BROWN AND CALDWELL

Attachment 3

Memorandum

Date: May 4, 2005

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Subject: Contra Costa County Clean Water Program Hydrograph Modification Program HSPF Modeling Guidance

Introduction

This memorandum provides technical guidance on how to build an HSPF (Hydrologic Simulation Program-Fortran) model to evaluate the performance of hydrograph modification facilities within Contra Costa County. As an alternative to the simplified IMP sizing approach,[1] an HSPF model may be used to ensure site-specific stormwater facilities are designed to achieve the Contra Costa County Clean Water Program's standard for runoff peak flows and durations.

Building an HSPF model for a project may be a better alternative than using simplified IMP sizing:

- When it is proposed to control runoff peaks and durations by routing runoff through detention basins, constructed wetlands, or other facilities for which a simplified sizing procedure has not been developed.
- For large drainage areas with complex drainage where the simplified approach cannot adequately represent project and pre-project conditions.
- To design facilities that serve more than one project site.
- For sites with steep slopes, dense vegetation, thin top soil, or other atypical hydrologic conditions.

The following sections of this memorandum discuss how to obtain HSPF software, the major data entry components of an HSPF runoff model, and the model parameters used to develop the IMP sizing factors. The memo is intended as a guide to building an HSPF model in Contra Costa County, but it is not a general HSPF user manual. The technical level of the discussion assumes the user is an experienced hydrologic modeler and has some familiarity with HSPF.

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[1] The simplified IMP sizing approach uses a spreadsheet tool to select the necessary sizes for hydromodification facilities based on the user's description of a project site's drainage characteristics. The IMP sizes were computed through an extensive HSPF modeling process. The simplified IMP sizing approach is summarized in a technical memorandum, *Contra Costa County Clean Water Program Hydrograph Modification Program: Integrated Management Practices Modeling Methods and Results*, dated April 29, 2005.

The remainder of this memorandum is arranged as follows:

- The **Obtaining HSPF Software** section describes where to download the software and identifies some valuable tools for model creation and data management for new HSPF users.
- **The Building and Running an HSPF Model** section describes the major data requirements of HSPF and describes the components of the model, with particular emphasis on the model elements that are used for hydromodification simulations.
- The **HSPF Modeling Analysis** section describes the iterative procedure for sizing hydromodification facilities with HSPF simulations.
- **Appendix A** provides detailed descriptions of the pervious and impervious land segment model parameters included in HSPF.

Obtaining HSPF Software

HSPF is publicly available software maintained and distributed by the US Environmental Protection Agency (EPA). HSPF is distributed as part of the EPA BASINs software suite, which includes HSPF, Soil Water Assessment Tool (SWAT), and PLOAD, which is a GIS-based model for estimating non-point source pollutant loads, and other GIS-based watershed analysis tools. BASINs also includes three utilities for building and running HSPF models and for managing time series data (Table 1) that may be very helpful to the novice HSPF user who is getting started building a model. The BASINs software suite may be downloaded from the EPA's web site, http://www.epa.gov/OST/BASINS/.

Table 1. EPA BASINs Utilities for HSPF

Utility	Description
WinHSPF	WinHSPF provides a Windows-based graphical user interface with menus and input forms for building HPSF models. This tool may be particularly valuable to new HSPF users who would prefer to develop models interactively rather than using a text editor to create a user control input (UCI) file from scratch.
WinHSPF Lite	WinHSPF Lite is a convenient tool for running already-built HSPF models. This utility loads separately-prepared HSPF input files (i.e., UCI files) and launches the HSPF executable.
WDM Utility	WDM Utility is a useful tool for managing WDM (watershed data management) files, which are the binary-formatted files used by HSPF to store time series data. WDM Utility can create time series datasets, and perform basic statistical, graphical and data aggregation functions.

Building and Running an HSPF Model for the Project Site

Building an HSPF model to simulate stormwater runoff and evaluate the performance of stormwater control facilities involves examining the drainage patterns of the site, computing the pervious and impervious areas, examining the local soil types, collecting time series input data, and expressing the site hydrology using a collection of model parameters. Building the HSPF model and analyzing the stormwater runoff are parts of the overall site development process. The procedure may be summarized as follows:

1. The developer's team develops a site plan that includes existing and proposed grading, new impervious areas, changes in land cover and soil depth, and other site characteristics that affect stormwater runoff.

