P8

URBAN CATCHMENT MODEL

Program Documentation

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prepared for

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&
Narragansett Bay Project

by

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URBAN CATCHMENT MODEL

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

A B S T R A C T

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.

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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)
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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 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).

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). 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 tabulated 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 <F8> 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 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:

$$\frac{dV}{dt} = Q_{in} - SUM[\,Q\,]$$

The analytical solution for volume increase is as follows:

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

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

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

$$K = SUM [d_1]$$

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:

$$\frac{dM}{dt} = W - D\,M$$

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

Analytical Solution:

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

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

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.

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 ~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 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 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 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 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 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., 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 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%.

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 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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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		

Table 3
Calibrated Runoff Concentrations

COMPONENT	Median, Event-Mean Concentration (ppm) 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)

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

Table 2
Calibration of Particle Parameters

Impervious Washoff Parameters - Particle Classes P10%-P80%:

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)

Impervious Washoff Parameters - P0%:

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

Pervious Runoff Concentrations - Particle Classes P10%-P80%:

C0 = 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)

Pervious Runoff Concentrations - P0%:

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

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 Screens

*** Accessed from ADVANCED USER MODE only**

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'

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 NOAA'
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

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).**