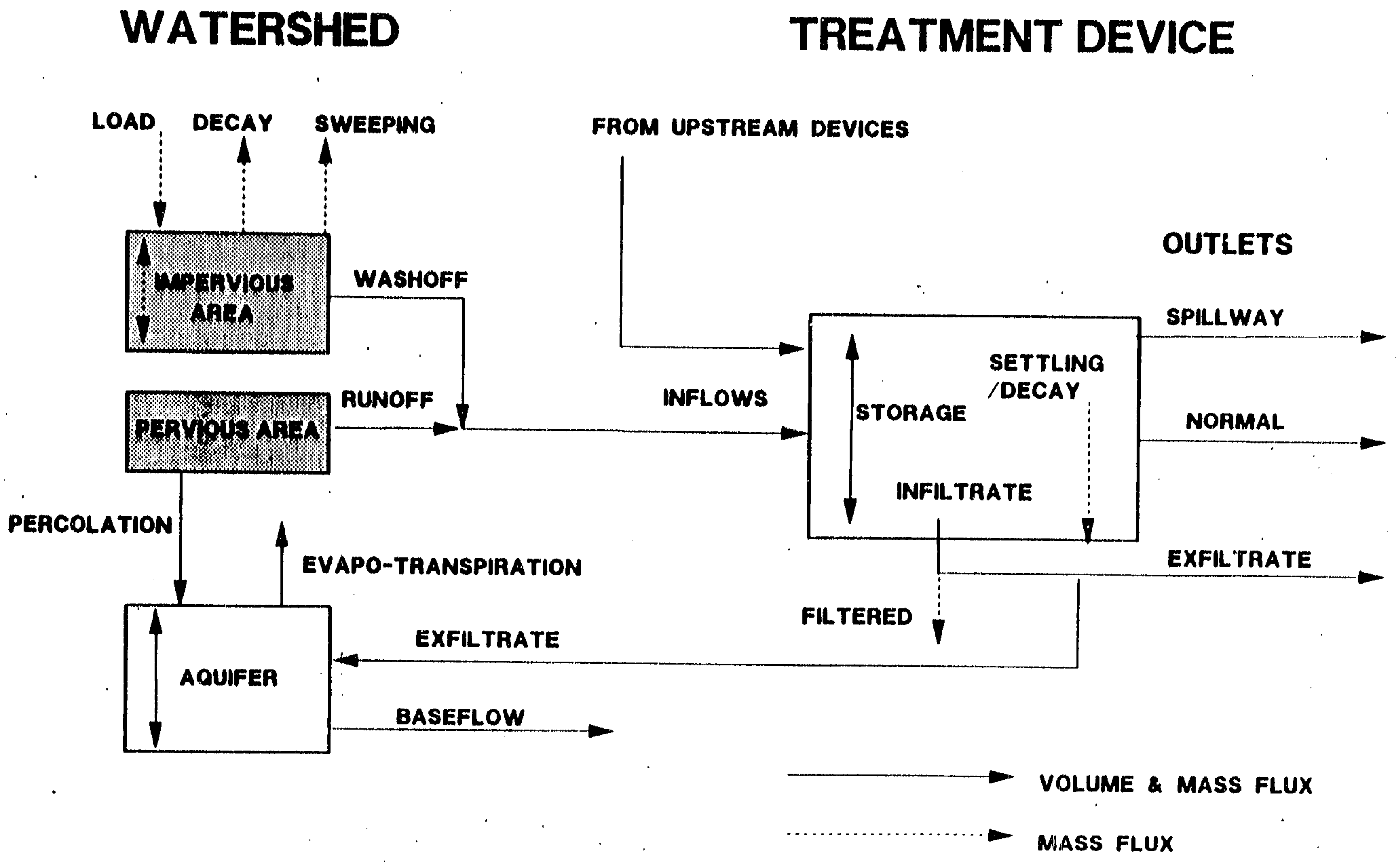


Figure 3

P8 MASS-BALANCE SCHEMATIC



NURP90.PAR
same as NURP50.PAR, except component concentrations calibrated to NURP 90th percentile sites; these will generally predict runoff concentrations which are 2-3 times higher than those predicted by NURP50.PAR.

SIMPLE.PAR
a simple case (one particle class = NURP 10th percentile setting velocity) for preliminary runs; requires less run time than other files, which include five particle classes; runoff treatment criteria may be based upon a single particle class (See Section 8.0).

BARESOIL.PAR
NURP50.PAR with pervious runoff parameters adjusted to give TSS concentrations typical of runoff from construction sites (~10,000 ppm, Schueler, 1987).

Any additional particle input files are listed and described in the 'PARTIC.DOC' file contained on the distribution disk.

3.3 Precipitation and Air Temperature

The distribution diskette contains precipitation and air temperature measurements from Providence Airport. Runoff simulations are driven by hourly precipitation time series, summarized on a storm-event basis. A routine is provided to convert hourly precipitation files available from the National Climatic Data Center for any NOAA Weather Station into the appropriate format. There is no limit (except for disk storage capacity) on the length of rainfall files. Longer files and larger cases will naturally require more computer time.

The following input files containing storm event sequences for use with the model are provided:

PROV##.STM
yearly file from Providence Airport
= year type (see Section 7.4)
= 65, 81 "dry years"
= 74, 76, 80 "average years"
= 79, 83 "wet years"
= 6987 1969 thru 1987

TYPE2.STM
24-hour, SCS Type 2 Storm, 1-inch, 75-hr interval
Longterm average TSS removal efficiencies can be estimated by running this storm file (see Section 7.4).

AVERAGE.STM
one average storm, .4 inches, 6-hr duration, 75-hr interval

The desired file name is entered in the first case input screen; from the main menu, type 'CEF' (Case Edit First). Any additional storm input files are listed and described in the 'STORMS.DOC' file contained on the distribution diskette.

Before starting a simulation, model state variables (particle buildup on impervious watershed surfaces, device storage volumes, device concentrations) are initialized. In order to purge effects of initial conditions, it is necessary to run the model for a number of storms before saving results. This is done by specifying the following dates on the first 'CEF' input screen:

START DATE (YYMMDD format)
KEEP DATE "
STOP DATE "

The storm file **'PROV6987.STM'** can be specified for simulating any date interval between 1969 and 1987, inclusive. The model skips storms in the specified storm file until the START DATE is encountered, at which point the simulation begins. If the START DATE = 0, simulation begins with the first storm contained in the storm file. Simulation continues (but without saving results) until the specified KEEP DATE is encountered, on and after which results are saved. If KEEP DATE = 0, all simulation results are saved. The simulation continues until the STOP DATE is encountered, or until the end of the storm file, whichever occurs first.

The minimum duration of the startup period (KEEP DATE - START DATE) depends upon the storage or "memory" of the devices included in the simulation. A month is usually more than adequate for simulating runoff treatment devices. Cases involving aquifers or other devices with long times of concentration would require longer warmup periods to flush out initial conditions (at least >= time of concentration). When in doubt, sensitivity to startup period can be investigated on a case-by-case basis (e.g., compare removal efficiencies computed with 1-month vs. 2-month startup period for same KEEP and STOP DATES).

As alternatives to real rainfall sequences, single 'design storms' can also be simulated. These are defined based upon an hourly rainfall sequence, followed by a specified dry-weather period. Examples are 'TYPE2.STM' and 'AVERAGE.STM'. When using a design storm, set the START DATE, KEEP DATE, and KEEP DATE to 0. To purge initial conditions, the design storm can be repeated for a specified NUMBER OF PASSES. Results are saved only on the last PASS. Five PASSES are usually adequate for simulating runoff treatment schemes using TYPE2.STM (1-inch, 24-hr storm with 51-hour dry-weather period). Effects of alternative PASSES can be easily checked by adjusting the input value and re-running the model.

Air temperature data are required only if the device network includes an AQUIFER (TYPE=7) for simulation of baseflow. The daily air temperature record for Providence Airport between 1969 and 1988 is contained in the file 'PROV6988.TMP'. This file is specified on the evapotranspiration input screen ('CEE' = 'Case Edit Evapotrans'). Specification of daily air temperature data is transparent to the model user, as long as storm dates between 1969 and 1988 are simulated. If storm dates are outside of this range or if the air temperature file is not specified, longterm monthly mean air temperatures are used, as defined on the evapotranspiration input screen.

3.4 Sample Case Files

The program distribution disk contains a number of sample input files which illustrate various model applications and can serve as templates for building new applications. The **'CASES.DOC'** file contains an updated list and description of sample cases. Running sample cases is recommended before attempting to define and enter new cases. To load a sample case file from the main menu, type 'CRA' ('Case Read All'), press <Enter>, use cursor or space bar to point to desired input file, and press <Enter>. Sample input files describe simple cases for program demonstration purposes:

DEFAULT.CAS
simple case for preliminary testing one watershed, one device (wet pond), one particle class; automatically read when program is first loaded.

TEST.CAS
illustrates each type of treatment device; many devices are run simultaneously in parallel; each device has same watershed characteristics

The following case input files describe actual stormwater control systems under design/operation in New England:

TRACER.CAS
One Tracer Lane Development, Lexington, MA
Offline Infiltration Basin, Detention Pond in Series

ESM_L.CAS
Emerald Square Mall, N. Attleborough, MA
Lower Watershed
2 Detention Ponds, Swale, 3 Wetland Cells in Series

ESM_U.CAS
Emerald Square Mall, N. Attleborough, MA
Upper Watershed
Detention Pond, 3 Wetland Cells in Series

HUNT.CAS
Hunt-Potowomut River, Narragansett Bay, RI
Watershed-Scale Application, with Baseflow Simulation

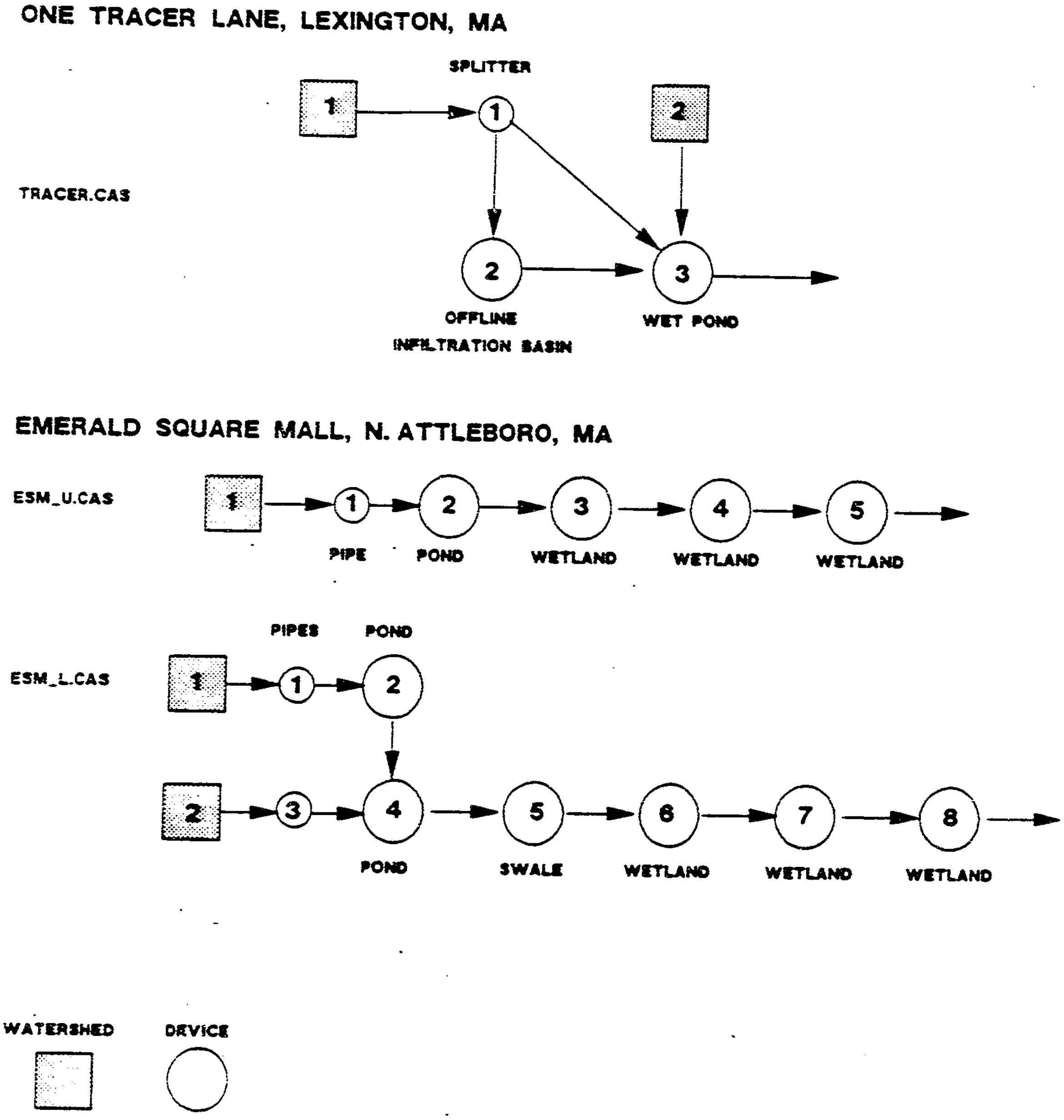
Schematic diagrams for selected cases are shown in Figures 4.

3.5 Entering New Cases

Appendix E outlines recommended procedures for defining and entering a new case. The process is facilitated by first constructing a schematic diagram of the site which illustrates the linkage of watersheds and treatment devices (similar to diagrams used in TR-20 applications).

Figure 4

SCHEMATIC DIAGRAMS - P8 TEST CASES



Appendix B illustrates the screens which are used to enter or edit data. Help screens designed to assist the user in estimating various input values (curve numbers, infiltration rates, etc.) are also printed in Appendix B. Data entry/editing is performed using the following commands:

COMMAND	**DATA GROUP**
CEF	Case Title & Storm File
CEDI	Device Index
CEDD	Device Data (Separate Screen for Each Device Type)
CEWI	Watershed Index
CEWD	Watershed Data (Separate Screen for Each Watershed)
CEE	Evapotranspiration Parameters (Optional)
CET	Simulation Time Steps
CEP	Particle Characteristics
CECF	Water Quality Components

Editing of particle and water quality component input data is permitted only in the program's ADVANCED USER MODE; press <Shift-F1> to switch user modes.

A HELP SCREEN (shown on the bottom of each page in Appendix B) provides online documentation for each data entry screen. Help screens are accessed by pressing <F1>. In addition, a one-line help message appears at the bottom center of each data-entry screen and refers to the current cursor location. More detailed help on certain data input values (e.g., infiltration rates, Curve Numbers, Manning's n) are accessed by pressing <F8> when pointing to the input field on a data-entry screen. Some input fields are checked for valid ranges and warning messages are flashed accordingly. To access the program's general HELP utility from a data entry screen, press <F9>.

Input data can be listed using the 'CLS' (= Case List Site) command, stored in a disk file using 'CSI' (= Case Save Inputs), and subsequently retrieved using 'CRA' (= Case Read All).

In order to track results for each time step, devices must be **TRACED**. Trace switches are set using the 'UT' = 'Utilities Trace' command (ADVANCED USER MODE). Tracing is not required unless plotting of within-event variations or daily-average values is desired. Since tracing consumes disk space and computer time, devices should be traced only when necessary.

Once the input data have been entered for a given case, the model must be executed via the 'RM' (= 'Run Model') command. Input values are checked for validity and error messages (if any) are issued. The sequence of storms is tracked on the screen until the simulation is completed. A red message 'MODEL EXECUTED' appears in the lower right corner of the menu screen to indicate that the simulation is complete.

When the model is executed for a given set of input values and storm sequence, results are saved in temporary disk files for subsequent use by listing and plotting routines. Stored values normally include event total flows and loads for each device, particle class, and mass-balance term. Output routines (tables, graphs) are accessible from the menu as long as the "MODEL EXECUTED" message appears. This message disappears when input values are edited or when a new case is loaded from disk.

To store output values on disk for later retrieval and review, use the 'Case Save Archive' command. This saves both the input and the output values for the current case. Use 'Case Save Inputs' to save input values only. The archive format consumes more disk space but permits future review of output without re-running the simulation.

4.0 MODEL OUTPUTS

4.1 Simulation Results

Simulation results are stored in temporary disk files for access by reporting and graphing routines. Tabular output formats include the following:

BALANCES - water and mass balances by device and component

REMOVALS - removal efficiencies by device and component

TERMS - comparison of flow, loads, and concs. across devices

VIOLATIONS - violation frequencies for event-mean concentrations

PEAKS elevation and outflow ranges for each device

SEDIM sediment accumulation rates by device

MEANS - mean inflow or outflow concs by device and component

DETAILS - detailed statistical summaries by device and component

CONTINUITY - continuity (mass-balance) check on simulation results

Tabular output may be displayed on the screen or routed to a disk file for subsequent printing or other use (see 'UO' = 'Utilities Output').

Graphic output (to screen only) is available in the following formats:

EVENTS	precip., flows, loads, concs., etc., in 5 formats: time series cumulative time series (running totals) cumulative frequency distributions lognormal frequency plots scatter plots
DAILY	time series of daily total precip., volumes, or flows (available for TRACED devices only)
MONTHLY	time series of monthly total precip., flows, or loads
YEARLY	time series of yearly total precip., flows, or loads

TRACED detailed time series of precipitation, elevation, volume, discharge, concentrations, or loads for specific devices.

Independent screen-dump utilities may be used to print screen displays. (See 'Help - Program Operation - Printing Graphs' for a list of such utilities). Plot data may be dumped to disk in ASCII format convenient for input to spreadsheets or word processors (Press "d" when viewing graphic screen). Graphic routines have been developed primarily for use in model development and testing. Advanced users will find these routines helpful for developing an understanding of the hydraulic and water quality dynamics of individual cases. Graphic routines are accessible only in the ADVANCED USER MODE <Shift-F1>.

Appendix C illustrates tabular and graphic output formats. Help screens associated with each output screen (shown on the right in Appendix C) and are accessed by pressing <F1> in response to the screen hold prompt <H> which appears in the lower left hand corner of the screen. Aside from holding the screen and providing help access, the <H> prompt provides a way of stopping execution of a current procedure. Some output procedures produce several screens in series; to stop the output sequence and return to menu, press <Esc> when the <H> prompt occurs. In general, the <Esc> key (sometimes hit more than once) provides the fastest route back to the program menu.

4.2 Design Functions

The model can be used in a "design mode" to select and size devices appropriate for treating runoff from specified watershed(s). Appendix E contains step-by-step procedures for using the program in a design mode.

One procedure ('RDL' = 'Run Design Lookup') selects and sizes a device to achieve ~70% or ~85% total suspended solids removal for one user-defined watershed. To use this routine, a valid case with at least one watershed and one device must be pre-defined. The program disk contains a catalogue of devices sized to achieve total suspended solids removal efficiencies of 70% and 85%, based upon simulation of Providence 1980 rainfall data (see Sections 7.4 and 8.0, Figure 24, Tables 8-9). Devices are defined based upon type (wetpond, buffer, etc.) and other factors determining TSS removal (mean depth, flood pool drawdown time, infiltration rate, etc.).

The user specifies the watershed to be treated, the device prototype, and the location (device number) for the new device (overwrites any pre-defined device). To size the device for the specified watershed, device areas and volumes are rescaled based upon ratio of device area to impervious watershed area. This represents an "initial guess" of design requirements for a particular watershed, device type, and TSS removal objective. This design can be modified to suit site characteristics and constraints. Performance can be estimated using the 'RM' (= Run Model) command.

Another procedure ('RDT' = 'Run Design Tune') tunes or rescales device(s) to achieve a user-defined removal efficiency for any particle class or water quality component. In order to use this procedure, the user must first define a case containing a preliminary design and execute it via the 'Run Model' command. The user is prompted for the list of devices to be rescaled, target particle class, and target removal efficiency. Rescaling options include areas, volumes, and outlet capacities (for detention ponds only). The model is run repeatedly using the specified storm sequence. An iterative solution is attempted for the device SCALE FACTOR, using the Newton-Raphson technique (Burden et al., 1981). Device dimensions are multiplied by the SCALE FACTOR to achieve the target removal efficiency. Solutions are not always feasible. A maximum of 12 iterations is performed.

4.3 Sensitivity Analysis

Another procedure ('RS' = 'Run Sensitivity') tests sensitivity of removal efficiency and device outflow concentration to each model input value. Each input value is increased by a fixed percentage (one at a time). The model is re-executed. Effects on removal efficiency and outflow concentration are tabulated. Tested inputs include watershed variables, device variables, particle parameters, and storm scale factors. This procedure is especially useful for obtaining perspectives on which model inputs have the greatest impact on model predictions and are therefore most important to estimate accurately (Walker, 1982). Calculations may be lengthy; overnight computer runs may be convenient. Trial runs on short storm sequences are recommended. The procedure can be stopped at any time by pressing <Esc>.

Because it has a maximum feasible value of 100, the SCS curve number (used for predicting runoff from pervious watersheds) is treated differently than other input values in the sensitivity analysis. Instead of increasing the curve number by 25% (which may lead to curve numbers exceeding 100), the corresponding value for the maximum soil moisture retention (= 1000/CN-10, inches, USDA/SCS(1964)) is decreased by 25%.

4.4 Flow Calibration

Calibration of the model to predict measured daily flow time series is facilitated by the 'RC' (= 'Run Calibrate') command. This procedure compares predicted daily-mean outflow time series from a specified device with measured values contained in a disk file. Observed flow data are stored in free-format, ASCII files, one line per month (example = 'HUNT.FLO'). The model must be executed beforehand ('RM' command) and the device used in the calibration must be traced in order to obtain daily output values ('UT' = 'Utilities Trace' command). The program merges observed and predicted daily flows by date. Moving averages are calculated at a user-defined interval. Observed and predicted time series are plotted and compared statistically. Flow calibration typically involves adjusting times of concentration (for surface runoff and baseflow) to match observed time series for short (1-day) and long (e.g. 30-day) averaging intervals. Application to the Hunt-Potowomut watershed is described in Section 7.3. This procedure is not relevant to designing BMP's for individual developments.

5.0 SIMULATION METHODS

5.1 Watershed Runoff Volumes

Runoff from pervious areas is computed using the SCS curve number technique (USDA,1964). Haith and Shoemaker (1987) demonstrate use of the SCS method for continuous watershed simulations. Antecedent moisture conditions (AMC's) are adjusted based upon 5-day antecedent precipitation and season. In calculating AMC's, the "growing season" is assumed to extend from May through October (Haith and Shoemaker,1987).

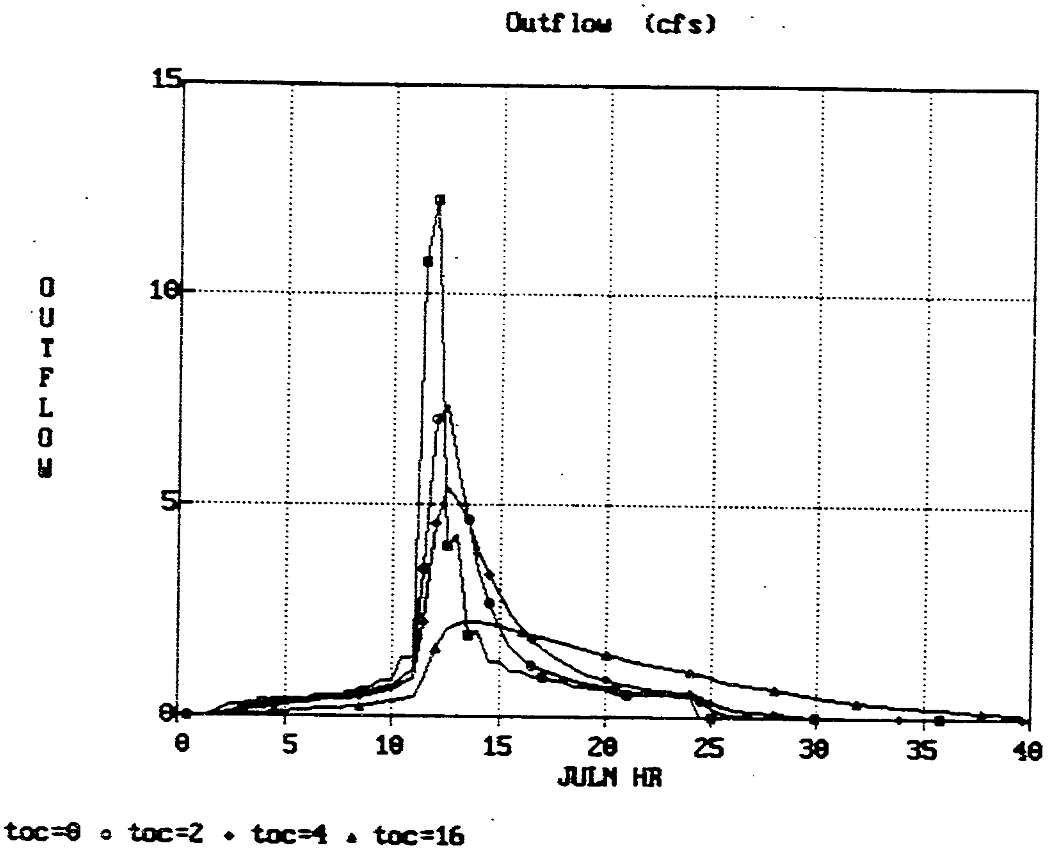
Although several other techniques are available for predicting runoff from pervious areas (Huber and Dikinson,1988; Donigian et al., 1984), the SCS technique has been selected because it is easily parameterized in terms which are familiar to the planner/engineer (Curve Numbers). The model is designed primarily for use in urban watersheds, where impervious surfaces are the primary sources of runoff and contaminant load. Since pervious and impervious areas are modeled separately, **curve numbers refer to the pervious portion of the site only (reflecting soil types and vegetative cover, not impervious area!).** Use of SCS tabulate curve numbers for urban land uses in P8 will result in double-counting of impervious areas and will overpredict runoff volumes. A help screen is provided to facilitate estimation of curve numbers (press <F > when pointing to Curve Number input field on data entry screen, or see Help - Site Parameter Estimation'). Pervious portions of urban watersheds may suffer from compaction; curve numbers should be estimated conservatively (on the high side).

Percolation from pervious areas is estimated by difference (rainfall - runoff - evapotranspiration). Percolation is not tracked unless explicitly routed to an "AQUIFER" (Device Type = 7), which can be used to predict stream baseflow. Evapotranspiration is computed from air temperature and season using Hamon's (1961) method, as implemented by Haith and Shoemaker (1987). Air temperatures can be specified on a daily basis (linked by date to rainfall sequence) or on a longterm monthly-average basis (as entered via the 'Case Edit Evapotrans' input screen). Both daily and monthly air temperature data from Providence Airport are supplied with the program (Section 3.3). Specification of air temperatures and routing of percolation are relevant only if the device network contains an AQUIFER and predictions of baseflow are desired.

Runoff from impervious areas starts after the cumulative storm rainfall exceeds the specified depression storage. Thereafter, runoff rate equals rainfall intensity. All precipitation is assumed to be rainfall. Consideration of snowfall and snowmelt is recommended for future versions of the program. A help screen is provided to facilitate estimation of watershed impervious fraction based upon land use.

Watershed runoff is transported directly to downstream devices (without lag). This assumes that the watershed time of concentration is small in relation to the rainfall time step (1 hr), generally the case for individual urban developments. Large watersheds will respond more slowly than predicted. To retard watershed responses, runoff can be routed to a "pipe" (Device Type = 5) with a positive time of concentration. Figure 5

Figure 5
Effect of Time of Concentration on Watershed Response



TOC = time of concentration (hours)
Storm = 24-hr, SCS TYPE II distribution, 1-inch

shows watershed responses for various times of concentration. Putting two or more pipes in series will impose a delay on the response (in addition to decreasing peak flow). Sensitivity analyses (Section 7.2) indicate that BMP removal efficiencies are usually insensitive to watershed time of concentration. Note that lags or delays in storm hydrographs which are caused by storage in upstream devices (e.g., detention ponds) are simulated by the model.

5.2 Watershed Loads

Particle concentrations in runoff from pervious areas are computed using the following empirical equation:

$$C_p = C_{po} I^f$$

where,

C_p = particle concentration in pervious runoff (ppm)

C_{po} = concentration at a runoff intensity of 1 inch/hr (ppm)

I = runoff intensity from pervious area (in/hr)

f = exponent (~1)

This is similar to the sediment rating model included in SWMM (Huber and Dikinson, 1988). Based upon typical sediment rating curves for rivers, values of the exponent (f) range from 0.1 to 1.6, with most values near 1.0 (Huber and Dikinson, 1988). If percolation from pervious areas is routed to an aquifer (Device Type= 7), concentration in percolating flow is assigned to the runoff concentration (C_p), reduced based upon the "filtration efficiency" defined for each particle class (Section 6.3).

Particle loads from impervious areas are computed using two techniques:

(1) particle accumulation and washoff
(2) fixed runoff concentration

Either or both of these methods may be used; results are totaled. The first method is used in default particle data sets.

The following differential equation describes the simulation of particle buildup and washoff on impervious surfaces, as implemented by the model:

$$\frac{dB}{dt} = L - k B - f s B - a r^c B$$

where,

B = buildup or accumulation on impervious surface (lbs/acre)

L = rate of deposition (lbs/acre-hr)

k = rate of decay due to non-runoff processes (1/hr)

s = rate of street sweeping (passes per hr)

f = efficiency of street sweeping (fraction removed per pass)

a = washoff coefficient

c = washoff exponent

r = runoff intensity from impervious surfaces (in/hr)

The exponential washoff relationship is similar to that employed in EPA's Stormwater Management Model (SWMM, Huber and Dikinson, 1988). The parameters "a" and "c" are analogous to SWMM's "RCOEFX" and "WASHPO", respectively. Values are updated using the analytical solution of this equation for each time step. At the start of the simulation, B values are set equal to one day's worth of deposition.

Computed loads from pervious and impervious areas are multiplied by a constant "Pollutant Load Factor" specified for each watershed. This factor (normally = 1) can be used to adjust for differences in loading intensity due to land use, for example, if sufficient calibration data are available. The load factor can also be adjusted to account for areas which are not expected to contribute contaminants (e.g., = 0 for a 'watershed' representing the surface of a pond).

5.3 Device Flows

When the model is executed (via the 'RM' = 'Run Model' command), the watershed/device network is first sorted in downstream order. If this is impossible, the network contains feedback loops and a warning is issued. An elevation/volume/discharge table is calculated for each device based upon input information. This information is entered directly by the user in the case of a General Device (Type=4). The table directs flow-balance calculations using methods described below.

Flow and mass routing is performed in downstream order. For each device and outlet, the relationship between storage volume and outflow is represented by the following linear approximation:

$$Q = d_0 + d_1 V$$

where,

Q = outflow for a given device and outlet (ac-ft)

V = current device volume (ac-ft)

d_o = intercept of outflow vs. storage volume curve (ac-ft/hr)

d_1 = slope of outflow vs. storage volume curve (1/hr)

Values of d_0 and d_1 are updated at each time step, based upon interpolation from the elevation/area/volume/outflow table developed for each device.

Linearization of the storage/outflow relationship in the above manner permits analytical solution of the device flow balance at each time step:

$$\frac{d\ V}{d\ t} = Q_{in} - \mathrm{SUM}\ [\ Q\ ]$$

The analytical solution for volume increase is as follows:

$$V_2 - V_1 = F(V,t)$$

$$= A/K + (V_1 - A/K)\ \exp(-\ K\ t) - V_1$$

$$A = Q_{in} - \mathrm{SUM}\ [\ d_0\ ]$$

$$K = \mathrm{SUM}\ [\ d_1\ ]$$

where,

V_1, V_2 = volume at start and end of time step (ac-ft)

Q_{in} = total inflows to device; from watersheds and upstream devices (ac-ft/hr)

SUM = sum over device outlets (infiltration, normal, spillway)

t = time step length (hours)

Since the slope and intercept (d_1 & d_0) may vary with volume and elevation, a three-stage procedure is used to estimate the volume change at each time step. The following calculations are performed in sequence:

$$V_m = V_1 + .5\ F(V_1,t)$$

$$V_2 = V_1 + F(V_m,t)$$

$$V_m = (V_1 + V_2)/2$$

$$V_2 = V_1 + F(V_m,t)$$

$$V_m = (\ V_1 + V_2\ )\ /\ 2.$$

where,

V_m = average volume during time step (ac-ft)

Device volumes are constrained to maximum values consistent with input data specifications. Excess inflows are discharged through the "spillway"

(Outlet Number 3). Device areas and elevations are updated by interpolating against V_m in the elevation/area/discharge table.

Continuous water-balance and mass-balance checks are maintained on each device and on the overall device network. A warning message is issued if continuity errors exceed the maximum value specified on the timestep input screen ('Case Edit Timesteps'). Continuity errors can be reduced by specifying shorter simulation time steps. Continuity errors are more likely for devices with large, rapid fluctuations in volume (e.g., buffers/swales). Typical time step lengths are .25-1 hours during storm periods and 2-8 hours for dry periods for volume continuity errors less than 2%. Sensitivity of device performance to time step lengths can be tested by adjusting lengths and re-running the model.

5.4 Device Outlet Capacities

Manning's equation (Bedient and Huber, 1988) is used for predicting flow velocities in overland flow areas (buffers/swales, device type = 3):

$$u = 1.49\ r^{2/3}\ s^{1/2} / n$$

where,

u = overland flow velocity (ft/sec)

r = hydraulic radius = cross-section/wetted perimeter (ft)

s = slope (ft/ft)

n = Manning's n

A trapezoidal geometry is assumed for calculating the hydraulic radius at any elevation, based upon input buffer dimensions (bottom width, side slope, maximum depth).

The maximum depth of overland flow (input variable) is defined as the maximum depth at which the specified value of Manning's n applies. According to TR-55 (USDA/SCS, 1985), this value is on the order of .1 feet. High values of n typically used for grassed areas (.2-.4) assume that flow is in contact with the vegetation. The specified maximum depth should not exceed the effective vegetation height. The model constrains buffer flow depth to the specified maximum value. If this depth is reached, routing based upon Manning's equation stops and excess inflows are forced through the device at a fixed water depth and hydraulic cross-section. This procedure is conservative with respect to predicting overland flow velocities because flow depths would actually continue to increase, but be governed by lower n values. Model testing indicates that predicted particle removal efficiencies are generally insensitive to the specified maximum depth of overland flow. Predicted peak flow velocities (for comparison with erosion/scouring criteria, typically ~4 ft/sec, RIDEM (1988)) can be sensitive to maximum flow depth, however, and are likely to be conservative (over-estimated). Future investigation of alternative procedures for handling high flow depths in buffers (including direct simulation of particle scouring) is recommended.

Detention pond (type=1) outlet capacities are calculated from input dimensions using standard hydraulic formulae for weirs and orifices Bedient and Huber, 1988):

$$q_w = c_w\ l_w\ h^{1.5}$$

$$q_o = c_o\ a_o\ (2\ g\ h)^{1/2}$$

where,

q_w = weir flow (cfs)

c_w = weir coefficient ~ 3.33

l_w = weir length (ft)

h = height above weir crest or above orifice centerline (ft)

q_o = orifice flow (cfs)

c_o = orifice coefficient ~ .6

a_o = orifice area (ft^2)

g = acceleration of gravity = 32.2 ft/sec^2

Outlet dimensions (orifice diameter, weir length) and discharge coefficients are supplied on the data-entry screen for detention ponds (see Appendix B). If flood pool drawdown time is input directly (based, for example, upon output from TR-20 or other flood routing model), the assumed shape of the drawdown curve is similar to that obtained for a weir. Vertical perforated risers are assumed to consist of a number of holes (orifices) of a given diameter distributed uniformly over the specified riser height. The orifice discharge coefficient (c_o) is also used for computing riser flows.

Only one controlled outlet can be specified for the flood pool of a detention pond (orifice, weir, riser, or direct input of drawdown time). The is referenced as the "normal" outlet (see Figures 2 and 3). When the flood pool of a detention pond is full, the pond elevation is fixed and the "spillway" outlet is activated to pass excess overflows. In the case of a wet detention pond with no flood storage, the "normal outlet" is not used and all outflows occur through the "spillway". User's should take care to assign appropriate device numbers to each detention pond outlet. Ponds with more complex designs (multiple outlets at different elevations) can be handled by defining them as "general" devices (type=4); this requires direct entry of the elevation/area/discharge table. Such information is often available from TR-20 input or output tables.

5.5 Device Concentrations

Each device is assumed to be completely mixed for the purposes of computing concentrations and outflow loads. The following equations are solved:

$$\frac{d\,M}{d\,t} = W - D\,M$$

$$D = Q/V_m + f\,K_1 + f\,K_2\,C_m + f\,U\,A_m/V_m$$

Analytical Solution:

$$M_2 = W/D + (M_1 - W/D)\exp(-D\,t), \quad \text{if } D > 0$$

$$= M_1 + W\,t \quad , \quad \text{if } D = 0$$

where:

D = sum of first-order loss terms (1/hr)

C_m = average concentration during step (ppm)

V_m = average device volume during time step (ac-ft)

M_1, M_2 = particle mass in device at start and end of time step (ac-ft*ppm)
t = time step length (hours)

W = total inflow load to device, from watersheds and upstream devices (ac-ft*ppm/hr)

Q = average outflow from device, from flow balance (ac-ft/hr)

U = particle settling velocity (ft/hr)

A_m = average device surface area during time step (acres)

K_1 = first-order decay coefficient (1/hr)

K_2 = second-order decay coefficient (1/hr-ppm)

f = particle removal scale factor, device-specific

The solution technique is similar to that used in the SWMM Transport Block (Huber & Dikinson, 1988), except it is based upon mass rather than concentration. Concentrations are computed as follows:

$$C_2 = M_2/V_2$$

$$C_m = [\,W + (M_1 - M_2)/t\,]\;V_m\,/\,D \qquad \text{(from mass balance)}$$

where,

C_2 = concentration at end of time step (ppm)

V_2 = volume at end of time step (ac-ft)

C_m = average concentration during time step, used for routing outflows to downstream devices (ppm)

If a nonzero 2nd-order decay rate (K_2) is specified, three iterations are performed, updating the first-order loss term (D) each time based upon the average concentration (C_m) computed in the previous iteration.

Depending upon device type, up to 15 mass-balance terms are considered in the simulations, as identified in Table 1 and Figure 3. The following mass-balance equations apply to simulations of volume and particle mass in each treatment device:

Inflows = Outflows + Incr.-in-Storage + Removals + Continuity Error

Inflows = Watershed Disch. + Inflows from Upstream Devices

Outflows = Infiltration + Normal Outlet + Spillway

Increase-in-Storage = Final Storage - Initial Storage

Removals = Sedimentation + Decay + Filtration

5.6 Particle Removal Scale Factors

Using the above equations and parameter estimates discussed in the next section, the model simulates the inflow, removal, and outflow of particles in devices. Calibrated particle settling velocities are based upon settling column tests conducted using urban runoff (Driscoll, 1983; USEPA, 1986, see Section 6.1). Settling velocities may be modified in any device by adjusting the 'Particle Removal Scale Factor', which is specified on the input screen for each device type. This factor (usually = 1) modifies settling velocities and decay rates specified on particle input screens to account for device-specific characteristics.

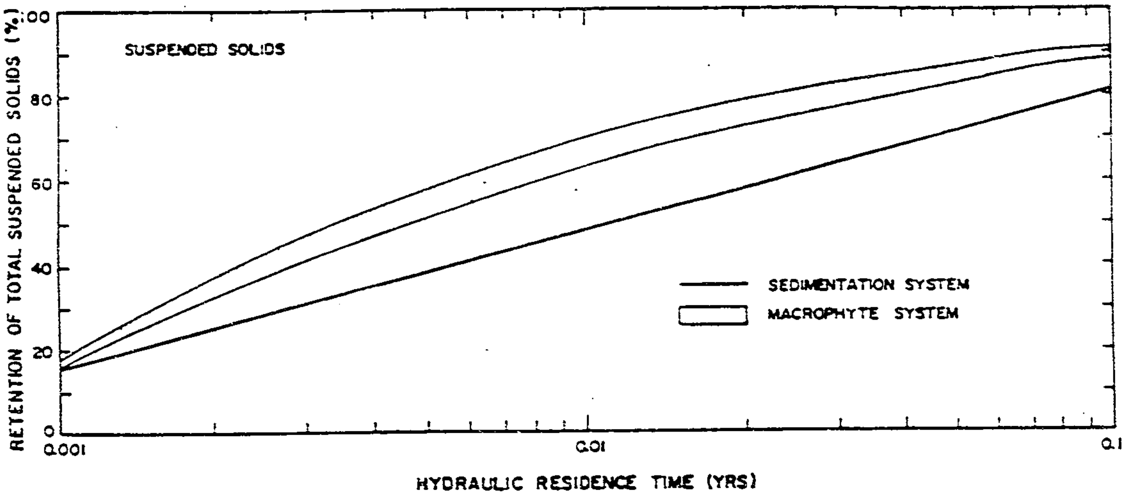
One potentially important use of the 'Particle Removal Scale Factor' is to account for effects aquatic vegetation in detention ponds and wetlands. Theoretically, macrophytes can increase particle removal rates under a given hydraulic regime by increasing the effective surface area for settling (tray-settling concept), stabilizing bottom sediments, and/or through biological mechanisms. Design methodologies developed in Australia account for a ~5-30%% increase in sediment and phosphorus removal at a given hydraulic residence time in ponds with macrophytes vs. ponds without macrophytes (Phillips & Goyen, 1987; Lawrence, 1986). Their removal efficiency curves are consistent with scale factors of 2-3 for suspended solids and 3-6 for total phosphorus attributed to macrophyte presence in wet detention ponds (Figure 6). The effect of vegetation is to shift the removal vs. residence time curves to the left, so that lower residence times (and treatment areas) are sufficient to achieve the same removal efficiency, as compared with ponds with similar hydraulic features but without macrophytes.

Alternatively, removal scale factors less than 1.0 can be assumed to account for poor hydraulic design (outlet next to inlet, promoting short-circuiting of inflows). Such adjustments would have to be made on a case-by-case basis, depending upon design characteristics and user judgement. Such designs should be avoided.

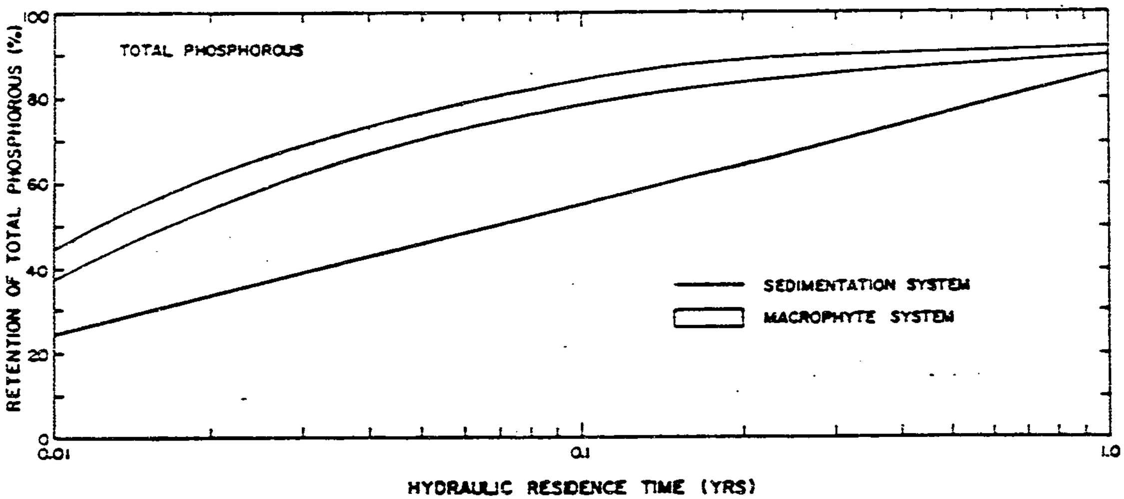
Table 1
Mass Balance Terms

Term	Description
01 Watershed Inflows	Inflow from watersheds linked to device via surface runoff or percolation (aquifer)
02 Upstream Device	Inflow from upstream devices
03 Infiltrate	Outflow passing through bottom/sides of device through outlet # 1
04 Exfiltrate	Equals Infiltrate(03) minus Filtered(05)
05 Filtered	Mass removed during infiltration (trapped in soil)
06 Normal Outlet	Outflow passing thru outlet 2
07 Spillway	Outflow thru outlet 3, used as a "relief" when device is full
08 Sedim.+Decay	Mass removed via sedimentation and/or decay
09 Total Inflow	Sum of inflows from watershed and upstream devices
10 Surface Outflow	Sum outlets 2 and 3; also includes outlet 1, if its device number > 0
11 Groundw Outflow	Outflow thru outlet 1, if its device number = 0
12 Total Outflow	Sum of surface and groundwater outflows
13 Total Trapped	Sum of sedimentation, decay, and filtration
14 Storage Increase	Increase in storage volume (or mass)
15 Mass Bal. Check	Error term in mass-balance equation; should be small in relation to total inflows if appropriate time steps are used

Figure 6
Effects of Macrophytes on Wet Pond Removal Efficiencies
(Phillips & Goyen, 1987)



Retention of Suspended Solids Against Hydraulic Residence Time (After Lawrence [4])



Retention of Total Phosphorous Against Hydraulic Residence Time (After Lawrence [4])

6.0 MODEL CALIBRATION

The model can be calibrated to simulate contaminants with first-order settling, first-order decay, and/or second-order decay kinetics. Several approaches are feasible. The preliminary calibrations described below are based upon NURP monitoring results for median and 90th percentile sites. These calibrations (stored in data files 'NURP50.PAR' and 'NURP90.PAR', respectively) provide initial frames of reference for users lacking site-specific runoff water quality data. Sensitivity to particle parameter values is in Section 7.2. Additional testing and refinement of the particle/water quality component calibrations are recommended for future research.

6.1 Particle Classes

The following particle classes are included in the particle input files distributed with the program (NURP50.PAR and NURP90.PAR), based primarily upon calibration to runoff concentrations and settling velocity distributions measured under the Nationwide Urban Runoff Program:

Class	Description	% of TSS	Settling Veloc.(ft/hr)
P0%	Dissolved	0	0
P10%	10th Percentile	20	.03
P30%	30th Percentile	20	.3
P50%	50th Percentile	20	1.5
P80%	80th Percentile	40	15

The first class permits consideration of dissolved (non-settling) fractions of runoff water quality components. The remaining classes are based upon NURP settling velocity distributions (Driscoll, 1983; USEPA, 1986). Other particle input parameters are described in Table 2.

Watershed buildup/washoff parameters have been calibrated to so that median, event-mean TSS concentrations for both pervious and impervious areas equal those reported under NURP (100 ppm for median site, 300 ppm for 90th percentile site). As a consequence of the particle buildup/washoff dynamics, the predicted flow-weighted-mean concentration of total suspended solids (used for computing annual load) is approximately equal to the median, event-mean concentration (100 ppm for median site). Athayede et al. (1983) used a flow-weighted-mean concentration of 180 ppm for computing annual loads from impervious areas. This concentration was calculated by applying a factor of 1.8 to the median, event-mean concentration. The factor accounts for the lognormal distribution of event-mean concentrations (transformation from median to arithmetic mean). The adjustment assumes that concentration is independent of runoff volume and ignores particle buildup/washoff dynamics, which typically cause decreases in mean concentration at high storm volumes ("first-flush" effect). The NURP mean TSS concentration of 180 ppm was not directly calibrated against runoff data.

The flow-weighted-mean TSS concentration of ~100 ppm predicted using the parameter values in Table 2 is consistent with values reported by Schueler (1987, p. A6) for ~19 urban watersheds in the Washington DC area with drainage areas less than 100 acres (range ~20 to ~190 ppm, average

Table 2
Calibration of Particle Parameters

<u>**Impervious Washoff Parameters - Particle Classes P10%-P80%**</u>:

Accumulation Rates = 1.75 lbs/ac-day (P10%,P30%,P50%)
= 3.5 lbs/ac-day (P80%)
calibrated so that sum of particle fractions yields median EMC = 100 ppm TSS), using Providence Airport 1983-1987 rainfall time series applied to impervious watershed.

Accum. Decay Rate = .25 1/day
assumes buildup on impervious surfaces reaches 90% of steady-state after 10 days of dry weather without sweeping

Washoff Exponent = 2
provides intensity-dependent washoff, as in SWMM (Huber et al., 1988)

Washoff Coefficient = 20
calibrated so that runoff load vs. storm volume relationship for impervious watersheds saturates at ~1 inch of rainfall; provides 92% washoff for a 1-inch, 8-hour storm.

Filtration Efficiency = 100%
assumes complete particle removal during infiltration in a device or pervious watershed area.

Street Sweeper Efficiencies = 4-16%
lower range of sweeper efficiencies reported by Sartor et al. (1974)

<u>**Impervious Washoff Parameters - P0%:**</u>

Impervious Runoff Conc = 1 mg/liter
arbitrary; used for calibrating dissolved fractions of water quality components

<u>**Pervious Runoff Concentrations - Particle Classes P10%-P80%:**</u>

CO = Conc at Runoff Intensity of 1 in/hr = 100 ppm (P10%,P30%,P50%)
= 200 ppm (P80%)
calibrated so that flow-weighted mean TSS EMC from pervious watersheds = 100 ppm (**NURP** median site); calibration period = 1983-1987; curve number = 74

f = Pervious Concentration/Runoff Intensity Exponent = 1
provides linear log(C) vs. log(Runoff) relationship; typical of watershed sediment rating curves (Huber & Dikinson,1988)

<u>**Pervious Runoff Concentrations - P0%:**</u>

Pervious Runoff Conc = 1 mg/liter
arbitrary; used for calibrating dissolved fractions of water quality components

~75 ppm). Users wishing to make alternative assumptions regarding TSS (or other contaminant) concentrations can do so by adjusting the appropriate values. The easiest way to adjust runoff concentrations is by using the 'scale factors' on the water quality component input screens (Appendix B, Procedure = 'CEC' = 'Case Edit Components'). For example, to assume a mean runoff TSS concentration of 180 ppm (vs. 100 ppm), assign a value of 1.8 to the TSS scale factor (particle file = NURP50.PAR). Computed particle removal efficiencies will be insensitive to such adjustments.

6.2 Particle Composition

Particle compositions (mg/kg) are used to translate particle concentrations into concentrations of total suspended solids, total phosphorus, total Kjeldahl nitrogen, copper, lead, zinc, and hydrocarbons. Compositions have been calibrated so that median, event-mean runoff concentrations correspond to values reported by the Nationwide Urban Runoff Program (Athayede et al., 1983), as listed in Table 3. The calibration is based upon simulation of 1983-1987 Providence Airport rainfall. A high degree of site-to-site variability is reflected by the 2- to 3-fold differences between the NURP median and 90th percentile sites. Because of this variability, specification of particle composition and prediction of runoff concentrations at a given site are subject to considerable uncertainty. Calibration of the model to local or regional runoff data may help to reduce this uncertainty.

NURP lead EMC's (.144 ppm for median site, .350 ppm for 90th percentile site) have been reduced to .02 and .05 ppm, respectively, to account for the more than ten-fold reduction in the maximum lead content of gasoline which occurred after NURP monitoring. A recent urban runoff study in Minnesota (Oberts et al., 1989) reported annual, flow-weighted-mean concentrations ranging from .004 to .027 ppm at 5 sites. Schueler (1987) reported a median, event-mean concentration of .02 ppm for urban runoff in Washington, DC.

Distribution of water quality components among particle classes is based upon results of direct runoff measurements, settling column tests, and typical pollutant removal efficiencies in treatment devices (see Section 7.1). TSS concentration is computed as the sum of the individual particle fractions. For lead and hydrocarbons, approximately 10% of the total runoff concentration is assumed to be associated with the dissolved class (P0%); the remainder is evenly distributed among the remaining particle classes. For total phosphorus, 30% of the total runoff concentration is assumed to be associated with the dissolved particle class (P0%). A dissolved fraction of 40% is assumed for total kjeldahl nitrogen, copper, and zinc. Non-dissolved portions of total phosphorus, Kjeldahl nitrogen, copper, and zinc are distributed equally among the three smallest particle classes (P10%, P30%, P50%). Soluble fractions are based partially upon results of runoff monitoring conducted under the NURP Priority Pollutant Monitoring Project (Cole et al.,1983), settling column tests (Whipple and Hunter, 1981), modelling studies by Driscoll (1983), and removal efficiencies for wet ponds (Schueler, 1987, Figure 4.6). Removal efficiencies for nutrients and heavy metals predicted with these parameter values may be conservative because chemical and biochemical

Table 3
Calibrated Runoff Concentrations

	Median, Event-Mean Concentration (ppm)		
COMPONENT	NURP MEDIAN SITE	90th % SITE	%DISSOLVED
Total Suspended Solids	100	300	0%
Total Phosphorus	.33	.70	30%
Total Kjeldahl Nitrogen	1.50	3.30	40%
Total Copper	.034	.093	40%
Total Lead	.020 a	.050 a	10%
Total Zinc	.160	.500	40%
Hydrocarbons	2.5 b	5.0 b	10%
P8 Particle File -------->	NURP50.PAR	NURP90.PAR	

a - NURP lead values reduced to account for >10-fold reduction in gasoline lead content since NURP monitoring.
b - Hydrocarbons estimated from load factors reported by Hoffman et al. (1985)

Table 4
Water Quality Criteria

COMPONENT (ppm)	LEVEL A	LEVEL B	LEVEL C
Total Sus. Solids	5	10	20
Total Phosphorus	.025	.05 d	.10 e
Total Kjeldahl N	2.0	1.0	0.5
Total Copper	2.0 a	.0048 b	.02 c
Total Lead	.02 a	.0140 b	.15 c
Total Zinc	5.0 a	.0362 b	.38 c
Total Hydrocarbons	.1	.5	1.0

a - USEPA primary drinking water standard
b - RI standard, acute toxicity, fresh waters, hardness = 25 ppm
c - NURP threshold for aquatic life, intermittent exposure, soft waters (Athayede et al, 1983)
d - USEPA (1976) guideline for eutrophication in streams
e - USEPA (1976) guideline for streams entering lakes
others are arbitrary benchmarks (no standards or criteria)

mechanisms responsible for removal of dissolved fractions are not considered.

A fundamentally different approach to simulating contaminant partitioning and behavior in devices would assign each contaminant to a separate particle class and use second-order decay kinetics (instead of first-order settling). The effect of second-order kinetics is to slow down the rate of removal as concentrations decrease. The same effect is achieved in the above calibration by distributing each contaminant among dissolved and particulate fractions with different setting velocities. This partitioning is artificial because size fractions and effective settling velocities are actually distributed continuously. The applicability of second-order decay kinetics has been demonstrated for hydrocarbons in NURP settling column tests (Athayede et al., 1983, Volume II), phosphorus removal in reservoirs and detention ponds (Walker, 1985, 1987), and TSS, phosphorus, and zinc removal in settling columns (author's unpublished analysis of settling column data reported by Grizzard et al., 1986). Second-order kinetics are consistent with removal mechanisms involving particle interactions (e.g., flocculation), as opposed to discrete settling. Such processes may be very important in treatment devices, as well as in receiving waters. Investigation of this modeling approach is recommended for future work.

6.3 Filtration Efficiency

Filtration efficiency (percent of particle class removed when water infiltrates a device or pervious watershed area) is assumed to be 100% for each suspended solids fraction (P10% - P80%). A filtration efficiency of 90% is assumed for the dissolved fraction (P0%), to account for adsorption, precipitation, and other reactions between dissolved runoff contaminants and the soil matrix. Such reactions are responsible for the generally low concentrations of phosphorus and heavy metals found in groundwaters beneath runoff swales and retention basins (Wigington et al., 1986; Youseff et al., 1986; Nightingale, 1987ab, Schiffer, 1988). The effects of assuming alternative values for filtration efficiency can be easily investigated by editing the filtration efficiency contained on the particle input screen ('CEP' = 'Case Edit Particles').

With these parameter values, the predicted total phosphorus concentrations in groundwater is ~.01 ppm (median runoff total P = .33 ppm, 30% dissolved, 90% removal of dissolved fraction upon infiltration), which is typical of this region. Predicted average streamflow total phosphorus concentrations (baseflow + runoff) range from .014 to .15 ppm for impervious fractions ranging from 0% to 25%. This range is similar to that derived from regression analysis of average stream phosphorus concentrations in 116 Northeastern watersheds sampled by the EPA National Eutrophication Survey (Walker, 1978, 1982).

6.4 Water Quality Criteria

Water quality criteria included in the particle/component files NURP50.PAR and NURP90.PAR are listed in Table 4. The 'LV' (='List Violations') procedure compares these values with the distribution of event-mean concentrations for any device and mass-balance stream. Output summarizes the percent of events in which the event-mean concentration exceeds each of three criteria specified for each water quality component. Criteria can be modified via the 'CEC' (= 'Case Edit Components') procedure (ADVANCED USER MODE only). The concept of using violation frequencies for evaluating urban runoff impacts is discussed in the NURP final report (Athayede et al., 1983). The lack of criteria which are realistic for urban runoff situations (Mancini and Plummer, 1986) limits the interpretation of violation frequencies and the extent to which they can be properly used in the context of site planning, design, or impact assessments. Predictions violation frequency are also uncertain because of high site-to-site variations in runoff quality.

7.0 MODEL TESTING

7.1 Device Performance

As stated in the introduction, the program is intended primarily for use in evaluating compliance with a treatment goal expressed in terms of percentage removal for total suspended solids or a single particle class. One method for testing the model is to compare predicted removal efficiencies with predictions based upon other theoretical or empirical models which have been tested against observed performance data (Driscoll, 1983; USEPA, 1986; Schueler, 1987; Walker, 1987).

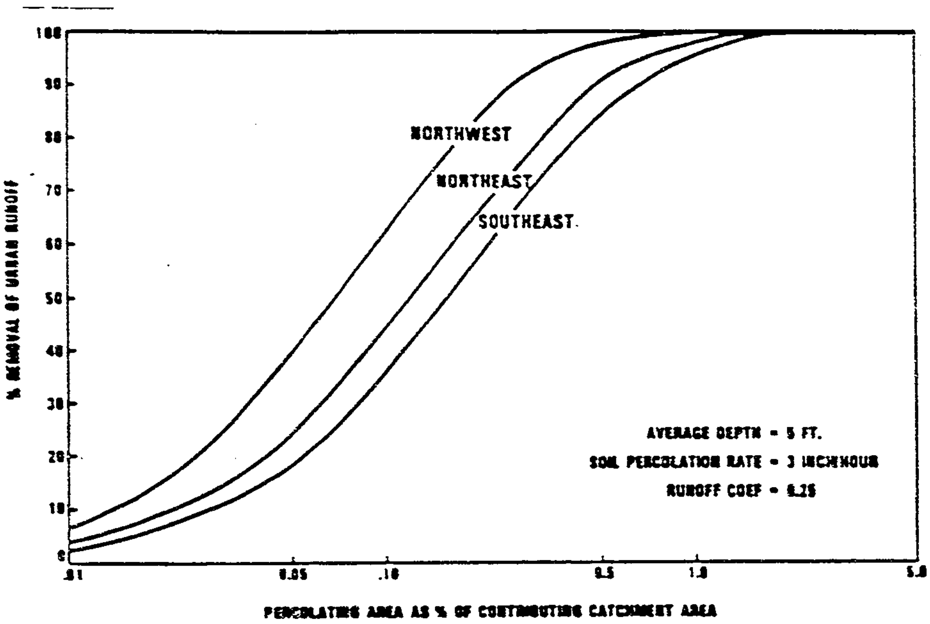
Figures 7 and 8 compare simulated volume capture efficiencies for infiltration basins with predictions of a probabilistic model developed by Driscoll (USEPA, 1986). The curves relate volume capture efficiency to ratio of basin area to watershed area for different regions, basin mean depths, and infiltration rates. The simulations are based upon Providence 1983-1987 rainfall. Since Driscoll's methodology assumes a fixed runoff coefficient, runoff from pervious areas is not included in the P8 simulations. Figure 8 is based upon typical precipitation patterns for the Great Lakes area. The Providence rainfall time series has been adjusted to give the same mean storm volume and intensity used in the Driscoll's simulations. Symbols on the lower graph in each figure show Driscoll's predictions (extracted from upper graph) in relation to P8 predictions. Agreement between the two methodologies for predicting volume capture in infiltration basins is good.

Figure 9 compares simulated suspended solids removal efficiencies for wet detention ponds with Driscoll's (1983; USEPA, 1986) results. The curves relate removal efficiency to the ratio of basin area to watershed area for different regions of the country. To permit comparison of model results for equivalent watershed dynamics, constant runoff coefficients and constant runoff concentrations have been used in the P8 simulations. Supplementary testing indicates that predicted removal efficiencies are insensitive to washoff dynamics. The settling velocity used in the simulations is equivalent to that developed by Driscoll (1983), based upon NURP data. Predicted removal efficiencies in each particle class are shown in Figure 10.