2. The developer's team divides the project areas into separate drainage areas (referred to as Drainage Management Areas in the simplified IMP sizing approach) and determines where stormwater control facilities, such as integrated management practices (IMPs) and detention ponds, will be located. These first two steps should be completed before attempting to model the site runoff.
3. Once a proposed site plan is in place, an HSPF model should be built to reflect the site conditions, linking stormwater runoff from different parts of the project site with proposed IMPs and other stormwater capture devices. Building the model involves time series data collection, estimating appropriate model parameter values, and adding any necessary flow routing and stormwater control facilities to the model.

HPSF Input File Components and Data Requirements

HSPF requires extensive input information to define the hydrology of the project site. Time series data are compiled in a WDM file; hydrologic parameters, stormwater control facilities, flow routing and data output controls are all defined in the UCI input file. The following section lists recommended sources for time series data, model parameter values, and instructions on building the stage-storage-discharge relationships that define how hydromodification facilities perform.

Time Series Data Sources

HSPF requires, at a minimum, two time series datasets: precipitation and pan evaporation. Including a temperature time series improves HSPF's representation of evapotranspiration. The time series should have uniform time steps no greater than one hour. All time series should cover the entire simulation period. (In fact, the length of the time series data usually determines the length of the model simulation period.)

For Contra Costa County, precipitation and evapotranspiration data are available from the National Oceanic and Atmospheric Administration (NOAA) and the Contra Costa Flood Control District (Table 2). These datasets were used to develop the sizing factors used in the simplified IMP sizing approach.

Table 2. Time Series Input Data Sources

Station Name	Location	Period of Record	Latitude; Longitude	Elev. (ft)	Mean Annual Rain
Hourly Precipitation Data Sources					
Martinez[A]	City of Martinez	7/48 thru 2/04	37° 58' N; -122° 08' W	70.1	20.2 in
Flood Control	CCC Flood Control HQ	9/71 thru 5/04	37° 59' N; 122° 05' W	160'	16.4 in
St. Mary's	St. Mary's College	9/72 thru 5/04	37° 51' N; 122° 06' W	620'	24.8 in
Orinda Fire	Orinda Fire Station 3	9/73 thru 5/04	37° 54' N; 122° 10' W	700'	25.1 in
Los Medanos	Chevron Pipeline Pump Plant	7/74 thru 5/04	38° 00' N; 121° 51' W	130'	8.4 in
Dublin Fire	Dublin-San Ramon Fire House	9/73 thru 5/04	37° 44' N; 121° 56' W	355'	12.5 in

Hourly Evaporation Data Sources[B]

Source	Location	Data Type	Period of Record
Los Alamitos	Los Alamitos Recharge Basin, San Jose	Pan Evaporation	1960 to 1996
SFO	San Francisco Airport	Pan Evaporation	1948 to 2004

A. Our examination of the Martinez Gauge record showed several questionable records where an entire storm's depth was recorded in a single hour. For these questionable storms, the recorded rainfall depth at Martinez was distributed according to the storm timing recorded at the nearest gauge (Flood Control District Gauge 11). A similar procedure should be used for simulations that use the Martinez gauge data.

B. The two data sources were combined because the higher quality dataset from Los Alamitos did not cover the entire modeling period.

HSPF Land Segment Parameters

The project site should be divided into separate drainage management areas (DMAs) based on project drainage design (e.g., location of grade breaks, direction of roof drainage, and routing of surface and piped drainage) and preliminary location of the hydrograph modification management facilities. DMAs should be configured to minimize the amount of undeveloped or landscaped area draining to the hydrograph modification management facilities. Each drainage management area should be represented by a combination of PERLND and IMPLND land segments in HSPF. The hydrograph modification management facilities should be located to capture runoff from all impervious areas while minimizing capture of runoff from pervious areas. PERLNDs represent pervious land surfaces and IMPLNDs represent impervious surfaces. Table 3 and Table 4 below contain a set of recommended PERLND and IMPLND parameters, respectively, for Contra Costa County. Appendix A contains a more detailed description of the PERLND and IMPLND parameters below. These parameters values were used in the IMP sizing analysis.

The recommended parameters may be modified if appropriate technical justification is provided. Consult the EPA publication, *EPA BASINs Technical Note 6 Estimating Hydrologic and Hydraulic Parameters for HSPF* (July 2000) for recommended ranges of HSPF parameter values. Examples of appropriate technical justification for modifying the parameters listed below include:

1. Local field measurements that differ from the recommended parameters.
2. Local land cover may differ from the cover types provided. For example, heavy forest cover could be represented by increasing the interception storage (CEPSC) and evapotranspiration fractions.