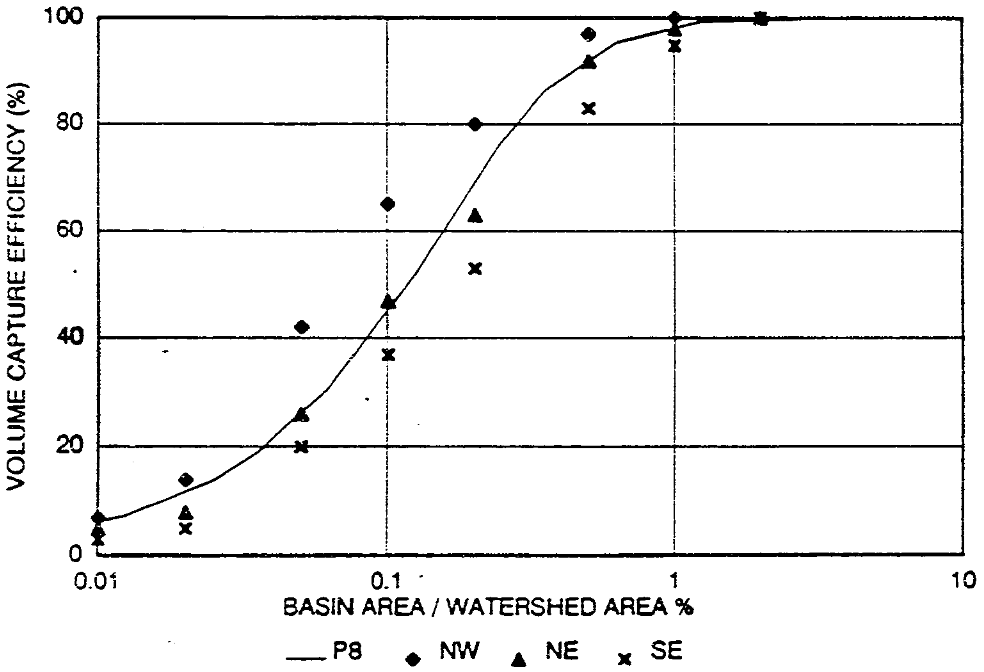
Figure 9 shows that while the methodologies agree on the average, P8 over-predicts Driscoll's results at low A_b/A_w and under-predicts Driscoll's results at high A_b/A_w ratios. As noted by Driscoll (1983), particle

Figure 7
Comparison of Predicted Volume Capture Efficiencies

Probabilistic Method (Driscoll, 1983; USEPA, 1986):



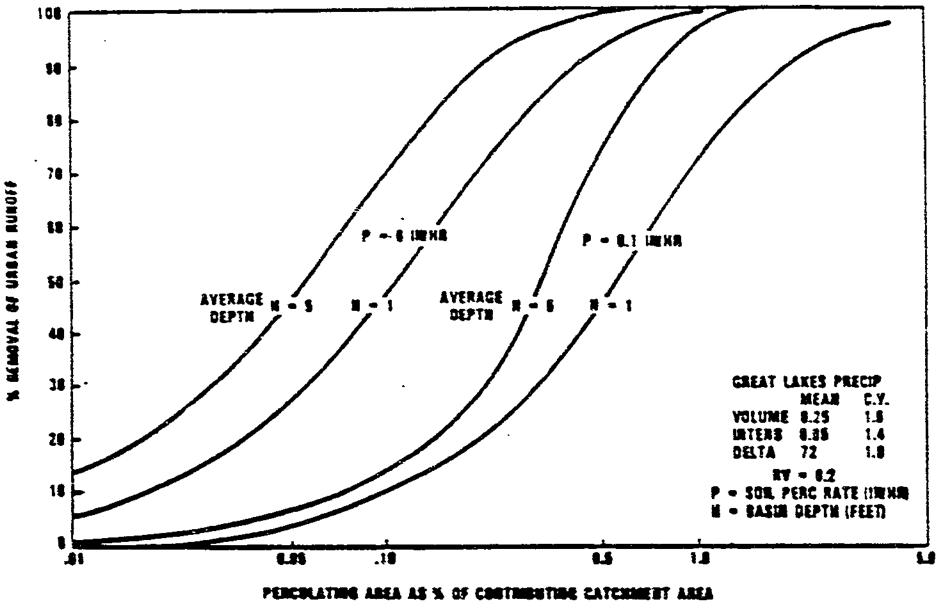
P8 Simulation of 1983-1987 Providence Rainfall:



Mean Depth = 5 ft, Inf Rate = 3 in/hr, Rc = .25

Figure 8
Comparison of Predicted Volume Capture Efficiencies Great Lakes Precipitation Sequence

Probabilistic Method (Driscoll, 1983; USEPA, 1986):



P8 Simulation of 1983-1987 Providence Rainfall, Adjusted to Great Lakes Mean Storm Volume and Intensity:

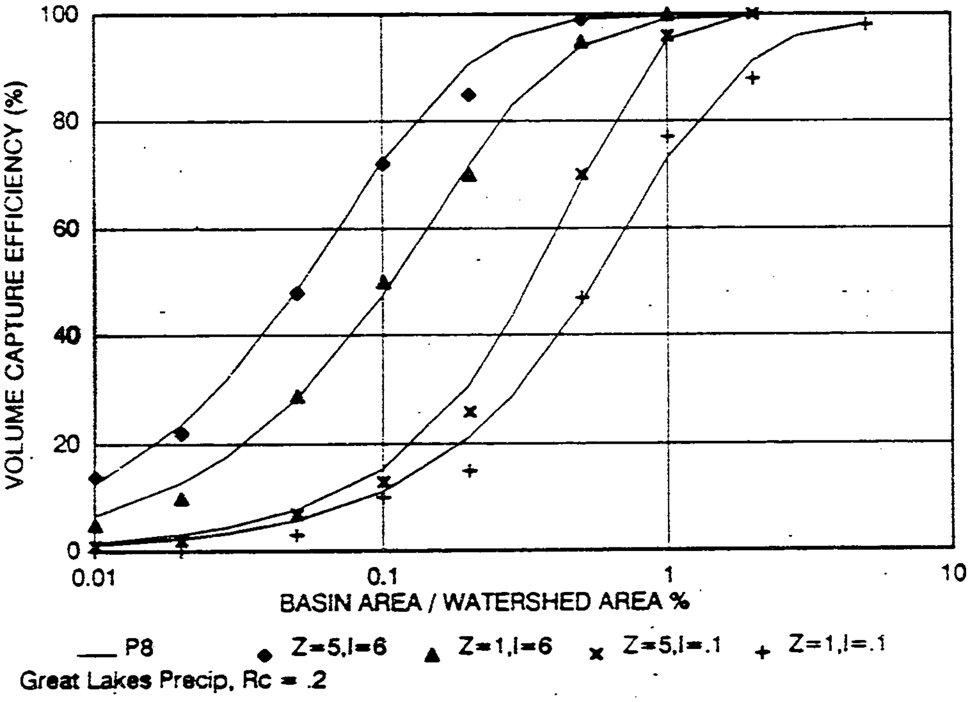
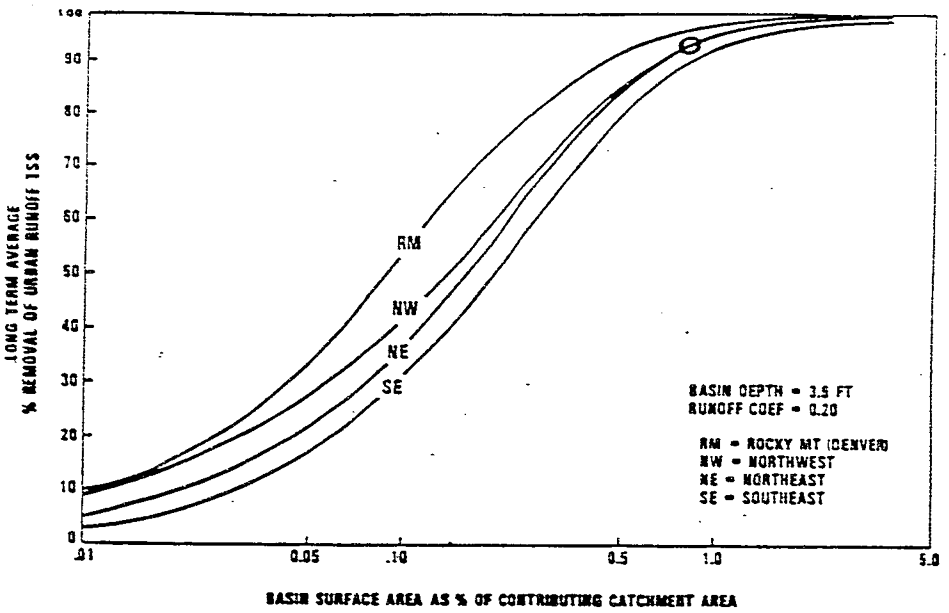
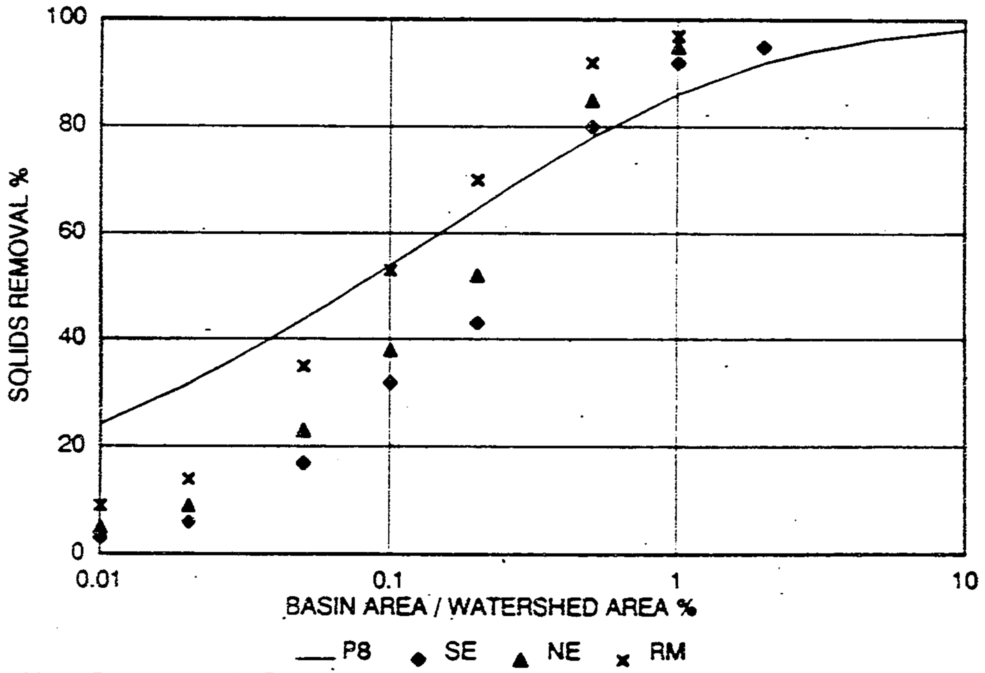


Figure 9
Comparison of Predicted Suspended Solids Removal Efficiencies for Wet Detention Ponds

Probabilistic Method (Driscoll, 1983; USEPA, 1986):



P8 Simulation of 1983-1987 Providence Rainfall:



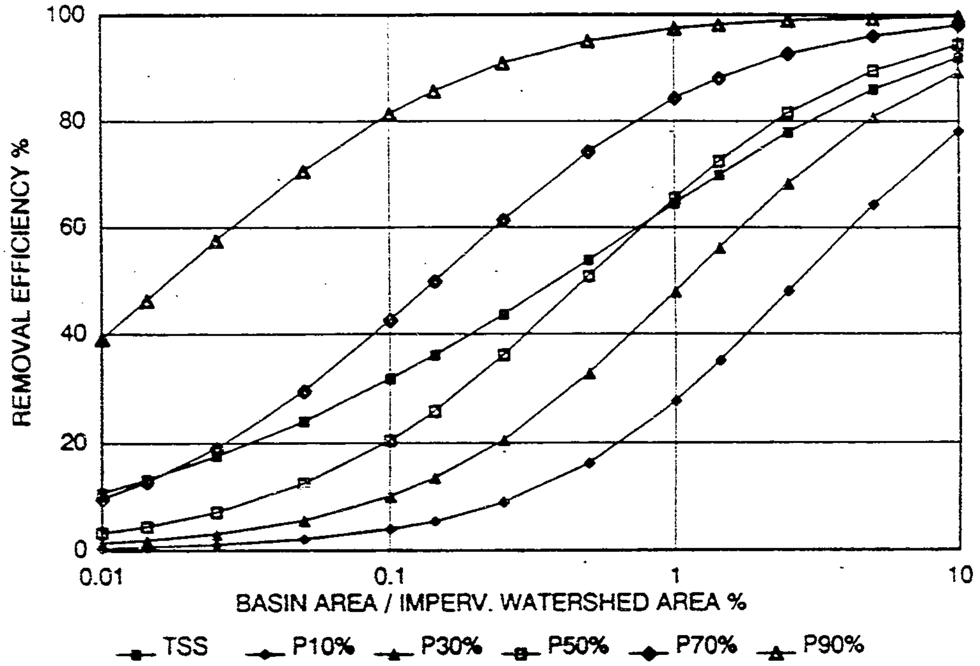
Mean Depth = 3.5 ft, Rc = .2

Figure 10
Predicted Suspended Solids Removal Efficiencies vs. Particle Class

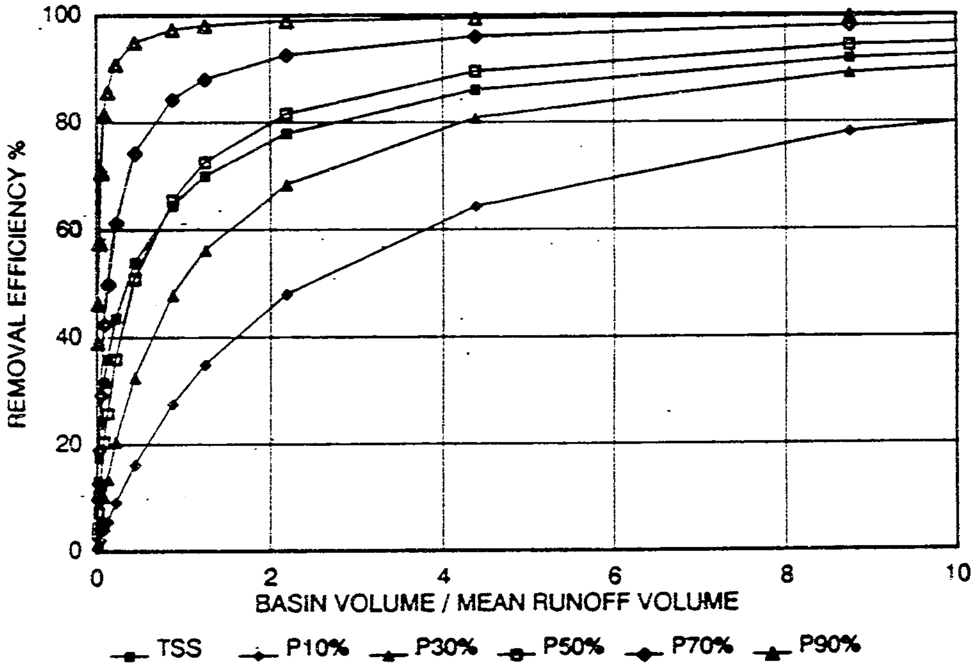
P8 Simulation of 1983-1987 Providence Rainfall

Driscoll (1983) Settling Velocity Distribution:

Particle Class:	**P10%**	**P30%**	**P50%**	**P70%**	**P90%**
Settling Veloc. (ft/hr):	**.03**	**.3**	**1.5**	**7**	**65**



Providence 1983–1987 Rainfall, Mean Depth = 3.5 ft



removal under dynamic conditions occurs when the settling velocity exceeds the basin overflow rate (ft/hr). The average basin overflow rate (outflow per unit area) can be estimated as follows:

$$Q_s = A_w \; r \; I \; / \; 12 \; A_b$$

where,

Q_s = average overflow rate (ft/hr)

A_b = basin surface area (acres)

A_w = watershed area (ac-ft)

r = watershed runoff coefficient

I = mean storm intensity (in/hr) ~.06 in/hr

For the lowest area ratio shown in Figure 9 (.01 %), the above expression evaluates to 10 ft/hr, much less than the settling velocity of the largest particle fraction (65 ft/hr), which is assumed to account for 20% of the total suspended solids. When removal under quiescent conditions is also considered, TSS removals in excess of 20% would be expected for A_b/A_w = .01%, yet Driscoll's method predicts removals less than 10% (~5% for NE rainfall).

At high A_b/A_w ratios, P8 under-predicts Driscoll's results by 5-10%. Driscoll (1983) compared measured TSS removal efficiencies for NURP basins with predictions of his model. In a total of four cases, predicted removal efficiencies exceeded 90%. In each of these cases, however, observed removals were ~6 to ~30% lower than model predictions. The fact that P8 under-predicts results of Driscoll's model at high removal efficiencies is consistent with observed performance data.

Walker (1987) showed that an empirical model originally developed for predicting phosphorus retention in reservoirs (Walker, 1985) could be used to predict phosphorus removal in urban runoff detention basins. Figure 11 compares phosphorus removal efficiencies computed by P8 with predictions of the empirical model, based upon Providence 1983-1987 rainfall. Saturation at high A_b/A_w ratios reflects assignment of 30% of the runoff total phosphorus to the conservative particle class (P0%). Results are in good agreement.

The above comparisons indicate that P8 predictions of removal efficiency in infiltration basins and wet detention ponds are in reasonable agreement with predictions derived from other models. Additional testing of the model and refinement of the preliminary calibration using regional monitoring data are recommended for future work.

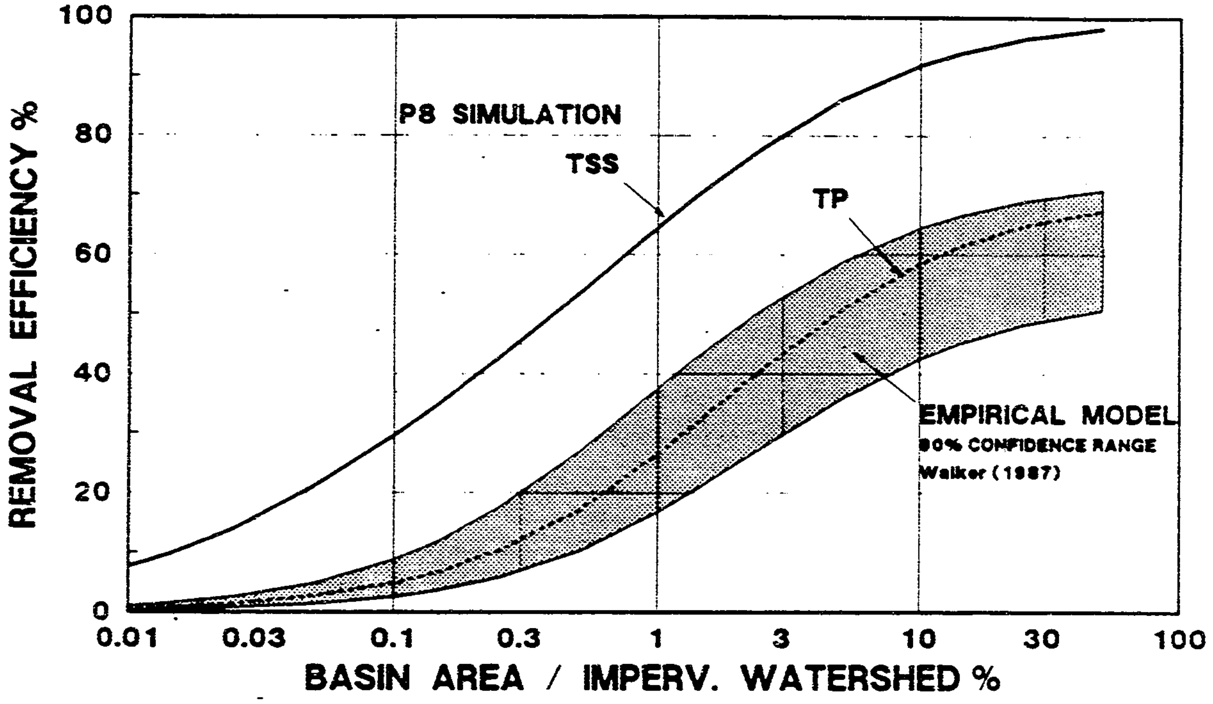
7.2 Sensitivity Analysis

Specification of model input values defining watershed, device, particle, and storm characteristics is based partially upon direct

Figure 11
Comparison of Predicted Phosphorus Removal Efficiencies

P8 Predictions:
TSS and TP
Simulation of 1983-1987 Providence Rainfall
Basin Mean Depth = 3.5 feet

Empirical Model:
Walker (1987)
Developed from Input/Output Data from Corps of Engineer Reservoirs
Model Tested Against Data from 24 Runoff Detention Basins
Prediction Assumes NURP Median Runoff Total P Conc = .33 mg/l
and Providence Rainfall Statistics
Approximate Confidence Limits for Empirical Model Shown



Providence 1983-1987 Rainfall, Mean Depth = 3.5 ft, Runoff Total P = .33 ppm measurement, estimation, and the generalized calibrations discussed above. The sensitivity analysis procedure ('Run Sensitivity') provides insights into which input values have the greatest impact on computed removal efficiencies and outflow concentrations. This, in turn, helps to prioritize inputs (and their inherent assumptions) with respect to their importance. This procedure is demonstrated below for six device types (pipe, wet pond, dry pond, extended pond, infiltration basin, and buffer strip/swale) with identical watershed characteristics.

Using the 'Run Design Tune' procedure, each device was originally sized to achieve 70% TSS removal for a 1-inch, 24-hour, Type-2 storm with 75-hour period between storm midpoints (storm file = 'TYPE2.STM'). Device and watershed characteristics are given in Table 5. Input values are stored in the file 'SENSIT.CAS' on the program distribution disk. Simulations were then run using Providence rainfall time series for 1984 through 1986. Results from the 'Run Sensitivity' procedure are shown in Table 6. Each input variable was increased by 25% (one at a time) and impacts on TSS removal efficiency and flow-weighted-mean outflow concentration were tabulated. Note that this type of calculation is time consuming (~4 hours on an 80386/80387/20 mhz machine) because the entire 3-year simulation is repeated 38 times (once for each model input variable).

Input variables are grouped in four categories: watershed, device, particle, and storm. In typical applications, the first two groups are specified by the model user and the last two groups are specified in the default particle file ('NURP50.PAR') and storm data files. The following points are based upon review of sensitivity analysis results in Table 6:

(1) Removal efficiencies are much less sensitive to variations in input values than are outflow concentrations. For example, changes in wet pond removal efficiencies range from -5.7% to +1.7% for a 25% increase in input values. Corresponding changes in outflow concentrations range from -14.5% to +25%. This reflects the fact that variations in factors determining runoff (inflow) concentrations are "canceled out" in computing removal efficiencies. As discussed in Section 1.2, removal efficiencies ("relative predictions") are expected to be more accurate then outflow concentrations or loads ("absolute predictions").

(2) The 'washoff exponent' for impervious surfaces has a high sensitivity ranking for removal efficiencies. Reductions in removal efficiency resulting from a 25% increase in this parameter range from 2.7% to 6.6% for the various devices (exclusive of 'pipe'). Sensitivity reflects the fact that this parameter is an exponent (rather than a coefficient or linear term). The value selected for this parameter (2.0) provides intensity-dependent washoff, as included as an option in the most recent version of SWMM (Huber and Dikinson, 1988). Early versions of SWIM and other models (e.g., STORM) assumed a washoff exponent of 1. The effect of a higher washoff exponent is to attribute a higher portion of the annual washoff load to intense storms, when device residence times and particle removal efficiencies tend to be lower. In essence, use of a higher

Table 5
Input Values for Sensitivity Analysis

```
Note: Each device sized to remove 70% TSS for TYPE2.STM

WATERSHED INPUTS (identical for each device):

 watershed area                     acres    =   100.000
 impervious fraction                         =      .250
 impervious depression storage    inches     =      .020
 scs curve number (pervious portion)         =    74.000
 sweeping frequency             times/week   =      .000
 water quality load factor           -       =     1.000

DEVICE INPUTS - PIPE:

 time of concentration =     2.000 hours

DEVICE INPUTS - WET POND:

 bottom area                 acres   =      .269
 permanent pool area         acres   =      .538
 permanent pool volume       ac-ft   =     1.614
 flood pool area             acres   =      .807
 flood pool volume           ac-ft   =     3.228
 flood pool drain time       hours   =     6.000
 flood pool infiltr. rate    in/hr   =      .500

DEVICE INPUTS - DRY POND:

 bottom area                 acres   =     1.310
 permanent pool area         acres   =     0.000
 permanent pool volume       ac-ft   =     0.000
 flood pool area             acres   =     3.930
 flood pool volume           ac-ft   =    23.583
 flood pool drain time       hours   =     6.000

DEVICE INPUTS - EXTENDED DETENTION POND:

 bottom area                 acres   =      .483
 permanent pool area         acres   =      .000
 permanent pool volume       ac-ft   =      .000
 flood pool area             acres   =     1.448
 flood pool volume           ac-ft   =     8.686
 flood pool drain time       hours   =    24.000

DEVICE INPUTS - INFILTRATION BASIN:

 bottom area                 acres   =      .182
 storage pool area           acres   =      .364
 storage pool volume         ac-ft   =     1.092
 infiltration rate           in/hr   =      .500
 void volume                   %     =   100.000

DEVICE INPUTS - BUFFER/SWALE:

 length of flow path          feet   =   471.223
 slope of flow path            %     =     2.000
 bottom width                 feet   =   100.000
 side slope                ft-h/ft-v =    10.000
 maximum flow depth           feet   =      .500
 infiltration rate           in/hr   =      .500
 mannings n                    -     =      .400

PARTICLE/WATER QUALITY COMPONENT INPUTS :
 see 'NURP50.PAR'
```

Table 6
Sensitivity Analysis Results

Notes: Effects of increasing each input variable by 25% are tabulated
Storm sequence = Providence 1984-1986; Input values given in Table 5
T = input variable type (w = watershed, d = device, p = particle, s = storm
SENS = sensitivity coefficient = % increase in Y / % increase in X (Walker, 1982)

DEVICE = PIPE

T	INPUT VARIABLE	PERCENT REMOVAL	CHANGE	%CH	SENS	OUTFLOW CONC	CHANGE	%CH	SENS
	original run -->	.00				110.9052			
w	watershed area	.00	.00	.00	.000	110.9156	.0104	.01	.000
w	imperv fraction	.00	.00	.00	.000	110.1926	-.7126	-.64	-.026
w	depression stor	.00	.00	.00	.000	111.3883	.4831	.44	.017
w	curve number	.00	.00	.00	.000	112.8956	1.9904	1.79	.072
w	wtshd load fac	.00	.00	.00	.000	138.6315	27.7263	25.00	1.000
d	time of conc	.00	.00	.00	.000	110.8607	-.0444	-.04	-.002
p	accumulation rat	.00	.00	.00	.000	135.0334	24.1282	21.76	.870
p	accum decay	.00	.00	.00	.000	96.7259	-14.1792	-12.79	-.511
p	washoff coeff	.00	.00	.00	.000	116.3339	5.4287	4.89	.196
p	washoff expon	.00	.00	.00	.000	84.9189	-25.9863	-23.43	-.937
p	perv runoff c	.00	.00	.00	.000	114.5033	3.5981	3.24	.130
s	storm volume fac	.00	.00	.00	.000	106.2643	-4.6409	-4.18	-.167
s	storm duration f	.00	.00	.00	.000	101.4222	-9.4830	-8.55	-.342

DEVICE = WET POND

T	INPUT VARIABLE	PERCENT REMOVAL	CHANGE	%CH	SENS	OUTFLOW CONC	CHANGE	%CH	SENS
	original run -->	72.65				30.3631			
w	watershed area	69.75	-2.90	-3.99	-.160	33.5834	3.2203	10.61	.424
w	imperv fraction	71.04	-1.61	-2.22	-.089	31.9484	1.5852	5.22	.209
w	depression stor	72.62	-.04	-.05	-.002	30.5354	.1723	.57	.023
w	curve number	70.99	-1.66	-2.28	-.091	32.7828	2.4196	7.97	.319
w	wtshd load fac	72.65	.00	.00	.000	37.9539	7.5908	25.00	1.000
d	bottom area	72.65	.00	.00	.000	30.3629	-.0002	.00	.000
d	perm pool area	73.93	1.28	1.76	.070	28.9449	-1.4183	-4.67	-.187
d	perm pool volume	73.81	1.16	1.60	.064	29.0679	-1.2952	-4.27	-.171
d	flood pool area	73.24	.59	.81	.032	29.7105	-.6526	-2.15	-.086
d	flood pool vol	72.55	-.10	-.14	-.005	30.4730	.1099	.36	.014
d	drawdown time	73.10	.45	.62	.025	29.8664	-.4967	-1.64	-.065
d	infilt rate	72.68	.03	.04	.002	30.3301	-.0330	-.11	-.004
p	accumulation rat	73.35	.70	.97	.039	36.0211	5.6580	18.63	.745
p	accum decay	72.07	-.58	-.80	-.032	27.0404	-3.3227	-10.94	-.438
p	washoff coeff	73.19	.54	.74	.030	31.2235	.8604	2.83	.113
p	washoff expon	69.45	-3.20	-4.40	-.176	25.9618	-4.4014	-14.50	-.580
p	perv runoff c	71.83	-.83	-1.14	-.046	32.2959	1.9328	6.37	.255
p	settling veloc	74.39	1.74	2.39	.096	28.4378	-1.9254	-6.34	-.254
p	filtration effic	72.69	.03	.04	.002	30.3270	-.0361	-.12	-.005
s	storm volume fac	66.95	-5.70	-7.85	-.314	35.1560	4.7929	15.79	.631
s	storm duration f	73.57	.91	1.26	.050	26.8351	-3.5280	-11.62	-.465

DEVICE = DRY POND

T	INPUT VARIABLE	PERCENT REMOVAL	CHANGE	%CH	SENS	OUTFLOW CONC	CHANGE	%CH	SENS
	original run -->	72.64				30.3795			
w	watershed area	70.61	-2.03	-2.80	-.112	32.6384	2.2588	7.44	.297
w	imperv fraction	71.43	-1.21	-1.67	-.067	31.5186	1.1391	3.75	.150
w	depression stor	72.58	-.06	-.09	-.003	30.5818	.2022	.67	.027
w	curve number	71.54	-1.11	-1.52	-.061	32.1734	1.7938	5.90	.236
w	wtshd load fac	72.64	.00	.00	.000	37.9744	7.5949	25.00	1.000
d	bottom area	74.62	1.98	2.73	.109	28.1781	-2.2014	-7.25	-.290
d	flood pool area	72.90	.26	.36	.014	30.0886	-.2910	-.96	-.038
d	flood pool vol	72.47	-.17	-.23	-.009	30.5683	.1887	.62	.025
d	drawdown time	73.52	.88	1.21	.048	29.4057	-.9738	-3.21	-.128
p	accumulation rat	73.14	.50	.69	.028	36.3081	5.9286	19.51	.781
p	accum decay	72.20	-.44	-.61	-.024	26.9254	-3.4542	-11.37	-.455
p	washoff coeff	73.30	.66	.90	.036	31.1032	.7237	2.38	.095
p	washoff expon	69.13	-3.51	-4.83	-.193	26.2435	-4.1360	-13.61	-.545
p	perv runoff c	72.05	-.59	-.82	-.033	32.0459	1.6663	5.49	.219
p	settling veloc	74.68	2.04	2.81	.112	28.1170	-2.2626	-7.45	-.298
s	storm volume fac	69.29	-3.35	-4.61	-.184	32.6620	2.2824	7.51	.301
s	storm duration f	73.73	1.08	1.49	.060	26.6787	-3.7008	-12.18	-.487

(ct.)

Sensitivity Analysis Results (ct)

DEVICE = EXTENDED DETENTION POND

T	INPUT VARIABLE	PERCENT REMOVAL	CHANGE	%CH	SENS	OUTFLOW CONC	CHANGE	%CH	SENS
	original run -->	71.48				31.7144			
w	watershed area	69.64	-1.83	-2.56	-.102	33.7506	2.0362	6.42	.257
w	imperv fraction	70.53	-.95	-1.32	-.053	32.5484	.8340	2.63	.105
w	depression stor	71.43	-.04	-.06	-.002	31.8999	.1854	.58	.023
w	curve number	70.55	-.93	-1.30	-.052	33.3577	1.6433	5.18	.207
w	wtshd load fac	71.48	.00	.00	.000	39.6430	7.9286	25.00	1.000
d	bottom area	72.97	1.49	2.09	.084	30.0534	-1.6611	-5.24	-.210
d	flood pool area	72.29	.82	1.14	.046	30.8072	-.9072	-2.86	-.114
d	flood pool vol	70.96	-.52	-.72	-.029	32.2879	.5735	1.81	.072
d	drawdown time	72.91	1.43	2.01	.080	30.1208	-1.5936	-5.02	-.201
p	accumulation rat	71.89	.41	.58	.023	38.0058	6.2913	19.84	.793
p	accum decay	71.11	-.36	-.51	-.020	28.0422	-3.6722	-11.58	-.463
p	washoff coeff	72.00	.53	.74	.030	32.6404	.9260	2.92	.117
p	washoff expon	68.82	-2.65	-3.71	-.149	26.5977	-5.1167	-16.13	-.645
p	perv runoff c	70.99	-.49	-.68	-.027	33.3517	1.6373	5.16	.207
p	settling veloc	73.57	2.09	2.93	.117	29.3879	-2.3265	-7.34	-.293
s	storm volume fac	68.31	-3.17	-4.43	-.177	33.8773	2.1629	6.82	.273
s	storm duration f	71.97	.50	.69	.028	28.4685	-3.2459	-10.23	-.409

DEVICE = INFILTRATION BASIN

T	INPUT VARIABLE	PERCENT REMOVAL	CHANGE	%CH	SENS	OUTFLOW CONC	CHANGE	%CH	SENS
	original run -->	78.74				23.6115			
w	watershed area	73.26	-5.48	-6.96	-.278	29.6931	6.0816	25.76	1.030
w	imperv fraction	75.18	-3.55	-4.51	-.181	27.3786	3.7671	15.95	.638
w	depression stor	78.73	-.01	-.01	-.000	23.7222	.1107	.47	.019
w	curve number	75.96	-2.78	-3.53	-.141	27.1716	3.5601	15.08	.603
w	wtshd load fac	78.74	.00	.00	.000	29.5144	5.9029	25.00	1.000
d	bottom area	79.03	.29	.37	.015	23.2875	-.3240	-1.37	-.055
d	flood pool area	80.51	1.77	2.25	.090	21.6407	-1.9708	-8.35	-.334
d	flood pool vol	81.55	2.82	3.58	.143	20.4846	-3.1269	-13.24	-.530
d	infilt rate	79.68	.94	1.20	.048	22.5651	-1.0464	-4.43	-.177
p	accumulation rat	79.96	1.22	1.55	.062	27.0977	3.4862	14.76	.591
p	accum decay	77.65	-1.09	-1.38	-.055	21.6457	-1.9658	-8.33	-.333
p	washoff coeff	79.94	1.20	1.53	.061	23.3688	-.2427	-1.03	-.041
p	washoff expon	72.17	-6.57	-8.34	-.334	23.6596	.0481	.20	.008
p	perv runoff c	77.30	-1.44	-1.83	-.073	26.0282	2.4167	10.24	.409
p	settling veloc	79.81	1.08	1.37	.055	22.4165	-1.1950	-5.06	-.202
p	filtration effic	80.98	2.24	2.85	.114	21.1237	-2.4878	-10.54	-.421
s	storm volume fac	69.45	-9.29	-11.80	-.472	32.4997	8.8882	37.64	1.506
s	storm duration f	79.72	.99	1.25	.050	20.5904	-3.0211	-12.80	-.512

DEVICE = BUFFER STRIP / SWALE

T	INPUT VARIABLE	PERCENT REMOVAL	CHANGE	%CH	SENS	OUTFLOW CONC	CHANGE	%CH	SENS
	original run -->	73.84				29.0381			
w	watershed area	70.71	-3.14	-4.25	-.170	32.5221	3.4840	12.00	.480
w	imperv fraction	72.02	-1.82	-2.47	-.099	30.8630	1.8249	6.28	.251
w	depression stor	73.76	-.08	-.11	-.005	29.2573	.2192	.75	.030
w	curve number	72.02	-1.82	-2.46	-.099	31.6140	2.5759	8.87	.355
w	wtshd load fac	73.84	.00	.00	.000	36.2976	7.2595	25.00	1.000
d	infilt rate	75.07	1.23	1.66	.066	27.6703	-1.3678	-4.71	-.188
d	buffer length	77.58	3.74	5.07	.203	24.8827	-4.1554	-14.31	-.572
d	buffer width	76.89	3.05	4.13	.165	25.6488	-3.3893	-11.67	-.467
d	buf side slope	73.97	.13	.18	.007	28.8946	-.1435	-.49	-.020
d	mannings n	74.44	.60	.81	.032	28.3755	-.6626	-2.28	-.091
d	buffer slope	73.56	-.28	-.38	-.015	29.3497	.3116	1.07	.043
d	buffer max depth	73.91	.07	.09	.004	28.9657	-.0724	-.25	-.010
p	accumulation rat	74.63	.78	1.06	.042	34.2967	5.2586	18.11	.724
p	accum decay	73.15	-.69	-.94	-.037	25.9953	-3.0428	-10.48	-.419
p	washoff coeff	74.84	.99	1.35	.054	29.3024	.2643	.91	.036
p	washoff expon	68.38	-5.46	-7.40	-.296	26.8795	-2.1586	-7.43	-.297
p	perv runoff c	72.92	-.92	-1.25	-.050	31.0391	2.0009	6.89	.276
p	settling veloc	75.52	1.68	2.28	.091	27.1721	-1.8660	-6.43	-.257
p	filtration effic	75.30	1.46	1.98	.079	27.4178	-1.6203	-5.58	-.223
s	storm volume fac	68.44	-5.40	-7.32	-.293	33.5679	4.5298	15.60	.624
s	storm duration f	75.99	2.15	2.91	.116	24.3719	-4.6662	-16.07	-.643

washoff exponent (2 vs. 1) decreases the importance of first-flush responses over long storm time series. This will cause conservative estimation of particle removal efficiencies below watersheds which have strong first-flush responses.

(3) Changes in removal efficiency resulting from a 25% increase in particle settling velocities range from +1.7% to +2.4%. Although settling velocity ranks high in relation to other input values, the degree of sensitivity is low.

(4) Removal efficiencies are more sensitive to storm volume (-3.1% to -9.3%) than to storm duration (+.5% to +2.2%). This reflects the fact that removals are more dependent upon the total runoff volume (e.g., "quiescent removal", V_b/V_r relationships) than to overflow rate during storm periods ("dynamic conditions", Driscoll, 1983). Because it has the lowest effective storage volume, the swale/buffer has the highest sensitivity to storm duration (2.2% increase removal efficiency for a 25% increase in storm duration). The low sensitivity to storm duration (or intensity) means that removal efficiencies will be insensitive to errors in predicting the temporal distribution of runoff flows and loads within storm events (e.g., time of concentration, watershed lag).

7.3 Watershed-Scale Application

This section describes calibration and testing of the model against measured streamflows in the Hunt-Potowomut watershed. Watershed characteristics derived from GIS data bases are summarized in Table 7. Segmentation of the model to predict surface runoff and baseflow at the mouth of the watershed is illustrated in Figure 12. An 'AQUIFER' device is used to simulate baseflow and a 'PIPE' is used to collect surface runoff. Outflows from these devices are routed to a second 'PIPE' for prediction of total streamflow. The model has been calibrated against streamflows measured by the USGS (Gauge 01117000) for Water Years 1981-1983 and tested against data for Water Years 1984-1986.

Calibration involves adjusting times of concentration for baseflow and surface runoff to match observed peak flows over various averaging intervals. Observations and predictions are compared using the 'RC' (= 'Run Calibrate') procedure, as illustrated in Figure 13. The baseflow time of concentration (700 hours or ~ 30 days) has been calibrated against the measured 30-day-moving-average peak flow for Water Years 1981-1983 (~230 cfs, April 1983). The 30-day-moving average is used for baseflow calibration because it is insensitive to runoff time of concentration (much shorter than 30 days). The surface runoff time of concentration (70 hours) has been calibrated against the instantaneous peak flow observed on April 11, 1983 at 4:30 am (968 cfs). As shown in Figure 14, the model accurately predicts both the magnitude and the time of this peak with the calibrated times of concentration.

Results of model testing against measured daily streamflows for Water Years 1984-1986 are shown in Figures 15 and 16. Observed and predicted monthly total flows (expressed in inches over entire watershed) for the

Table 7
Input Values for Hunt-Potowomut Watershed

Watershed	Total Area acres	Imperv. Fraction -	Dominant Soil Grp -	Perv. Curve No. -
Mauny Frenchtown	4486.6	0.049	B	58
Fry Brook	1986.8	0.093	B	58
Sandhill River	2351.2	0.126	A	32
Hunt River	2621.5	0.140	A	32
Unnamed - 2	918.1	0.015	B	58
Scrabbletown	1727.6	0.055	A/B	45
Unnamed - 1	603.6	0.210	A/B	45
Total	14695.4	0.089		

Figure 12

P8 APPLICATION TO HUNT-POTOWOMUT WATERSHED

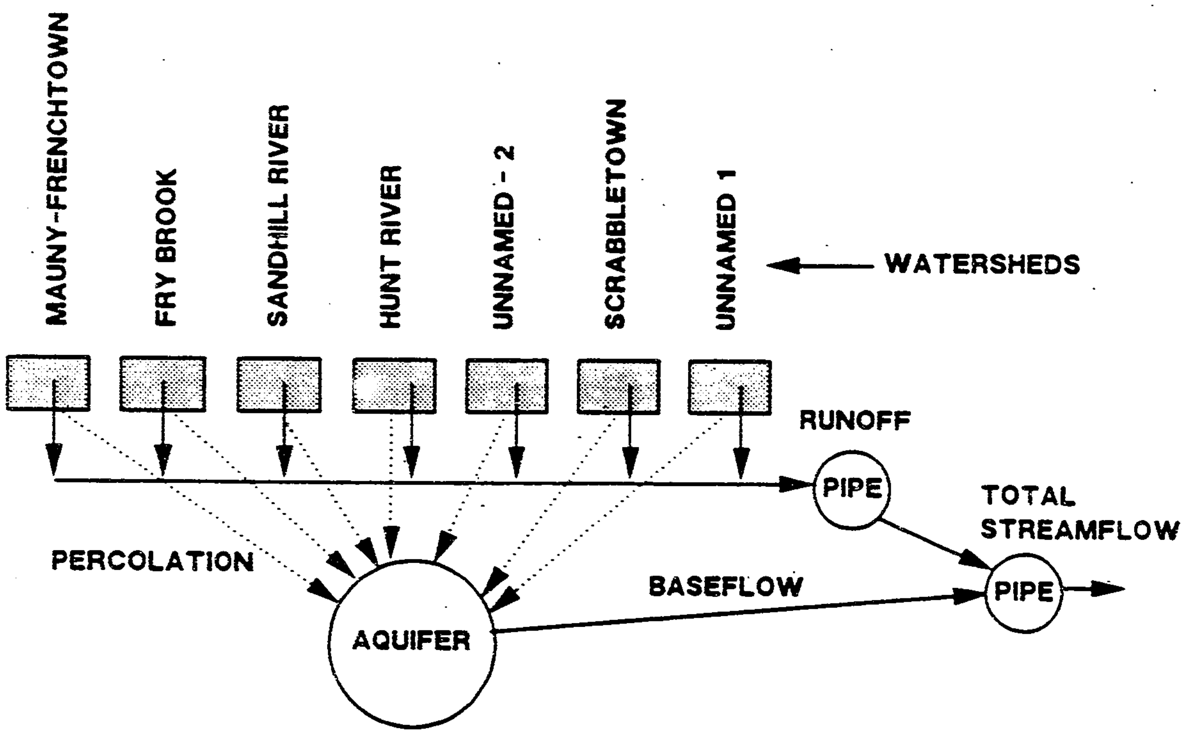


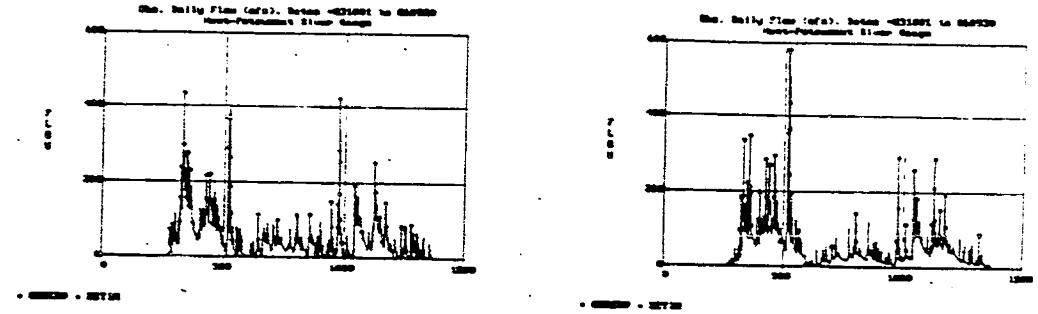
Figure 13
Predicted and Observed Flows - Hunt-Potowomut River
Calibration Period - Water Years 1981-1983

X-Axis = Julian Days from 12/31/80
Y-Axis = Streamflow (cfs)

PREDICTED - WY 1984-1986
DAILY FLOWS

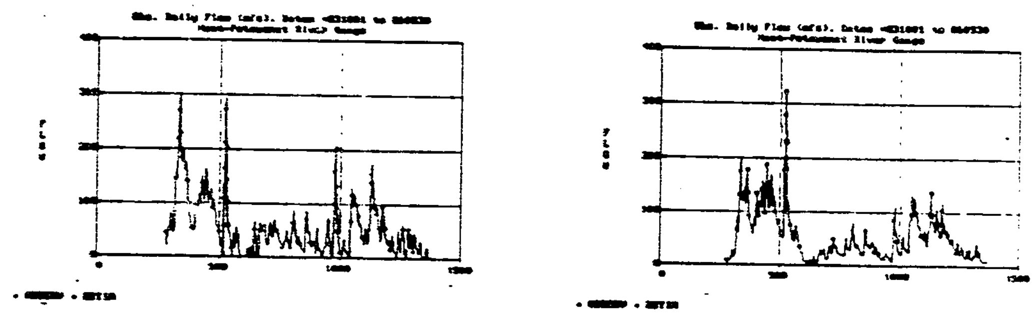
OBSERVED - WY 1984-1986

R^2 = .79
SE = 31.1



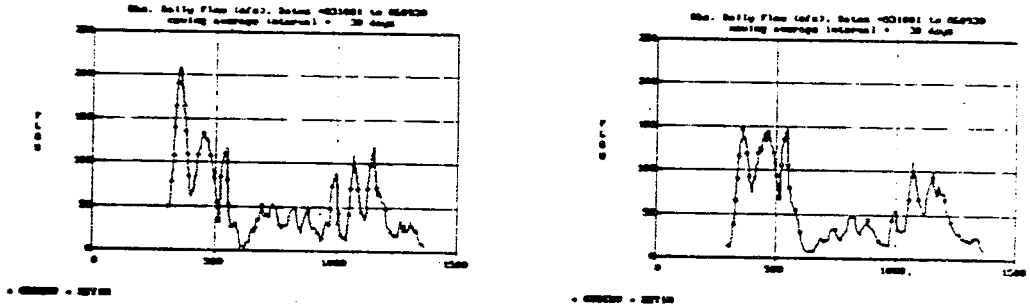
7-DAY MOVING AVERAGE

R^2 = .79
SE = 26.3



30-DAY MOVING AVERAGE

R^2 = .80
SE = 22.3



180-DAY MOVING AVERAGE

R^2 = .83
SE = 13.8

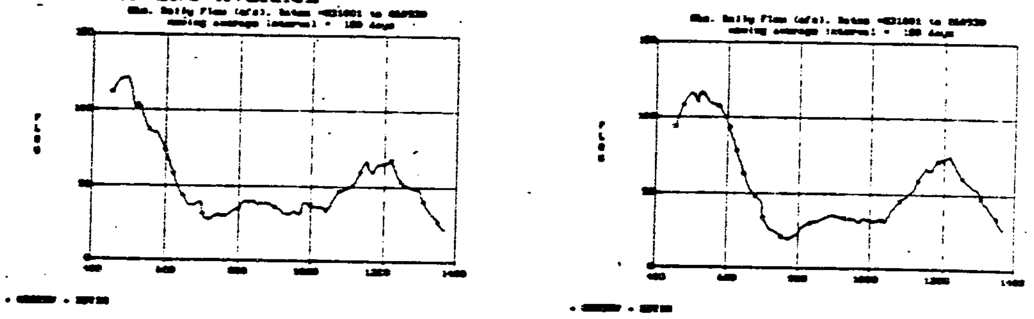


Figure 14
Predicted Instantaneous Peak Flow - Hunt-Potowomut River

PREDICTED PEAK FLOW
APRIL 11, 1983 4:30 AM
JULIAN HOUR = 28,708 (FROM 12/31/79)
OBSERVED PEAK = 968 CFS

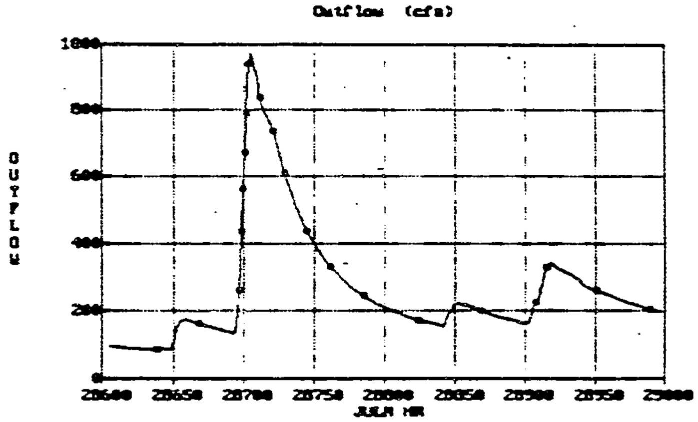


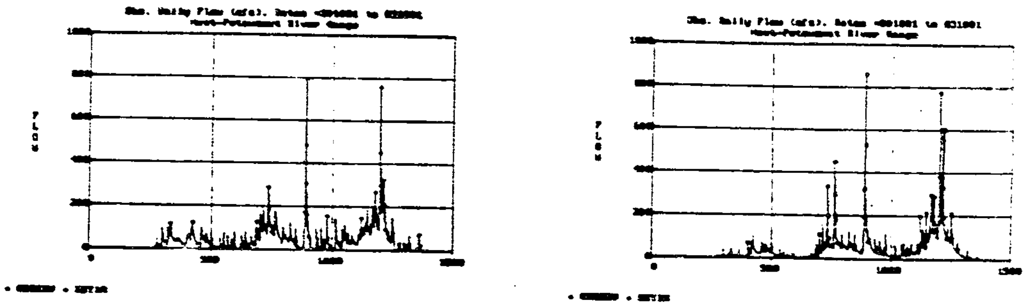
Figure 15
Predicted and Observed Flows - Hunt-Potowomut River
Verification Period - Water Years 1984-1986

X-Axis = Julian Days from 12/31/83
Y-Axis = Streamflow (cfs)

PREDICTED - WY 1981-1983
DAILY FLOWS

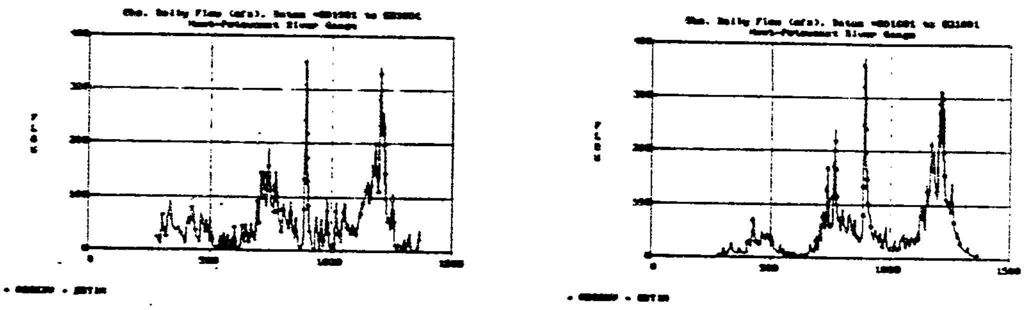
OBSERVED - WY 1981-1983

R^2 = .70
SE = 29



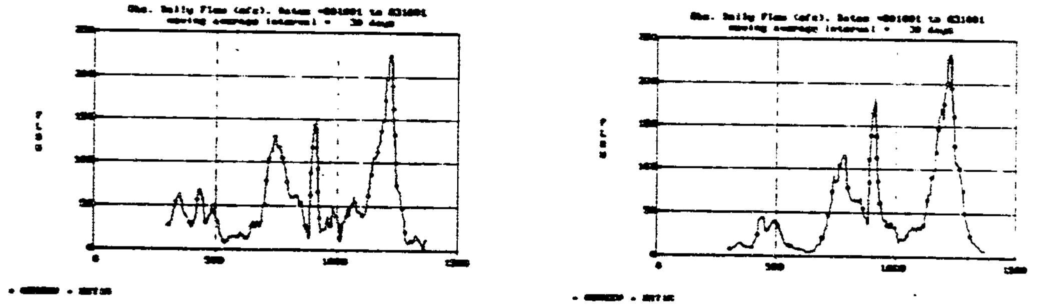
7-DAY MOVING AVERAGE

R^2 = .70
SE = 25



30-DAY MOVING AVERAGE

R^2 = .70
SE = 21.3



180-DAY MOVING AVERAGE

R^2 = .87
SE = 10.2

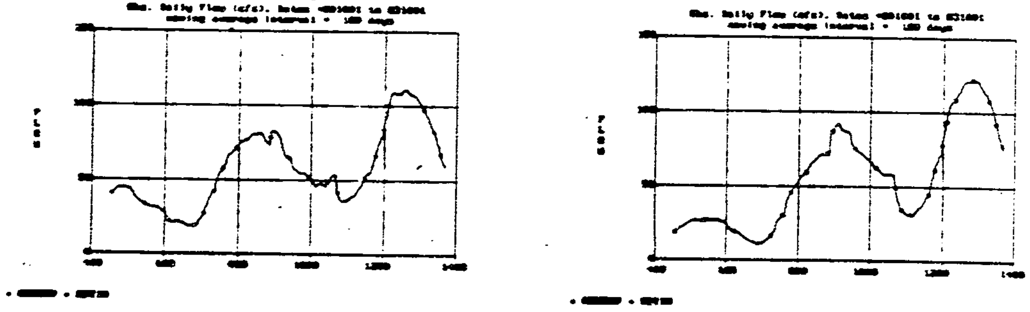


Figure 16
Observed and Predicted Mean Daily Flows

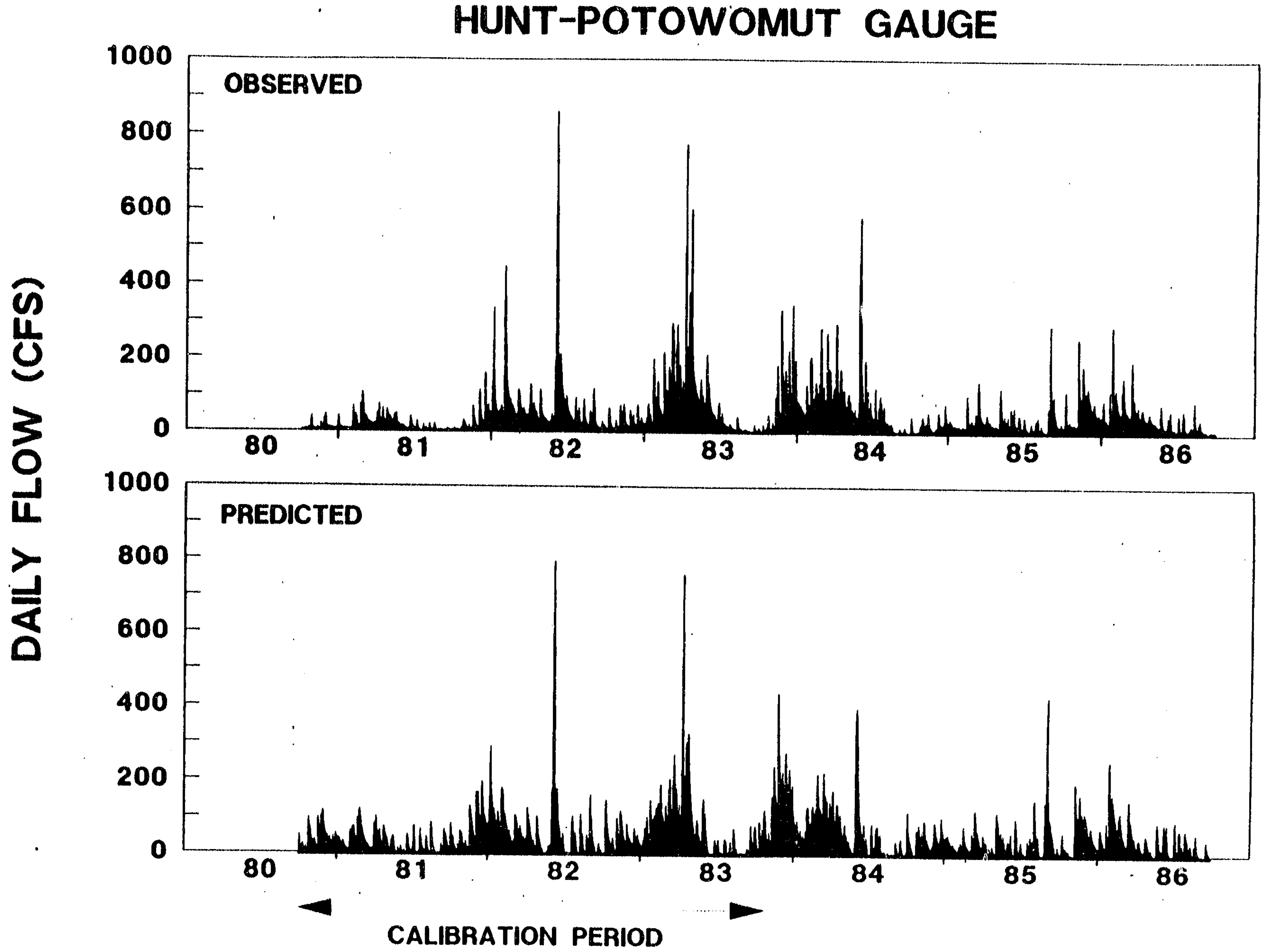


Figure 17
Observed and Predicted Monthly Total Streamflow

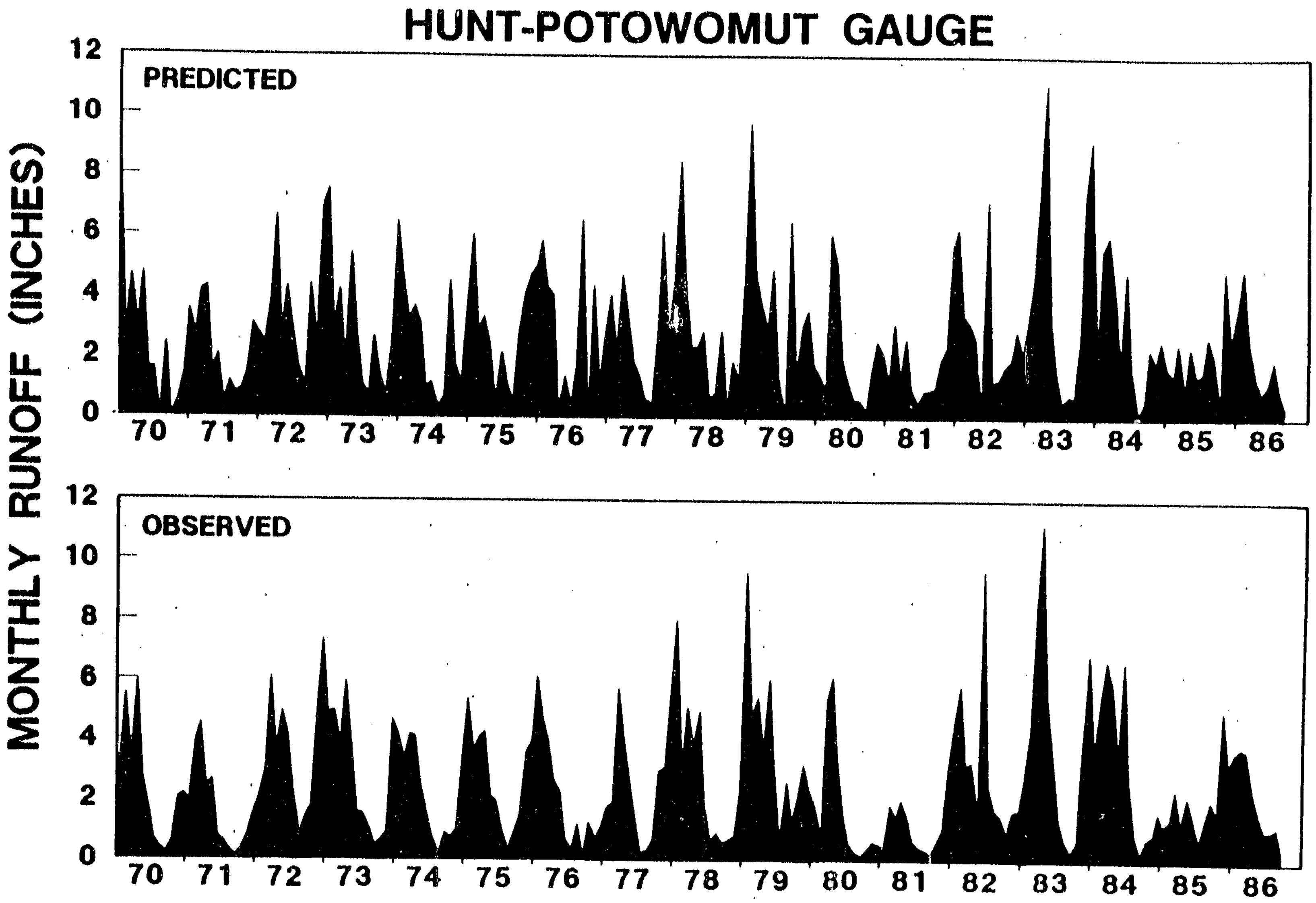
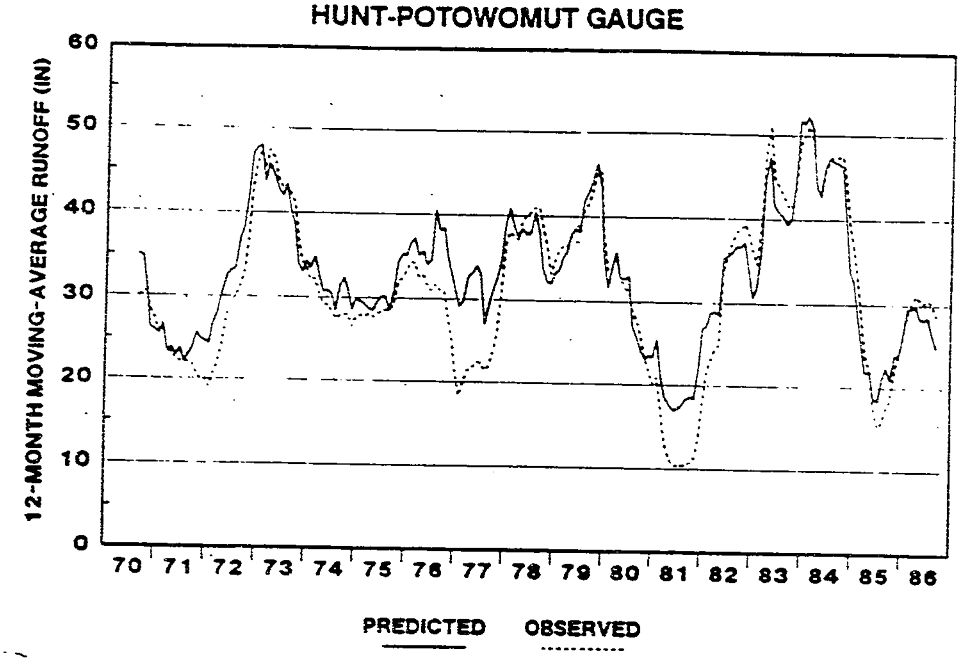


Figure 18
Observed and Predicted 12-Month Moving-Average Streamflow



entire period of flow record (Water Years 1970-1986) are compared in Figure 17. Yearly moving-average flows are compared in Figure 18. The model over-predicts yearly-mean flows during drought periods (1971, 1977, 1981). This may be related to errors in the prediction of evapotranspiration or to the effects of diversion from the watershed for water supply purposes (not considered in simulations). The USGS (1977) reports that measured flows are affected by water supply diversions for East Greenwich, North Kingstown, Warwick, and Quonset Point (magnitudes of diversions not reported). Such diversions would tend to have greater impacts on measured streamflows during drought periods. Provision for flow diversions into or out of watersheds is suggested for future versions of the model; diversions would tend to be more important for simulation of large watersheds, as compared with simulations of individual urban developments.

The above comparisons support the structure and calibration of the hydrologic components of the model for predicting streamflow. Calibration and testing of water quality components against site-specific data (site-scale and watershed-scale) are recommended for future work.

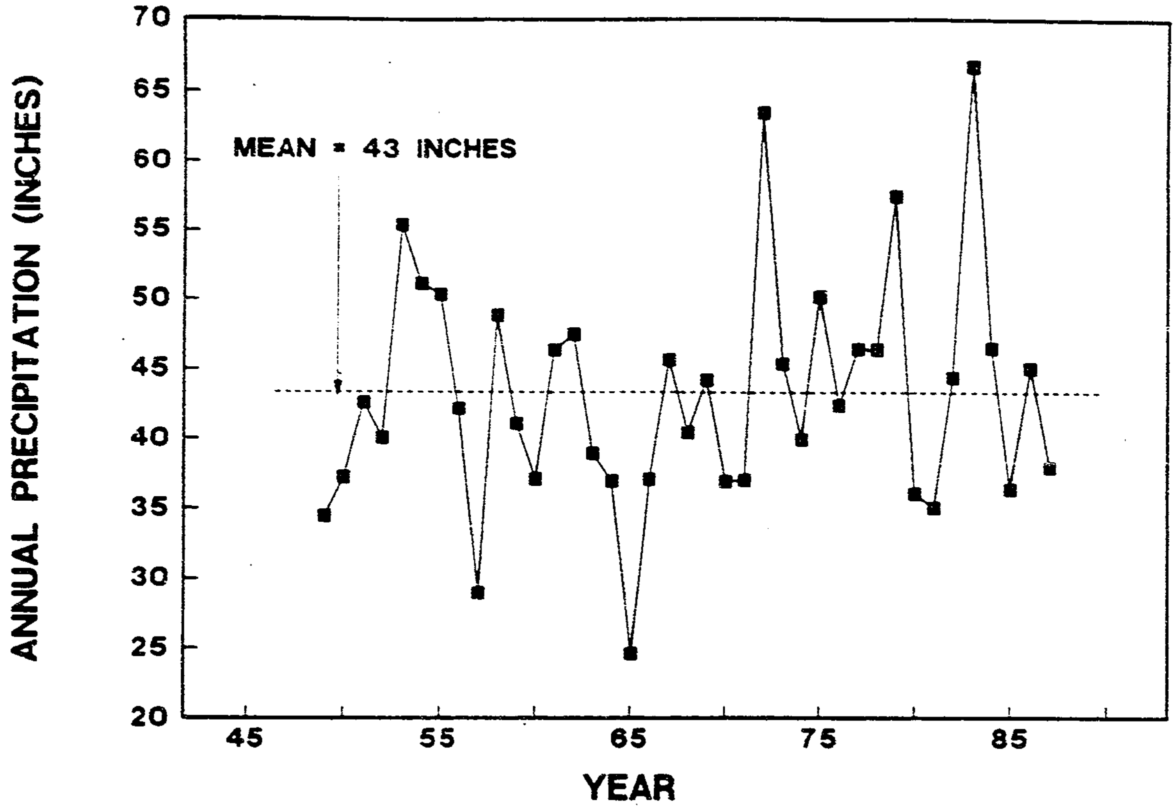
7.4 Effects of Precipitation Variations

Climatologic variations influence the quantity and quality of watershed runoff and the performance of runoff treatment devices. This section evaluates these variations using the entire precipitation record from Providence Airport (1948-1988). Results have implications for selecting appropriate time periods for simulating device performance, given the objective of estimating longterm means and/or extremes.

Figure 19 shows yearly variations in precipitation and flow-weighted-mean total suspended solids concentration. Simulations are for a typical urban watershed (25% impervious, pervious curve number = 74, NURP50.PAR parameter estimates). An inverse relationship between annual precipitation and mean TSS concentration is apparent. This reflects washoff dynamics inherent in the particle parameter estimates.

The simulated loads have been routed through five treatment devices, each initially sized for 70% TSS removal from a 1-inch, 24-hour, SCS Type-2 storm with a 75-hour time between storm midpoints. These are the same devices used in the sensitivity analysis discussed in Section 7.2. Figure 20 shows predicted longterm average removal efficiencies for TSS, fine particles (P10%), and dissolved species (P0%). Removal of dissolved species (filtration) occurs only in the infiltration basin and buffer strip. Longterm average TSS removal efficiencies range from 71.6% (extended detention pond) to 78.9% (infiltration basin), as compared with the 70% initial design basis. This indicates that the 1-inch, Type-2 storm provides a conservative basis for estimating longterm average TSS removal efficiency, particularly for infiltration basins. The advantage of using the 1-inch storm (in place of simulating the entire rainfall record) is that it requires much less computer time. The 1-inch storm can be used in preliminary design calculations to evaluate compliance with TSS removal objectives. Final evaluations should be based upon simulation of historical records (choice of time periods discussed below). Results are relatively insensitive to intensity distribution within the storm (e.g.,

Figure 19
Yearly Precipitation and Mean Runoff TSS Concentration



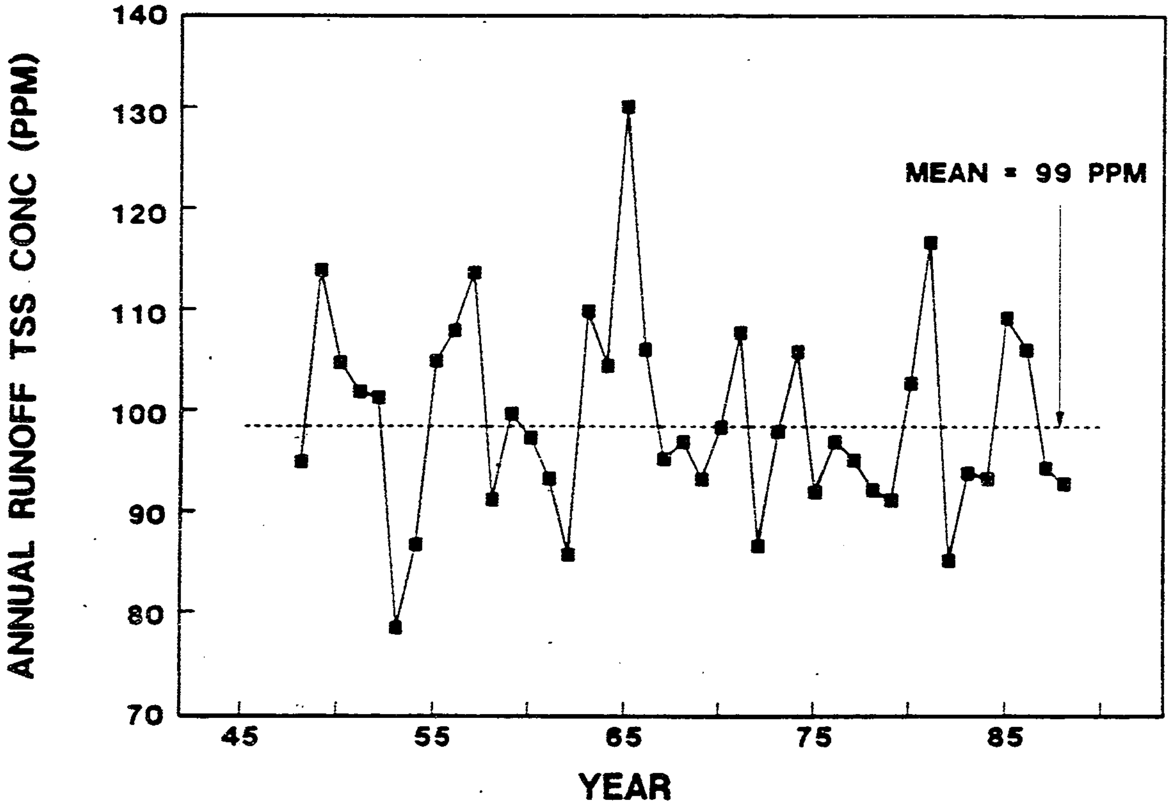
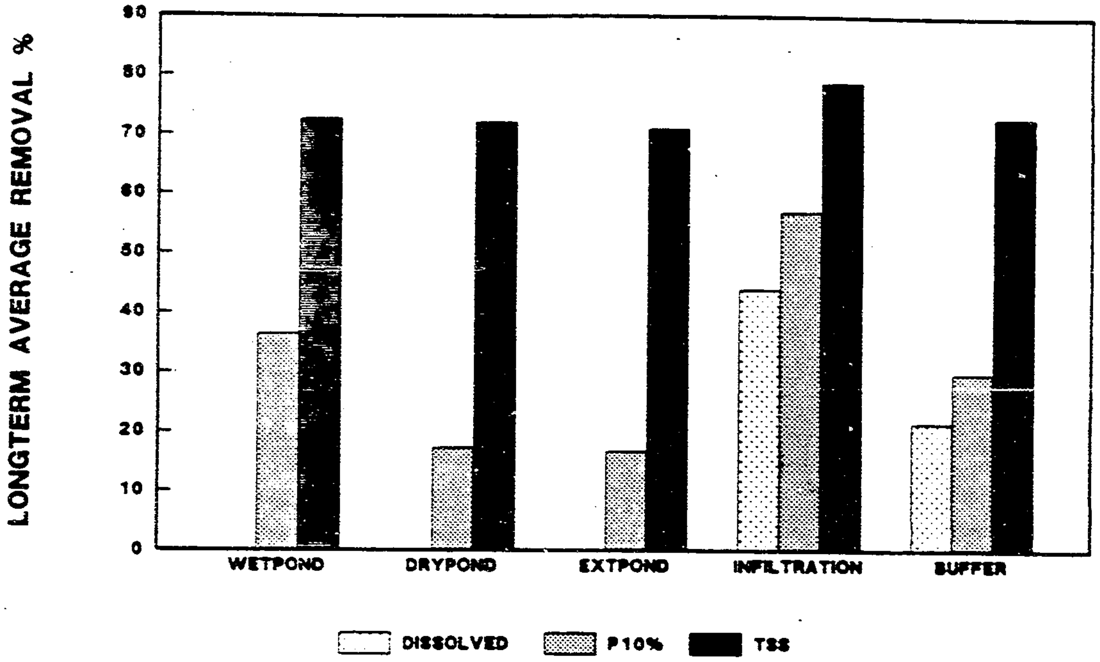


Figure 20
Longterm Average Removal Efficiencies for Dissolved Species, Fine Particles, and Total Suspended Solids



DEVICES DESIGNED FOR 70% TSS REMOVAL, 1-INCH, 24-HR TYPE2 STORM
LONGTERM AVERAGE REMOVALS COMPUTED USING PROVIDENCE 1948-87 RAINFALL

Type-2 vs. Type-3 vs. triangular). The Type-2 distribution has been selected arbitrarily.

Figure 21 shows yearly variations in TSS and fine particle (P10%) removal in each device. The strong year-to-year covariance in these time series reflects the influences of storm intensity and volume on device performance. It is apparent from Figures 20 and 21 that devices sized to achieve a given TSS removal objective will not necessarily have the same removal efficiencies for fine particles (or dissolved species). The dry pond and extended ponds, in particular, are considerably less effective than the other devices at removing fine particles at a given TSS removal. This is one important limitation of using TSS removal as the exclusive design objective. It may be more desirable to target a specific particle class. This limitation is discussed further in Section 8.0.

Figures 22 and 23 show yearly variations in TSS removal and outflow TSS concentrations for each device, respectively. Values are expressed as deviations from the 1948-1988 means. These plots can be used to identify years in which predicted removal efficiencies and outflow quality are similar to longterm averages. For years 1951, 1968, 1974, 1976, and 1980, both removal efficiencies and outflow concentrations are within two units (% or ppm) of the longterm mean for each device type. Results are similar for individual particle fractions. Annual rainfall was also within 2-inches of the longterm mean (43 in/yr) in 1951, 1968, and 1976. These years are logical choices for evaluating BMP's, given the objective of estimating the longterm-average removal efficiency or outflow quality. "Worst-case" (wet) years would include 1955, 1979, and 1983. "Best-case" (dry) years would include 1965 and 1981.

8.0 TREATMENT CRITERIA

As discussed in the Section 1.3, the primary intended use of the program is for designing BMP's to achieve compliance with removal objectives, expressed in terms of removal efficiency for a given particle class and time period. Appendix E outlines suggested procedures for using the model to design BMP(s) for a given site and objective. RIDEM (1988) has recommended two longterm TSS removal objectives (70% and 85%), depending upon receiving water characteristics. This section describes typical device designs to achieve these objectives and examines the water quality implications of meeting these objectives.

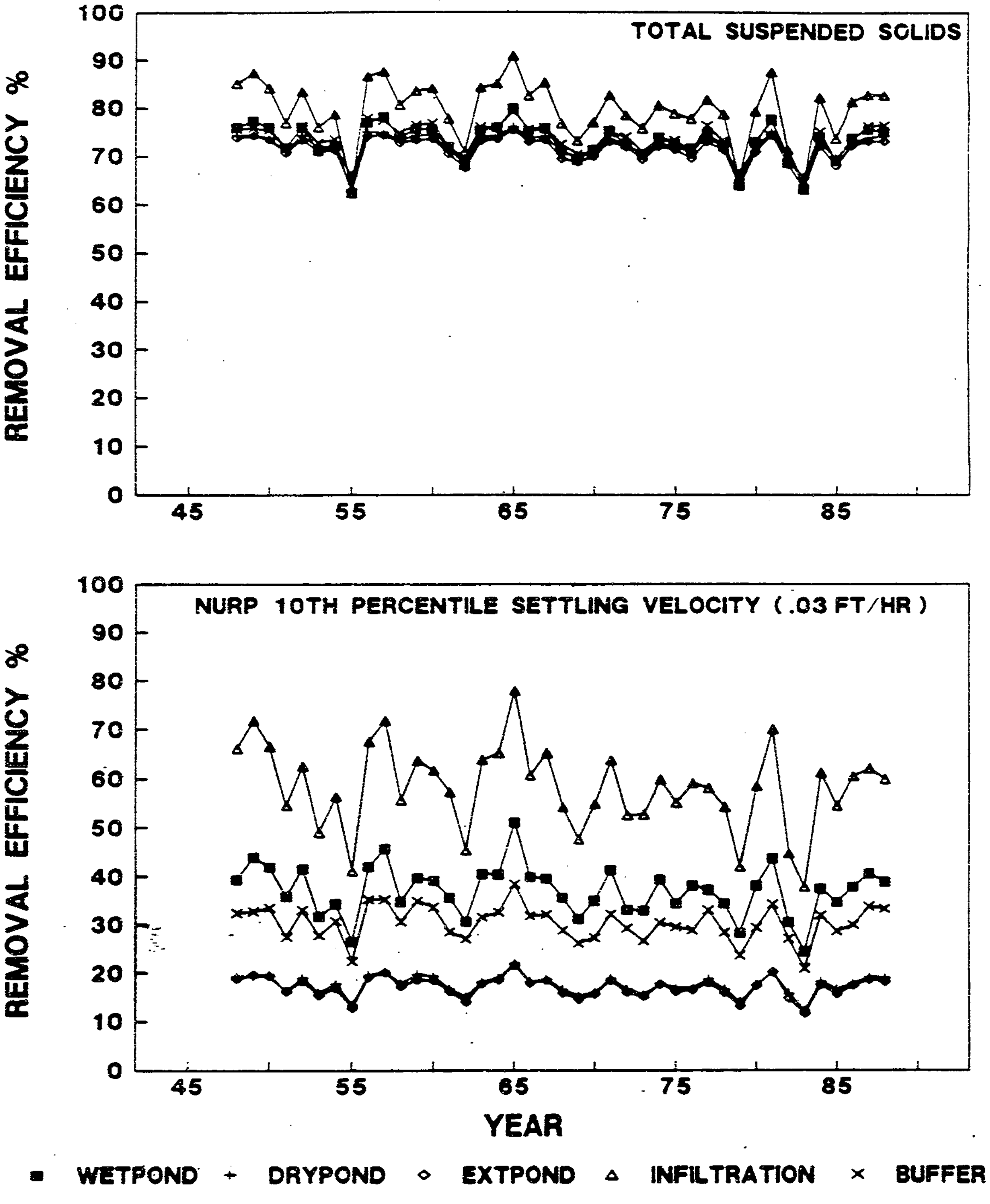
The model has been used to size four basic device types to achieve 70% and 85% TSS removal for an average year. Based upon results in Section 7.4, precipitation data from 1980 have been used for this purpose. The following device types have been considered:

(1) Wet detention ponds with mean depths of 2, 3.5 and 5 feet.

(2) Dry detention ponds with flood pool mean depths of 3.5 feet and drawdown times of 3, 6, 12, 24, and 48 hours.

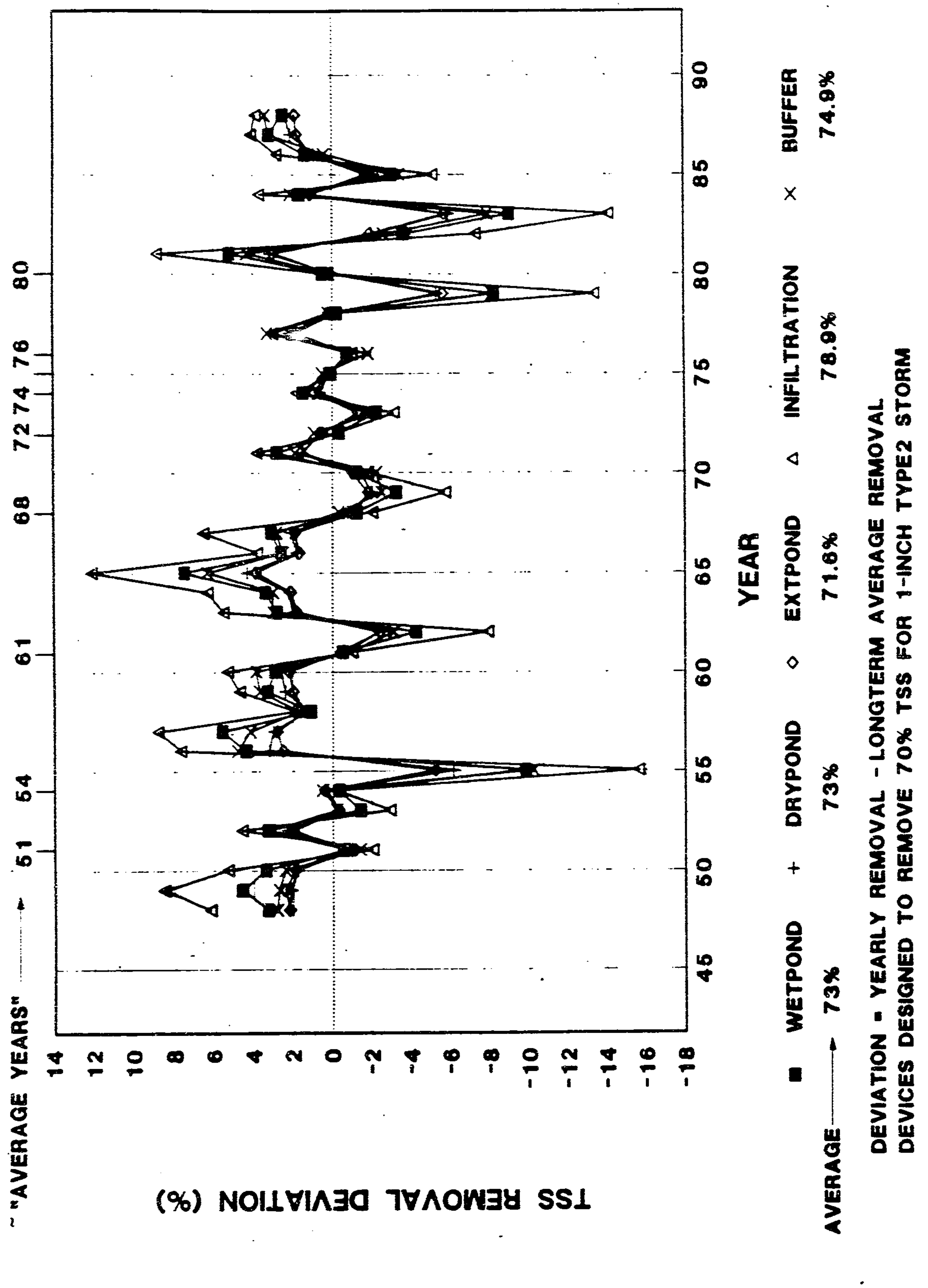
(3) Infiltration basins with infiltration rates of .1, .25, .5, and 1.0 inches/hr and maximum drawdown time of 72 hours (maximum

Figure 21
Yearly Variations in TSS and Fine Particle Removal Efficiency



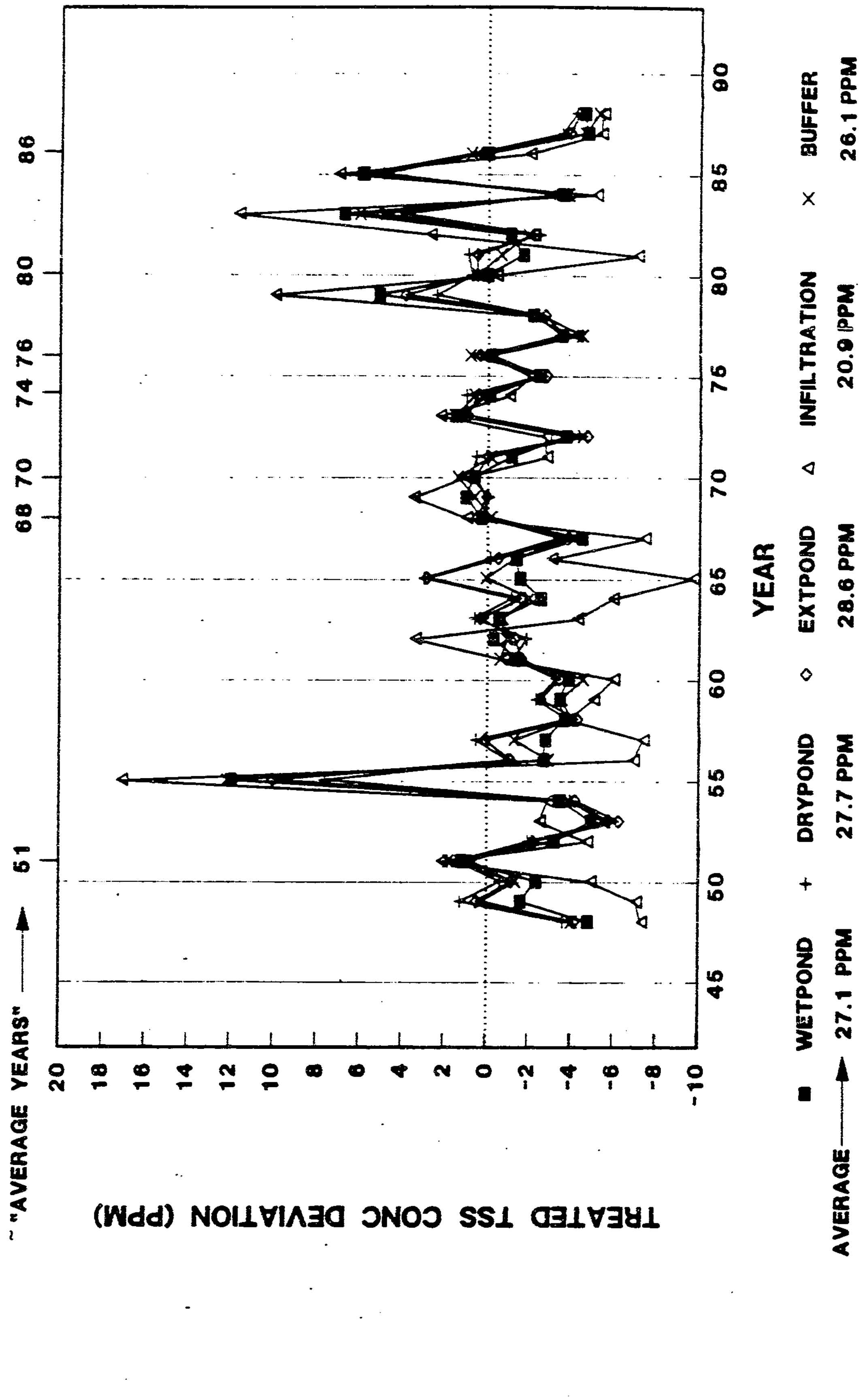
DEVICES DESIGNED FOR 70% TSS REMOVAL, 1-INCH, 24-HR TYPE2 STORM

Figure 22
Yearly Deviations from Longterm Average TSS Removal



DEVIATION = YEARLY REMOVAL - LONGTERM AVERAGE REMOVAL
DEVICES DESIGNED TO REMOVE 70% TSS FOR 1-INCH TYPE2 STORM

Figure 23
Yearly Deviations from Longterm Average TSS Outflow Concentration



DEVIATION = YEARLY MEAN OUTFLOW CONC - LONGTERM AVERAGE OUTFLOW CONC
DEVICES DESIGNED TO REMOVE 70% TSS FOR 1-INCH TYPE2 STORM

drawdown time and infiltration rate determine maximum depth of storage volume).

(4) Buffer strips with infiltration rates of 0, .25, .5, and 1.0 inches/yr and slope of 2% and manning's n of .2.

This is not intended to be a comprehensive list of all possible device types. Alternative designs can be investigated using the model and approach described below.

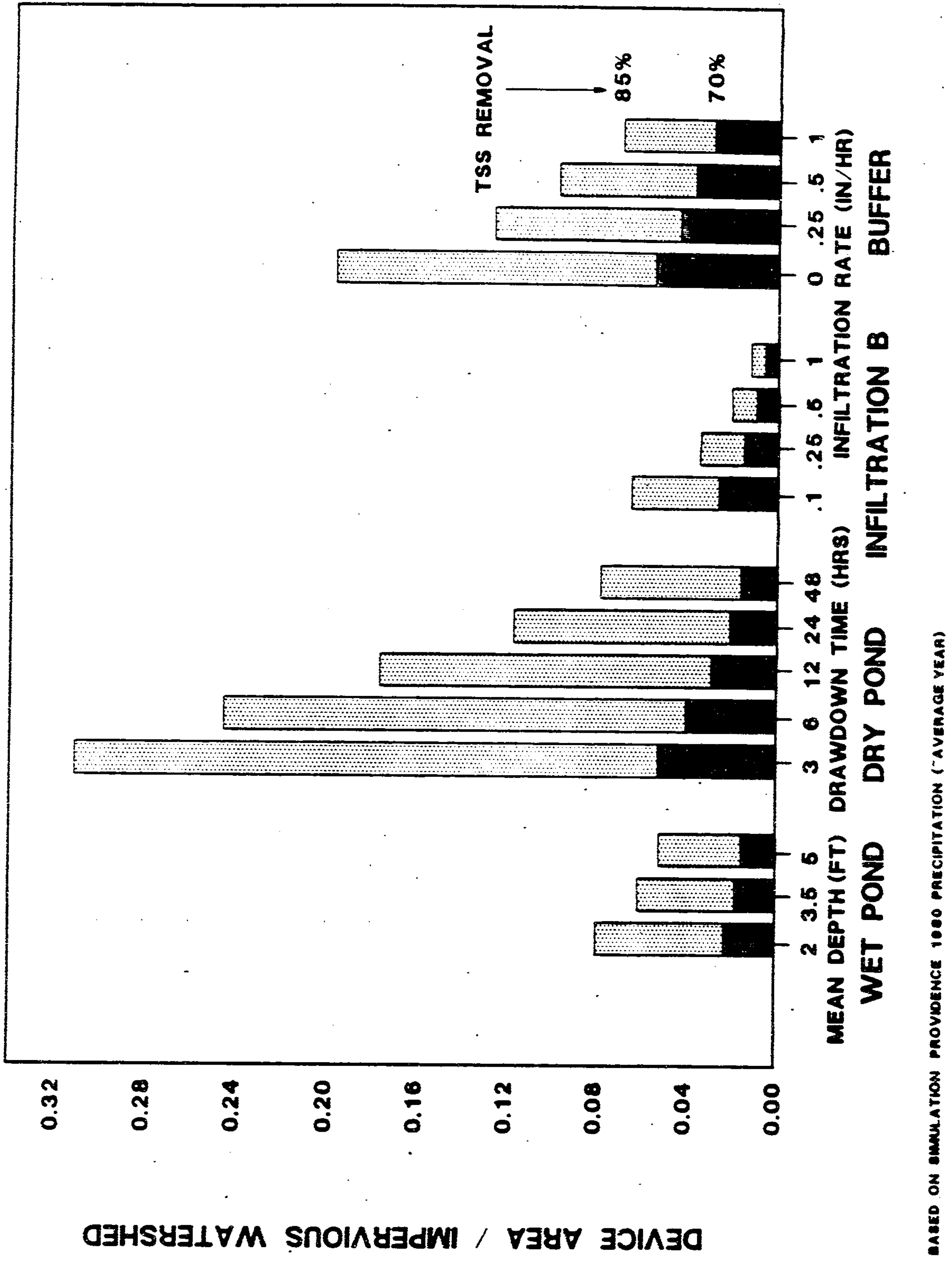
The model's 'Run Design Tune' procedure, has been used to estimate the area of each device required to achieve each treatment objective for 1980 rainfall. Each device treats runoff from a watershed with 25% imperviousness and pervious curve number of 74. Resulting device dimensions are expressed in terms of ratio of device surface area to impervious watershed area. Relative areas are plotted in Figure 24. Any of these devices can be rescaled to a user-defined watershed by applying the 'Run Design Lookup' procedure (see Section 4.2).

Removal efficiencies and average outflow concentrations for each particle class, water quality component, and device are summarized in Tables 8 and 9 for TSS removals of 70% and 85%, respectively. Because of differences in dynamics, different device types designed to achieve the same total suspended solids removal will not necessarily have the same removal efficiency for each particle class or the same distribution of outflow quality. This is also apparent in Figure 21.

One important factor is the reduction in concentration variability which is achieved in devices with appreciable storage volume (e.g., wet ponds), as compared with devices without storage (e.g., buffers, dry ponds). This reduction in variability causes maximum outflow concentrations to be lower in ponds, as compared with buffers, even though mean concentrations may be similar. For example, compare mean and maximum outflow copper concentrations in wet detention ponds (~.018 and ~.021 ppm) with values for buffer strips (~.013 and ~.027) for the same TSS removal objective (Table 9). NURP identified copper as a key urban runoff contaminant based upon comparison of typical runoff concentrations with aquatic toxicity criteria (Athayede et al., 1983). A concentration of .02 ppm was proposed as an appropriate criterion for onset of toxic effects attributed to intermittent exposure in soft waters.

Figure 25 justifies the 85% TSS removal objective based upon predicted violation frequencies of the NURP .02 ppm copper criterion. Copper violation frequency is plotted against TSS removal efficiency, based upon simulation of wet detention ponds with a range of basin/watershed area ratios and 1980 rainfall. At low solids removal efficiencies, violation frequency averages ~70%, which essentially reflects the distribution of untreated runoff concentrations simulated by the model. As TSS removal efficiency increases, violation frequency decreases and drops below ~5% at or above a TSS removal of ~85%. A similar relationship is shown for fine particle removal efficiencies (P10% = NURP 10th percentile, settling velocity = .03 ft/hr); copper violations are eliminated at P10% removal efficiencies exceeding ~60-65%.

Figure 24
Device Relative Areas Required to Achieve 70% and 85% TSS Removal



BASED ON SIMULATION PROVIDENCE 1980 PRECIPITATION (~AVERAGE YEAR)

Table 8
Performance of Devices Designed for 70% TSS Removal

DEVICE	P0%	P10%	P30%	P50%	P80%	TSS	TP	TKN	COPPER	LEAD	ZINC	HC
REMOVAL EFFICIENCIES (%)												
1	0.0	36.7	53.3	71.9	94.1	70.0	38.2	32.8	32.8	63.2	32.8	63.2
2	0.0	38.0	55.5	70.8	92.9	70.0	38.7	33.3	33.3	63.2	33.3	63.2
3	0.0	38.2	57.2	70.5	92.1	70.0	39.1	33.6	33.6	63.2	33.6	63.2
4	0.0	15.0	55.9	83.6	97.8	70.0	36.4	31.3	31.3	63.2	31.3	63.2
5	0.0	15.5	55.7	83.4	97.7	70.0	36.4	31.3	31.3	63.2	31.3	63.2
6	0.0	16.5	55.9	82.9	97.4	70.0	36.6	31.5	31.5	63.2	31.5	63.2
7	0.0	18.2	56.7	81.9	96.6	70.0	37.0	31.8	31.8	63.2	31.8	63.2
8	0.0	20.6	57.4	80.3	95.8	70.0	37.3	32.1	32.1	63.2	32.1	63.2
9	19.8	30.4	52.2	76.0	95.7	70.0	43.2	39.9	39.9	65.1	39.9	65.1
10	26.7	37.9	52.5	72.1	93.7	70.0	46.1	43.4	43.4	65.8	43.4	65.8
11	31.4	43.1	53.6	69.7	91.7	70.0	48.4	46.0	46.0	66.3	46.0	66.3
12	35.7	48.3	55.2	67.8	89.3	70.0	50.8	48.7	48.7	66.7	48.7	66.7
13	0.0	16.5	55.7	82.6	97.6	70.0	36.5	31.4	31.4	63.2	31.4	63.2
14	12.2	21.7	53.7	80.4	97.1	70.0	40.3	36.4	36.4	64.4	36.4	64.4
15	17.8	25.4	52.6	78.7	96.7	70.0	42.1	38.7	38.7	64.9	38.7	64.9
16	24.3	30.6	51.5	76.1	95.9	70.0	44.4	41.6	41.6	65.6	41.6	65.6
FLOW-WEIGHTED-MEAN OUTFLOW CONCENTRATIONS (PPM)												
1	1.00	13.07	9.67	5.82	2.46	31.02	0.21	1.03	0.023	0.008	0.110	0.95
2	1.00	12.77	9.23	6.05	2.95	31.00	0.21	1.02	0.023	0.008	0.109	0.95
3	1.00	12.73	8.85	6.12	3.29	30.98	0.21	1.01	0.023	0.008	0.108	0.95
4	1.00	17.60	9.13	3.41	0.93	31.07	0.22	1.05	0.024	0.008	0.112	0.95
5	1.00	17.51	9.18	3.44	0.94	31.07	0.22	1.05	0.024	0.008	0.112	0.95
6	1.00	17.30	9.13	3.54	1.09	31.07	0.21	1.05	0.024	0.008	0.112	0.95
7	1.00	16.94	8.98	3.78	1.39	31.07	0.21	1.05	0.024	0.008	0.111	0.95
8	1.00	16.46	8.82	4.07	1.72	31.08	0.21	1.04	0.024	0.008	0.111	0.95
9	0.80	14.43	9.91	4.99	1.79	31.12	0.19	0.92	0.021	0.007	0.098	0.90
10	0.73	12.88	9.84	5.78	2.60	31.09	0.18	0.87	0.020	0.007	0.092	0.88
11	0.69	11.78	9.61	6.27	3.42	31.09	0.17	0.83	0.019	0.007	0.088	0.87
12	0.64	10.72	9.28	6.66	4.41	31.07	0.17	0.79	0.018	0.007	0.084	0.86
13	0.99	17.13	9.09	3.56	0.99	30.77	0.21	1.04	0.024	0.008	0.111	0.94
14	0.87	15.99	9.46	4.01	1.19	30.65	0.20	0.96	0.022	0.007	0.103	0.91
15	0.82	15.35	9.76	4.39	1.37	30.87	0.19	0.93	0.021	0.007	0.099	0.90
16	0.77	14.57	10.20	5.03	1.71	31.50	0.19	0.91	0.021	0.007	0.097	0.90

EVENT-MEAN COPPER CONCENTRATIONS (PPM)

			VIOLATION FREQUENCIES (%)		
DEVICE	MEAN	MAX	A	B	C
1	0.023	0.034	0.0	79.1	32.7
2	0.023	0.032	0.0	79.1	31.8
3	0.023	0.030	0.0	79.1	30.9
4	0.024	0.044	0.0	80.9	39.1
5	0.024	0.042	0.0	83.6	38.2
6	0.024	0.040	0.0	86.4	38.2
7	0.024	0.038	0.0	89.1	38.2
8	0.024	0.038	0.0	93.6	39.1
9	0.021	0.038	0.0	42.7	23.6
10	0.020	0.035	0.0	33.6	19.1
11	0.019	0.035	0.0	27.3	14.6
12	0.018	0.036	0.0	20.9	12.7
13	0.024	0.046	0.0	83.6	35.5
14	0.022	0.046	0.0	62.7	29.1
15	0.021	0.046	0.0	53.6	26.4
16	0.021	0.050	0.0	45.5	26.4

DEVICE	Ab/Ai
1 wet pond, z=2	2.24%
2 wet pond, z=3.5	1.77%
3 wet pond, z=5	1.52%
4 dry pond, z=3.5, td=3	5.26%
5 dry pond, z=3.5, td=6	4.02%
6 dry pond, z=3.5, td=12	2.90%
7 dry pond, z=3.5, td=24	2.09%
8 dry pond, z=3.5, td=48	1.59%
9 infilt b, i=.1	2.63%
10 infilt b, i=.25	1.50%
11 infilt b, i=.5	0.94%
12 infilt b, i=1	0.58%
13 buffer, i=0	5.49%
14 buffer, i=.25	4.37%
15 buffer, i=.5	3.70%
16 buffer, i=1.0	2.89%

* COPPER CRITERIA		PPM
A	Drinking Water	2
B	RI Fresh. Aquatic Life	0.0048
C	NURP Threshold	0.02

Ab/Ai = Device Area/Imperv. Watershed Area

Based upon simulation of Providence 1980 precipitation. Outflow concentrations and violation frequencies refer to sum of surface and groundwater discharges.

Table 9
Performance of Devices Designed for 85% TSS Removal

REMOVAL EFFICIENCIES (%)

DEVICE	P0%	P10%	P30%	P50%	P80%	TSS	TP	TKN	COPPER	LEAD	ZINC	BC
1	0.0	63.0	76.7	88.8	98.2	85.0	53.9	46.4	46.4	76.8	46.4	76.8
2	0.0	63.8	77.8	87.8	97.8	85.0	54.1	46.5	46.5	76.8	46.5	76.8
3	0.0	63.7	78.9	87.5	97.5	85.0	54.3	46.7	46.7	76.8	46.7	76.8
4	0.0	44.4	85.1	96.2	99.6	85.0	53.2	45.8	45.8	76.7	45.8	76.7
5	0.0	44.6	85.0	96.1	99.6	85.0	53.2	45.8	45.8	76.7	45.8	76.7
6	0.0	45.0	84.8	96.0	99.6	85.0	53.2	45.8	45.8	76.7	45.8	76.7
7	0.0	45.4	84.5	95.9	99.6	85.0	53.3	45.8	45.8	76.8	45.8	76.8
8	0.0	46.8	84.1	95.3	99.4	85.0	53.3	45.9	45.9	76.8	45.9	76.8
9	38.5	59.0	77.7	90.8	98.7	85.0	64.9	61.2	61.2	80.5	61.2	80.5
10	45.3	64.3	76.6	88.5	97.9	85.0	67.3	64.2	64.2	81.2	64.2	81.2
11	49.5	68.4	76.3	86.3	97.0	85.0	69.0	66.3	66.3	81.6	66.3	81.6
12	53.4	72.1	76.8	84.6	95.7	85.0	70.7	68.3	68.3	81.9	68.3	81.9
13	0.0	47.2	83.6	95.3	99.5	85.0	53.3	45.8	45.8	76.8	45.8	76.8
14	31.3	52.8	80.3	93.5	99.2	85.0	62.6	58.2	58.2	79.8	58.2	79.8
15	37.9	56.2	78.5	92.3	99.0	85.0	64.6	60.9	60.9	80.4	60.9	80.4
16	43.9	60.6	76.9	90.5	98.7	85.1	66.6	63.4	63.4	81.1	63.4	81.1

FLOW-WEIGHTED-MEAN OUTFLOW CONCENTRATIONS (PPM)

DEVICE	P0%	P10%	P30%	P50%	P80%	TSS	TP	TKN	COPPER	LEAD	ZINC	BC
RUNOFF	1.00	20.71	20.71	20.71	41.43	103.6	0.34	1.53	0.035	0.021	0.163	2.58
1	0.98	7.59	4.82	2.32	0.74	15.5	0.15	0.81	0.018	0.005	0.086	0.59
2	0.97	7.40	4.59	2.52	0.93	15.4	0.15	0.80	0.018	0.005	0.085	0.59
3	0.96	7.39	4.36	2.60	1.06	15.4	0.15	0.79	0.018	0.005	0.084	0.59
4	1.00	11.52	3.09	0.80	0.17	15.6	0.16	0.83	0.019	0.005	0.089	0.60
5	1.00	11.47	3.12	0.81	0.18	15.6	0.16	0.83	0.019	0.005	0.089	0.60
6	1.00	11.38	3.16	0.84	0.18	15.6	0.16	0.83	0.019	0.005	0.089	0.60
7	1.00	11.31	3.20	0.85	0.18	15.5	0.16	0.83	0.019	0.005	0.089	0.60
8	1.00	11.02	3.30	0.98	0.25	15.5	0.16	0.83	0.019	0.005	0.088	0.60
9	0.51	8.49	4.61	1.90	0.56	15.5	0.12	0.59	0.013	0.004	0.063	0.50
10	0.55	7.40	4.85	2.39	0.86	15.5	0.11	0.55	0.012	0.004	0.058	0.49
11	0.50	6.55	4.92	2.83	1.26	15.6	0.11	0.52	0.012	0.004	0.055	0.48
12	0.47	5.78	4.81	3.21	1.80	15.6	0.10	0.49	0.011	0.004	0.052	0.47
13	1.00	10.93	3.39	[illegible]	0.23	15.5	0.16	0.83	0.019	0.005	0.088	0.60
14	0.68	9.77	4.08	1.35	0.33	15.5	0.13	0.64	0.014	0.004	0.068	0.52
15	0.62	9.16	4.49	1.62	0.42	15.7	0.12	0.60	0.014	0.004	0.064	0.51
16	0.58	8.46	4.99	2.04	0.57	16.1	0.12	0.58	0.013	0.004	0.062	0.51

EVENT-MEAN COPPER CONCENTRATIONS (PPM)

			VIOLATION FREQ (%) *		
DEVICE	MEAN	MAX	A	B	C
1	0.018	0.021	0.0	79.1	1.8
2	0.018	0.021	0.0	79.1	0.9
3	0.018	0.021	0.0	79.1	0.9
4	0.019	0.028	0.0	80.9	15.5
5	0.019	0.027	0.0	83.6	14.6
6	0.019	0.025	0.0	86.4	13.6
7	0.019	0.025	0.0	89.1	14.6
8	0.019	0.027	0.0	93.6	14.6
9	0.013	0.023	0.0	18.2	1.8
10	0.012	0.023	0.0	14.6	1.8
11	0.012	0.023	0.0	11.8	1.8
12	0.011	0.023	0.0	9.1	0.9
13	0.019	0.026	0.0	91.8	13.6
14	0.014	0.024	0.0	39.1	1.8
15	0.014	0.025	0.0	32.7	2.7
16	0.013	0.027	0.0	28.2	3.6

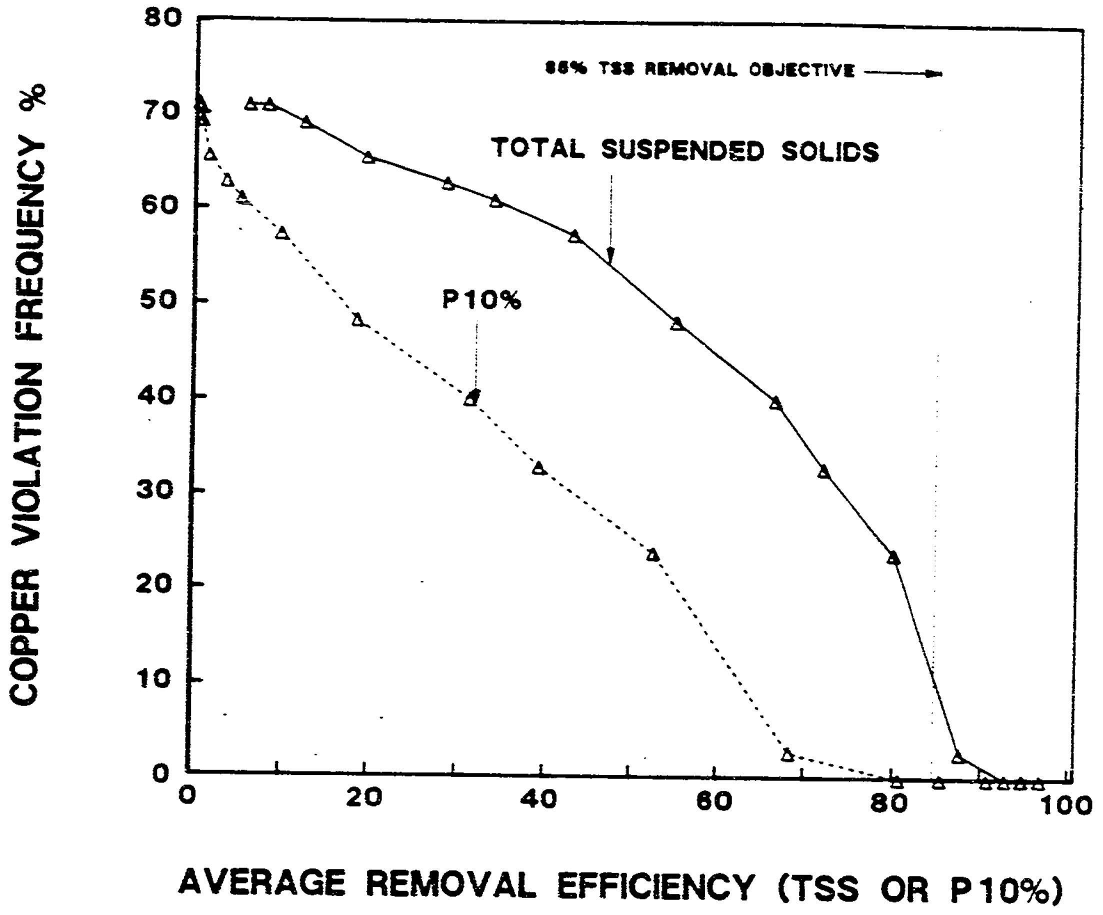
* COPPER CRITERIA		PPM
A	Drinking Water	2
B	RI Fresh. Aquatic Life	0.0048
C	NURP Threshold	0.02

DEVICE		Ab/Ai
1	wet pond, z=2	8.02%
2	wet pond, z=3.5	6.18%
3	wet pond, z=5	5.23%
4	dry pond, z=3.5, td=3	31.12%
5	dry pond, z=3.5, td=6	24.53%
6	dry pond, z=3.5, td=12	17.70%
7	dry pond, z=3.5, td=24	11.74%
8	dry pond, z=3.5, td=48	7.88%
9	infilt b, i=.1	6.56%
10	infilt b, i=.25	3.49%
11	infilt b, i=.5	2.07%
12	infilt b, i=1	1.22%
13	buffer, i=0	19.75%
14	buffer, i=.25	12.68%
15	buffer, i=.5	9.82%
16	buffer, i=1.0	6.98%

Ab/Ai = Device Area/Imperv. Watershed Area

Based upon simulation of Providence 1980 precipitation. Outflow concentrations and violation frequencies refer to sum of surface and groundwater discharges.

Figure 25
Relationship between Suspended Solids Removal and Violations in Copper Toxicity Criterion for Wet Ponds Treating Median NURP Sites



Y-AXIS = PERCENT OF EVENTS WITH MEAN OUTFLOW COPPER CONC. > .02 PPM

.02 PPM = NURP COPPER TOXICITY CRITERION FOR SOFT WATERS

= THRESHOLD EFFECT LEVEL FOR INTERMITTENT EXPOSURE

P10% = PARTICLE SETTING VELOCITY = .03 FT/HR = NURP 10TH PERCENTILE

BASED ON SIMULATION OF WET PONDS WITH VARIOUS AB/AW RATIOS

PROVIDENCE 1980 PRECIPITATION

MEDIAN NURP SITE - RUNOFF COPPER CONC. = .034 PPM

These results indicate that a TSS removal objective of 85% for wet pond design is consistent with avoiding violations in the NURP .02 ppm copper criterion for the 1980 storm sequence. The Rhode Island freshwater toxicity standard (.0048 ppb, Table 4) is practically unachievable in runoff treatment systems (at least insofar as the model is concerned because soluble copper removal mechanisms are not considered). The applicability of such standards (based upon laboratory dosing studies using dissolved copper) to runoff situations (intermittent exposure, appreciable particulate fraction) has been questioned, however (Athayede et al.,1983; Daves, 1986; Mancini and Plummer, 1986).

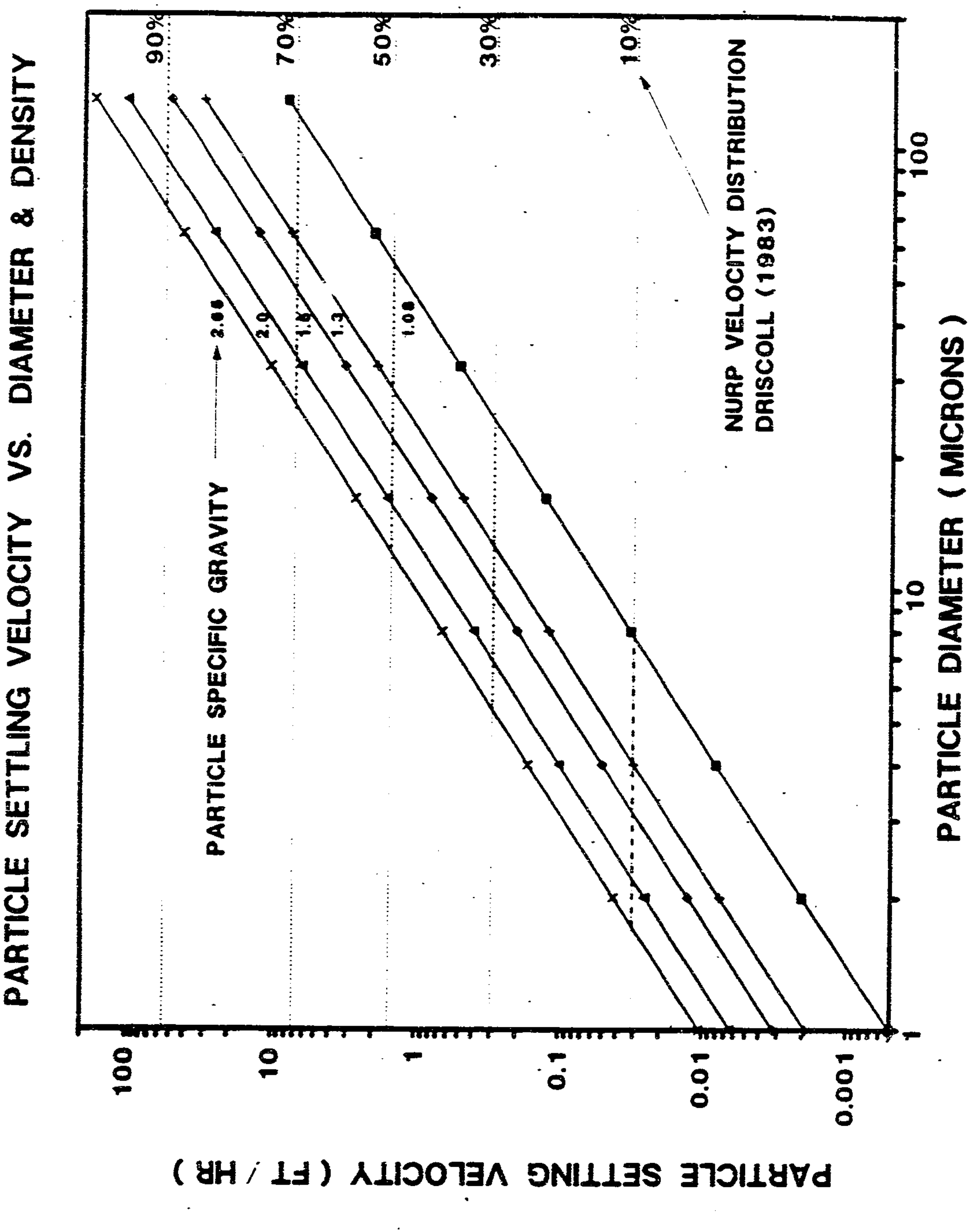
Figure 25 applies to a typical NURP monitoring site (median runoff copper concentration ~.034 ppm, Table 3). A logical extension of these results would be to incorporate effects of site-to-site variability in runoff concentrations. In this way, predictions of violation frequency could be made which reflect both the temporal variability simulated by the model (driven by storm sequence, watershed characteristics, device characteristics, particle characteristics) and uncertainty in predicting untreated runoff concentrations. As discussed in Section 6.4, lack of realistic toxicity criteria limits interpretation of violation frequencies and extent to which they can be used as direct bases for BMP design or for impact analyses.

Alternative design criteria targeting fine particles (e.g., P10%) may provide better protection of downstream water quality than criteria based upon TSS alone, given the tendency of many runoff contaminants to be associated with fine particles. For example, a 60-65% removal efficiency for P10% is typical of wet ponds designed for 85% total suspended solids removal (Table 9) and is consistent with reductions in copper violation frequency (Figure 25). The development of new performance standards or design criteria for BMP's has important economic and environmental implications and is beyond the scope of this report. The model could be used to evaluate the engineering implications of adopting alternative performance standards on a site-specific or regional basis.

Figure 26 shows particle settling velocities predicted from Stoke's Law as a function of particle diameter and specific gravity over ranges which are typical of urban runoff (Stahre and Urbonas, 1990). The NURP settling velocity distribution used in model calibration was based upon direct measurement of settling velocities in ~50 runoff samples (Driscoll, 1983; USEPA, 1986). Figure 26 shows that the NURP 10th percentile velocity (.03 ft/hr) corresponds to particle diameters from ~2 to ~8 microns for specific gravities between 2.65 and 1.08.

Through analysis of site-specific or regional runoff data, it should be possible to identify local runoff treatment objectives, expressed in terms of a target settling velocity (or equivalent particle diameter and density) and removal efficiency. If the water quality contaminant of primary concern is found to be concentrated in particles of a certain particle diameter and density, Figure 26 can be used to estimate an equivalent settling velocity for use in the model. For example, if the key contaminant is associated with particles exceeding 10 microns in diameter with a specific gravity of 1.5, then simulations of a particle class with a settling velocity of .3 ft/hr would provide a conservative

Figure 26
Particle Settling Velocity vs. Diameter and Density



VELOCITIES PREDICTED FROM STOKE'S LAW
FIGURE MODIFIED FROM STAHRE & URBONAS (1990)

estimate of the degree of contaminant control. Alternatively, settling velocity distributions for individual contaminants could be measured directly from runoff samples using methodologies described by Whipple and Hunter (1981), Driscoll (1986), Grizzard et al. (1986), and USEPA (1986). In this way, model parameters and treatment objectives can be adapted to regional or site-specific conditions.

9.0 MODEL LIMITATIONS

Model limitations must be considered by the user in running the model and interpreting its output. Following are the major limitations associated with watershed simulations:

(1) All precipitation is assumed to be rainfall. No snowfall or snowmelt.

(2) Effects of variations in vegetation type on evapotranspiration are not considered. This relationship is not easily parameterized and influences the computation of baseflow only. Reasonable simulations of observed streamflows in the Hunt-Potowomut River have been produced without adjusting default evapotranspiration coefficients or accounting for snowfall/snowmelt.

(4) Watershed runoff response to excess precipitation is instantaneous. A "PIPE" can be used to retard response if watershed time of concentration is sizeable in relation to the rainfall time step (1 hour). This will be more important in simulating intensity-sensitive devices (buffers, swales) than in simulating devices with appreciable storage volumes (detention ponds, infiltration basins). Watershed lag is not simulated.

(5) Erosion is not directly simulated. The model is geared to stable urban watersheds in which impervious surfaces are the primary sources of runoff and loads. The empirical concentration vs. intensity relationship used for pervious areas is sufficient for relative predictions (removal efficiency). If absolute predictions are desired, the empirical "load factor" must be adjusted to account for variations in erosion factors (soil types, slopes, slope lengths, vegetative cover, land use practices) from one watershed to another.

(6) The model is oriented more to predicting effectiveness of onsite or regional treatment devices (detention ponds, etc.) than to predicting effectiveness of source controls (erosion controls, street sweeping, etc.). The calibration of street-sweeping efficiencies is approximate and should be revised based upon site-specific data if the model is used to evaluate benefits of street sweeping.

(7) Effects of land uses on particle and contaminant loadings are related to impervious area and soil type. Particle and contaminant concentrations in surface runoff from pervious and impervious areas are similar. For a given impervious fraction and curve number, runoff concentrations are assumed to be independent of land use. Essentially, this reflects NURP conclusions (Athayede et al, 1983). Alternative assumptions may be made by adjusting the appropriate watershed input parameters (e.g., watershed pollutant scale factors).

Future versions of the model may provide greater flexibility for predicting contaminant loads by permitting specification of multiple particle/component matrices (to reflect different land uses, for example). Lack of calibration data would preclude exercise of this freedom in most cases, however.

(8) Runoff from impervious surfaces is equated to rainfall, once depression storage has been filled. This is a conservative assumption which is consistent with SWMM and other models. Direct field measurements of rainfall and runoff from various surface types (flat roofs, pitched roofs, roadways) suggest that actual runoff volumes often tend to be lower than those predicted based upon this assumption because of water losses attributed to interception by overhanging vegetation, evaporation, infiltration through pavement, and sorption by dirt/debris (Pitt, 1987; Pitt and Potter, 1990). Because of the complexities, data needs, and uncertainties involved in predicting these losses, they are ignored in this version of the model.

(9) Runoff from pervious surfaces is predicted using the SCS Curve Number methodology. This methodology is geared to large storms. Field data indicate that the procedure may under-estimate runoff volumes from pervious surfaces in small storms (Pitt, 1987). This effect is relatively small and partially compensates for over-prediction of runoff volumes from impervious areas.

(10) Tests of alternative model formulations for typical urban watersheds and BMP designs indicates that the current version of the model will lead to conservative BMP designs because the overprediction in impervious runoff tends to exceed the underprediction in pervious runoff. These limitations are not serious enough to warrant modifying the model structure and expanding input data requirements for this version of the model. They should be considered, however, in calibrating/testing the model against measured hydrographs from urban watersheds. In such cases, adjusting the impervious fraction to represent an "effective impervious fraction" may be necessary in order to achieve calibration.

(11) The calibration of particle buildup/washoff parameters to predict the NURP median, event-mean runoff TSS concentration is based simulation of Providence 1983-1987 rainfall. Since buildup/washoff processes are intensity-dependent and volume-dependent, recalibration may be necessary to predict NURP TSS levels using rainfall data from other regions. This would involve rescaling particle accumulation rates and pervious runoff concentrations (Procedure = 'Case Edit Particles') to predict the NURP median TSS concentration (100 ppm) for a given rainfall period. Alternatively, the 'Scale Factors' on the component input screens ('Procedure = 'Case Edit Components') can be adjusted. Recalibration may be necessary if "absolute" predictions (concentrations, loads) are desired for rainfall patterns which are significantly different from Providence rainfall patterns. Recalibration should not be necessary if the model is being used only for "relative" predictions (removal efficiencies).

(12) The emphasis of NURP data in the initial calibration of the model does not imply that other sources of data on runoff quality are unimportant or should be ignored. High site-to-site variability in urban runoff quality dictates that actual runoff quality will rarely equal that predicted using the default calibration. Calibration of the model to local runoff data should be considered, particularly in cases where absolute predictions (concentrations, loads) are emphasized over relative predictions (removal efficiency).

Following are the major limitations associated with device simulations:

(1) No backwater effects. These may be important in linking devices (e.g., series of wet ponds with small downstream changes in elevation). Backwater conditions may cause the model to under-estimate or to over-estimate removal efficiencies, depending upon the device linkage. Over-estimation would occur, for example, if a backwater condition causes a device to overflow into a receiving water instead of discharging to a downstream device.

(2) Devices are assumed to be completely-mixed. Effects of plug flow can be simulated by splitting one device into two or more consecutive devices. Driscoll (1986) notes, however, that performance of wet ponds is relatively insensitive to geometry (plug flow vs. completely mixed conditions) because most of the particle removal occurs under quiescent conditions.

(3) Ideal sheet flow is assumed for swales and buffers (Type = 3). Potential effects of channelization must be considered by the user in interpreting output. Although the use of Manning's equation is generally accepted for swales and buffers (McCuen, 1982; Wanieliesta and Youseff, 1986), the model has not been tested against observed performance data or against other methodologies for such devices.

(4) Particle resuspension is not simulated. Maximum simulated velocities in buffers and swales are tabulated for comparison with independent souring criteria (typically ~4 ft/sec, RIDEM, 1988). Scouring of recently settled particles may occur at lower flow velocities, however, leading to overall removal efficiencies which are lower than those predicted by the model, particularly in swales and dry ponds. High maintenance frequencies (sediment removal) may be required to achieve the removal efficiencies predicted by the model for such devices, particularly when the predominant removal mechanism is settling (vs. infiltration).

(5) Particle interactions (flocculation) are not directly simulated, except insofar as NURP settling velocities (measured) reflect such processes. Regional calibration of particle settling velocity distributions may be appropriate.

(6) Chemical and biological mechanisms responsible for contaminant removal in devices are not considered in the default particle calibrations. Possibilities for modifying P8 calibrations and/or

structure to account for these mechanisms should be explored in future work.

(7) Engineering aspects of BMP design (e.g., length/width ratio, avoiding short circuiting, side slope stability, aquatic benches) are not considered in the model. The model provides perspectives on BMP scales only. It is assumed that devices are otherwise engineered correctly (Schueler, 1987; Stahre and Urbonas, 1990).

(8) The model does not account for precipitation and evaporation directly to and from devices. Since devices generally occupy a small portion of the contributing watershed, this is usually not a problem. Rainfall onto devices can be considered by accounting for device areas when specifying watershed characteristics.

Future refinements to the model should address the above limitations. Further testing and refinement of the preliminary calibrations using regional runoff monitoring data are recommended. Although there is room for refinement in treatment criteria, the 70%/85% TSS removal objectives recommended by RIDEM(1988) are reasonable with respect to water quality protection and achievability.

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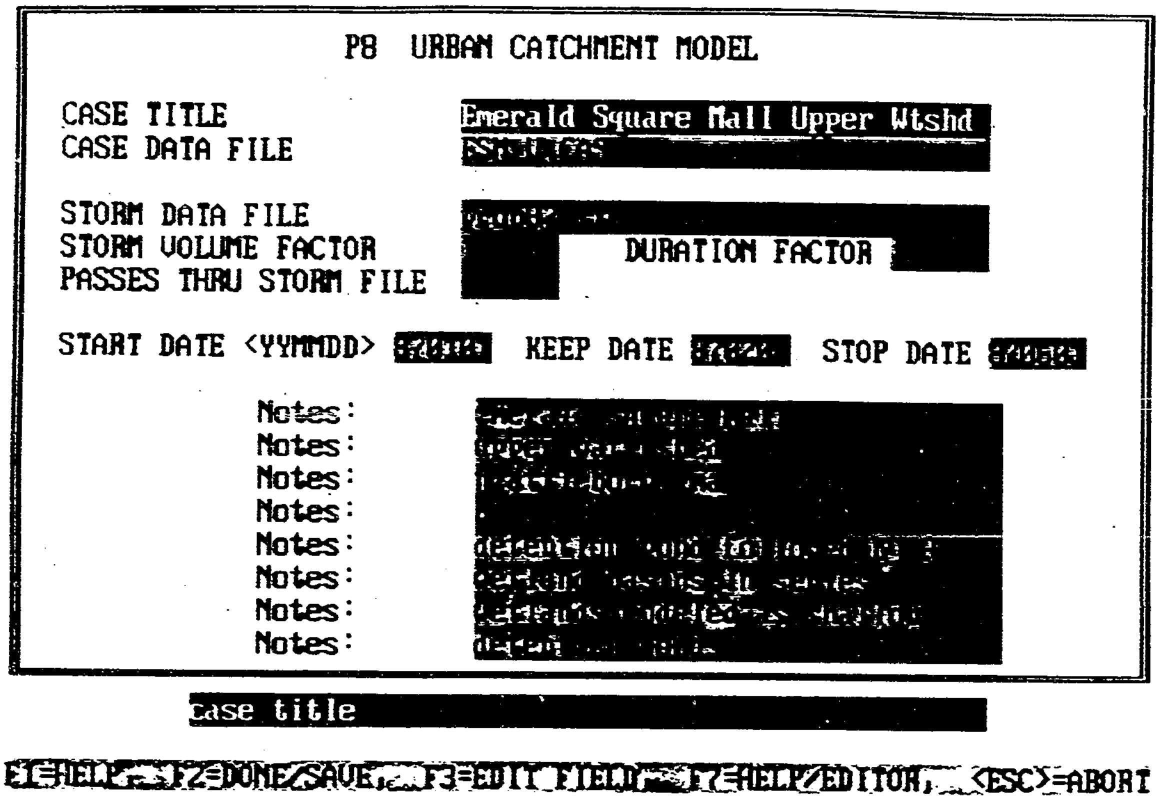
APPENDIX A
P8 Menu Structure

PROCEDURE	DESCRIPTION	HELP	MODE
Case	Define Case	180	0
Edit	Edit Case Variables	180	0
First	Edit Title, Data File Names, Storm File Names, Storm Dates	5	0
Devices	Edit Device Index or Data	70	0
Index	Edit Device Index (Device Labels & Types)	9	0
Data	Edit Device Data (Dimensions, Infiltration Rates, Slopes, etc.)	10	0
Watersheds	Edit Watershed Index or Data	40	0
Index	Edit Watershed Index (Watershed Labels & Outflow Devices)	7	0
Data	Edit Watershed Data (Area, Imperv. Frac., Curve Number, etc.)	8	0
Particles	Edit Particle Data (Runoff Conc., Settling Veloc., etc.)	4	1
Components	Edit Water Quality Components & Criteria	17	1
First	Edit First Group (Components 1 - 5)	17	1
Second	Edit Second Group (Components 6 - 10)	17	1
Evapotrans	Edit Evapotranspiration Factors	98	1
TimeSteps	Edit Time Step Lengths & Continuity Error Limit	18	1
All	Edit All Site Input Data Groups	19	0
Read	Read Input Data File	20	0
All	Read All Input Data Groups from a Disk File	20	0
Particles	Read Particle/Component Input Data Groups from Disk File	20	0
Save	Save Input Data File	22	0
Inputs	Save all Input Data Groups in a Disk File	22	0
Particles	Save Particle/Component Input Groups in a Disk File	22	1
Archive	Save All Input Data Groups and Output Files	22	1
Zero	Erase All Case Input Values	24	0
List	List Input Values for Current Case	1	0
Site	List Watershed & Device Input Data	1	0
Network	List Watershed / Device Network	1	0
Tables	List Device Morphometry & Outflow vs. Elevation Tables	33	0
Parameters	List Particle & Water Quality Component Input Data	1	0
Run	Run Model or Size Devices	180	0
Model	Run Model for Current Watershed/Device Network	25	0
Design	Select / Size Devices for Defined Watershed(s)	77	0
Lookup	Retrieve Preliminary Designs for One Device	78	0
70%	Retrieve a Device to Achieve TSS Removal = 70%	78	0
85%	Retrieve a Device to Achieve TSS Removal = 85%	78	0
Tune	Rescale Device(s) to Achieve Target Removal Efficiency	79	0
One	Target Removal Efficiency for One Device	79	0
All	Target Removal Efficiency for Entire Device Network	79	0
Sensitivity	Run Sensitivity Analysis on Model Input Variables	89	1
Watersheds	Run Sensitivity Analysis on Watershed Input Variables	89	1
Devices	Run Sensitivity Analysis on Device Input Variables	89	1
Both	Run Sensitivity Analysis on Watershed & Device Inputs	89	1
Particles	Run Sensitivity Analysis on Particle Parameters	89	1
All	Run Sensitivity Analysis on All Input Variables	89	1
Calibrate	Run Flow Calibration - Compare Observed & Predicted Flows	97	1
List	List Model Output (Must Run Model First)	23	0
Balances	Water & Mass Balances by Device & Component	27	0
All	Water & Mass Balances for All Storms	27	0
Each	Water & Mass Balances for Each Storm Separately	27	1
Removals	List Removal Efficiencies (%) by Device & Component	29	0
Terms	List/Plot Flow & Mass-Balance Terms by Device & Component	90	0
Outflow	List/Plot Device Total Outflows (Infilt.+Normal+Spillway)	90	0
Surface	List/Plot Device Surface Outflows (Normal + Spillway)	90	0
Inflow	List/Plot Device Total Inflows	90	0
Any	List/Plot Any Mass-Balance Term	90	0
Violations	Violation Frequencies for Event-Mean Concentrations	28	1
Outflow	Violation Frequencies for Total Outflow Concentrations	28	1
Surface	Violation Frequencies for Surface Outflow Concentrations	28	1
Inflow	Violation Frequencies for Total Inflow Concentrations	28	1
Any	Violation Frequencies for Any Mass-Balance Term	28	1
Peaks	List Maximum Elevations, Outflows, and Velocities by Device	81	0
Sedim	List Sediment Accumulation Rates by Device	37	0
Means	List Flow-Weighted-Mean Concentrations Device & Component	21	1
Inflow	List Flow-Weighted-Mean Inflow Concentrations	21	1
Outflow	List Flow-Weighted-Mean Total Outflow Concentrations	21	1
Surface	List Flow-Weighted-Mean Surface Outflow Concentrations	21	1
Any	List Flow-Weighted-Mean Concs for Any Mass-Balance Term	21	1

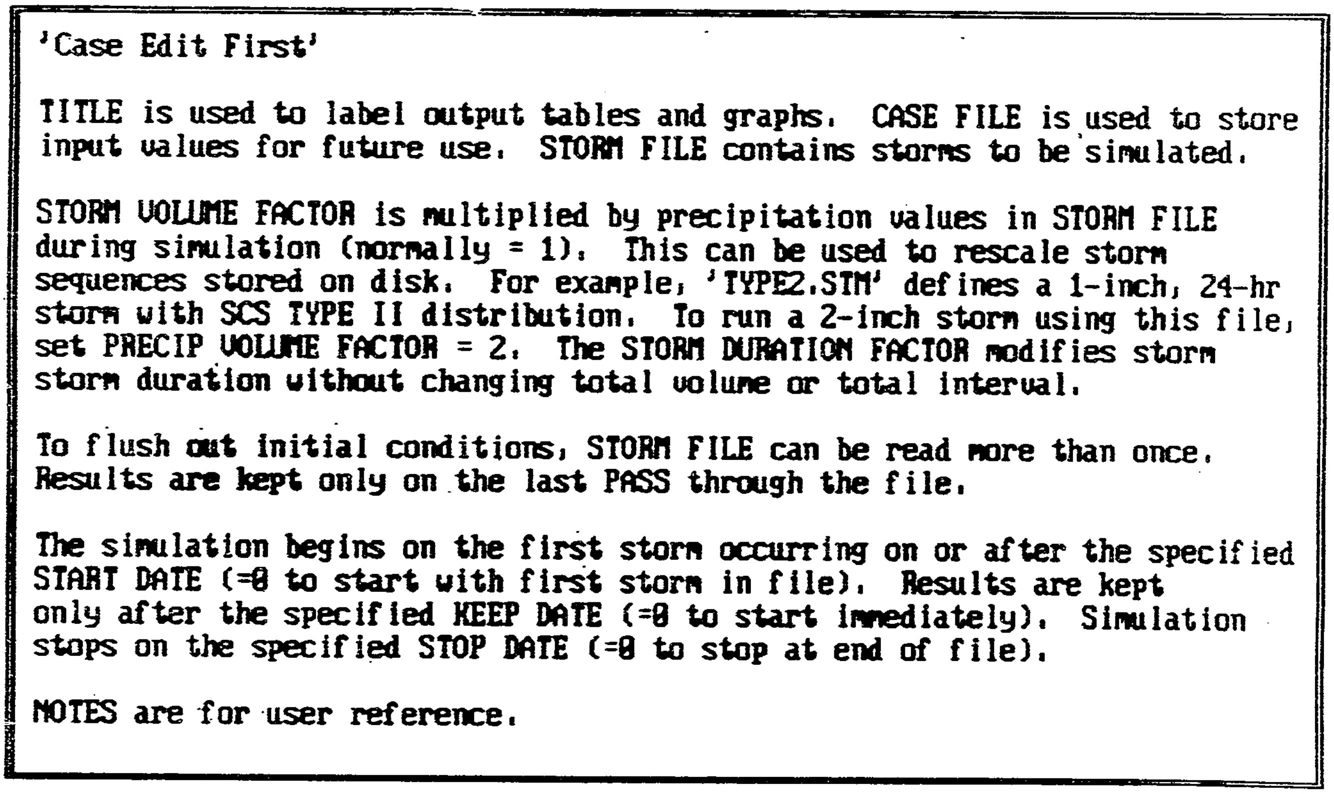
P8 Menu Structure (ct.)

PROCEDURE	DESCRIPTION	HELP	MODE
Detail	Detailed Statistical Summaries of Simulation Results	30	1
Flows	Summarize Event-Total Flows (acre-ft)	30	1
Loads	Summarize Event-Mean Loads (lbs)	30	1
Concs	Summarize Event-Mean Concentrations (ppm)	30	1
Precip	Summarize Event-Mean Precipitation (inches)	30	1
Traced	Detailed Output Statistics by Time Step for Traced Devices	31	1
Continuity	List Continuity (Water-Balance & Mass-Balance) Errors	32	1
Plot	Plot Simulation Results (Must Run Model First)	188	1
Events	Plot Event Summary Values	71	1
Timeser	Plot Event Time Series	71	1
Volumes	Plot Event Total Flow Volume (ac-ft) vs. Time (Julian Day)	71	1
Loads	Plot Event Total Loads (lbs) vs. Time (Julian Day)	71	1
Concs	Plot Event Mean Concentrations (ppm) vs. Time (Julian Day)	71	1
Precip	Plot Event Total Precipitation (inches) vs. Time (Julian Day)	71	1
Elev	Plot Event Maximum Elevations (ft) vs. Time (Julian Day)	71	1
Flows	Plot Event Maximum Flows (cfs) vs. Time (Julian Day)	71	1
Other	Plot Other Storm Values vs. Time (Julian Day)	71	1
Cumulatives	Plot Event Cumulative Totals vs. Time (Julian Day)	72	1
Flows	Plot Cumulative Flows (ac-ft) vs. Time (Julian Day)	72	1
Loads	Plot Cumulative Loads (lbs) vs. Time (Julian Day)	72	1
Precip	Plot Cumulative Precip. (inches) vs. Time (Julian Day)	72	1
Frequency	Plot Cumulative Frequency Distributions of Event Values	73	1
LogNormal	Plot Frequency Distributions of Event Values - Lognormal Scale	74	1
Scatter	Scatter Plots for Event-Mean Values	75	1
1CvsQ	Plot Event-Mean Concentration (ppm) vs. Event-Mean Flow (cfs)	75	1
2CvsP	Plot Event-Mean Concentration (ppm) vs. Event Total Precip (in)	75	1
3CvsI	Plot Event-Mean Concentration (ppm) vs. Precip Intens (in/hr)	75	1
4Other	Scatter Plot of Other Variables	75	1
Yearly	Plot Yearly Total Flows, Loads, or Precip. vs. Year	99	1
Flows	Plot Yearly Total Flows (ac-ft) vs. Year	99	1
Loads	Plot Yearly Total Loads (lbs) vs. Year	99	1
Precip	Plot Yearly Total Precipitation (inches) vs. Year	99	1
Monthly	Plot Monthly Total Flows, Loads, or Precip. vs. Date	99	1
Flows	Plot Monthly Total Flows (ac-ft) vs. Date	99	1
Loads	Plot Monthly Total Loads (lbs) vs. Date	99	1
Precip	Plot Monthly Total Precipitation (inches) vs. Date	99	1
Daily	Plot Daily-Average Time Series - for Traced Devices Only	34	1
Precip	Plot Daily Avg. Precipitation Intensity (in/hr) vs. Julian Day	34	1
Elevations	Plot Daily Avg. Device Elevations (ft) vs. Julian Day	34	1
Volumes	Plot Daily Avg. Storage Volumes (ac-ft) vs. Julian Day	34	1
Flows	Plot Daily Average Surface Outflows (cfs) vs. Julian Day	34	1
Traced	Plot Time-Step Results for Traced Devices	36	1
Precip	Plot Precipitation Intensity (in/hr) vs. Julian Hours	36	1
Elevations	Plot Device Elevations (ft) vs. Julian Hours	36	1
Volumes	Plot Device Storage Volumes (ac-ft) vs. Julian Hours	36	1
Flows	Plot Device Surface Outflows (cfs) vs. Julian Hours	36	1
Concs	Plot Surface Outflow Concentrations (ppm) vs. Julian Hours	36	1
Loads	Plot Surface Outflow Loads (lbs/hr) vs. Julian Hours	36	1
Utilities	Program Utilities	180	1
Output	Select Destination for Program Output	194	1
Screen	Send Output to Screen (Default)	194	1
File	Send Output to Disk File	194	1
Trace	Select Devices to be Traced - Save Time-Step Results	38	1
Some	Trace Simulation Results for Specific Devices	38	1
None	Do Not Trace Results (Default)	38	1
All	Trace All Devices (Careful !! - Ample Disk Space Required)	38	1
View	View any DOS Text/ASCII File	186	1
NOAA	Translate NOAA/NCDC Hourly Precipitation File	43	1
Batch	Batch Processing - Run Model for List of Cases	76	1
NoArchive	Batch - Do Not Archive Results	76	1
Archive	Batch - Archive Results - Save Output for Future Analysis	76	1
Help	View Supplementary Help Screens	195	0
Quit	End Session	180	0

USER MODES <SHIFT><F1>: 0=NOVICE, 1=ADVANCED, HELP: Screen Numbers Listed in Appendix D



```
                 P8  URBAN CATCHMENT MODEL

CASE TITLE                    Emerald Square Mall Upper Wtshd
CASE DATA FILE                [illegible]

STORM DATA FILE               [illegible]
STORM VOLUME FACTOR                     DURATION FACTOR
PASSES THRU STORM FILE

START DATE <YYMMDD> [illegible]  KEEP DATE [illegible]  STOP DATE [illegible]

              Notes:          [illegible]
              Notes:          [illegible]
              Notes:          [illegible]
              Notes:
              Notes:          [illegible]
              Notes:          [illegible]
              Notes:          [illegible]
              Notes:          [illegible]

        case title

F1=HELP, F2=DONE/SAVE, F3=EDIT FIELD, F7=HELP/EDITOR, <ESC>=ABORT
```



'Case Edit First'

TITLE is used to label output tables and graphs. CASE FILE is used to store input values for future use. STORM FILE contains storms to be simulated.

STORM VOLUME FACTOR is multiplied by precipitation values in STORM FILE during simulation (normally = 1). This can be used to rescale storm sequences stored on disk. For example, 'TYPE2.STM' defines a 1-inch, 24-hr storm with SCS TYPE II distribution. To run a 2-inch storm using this file, set PRECIP VOLUME FACTOR = 2. The STORM DURATION FACTOR modifies storm storm duration without changing total volume or total interval.

To flush out initial conditions, STORM FILE can be read more than once. Results are kept only on the last PASS through the file.

The simulation begins on the first storm occurring on or after the specified START DATE (=0 to start with first storm in file). Results are kept only after the specified KEEP DATE (=0 to start immediately). Simulation stops on the specified STOP DATE (=0 to stop at end of file).

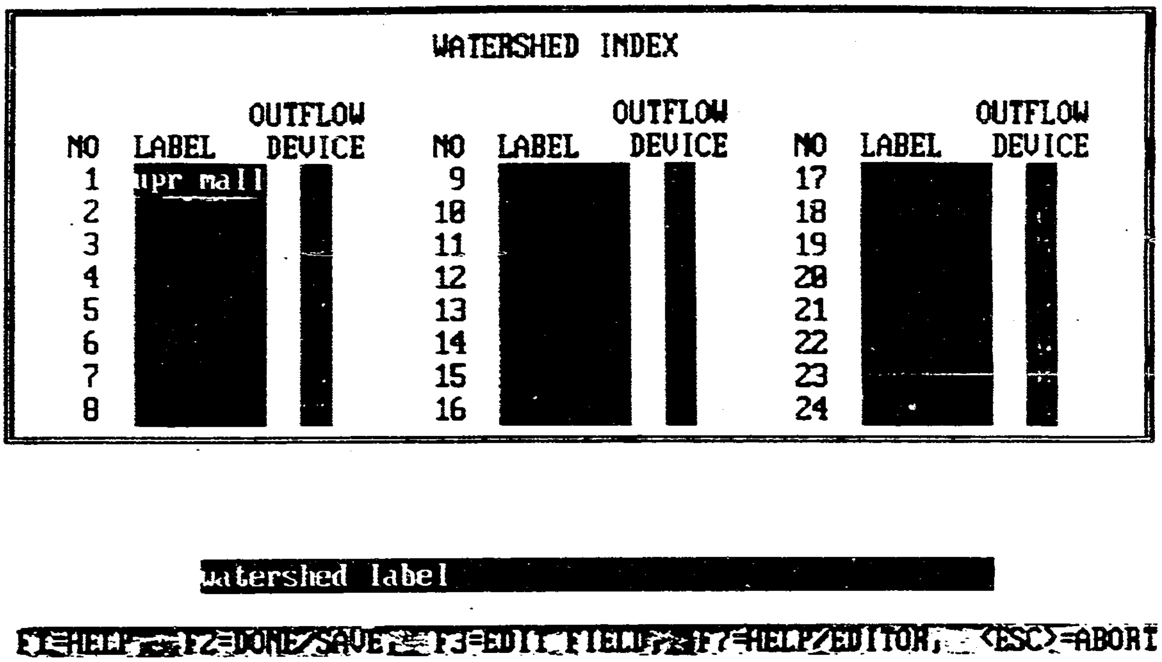
NOTES are for user reference.

APPENDIX B

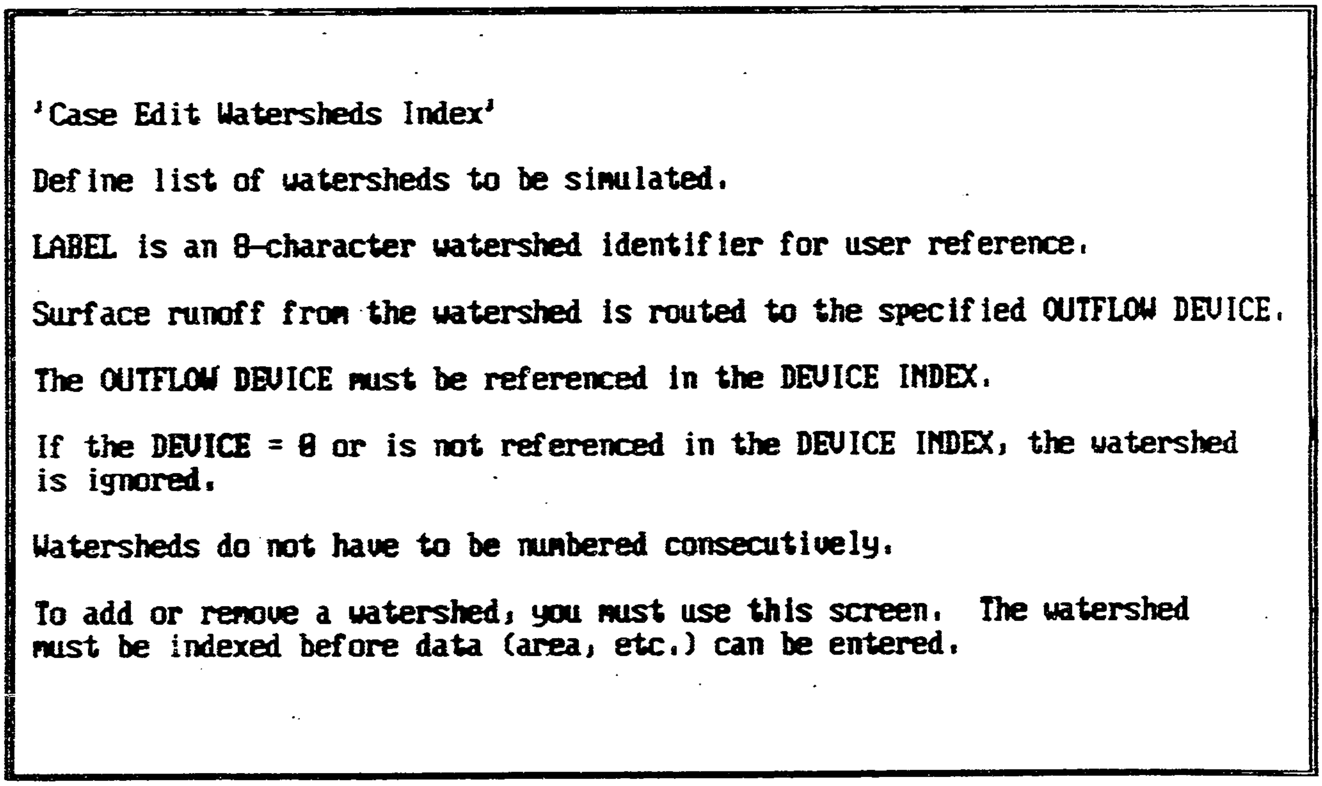
Data Entry Screens

B-1 Case Title and Data File Names
B-2 Watershed Index
B-3 Watershed Data
B-4 Device Index
B-5 Device Data - Type=1 - Detention Pond
B-6 Device Data - Type=2 - Infiltration Basin
B-7 Device Data - Type=3 - Swale/Buffer Strip
B-8 Device Data - Type=4 - Generalized Device
B-9 Device Data - Type=5 - Pipe/Manhole
B-10 Device Data - Type=6 - Splitter
B-11 Device Data - Type=7 - Aquifer
B-12 Evapotranspiration Parameters
B-13 Simulation Time Steps *
B-14 Particle Characteristics *
B-15 Water Quality Components *
B-16 Translate NOAA/NCDC Precipitation Files *
B-17 Misc. Help Screens for Site Parameter Estimation

* Accessed from ADVANCED USER MODE only



```
                           WATERSHED INDEX

              OUTFLOW                    OUTFLOW                    OUTFLOW
NO  LABEL     DEVICE       NO  LABEL     DEVICE       NO  LABEL     DEVICE
 1  upr mall                9                         17
 2                         10                         18
 3                         11                         19
 4                         12                         20
 5                         13                         21
 6                         14                         22
 7                         15                         23
 8                         16                         24


          watershed label

F1=HELP  F2=DONE/SAVE  F3=EDIT FIELD  F7=HELP/EDITOR  <ESC>=ABORT
```



'Case Edit Watersheds Index'

Define list of watersheds to be simulated.

LABEL is an 8-character watershed identifier for user reference.

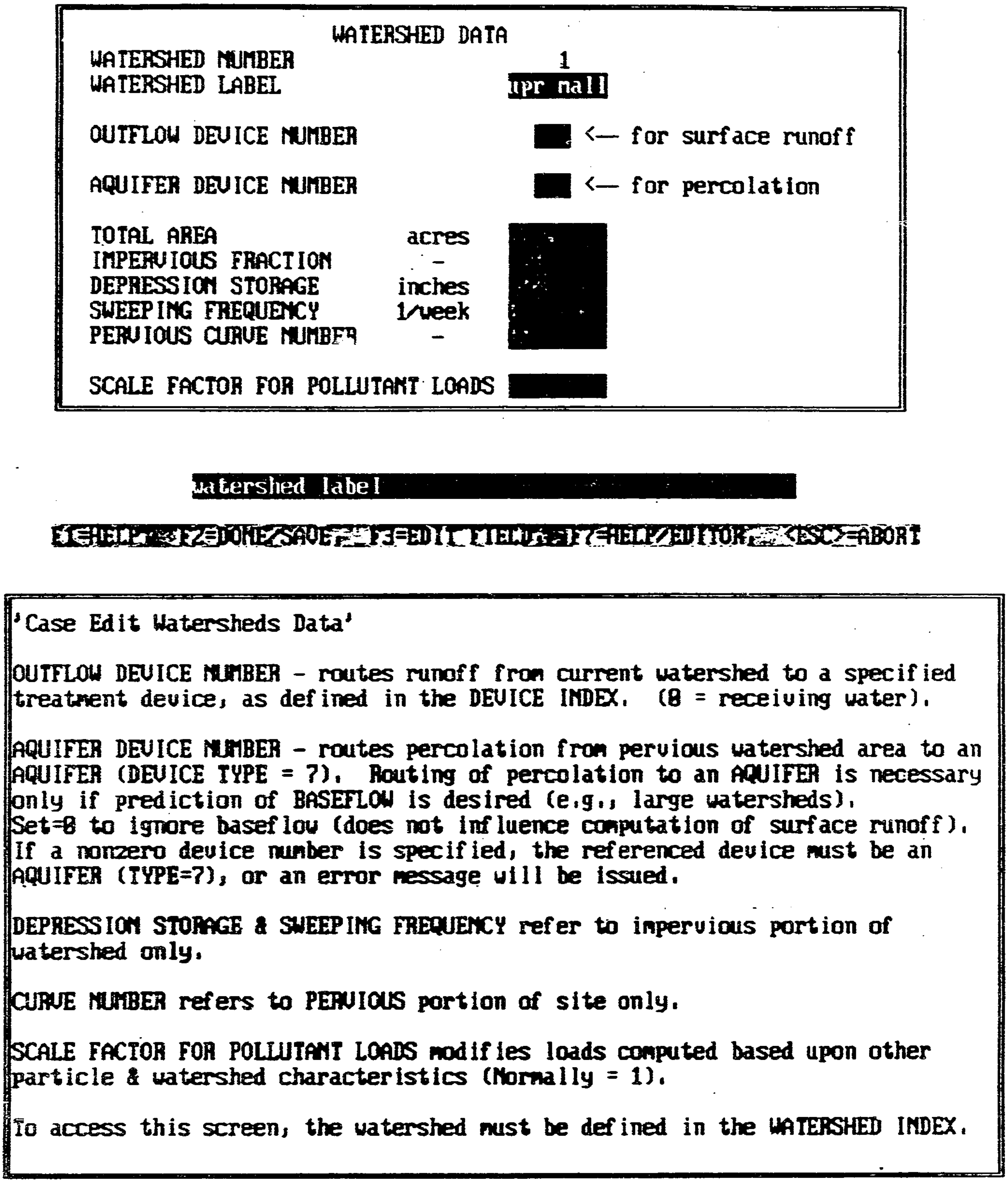
Surface runoff from the watershed is routed to the specified OUTFLOW DEVICE.

The OUTFLOW DEVICE must be referenced in the DEVICE INDEX.

If the DEVICE = 0 or is not referenced in the DEVICE INDEX, the watershed is ignored.

Watersheds do not have to be numbered consecutively.

To add or remove a watershed, you must use this screen. The watershed must be indexed before data (area, etc.) can be entered.



```
                    WATERSHED DATA
WATERSHED NUMBER                            1
WATERSHED LABEL                         upr nall

OUTFLOW DEVICE NUMBER                            <— for surface runoff

AQUIFER DEVICE NUMBER                            <— for percolation

TOTAL AREA                 acres
IMPERVIOUS FRACTION          -
DEPRESSION STORAGE         inches
SWEEPING FREQUENCY         1/week
PERVIOUS CURVE NUMBER        -

SCALE FACTOR FOR POLLUTANT LOADS
```

```
watershed label

F1=HELP  F2=DONE/SAVE  F3=EDIT FIELD  F7=HELP/EDITOR  <ESC>=ABORT
```

'Case Edit Watersheds Data'

OUTFLOW DEVICE NUMBER - routes runoff from current watershed to a specified treatment device, as defined in the DEVICE INDEX. (0 = receiving water).

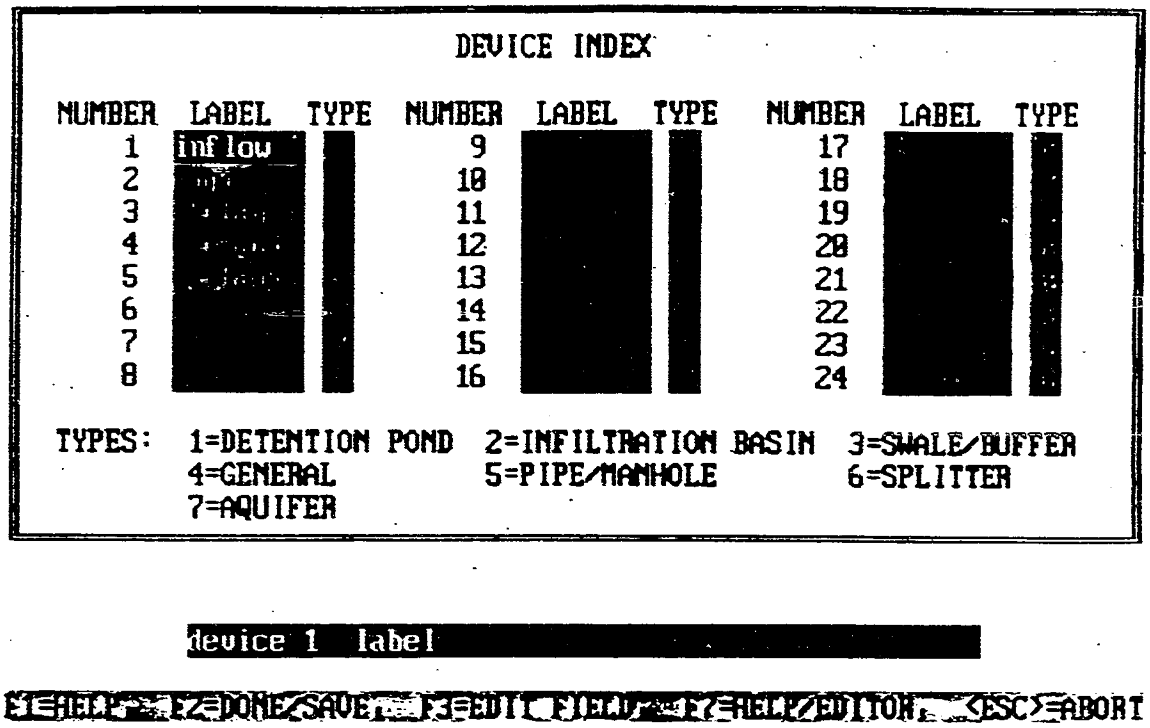
AQUIFER DEVICE NUMBER - routes percolation from pervious watershed area to an AQUIFER (DEVICE TYPE = 7). Routing of percolation to an AQUIFER is necessary only if prediction of BASEFLOW is desired (e.g., large watersheds).
Set=0 to ignore baseflow (does not influence computation of surface runoff).
If a nonzero device number is specified, the referenced device must be an AQUIFER (TYPE=7), or an error message will be issued.

DEPRESSION STORAGE & SWEEPING FREQUENCY refer to impervious portion of watershed only.

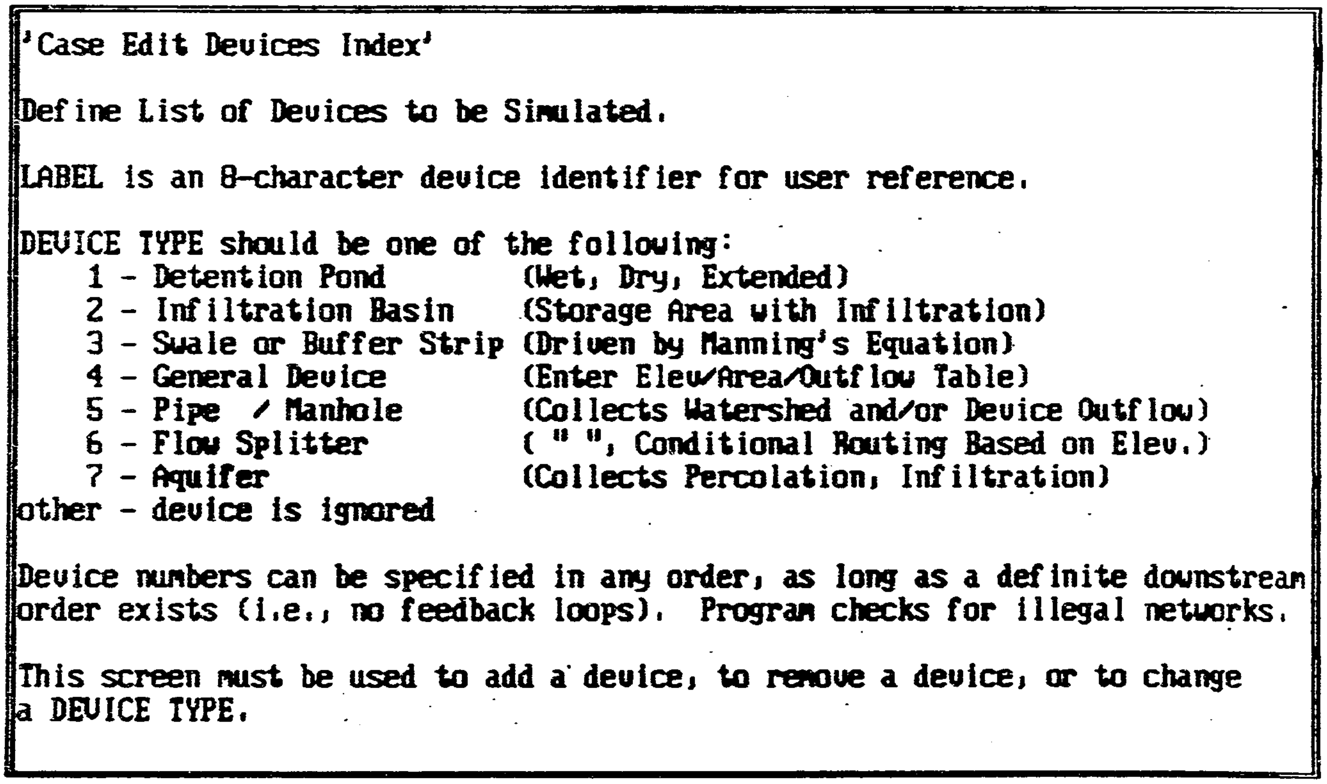
CURVE NUMBER refers to PERVIOUS portion of site only.

SCALE FACTOR FOR POLLUTANT LOADS modifies loads computed based upon other particle & watershed characteristics (Normally = 1).

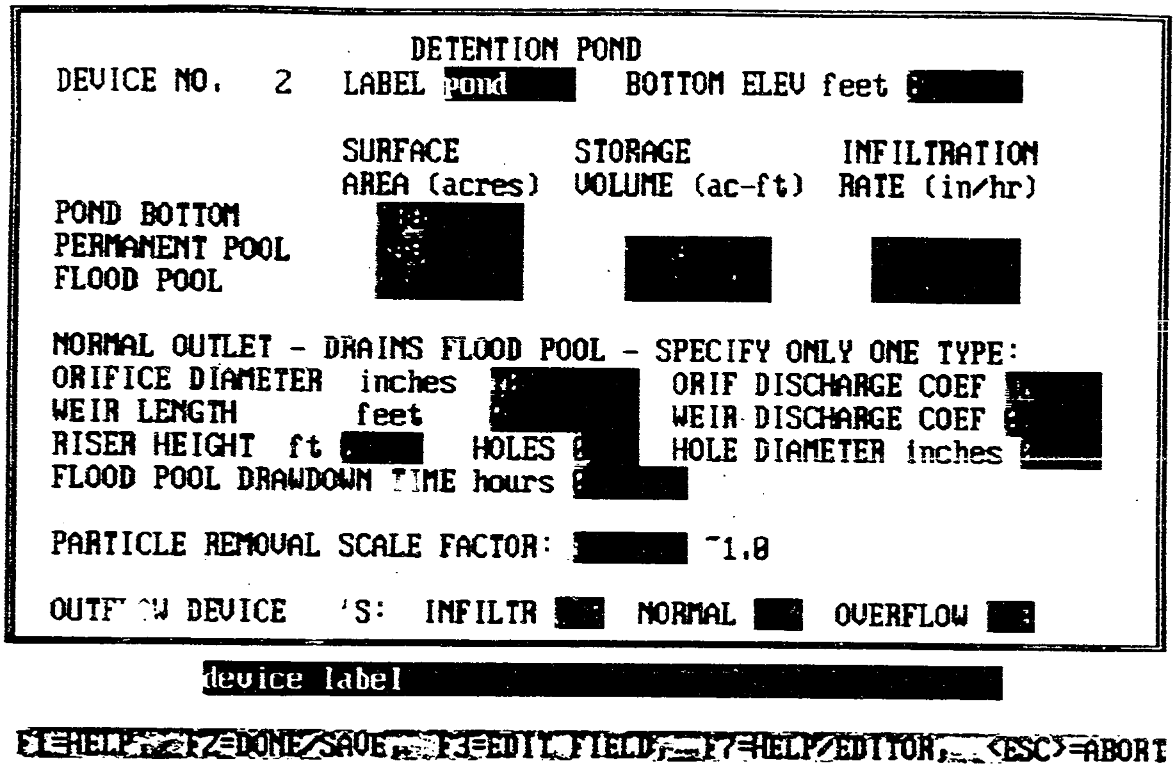
To access this screen, the watershed must be defined in the WATERSHED INDEX.



```
                               DEVICE INDEX

NUMBER  LABEL   TYPE  NUMBER  LABEL   TYPE   NUMBER  LABEL   TYPE
   1   inflow            9                     17
   2                    10                     18
   3                    11                     19
   4                    12                     20
   5                    13                     21
   6                    14                     22
   7                    15                     23
   8                    16                     24

TYPES:  1=DETENTION POND  2=INFILTRATION BASIN  3=SWALE/BUFFER
        4=GENERAL         5=PIPE/MANHOLE        6=SPLITTER
        7=AQUIFER

               device 1  label

F1=HELP  F2=DONE/SAVE  F3=EDIT FIELD  F7=HELP/EDITOR  <ESC>=ABORT
```



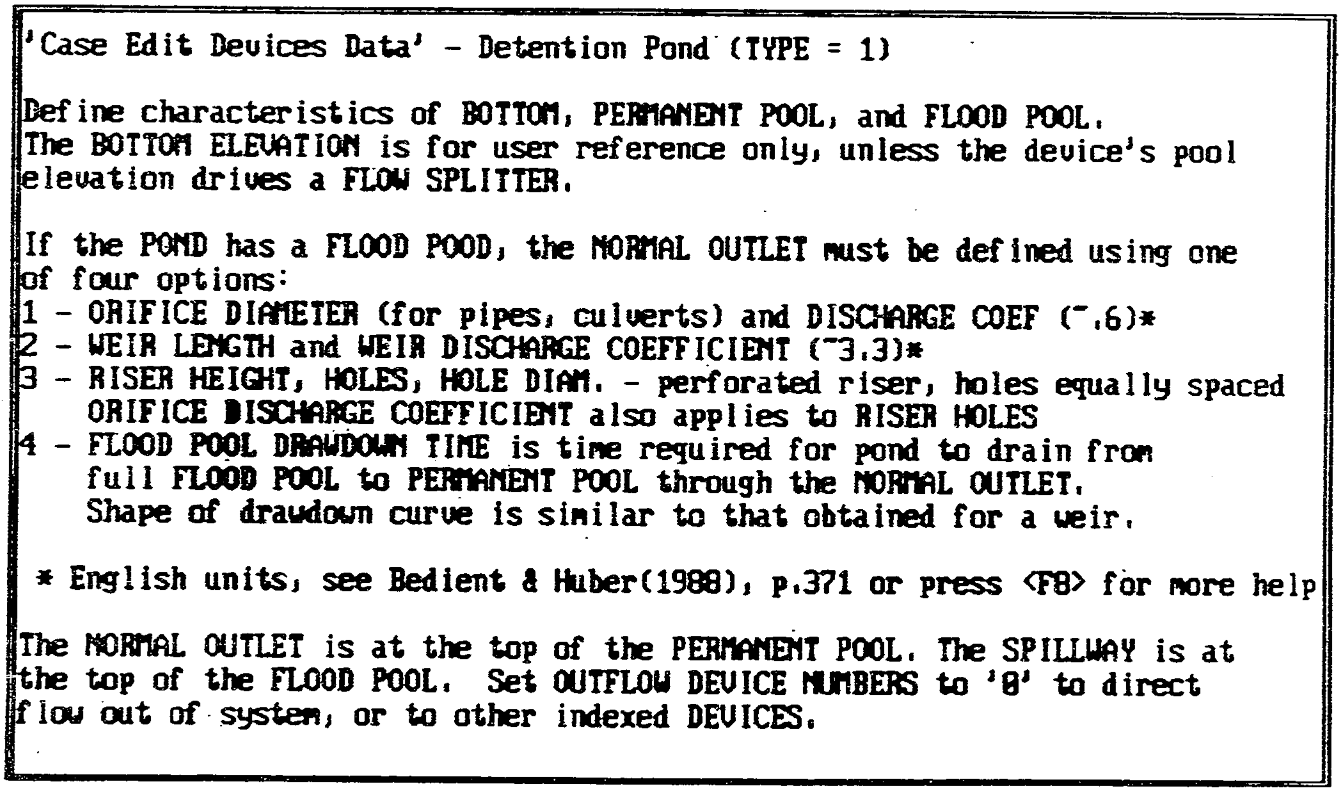
```
'Case Edit Devices Index'

Define List of Devices to be Simulated.

LABEL is an 8-character device identifier for user reference.

DEVICE TYPE should be one of the following:
    1 - Detention Pond        (Wet, Dry, Extended)
    2 - Infiltration Basin    (Storage Area with Infiltration)
    3 - Swale or Buffer Strip (Driven by Manning's Equation)
    4 - General Device        (Enter Elev/Area/Outflow Table)
    5 - Pipe  / Manhole       (Collects Watershed and/or Device Outflow)
    6 - Flow Splitter         ( " ", Conditional Routing Based on Elev.)
    7 - Aquifer               (Collects Percolation, Infiltration)
other - device is ignored

Device numbers can be specified in any order, as long as a definite downstream
order exists (i.e., no feedback loops).  Program checks for illegal networks.

This screen must be used to add a device, to remove a device, or to change
a DEVICE TYPE.
```



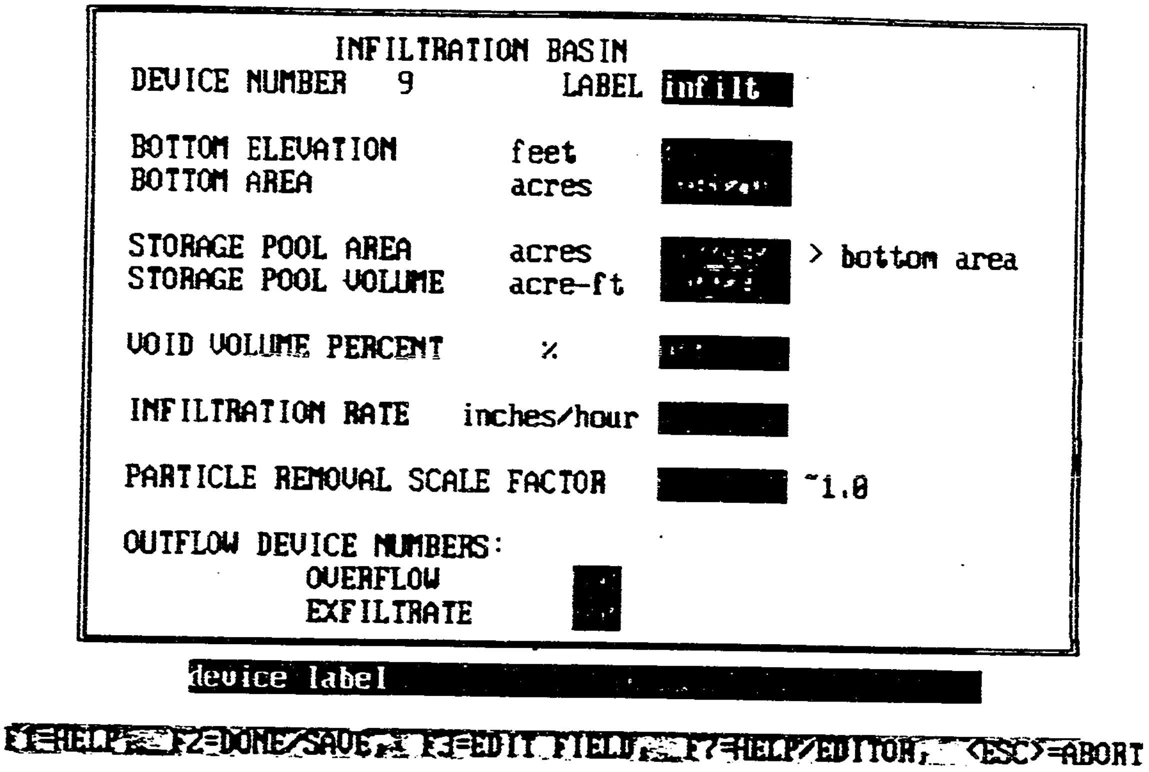
```
                         DETENTION POND
DEVICE NO.   2    LABEL pond          BOTTOM ELEV feet

                  SURFACE        STORAGE         INFILTRATION
                  AREA (acres)  VOLUME (ac-ft)  RATE (in/hr)
POND BOTTOM
PERMANENT POOL
FLOOD POOL

NORMAL OUTLET - DRAINS FLOOD POOL - SPECIFY ONLY ONE TYPE:
ORIFICE DIAMETER  inches              ORIF DISCHARGE COEF
WEIR LENGTH        feet               WEIR DISCHARGE COEF
RISER HEIGHT  ft        HOLES 0       HOLE DIAMETER inches
FLOOD POOL DRAWDOWN TIME hours

PARTICLE REMOVAL SCALE FACTOR:           ~1.0

OUTFLOW DEVICE #'S:   INFILTR     NORMAL     OVERFLOW
```

```
device label
```

```
F1=HELP, F2=DONE/SAVE, F3=EDIT FIELD, F7=HELP/EDITOR, <ESC>=ABORT
```



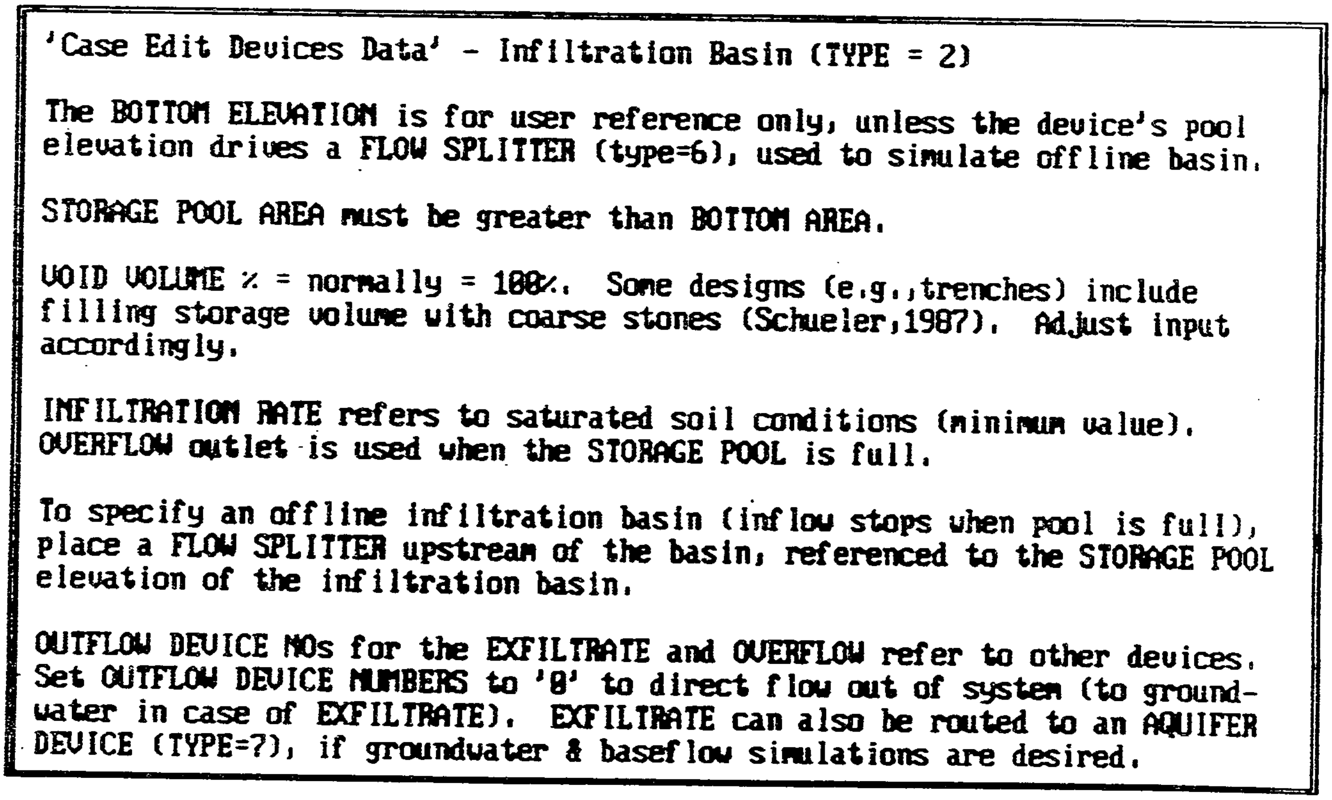
```
'Case Edit Devices Data' - Detention Pond (TYPE = 1)

Define characteristics of BOTTOM, PERMANENT POOL, and FLOOD POOL.
The BOTTOM ELEVATION is for user reference only, unless the device's pool
elevation drives a FLOW SPLITTER.

If the POND has a FLOOD POOD, the NORMAL OUTLET must be defined using one
of four options:
1 - ORIFICE DIAMETER (for pipes, culverts) and DISCHARGE COEF (~.6)*
2 - WEIR LENGTH and WEIR DISCHARGE COEFFICIENT (~3.3)*
3 - RISER HEIGHT, HOLES, HOLE DIAM. - perforated riser, holes equally spaced
    ORIFICE DISCHARGE COEFFICIENT also applies to RISER HOLES
4 - FLOOD POOL DRAWDOWN TIME is time required for pond to drain from
    full FLOOD POOL to PERMANENT POOL through the NORMAL OUTLET.
    Shape of drawdown curve is similar to that obtained for a weir.

 * English units, see Bedient & Huber(1988), p.371 or press <F8> for more help

The NORMAL OUTLET is at the top of the PERMANENT POOL. The SPILLWAY is at
the top of the FLOOD POOL.  Set OUTFLOW DEVICE NUMBERS to '0' to direct
flow out of system, or to other indexed DEVICES.
```



```
               INFILTRATION BASIN
DEVICE NUMBER   9            LABEL infilt

BOTTOM ELEVATION        feet
BOTTOM AREA             acres

STORAGE POOL AREA       acres           > bottom area
STORAGE POOL VOLUME     acre-ft

VOID VOLUME PERCENT       %

INFILTRATION RATE     inches/hour

PARTICLE REMOVAL SCALE FACTOR           ~1.0

OUTFLOW DEVICE NUMBERS:
              OVERFLOW
              EXFILTRATE
```

```
device label
```

```
F1=HELP, F2=DONE/SAVE, F3=EDIT FIELD, F7=HELP/EDITOR, <ESC>=ABORT
```



'Case Edit Devices Data' - Infiltration Basin (TYPE = 2)

The BOTTOM ELEVATION is for user reference only, unless the device's pool elevation drives a FLOW SPLITTER (type=6), used to simulate offline basin.

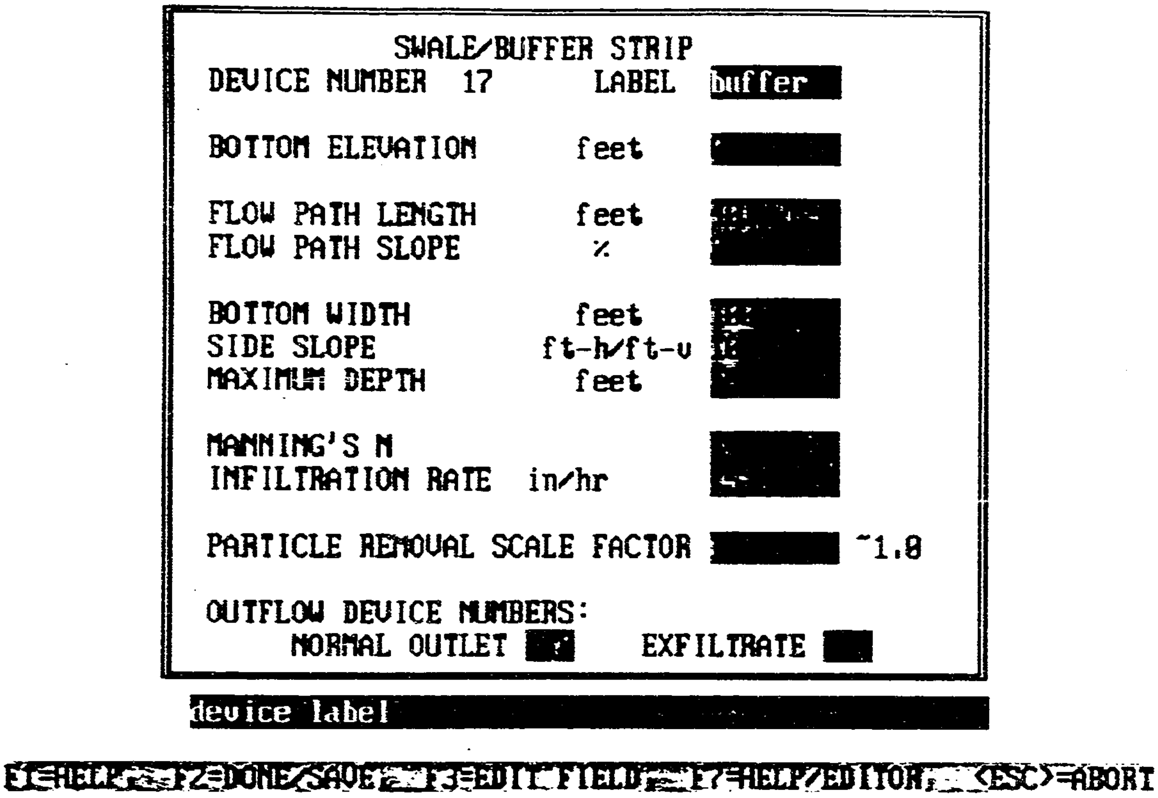
STORAGE POOL AREA must be greater than BOTTOM AREA.

VOID VOLUME % = normally = 100%. Some designs (e.g.,trenches) include filling storage volume with coarse stones (Schueler,1987). Adjust input accordingly.

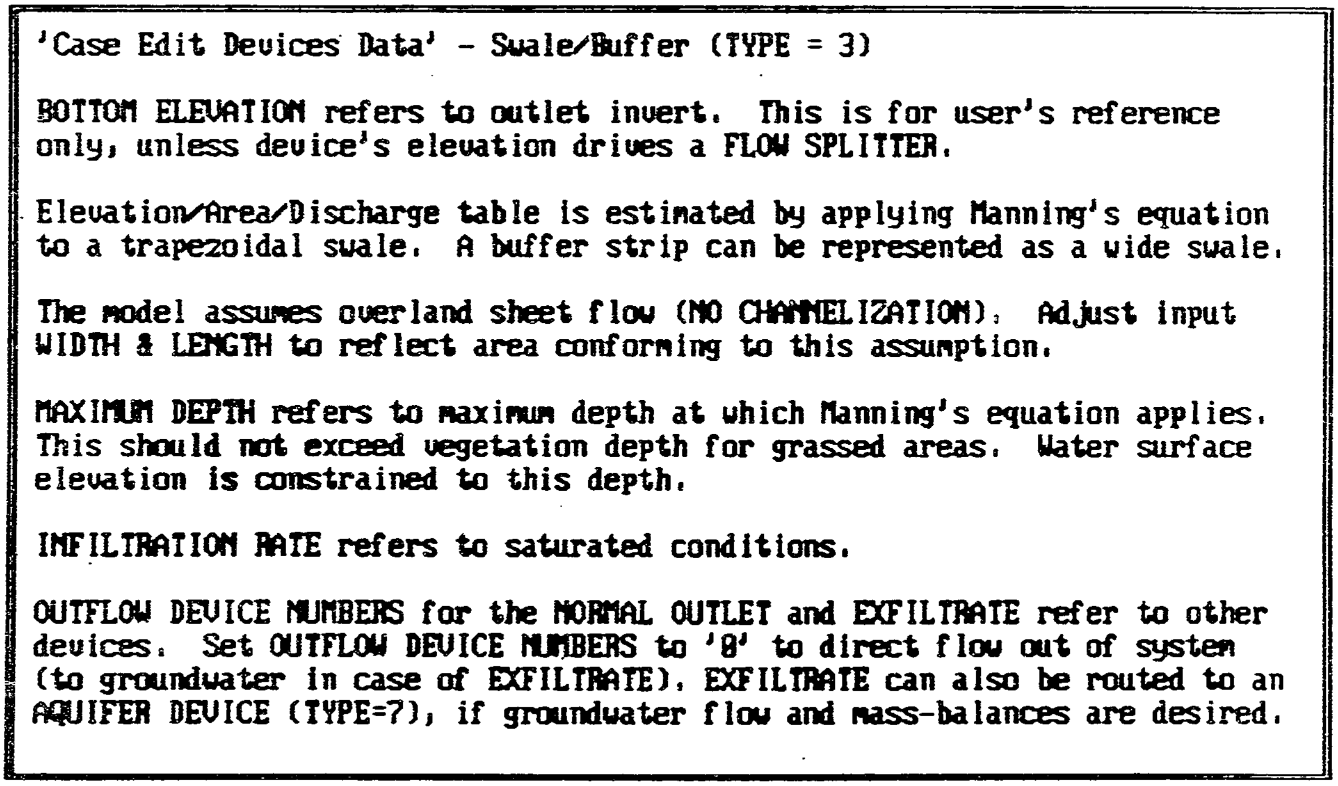
INFILTRATION RATE refers to saturated soil conditions (minimum value). OVERFLOW outlet is used when the STORAGE POOL is full.

To specify an offline infiltration basin (inflow stops when pool is full), place a FLOW SPLITTER upstream of the basin, referenced to the STORAGE POOL elevation of the infiltration basin.

OUTFLOW DEVICE NOs for the EXFILTRATE and OVERFLOW refer to other devices. Set OUTFLOW DEVICE NUMBERS to '0' to direct flow out of system (to groundwater in case of EXFILTRATE). EXFILTRATE can also be routed to an AQUIFER DEVICE (TYPE=7), if groundwater & baseflow simulations are desired.



```
                 SWALE/BUFFER STRIP
DEVICE NUMBER  17        LABEL     buffer

BOTTOM ELEVATION        feet

FLOW PATH LENGTH        feet
FLOW PATH SLOPE          %

BOTTOM WIDTH            feet
SIDE SLOPE            ft-h/ft-v
MAXIMUM DEPTH           feet

MANNING'S N
INFILTRATION RATE  in/hr

PARTICLE REMOVAL SCALE FACTOR          ~1.0

OUTFLOW DEVICE NUMBERS:
     NORMAL OUTLET        EXFILTRATE
device label
F1=HELP  F2=DONE/SAVE  F3=EDIT FIELD  F7=HELP/EDITOR  <ESC>=ABORT
```



'Case Edit Devices Data' - Swale/Buffer (TYPE = 3)

BOTTOM ELEVATION refers to outlet invert. This is for user's reference only, unless device's elevation drives a FLOW SPLITTER.

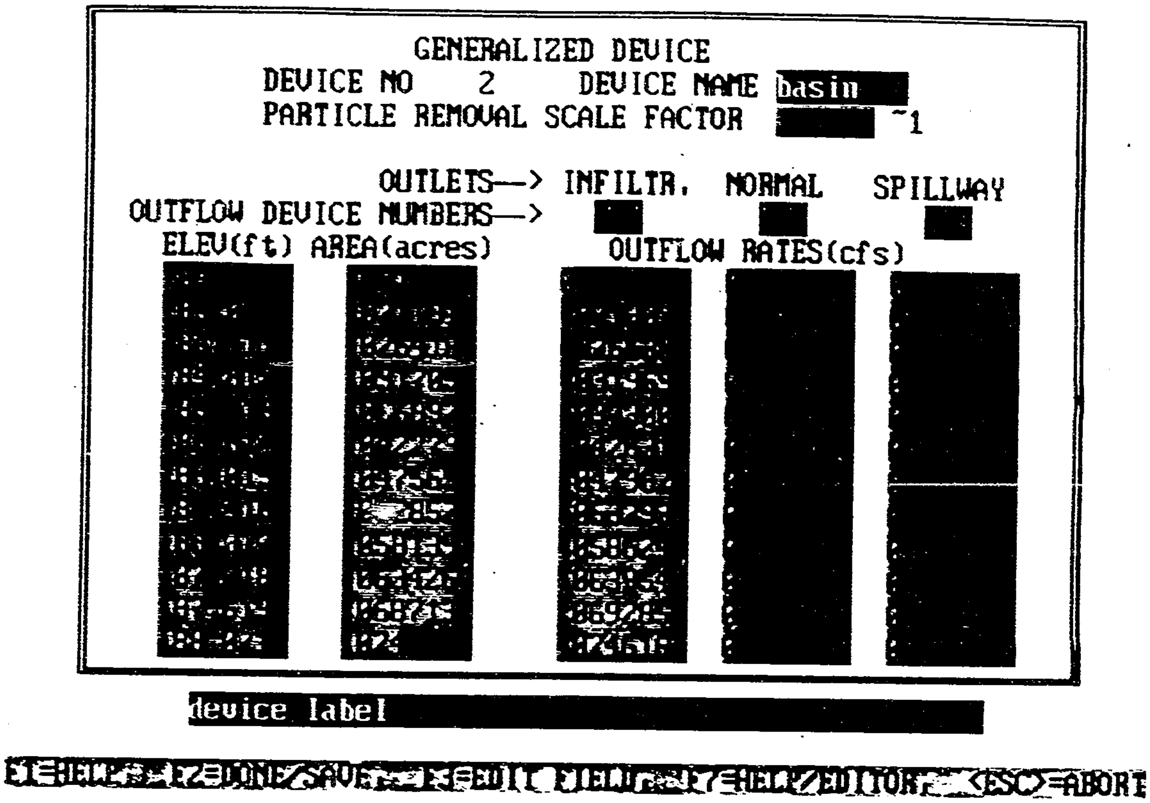
Elevation/Area/Discharge table is estimated by applying Manning's equation to a trapezoidal swale. A buffer strip can be represented as a wide swale.

The model assumes overland sheet flow (NO CHANNELIZATION). Adjust input WIDTH & LENGTH to reflect area conforming to this assumption.

MAXIMUM DEPTH refers to maximum depth at which Manning's equation applies. This should not exceed vegetation depth for grassed areas. Water surface elevation is constrained to this depth.

INFILTRATION RATE refers to saturated conditions.

OUTFLOW DEVICE NUMBERS for the NORMAL OUTLET and EXFILTRATE refer to other devices. Set OUTFLOW DEVICE NUMBERS to '0' to direct flow out of system (to groundwater in case of EXFILTRATE). EXFILTRATE can also be routed to an AQUIFER DEVICE (TYPE=7), if groundwater flow and mass-balances are desired.



GENERALIZED DEVICE

DEVICE NO 2 DEVICE NAME basin

PARTICLE REMOVAL SCALE FACTOR ~1

OUTLETS—> INFILTR. NORMAL SPILLWAY

OUTFLOW DEVICE NUMBERS—>

ELEV(ft) AREA(acres) OUTFLOW RATES(cfs)

device label

'Case Edit Device Data' - General Device (TYPE = 4)

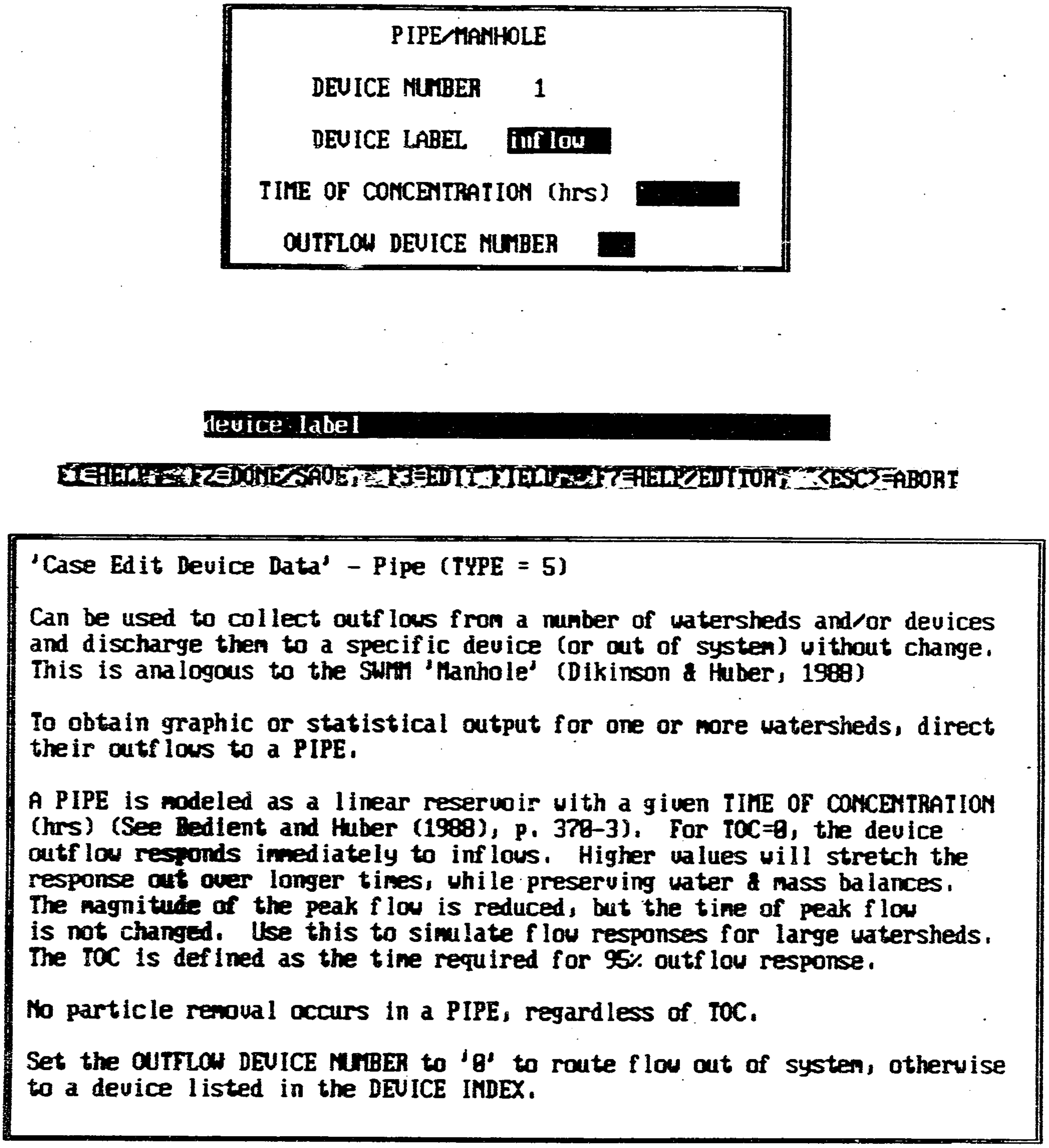
Defines elevation, area, discharge table for device with up to three outlets, labeled EXFILTRATE, NORMAL OUTLET, SPILLWAY. Similar input is required for hydrologic models (e.g., TR-20).

ELEVATION can be referenced to an arbitrary datum, unless device drives a FLOW SPLITTER. ELEVATION values must be entered in increasing order. Blank rows at bottom of table are ignored.

AREA & DISCHARGE must also be specified in increasing order. The SPILLWAY is automatically activated when the water elevation reaches the maximum value specified in this table.

Prior to simulation, a similar elevation/area/discharge table is generated for DEVICE TYPES 1, 2, and 3, based upon input values.

OUTFLOW DEVICE NUMBERS refer to other devices. Set OUTFLOW DEVICE NUMBERS to '0' to route flow out of system (to groundwater in case of EXFILTRATE). EXFILTRATE can also be routed to an AQUIFER DEVICE (TYPE=7), if groundwater flow and mass-balances are desired.



PIPE/MANHOLE

DEVICE NUMBER 1

DEVICE LABEL inflow

TIME OF CONCENTRATION (hrs)

OUTFLOW DEVICE NUMBER

device label

F1=HELP, F2=DONE/SAVE, F3=EDIT FIELD, F7=HELP/EDITOR, <ESC>=ABORT

'Case Edit Device Data' - Pipe (TYPE = 5)

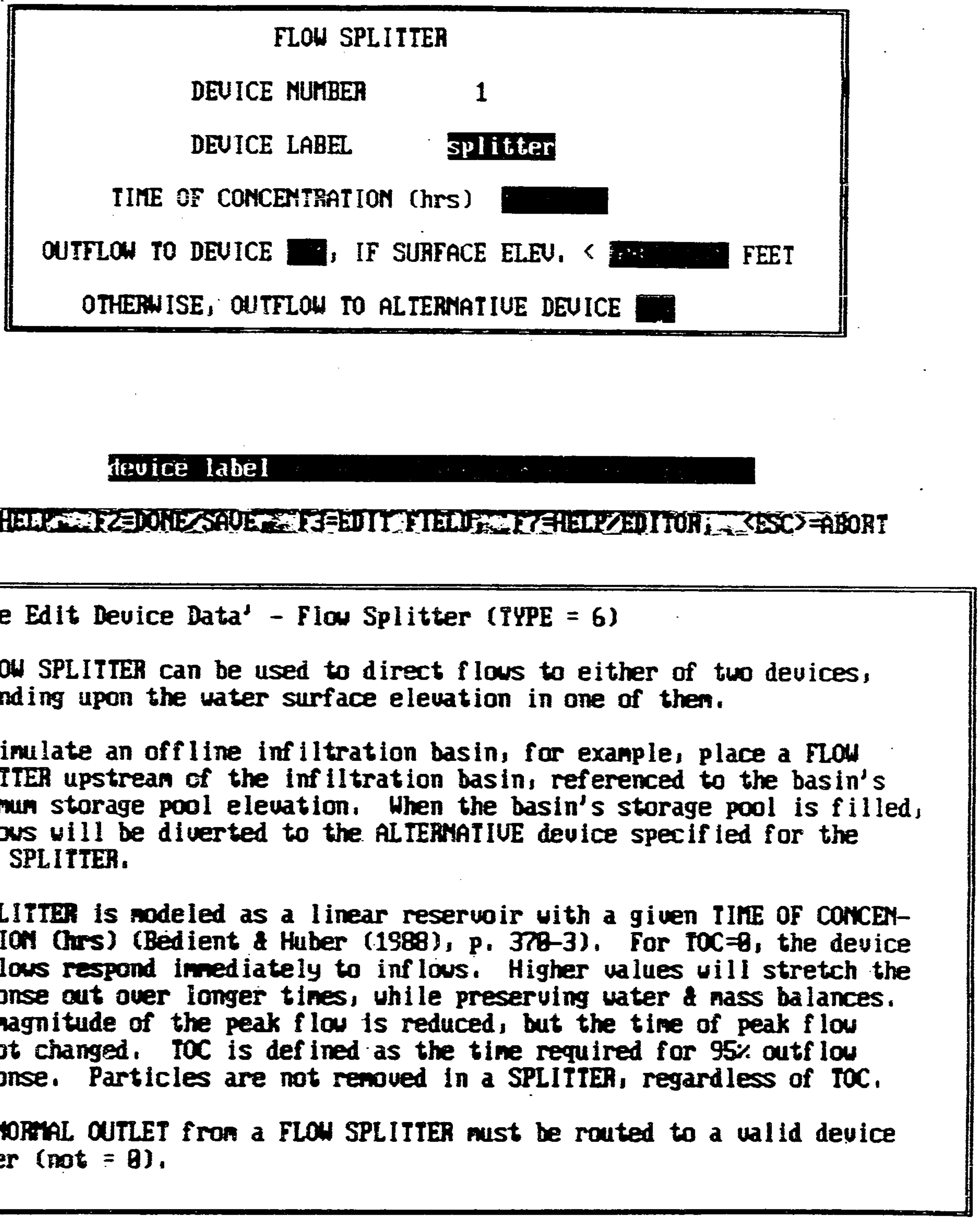
Can be used to collect outflows from a number of watersheds and/or devices and discharge them to a specific device (or out of system) without change. This is analogous to the SWMM 'Manhole' (Dikinson & Huber, 1988)

To obtain graphic or statistical output for one or more watersheds, direct their outflows to a PIPE.

A PIPE is modeled as a linear reservoir with a given TIME OF CONCENTRATION (hrs) (See Bedient and Huber (1988), p. 370-3). For TOC=0, the device outflow responds immediately to inflows. Higher values will stretch the response out over longer times, while preserving water & mass balances. The magnitude of the peak flow is reduced, but the time of peak flow is not changed. Use this to simulate flow responses for large watersheds. The TOC is defined as the time required for 95% outflow response.

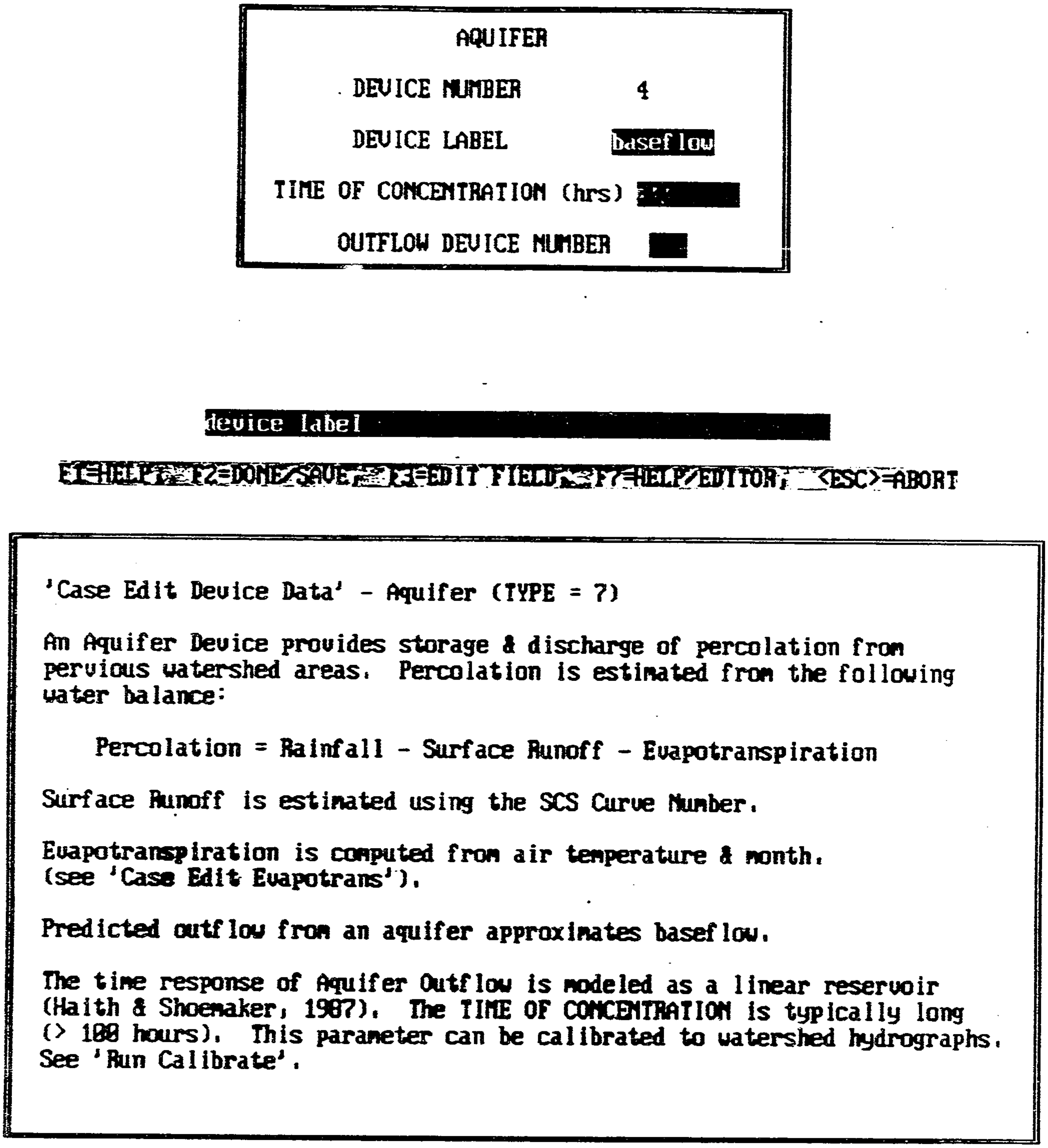
No particle removal occurs in a PIPE, regardless of TOC.

Set the OUTFLOW DEVICE NUMBER to '0' to route flow out of system, otherwise to a device listed in the DEVICE INDEX.

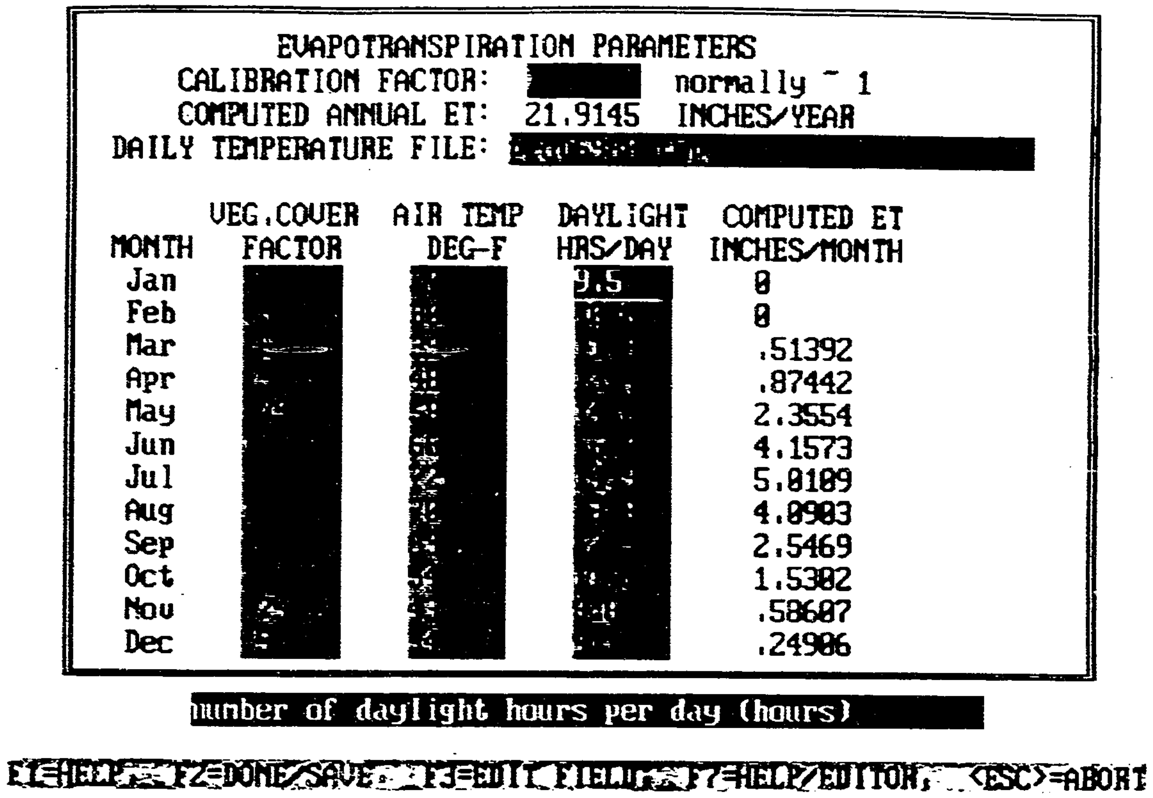


```
                    FLOW SPLITTER

            DEVICE NUMBER        1

            DEVICE LABEL       splitter

     TIME OF CONCENTRATION (hrs)

OUTFLOW TO DEVICE    , IF SURFACE ELEV. <          FEET

   OTHERWISE, OUTFLOW TO ALTERNATIVE DEVICE


          device label

F1=HELP, F2=DONE/SAVE, F3=EDIT FIELD, F7=HELP/EDITOR, <ESC>=ABORT
```

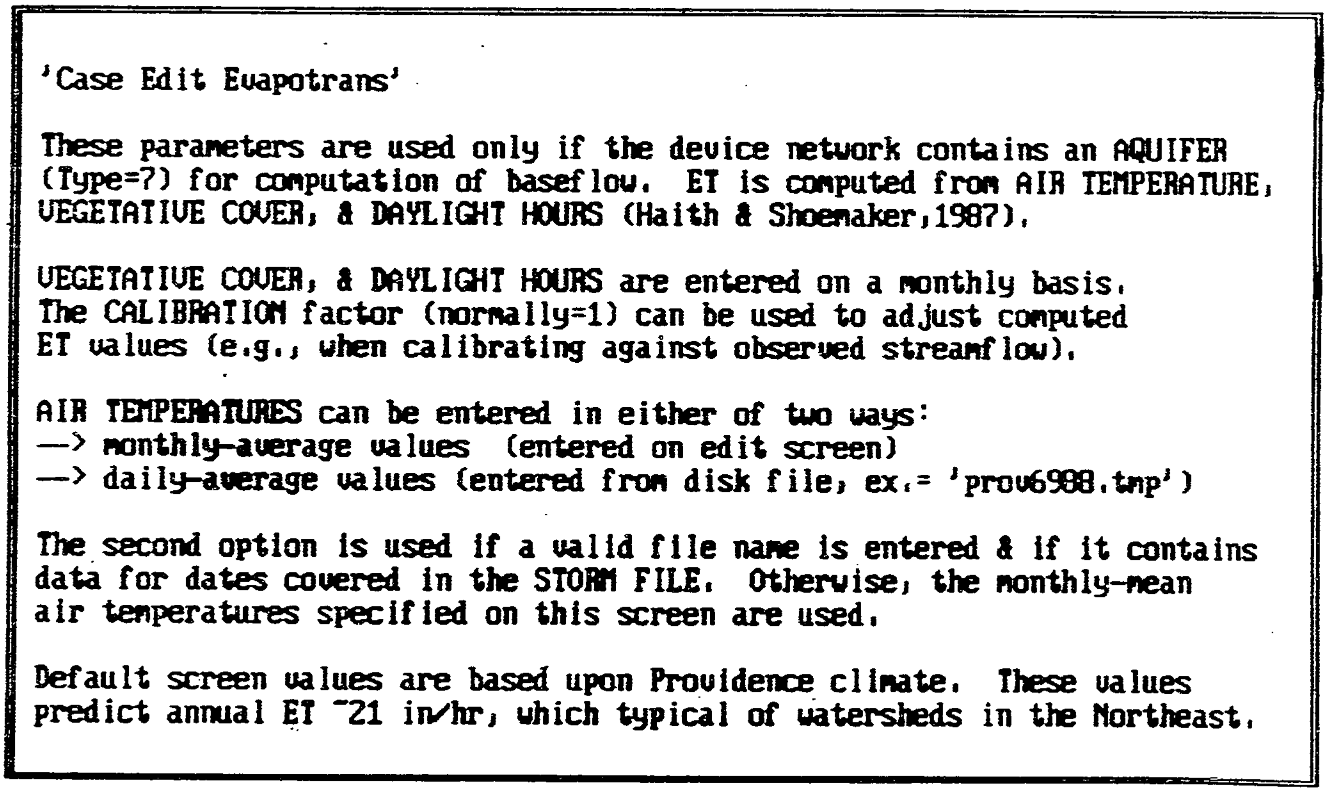
```
'Case Edit Device Data' - Flow Splitter (TYPE = 6)

A FLOW SPLITTER can be used to direct flows to either of two devices,
depending upon the water surface elevation in one of them.

To simulate an offline infiltration basin, for example, place a FLOW
SPLITTER upstream of the infiltration basin, referenced to the basin's
maximum storage pool elevation. When the basin's storage pool is filled,
inflows will be diverted to the ALTERNATIVE device specified for the
FLOW SPLITTER.

A SPLITTER is modeled as a linear reservoir with a given TIME OF CONCEN-
TRATION (hrs) (Bedient & Huber (1988), p. 370-3). For TOC=0, the device
outflows respond immediately to inflows. Higher values will stretch the
response out over longer times, while preserving water & mass balances.
The magnitude of the peak flow is reduced, but the time of peak flow
is not changed. TOC is defined as the time required for 95% outflow
response. Particles are not removed in a SPLITTER, regardless of TOC.

The NORMAL OUTLET from a FLOW SPLITTER must be routed to a valid device
number (not = 0).
```



```
                    AQUIFER

           DEVICE NUMBER          4

           DEVICE LABEL          baseflow

    TIME OF CONCENTRATION (hrs) [illegible]

           OUTFLOW DEVICE NUMBER



device label

F1=HELP; F2=DONE/SAVE; F3=EDIT FIELD; F7=HELP/EDITOR; <ESC>=ABORT


'Case Edit Device Data' - Aquifer (TYPE = 7)

An Aquifer Device provides storage & discharge of percolation from
pervious watershed areas.  Percolation is estimated from the following
water balance:

     Percolation = Rainfall - Surface Runoff - Evapotranspiration

Surface Runoff is estimated using the SCS Curve Number.

Evapotranspiration is computed from air temperature & month.
(see 'Case Edit Evapotrans').

Predicted outflow from an aquifer approximates baseflow.

The time response of Aquifer Outflow is modeled as a linear reservoir
(Haith & Shoemaker, 1987).  The TIME OF CONCENTRATION is typically long
(> 100 hours).  This parameter can be calibrated to watershed hydrographs.
See 'Run Calibrate'.
```



```
              EVAPOTRANSPIRATION PARAMETERS
          CALIBRATION FACTOR: [illegible]  normally ~ 1
          COMPUTED ANNUAL ET:  21.9145  INCHES/YEAR
      DAILY TEMPERATURE FILE: [illegible]

           VEG.COVER   AIR TEMP   DAYLIGHT   COMPUTED ET
    MONTH   FACTOR      DEG-F     HRS/DAY   INCHES/MONTH
     Jan  [illegible] [illegible]   9.5           0
     Feb  [illegible] [illegible] [illegible]     0
     Mar  [illegible] [illegible] [illegible]   .51392
     Apr  [illegible] [illegible] [illegible]   .87442
     May  [illegible] [illegible] [illegible]   2.3554
     Jun  [illegible] [illegible] [illegible]   4.1573
     Jul  [illegible] [illegible] [illegible]   5.0109
     Aug  [illegible] [illegible] [illegible]   4.0903
     Sep  [illegible] [illegible] [illegible]   2.5469
     Oct  [illegible] [illegible] [illegible]   1.5302
     Nov  [illegible] [illegible] [illegible]   .58607
     Dec  [illegible] [illegible] [illegible]   .24906

        number of daylight hours per day (hours)

F1=HELP; F2=DONE/SAVE; F3=EDIT FIELD; F7=HELP/EDITOR; <ESC>=ABORT
```



'Case Edit Evapotrans'

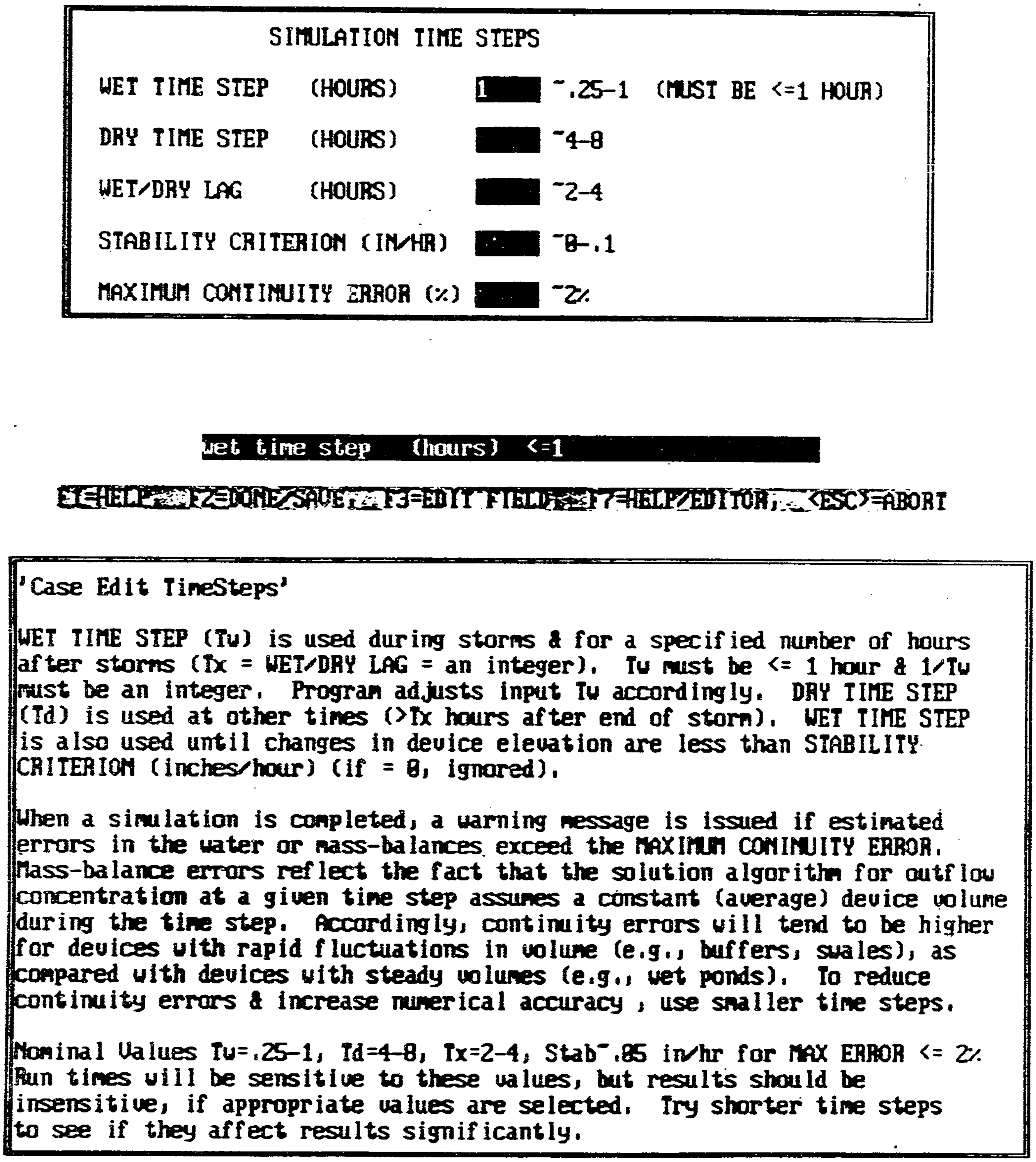
These parameters are used only if the device network contains an AQUIFER (Type=7) for computation of baseflow. ET is computed from AIR TEMPERATURE, VEGETATIVE COVER, & DAYLIGHT HOURS (Haith & Shoemaker,1987).

VEGETATIVE COVER, & DAYLIGHT HOURS are entered on a monthly basis. The CALIBRATION factor (normally=1) can be used to adjust computed ET values (e.g., when calibrating against observed streamflow).

AIR TEMPERATURES can be entered in either of two ways:
—> monthly-average values (entered on edit screen)
—> daily-average values (entered from disk file, ex.= 'prov6988.tmp')

The second option is used if a valid file name is entered & if it contains data for dates covered in the STORM FILE. Otherwise, the monthly-mean air temperatures specified on this screen are used.

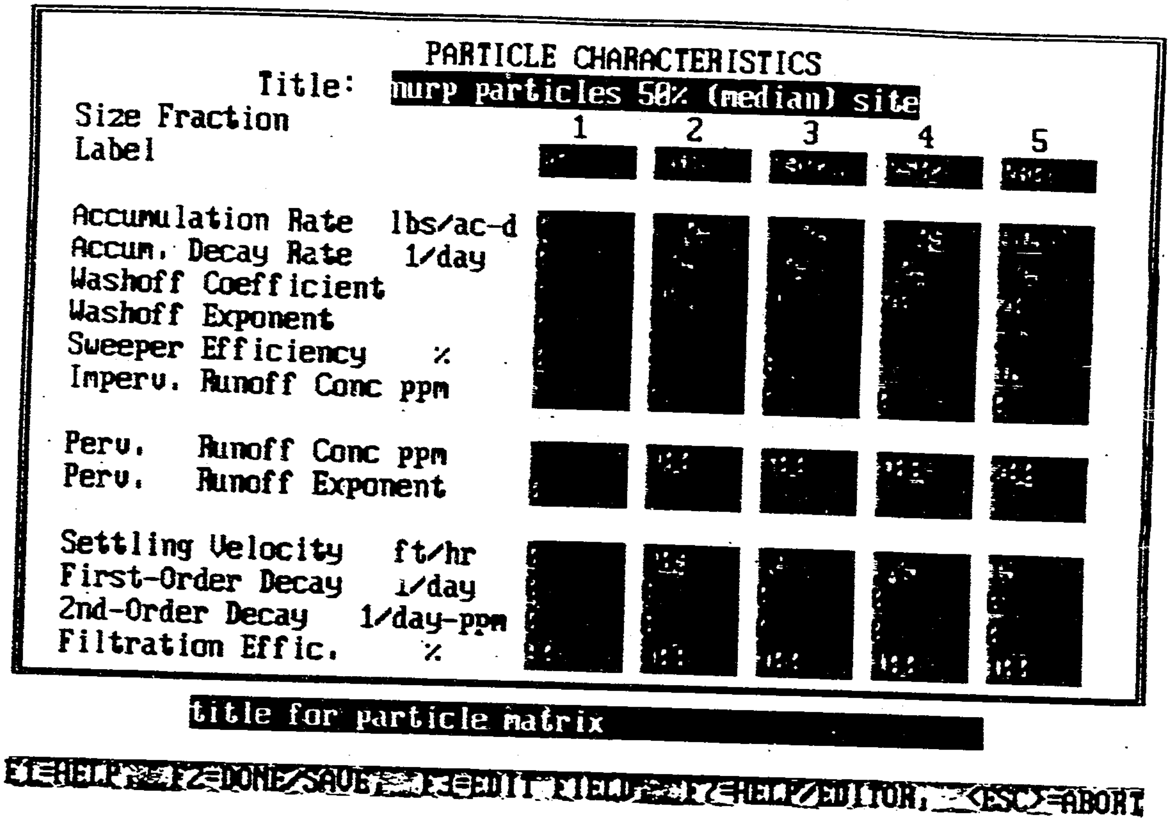
Default screen values are based upon Providence climate. These values predict annual ET ~21 in/hr, which typical of watersheds in the Northeast.



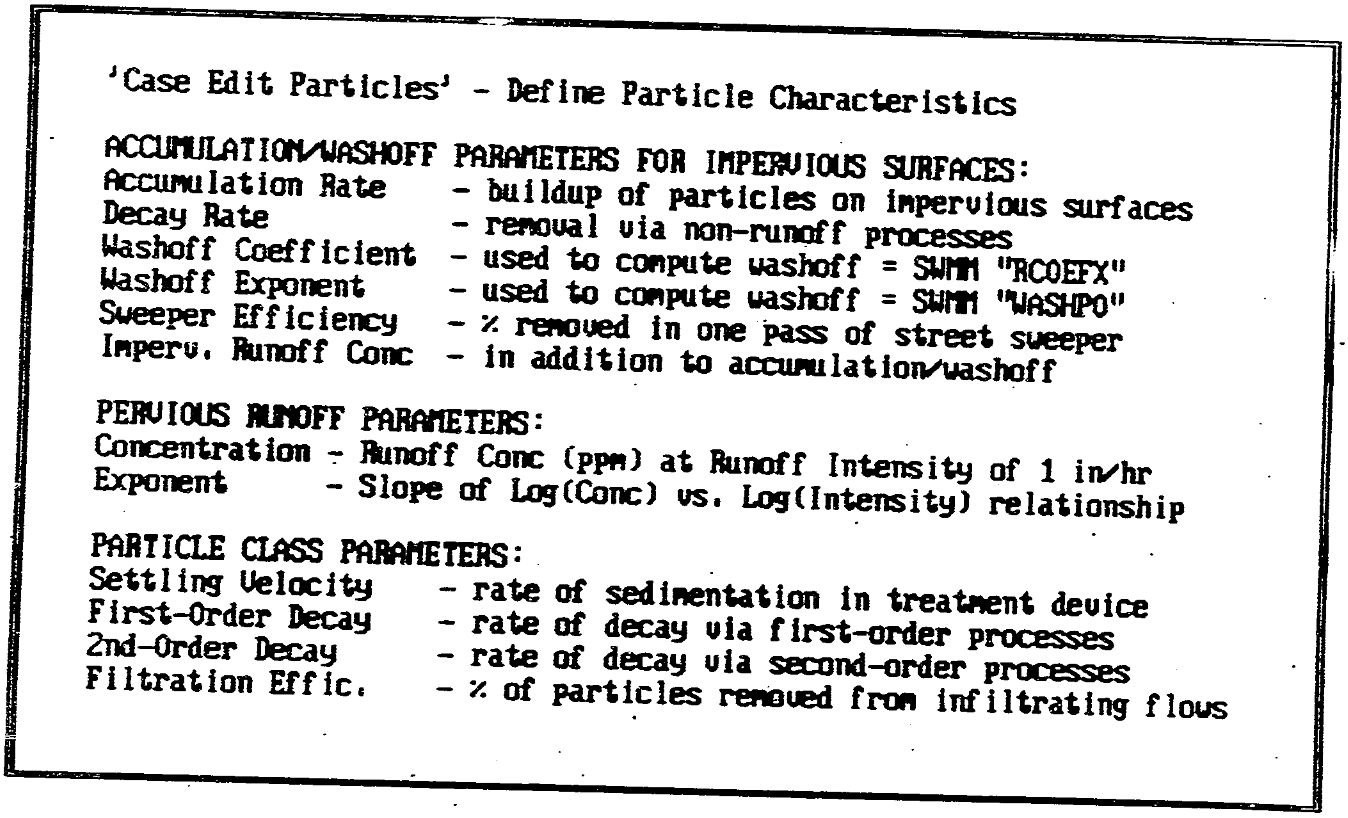
```
                SIMULATION TIME STEPS

WET TIME STEP    (HOURS)           1    ~.25-1  (MUST BE <=1 HOUR)

DRY TIME STEP    (HOURS)                ~4-8

WET/DRY LAG      (HOURS)                ~2-4

STABILITY CRITERION (IN/HR)             ~0-.1

MAXIMUM CONTINUITY ERROR (%)            ~2%
```

```
wet time step    (hours)  <=1

F1=HELP; F2=DONE/SAVE; F3=EDIT FIELD; F7=HELP/EDITOR; <ESC>=ABORT
```

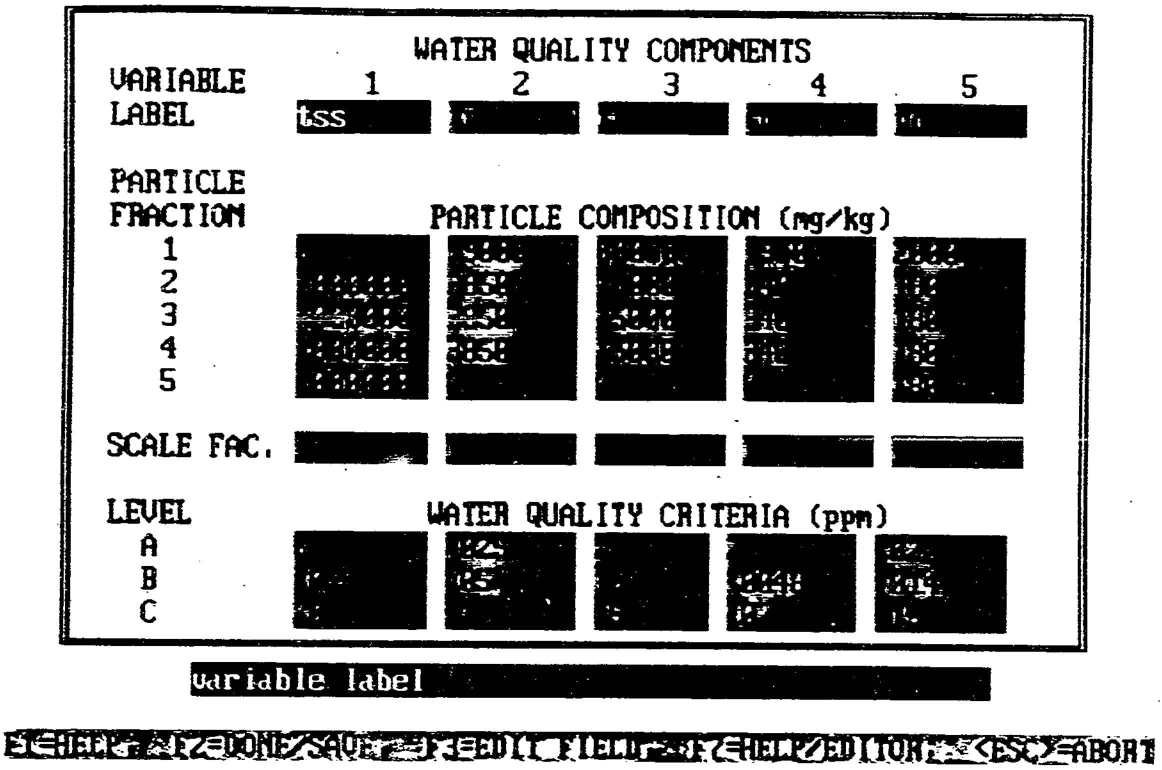
```
'Case Edit TimeSteps'

WET TIME STEP (Tw) is used during storms & for a specified number of hours
after storms (Tx = WET/DRY LAG = an integer).  Tw must be <= 1 hour & 1/Tw
must be an integer.  Program adjusts input Tw accordingly.  DRY TIME STEP
(Td) is used at other times (>Tx hours after end of storm).  WET TIME STEP
is also used until changes in device elevation are less than STABILITY
CRITERION (inches/hour) (if = 0, ignored).

When a simulation is completed, a warning message is issued if estimated
errors in the water or mass-balances exceed the MAXIMUM CONINUITY ERROR.
Mass-balance errors reflect the fact that the solution algorithm for outflow
concentration at a given time step assumes a constant (average) device volume
during the time step.  Accordingly, continuity errors will tend to be higher
for devices with rapid fluctuations in volume (e.g., buffers, swales), as
compared with devices with steady volumes (e.g., wet ponds).  To reduce
continuity errors & increase numerical accuracy , use smaller time steps.

Nominal Values Tw=.25-1, Td=4-8, Tx=2-4, Stab~.05 in/hr for MAX ERROR <= 2%
Run times will be sensitive to these values, but results should be
insensitive, if appropriate values are selected.  Try shorter time steps
to see if they affect results significantly.
```



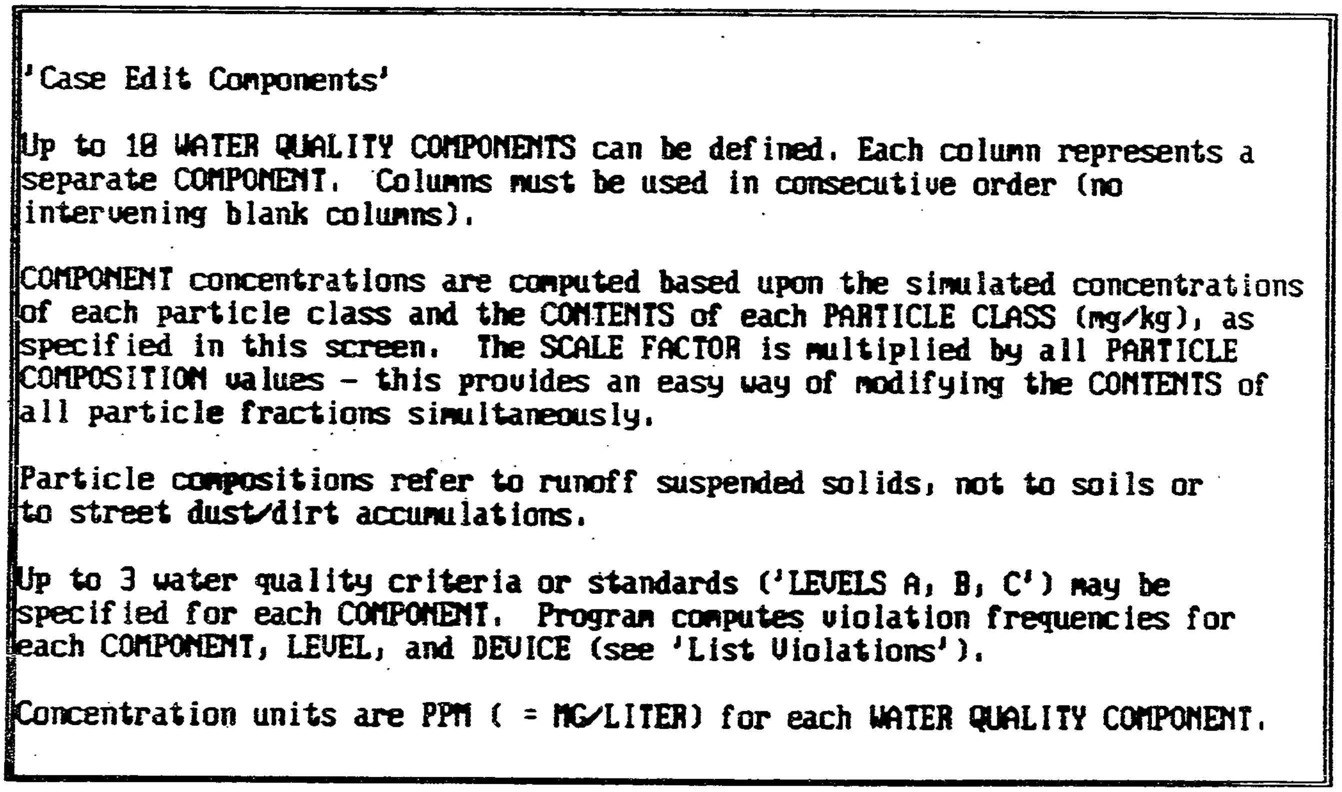
```
                     PARTICLE CHARACTERISTICS
              Title:  nurp particles 50% (median) site
Size Fraction
Label                                1      2      3      4      5

Accumulation Rate   lbs/ac-d
Accum. Decay Rate   1/day
Washoff Coefficient
Washoff Exponent
Sweeper Efficiency    %
Imperv. Runoff Conc ppm

Perv.    Runoff Conc ppm
Perv.    Runoff Exponent

Settling Velocity   ft/hr
First-Order Decay   1/day
2nd-Order Decay    1/day-ppm
Filtration Effic.     %

          title for particle matrix

F1=HELP, F2=DONE/SAVE, F3=EDIT FIELD, F7=HELP/EDITOR, <ESC>=ABORT
```



```
'Case Edit Particles' - Define Particle Characteristics

ACCUMULATION/WASHOFF PARAMETERS FOR IMPERVIOUS SURFACES:
Accumulation Rate    - buildup of particles on impervious surfaces
Decay Rate           - removal via non-runoff processes
Washoff Coefficient  - used to compute washoff = SWMM "RCOEFX"
Washoff Exponent     - used to compute washoff = SWMM "WASHPO"
Sweeper Efficiency   - % removed in one pass of street sweeper
Imperv. Runoff Conc  - in addition to accumulation/washoff

PERVIOUS RUNOFF PARAMETERS:
Concentration - Runoff Conc (ppm) at Runoff Intensity of 1 in/hr
Exponent      - Slope of Log(Conc) vs. Log(Intensity) relationship

PARTICLE CLASS PARAMETERS:
Settling Velocity    - rate of sedimentation in treatment device
First-Order Decay    - rate of decay via first-order processes
2nd-Order Decay      - rate of decay via second-order processes
Filtration Effic.    - % of particles removed from infiltrating flows
```



```
                    WATER QUALITY COMPONENTS
VARIABLE        1          2          3          4          5
LABEL        tss

PARTICLE
FRACTION              PARTICLE COMPOSITION (mg/kg)
   1
   2
   3
   4                    858
   5

SCALE FAC.

LEVEL                 WATER QUALITY CRITERIA (ppm)
  A
  B
  C

        variable label

F1=HELP F2=DONE/SAVE F3=EDIT FIELD F7=HELP/EDITOR <ESC>=ABORT
```



'Case Edit Components'

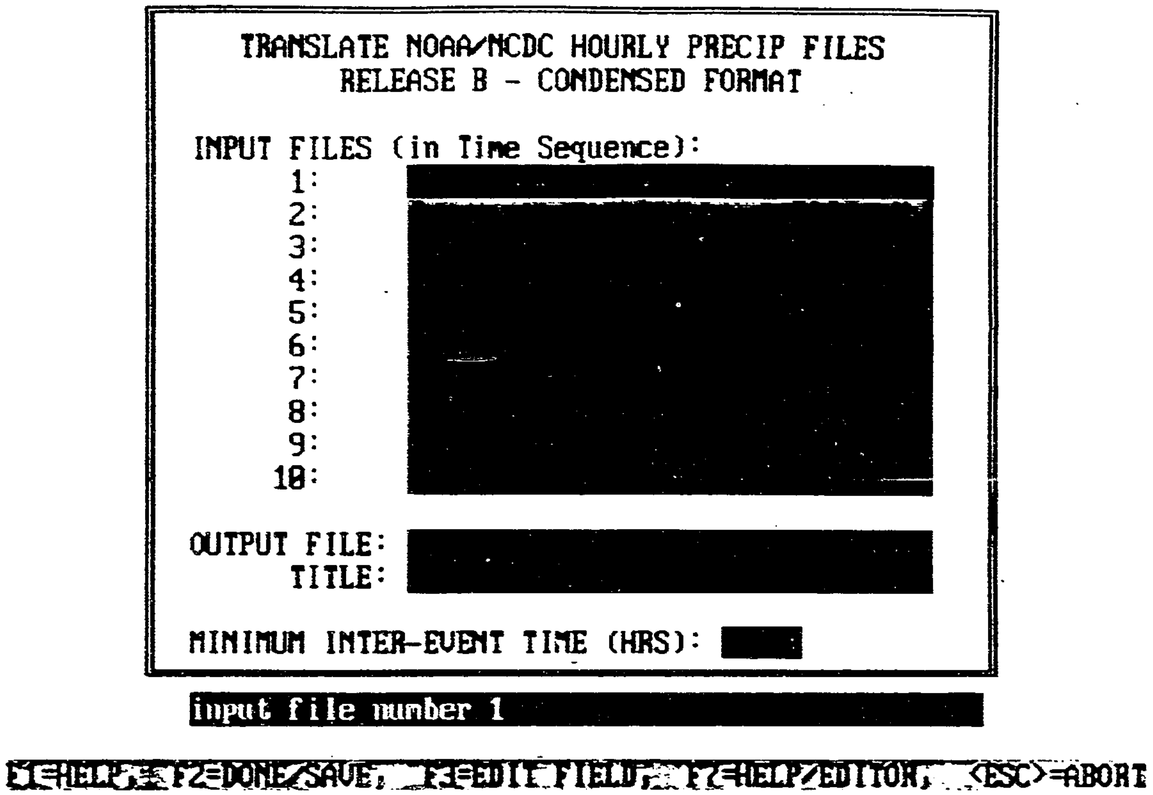
Up to 10 WATER QUALITY COMPONENTS can be defined. Each column represents a separate COMPONENT. Columns must be used in consecutive order (no intervening blank columns).

COMPONENT concentrations are computed based upon the simulated concentrations of each particle class and the CONTENTS of each PARTICLE CLASS (mg/kg), as specified in this screen. The SCALE FACTOR is multiplied by all PARTICLE COMPOSITION values - this provides an easy way of modifying the CONTENTS of all particle fractions simultaneously.

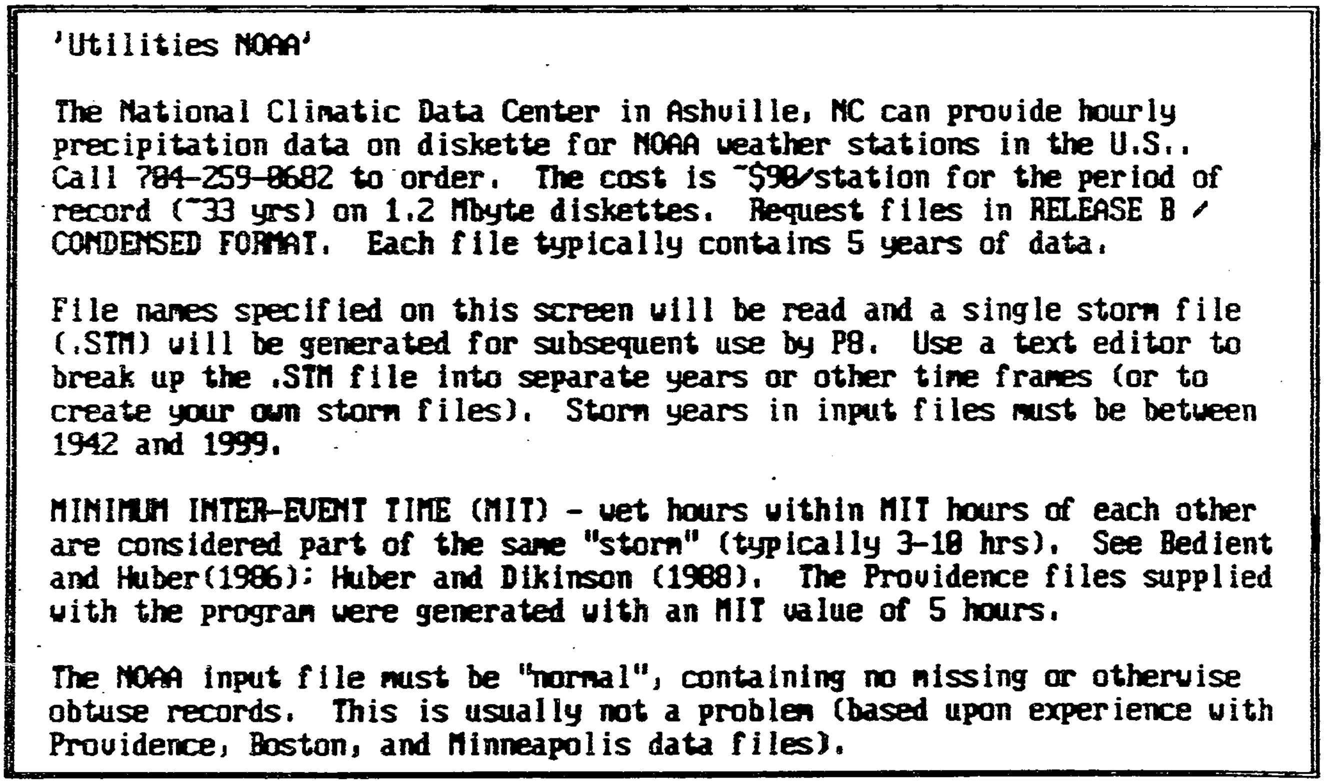
Particle compositions refer to runoff suspended solids, not to soils or to street dust/dirt accumulations.

Up to 3 water quality criteria or standards ('LEVELS A, B, C') may be specified for each COMPONENT. Program computes violation frequencies for each COMPONENT, LEVEL, and DEVICE (see 'List Violations').

Concentration units are PPM (= MG/LITER) for each WATER QUALITY COMPONENT.



```
        TRANSLATE NOAA/NCDC HOURLY PRECIP FILES
            RELEASE B - CONDENSED FORMAT

   INPUT FILES (in Time Sequence):
                1:
                2:
                3:
                4:
                5:
                6:
                7:
                8:
                9:
               10:

   OUTPUT FILE:
         TITLE:

   MINIMUM INTER-EVENT TIME (HRS):

input file number 1

F1=HELP, F2=DONE/SAVE, F3=EDIT FIELD, F7=HELP/EDITOR, <ESC>=ABORT
```



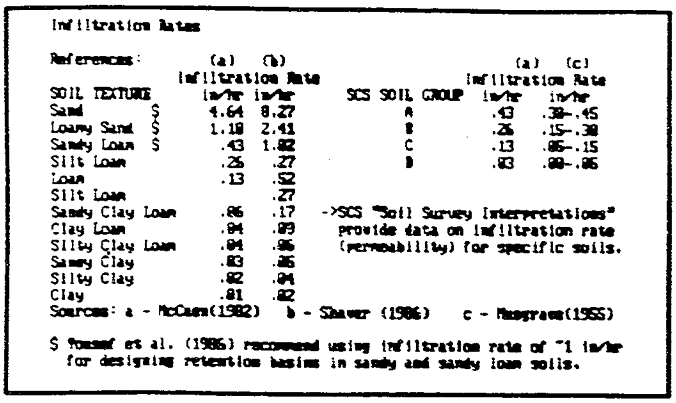
'Utilities NOAA'

The National Climatic Data Center in Ashville, NC can provide hourly precipitation data on diskette for NOAA weather stations in the U.S.. Call 704-259-0682 to order. The cost is ~$90/station for the period of record (~33 yrs) on 1.2 Mbyte diskettes. Request files in RELEASE B / CONDENSED FORMAT. Each file typically contains 5 years of data.

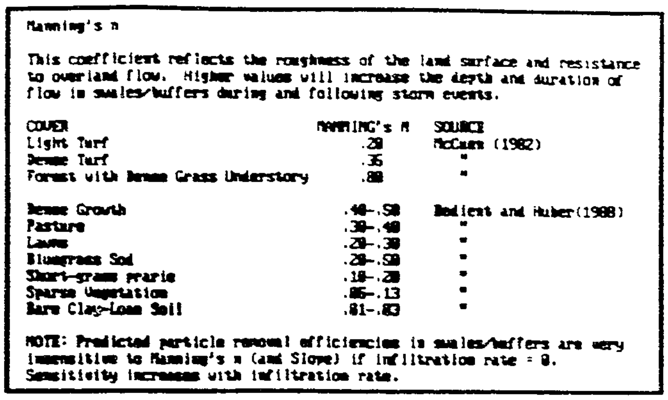
File names specified on this screen will be read and a single storm file (.STM) will be generated for subsequent use by P8. Use a text editor to break up the .STM file into separate years or other time frames (or to create your own storm files). Storm years in input files must be between 1942 and 1999.

MINIMUM INTER-EVENT TIME (MIT) - wet hours within MIT hours of each other are considered part of the same "storm" (typically 3-10 hrs). See Bedient and Huber(1986); Huber and Dikinson (1988). The Providence files supplied with the program were generated with an MIT value of 5 hours.

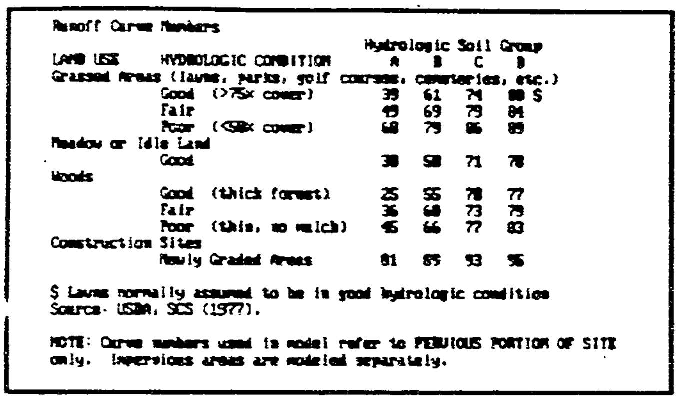
The NOAA input file must be "normal", containing no missing or otherwise obtuse records. This is usually not a problem (based upon experience with Providence, Boston, and Minneapolis data files).



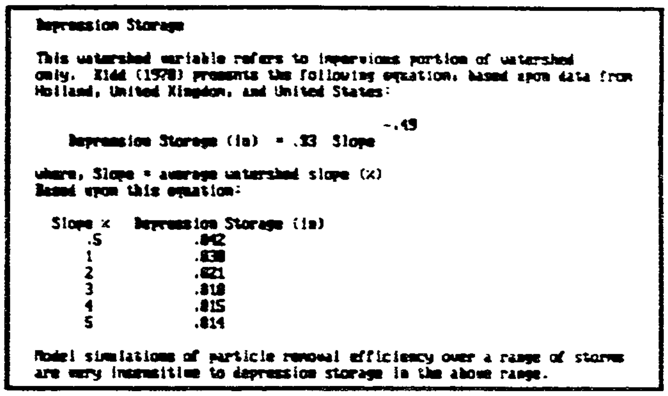
```
Infiltration Rates

References:          (a)   (b)                          (a)   (c)
                  Infiltration Rate               Infiltration Rate
SOIL TEXTURE        in/hr in/hr     SCS SOIL GROUP   in/hr    in/hr
Sand           $    4.64  8.27            A            .43   .30-.45
Loamy Sand     $    1.18  2.41            B            .26   .15-.30
Sandy Loam     $     .43  1.02            C            .13   .05-.15
Silt Loam            .26   .27            D            .03   .00-.05
Loam                 .13   .52
Silt Loam                  .27
Sandy Clay Loam      .06   .17    ->SCS "Soil Survey Interpretations"
Clay Loam            .04   .09      provide data on infiltration rate
Silty Clay Loam      .04   .06      (permeability) for specific soils.
Sandy Clay           .03   .05
Silty Clay           .02   .04
Clay                 .01   .02
Sources: a - McCuen(1982)   b - Shaver (1986)    c - Musgrave(1955)

$ Yousef et al. (1986) recommend using infiltration rate of ~1 in/hr
  for designing retention basins in sandy and sandy loam soils.
```



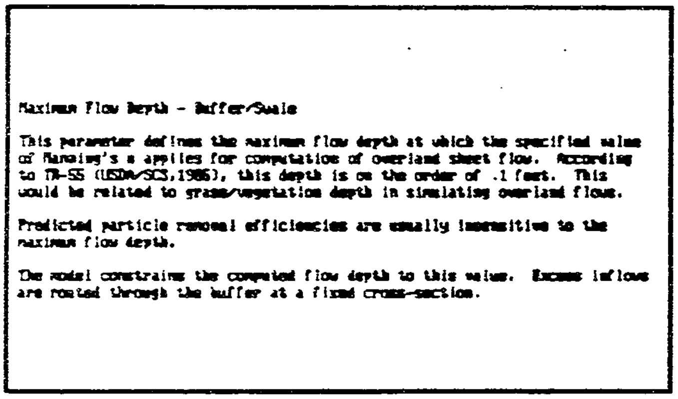
```
Manning's n

This coefficient reflects the roughness of the land surface and resistance
to overland flow.  Higher values will increase the depth and duration of
flow in swales/buffers during and following storm events.

COVER                                   MANNING's N   SOURCE
Light Turf                                  .20       McCuen (1982)
Dense Turf                                  .35          "
Forest with Dense Grass Understory          .80          "

Dense Growth                              .40-.50     Bedient and Huber(1988)
Pasture                                   .30-.40        "
Lawns                                     .20-.30        "
Bluegrass Sod                             .20-.50        "
Short-grass prarie                        .10-.20        "
Sparse Vegetation                         .05-.13        "
Bare Clay-Loam Soil                       .01-.03        "

NOTE: Predicted particle removal efficiencies in swales/buffers are very
insensitive to Manning's n (and Slope) if infiltration rate = 0.
Sensitivity increases with infiltration rate.
```



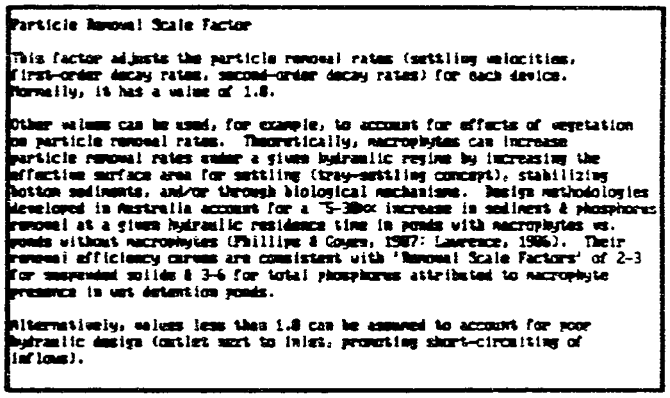
```
Runoff Curve Numbers
                                          Hydrologic Soil Group
LAND USE      HYDROLOGIC CONDITION          A    B    C    D
Grassed Areas (lawns, parks, golf courses, cemeteries, etc.)
              Good  (>75% cover)            39   61   74   80 $
              Fair                          49   69   79   84
              Poor  (<50% cover)            68   79   86   89
Meadow or Idle Land
              Good                          30   58   71   78
Woods
              Good  (thick forest)          25   55   70   77
              Fair                          36   60   73   79
              Poor  (thin, no mulch)        45   66   77   83
Construction Sites
              Newly Graded Areas            81   89   93   95

$ Lawns normally assumed to be in good hydrologic condition
Source- USDA, SCS (1977).

NOTE: Curve numbers used in model refer to PERVIOUS PORTION OF SITE
only.  Impervious areas are modeled separately.
```



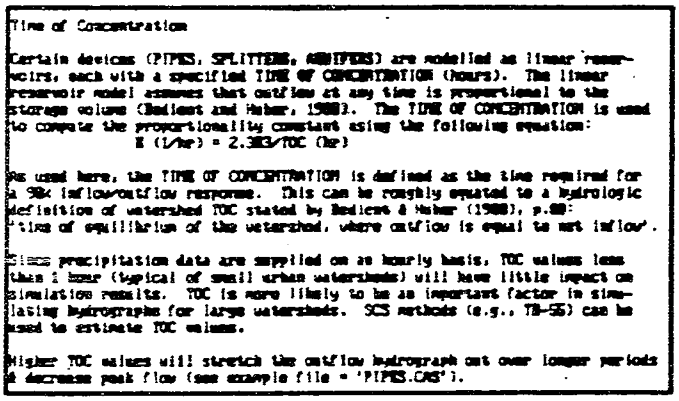
```
Depression Storage

This watershed variable refers to impervious portion of watershed
only.  Kidd (1978) presents the following equation, based upon data from
Holland, United Kingdom, and United States:

                                              -.49
   Depression Storage (in)  = .03  Slope

where, Slope = average watershed slope (%)
Based upon this equation:

  Slope %   Depression Storage (in)
    .5              .042
    1               .030
    2               .021
    3               .018
    4               .015
    5               .014

Model simulations of particle removal efficiency over a range of storms
are very insensitive to depression storage in the above range.
```



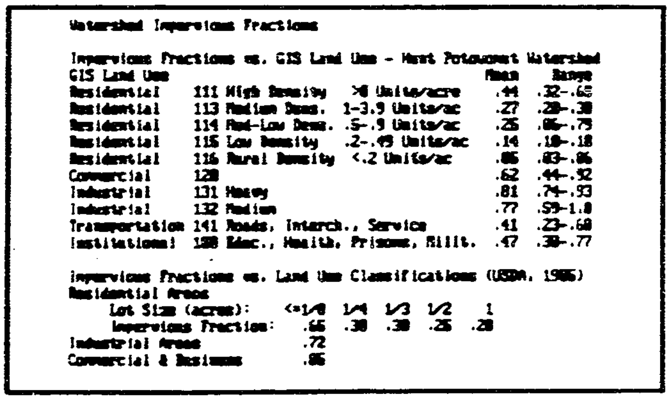
```
Maximum Flow Depth - Buffer/Swale

This parameter defines the maximum flow depth at which the specified value
of Manning's n applies for computation of overland sheet flow.  According
to TR-55 (USDA/SCS,1986), this depth is on the order of .1 feet.  This
would be related to grass/vegetation depth in simulating overland flows.

Predicted particle removal efficiencies are usually insensitive to the
maximum flow depth.

The model constrains the computed flow depth to this value.  Excess inflows
are routed through the buffer at a fixed cross-section.
```



```
Particle Removal Scale Factor

This factor adjusts the particle removal rates (settling velocities,
first-order decay rates, second-order decay rates) for each device.
Normally, it has a value of 1.0.

Other values can be used, for example, to account for effects of vegetation
on particle removal rates.  Theoretically, macrophytes can increase
particle removal rates under a given hydraulic regime by increasing the
effective surface area for settling (tray-settling concept), stabilizing
bottom sediments, and/or through biological mechanisms.  Design methodologies
developed in Australia account for a ~5-300% increase in sediment & phosphorus
removal at a given hydraulic residence time in ponds with macrophytes vs.
ponds without macrophytes (Phillips & Goyen, 1987; Lawrence, 1986).  Their
removal efficiency curves are consistent with 'Removal Scale Factors' of 2-3
for suspended solids & 3-6 for total phosphorus attributed to macrophyte
presence in wet detention ponds.

Alternatively, values less than 1.0 can be assumed to account for poor
hydraulic design (outlet next to inlet, promoting short-circuiting of
inflows).
```



```
Time of Concentration

Certain devices (PIPES, SPLITTERS, AQUIFERS) are modelled as linear reser-
voirs, each with a specified TIME OF CONCENTRATION (hours).  The linear
reservoir model assumes that outflow at any time is proportional to the
storage volume (Bedient and Huber, 1988).  The TIME OF CONCENTRATION is used
to compute the proportionality constant using the following equation:
                K (1/hr) = 2.303/TOC (hr)

As used here, the TIME OF CONCENTRATION is defined as the time required for
a 90% inflow/outflow response.  This can be roughly equated to a hydrologic
definition of watershed TOC stated by Bedient & Huber (1988), p.80:
"time of equilibrium of the watershed, where outflow is equal to net inflow'.

Since precipitation data are supplied on an hourly basis, TOC values less
than 1 hour (typical of small urban watersheds) will have little impact on
simulation results.  TOC is more likely to be an important factor in simu-
lating hydrographs for large watersheds.  SCS methods (e.g., TR-55) can be
used to estimate TOC values.

Higher TOC values will stretch the outflow hydrograph out over longer periods
& decrease peak flow (see example file = 'PIPES.CAS').
```



```
Watershed Impervious Fractions

Impervious Fractions vs. GIS Land Use - West Potomac Watershed
GIS Land Use                                               Mean    Range
Residential     111 High Density   >8 Units/acre            .44   .32-.65
Residential     113 Medium Dens.  1-3.9 Units/ac            .27   .20-.38
Residential     114 Med-Low Dens. .5-.9 Units/ac            .25   .06-.75
Residential     115 Low Density   .2-.49 Units/ac           .14   .10-.18
Residential     116 Rural Density  <.2 Units/ac             .05   .03-.06
Commercial      120                                         .62   .44-.92
Industrial      131 Heavy                                   .81   .74-.93
Industrial      132 Medium                                  .77   .59-1.0
Transportation  141 Roads, Interch., Service                .41   .23-.60
Institutional   150 Educ., Health, Prisons, Milit.          .47   .30-.77

Impervious Fractions vs. Land Use Classifications (USDA, 1986)
Residential Areas
     Lot Size (acres):     <=1/8  1/4  1/3  1/2    1
     Impervious Fraction:   .65   .38  .30  .25  .20
Industrial Areas            .72
Commercial & Business       .85
```

APPENDIX C

Output Formats

Output screens are shown on left, corresponding help screens, on right. These screens were generated by running the sample case 'TEST.CAS' contained on the distribution disk. Procedures are outlined in Appendix A.

C-1 'Run Model', 'List Balances'

C-2 'List Removals'

C-3 'List Terms Outflow'

C-4 'List Violations Outflow', 'List Sedimen'

C-5 'List Peaks', 'List Details Events'

C-6 'List Means Outflow'

C-7 'List Continuity', 'Case List Tables'

C-8 'Plot Events Timeser','Plot Events Cumulative',
'Plot Events Frequency'

C-9 'Plot Events Lognormal','Plot Events Scatter','Plot Events Monthly'

```
1
PRESS <ESC> TO STOP SIMULATION
CASE TITLE = test case
CASE FILE  = TEST.CAS                                DEVICES    = 11
STORM FILE = prov0307.stm                            WATERSHEDS =  9

PASS   =  1/  1  STORM    =    111  DATE     =  060927
PRECIP =     .10  DURATION =      5  INTERVAL =     139
KEEP   =      1

warning: device overflow:  9 online  , storm =   0
warning: device overflow: 12 offline , storm =   0
warning: device overflow: 17 buffer  , storm =  93
warning: device overflow: 16 swale   , storm =  98
warning: device overflow: 19 general , storm =  98



RUN TIME =     3.284 MINUTES,  =       .170 MINUTES/DEVICE/YEAR
calculating totals over all storms...

number of storms =        111
interval =  0001..hrs, storm duration =   709. hrs,  precip =  39.44 inches
device =  7 extpond ,  type = pond    ,  variable = tss
                                  flow          load          conc
mass-balance term               acre-ft          lbs           ppm
01 watershed inflows              91.56      29720.70      119.4302
06 normal outlet                  91.56       8883.23       35.6965
08 sedimen + decay                  .00      20837.47         .0000

09 total inflow                   91.56      29720.70      119.4302
10 surface outflow                91.56       8883.23       35.6965
12 total outflow                  91.56       8883.23       35.6965
13 total trapped                    .00      20837.47
14 storage increase                 .00           .00
15 mass balance check               .00           .00

load removal efficiency    =  70.11 %,  adjusted =  70.11 %
continuity errors:  volume =     .00 %,  load     =     .00 %
```

'Run Model'

Model input values are checked for validity.

If errors are found, messages are printed and program returns to main menu. See 'Help Errors' for explanation of error messages.

Otherwise, simulation begins.

Storm characteristics are listed as they are encountered in the input storm file (PASS, STORM, PRECIP, DURATION, INTERVAL, KEEP).

KEEP is set to 1 during last pass through storm file. When KEEP=1, results are saved for subsequent listing and display.

To stop simulation before end of storm file, press <ESC>: results will be saved, if possible.

'List Balances'

Lists water and mass balances.

Prompts for devices and components to be used. Use cursor arrows and space bar to select ('*') or unselect (' ') items. Press <ENTER> key when done, <ESC> to quit and return to menu.

Prints storm statistics, flow, load, and flow-weighted concentration for each non-zero mass-balance term.

Load reduction efficiencies are computed with and without adjusting for continuity errors.

Options:

'List Balances All' - results over all storms

'List Balances Each' - results for each storm separately

```
2

removal efficiencies (%) vs. device and particle class
                        1         2         3         4         5
device                P0%      P10%      P30%      P50%      P80%
 1 pipe                .0        .0        .0        .0        .0
 3 wetpond             .6      49.6      66.2      80.7      96.0
 5 drypond             .0       9.0      40.0      71.5      95.1
 7 extpond             .0      16.0      66.3      83.6      97.9
 9 online            66.2      66.7      72.0      80.6      92.0
11 splitter            .0        .0        .0        .0        .0
12 offline           70.7      90.1      91.2      98.3      97.0
13 outflow             .0        .0        .0        .0        .0
16 swale              9.1      11.1      30.7      67.9      80.1
17 buffer            16.1      18.6      42.6      68.1      92.0
19 general             .0      60.2      87.0      97.6      99.7
25 OVERALL           14.7      32.3      61.0      68.1      82.1
```

```
removal efficiencies (%) vs. device and water quality component
  device          tss        tp       tkn        cu        pb        zn        hc
 1 pipe            .0        .0        .0        .0        .0        .0        .0
 3 wetpond       77.0      42.4      42.4      42.4      71.2      42.4      71.2
 5 drypond       62.1      18.1      18.1      18.1      56.9      18.1      56.9
 7 extpond       70.1      26.2      26.2      26.2      64.1      26.2      64.1
 9 online        80.0      66.6      66.6      65.6      78.7      65.6      78.7
11 splitter        .0        .0        .0        .0        .0        .0        .0
12 offline       94.0      87.9      87.9      87.9      92.9      87.9      92.9
13 outflow         .0        .0        .0        .0        .0        .0        .0
16 swale         55.2      17.0      17.0      17.0      51.3      17.0      51.3
17 buffer        62.6      26.4      26.4      26.4      58.6      26.4      58.6
19 general       87.0      60.0      60.0      60.0      79.6      60.0      79.6
25 OVERALL       63.2      34.0      34.0      34.0      69.1      34.0      69.1
```

'List Removals'

Lists removal efficiencies for each device, particle class, and water quality component, based upon all storms.

OVERALL = value based upon mass-balance for entire device network.

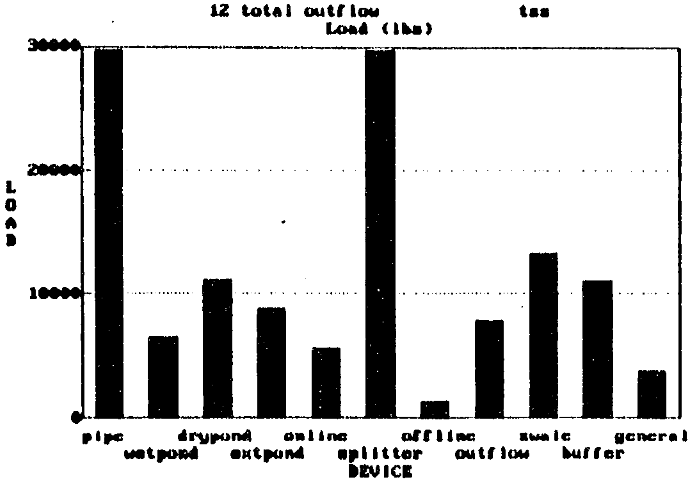
Removal is attributed to the combined effects of settling, decay, and filtration occuring the devices.

Since street sweeping reduces loads upstream of devices, computed removal efficiencies do not include effects of street sweeping.

To force a mass balance in computing removal efficiencies, continuity errors are apportioned to the device outflow and removal terms. Effects of continuity errors should be neglible if proper time steps are used.

3

```
variable =  6 tss
mass balance term = 12 total outflow
                     volume        load       conc     removal
device                ac-ft         lbs        ppm           %
 1 pipe               91.56    29720.70    119.430         .00
 3 wetpond            91.56     6585.97     26.465       77.83
 5 drypond            91.56    11249.94     45.207       62.16
 7 extpond            91.56     8883.23     35.697       70.11
 9 online             91.56     5708.72     22.940       80.79
11 splitter           91.56    29720.70    119.430         .00
12 offline            60.21     1382.66      8.449       94.05
13 outflow            38.41     7969.09     76.378         .00
15 swale              91.56    13316.44     53.511       55.19
17 buffer             91.56    11099.69     44.603       62.64
19 general            91.56     3863.74     15.526       87.00
```



'List Terms'

Alternative tabulation of water-balance & mass-balance terms.

Prompts for list of particle classes & list of devices.

Each screen refers to one mass-balance term & particle class.

For each device, lists total flow, total load, average concentration, & removal efficiency.

Produces barchart which compares flows, loads, concentrations, or removal efficiencies across devices.

Options:

'List Terms Outflow'	Total Outflows (Infilt.+Normal+Spillway)
'List Terms Surface'	Surface Outflows (Normal + Spillway)
'List Terms Inflow'	Total Inflows (Watersheds + Upstr. Devices)
'List Terms Any'	List User-Selected Term

```
4

test case
storm events =  111
water quality component =  4 cu
                                                   ---- criteria (ppm) ----
                                                        2.000    .002    .020
                               nonzero     flow-wtd conc  violation frequency (%)
device      term                events     mean   maximum level-a level-b level-c

 1 pipe      12 total outflow      97      .039      .087     .00   87.39   68.47
 3 wetpond   12 total outflow     101      .022      .034     .00   90.99   14.41
 5 drypond   12 total outflow      99      .032      .060     .00   89.19   44.14
 7 extpond   12 total outflow     101      .029      .051     .00   90.99   38.74
 9 online    12 total outflow     102      .013      .037     .00   13.51    2.70
11 splitter  12 total outflow      97      .039      .087     .00   87.39   68.47
12 offline   12 total outflow     102      .006      .034     .00    4.50     .90
13 outflow   12 total outflow      25      .030      .040     .00   22.52    7.21
15 swale     12 total outflow      97      .032      .066     .00   87.39   41.44
17 buffer    12 total outflow      97      .028      .066     .00   80.18   36.04
19 general   12 total outflow     111      .019      .034     .00  100.00   18.02
```

```
sediment accumulation rates by device,  variable = tss
assuming density =     1.0 tons/yd3 wet sediment
                                        total device       permanent pool only
device         lbs/yr     yd3/yr  inches/yr       %/yr  inches/yr        %/yr
 3 wetpond    23022.7      11.61        .06        .08        .09         .24
 5 drypond    18304.7       9.19        .05        .06        .00         .00
 7 extpond    20740.4      10.37        .06        .07        .00         .00
 9 online     23099.9      11.96        .10        .49        .00         .00
12 offline    21740.0      10.87        .16        .45        .00         .00
15 swale      16326.4       8.16        .13       1.22        .00         .00
17 buffer     18631.0       9.27        .10       1.63        .00         .00
19 general    25736.6      12.87        .02        .06        .00         .00
```

'List Violations'

Prompts for devices and components to be used. Use cursor arrows and space bar to select ('*') or unselect (' ') items. Press <ENTER> key when done, <ESC> to quit and return to menu.

Calculates flow-weighted concentrations (mean & maximum over all events) & percent of events exceeding water quality criteria (Levels A, B, C specified on input, see 'Case Edit Components').

Options:

'List Violations Outflow' - device total outflows

'List Violations Surface' - device surface outflows (normal+spillway)

'List Violations Inflow' - device inflows only

'List Violations Any' - any mass-balance term (selected by user)

'List Sedim'

Lists predicted sediment accumulation rates in each device. This provides perspectives on expected lifetime & dredging frequency required to maintain performance.

Prompts for particle class/water quality component to be used. Normal response would be 'tss' (total suspended solids).

Rates are calculated on an areal basis (inches/year) & on a volumetric basis (% of device volume/year). Values are referenced to the total area/volume & to the permanent pool area/volume of the device.

Areal & volumetric accumulation rates assume a sediment density of 1 ton of solids per cubic yard of wet sediment (Schueler, 1987).

If runoff is routed through natural stream channels before reaching a device, actual sediment accumulation rates may be higher than predicted because of streambank erosion (not simulated by model).

```
5

extreme values over all storms
                  base minimum maximum   maximum   maximum   maximum     wet
                  elev    elev    elev    inflow   outflow  velocity  period
device              ft      ft      ft       cfs       cfs    ft/sec       %
  1 pipe           .00     .00     .00     65.96     65.96       .00      .0
  3 wetpond        .00    4.00    7.04     65.95     37.63       .00   100.0
  5 drypond        .00     .00    5.33     65.96     42.12       .00     5.3
  7 extpond        .00     .00    8.20     65.96     19.57       .00    13.2
  9 online         .00     .01    4.00     65.96     65.71       .00    42.7
 11 splitter       .00     .00     .00     65.96     65.96       .00      .0
 12 offline        .00     .01    4.00     65.27     42.51       .00    40.7
 13 outflow        .00     .00     .00     65.96     65.96       .00      .0
 15 swale          .00     .01    1.00     65.96     65.57      1.46     3.1
 17 buffer         .00     .00     .50     65.96     65.10       .64     1.6
 19 general       .00    1.00    5.00     65.96     26.41       .00   100.0
```

```
statistical summary by event (nonzero values) - concentrations (ppm)
device =  9 online   ,   component = cu       ,   total events =  111

term              count           sum       mean       cv    minimum    maximum
01 watershed inf     97   3.31          .341E-01     .482   .146E-01   .870E-01
03 infiltrate       102   2.11          .207E-01     .442   .111E-01   .607E-01
04 exfiltrate       102   .103          .101E-02     .026   .928E-03   .106E-02
07 spillway outl     17   .566          .333E-01     .282   .210E-01   .513E-01
09 total inflow      97   3.31          .341E-01     .482   .146E-01   .870E-01
10 surface outfl     17   .566          .333E-01     .282   .210E-01   .513E-01
11 groundw outfl    102   .103          .101E-02     .026   .928E-03   .106E-02
12 total outflow    102   .303          .297E-02    1.092   .928E-03   .367E-01
```

'List Peaks'

Lists extreme values for each device, based upon individual time-step results (not event means):

Minimum Water Elevation (ft)
Maximum Water Elevation (ft)
Maximum Total Inflow (cfs)
Maximum Surface Outflow (cfs)
Maximum Flow Velocities (ft/sec)
Wet Period (%)

Wet Period = percent of total time that there is more than 1 inch of standing water in the device.

Velocities are defined only for Device Type 3 (Swale/Buffer Strip). These are relevant to evaluating potential for device failure due to erosion or sediment resuspension.

'List Detail'

Lists detailed statistical summary of event-mean values for each flow or mass-balance term. This information is not needed for normal program applications.

Prompts for devices and components to be used.

Terms: number of non-zero events, sum, mean, coefficient of variation,
minimum, maximum

Options:
'List Detail Flows'
'List Detail Loads'
'List Detail Concs'
'List Detail Precip'

Only non-zero events are considered. If no flow occurs for a given device, event, and mass-balance term, it is not included in the statistical summary.

6

```
mass-balance term: 12 total outflow
concentrations (ppm)      vs. device and particle class
                   1       2       3       4       5
device           P0%    P10%    P30%    P60%    P80%
 1 pipe        1.000  23.006  23.006  23.006  47.772
 3 wetpond      .900  12.011   8.322   4.600   1.532
 5 drypond      .998  21.731  14.322   6.799   2.354
 7 extpond      .999  20.100  10.673   3.920    .907
 9 online       .436   8.202   6.601   4.624   3.433
11 splitter    1.000  23.006  23.006  23.006  47.772
12 offline      .210   2.000   2.407   1.094   1.260
13 outflow     1.000  16.028  16.326  15.396  26.029
15 swale        .986  21.223  16.644  10.066   5.670
17 buffer       .045  19.446  13.731   7.613   3.012
19 general     1.000  11.901   2.907    .609    .120
25 OVERALL   .  .850  16.174  11.546   7.610   0.550
```

```
concentrations (ppm)     vs. device and water quality component
 device          tss      tp     tkn     cu     pb     zn      hc
 1 pipe      119.430    .376   1.704   .039   .023   .102   2.937
 3 wetpond    26.466    .215    .970   .022   .007   .104    .042
 5 drypond    46.207    .307   1.396   .032   .010   .149   1.267
 7 extpond    36.697    .277   1.250   .029   .000   .134   1.053
 9 online     22.940    .129    .607   .013   .006   .063    .626
11 splitter  119.430    .376   1.704   .039   .023   .102   2.937
12 offline     0.449    .061    .233   .006   .002   .026    .242
13 outflow    76.370    .291   1.324   .030   .016   .141   1.940
15 swale      63.511    .300   1.399   .032   .011   .149   1.431
17 buffer     44.603    .276   1.261   .020   .010   .133   1.216
19 general    15.626    .106    .039   .019   .006   .009    .699
25 OVERALL    43.009    .244   1.110   .025   .010   .110   1.200
```

'List Means'

Lists flow-weighted-mean concentrations for each device, particle class, & water quality component, based upon all storms.

OVERALL = value based upon mass-balance for entire device network.

Options:
- 'List Means Inflow' - Inflow concentrations (ppm)
- 'List Means Outflow' - Total outflow concs (infiltr.+normal+spillway)
- 'List Means Surface' - Surface outflow concs (normal+spillway)
- 'List Means Any' - User-defined mass-balance term

```
7

continuity errors (%) vs. device & particle class
device          flow     P0%     P10%     P30%     P50%     P80%
 1 pipe          .00     .00      .00      .00      .00      .00
 3 wetpond       .00     .00      .00      .00      .00      .00
 5 drypond       .00     .00      .00      .00      .00      .00
 7 extpond       .00     .00      .00      .00      .00      .00
 9 online        .00     .00      .00      .00      .00      .00
11 splitter      .00     .00      .00      .00      .00      .00
12 offline       .00     .00      .00      .00      .00      .00
13 outflow       .00     .00      .00      .00      .00      .00
15 swale         .00     .00      .00      .00      .00      .00
17 buffer        .00    -.00     -.00      .00      .00      .00
19 general       .00     .00      .00      .00      .00      .00
25 OVERALL       .00     .00      .00      .00      .00      .00
```

'List Continuity'

Lists continuity check on simulation results for each device; flow volume, and particle class.

Based upon mass-balance equation:

Error = Inflows - Outflows - Removals - Increase in Storage

%Error = 100% x Error / Inflows

Large errors in water or mass balances generally indicate that the simulation time steps should be decreased (See 'Case Edit TimeSteps').

To minimize simulation times, adjust time steps to maximum values that give acceptable continuity errors (~< 2%).

```
routing table for device: 15 swale

        outflow  devices:        0         0        0
 elev     area    volume   qinfilt   qnormal   qflood    qtotal  velocity
 feet    acres     ac-ft       cfs       cfs      cfs       cfs    ft/sec
  .00     .367      .000      .185      .000     .000      .185      .000
  .05     .372      .018      .188      .287     .000      .474      .142
  .14     .381      .054      .192     1.697     .000     1.800      .287
  .24     .389      .091      .196     3.945     .000     4.141      .399
  .33     .398      .128      .201     6.985     .000     7.185      .495
  .43     .407      .166      .205    10.511     .000    10.716      .580
  .52     .416      .205      .209    14.723     .000    14.932      .658
  .62     .424      .245      .214    19.511     .000    19.725      .738
  .72     .433      .286      .218    24.854     .000    25.072      .798
  .81     .442      .328      .223    30.738     .000    30.960      .861
  .91     .450      .370      .227    37.149     .000    37.376      .922
 1.00     .459      .413      .231    44.080     .000    44.311      .980
```

'Case List Tables'

List elevation/storage/discharge table for specified devices.

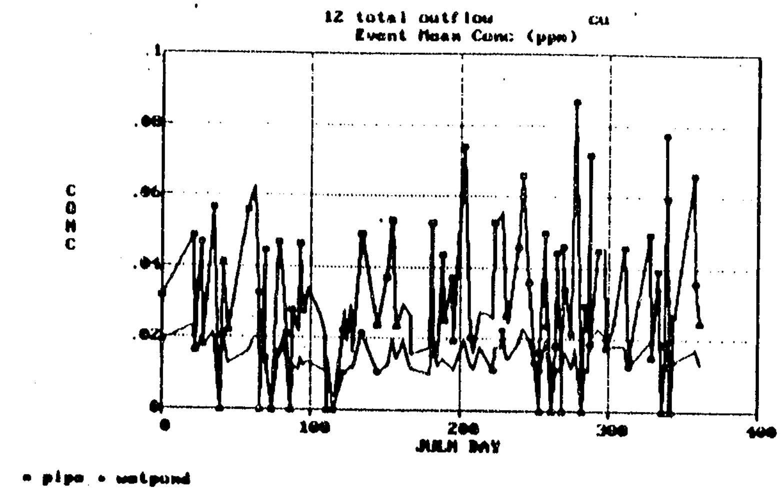
This table defines the "rules" used for routing flow through devices.

For device types 1,2, and 3, the table is generated from the specified input data. For device type 4 (general), the table is entered directly by the user.

Volume increments are calculated from the average area and thickness of each elevation increment.

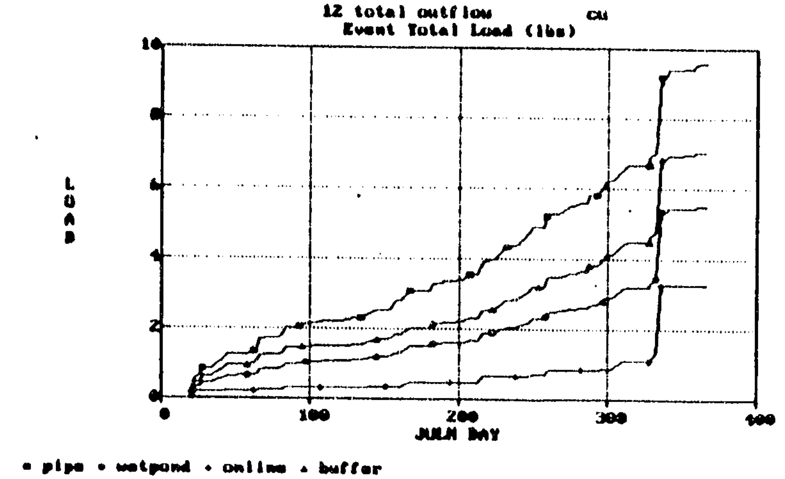
Estimates of flow velocity (ft/sec) are also provided for Device Type 3 (swale/buffer). These are important for considering the potential for scouring (resuspension) of sediments.

Tables are not generated for device types 5 (pipe), 6 (flow splitter), or 7 (aquifer), which are driven by linear reservoir models.

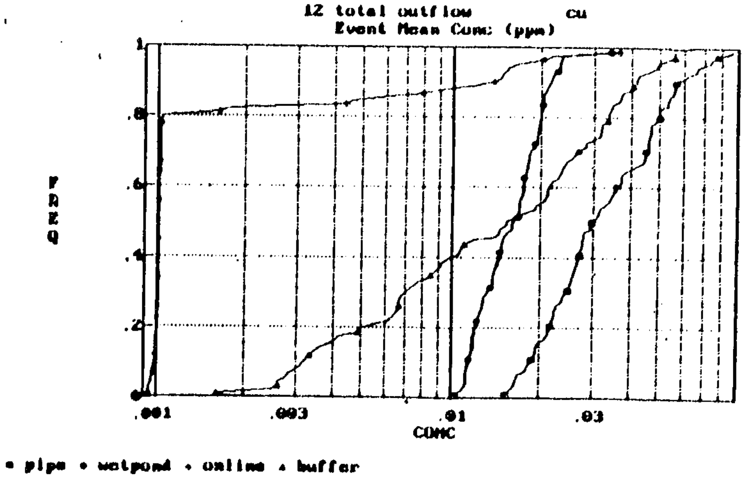


PRESS R to Rescale, D to Dump

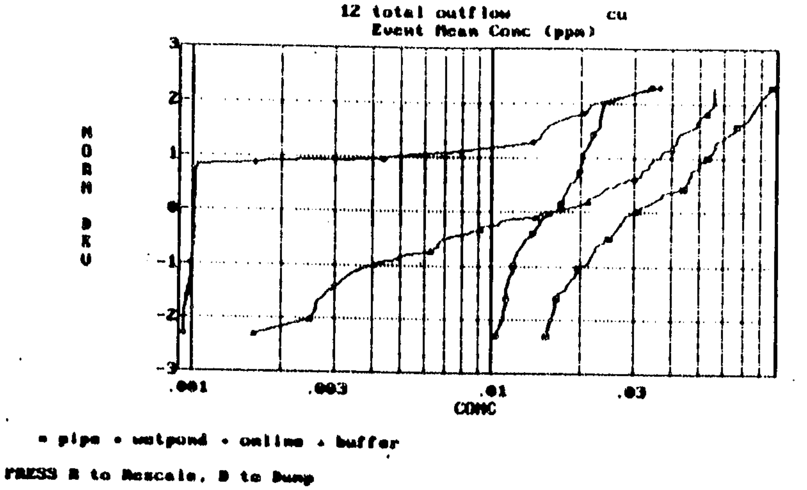
```
'Plot Events'

Prompts for devices, components, and mass-balance terms to be used.
A separate display is produced for each mass-balance term and component.
Different line colors/symbols are used to represent different devices
Up to 8 devices may be selected (4 for CGA graphics).

Plots event flows, loads, concentration, or precipitation vs. time in
hours from start of simulation.  Times refer to midpoints of storms.

Options:
  'Plot Events Timser'  .     Event Totals or Means vs. Time (Julian Day)
  'Plot Events Cumulatives'   Running Totals vs. Time
  'Plot Events Frequency'     Cumulative Frequency Distributions
  'Plot Events Lognormal'     Lognormal Freq. Distributions
  'Plot Events Scatter'       Scatter Plots

To stop display sequence, press <ESC> when the <H> prompt appears.
```



PRESS R to Rescale, D to Dump

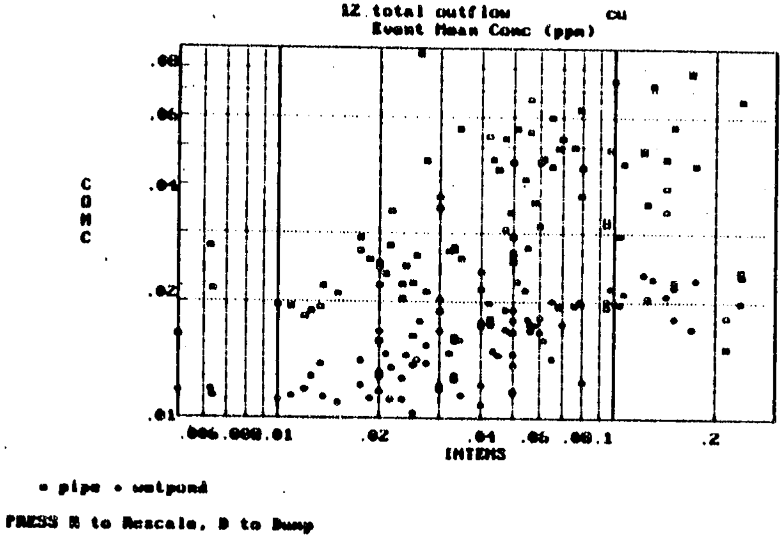


PRESS R to Rescale, D to Dump

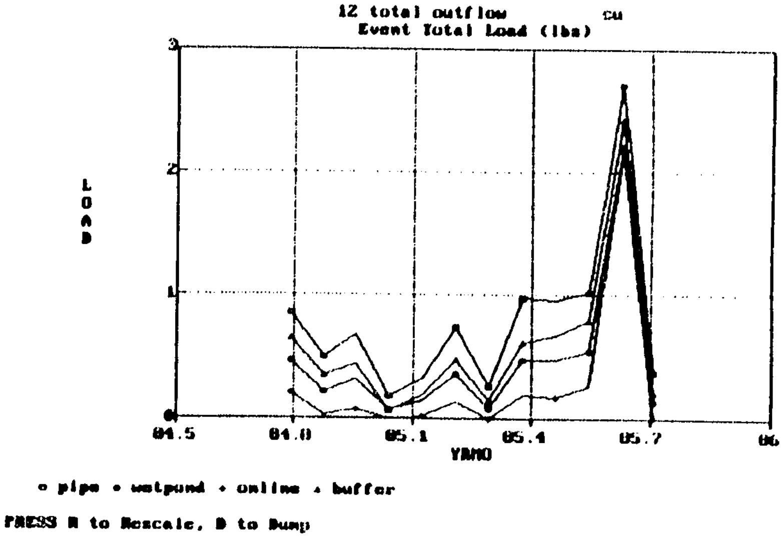


PRESS R to Rescale, D to Dump

```
'Plot Events'

Prompts for devices, components, and mass-balance terms to be used.
A separate display is produced for each mass-balance term and component.
Different line colors/symbols are used to represent different devices
Up to 8 devices may be selected (4 for CGA graphics).

Plots event flows, loads, concentration, or precipitation vs. time in
hours from start of simulation.  Times refer to midpoints of storms.

Options:
  'Plot Events Timser'       Event Totals or Means vs. Time (Julian Day)
  'Plot Events Cumulatives'  Running Totals vs. Time
  'Plot Events Frequency'    Cumulative Frequency Distributions
  'Plot Events Lognormal'    Lognormal Freq. Distributions
  'Plot Events Scatter'      Scatter Plots

To stop display sequence, press <ESC> when the <H> prompt appears.
```



PRESS R to Rescale, D to Dump



PRESS R to Rescale, D to Dump

APPENDIX D

Help Screen Index

Titles to help screens provided with the program are listed below. These titles are indexed numerically, but are otherwise in no particular order. These screens are accessed through the main program (<F1>, <F8> keys) or through the independent utility 'HELP.EXE' provided with the program. This program can be used to search the entire help data base for any user-defined phrase. For additional details, see USER's MANUAL.

1 'Case List'
2 Particle Removal Scale Factor
3 Orifice & Weir Coefficients
4 'Case Edit Particles' - Define Particle Characteristics
5 'Case Edit First'
6 Storm Data File Format
7 'Case Edit Watersheds Index'
8 'Case Edit Watersheds Data'
9 'Case Edit Devices Index'
10 'Case Edit Devices Data'
11 'Case Edit Devices Data' - Detention Pond (TYPE = 1)
12 'Case Edit Devices Data' - Infiltration Basin (TYPE = 2)
13 'Case Edit Devices Data' - Swale/Buffer (TYPE = 3)
14 'Case Edit Device Data' - General Device (TYPE = 4)
15 'Case Edit Device Data' - Pipe (TYPE = 5)
16 'Case Edit Device Data' - Flow Splitter (TYPE = 6)
17 'Case Edit Components'
18 'Case Edit TimeSteps'
19 'Case Edit Data All'
20 'Case Read'
21 'List Means'
22 'Case Save'
23 'List'
24 'Case Zero'
25 'Run Model'
26 Run Times
27 'List Balances'
28 'List Violations'
29 'List Removals'
30 'List Detail'
31 'List Detail Traced'
32 'List Continuity'
33 'Case List Tables'
34 'Plot Daily'
35 'Case Edit Device Data' - Aquifer (TYPE = 7)
36 'Plot Traced'
37 'List Sedim'
38 'Utilities Trace'
39 Simulation Methods - Device Concentrations (ct.)
40 'Case Edit Watersheds'
42 Simulation Methods - Device Flows (ct.)
43 'Utilities NCAA'
44 Simulation Methods - Watershed Runoff
45 Simulation Methods - Watershed Loadings
46 Simulation Methods - Buildup and Washoff
47 Simulation Methods - Device Flows
48 Simulation Methods - Device Concentrations
49 Device Outlets
50 Warning: Device Overflow
51 Run Times vs. Hardware
52 File Errors
53 Device Elevations
54 Time of Concentration
55 Illegal Device Linkage
56 Computer System Requirements
57 Mass Balance Terms 01-05
58 Mass Balance Terms 06-12
59 Mass Balance Terms 13-15
60 Mass Balance Equations
61 Particle/Component Files
62 Air Temperature Files
63 Storm Data Files

Help Screen Index (ct.)

APPENDIX E

Installation and Application Procedures

E-1	Installing Program
E-2	Running Sample Cases
E-3	Entering New Cases
E-4	Designing Site BMP's

Note: See **P8 User's Manual** (IEP, Inc., 1990) for more detailed, step-by-step instructions and examples.

Table E-1
Installing Program

1. Verify that your computer conforms to the following:
   - IBM/PC Compatible (AT or higher class strongly recommended)
   - MSDOS or PCDOS operating system (Version >=3.2 recommended)
   - At least 460K available memory (beyond that required by DOS)
   - Hard disk with at least 2.2 megabytes of available storage
   - Numeric Coprocessor (strongly recommended)
   - CGA, MONOCHROME CGA, EGA or VGA graphics (optional)

2. The program is distributed on a 1.2 megabyte (AT style), 5.25 inch floppy disk. If you require other media (e.g., 3.5 inch disk) contact program source.

3. Place distribution diskette in Drive A: and enter the following:

```
>A:
>type readme    (file contains updated info. on installation)
```

4. To install on hard disk 'C' in directory 'P8' (you may use other names), enter one of the following lines:

For computers with EGA graphics:

```
>INSTALL  C  P8  EGA
```

For computers with VGA (PS/2) graphics:

```
>INSTALL  C  P8  VGA
```

For computers with CGA (standard IBM-PC) color graphics:

```
>INSTALL  C  P8  CGA
```

For computers with CGA monochrome graphics:

```
>INSTALL  C  P8  MCGA
```

For computers with other graphics:

```
>INSTALL  C  P8  XXX
  (note: program will run, but without plotting routines)
```

5. Add the following line to the CONFIG.SYS file in the root directory of your hard disk and reboot computer:

```
FILES=20                              (note: can be >20 )
```

6. Change to P8 directory (required each time you run program):

```
>C:
>CD\P8
```

7. Review and/or print documentation update files:

```
>TYPE  XXX.DOC   (where, XXX = BUGS, CASES, PARTIC, or STORMS)
```

8. To review help screens, enter the following line:

```
>HELP
```

9. To run program, enter the following line:

```
>P8
```

Table E-2
Running Sample Cases

1. Type/print list of sample cases provided with program:

   ```
   >Copy CASES.DOC  prn
   ```

2. Run program:

   ```
   >P8
   ```

3. Review introductory help screens. Press any key to continue with next screen, or press <Esc> to move directly to program menu.

4. Try moving around the menu with the cursor keys without pressing <Enter>. To view help screens associated with any procedure on the menu, press <F1>. To get help on operating the menu, press <F7>.

5. The program loads 'DEFAULT.CAS' automatically. Work with this case initially. Enter the following commands from the main menu:
   'CLS' = Case List Site = list input values for case
   'RM' = Run Model
   'LR' = List Removal Efficiencies
   'LBA' = List Water and Mass Balances

6. Try editing input values and re-running model:
   'CEA' = Case Edit All
   Each edit screen is presented. Move around edit screen with cursor. Try making changes to input fields. Try help keys <F1>,<F7>,<F8>. Press <F2> to save results or <Esc> to move onto next screen without making changes. Repeat Step 5 to see how changes affect outputs.

7. Now try loading and running a sample case. Review the CASES.DOC listing (Step 1) and select a case. To load a sample case:
   'CRA' = Case Read All

8. You will be asked to specify a 'PATH' to search for the input case. The default PATH is '*.CAS', which specifies that all files with the 'CAS' extension will be searched. Press the <Enter> key to accept the default PATH.

9. A list of all '.CAS' files will be displayed. Use the cursor arrows to locate the desired file. Note that the file list may extend beyond the bottom of the window. When you have located the file, press <Enter>. The file will be loaded. The network of devices and watersheds will be listed. Press any key to return to menu. Repeat Steps 5-6 with the new case.

10. Try entering the ADVANCED USER MODE. From the main menu, press <SHIFT><F1>. A message should appear indicating the new user mode. Press any key to continue. Note expansion of the menu. Review other output formats ('List' or 'Plot' procedures).

Table E-3
Entering New Cases

1. Assemble reference materials for site (maps, engineering reports).
2. Construct schematic diagram illustrating downstream linkage of watersheds and devices.
3. Assign a name (<=8 characters) and number (1-24) to each watershed. Write these on your schematic.
4. Tabulate basic watershed characteristics needed for model input, as listed in Appendix B.
5. Assign a name (<=8 characters), number (1-24), and device type code (1-7) to each device. It is often convenient (but not necessary) to assign device numbers in downstream order. Write these on your schematic.
6. Tabulate basic device characteristics needed for model input, as listed in Appendix B.
7. Run program. Move to program directory on hard disk and enter 'P8'.
8. Review introductory help screens (to skip these, press <ESC>).
9. Clear existing data (Procedure = 'CZ' = 'Case Zero').
10. Enter site data (Procedure = 'CEA' = 'Case Edit All'). Refer to your schematic to identify device/watershed numbers and names.
11. Load desired particle file (Procedure = 'CRP' = 'Case Read Particles'); suggest using 'SIMPLE.PAR' and 'TYPE2.STM' in preliminary runs; this will speed computations.
12. Print a copy of the watershed/device network linkage for future reference; Procedure = 'CLN' = 'Case List Network'; hit 'Print Scrn' key at <H> prompt.
13. Save input case values on disk (Procedure = 'CSI' ='Case Save Inputs').
14. Run simulation (Procedure = 'RM' = 'Run Model') etc...

Table E-4
Designing Site BMP's

1. Define treatment objectives, expressed in terms of target particle class, removal efficiency, and time period.
   e.g.: (a) - 85% TSS removal for average year (~1980, 1974, 1976)
   (b) - 60% Fine Particle Removal (P10%) for average year

2. Enter a rough site plan, accounting for basic hydrologic units (subwatersheds) and likely locations for BMP's (use 'pipes' temporarily, if device types are unknown) (see Table E-3).

3. In preliminary design runs, use the 1-inch TYPE2.STM file with 5 PASSES and the NURP50.PAR parameter file. SIMPLE.PAR can be used if your target particle class is P10% (this will speed computations, relative to NURP50.PAR).

4. Verify that watershed/device linkage is correct ('LCN' = 'List Case Network') and execute model 'Run Model'. Correct inputs as needed.

5. 'Run Design Lookup' to retrieve preliminary designs(s) and place at appropriate locations in site plan. Or enter your own designs, based upon your preferences and site constraints. If your objective is 1.(b) above, retrieve designs for 85% TSS removal as starting points.

6. 'Run Design Tune' to rescale device(s) based upon target removal efficiency. Or modify BMP design manually to achieve target for TYPE2.STM.

7. Rerun model using design rainfall period (e.g., 1980) and 1-month startup period (STORM FILE=PROV6987.STM, START DATE=791201, KEEP DATE=800101, STOP DATE=81001, PASSES=1, on screen 'Case Edit First'). Other "average years" are 1974 or 1976.

8. Adjust design to achieve compliance with treatment objective for yearly rainfall sequence. Do this manually or use the 'Run Design Tune' procedure.*

9. 'Run Sensitivity' analysis to evaluate sensitivity of removal efficiency to site input values.* Refine input value estimates and adjust design, as appropriate.

10. Check that BMP design also complies with engineering guidelines (e.g., Schueler,1987) and iterate as needed.

* May require lengthy computer run (overnight execution may be most convenient).

EVALUATION OF EXISTING MODELS, DESIGN CONCEPTS, AND HUNT-POTOWOMUT DATA INVENTORY

Working Document No. 1

Prepared For:

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JUL 2 1990

The following is a compilation of several documents utilized in the development of the P8 Urban Catchment Model. In the rppocess of developing a land-based water quality model, an evaluation of existing models was completed to identify models which could be readily adapted for use in a mixed land use setting, or that had valuable algorithms which could be incorporated in the developmnet of a new model. In addition, an inventory of available water quality data for the Hunt-Potowomut watershed was made. The purpose of this inventory was to determine if sufficient data existed to be used either in the development of and land-based water quality model or to support the calibration of such a model.

The results of these evaluations and inventories, as well as a summary of concepts for the design of a land based water quality model given the results of the evaluation and inventory are provided in Attachments 1 - 3.

ATTACHMENT 1

Design Concepts for a Land-Based
Water Quality Model

DESIGN CONCEPTS FOR A LAND-BASED WATER QUALITY MODEL OF THE HUNT-POTOWOMUT RIVER

prepared for

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INTRODUCTION

As stated in the RFP issued by the Narragansett Bay Project, the objectives of the study are as follows:

- "evaluate existing land-based water quality models in terms of their practical application to a watershed characterized by multiple land uses;
- adapt or link existing models which are capable of simulating the contribution of nonpoint source pollutants and the water quality benefits of available control practices under a variety of land use scenarios, using information typically available to Rhode Island planners;
- apply the selected method/model to the Potowomut-Hunt River watershed or some representative hydrographic regime(s) within the Potowomut-Hunt watershed;
- present a "user friendly" method/model for state and local planners to use in estimating potential water quality impacts associated with various land uses and mitigation/control practices; and
- train selected state and/or local planners to the method/model presented"

In addition, "the methods/models selected for evaluation should be capable of simulating watershed-level impacts on receiving waters considering both dry and wet weather nonpoint pollution sources and mitigation practices, using various land use scenarios".

Available watershed models have wide ranges of applicability, complexity, temporal scales, spatial scales, and data requirements, as documented in Tables 1,2, and 3 (Donigian and Beyerlein, 1985). A single model or procedure which satisfies all of the above project objectives does not exist. The selection/development of an appropriate model must consider tradeoffs between complexity and practicality. Basic alternatives and recommended directions are discussed below.

WATERSHED SIMULATION MODELS

Detailed watershed simulation models, such as **HSPF** (Donigian et al, 1984) or **SWMM** (Huber et al., 1983), represent the most comprehensive land-based water quality models. **HSPF**, in particular, has the broadest range of capabilities for diverse watersheds such as the Hunt-Potowomut. **HSPF** has been used extensively in water quality planning under the Chesapeake Bay Program. **HSPF** and **SWMM** can be applied on any spatial scale and can generate continuous time series of flow and water quality, which could be used to drive a Bay simulation model.

Basic characteristics of **HSPF** are summarized by Schnoor et al. (1987):

> "HSPF includes time series-based simulation modules (PERLIND, IMPLND, and RCHRES), and utility modules (COPY, PLTGEN, DISPLAY, DURANL, and GENER). The simulation (application) modules include mathematics for the behaviour of processes that occur in a study watershed. The watershed is divided into three segments -- pervious land, impervious land, and a receiving water system (i.e., a single reach of an open channel or a completely mixed impoundment). The module PERLND simulates the pervious land segment with snow accumulation and melt, water movement (overland flow, interflow, and groundwater flow), sediment erosion and scouring, and water quality (pesticides, nutrients). The IMPLND module simulates the impervious land segment where little or no infiltration occurs. The IMPLND processes include snow and water movements, solids, and water quality constituents. The model RCHRES simulates the segment of receiving water body, including hydrologic behaviour, conservative and nonconservative constituents, temperature, sediments, BOD and DO, nitrogen, phosphorus, carbon, and pH. The utility modules perform "house-keeping" operations, designed to provide the user flexibility in managing simulation inputs and outputs".

An inventory of input data and parameter estimates required for **HSPF** is contained in the Appendix. **SWMM** is oriented more towards urban watersheds, with a strong emphasis on hydraulics.

Table 1. Characteristics and Capabilities of Selected NPS Runoff Procedures and Models

	LAND USE/LOAD SOURCES						HYDROLOGY			WATER QUALITY			TIME SCALE			DATA NEEDS			SPACE SCALE		
	Urban	Agriculture	Forest /Natural	Mining	Precipitation	Chemical: Application	Surface Runoff	Subsurface Flow	Snowmelt	Sediments	Nutrients	Pesticides/Toxics	Annual Loads	Event Loads	Continuous Simulation	Detailed	Moderate	Minimal	Segmented/ Multiple Catchments	Lumped/ Single Catchment	Use, Documentation, Support
LOADING/SCREENING PROCEDURES																					
Hydroscience	●						●		●		●		○					●		●	A/M
EPA Screening Procedures	●	●	●		●					●	●	●	●	●				●		●	A
WRENS			●				●		●	●	●	●	●					●	●		A
WLFNPS		●	●				●		●	●	●			●			●		●		M/A
SWMM - Level I	●						●	○		●	●		●				●			●	A
RUNOFF MODELS																					
Simplified SWMM	●						●				●			●	●		●		●		M
ARM		●				●	●	●	●	●	●	●		●	●	●				●	E/A
NPS	●	●	●				●	●	●	●	●			●	●	●			●		E/A
HSPF/PERLND & IMPLND	●	●	●	●	○	●	●	●	●	●	●	●		●	●	●			●		E
CREAMS/CREAMS 2		●	●			●	●			●	●	●		●	●	●				●	E
ANSWERS		●	●	●			●	●		●	●			●		●			●		A
ACTMO		●				●	●	●	●	●	●	●		●	●	●			●		M
SWMM	●						●	○	●	●	●			●	●	●			●		E
STORM	●						●	○	●	●	●				●		●			●	E
MUNP	●						●			●	●			●			●			●	M
ILLUDAS/DRAINQUAL	●						●	●			●			●		●	●		●		A
DR3M	●				●		●	○		●					●	●			●		A
PRMS			●				●	●	●	●				●	●	●			●		A

Donigian and Beyerlein (1985)

Notes: ● - Capability included in model

○ - Capability not explicity included but can be user-defined

Use/Documentation/Support

E - Extensive

A - Adequate

M - Minimal

Table 2. Characteristics and Capabilities of Integrated Watershed Models

	WATERBODY & FLOW CONDITIONS						WATER QUALITY								TIME SCALE		DATA NEEDS		SPACE SCALE			
INTEGRATED WATERSHED MODELS	Rivers/Streams	Lakes/Impoundments	Estuaries	Confined Flow	Drainage/Control Structures	Point Source Discharges	Temperature	D.O./BOD/NBOD	Suspended Sediment Transport	Sediment Scour/Deposition	Sediment Contaminant Interaction	Nutrient Kinetics	Pesticides/Toxics	Biologic Simulation	Dynamic	Steady-State	Detailed	Moderate	Multi Land Use Multiple Catchments	Single Land Use Single Catchment	Data/File Management	Use, Documentation, Support
HSPF	●	●		○	●	●	●	●	●	●	●	●	●	●	●		●		●		●	E
SWMM (RECEIV)	●	●	●	●	●	○		●				●	○	●	●		●		●			E
PRS	●	●											●		●		●		●			A
UTM-TOX	●		●		●	●	○		●	●			●		●		●		●			M
SWAM	●	●					●		●	●		●	●		●		●		●			M/A

Notes: ●-Capability included in model

○-Capability not explicity included but can be user-defined

Use/Documentation/Support

E -·Extensive
A - Adequate
M - Minimal

Donigian and Beyerlein (1985)

TABLE 3 PRELIMINARY LIST OF NPS AND INTEGRATED WATERSHED MODELS SELECTED FOR REVIEW

MODELS	NAME	SOURCE	REFERENCE
Loading/Screening Procedures			
Hydroscience	Hydroscience Simplified Model	Hydroqual/EPA	EPA, 1976
EPA Screening Procedures	EPA Water Quality Screening Procedures	EPA	McElroy et al., 1976; Mills et al., 1982
WLFNPS	Watershed Loading Functions for Non-Point Sources	U.S. Forest Service, 1980	U.S. Forest Service
WRENS	Water Resources Evaluation of Non-Point Silvicultural Sources	Cornell University	Haith and Tubbs, 1981
SWMM-Level I	SWMM-Level I	EPA	Heaney et al., 1976
NPS Runoff Models			
HSPF/PERLND & IMPLND	Hydrological Simulation Program - FORTRAN (land simulation modules)	EPA	Johanson et al., 1984
ARM	Agricultural Runoff Management Model	EPA	Donigian et al., 1977
NPS	Nonpoint Source Model	EPA	Donigian and Crawford, 1977
CREAMS/CREAMS2	Chemicals, Runoff, and Erosion From Agricultural Management Systems	USDA	USDA, 1980
ANSWERS	Areal, Nonpoint Source Watershed Environment Response, Simulation Model	Purdue University	Beasley et al., 1980 Beasley and Huggins, 1981
ACTMO	An Agricultural Chemical Transport Model	USDA/ARS	Frere et al., 1975
SWMM	Stormwater Management Model (land simulation modules)	EPA	Huber et al., 1975
STORM	Storage, Treatment, Overflow Runoff Model	COE	HEC, 1977
MUNP	Management of Urban Nonpoint Pollution Model	Univ. of Maryland	Sutherland and McCuen 1978
ILLUDAS/DRAINQUAL	Illinois Urban Drainage Area Simulator	Illinois State Water Survey	Terstriep and Stall, 1974
DR3M	Distributed Routing Rainfall-Runoff Model	USGS	Alley and Smith, 1982a, 1982b
PRMS	Precipitation-Runoff Modeling System	USGS	Leavesley et al., 1983
Simplified SWMM	Simplified SWMM	EPA/M&E	Lager et al., 1976
Integrated Watershed Models			
HSPF	Hydrological Simulation Program - FORTRAN	EPA	Johanson et al., 1984
SWMM	Stormwater Management Model	EPA	Huber et al., 1975
PRS	Pesticide Runoff Simulator	EPA/CSC	CSC, 1980
UTM-TOX	Unified Transport Model for Toxics	Oak Ridge/EPA	Patterson et al., 1983
SWAM	Small Watershed Model	USDA/ARS	DeCoursey, 1982

Donigian and Beyerlein (1985)

The complexity of these models does not guarantee that they are "better" or "more accurate" than alternative, simpler techniques, however, because the detailed information required to drive them is rarely available. When viewed in relation to the stated project objectives, limitations of this class of models include:

(1) **Extensive Data Requirements.** Watershed and stream characteristics must be parameterized in detail (see Appendix). To a limited extent, this would be facilitated by a GIS interface. More importantly, the models must be calibrated and tested against watershed/stream response data. This generally requires continuous flow monitoring and sufficient concentration sampling to permit estimation of dry-weather and wet-weather loadings over an annual period. To support model application to a given watershed, a typical monitoring program would involve weekly periodic sampling combined with flow-weighted composite sampling for at least three storm events per season.

(2) **Complexity.** The models are large and not designed for use by the typical "state and local planner". Considerable training is required and previous modeling experience is desirable. For example, a 2-3 month minimum project time frame is needed for **HSPF** if the user has no prior experience with the model (Donigian and Beyerlein, 1985). The local planner would rarely be in a position to supply the input data and parameter estimates inventoried in the Appendix. PC versions of **HSPF** and SWMM are distributed on 6 and 4 diskettes, respectively.

(3) **Scope.** Although these models are the most comprehensive ones available, they may lack certain capabilities which are important for this project (e.g., simulation of buffer strips). Owing to their size and complexity, modification of these models to account for additional processes would be difficult.

Because of these limitations, application of **HSPF** or **SWMM** to this project would only make sense if a commitment is also made to a substantial stream monitoring program and additional watershed data collection. Future use would probably be limited to a few highly trained individuals. This approach would focus more on modeling whole watersheds or subwatersheds, as opposed to modeling individual urban developments.

Within the project time frame, it would be possible to set up an **HSPF** or **SWMM** application to the Hunt/Potowomut watershed, including an interface to GIS data bases. Calibration would be deferred to subsequent year(s), pending collection of appropriate stream and watershed data.

SIMPLER APPROACHES

Other classes of models, typically described as "screening procedures", "loading functions", or "simplified techniques", are less detailed, have less demanding data requirements, and seem more easily adaptable to project needs. These include:

(1) Schueler's (1987) "Simplified Method"

(2) Probabilistic techniques developed under EPA's Nationwide Urban Runoff Program (USEPA, 1982; Athayde et al. 1983; DiTorro, 1984; Driscoll, 1986).

(3) Simplified models for predicting BMP performance (Driscoll, 1983; USEPA, 1986; Walker, 1987, 1989)

(4) Haith and Shoemaker's (1987) "Generalized Watershed Loading Functions"

(5) Screening Procedures for Nonpoint Sources (Mills et al., 1985)

(6) BMP performance models and design criteria developed by the Rhode Island Department of Environmental Management (1988)

(7) Urban runoff loading factors developed for Narragansett Bay Watersheds (Hoffman,1985)

Compared with the simulation models discussed above, these techniques rely more upon generalized sources of information and have less demanding requirements for site-specific data. Possible integration of these techniques into a model useful for project purposes is discussed below.

SOURCE CHARACTERIZATION

Essentially, loading functions de-emphasize or ignore water quality transformations which may occur in the river. This is valid to the extent that land-based sources are generally related to high-flow conditions and short travel times. The primary objective is to estimate loadings to the Bay and their relationships to land uses and management practices. They are ultimately driven by "export coefficients", runoff concentrations, and/or baseflow concentrations which must be estimated for each land use and water quality component.

Data bases developed under NURP (Athayde et al, 1983) and other regional studies (e.g., Hoffman, 1985) provide a basis for estimation of the required source concentrations or export coefficients. The high degree of variability in urban runoff concentrations from site-to-site and from storm-to-storm at a given site must be considered in the calibration process. In the case of NURP event-mean copper concentrations, for example, the site-to-site coefficient of variation was .77 and the storm-to-storm coefficient of variation was typically between .5 and 1 (Athayde et al, 1983). Because of the latter, the accuracy of mean runoff concentrations or export coefficients calculated from sampling data at a given site can be extremely limited.

For example, for a variable with a storm-to-storm coefficient of variation of .75, a site-mean concentration estimated from monitoring 5 storm events would have a standard error of .34. The 90 percent confidence range for the site mean would be roughly between 50% and 200% of the calculated mean value. Because of this degree of variability, probabilistic approaches which account for uncertainty in the source concentrations (as well as temporal variability) seem appropriate. Blind "calibration" to a few site-specific measurements (ignoring information from much larger and more generalized data bases, e.g., NURP) is not recommended. The existing water quality data base on the Hunt-Potowomut is clearly inadequate to support calibration of any land-based model or loading function.

MODEL STRUCTURE

The model will be developed primarily for use by local planners and engineers involved in the design and evaluation of urban developments. It will generally be applied to a specific development or subwatershed consisting of a number of hydrologic units. Characteristics of each hydrologic unit will be supplied by the model user:

(1) **watershed parameters**
surface areas
hydrologic soil groups (or assoc. names)
land use/cover (as required for SCS Curve Numbers)
impervious area
non-runoff sources (e.g., onsite disposal systems)

(2) **BMP parameters**
types (wet pond, buffer strip, infilt. basin, etc.)
relevant dimensions (volume, area, depth, etc.)
treatment capacities (infiltration rates, etc.)

(3) **Configuration**
one or more BMP's may be applied in series

Flow and contaminants leave the hydrologic unit in two forms: surface runoff and groundwater (baseflow). There are two basic approaches which are feasible for predicting variations in these flows at a given site:

(1) **Statistical (USEPA/NURP, 1982;1983)**

surface runoff intensity is calculated from impervious area and precipitation intensity; baseflow is estimated from pervious area and regional streamflow values; baseflow and surface runoff may be correlated statistically.

(2) **Deterministic (e.g., Haith and Shoemaker, 1987)**
model is driven by daily time series of precipitation and temperature; surface runoff is estimated from daily rainfall using SCS techniques; evapotranspiration is estimated from air temperature, season, and vegetative cover; groundwater flow is calculated essentially by difference, accounting for seasonal variations in storage.

The first method is much simpler and requires less input data. The second method is more realistic but requires more extensive input data and parameter estimates. An appropriate technique will be developed and calibrated using regional precipitation and streamflow data.

Once flows have been estimated, loadings can be calculated from mass-balance relationships. This requires estimation of the following:

(1) **Surface Runoff Concentrations**
probability distributions derived from NURP and other regional data, possibility adjusted based upon land use/cover/soil type; regional NURP data sets have been obtained for calibration purposes (including Worcester (MA), Mystic Lake (MA), Durham (NH), Long Island (NY)).

(2) **Baseflow Concentrations**
probability distributions derived from regional stream monitoring data from undeveloped watersheds; derived from STORET, state and local sources.

(3) **Direct Loads**
onsite disposal systems, package treatment plants, industrial; onsite loads estimated from population; others input by model user.

(4) **BMP Treatment Efficiency**
reductions in runoff and baseflow loads attributed to combinations of management practices on the site; estimation procedures discussed below.

To reflect uncertainty in input variables (e.g., runoff and baseflow concentrations, treatment efficiencies) and temporal variability (rainfall statistics, baseflow), model output (flows, concentrations, loads) will be expressed in probabilistic terms (frequency distributions vs. absolute values). Output distributions will be estimated by applying first-order and/or

Monte Carlo simulation techniques to the basic model equations (Walker, 1982). The model will not generate "real-time" predictions (daily, monthly time series), but statistical frequency distributions of flow, loading, and concentration applicable to non-winter conditions, following probabilistic procedures developed under NURP for modeling urban runoff impacts (USEPA, 1982; Athayde et al,1983).

The model will consider the following water quality components:

- suspended solids
- total nitrogen
- total phosphorus
- copper
- lead
- zinc

These variables have been selected based upon the availability of regional data (NURP and other sources) for estimating urban runoff concentrations and BMP effectiveness and upon their probable importance with respect to urban runoff impacts on the Bay. The model will be structured so that the list of water quality components can be easily modified, given the appropriate input data (runoff concentrations, baseflow concentrations, etc.).

Model users are assumed to have basic familiarity with hydrologic and water quality concepts, but limited computer experience. An extensive user interface will be provided (help screens, menus, graphics, etc.). It will run on an IBM-PC or compatible computer without special hardware.

SIMULATION OF BMP's

BMP's considered by the model will consist of buffer strips, grassed swales, infiltration basins, and/or wet detention ponds. The model will provide estimates of treatment efficiency, based upon some combination of the following:

(1) "lookup tables" which relate removal efficiencies to engineering parameters, developed from literature review (e.g., Schueler(1987), Maine DEP (1989))

(2) simplified performance models which predict removal efficiency (or probable range thereof) as a function of engineering parameters and regional climatologic factors (e.g., Driscoll's models for infiltration basins and detention ponds (Driscoll, 1983; USEPA, 1986); swale/buffer strip models, etc.)

(3) detailed simulation of rainfall runoff, washoff, and removal processes (using dynamics borrowed from STORM, SWMM, an other urban runoff models). These models are generally geared to simulating suspended solids.

Solids and associated contaminants can be partitioned into size classes with different settling velocities.

The appropriate estimation technique will vary with BMP and water quality component. Performance will be estimated as a probable range of removal efficiencies, rather than an absolute value. In this way, the model predictions will reflect uncertainty in BMP performance, in addition to other sources of variation and uncertainty. The model will permit application of BMP's in series (e.g., grassed buffer strip followed by detention pond, etc.). Where appropriate, model predictions of removal efficiency for particular BMP's will be developed from and/or tested against SWMM or other detailed simulations. An accompanying report (Walker, 1989) describes use of dimensionless analysis to summarize simulation output.

MODEL APPLICATIONS

The primary functions of the model in a local planning context will be:

(1) to insure that urban BMP's included in a particular site plan are designed properly (i.e., conform to design criteria, which relate BMP dimensions and other engineering features to site characteristics, generally based upon hydrologic aspects); this is probably the most important function, given the lack of specific objectives or quantitative estimates of downstream assimilative capacity; regional design criteria have been developed by RIDEM(1988) for various types of treatment devices;

(2) to characterize the quantity and quality of discharge from the site (surface runoff, baseflow, combined) in probabilistic terms;

(3) to provide a rational, quantitative basis for determining whether or not the proposed discharge is "acceptable" from a water quality perspective, based upon the following types of criteria:

    (a) probability or "risk" that the combined site discharge will violate existing water quality standards/criteria with respect to certain components (e.g., nitrogen, heavy metals);

    (b) maximum increase in average pollutant export from the site, expressed in absolute terms (lbs/acre-yr) or relative terms (% above existing or undeveloped condition); and/or

(c) minimum specified degree of treatment (percent removal) for a target or "keystone" pollutant.

Application of criteria under item (3) to "regulate" developments in the Narragansett Bay watershed would amount to a policy decision. A uniform set of criteria would have to be established by regional authorities in order to permit fair application of the methodology in planning new developments. Examples are the Chesapeake Bay's "-10%" rule and Maine's "+1 ppb" lake protection scheme. Such criteria would be based upon existing state and federal water quality standards, the assimilative capacity of the Bay for specific pollutants, and local priorities.

In a planning context, a proposed development which does not meet the adopted criteria would either be "rejected" or revised to provide "acceptable" water quality. The latter would generally be achieved by reducing the "source" (lower density, less impervious area) and/or by increasing treatment efficiency (design/mix of BMP's).

The Rhode Island Department of Environmental Management (1988) has recommended that BMP's in "sensitive" urban watersheds (water supply reservoirs, coastal ponds) be designed to remove 85% of suspended solids loading. The type of "rule" is particularly suitable for consideration in a model. Desirable features include:

(1) **Existing urban runoff models are geared to simulating suspended solids.**

(2) **A generalized probability distribution for particle settling velocities in urban runoff has been developed from NURP results (Driscoll, 1983).** The applicability of this distribution could be examined with regional data, if available.

(3) **Estimation of suspended solids removal efficiency is independent of the assumed runoff (inflow) concentrations.** Since the sedimentation processes are modeled as first-order reactions, the predicted removal efficiency (%) would be the same for an assumed inflow concentration of 100 mg/liter as for an inflow concentration of 1 mg/liter, for a given distribution of settling velocities. This eliminates effects of errors in estimating the source loading factors.

These factors suggest that a reasonably reliable model for predicting suspended solids removal efficiency could be developed and would be compatible with above RIDEM policy recommendation.

One limitation is that a "rule" based upon suspended solids removal efficiency would not directly consider impacts of dissolved contaminants. Direct simulation of processes influencing dissolved contaminants (adsorption, precipitation, uptake, filtration, decay) is generally infeasible. When treatment devices are sized adequately to remove fine particulate fractions via settling, however, residence time is often sufficient to promote other removal mechanisms. With the exception of inert materials (e.g., road salt), appreciable removal of dissolved species occurs in detention basins which are properly sized (particularly if the organic soils and wetland vegetation are also involved). For example, removal of dissolved phosphorus generally equals or exceeds removal of total phosphorus in wet detention ponds which are adequately sized (Walker, 1987). Harper et al. (1984) report removal efficiencies of 88% for dissolved zinc, 56% for dissolved copper, and 63% for dissolved lead in a retention basin fed by runoff from a Florida highway. Removal efficiencies were 98% for total zinc, 73% for total copper, and 97% for total lead.

Additional analysis is suggested to determine whether a solids-based "rule" would provide adequate water quality protection for the broad spectrum of urban runoff contaminants, given their runoff concentration distributions, observed BMP performance data, and water quality standards/criteria.

BASINWIDE APPLICATIONS

An important concept is that the model would provide a basis for considering each urban development individually with limited input data requirements. This simplifies things for local applications. If the total discharge from each development conforms to water quality standards, then chances are good that the stream/river will also conform to water quality standards. This will not necessarily be true for the Bay, however, especially with respect to nutrients or contaminants with cumulative impacts. For example, stream standards for nitrogen generally do not exist, except for the 10 ppm nitrate nitrogen standard for water supplies. It is possible, if not likely, that severe eutrophication would occur in portions Bay at stream nitrogen concentrations well below 10 ppm. For this reason, appropriate criteria for protection of the Bay may be well below existing state and federal stream standards for nitrogen (and for other components with cumulative or otherwise complicated impacts). In order to define such criteria, Bay assimilative capacity would have to be expressed in terms of an "acceptable" concentration and/or loading to be applied on a stream and individual site basis. The model will provide a rational framework for determining compliance with specified criteria, which must be developed/specified independently.

The model will be applicable in a "lumped-parameter" mode to estimate loading potential for an entire watershed or river basin, based upon the appropriate mix of soil types and land uses. Instream transformations will be ignored. Basinwide applications will not account directly for the specific combinations of BMP's present in the watershed. They will be useful, however, for estimating overall loading potential as function of degree of development (pristine vs. existing vs. full development at various densities and BMP effectiveness). A similar calculation has been performed by Hoffman (1985) for the entire Narragansett Bay watershed. This type of application will provide overall perspectives on the watershed and would presumably be undertaken more often by statewide or regional planners than by local planners involved in reviewing specific developments. Insights gained from basinwide applications, combined with Bay characteristics and sensitivities, will provide a basis for identifying basin water quality constraints and for developing criteria to be applied in planning at the local level.

GIS DATA BASE

GIS data bases will be utilized primarily for basinwide applications. An appropriate spatial scale (resolution) will be selected based upon homogeneity of land uses and soil types in the watershed. This will involve developing a software interface to convert GIS parameters to model input parameters (hydrologic soil groups, cover types, impervious areas). Local applications will probably not involve GIS, since the data required for simulation of individual developments will generally be available from site plans and other local data sources. The development of procedures for estimating impervious areas from GIS parameters is an important task.

CONCLUSION

Possible directions for the modeling effort are discussed above for consideration by the Narragansett Bay Project. A single model or procedure which satisfies all of the initial project objectives does not exist. The selection/development of an appropriate model must consider tradeoffs between complexity and practicality. A comprehensive watershed simulation model would have exhaustive input data requirements and limited application at the local level. Generally, a model consisting of an integration of loading functions and other simplified techniques in a probabilistic framework would seem to have the broadest application potential.

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TABLE B3. HSPF INPUTS

INPUTS TO PERLND

(1) Inputs to correct air temperature for elevation difference.

- Difference in elevation between the temperature gage and the pervious land segment.
- Air temperature over the pervious land segment.

(2) Inputs to simulate accumulation and melting of snow and ice.

- Latitude of the pervious land segment.
- Mean elevation of the pervious land segment.
- Fraction of the pervious land segment which is shaded from solar radiation by, for example, trees.
- Maximum pack (water equivalent) at which the entire pervious land segment will be covered with snow.
- Density of cold, new snow relative to water.
- Air temperature below which precipitation will be snow, under saturated conditions.
- A parameter which adapts the snow evaporation equation to field conditions.
- A parameter which adapts the snow condensation/convection melt equation to field conditions.
- Maximum water content of the snow pack, in depth water per depth water equivalent.
- Maximum rate of snowmelt by ground heat, in depth of water equivalent per day.
- Quantities of snow, ice and liquid water in the pack (water equivalent).
- Density of the frozen contents (snow + ice) of pack, relative to water.
- Mean temperature of the frozen contents of the pack.
- Current pack (water equivalent) required to obtain complete areal coverage of the pervious land segment.
- Current remaining possible increment to ice storage in the pack.
- Fraction of sky which is assumed to be clear at the present time.

(3) Inputs to simulate water budget for pervious land segment.

- Fraction of the pervious land segment which is covered by forest which will continue to transpire in winter.
- Lower zone nominal storage
- Length and slope of the assumed overland flow plane
- Basic groundwater recession rate.
- Air temperature below which evapotranspiration will arbitrarily be reduced below the value obtained from the input time series.

- Temperature below which evapotranspiration will be zero regardless of the value in the input time series.
- Exponent in the infiltration equation.
- Ratio between the max and mean infiltration capacities over the pervious land segment.
- Fraction of groundwater inflow which will enter deep (inactive) groundwater and, thus, be lost from the system.
- Fraction of remaining potential evapotranspiration which can be satisfied from baseflow (groundwater outflow), if enough is available.
- Fraction of remaining potential evapotranspiration which can be satisfied from active groundwater storage if enough is available.
- Interception storage capacity.
- Upper zone nominal storage.
- Manning's n for the assumed overland flow plane.
- Interflow inflow and recession parameters.
- Lower zone evapotranspiration parameter.
- Monthly interception storage capacity.
- Monthly upper zone storage.
- Monthly Manning's n values.
- Monthly interflow parameters.
- Monthly interflow recession constants.
- Monthly lower zone evapotranspiratino parameter.
- Interception storage.
- Surface (overland flow) storage.
- Storages of upper, lower and interflow zones.
- Active groundwater storage.
- Surface storage (upper zone and interflow).

(4) Inputs to produce and remove sediment.

- Supporting management practice factor. It is used to simulate the reduction in erosion achieved by use of erosion control practices.
- Coefficient in the soil detachment equation.
- Exponent in the soil detachment equation.
- Fraction by which detached sediment storage decreases eaach day, as a result of soil compaction.
- Fraction of land surface which is shielded from erosion by rainfall.
- Rate at which sediment enters detached storage from the atmosphere.
- Coefficient and exponent in the detached sediment washoff equation.
- Coefficient and exponent in the matrix soil scour equation.
- Monthly erosion related cover values.
- Monthly net vertical sediment input.
- Initial storage of detached sediment.

(5) Inputs to estimate soil temperature.

- Surface layer temperature, when the air temperature is 32 degrees F (ASLT).
- Slope of the surface layer temperature regression equation (BSLT).
- Smoothing factor in upper layer temperature calculation (ULTP1).
- Mean difference between upper layer soil temperature and air temperature (ULTP2).
- Smoothing factor for calculating lower layer/groundwater soil temperature (UGTP1).
- Mean departure from air temperature for calculating lower layer/groundwater soil temperature (UGTP2).
- Intercept in the upper layer soil temperature regression equation.
- Slope in the upper layer soil temperature regression equation.
- Monthly values for ASLT, BSLT, ULTP1, ULTP2, LGTP1, and LGTP2.
- Initial air temperature.
- Initial surface layer soil temperature.
- Initial upper layer soil temperature.
- Initial layer/groundwater layer soil temperature.

(6) Inputs to estimate water temperature and dissolved gas concentrations.

- Elevation of the pervious land segment above seal level.
- Concentration of dissolved oxygen nd CO2 in interflow outflow, and in active groundwater flow.
- Monthly interflow DO and CO2 concentrations.
- Monthly groundwater DO and CO2 concentrations.
- Initial surface and interflow outflow temperature.
- Initial active groundwater outflow temperature.
- Initial DO and CO2 concentrations in surface outflow, interflow outflow, and active groundwater outflow.

(7) Inputs to simulate quality constituents using simple relationships with sediment and water yield.

- Washoff potency factor.
- Scour potency factor.

  Note: A potency factor is the ratio of constituent yield to sediment (washoff or scour) outflow.
- Initial storage of constituent on the surface of the pervious land segment.
- Rate of accumulation of constituent.
- Maximum storage of constituent.
- Rate of surface runoff which will remove 90 percent of stored constituent per hour.
- Concentration of the constituent in interflow outflow.
- Concentration of the constituent in active groundwater outflow.
- Monthly washoff and scour potency factors.
- Monthly accumulation rates of constituent.
- Monthly limiting storage of constituent.

- Monthy concentrations of constituent in interflow and groundwater.

(8) Inputs to estimate the moisture and fractions of solutes being transported in the soil layers.

- Nominal upper and lower zones storage.
- Initial surface detention storage.
- Initial surface detention storage on each block of the pervious land segment.
- Initial moisture content in the surface storage, in the upper principal storage, and in the upper transitory (interflow) storage.
- Initial moisture storages in the lower layer, and in the active groundwater layer.

(9) Inputs to simulate pesticide behavior in detail.

- Chemical first-order reaction temperature correction parameters which is used to adjust the desorption and adsorption rates.
- Desorption and adsorption rates (first-order) at 35°C.
- Maximum solubility of the pesticide in water.
- Maximum concentration (on the soil) of pesticide which is permanently fixed to the soil.
- Coefficient and exponent parameters for the Freundlich adsorption-desorption equation.
- Pesticides degradation rates in the surface, upper, and active groundwater layers.
- Initial storage of pesticide in crystalline adsorbed and solution forms in surface, upper, lower or groundwater layer.
- Initial storage of pesticide in the upper layer transitory (interflow) storage.

(10) Inputs to simulate nitrogen behavior in detail.

- Plant nitrogen uptake reaction rate parameters for the surface layer, upper layer, lower layer, and active groundwater layer.
- Monthly plant uptake parameters for nitrogen, for the surface, upper, lower or groundwater layer.
- Parameters intended to designate which fraction of nitrogen uptake comes from nitrite and ammonium.
- Temperature coefficients for plant uptake, ammonium desorption, ammonium adsorption, nitrate immobilization, organic N ammonification, NO3 denitrification, Nitrification, and ammonium immobilization.
- Maximum solubility of ammonium in water.
- Initial storage of N in organic N, adsorbed ammonium, nitrate, and plants.
- Initial storages of ammonium and nitrate in the upper layer transitory (interflow) storage.

(11) Inputs to simulate phosphorus behavior in detail.

- Plant phosphorus uptake reaction rate parameters for the surface layer, upper layer, lower layer, and active groundwater layer.
- Monthly plant uptake parameters for phosphorus, for the surface, upper, lower or groundwater layer.
- Temperature correction parameters for phosphorus plant uptake, phosphate desorption, phosphate immobilization, and organic P mineralization.
- First-order reaction rates for phosphate desorption, phosphate adsorption, phosphate immobilization, and organic P mineralization.
- Maximum solubility of phosphorus in water.
- Initial phosphorus storage (in organic P, adsorbed P, solution P, and P stored in plants) in the surface, upper, lower or groundwater layer.
- Initial storage of phosphate in upper layer transitory (interflow) storage.

(12) Inputs to simulate the movement of a tracer (conservative).

- Initial storage of tracer (conservative) in the surface storage, upper principal storage, upper transitory storage, lower groundwater layer, and active groundwater layers.

INPUTS TO IMPLND

(1) Inputs to correct air temperature for elevation difference.

- See temperature inputs in the PERLAND section.

(2) Inputs to simulate the accumulation and melting of snow and ice.

- See snow inputs in the PERLND section.

(3) Inputs to simulate water budget for impervious land segment.

- Length and slope of the assumed overland flow plane.
- Manning's n for the overland flow plane.
- Retention (interception) storage capacity of the surface.
- Air temperature below which evapotranspiration will arbitrarily be reduced below the value obtained from the input time series.
- Temperature below which evapotranspiration will be zero regardless of the value in the input time series.
- Monthly retention storage capacity.
- Monthly Manning's n values.
- Initial retention storage.
- Initial surface (overland flow) storage.

(4) Inputs to estimate accumulation and removal of solids.

- Coefficient in the solids washoff equation.

- Exponent in the solids washoff equation.
- Rate at which solids are placed on the land surface.
- Fraction of solids storaage which is removed each day; when there is no runoff, for example, because of street sweeping.
- Monthly solids accumulation rates.
- Monthly solids unit removal rates.
- Initial storage of solids.

(5) Inputs to estimate water temperature and dissolved gas concentrations.

- Elevation of the impervious land segment above sea level.
- Surface water temperature, when the air temperature is 32°F (AWTF).
- Slope of the surface water temperature regression equation (BWTF).
- Monthly values for AWTF and BWTF.
- Initial values for the temperature, DO and CO2.

(6) Inputs to simulate quality constituents using simple relationships with solids and/or water yield.

- Washoff potency factor.
- Initial storage of constituent on the surface of the impervious land segment.
- Rate of accumulation of constituent.
- Maximum storage of constituent.
- Rate of surface runoff which will remove 90 percent of stored constituent per hour.

INPUT TO RCHRES

(1) Inputs to simulate hydraulic behavior.

- Length of the receiving water body (RCHRES).
- Drop in water elevation from the upstream to the downstream extremities of the RCHRES.
- Correction to the RCHRES depth to calculate stage.
- Weighting factor for hydraulic routing.
- Median diameter of the bed sediment (assumed constant throughout the run).
- Initial volume of water in the RCHRES.

(2) Inputs to prepare to simulate advection of entrained constituents.

- Ration of maximum velocity to mean velocity in the RCHRES cross section under typical flow conditions.
- Volume of water in the RCHRES at the start of the simulation.

(3) Inputs to simulate behavior of conservative constituents.

- Initial concentration of the conservative.

(4) Inputs to simulate heat exchange and water temperature.

- Mean RCHRES elevation.
- Difference in elevation between the RCHRES and the air temperature gage.
- Correction factor for solar radiation.
- Longwave radiation coefficient.
- Conduction-convection heat transport coefficient.
- Evaporation coefficient.
- Water temperature at the RCHRES.
- Air temperature at the RCHRES.

(5) Inputs to simulate behavior of inorganic sediment.

- Width of the cross-section over which HSPF will assume bed sediment is deposited regardless of stage, top-width, etc.
- Bed depth.
- Porosity of the bed (volume voids/total volume).
- Effective diameter of the transported sand, silt and clay particles.
- Fall velocity of the sand, silt and clay particles in still water.
- Density of the sand, silt and clay particles.
- Critical bed shear stresses for deposition and scour.
- Erodibility coefficient of the sediment.
- Initial concentrations (in suspension) of sand, silt, and clay.
- Initial total depth (thickness) of the bed.
- Initial fractions (by weight) of sand, silt and clay in the bed material.

(6) Inputs to simulate behavior of a generalized quality constituent.

- Latitude of the RCHRES.
- Initial concentration of constituent.
- Second order acid and base rate constants for hydrolysis.
- First order rate constant of neutral reaction with water.
- Temperature correction coefficient for hydrolysis.
- Second order rate constant for oxidation by free radical oxygen.
- Temperature correction coefficient for oxidation by free radical oxygen.
- Molar absorption coefficients for constituent for 18 wavelength ranges of light.
- Quantum yield for the constituent in air-saturated pure water.
- Temperature correction coefficient for photolysis.
- Ratio of volatilization rate to oxygen reaeration rate.
- Second order rate constant for biomass concentration causing biodegradatino of constituent.
- Temperature correction coefficient for biodegradation of constituent.
- Concentration of biomass causing biodegradation of constituent.
- Monthly concentration of biomass causing biodegradation of constituent.

- First order decay rate for constituent.
- Temperature correction coefficient for first order decay of constituent.
- Decay rate for constituent adsorbed to suspended sediment.
- Temperature correction coefficient for decay of constituent on suspended sediment.
- Decay rate for constituent adsorbed to bed sediment.
- Temperature correction coefficient for decay of constituent on bed sediment.
- Partition coefficient - distribution coefficients for constituent with: suspended sand, suspended silt, suspended clay, bed sand, bed silt, bed clay.
- Transfer rate between adsorbed and desorbed states for constituent with: suspended sand, suspended silt, suspended clay, bed sand, bed silt, bed clay.
- Temperature correction coefficients for adsorbtion-desorbtion on: suspended sand, suspended silt, suspended clay, bed sand, bed silt, bed clay.
- Initial concentration of constituent on: suspended sand, suspended silt, suspended clay, bed sand, bed silt, bed clay.
- Initial values for water temperature, pH, free radical oxygen concnetration, cloud cover, and total suspended sediment concentration.
- Phytoplankton concentration (as biomass).
- Monthly values of water temperature, pH, and free radical oxygen.
- Base adsorption coefficients for 18 wavelengths of light passing through clear water.
- Increments to base absorbance coefficient for light passing through sediment-laden water.
- Increments to the base absorption coefficient for light passing through plankton-laden water.
- Light extenction efficiency of cloud cover for each of 18 wavelengths.
- Monthly values of average cloud cover.
- Monthly average suspended sediment concentration values.
- Monthly values of phytoplankton concentration.

(7) Inputs to simulate behavior of constituents involved in biochemical transformations.

- Velocity above which effects of scouring on benthal release rates is considered.

(a) Inputs to simulate primary DO, BOD balances.

- Unit BOD decay at 20 °C.
- Temperature correction coefficient for BOD decay.
- Rate of BOD settling.
- Allowable dissolved oxygen supersaturation.
- RCHRES elevation above sea level.
- Benthal oxygen demand at 20°C.

- Temperature correction coefficient for benthal oxygen demand.
- Benthal release of BOD at high oxygen concentration.
- Increment to benthal release of BOD under anaerobic conditions.
- A correction factor in the lake reaeration equation to account for good or poor circulation characteristics.
- Empirical constant in Tsivoglou's equation for reaeration.
- Temperature coefficient for surface gas invasion.
- Length of the RCHRES.
- Energy drop over its length.
- Temperature correction coefficient for surface gas invasion.
- Empirical constnat for equation used to calculate reaeration coefficient.
- Exponent to depth used in calculation of reaeration coefficient.
- Exponent to velocity used in calculation of reaeration coefficient.
- Dissolved oxygen.
- Biochemical oxygen demand.
- Dissolved oxygen saturation concentration.

(b) Inputs to determine primary inorganic nitrogen and phosphorous balances.

- Benthal release of inorganic nitrogen, and orthophosphate.
- Concentration of dissolved oxygen below which anerobic conditions exist.
- Unit oxidation rate of ammonia and nitrite at 20°C.
- Initial concentration of nitrate (as N), ammonia (as N), and nitrite (as N).
- Concentration of ortho-phosphorus (as phosphorus).
- Concentration of denitrifying bacteria.

(c) Inputs to simulate behavior of plankton populations and associated reactions.

- Ratio of chlorophyll "A" content of biomass to phosphorus content.
- Nonrefractory fraction of algae and zooplankton biomass.
- Fraction of nitrogen requirements for phytoplankton growth satisfied by nitrate.
- Base extinction coefficient for light.
- Maximal unit algal growth rate.
- Michaelis-Menten constant for light limited growth.
- Nitrate Michaelis-Menten constant for nigrogen limited growth.
- Nitrate Michaelis-Menten constant for phosphorus limited growth.
- Phosphate Michaelis-Menten constant for phosphorus limited growth.

- Temperatures above and below which algal growth ceases.
- Temperature below which algal growth is retarded.
- Algal unit respiration rate at 20°C.
- High algal unit death rate.
- Low algal unit death rate.
- Inorganic nitrogen concentration below which high algal death rate occurs (as phosphorus).
- Minimum concentration of plankton not subject to advection (SEED).
- Concentration of plankton not subject to advection at very low flow (MISTAY).
- Outflow at which concentration of plankton not subject to advection is midway between SEED and MXSTAY.
- Chlorophyll "A" concentration above which high algal death rate occurs.
- Rate of phytoplankton settling.
- Rate of settling for dead refractory organics.
- Maximum zooplankton filtering rate at 20°C.
- Zooplankton filtering rate at 20°C (MZOEAT).
- Natural zooplankton unit death rate.
- Increment to unit zooplankton death rate due to anaerobic conditions.
- Temperature correction coefficient for filtering.
- Temperature correction coefficient for respiration.
- The fraction of nonrefractory zooplankton excretion which is immediately decomposed when ingestion rate is greater than MZOEAT.
- Average weight of a zooplankton organism.
- Maximum benthic algae density (as biomass).
- Ratio of benthic algal to phytoplankton respiration rate.
- Ratio of benthic algal to phytoplankton growth rate.
- Initial conditions for phystoplankton (as iomass), zooplankton algae (as biomass), benthic algae (as biomass), dead refractory organic nitrogen, dead refractory organic phosphorus, and dead refractory organic carbon.

(d) Inputs to simulate pH and carbon species.

- Ratio of carbon dioxide invasion rate to oxygen reaeration rate.
- Benthal release of CO2 (as C) for aerobic and anaerobic conditions.
- Initial total inorganic carbon for pH simulation.
- Initial carbon dioxide (as C) for pH simulation.
- Initial pH.

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DRAFT

DIMENSIONLESS ANALYSIS OF RUNOFF TREATMENT DEVICES

prepared for

Narragansett Bay Project
and
IEP, Inc.

by

William W. Walker, Jr.

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INTRODUCTION

The performance of a runoff treatment device generally depends upon its treatment capacity and storage volume relative to the rate and volume of runoff from the watershed over the range of storms encountered. Designs can be described in terms of two dimensionless variables (Driscoll, 1983; Yousef et al., 1986; USEPA, 1986; Walker, 1987):

> **Dimensionless Treatment Rate** = maximum rate of treatment (settling, infiltration) relative to rate of runoff
>
> **Dimensionless Storage Volume** = maximum storage volume relative to volume of runoff

Overall treatment efficiency increases with each of these two values. Higher volumes increase treatment efficiency by storing runoff and thereby permitting treatment to occur over prolonged periods between storm events. Treatment rate and storage volume can be scaled against the runoff rate and runoff volume for an average storm to develop dimensionless forms.

Once "calibrated", these variables provide a predictive basis for overall treatment efficiency. A simulation model (e.g., SWMM) can be used to estimate overall treatment efficiency for a range of dimensionless treatment rates and storage volumes, using regional rainfall time series. Model predictions can be summarized in terms of the dimensionless variables. This provides a simple way of estimating overall treatment efficiencies without resorting to detailed simulation in each application.

INFILTRATION BASINS

Dimensionless analysis is demonstrated in Figure 1 for an infiltration basin. These results are based upon simulation of rainfall time series from Worcester in 1968 (average year). Overall treatment efficiency refers to the percent of the total runoff volume which is filtered through the bottom of the basin. The "treatment rate" is the product of the infiltration rate (in/hr) and the surface area of the basin (acres). This is scaled against the rate of runoff from a storm with average intensity (.06 in/hr). As simulated by the model, the volume of water stored in the basin fluctuates in response to storm inflows and infiltration losses. The "dimensionless storage volume" refers to the maximum storage capacity of the basin, scaled against the volume of runoff from a mean storm (.4 inches).

Typical design criteria for infiltration basins are as follows (Schuler, 1987; Shaver, 1986):

Storage Volume = volume of runoff from 1-inch storm
Maximum Draining Time = 72 hours

Transformation of these criteria provides a basis for estimating filtration efficiency using Figure 1. The storage volume criterion corresponds to a dimensionless storage volume (V_b/V_r) of 1/.4 = 2.5. For a basin with a storage depth of 4 feet, the draining time criterion corresponds to an infiltration rate of 4 x 12 / 72 = .5 in/hr and (through further algebra) to a dimensionless treatment rate of 2.1. Figure 1 shows these dimensionless values correspond to a filtration efficiency which exceeds 90%.

Design relationships for infiltration basins developed under the NURP program (Driscoll,1986; USEPA,1986) relate performance to the following variables, as illustrated in Figure 2:

Percolating Area, As % of Catchment Area
Infiltration Rate
Average Depth

Results shown in Figure 2 are specific for watersheds with a runoff coefficient of .2 and for Great Lakes precipitation. The dimensionless form (Figure 1) is more concise, but still specific for the simulated rainfall time series. Additional analysis indicates that the design curves in Figure 2 can be successfully reproduced from dimensionless plots similar to Figure 1, with substitution of appropriate rainfall statistics.

Within certain limitations, a "buffer strip" might be represented as a type of infiltration basin, with a defined infiltration rate, infiltration area, and maximum storage volume. Such a model would assume sheet flow over the buffer area and shallow slopes. More complex models of buffer strip performance which consider effects of slope and roughness might be developed using techniques previously developed for grassed swales (Wanielista and Yousef, 1986).

WET DETENTION PONDS

Dimensionless analysis is demonstrated in Figure 3 for a wet detention pond, also based upon Worcester rainfall data. Overall treatment efficiency refers to the percent of the total runoff load which is removed by settling in the detention pond. The "treatment rate" is the product of the settling velocity (in/hr) and the surface area of the pond (acres). This is scaled against the rate of runoff from a storm with average intensity. As simulated by the model, pond volume is constant and concentrations vary in response to storm loads (driven by accumulation/washoff dynamics) and sedimentation. The "dimensionless storage volume" refers to the permanent pool volume, scaled against the volume of runoff from a mean storm (.4 inches).

Typical design criteria for wet detention ponds are as follows (USEPA, 1986):

Area = 1% of Watershed Area (for runoff coefficient = .2)
Mean Depth = 3.5 feet

Transformation of these criteria provides a basis for estimating removal efficiency using Figure 3. Calculations are performed for a particle settling velocity of 1.5 ft/hr (18 in/hr), which is a median value for urban runoff (Driscoll, 1983; USEPA, 1986). With some algebra, it can be shown that these criteria correspond to a dimensionless treatment rate of 15 and a dimensionless storage volume of 5.3, which, in turn, yield a removal efficiency exceeding 90%.

Design relationships for wet detention ponds developed under the NURP program (Driscoll,1986; USEPA,1986) relate performance to basin surface area, as a percent of contributing catchment area. Results shown in Figure 4 are specific for ponds with a mean depth of 3.5 feet, watersheds with a runoff coefficient of .2, and regional precipitation. Additional analysis indicates that the Northeast curve in Figure 4 can be generated from the more general dimensionless relationships in Figure 3 using the median settling velocity of 1.5 ft/hr.

CONCLUSIONS

A technique has been described for summarizing size/performance relationships for runoff treatment devices using dimensionless variables. The technique provides a simple way of condensing results derived from detailed simulation models. Future work will involve application of curve-fitting pl744Xtechniques to permit expression of performance plots in algebraic terms. This, in turn, will facilitate use in simple models and screening procedures for predicting BMP performance. The techniques will be calibrated and tested against results of detailed simulation models, such as SWMM, using regional rainfall time series.

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EVALUATION OF EXISTING MODELS, DESIGN CONCEPTS, AND HUNT-POTOWOMUT DATA INVENTORY

Working Document No. 1

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The following is a compilation of several documents utilized in the development of the P8 Urban Catchment Model. In the rppocess of developing a land-based water quality model, an evaluation of existing models was completed to identify models which could be readily adapted for use in a mixed land use setting, or that had valuable algorithms which could be incorporated in the developmnet of a new model. In addition, an inventory of available water quality data for the Hunt-Potowomut watershed was made. The purpose of this inventory was to determine if sufficient data existed to be used either in the development of and land-based water quality model or to support the calibration of such a model.

The results of these evaluations and inventories, as well as a summary of concepts for the design of a land based water quality model given the results of the evaluation and inventory are provided in Attachments 1 - 3.

ATTACHMENT 1

Design Concepts for a Land-Based Water Quality Model

DESIGN CONCEPTS FOR A LAND-BASED WATER QUALITY MODEL OF THE HUNT-POTOWOMUT RIVER

prepared for

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INTRODUCTION

As stated in the RFP issued by the Narragansett Bay Project, the objectives of the study are as follows:

- "evaluate existing land-based water quality models in terms of their practical application to a watershed characterized by multiple land uses;
- adapt or link existing models which are capable of simulating the contribution of nonpoint source pollutants and the water quality benefits of available control practices under a variety of land use scenarios, using information typically available to Rhode Island planners;
- apply the selected method/model to the Potowomut-Hunt River watershed or some representative hydrographic regime(s) within the Potowomut-Hunt watershed;
- present a "user friendly" method/model for state and local planners to use in estimating potential water quality impacts associated with various land uses and mitigation/control practices; and
- train selected state and/or local planners to the method/model presented"

In addition, "the methods/models selected for evaluation should be capable of simulating watershed-level impacts on receiving waters considering both dry and wet weather nonpoint pollution sources and mitigation practices, using various land use scenarios".

Available watershed models have wide ranges of applicability, complexity, temporal scales, spatial scales, and data requirements, as documented in Tables 1,2, and 3 (Donigian and Beyerlein, 1985). A single model or procedure which satisfies all of the above project objectives does not exist. The selection/development of an appropriate model must consider tradeoffs between complexity and practicality. Basic alternatives and recommended directions are discussed below.

WATERSHED SIMULATION MODELS

Detailed watershed simulation models, such as **HSPF** (Donigian et al, 1984) or **SWMM** (Huber et al., 1983), represent the most comprehensive land-based water quality models. **HSPF**, in particular, has the broadest range of capabilities for diverse watersheds such as the Hunt-Potowomut. **HSPF** has been used extensively in water quality planning under the Chesapeake Bay Program. **HSPF** and **SWMM** can be applied on any spatial scale and can generate continuous time series of flow and water quality, which could be used to drive a Bay simulation model.

Basic characteristics of **HSPF** are summarized by Schnoor et al. (1987):

> "HSPF includes time series-based simulation modules (PERLIND, IMPLND, and RCHRES), and utility modules (COPY, PLTGEN, DISPLAY, DURANL, and GENER). The simulation (application) modules include mathematics for the behaviour of processes that occur in a study watershed. The watershed is divided into three segments -- pervious land, impervious land, and a receiving water system (i.e., a single reach of an open channel or a completely mixed impoundment). The module PERLND simulates the pervious land segment with snow accumulation and melt, water movement (overland flow, interflow, and groundwater flow), sediment erosion and scouring, and water quality (pesticides, nutrients). The IMPLND module simulates the impervious land segment where little or no infiltration occurs. The IMPLND processes include snow and water movements, solids, and water quality constituents. The model RCHRES simulates the segment of receiving water body, including hydrologic behaviour, conservative and nonconservative constituents, temperature, sediments, BOD and DO, nitrogen, phosphorus, carbon, and pH. The utility modules perform "house-keeping" operations, designed to provide the user flexibility in managing simulation inputs and outputs".

An inventory of input data and parameter estimates required for **HSPF** is contained in the Appendix. **SWMM** is oriented more towards urban watersheds, with a strong emphasis on hydraulics.

Table 1. Characteristics and Capabilities of Selected NPS Runoff Procedures and Models

	LAND USE/LOAD SOURCES						HYDROLOGY			WATER QUALITY			TIME SCALE			DATA NEEDS			SPACE SCALE		
	Urban	Agriculture	Forest /Natural	Mining	Precipitation	Chemical Application	Surface Runoff	Subsurface Flow	Snowmelt	Sediments	Nutrients	Pesticides/Toxics	Annual Loads	Event Loads	Continuous Simulation	Detailed	Moderate	Minimal	Segmented/ Multiple Catchments	Lumped/ Single Catchment	Use, Documentation, Support
LOADING/SCREENING PROCEDURES																					
Hydroscience	●						●		●		●		●					●		●	A/M
EPA Screening Procedures	●	●	●		●					●	●	●	●	●				●		●	A
WRENS			●				●		●	●	●	●	●					●	●		A
WLFNPS		●	●				●		●	●	●			●			●		●		M/A
SWMM - Level I	●						●	○		●	●		●				●			●	A
RUNOFF MODELS																					
Simplified SWMM	●						●				●			●	●		●		●		M
ARM		●				●	●	●	●	●	●	●		●	●	●				●	E/A
NPS	●	●	●				●	●	●	●	●			●	●	●			●		E/A
HSPF/PERLND & IMPLND	●	●	●	●	○	●	●	●	●	●	●	●		●	●	●			●		E
CREAMS/CREAMS 2		●	●			●	●			●	●	●		●	●	●				●	E
ANSWERS		●	●	●			●	●		●	●			●		●			●		A
ACTMO		●				●	●	●	●	●	●	●		●	●	●			●		M
SWMM	●						●	○	●	●	●			●	●	●			●		E
STORM	●						●	○	●	●	●				●		●			●	E
MUNP	●						●			●	●			●			●			●	M
ILLUDAS/DRAINQUAL	●						●	●			●			●		●	●		●		A
DR3M	●				●		●	○		●					●	●			●		A
PRMS			●				●	●	●	●				●	●	●			●		A

Donigian and Beyerlein (1985)

Notes: ●-Capability included in model

○-Capability not explicity included but can be user-defined

Use/Documentation/Support

E - Extensive

A - Adequate

M - Minimal

Table 2. Characteristics and Capabilities of Integrated Watershed Models

	WATERBODY & FLOW CONDITIONS						WATER QUALITY								TIME SCALE		DATA NEEDS		SPACE SCALE			
INTEGRATED WATERSHED MODELS	Rivers/Streams	Lakes/Impoundments	Estuaries	Confined Flow	Drainage/Control Structures	Point Source Discharges	Temperature	D.O./BOD/NBOD	Suspended Sediment Transport	Sediment Scour/Deposition	Sediment Contaminant Interaction	Nutrient Kinetics	Pesticides/Toxics	Biologic Simulation	Dynamic	Steady-State	Detailed	Moderate	Multi Land Use Multiple Catchments	Single Land Use Single Catchment	Data/File Management	Use, Documentation, Support
HSPF	●	●		○	●	●	●	●	●	●	●	●	●	●	●		●		●		●	E
SWMM (RECEIV)	●	●	●	●	●	○		●				●	○	●	●		●		●			E
PRS	●	●											●		●		●		●			A
UTM-TOX	●		●		●	●	○		●	●			●		●		●		●			M
SWAM	●	●					●		●	●		●	●		●		●		●			M/A

Notes: ● - Capability included in model

○ - Capability not explicity included but can be user-defined

Use/Documentation/Support

E - Extensive
A - Adequate
M - Minimal

Donigian and Beyerlein (1985)

TABLE 3 PRELIMINARY LIST OF NPS AND INTEGRATED WATERSHED MODELS SELECTED FOR REVIEW

MODELS	NAME	SOURCE	REFERENCE
Loading/Screening Procedures			
Hydroscience	Hydroscience Simplified Model	Hydroqual/EPA	EPA, 1976
EPA Screening Procedures	EPA Water Quality Screening Procedures	EPA	McElroy et al., 1976; Mills et al., 1982
WLFNPS	Watershed Loading Functions for Non-Point Sources	U.S. Forest Service, 1980	U.S. Forest Service
WRENS	Water Resources Evaluation of Non-Point Silvicultural Sources	Cornell University	Haith and Tubbs, 1981
SWMM-Level I	SWMM-Level I	EPA	Heaney et al., 1976
NPS Runoff Models			
HSPF/PERLND & IMPLND	Hydrological Simulation Program - FORTRAN (land simulation modules)	EPA	Johanson et al., 1984
ARM	Agricultural Runoff Management Model	EPA	Donigian et al., 1977
NPS	Nonpoint Source Model	EPA	Donigian and Crawford, 1977
CREAMS/CREAMS2	Chemicals, Runoff, and Erosion From Agricultural Management Systems	USDA	USDA, 1980
ANSWERS	Areal, Nonpoint Source Watershed Environment Response, Simulation Model	Purdue University	Beasley et al., 1980 Beasley and Huggins, 1981
ACTMO	An Agricultural Chemical Transport Model	USDA/ARS	Frere et al., 1975
SWMM	Stormwater Management Model (land simulation modules)	EPA	Huber et al., 1975
STORM	Storage, Treatment, Overflow Runoff Model	COE	HEC, 1977
MUNP	Management of Urban Nonpoint Pollution Model	Univ. of Maryland	Sutherland and McCuen 1978
ILLUDAS/DRAINQUAL	Illinois Urban Drainage Area Simulator	Illinois State Water Survey	Terstriep and Stall, 1974
DR3M	Distributed Routing Rainfall-Runoff Model	USGS	Alley and Smith, 1982a, 1982b
PRMS	Precipitation-Runoff Modeling System	USGS	Leavesley et al., 1983
Simplified SWMM	Simplified SWMM	EPA/M&E	Lager et al., 1976
Integrated Watershed Models			
HSPF	Hydrological Simulation Program - FORTRAN	EPA	Johanson et al., 1984
SWMM	Stormwater Management Model	EPA	Huber et al., 1975
PRS	Pesticide Runoff Simulator	EPA/CSC	CSC, 1980
UTM-TOX	Unified Transport Model for Toxics	Oak Ridge/EPA	Patterson et al., 1983
SWAM	Small Watershed Model	USDA/ARS	DeCoursey, 1982

Donigian and Beyerlein (1985)

The complexity of these models does not guarantee that they are "better" or "more accurate" than alternative, simpler techniques, however, because the detailed information required to drive them is rarely available. When viewed in relation to the stated project objectives, limitations of this class of models include:

(1) **Extensive Data Requirements.** Watershed and stream characteristics must be parameterized in detail (see Appendix). To a limited extent, this would be facilitated by a GIS interface. More importantly, the models must be calibrated and tested against watershed/stream response data. This generally requires continuous flow monitoring and sufficient concentration sampling to permit estimation of dry-weather and wet-weather loadings over an annual period. To support model application to a given watershed, a typical monitoring program would involve weekly periodic sampling combined with flow-weighted composite sampling for at least three storm events per season.

(2) **Complexity.** The models are large and not designed for use by the typical "state and local planner". Considerable training is required and previous modeling experience is desirable. For example, a 2-3 month minimum project time frame is needed for HSPF if the user has no prior experience with the model (Donigian and Beyerlein, 1985). The local planner would rarely be in a position to supply the input data and parameter estimates inventoried in the Appendix. PC versions of HSPF and SWMM are distributed on 6 and 4 diskettes, respectively.

(3) **Scope.** Although these models are the most comprehensive ones available, they may lack certain capabilities which are important for this project (e.g., simulation of buffer strips). Owing to their size and complexity, modification of these models to account for additional processes would be difficult.

Because of these limitations, application of HSPF or SWMM to this project would only make sense if a commitment is also made to a substantial stream monitoring program and additional watershed data collection. Future use would probably be limited to a few highly trained individuals. This approach would focus more on modeling whole watersheds or subwatersheds, as opposed to modeling individual urban developments.

Within the project time frame, it would be possible to set up an HSPF or SWMM application to the Hunt/Potowomut watershed, including an interface to GIS data bases. Calibration would be deferred to subsequent year(s), pending collection of appropriate stream and watershed data.

SIMPLER APPROACHES

Other classes of models, typically described as "screening procedures", "loading functions", or "simplified techniques", are less detailed, have less demanding data requirements, and seem more easily adaptable to project needs. These include:

(1) Schueler's (1987) "Simplified Method"

(2) Probabilistic techniques developed under EPA's Nationwide Urban Runoff Program (USEPA, 1982; Athayde et al. 1983; DiTorro, 1984; Driscoll, 1986).

(3) Simplified models for predicting BMP performance (Driscoll, 1983; USEPA, 1986; Walker, 1987, 1989)

(4) Haith and Shoemaker's (1987) "Generalized Watershed Loading Functions"

(5) Screening Procedures for Nonpoint Sources (Mills et al., 1985)

(6) BMP performance models and design criteria developed by the Rhode Island Department of Environmental Management (1988)

(7) Urban runoff loading factors developed for Narragansett Bay Watersheds (Hoffman,1985)

Compared with the simulation models discussed above, these techniques rely more upon generalized sources of information and have less demanding requirements for site-specific data. Possible integration of these techniques into a model useful for project purposes is discussed below.

SOURCE CHARACTERIZATION

Essentially, loading functions de-emphasize or ignore water quality transformations which may occur in the river. This is valid to the extent that land-based sources are generally related to high-flow conditions and short travel times. The primary objective is to estimate loadings to the Bay and their relationships to land uses and management practices. They are ultimately driven by "export coefficients", runoff concentrations, and/or baseflow concentrations which must be estimated for each land use and water quality component.

Data bases developed under NURP (Athayde et al, 1983) and other regional studies (e.g., Hoffman, 1985) provide a basis for estimation of the required source concentrations or export coefficients. The high degree of variability in urban runoff concentrations from site-to-site and from storm-to-storm at a given site must be considered in the calibration process. In the case of NURP event-mean copper concentrations, for example, the site-to-site coefficient of variation was .77 and the storm-to-storm coefficient of variation was typically between .5 and 1 (Athayde et al, 1983). Because of the latter, the accuracy of mean runoff concentrations or export coefficients calculated from sampling data at a given site can be extremely limited.

For example, for a variable with a storm-to-storm coefficient of variation of .75, a site-mean concentration estimated from monitoring 5 storm events would have a standard error of .34. The 90 percent confidence range for the site mean would be roughly between 50% and 200% of the calculated mean value. Because of this degree of variability, probabilistic approaches which account for uncertainty in the source concentrations (as well as temporal variability) seem appropriate. Blind "calibration" to a few site-specific measurements (ignoring information from much larger and more generalized data bases, e.g., NURP) is not recommended. The existing water quality data base on the Hunt-Potowomut is clearly inadequate to support calibration of any land-based model or loading function.

MODEL STRUCTURE

The model will be developed primarily for use by local planners and engineers involved in the design and evaluation of urban developments. It will generally be applied to a specific development or subwatershed consisting of a number of hydrologic units. Characteristics of each hydrologic unit will be supplied by the model user:

(1) **watershed parameters**
surface areas
hydrologic soil groups (or assoc. names)
land use/cover (as required for SCS Curve Numbers)
impervious area
non-runoff sources (e.g., onsite disposal systems)

(2) **BMP parameters**
types (wet pond, buffer strip, infilt. basin, etc.)
relevant dimensions (volume, area, depth, etc.)
treatment capacities (infiltration rates, etc.)

(3) **Configuration**
one or more BMP's may be applied in series

Flow and contaminants leave the hydrologic unit in two forms: surface runoff and groundwater (baseflow). There are two basic approaches which are feasible for predicting variations in these flows at a given site:

(1) **Statistical (USEPA/NURP, 1982;1983)**

surface runoff intensity is calculated from impervious area and precipitation intensity; baseflow is estimated from pervious area and regional streamflow values; baseflow and surface runoff may be correlated statistically.

(2) **Deterministic (e.g., Haith and Shoemaker, 1987)**
model is driven by daily time series of precipitation and temperature; surface runoff is estimated from daily rainfall using SCS techniques; evapotranspiration is estimated from air temperature, season, and vegetative cover; groundwater flow is calculated essentially by difference, accounting for seasonal variations in storage.

The first method is much simpler and requires less input data. The second method is more realistic but requires more extensive input data and parameter estimates. An appropriate technique will be developed and calibrated using regional precipitation and streamflow data.

Once flows have been estimated, loadings can be calculated from mass-balance relationships. This requires estimation of the following:

(1) **Surface Runoff Concentrations**
probability distributions derived from NURP and other regional data, possibility adjusted based upon land use/cover/soil type; regional NURP data sets have been obtained for calibration purposes (including Worcester (MA), Mystic Lake (MA), Durham (NH), Long Island (NY)).

(2) **Baseflow Concentrations**
probability distributions derived from regional stream monitoring data from undeveloped watersheds; derived from STORET, state and local sources.

(3) **Direct Loads**
onsite disposal systems, package treatment plants, industrial; onsite loads estimated from population; others input by model user.

(4) **BMP Treatment Efficiency**
reductions in runoff and baseflow loads attributed to combinations of management practices on the site; estimation procedures discussed below.

To reflect uncertainty in input variables (e.g., runoff and baseflow concentrations, treatment efficiencies) and temporal variability (rainfall statistics, baseflow), model output (flows, concentrations, loads) will be expressed in probabilistic terms (frequency distributions vs. absolute values). Output distributions will be estimated by applying first-order and/or

Monte Carlo simulation techniques to the basic model equations (Walker, 1982). The model will not generate "real-time" predictions (daily, monthly time series), but statistical frequency distributions of flow, loading, and concentration applicable to non-winter conditions, following probabilistic procedures developed under NURP for modeling urban runoff impacts (USEPA, 1982; Athayde et al,1983).

The model will consider the following water quality components:

suspended solids
total nitrogen
total phosphorus
copper
lead
zinc

These variables have been selected based upon the availability of regional data (NURP and other sources) for estimating urban runoff concentrations and BMP effectiveness and upon their probable importance with respect to urban runoff impacts on the Bay. The model will be structured so that the list of water quality components can be easily modified, given the appropriate input data (runoff concentrations, baseflow concentrations, etc.).

Model users are assumed to have basic familiarity with hydrologic and water quality concepts, but limited computer experience. An extensive user interface will be provided (help screens, menus, graphics, etc.). It will run on an IBM-PC or compatible computer without special hardware.

SIMULATION OF BMP's

BMP's considered by the model will consist of buffer strips, grassed swales, infiltration basins, and/or wet detention ponds. The model will provide estimates of treatment efficiency, based upon some combination of the following:

(1) "lookup tables" which relate removal efficiencies to engineering parameters, developed from literature review (e.g., Schueler(1987), Maine DEP (1989))

(2) simplified performance models which predict removal efficiency (or probable range thereof) as a function of engineering parameters and regional climatologic factors (e.g., Driscoll's models for infiltration basins and detention ponds (Driscoll, 1983; USEPA, 1986); swale/buffer strip models, etc.)

(3) detailed simulation of rainfall runoff, washoff, and removal processes (using dynamics borrowed from STORM, SWMM, an other urban runoff models). These models are generally geared to simulating suspended solids.

Solids and associated contaminants can be partitioned into size classes with different settling velocities.

The appropriate estimation technique will vary with BMP and water quality component. Performance will be estimated as a probable range of removal efficiencies, rather than an absolute value. In this way, the model predictions will reflect uncertainty in BMP performance, in addition to other sources of variation and uncertainty. The model will permit application of BMP's in series (e.g., grassed buffer strip followed by detention pond, etc.). Where appropriate, model predictions of removal efficiency for particular BMP's will be developed from and/or tested against SWMM or other detailed simulations. An accompanying report (Walker, 1989) describes use of dimensionless analysis to summarize simulation output.

MODEL APPLICATIONS

The primary functions of the model in a local planning context will be:

(1) to insure that urban BMP's included in a particular site plan are designed properly (i.e., conform to design criteria, which relate BMP dimensions and other engineering features to site characteristics, generally based upon hydrologic aspects); this is probably the most important function, given the lack of specific objectives or quantitative estimates of downstream assimilative capacity; regional design criteria have been developed by RIDEM(1988) for various types of treatment devices;

(2) to characterize the quantity and quality of discharge from the site (surface runoff, baseflow, combined) in probabilistic terms;

(3) to provide a rational, quantitative basis for determining whether or not the proposed discharge is "acceptable" from a water quality perspective, based upon the following types of criteria:

  (a) probability or "risk" that the combined site discharge will violate existing water quality standards/criteria with respect to certain components (e.g., nitrogen, heavy metals);

  (b) maximum increase in average pollutant export from the site, expressed in absolute terms (lbs/acre-yr) or relative terms (% above existing or undeveloped condition); and/or

(c) minimum specified degree of treatment (percent removal) for a target or "keystone" pollutant.

Application of criteria under item (3) to "regulate" developments in the Narragansett Bay watershed would amount to a policy decision. A uniform set of criteria would have to be established by regional authorities in order to permit fair application of the methodology in planning new developments. Examples are the Chesapeake Bay's "-10%" rule and Maine's "+1 ppb" lake protection scheme. Such criteria would be based upon existing state and federal water quality standards, the assimilative capacity of the Bay for specific pollutants, and local priorities.

In a planning context, a proposed development which does not meet the adopted criteria would either be "rejected" or revised to provide "acceptable" water quality. The latter would generally be achieved by reducing the "source" (lower density, less impervious area) and/or by increasing treatment efficiency (design/mix of BMP's).

The Rhode Island Department of Environmental Management (1988) has recommended that BMP's in "sensitive" urban watersheds (water supply reservoirs, coastal ponds) be designed to remove 85% of suspended solids loading. The type of "rule" is particularly suitable for consideration in a model. Desirable features include:

(1) **Existing urban runoff models are geared to simulating suspended solids.**

(2) **A generalized probability distribution for particle settling velocities in urban runoff has been developed from NURP results (Driscoll, 1983).** The applicability of this distribution could be examined with regional data, if available.

(3) **Estimation of suspended solids removal efficiency is independent of the assumed runoff (inflow) concentrations.** Since the sedimentation processes are modeled as first-order reactions, the predicted removal efficiency (%) would be the same for an assumed inflow concentration of 100 mg/liter as for an inflow concentration of 1 mg/liter, for a given distribution of settling velocities. This eliminates effects of errors in estimating the source loading factors.

These factors suggest that a reasonably reliable model for predicting suspended solids removal efficiency could be developed and would be compatible with above RIDEM policy recommendation.

One limitation is that a "rule" based upon suspended solids removal efficiency would not directly consider impacts of dissolved contaminants. Direct simulation of processes influencing dissolved contaminants (adsorption, precipitation, uptake, filtration, decay) is generally infeasible. When treatment devices are sized adequately to remove fine particulate fractions via settling, however, residence time is often sufficient to promote other removal mechanisms. With the exception of inert materials (e.g., road salt), appreciable removal of dissolved species occurs in detention basins which are properly sized (particularly if the organic soils and wetland vegetation are also involved). For example, removal of dissolved phosphorus generally equals or exceeds removal of total phosphorus in wet detention ponds which are adequately sized (Walker, 1987). Harper et al. (1984) report removal efficiencies of 88% for dissolved zinc, 56% for dissolved copper, and 63% for dissolved lead in a retention basin fed by runoff from a Florida highway. Removal efficiencies were 98% for total zinc, 73% for total copper, and 97% for total lead.

Additional analysis is suggested to determine whether a solids-based "rule" would provide adequate water quality protection for the broad spectrum of urban runoff contaminants, given their runoff concentration distributions, observed BMP performance data, and water quality standards/criteria.

BASINWIDE APPLICATIONS

An important concept is that the model would provide a basis for considering each urban development individually with limited input data requirements. This simplifies things for local applications. If the total discharge from each development conforms to water quality standards, then chances are good that the stream/river will also conform to water quality standards. This will not necessarily be true for the Bay, however, especially with respect to nutrients or contaminants with cumulative impacts. For example, stream standards for nitrogen generally do not exist, except for the 10 ppm nitrate nitrogen standard for water supplies. It is possible, if not likely, that severe eutrophication would occur in portions Bay at stream nitrogen concentrations well below 10 ppm. For this reason, appropriate criteria for protection of the Bay may be well below existing state and federal stream standards for nitrogen (and for other components with cumulative or otherwise complicated impacts). In order to define such criteria, Bay assimilative capacity would have to be expressed in terms of an "acceptable" concentration and/or loading to be applied on a stream and individual site basis. The model will provide a rational framework for determining compliance with specified criteria, which must be developed/specified independently.

The model will be applicable in a "lumped-parameter" mode to estimate loading potential for an entire watershed or river basin, based upon the appropriate mix of soil types and land uses. Instream transformations will be ignored. Basinwide applications will not account directly for the specific combinations of BMP's present in the watershed. They will be useful, however, for estimating overall loading potential as function of degree of development (pristine vs. existing vs. full development at various densities and BMP effectiveness). A similar calculation has been performed by Hoffman (1985) for the entire Narragansett Bay watershed. This type of application will provide overall perspectives on the watershed and would presumably be undertaken more often by statewide or regional planners than by local planners involved in reviewing specific developments. Insights gained from basinwide applications, combined with Bay characteristics and sensitivities, will provide a basis for identifying basin water quality constraints and for developing criteria to be applied in planning at the local level.

GIS DATA BASE

GIS data bases will be utilized primarily for basinwide applications. An appropriate spatial scale (resolution) will be selected based upon homogeneity of land uses and soil types in the watershed. This will involve developing a software interface to convert GIS parameters to model input parameters (hydrologic soil groups, cover types, impervious areas). Local applications will probably not involve GIS, since the data required for simulation of individual developments will generally be available from site plans and other local data sources. The development of procedures for estimating impervious areas from GIS parameters is an important task.

CONCLUSION

Possible directions for the modeling effort are discussed above for consideration by the Narragansett Bay Project. A single model or procedure which satisfies all of the initial project objectives does not exist. The selection/development of an appropriate model must consider tradeoffs between complexity and practicality. A comprehensive watershed simulation model would have exhaustive input data requirements and limited application at the local level. Generally, a model consisting of an integration of loading functions and other simplified techniques in a probabilistic framework would seem to have the broadest application potential.

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TABLE B3. HSPF INPUTS

INPUTS TO PERLND

(1) Inputs to correct air temperature for elevation difference.

- Difference in elevation between the temperature gage and the pervious land segment.
- Air temperature over the pervious land segment.

(2) Inputs to simulate accumulation and melting of snow and ice.

- Latitude of the pervious land segment.
- Mean elevation of the pervious land segment.
- Fraction of the pervious land segment which is shaded from solar radiation by, for example, trees.
- Maximum pack (water equivalent) at which the entire pervious land segment will be covered with snow.
- Density of cold, new snow relative to water.
- Air temperature below which precipitation will be snow, under saturated conditions.
- A parameter which adapts the snow evaporation equation to field conditions.
- A parameter which adapts the snow condensation/convection melt equation to field conditions.
- Maximum water content of the snow pack, in depth water per depth water equivalent.
- Maximum rate of snowmelt by ground heat, in depth of water equivalent per day.
- Quantities of snow, ice and liquid water in the pack (water equivalent).
- Density of the frozen contents (snow + ice) of pack, relative to water.
- Mean temperature of the frozen contents of the pack.
- Current pack (water equivalent) required to obtain complete areal coverage of the pervious land segment.
- Current remaining possible increment to ice storage in the pack.
- Fraction of sky which is assumed to be clear at the present time.

(3) Inputs to simulate water budget for pervious land segment.

- Fraction of the pervious land segment which is covered by forest which will continue to transpire in winter.
- Lower zone nominal storage
- Length and slope of the assumed overland flow plane
- Basic groundwater recession rate.
- Air temperature below which evapotranspiration will arbitrarily be reduced below the value obtained from the input time series.

- Temperature below which evapotranspiration will be zero regardless of the value in the input time series.
- Exponent in the infiltration equation.
- Ratio between the max and mean infiltration capacities over the pervious land segment.
- Fraction of groundwater inflow which will enter deep (inactive) groundwater and, thus, be lost from the system.
- Fraction of remaining potential evapotranspiration which can be satisfied from baseflow (groundwater outflow), if enough is available.
- Fraction of remaining potential evapotranspiration which can be satisfied from active groundwater storage if enough is available.
- Interception storage capacity.
- Upper zone nominal storage.
- Manning's n for the assumed overland flow plane.
- Interflow inflow and recession parameters.
- Lower zone evapotranspiration parameter.
- Monthly interception storage capacity.
- Monthly upper zone storage.
- Monthly Manning's n values.
- Monthly interflow parameters.
- Monthly interflow recession constants.
- Monthly lower zone evapotranspiratino parameter.
- Interception storage.
- Surface (overland flow) storage.
- Storages of upper, lower and interflow zones.
- Active groundwater storage.
- Surface storage (upper zone and interflow).

(4) Inputs to produce and remove sediment.

- Supporting management practice factor. It is used to simulate the reduction in erosion achieved by use of erosion control practices.
- Coefficient in the soil detachment equation.
- Exponent in the soil detachment equation.
- Fraction by which detached sediment storage decreases eaach day, as a result of soil compaction.
- Fraction of land surface which is shielded from erosion by rainfall.
- Rate at which sediment enters detached storage from the atmosphere.
- Coefficient and exponent in the detached sediment washoff equation.
- Coefficient and exponent in the matrix soil scour equation.
- Monthly erosion related cover values.
- Monthly net vertical sediment input.
- Initial storage of detached sediment.

(5) Inputs to estimate soil temperature.

- Surface layer temperature, when the air temperature is 32 degrees F (ASLT).
- Slope of the surface layer temperature regression equation (BSLT).
- Smoothing factor in upper layer temperature calculation (ULTP1).
- Mean difference between upper layer soil temperature and air temperature (ULTP2).
- Smoothing factor for calculating lower layer/groundwater soil temperature (UGTP1).
- Mean departure from air temperature for calculating lower layer/groundwater soil temperature (UGTP2).
- Intercept in the upper layer soil temperature regression equation.
- Slope in the upper layer soil temperature regression equation.
- Monthly values for ASLT, BSLT, ULTP1, ULTP2, LCTP1, and LCTP2.
- Initial air temperature.
- Initial surface layer soil temperature.
- Initial upper layer soil temperature.
- Initial layer/groundwater layer soil temperature.

(6) Inputs to estimate water temperature and dissolved gas concentrations.

- Elevation of the pervious land segment above seal level.
- Concentration of dissolved oxygen nd CO2 in interflow outflow, and in active groundwater flow.
- Monthly interflow DO and CO2 concentrations.
- Monthly groundwater DO and CO2 concentrations.
- Initial surface and interflow outflow temperature.
- Initial active groundwater outflow temperature.
- Initial DO and CO2 concentrations in surface outflow, interflow outflow, and active groundwater outflow.

(7) Inputs to simulate quality constituents using simple relationships with sediment and water yield.

- Washoff potency factor.
- Scour potency factor.
  Note: A potency factor is the ratio of constituent yield to sediment (washoff or scour) outflow.
- Initial storage of constituent on the surface of the pervious land segment.
- Rate of accumulation of constituent.
- Maximum storage of constituent.
- Rate of surface runoff which will remove 90 percent of stored constituent per hour.
- Concentration of the constituent in interflow outflow.
- Concentration of the constituent in active groundwater outflow.
- Monthly washoff and scour potency factors.
- Monthly accumulation rates of constituent.
- Monthly limiting storage of constituent.

- Monthy concentrations of constituent in interflow and groundwater.

(8) Inputs to estimate the moisture and fractions of solutes being transported in the soil layers.

- Nominal upper and lower zones storage.
- Initial surface detention storage.
- Initial surface detention storage on each block of the pervious land segment.
- Initial moisture content in the surface storage, in the upper principal storage, and in the upper transitory (interflow) storage.
- Initial moisture storages in the lower layer, and in the active groundwater layer.

(9) Inputs to simulate pesticide behavior in detail.

- Chemical first-order reaction temperature correction parameters which is used to adjust the desorption and adsorption rates.
- Desorption and adsorption rates (first-order) at 35°C.
- Maximum solubility of the pesticide in water.
- Maximum concentration (on the soil) of pesticide which is permanently fixed to the soil.
- Coefficient and exponent parameters for the Freundlich adsorption-desorption equation.
- Pesticides degradation rates in the surface, upper, and active groundwater layers.
- Initial storage of pesticide in crystalline adsorbed and solution forms in surface, upper, lower or groundwater layer.
- Initial storage of pesticide in the upper layer transitory (interflow) storage.

(10) Inputs to simulate nitrogen behavior in detail.

- Plant nitrogen uptake reaction rate parameters for the surface layer, upper layer, lower layer, and active groundwater layer.
- Monthly plant uptake parameters for nitrogen, for the surface, upper, lower or groundwater layer.
- Parameters intended to designate which fraction of nitrogen uptake comes from nitrite and ammonium.
- Temperature coefficients for plant uptake, ammonium desorption, ammonium adsorption, nitrate immobilization, organic N ammonification; NO3 denitrification, Nitrification, and ammonium immobilization.
- Maximum solubility of ammonium in water.
- Initial storage of N in organic N, adsorbed ammonium, nitrate, and plants.
- Initial storages of ammonium and nitrate in the upper layer transitory (interflow) storage.

(11) Inputs to simulate phosphorus behavior in detail.

- Plant phosphorus uptake reaction rate parameters for the surface layer, upper layer, lower layer, and active groundwater layer.
- Monthly plant uptake parameters for phosphorus, for the surface, upper, lower or groundwater layer.
- Temperature correction parameters for phosphorus plant uptake, phosphate desorption, phosphate immobilization, and organic P mineralization.
- First-order reaction rates for phosphate desorption, phosphate adsorption, phosphate immobilization, and organic P mineralization.
- Maximum solubility of phosphorus in water.
- Initial phosphorus storage (in organic P, adsorbed P, solution P, and P stored in plants) in the surface, upper, lower or groundwater layer.
- Initial storage of phosphate in upper layer transitory (interflow) storage.

(12) Inputs to simulate the movement of a tracer (conservative).

- Initial storage of tracer (conservative) in the surface storage, upper principal storage, upper transitory storage, lower groundwater layer, and active groundwater layers.

INPUTS TO IMPLND

(1) Inputs to correct air temperature for elevation difference.

- See temperature inputs in the PERLAND section.

(2) Inputs to simulate the accumulation and melting of snow and ice.

- See snow inputs in the PERLND section.

(3) Inputs to simulate water budget for impervious land segment.

- Length and slope of the assumed overland flow plane.
- Manning's n for the overland flow plane.
- Retention (interception) storage capacity of the surface.
- Air temperature below which evapotranspiration will arbitrarily be reduced below the value obtained from the input time series.
- Temperature below which evapotranspiration will be zero regardless of the value in the input time series.
- Monthly retention storage capacity.
- Monthly Manning's n values.
- Initial retention storage.
- Initial surface (overland flow) storage.

(4) Inputs to estimate accumulation and removal of solids.

- Coefficient in the solids washoff equation.

- Exponent in the solids washoff equation.
- Rate at which solids are placed on the land surface.
- Fraction of solids storaage which is removed each day; when there is no runoff, for example, because of street sweeping.
- Monthly solids accumulation rates.
- Monthly solids unit removal rates.
- Initial storage of solids.

(5) Inputs to estimate water temperature and dissolved gas concentrations.

- Elevation of the impervious land segment above sea level.
- Surface water temperature, when the air temperature is 32°F (AWTF).
- Slope of the surface water temperature regression equation (BWTF).
- Monthly values for AWTF and BWTF.
- Initial values for the temperature, DO and CO2.

(6) Inputs to simulate quality constituents using simple relationships with solids and/or water yield.

- Washoff potency factor.
- Initial storage of constituent on the surface of the impervious land segment.
- Rate of accumulation of constituent.
- Maximum storage of constituent.
- Rate of surface runoff which will remove 90 percent of stored constituent per hour.

INPUT TO RCHRES

(1) Inputs to simulate hydraulic behavior.

- Length of the receiving water body (RCHRES).
- Drop in water elevation from the upstream to the downstream extremities of the RCHRES.
- Correction to the RCHRES depth to calculate stage.
- Weighting factor for hydraulic routing.
- Median diameter of the bed sediment (assumed constant throughout the run).
- Initial volume of water in the RCHRES.

(2) Inputs to prepare to simulate advection of entrained constituents.

- Ration of maximum velocity to mean velocity in the RCHRES cross section under typical flow conditions.
- Volume of water in the RCHRES at the start of the simulation.

(3) Inputs to simulate behavior of conservative constituents.

- Initial concentration of the conservative.

(4) Inputs to simulate heat exchange and water temperature.

- Mean RCHRES elevation.
- Difference in elevation between the RCHRES and the air temperature gage.
- Correction factor for solar radiation.
- Longwave radiation coefficient.
- Conduction-convection heat transport coefficient.
- Evaporation coefficient.
- Water temperature at the RCHRES.
- Air temperature at the RCHRES.

(5) Inputs to simulate behavior of inorganic sediment.

- Width of the cross-section over which HSPF will assume bed sediment is deposited regardless of stage, top-width, etc.
- Bed depth.
- Porosity of the bed (volume voids/total volume).
- Effective diameter of the transported sand, silt and clay particles.
- Fall velocity of the sand, silt and clay particles in still water.
- Density of the sand, silt and clay particles.
- Critical bed shear stresses for deposition and scour.
- Erodibility coefficient of the sediment.
- Initial concentrations (in suspension) of sand, silt, and clay.
- Initial total depth (thickness) of the bed.
- Initial fractions (by weight) of sand, silt and clay in the bed material.

(6) Inputs to simulate behavior of a generalized quality constituent.

- Latitude of the RCHRES.
- Initial concentration of constituent.
- Second order acid and base rate constants for hydrolysis.
- First order rate constant of neutral reaction with water.
- Temperature correction coefficient for hydrolysis.
- Second order rate constant for oxidation by free radical oxygen.
- Temperature correction coefficient for oxidation by free radical oxygen.
- Molar absorption coefficients for constituent for 18 wavelength ranges of light.
- Quantum yield for the constituent in air-saturated pure water.
- Temperature correction coefficient for photolysis.
- Ratio of volatilization rate to oxygen reaeration rate.
- Second order rate constant for biomass concentration causing biodegradatino of constituent.
- Temperature correction coefficient for biodegradation of constituent.
- Concentration of biomass causing biodegradation of constituent.
- Monthly concentration of biomass causing biodegradation of constituent.

- First order decay rate for constituent.
- Temperature correction coefficient for first order decay of constituent.
- Decay rate for constituent adsorbed to suspended sediment.
- Temperature correction coefficient for decay of constituent on suspended sediment.
- Decay rate for constituent adsorbed to bed sediment.
- Temperature correction coefficient for decay of constituent on bed sediment.
- Partition coefficient - distribution coefficients for constituent with: suspended sand, suspended silt, suspended clay, bed sand, bed silt, bed clay.
- Transfer rate between adsorbed and desorbed states for constituent with: suspended sand, suspended silt, suspended clay, bed sand, bed silt, bed clay.
- Temperature correction coefficients for adsorbtion-desorbtion on: suspended sand, suspended silt, suspended clay, bed sand, bed silt, bed clay.
- Initial concentration of constituent on: suspended sand, suspended silt, suspended clay, bed sand, bed silt, bed clay.
- Initial values for water temperature, pH, free radical oxygen concnetration, cloud cover, and total suspended sediment concentration.
- Phytoplankton concentration (as biomass).
- Monthly values of water temperature, pH, and free radical oxygen.
- Base adsorption coefficients for 18 wavelengths of light passing through clear water.
- Increments to base absorbance coefficient for light passing through sediment-laden water.
- Increments to the base absorption coefficient for light passing through plankton-laden water.
- Light extenction efficiency of cloud cover for each of 18 wavelengths.
- Monthly values of average cloud cover.
- Monthly average suspended sediment concentration values.
- Monthly values of phytoplankton concentration.

(7) Inputs to simulate behavior of constituents involved in biochemical transformations.

- Velocity above which effects of scouring on benthal release rates is considered.

(a) Inputs to simulate primary DO, BOD balances.

- Unit BOD decay at 20 °C.
- Temperature correction coefficient for BOD decay.
- Rate of BOD settling.
- Allowable dissolved oxygen supersaturation.
- RCHRES elevation above sea level.
- Benthal oxygen demand at 20°C.

- Temperature correction coefficient for benthal oxygen demand.
- Benthal release of BOD at high oxygen concentration.
- Increment to benthal release of BOD under anaerobic conditions.
- A correction factor in the lake reaeration equation to account for good or poor circulation characteristics.
- Empirical constant in Tsivoglou's equation for reaeration.
- Temperature coefficient for surface gas invasion.
- Length of the RCHRES.
- Energy drop over its length.
- Temperature correction coefficient for surface gas invasion.
- Empirical constnat for equation used to calculate reaeration coefficient.
- Exponent to depth used in calculation of reaeration coefficient.
- Exponent to velocity used in calculation of reaeration coefficient.
- Dissolved oxygen.
- Biochemical oxygen demand.
- Dissolved oxygen saturation concentration.

(b) Inputs to determine primary inorganic nitrogen and phosphorous balances.

- Benthal release of inorganic nitrogen, and orthophosphate.
- Concentration of dissolved oxygen below which anerobic conditions exist.
- Unit oxidation rate of ammonia and nitrite at 20°C.
- Initial concentration of nitrate (as N), ammonia (as N), and nitrite (as N).
- Concentration of ortho-phosphorus (as phosphorus).
- Concentration of denitrifying bacteria.

(c) Inputs to simulate behavior of plankton populations and associated reactions.

- Ratio of chlorophyll "A" content of biomass to phosphorus content.
- Nonrefractory fraction of algae and zooplankton biomass.
- Fraction of nitrogen requirements for phytoplankton growth satisfied by nitrate.
- Base extinction coefficient for light.
- Maximal unit algal growth rate.
- Michaelis-Menten constant for light limited growth.
- Nitrate Michaelis-Menten constant for nigrogen limited growth.
- Nitrate Michaelis-Menten constant for phosphorus limited growth.
- Phosphate Michaelis-Menten constant for phosphorus limited growth.

- Temperatures above and below which algal growth ceases.
- Temperature below which algal growth is retarded.
- Algal unit respiration rate at 20°C.
- High algal unit death rate.
- Low algal unit death rate.
- Inorganic nitrogen concentration below which high algal death rate occurs (as phosphorus).
- Minimum concentration of plankton not subject to advection (SEED).
- Concentration of plankton not subject to advection at very low flow (MISTAY).
- Outflow at which concentration of plankton not subject to advection is midway between SEED and MXSTAY.
- Chlorophyll "A" concentration above which high algal death rate occurs.
- Rate of phytoplankton settling.
- Rate of settling for dead refractory organics.
- Maximum zooplankton filtering rate at 20°C.
- Zooplankton filtering rate at 20°C (MZOEAT).
- Natural zooplankton unit death rate.
- Increment to unit zooplankton death rate due to anaerobic conditions.
- Temperature correction coefficient for filtering.
- Temperature correction coefficient for respiration.
- The fraction of nonrefractory zooplankton excretion which is immediately decomposed when ingestion rate is greater than MZOEAT.
- Average weight of a zooplankton organism.
- Maximum benthic algae density (as biomass).
- Ratio of benthic algal to phytoplankton respiration rate.
- Ratio of benthic algal to phytoplankton growth rate.
- Initial conditions for phystoplankton (as iomass), zooplankton algae (as biomass), benthic algae (as biomass), dead refractory organic nitrogen, dead refractory organic phosphorus, and dead refractory organic carbon.

(d) Inputs to simulate pH and carbon species.

- Ratio of carbon dioxide invasion rate to oxygen reaeration rate.
- Benthal release of CO2 (as C) for aerobic and anaerobic conditions.
- Initial total inorganic carbon for pH simulation.
- Initial carbon dioxide (as C) for pH simulation.
- Initial pH.

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DRAFT

DIMENSIONLESS ANALYSIS OF RUNOFF TREATMENT DEVICES

prepared for

Narragansett Bay Project
and
IEP, Inc.

by

William W. Walker, Jr.

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INTRODUCTION

The performance of a runoff treatment device generally depends upon its treatment capacity and storage volume relative to the rate and volume of runoff from the watershed over the range of storms encountered. Designs can be described in terms of two dimensionless variables (Driscoll, 1983; Yousef et al., 1986; USEPA, 1986; Walker, 1987):

Dimensionless Treatment Rate = maximum rate of treatment (settling, infiltration) relative to rate of runoff

Dimensionless Storage Volume = maximum storage volume relative to volume of runoff

Overall treatment efficiency increases with each of these two values. Higher volumes increase treatment efficiency by storing runoff and thereby permitting treatment to occur over prolonged periods between storm events. Treatment rate and storage volume can be scaled against the runoff rate and runoff volume for an average storm to develop dimensionless forms.

Once "calibrated", these variables provide a predictive basis for overall treatment efficiency. A simulation model (e.g., SWMM) can be used to estimate overall treatment efficiency for a range of dimensionless treatment rates and storage volumes, using regional rainfall time series. Model predictions can be summarized in terms of the dimensionless variables. This provides a simple way of estimating overall treatment efficiencies without resorting to detailed simulation in each application.

INFILTRATION BASINS

Dimensionless analysis is demonstrated in Figure 1 for an infiltration basin. These results are based upon simulation of rainfall time series from Worcester in 1968 (average year). Overall treatment efficiency refers to the percent of the total runoff volume which is filtered through the bottom of the basin. The "treatment rate" is the product of the infiltration rate (in/hr) and the surface area of the basin (acres). This is scaled against the rate of runoff from a storm with average intensity (.06 in/hr). As simulated by the model, the volume of water stored in the basin fluctuates in response to storm inflows and infiltration losses. The "dimensionless storage volume" refers to the maximum storage capacity of the basin, scaled against the volume of runoff from a mean storm (.4 inches).

Typical design criteria for infiltration basins are as follows (Schuler, 1987; Shaver, 1986):

Storage Volume = volume of runoff from 1-inch storm
Maximum Draining Time = 72 hours

Transformation of these criteria provides a basis for estimating filtration efficiency using Figure 1. The storage volume criterion corresponds to a dimensionless storage volume (V_b/V_r) of 1/.4 = 2.5. For a basin with a storage depth of 4 feet, the draining time criterion corresponds to an infiltration rate of 4 x 12 / 72 = .5 in/hr and (through further algebra) to a dimensionless treatment rate of 2.1. Figure 1 shows these dimensionless values correspond to a filtration efficiency which exceeds 90%.

Design relationships for infiltration basins developed under the NURP program (Driscoll,1986; USEPA,1986) relate performance to the following variables, as illustrated in Figure 2:

Percolating Area, As % of Catchment Area
Infiltration Rate
Average Depth

Results shown in Figure 2 are specific for watersheds with a runoff coefficient of .2 and for Great Lakes precipitation. The dimensionless form (Figure 1) is more concise, but still specific for the simulated rainfall time series. Additional analysis indicates that the design curves in Figure 2 can be successfully reproduced from dimensionless plots similar to Figure 1, with substitution of appropriate rainfall statistics.

Within certain limitations, a "buffer strip" might be represented as a type of infiltration basin, with a defined infiltration rate, infiltration area, and maximum storage volume. Such a model would assume sheet flow over the buffer area and shallow slopes. More complex models of buffer strip performance which consider effects of slope and roughness might be developed using techniques previously developed for grassed swales (Wanielista and Yousef, 1986).

WET DETENTION PONDS

Dimensionless analysis is demonstrated in Figure 3 for a wet detention pond, also based upon Worcester rainfall data. Overall treatment efficiency refers to the percent of the total runoff load which is removed by settling in the detention pond. The "treatment rate" is the product of the settling velocity (in/hr) and the surface area of the pond (acres). This is scaled against the rate of runoff from a storm with average intensity. As simulated by the model, pond volume is constant and concentrations vary in response to storm loads (driven by accumulation/washoff dynamics) and sedimentation. The "dimensionless storage volume" refers to the permanent pool volume, scaled against the volume of runoff from a mean storm (.4 inches).

Typical design criteria for wet detention ponds are as follows (USEPA, 1986):

Area = 1% of Watershed Area (for runoff coefficient = .2)
Mean Depth = 3.5 feet

Transformation of these criteria provides a basis for estimating removal efficiency using Figure 3. Calculations are performed for a particle settling velocity of 1.5 ft/hr (18 in/hr), which is a median value for urban runoff (Driscoll, 1983; USEPA, 1986). With some algebra, it can be shown that these criteria correspond to a dimensionless treatment rate of 15 and a dimensionless storage volume of 5.3, which, in turn, yield a removal efficiency exceeding 90%.

Design relationships for wet detention ponds developed under the NURP program (Driscoll,1986; USEPA,1986) relate performance to basin surface area, as a percent of contributing catchment area. Results shown in Figure 4 are specific for ponds with a mean depth of 3.5 feet, watersheds with a runoff coefficient of .2, and regional precipitation. Additional analysis indicates that the Northeast curve in Figure 4 can be generated from the more general dimensionless relationships in Figure 3 using the median settling velocity of 1.5 ft/hr.

CONCLUSIONS

A technique has been described for summarizing size/performance relationships for runoff treatment devices using dimensionless variables. The technique provides a simple way of condensing results derived from detailed simulation models. Future work will involve application of curve-fitting p1744Xtechniques to permit expression of performance plots in algebraic terms. This, in turn, will facilitate use in simple models and screening procedures for predicting BMP performance. The techniques will be calibrated and tested against results of detailed simulation models, such as SWMM, using regional rainfall time series.

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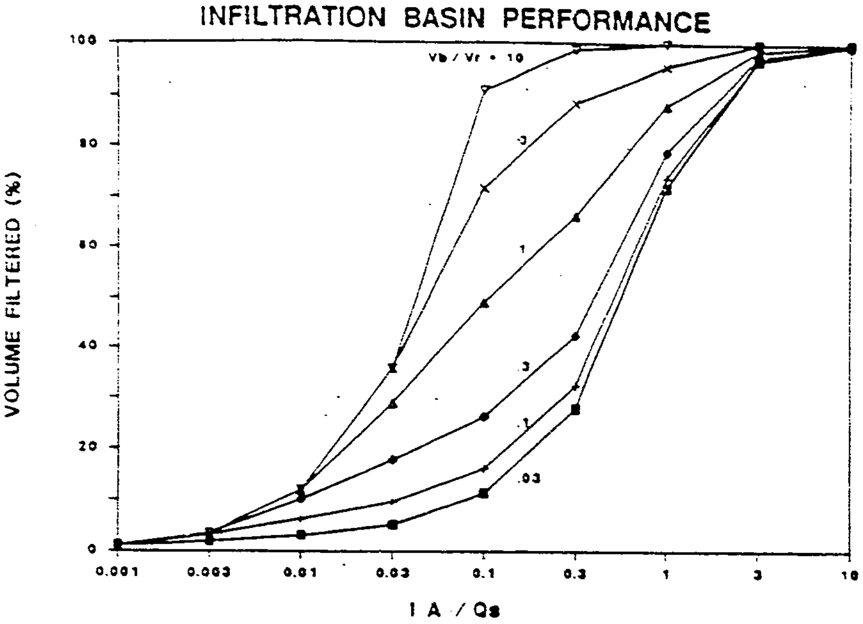
Yousef, Y.A., M.P. Wanielista, and H.H. Harper, "Design and Effectiveness of Urban Retention Basins", in B. Urbonas and L.A. Roesner, Urban Runoff Quality - Impact and Quality Enhancement Technology, American Society of Civil Engineers, pp. 338-350, 1986.

Figure 1
Dimensionless Analysis of Infiltration Basin



Y-Axis = Percent of Runoff Volume Filtered, Based upon Simulation of Worcester Rainfall in 1968, 109 storms, average year

X-Axis = Dimensionless Treatment Rate = $I\ A\ /\ Q_s$

Lines = Dimensionless Storage Volume = $V_b\ /V_r$

VARIABLES:

A_w = watershed area (acres)
f_i = impervious fraction
V_b = basin storage volume (acre-ft)
V_r = volume of runoff from mean storm (acre-ft)
A = infiltration basin area (acres)
I = infiltration rate (in/hr)
Q_s = mean storm runoff rate (acre-in/hr)
P_s = mean storm size (inches) = .4 in
I_s = mean storm intensity (in/hr) = .06 in/hr

CALCULATION OF FILTRATION EFFICIENCY:

Specify Site/Design Variables: A_w, f_i, V_b, A, I

Mean Storm Volume = $V_r = A_w\ f_i\ P_s\ /\ 12 = .033\ A_w\ f_i$

Dimensionless Storage Volume = V_b/V_r = Lines in Graph

Mean Storm Runoff Rate = $Q_s = A_w\ f_i\ I_s = .06\ A_w\ f_i$

Dimensionless Treatment Rate = $A\ I\ /\ Q_s$ = X-Axis

Read Filtration Efficiency from Graph

Figure 2
Infiltration Basin Size/Performance Relationships Developed under NURP Program (Driscoll, 1986; USEPA, 1986)

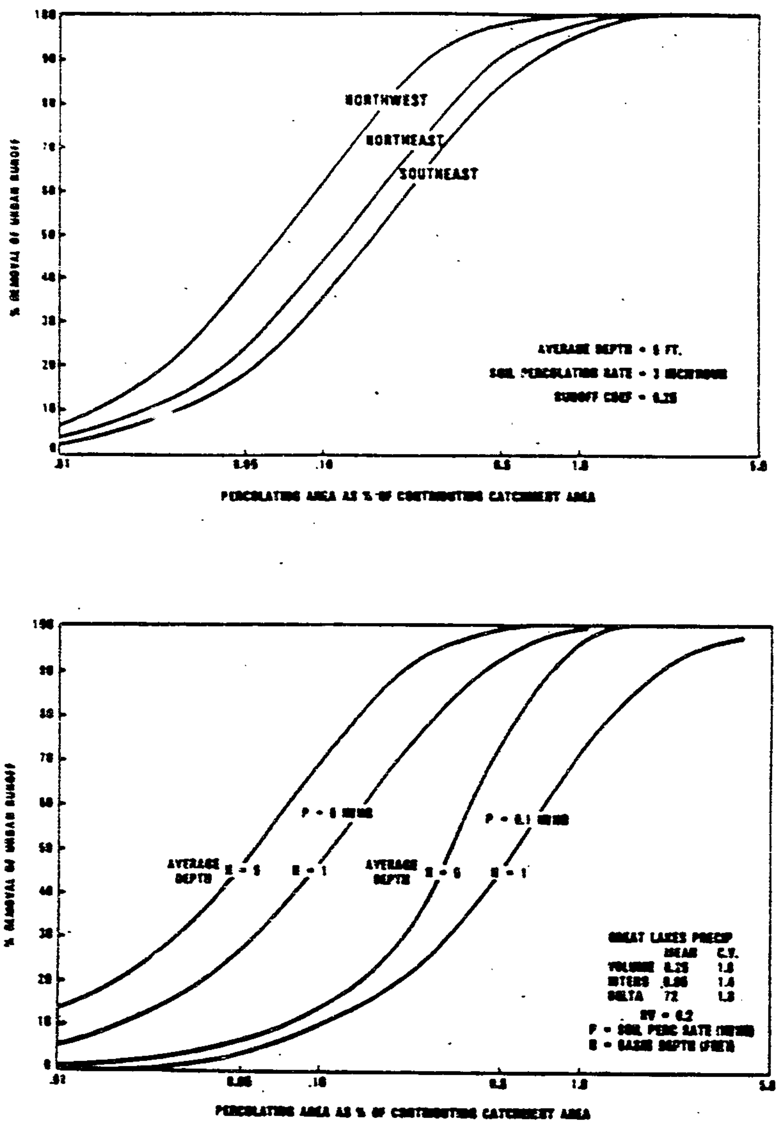
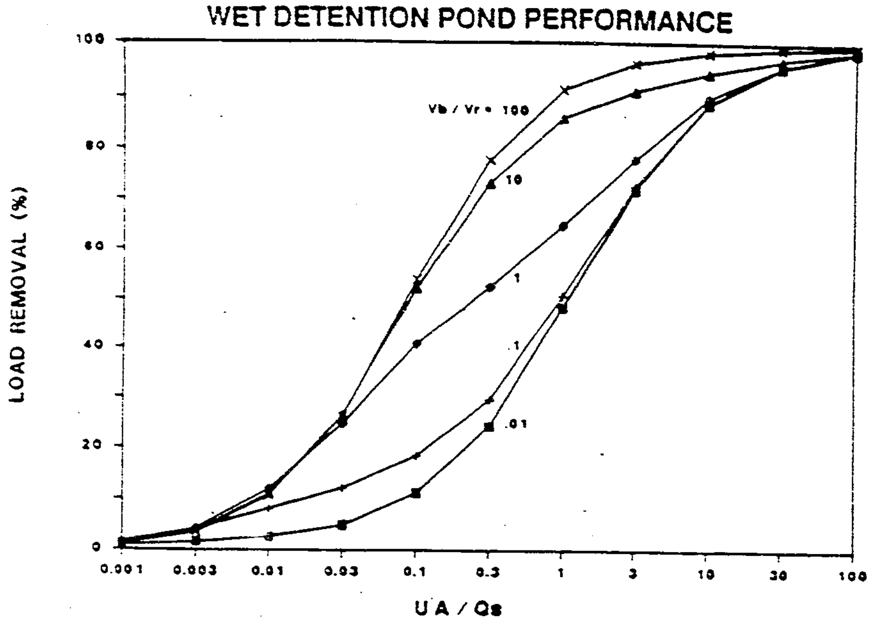


Figure 3
Dimensionless Analysis of Wet Detention Pond



Y-Axis = Percent of Load Removed (Settled), Based upon Simulation of Worcester Rainfall in 1968, 109 storms, average year
X-Axis = Dimensionless Treatment Rate = $U A / Q_s$
Lines = Dimensionless Storage Volume = V_b / V_r

VARIABLES:

A_w = watershed area (acres)
f_i = impervious fraction
V_b = basin permanent pool volume (acre-ft)
V_r = volume of runoff from mean storm (acre-ft)
A = basin permanent pool surface area (acres)
U = particle settling velocity (in/hr)
Q_s = mean storm runoff rate (acre-in/hr)
P_s = mean storm size (inches) = .4 in
I_s = mean storm intensity (in/hr) = .06 in/hr

CALCULATION OF REMOVAL EFFICIENCY:

Specify Site/Design Variables: A_w, f_i, V_b, A, U

Mean Storm Volume = $V_r = A_w \; f_i \; P_s / 12 = .033 \; A_w \; f_i$

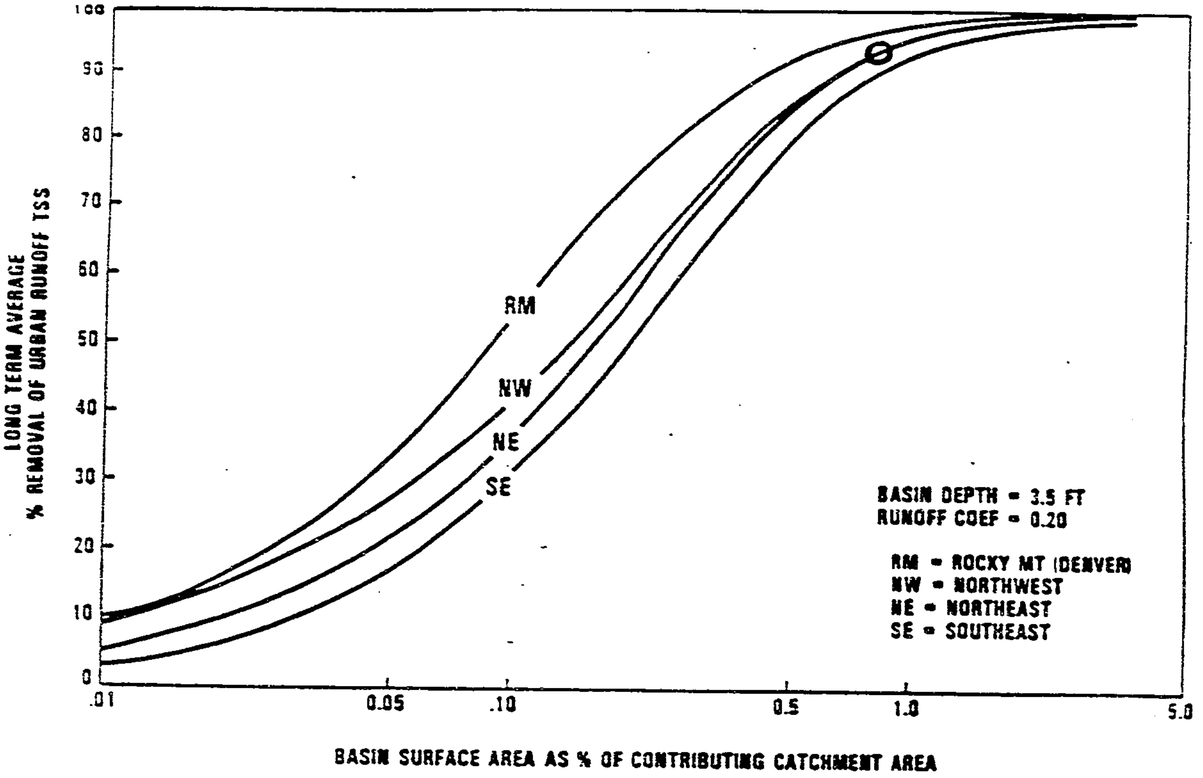
Dimensionless Storage Volume = V_b/V_r = Lines in Graph

Mean Storm Runoff Rate = $Q_s = A_w \; f_i \; I_s = .06 \; A_w \; f_i$

Dimensionless Treatment Rate = $U A / Q_s$ = X-Axis

Read Removal Efficiency from Graph

Figure 4
Detention Pond Size/Performance Relationships Developed under NURP Program (Driscoll, 1986; USEPA, 1986)



ATTACHMENT 2

Preliminary Model Evaluation Matrix

PRELIMINARY MODEL EVALUATION

Approximately ten models were evaluated based on application objectives, input/output parameters, computing requirements, and assumptions. The type of models evaluated ranged from those developed for site specific agricultural and storm water runoff quality/quantity predicition, to those used for aquatic toxicity and complex in-stream quality modeling. The findings of this preliminary evaluation are summarized in the following matrix. Based upon this preliminary evaluation, it is likely that AGNPS, ANSWERS, CREAMS, EXAMS, and QUAL II would not be applicable for the current project. A more intensive evaluation of Detailed Simulation Models, such as SWMM4 and HSPF is provided in Attachment 1.

PRELIMINARY MODEL EVALUATION

Model	Type	Inputs	Outputs	Requirements/Basis for Model
Detailed Simulation Models				
HSPF	· an integrated, modular model which considers production and behavior of conventional and organic pollutants from a variety of land uses.	· time series meteorologic and hydrologic data, land use, best management practices, watershed data.	· continuous hydrologic simulation, behavior of pollutants in runoff and receiving waters, evaluation of BMP effectiveness, exposure of aquatic organisms to toxics.	· a complex model requiring substantial training and computer resources. · incorporates other models (ARM, NPS). · set up in modules for pervious land uses, impervious land uses, and receiving water.
SWMM 4	· a simulation model of quantity and quality of runoff in urban areas. · continuous or single event simulations. · covers dynamic storms, snowmelt, pollutant build-up, washoff and transport. · distributed parameter type.	· hydrologic, meteorologic and water quality variables. · Extensive input data requirements	· hydrographs for urban and rural watersheds. · hydrographs through streams and reservoirs. · Others?	· can be used effectively for small problems and with limited data, as well as for larger scale applications. · runs interactively on PC or mainframe. · applicable for drainage areas 5 - 2000 hectares · Use for simulating NPS processes and problems limited.
ILLUDAS	· Detailed hydrologic simulation program for urban watersheds · Water quality routines developed by Illinois State Water Survey under NURP, but not available for general use (Q-ILLUDAS) · DRAINQUAL (another version has water quality routines derived from the Corp's STORM program	· moderate data requirements · watershed land-uses, soil types, topography, channel hydaulic parameters	· detailed hydrograghs · continuous or event	· runoff simulations for impervious areas, non-connected impervious areas, and pervious grass areas · pollutant buildup and washoff from impervious areas (DRAINQUAL version)

PRELIMINARY MODEL EVALUATION

Model	Type	Inputs	Outputs	Requirements/Basis for Model
Loading Function/Simplified Models				
GWLF	• loading model for nonpoint pollution from rural and urban land uses. • model only validated in rural/agricultural watershed. • urban runoff component based on STORM model.	• daily precipitation and temperature data, runoff source areas, and transport and chemical parameters	• estimates monthly nitrogen and phopshorus fluxes in stream flow. • prediction of stream flow.	• based on simple runoff, sediment, and ground water relationships combined with emprical chemical parameters. • estimateds monthly nutrient flux without calibration. • because nutrient chemistry not modeled explicitly, the model cannot be used to estimate effects of fertilizer management or urban storm water storage and treatment.
NURP	• statistical summary of urban runoff quality related to land use and region of the US; evaluation of BMP effectiveness based upon size relationships.	• land use type, geographic area, BMP design, precipitation, and stream flow statistics, watershed impervious and pervious areas.	• statistical characterization of urban runoff pollutant concentrations and laodings. • violation frequencies, and return intervals for aquatic toxicity criteria	• based upon NURP monitoring datam lognormal distribution, and mass-balance relationships. • BMP effectiveness derived from sample models applied to observed performance.
SIMPLE METHOD (Scheuler, 1987)	• simulates runoff volume & pollutant loading from urban watersheds.	• rainfall, watershed size, % impervious, area, pollutant concentration, BMP removal efficiency.	• runoff volume. • loading estimate for typical urban pollutants.	• can be used for annual, monthly, etc. simulations • consists of a set of equations; not a computer • based on NURP reported pollutant concentration.
SWMM Simplified	• simulates runoff and nutrient transport in urban watersheds.	• hourly precipitation, treatment rate, storage volume, receiving water characteristics.	• time-variable outflow and runoff quantity and quality. quality.	• limited documentation. • does not consider sedimentation. • can be limited to a receiving water model. • options for continuous or event based simulations.

PRELIMINARY MODEL EVALUATION

Model	Type	Inputs	Outputs	Requirements/Basis for Model
Simulation Models (Agricultural)				
AGNPS	· single event simulation of runoff quantity and quality from agricultural watersheds; BMP evaluation.	· rainfall, watershed, and BMP design data.	· runoff volume and peak rate, sediment, nutrients, COD concentrations.	· watershed size range 2.5-23,000 acres, subdivided into 1 acre cells. developed and tested in Minnesota only. · limited testing of pollutants runoff functions.
ANSWERS	· single event simulation of hydrology and sediment generation from agricultural watershed; BMP evaluation.	· rainfall, watershed and BMP design data.	· interception infiltration, surface storage, surface and subsurface flow, sediment detachment and transport.	· extensively validated for midwest. · has been used primarily for analysis of single sites. · modular program is easily modified. · considers sediment and erosion control only, no other water quality considerations.
CREAMS	· continuous simulation of hydrology and water quality in agricultural watershed.	· requires extensive meteorological, hydrologicial data, erosion of soil, and pollutant chemistry.	· surface runoff, evapotranspiration, sediment yield, nutrient and pesticide runoff, BMP evaluation.	· based on soil processes. · surface runoff only; no subsurface functions. · operates on a scale of one field (small).

PRELIMINARY MODEL EVALUATION

Model	Type	Inputs	Outputs	Requirements/Basis for Model
Other Simulation Models				
EXAMS	• steady state simulation of exposure, fate and persistence of organic chemicals in aquatic systems.	• environmental data and chemical type.	• compartmentalization of subject chemical in sediment, biota, dissolved and adsorbed forms under mixed conditions. Loadings and exports are represented as mass fluxes across compartments.	• based on conservation of mass. • developed for screening the effects on new chemicals; limited use for site specific analysis.
QUAL II	• steady state or dynamic in-stream water quality model for use on point and nonpoint waste load impact evaluation.	• extensive water quality and hydraulic data for stream or stream segments under investigation.	• provides graphic (DO & BOD only) and tabular output as concentration at given distances downstream (Temperature, DO, BOD, Organic-N, Ammonia, nitrate, nitrite, total-N, Organic-P dissolved-P, coliform, one non-conservative, and three conservative elements), as well as hydraulic info.	• applicable to dendritic streams which are well mixed. • requires extensive knowledge of stream chemical/physical and hydraulic characteristics. • Doesn't utilize land based information. • Not applicable for present project.

ATTACHMENT 3

Hunt-Potowomut Watershed
Existing Water Quality Data Inventory

MONITORING DATA INVENTORY

The extent of available water quality data for the Hunt-Potowomut River and its tributraries is limited. In most cases, sampling is confined to 1-2 stations on the Hunt River or Fry Brook, and is sporadic with respect to frequency, duration, and parameters measured. The most continuous baseline data were collected for the Quonset Point DEIR in 1984-85. However, this did not include storm sampling. The following is an inventory of available data in the Hunt-Potowomut watershed:

Location	Duration	Frequency	Parameters	Comments
Hunt River @ South Rd.	June-Nov. in 1984	bimonthly only 1 in Nov.	nutrients, metals, TSS, Cl	DEIR Quonset Point
Hunt River @ Davisville	June-Nov. in 1984	bimonthly only 1 in Nov.	nutrients, metals, TSS, Cl	DEIR Quonset Point
Hunt River @ Frenchtown Rd.	June-Nov. in 1984	bimonthly only 1 in Nov.	nutrients, metals, TSS, Cl, flow	DEIR Quonset Point
Hunt River @ Post Rd.	June-Nov. in 1984	bimonthly only 1 in Nov.	nutrients, metals, TSS, Cl	DEIR Quonset Point
Hunt River @ South Rd.	Jan-June in 1985	bimonthly	nutrients, metals, TSS, Cl	DEIR Quonset Point
Hunt River @ Davisville	Jan-June in 1985	bimonthly	nutrients, metals, TSS, Cl	DEIR Quonset Point
Hunt River @ Frenchtown	Jan-June in 1985	bimonthly	nutrients, metals, TSS, Cl	DEIR Quonset Point
Hunt River @ Post Rd.	Jan-June in 1985	bimonthly	nutrients, metals, TSS, Cl	DEIR Quonset Point
Frenchtown Bk @ Davisville	Jun-Oct 1984 Jan-June 1985	monthly bimonthly	nutrients, metals, TSS, Cl	DEIR Quonset Point
Fry Brook East	Jan-June 1985	bimonthly	nutrients, metals, TSS, Cl	DEIR Quonset Point

Location	Duration	Frequency	Parameters	Comments
Fry Brook West	Jan-June 1985	bimonthly	nutrients, metals, TSS, Cl	DEIR Quonset Point
Sandhill Bk @ Brookside Rd.	June-Oct 1984	monthly	nutrients, metals, TSS, Cl	DEIR Quonset Point
Hunt River @ Old Forge Dam, USGS Gage, E. Greenwich	1940-1984	daily	discharge	USGS long term gage record
Hunt River @ Frenchtown Rd.	1988	1 in July and April	flow, bacteria nutrients, metals	USGS supplemental RIDEM
Fry Bk @ Rte 4	1974-1978	4-6/year	nutrients, TSS metals (Zn, Cr, Cd, Cu, Ni), bacteria	only 1 total phosphorus value RIDEM
Fry Bk @ Rte 4	1983-84, 1987-88	1 late summer	same as 1974-1978	Additional metals (As, Pb, Se, Ag, Al) RIDEM

Notes: TSS = total suspended solids
Nutrients = total phosphorus, total dissolved phosphorus, nitrate
Metals = usually included cadmium, chromium, copper, lead, nickel, and zinc at a minimum
Basic parameters such as DO, Temerature, conductivity, pH, alkalinity measured in most cases.

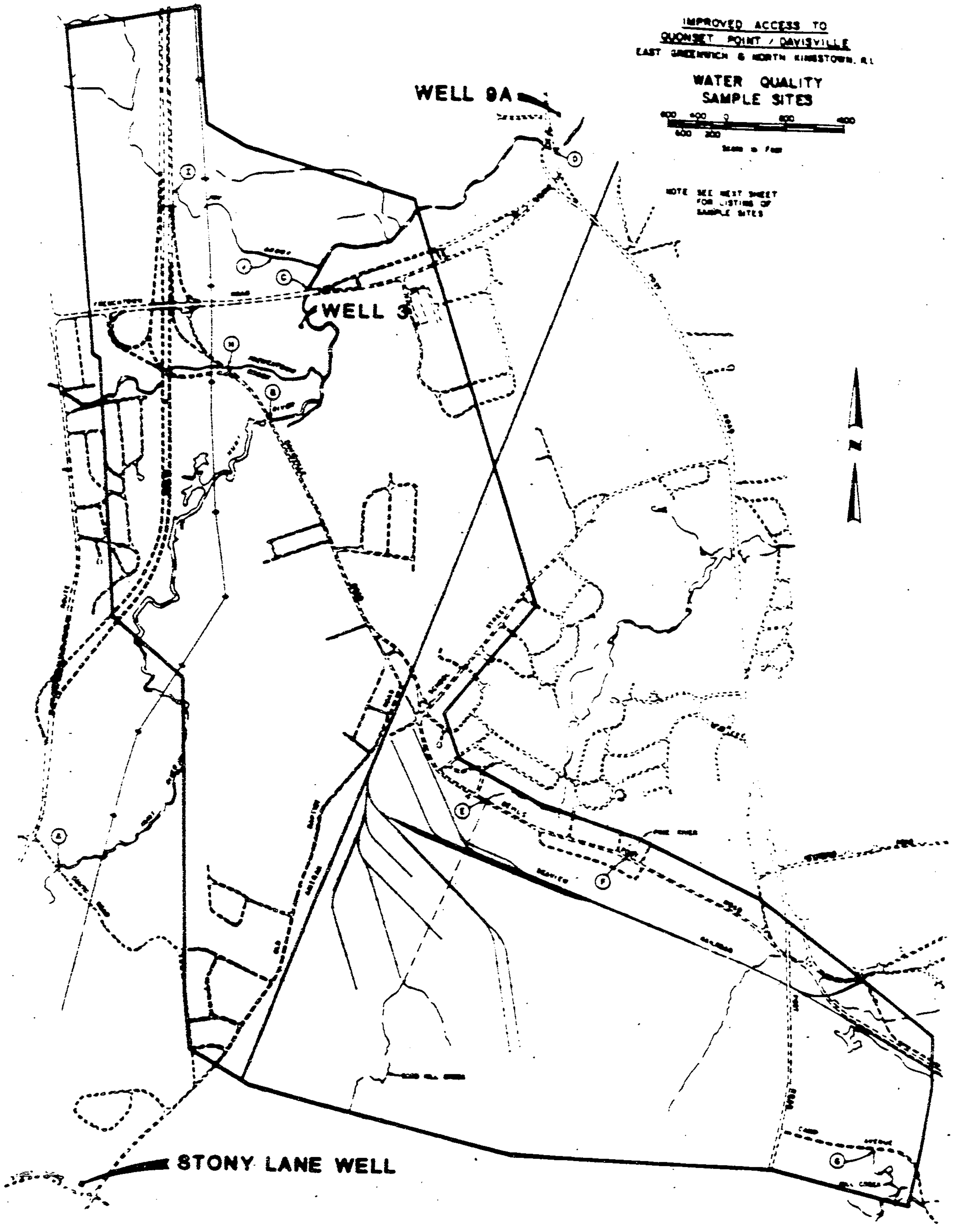


FIGURE 7

from Quonset Point EIR

FIGURE 7 (CONTINUED)

WATER QUALITY SAMPLE SITES
(Surface Waters)

A. Hunt River at South Road

B. Hunt River at Davisville Road

C. Hunt River at Frenchtown Road

D. Hunt River at Post Road

E. Sand Hill Brook at Brookside Road

F. Pine River at Sachem Road

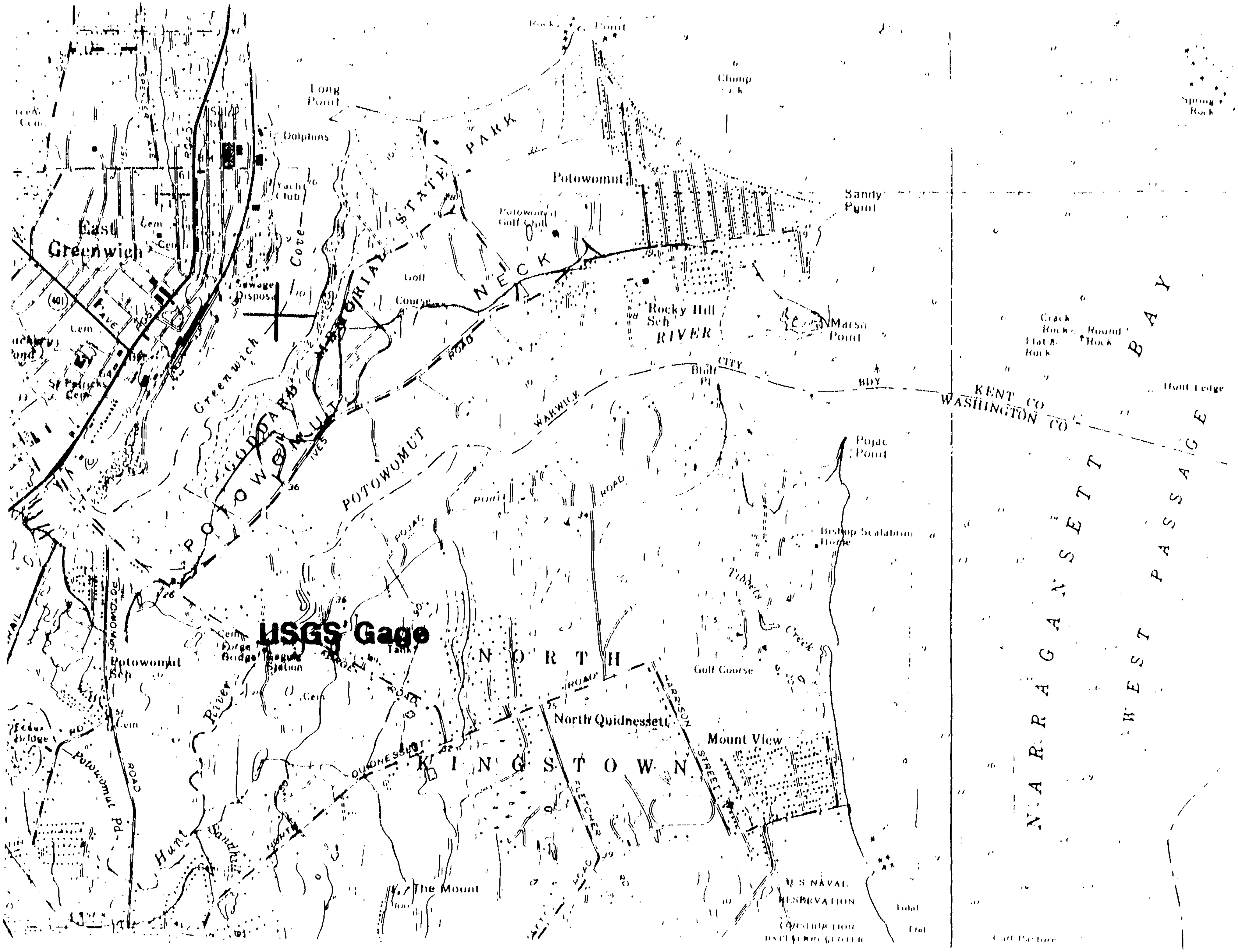
G. Mill Creek at Camp Avenue

H. Frenchtown Brook at Davisville Road

I. Fry Brook at Route 4

J. Fry Brook at River Sand and Gravel Co.

Note: Water samples were taken downstream of all road crossings.


USGS Gage
East Greenwich
Greenwich Cove
Long Point
Dolphins
Yacht Club
Sewage Disposal
Cem
St Patricks Cem
Spencer Ave
Post Road
Potowomut
Potowomut Golf Club
Sandy Point
Clump Rk
Rocks Point
Spring Rock
State Park
Goddard Memorial
Golf Course
Neck
Potowomut Neck
Potowomut River
Rocky Hill Sch
River
Marsh Point
Bluff Pt
City Bdy
Kent Co
Washington Co
Crack Rock
Flat Rock
Round Rock
Hunt Ledge
Narragansett Bay
West Passage
Warwick
Ives Road
Potowomut Road
Pojac Point Road
Pojac Point
Bishop Scalabrini Home
Tibbetts Creek
Golf Course
North Kingstown
North Quidnessett
Quidnessett Road
Harrison Street
Fletcher Road
Mount View
U S Naval Reservation
Tidal Flat
The Mount
Forge Bridge
Gaging Station
Tank
Potowomut Sch
Potowomut Pd
Hunt River
Sandhill
Rail
Gull Fiction