Table 3. HSPF PERLND Parameters for use in Contra Costa County

PERLND Parameter	Value	Units	Description
CSNO	0	None	Flag to determine whether snow data are used in simulation
RTOP	1	None	Flag to select overland flow routing method (see Appendix A)
UZFG	1	None	Flag to select upper zone inflow computation method
VCS	1	None	Flag to select constant or monthly-variable interception storage capacity
VUZ	0	None	Flag to select constant or monthly-variable upper zone nominal soil moisture storage
VNN	0	None	Flag to select constant or monthly-variable Manning's n parameter
VIFW	0	None	Flag to select constant or monthly-variable interflow parameter
VIRC	0	None	Flag to select constant or monthly varied interflow recession parameter
VLE	1	None	Flag to select constant or monthly varied lower zone ET parameter
FOREST	0	None	Fraction of forest covered area that will continue to transpire in winter
LZSN	7	Inch	Nominal lower zone soil moisture storage
INFILT	0.7 0.03	inch/hour	Mean soil infiltration rate. Ranges of values for NRCS Hydrologic Group B and C soils are in Appendix A. The upper value of INFILT = 0.7 was used for Group A soils; INFILT = 0.03 was used for Group D soils.
LSUR	660	Feet	Length of assumed overland flow plane. Value provided for generic 1-acre basin. For specific projects, the value should be calculated from the site plan.
SLSUR	0.1	None	Average slope of assumed overland flow path. For specific project sites, the value may be computed drafting or GIS software.
KVARY	0	per inch	Groundwater recession flow parameter used to describe non-linear groundwater recession rate. This parameter affects groundwater flow rates and is relevant to larger watershed studies that track groundwater influence on local streams.
AGWRC	0.95	per day	Groundwater recession rate, or ratio of current groundwater discharge to that from 24 hours earlier (when KVARY = 0)
PETMAX	40	deg F	Temperature below which ET will be reduced to 50% of that in the input time series
PETMIN	35	deg F	Temperature threshold where plant transpiration is effectively suspended, i.e. set to zero, due to temperatures approaching freezing

Table 3. HSPF PERLND Parameters for use in Contra Costa County (Cont.)

PERLND Parameter	Value	Units	Description
INFEXP	2	None	Exponent that determines how much a deviation from nominal lower zone storage affects the infiltration rate
INFILD	2	None	Ratio of maximum and mean soil infiltration capacities
DEEPFR	0.45 0.10	None	The fraction of infiltrating water which is lost to deep aquifers (i.e. inactive groundwater). DEEPFR = 0.45 was used for Group A soils; DEEPFR = 0.1 was used for Group D soils.
INFEXP	2	None	Exponent that determines how much a deviation from nominal lower zone storage affects the infiltration rate
AGWETP	0	None	Fraction of PERLND that is subject to direct evaporation from groundwater storage, e.g. wetlands or marsh areas
CEPSC	0.02 to 0.10	Inch	Amount of rainfall that is retained by vegetation, never reaches the land surface, and is eventually evaporated. CEPSC = 0.10 for Live Oak cover; CEPSC = 0.02 for Range cover.
UZSN	0.5	Inch	Nominal upper zone soil moisture storage
NSUR	0.3	None	Manning's friction coefficient, n, for overland flow plane
INTFW	0.4	None	The fraction of water in surface detention that becomes interflow, as opposed to direct overland flow or upper zone storage
IRC	0.3	None	The interflow recession coefficient is the ratio of the current daily interflow discharge to the interflow discharge on the previous day
LZETP	0	None	Lower zone evapotranspiration coefficient defines portion of the the ET opportunity that occurs in the lower soil zone (i.e. rooting zone)
CEPS	0	Inch	Interception storage initial value
SURS	0	Inch	Surface ponding storage initial value
UZS	0.15	Inch	Upper zone storage initial value
IFWS	0	Inch	Interflow storage initial value
LZS	4	Inch	Lower zone storage initial value
AGWS	0.05	Inch	Active groundwater storage initial value
GWVS	0	None	Initial groundwater storage slope

Table 4. HSPF IMPLND Parameters for use in Contra Costa County

IMPLND Parameter	Value	Unit	Description
CSNO	0	None	Flag to determine whether snow data are used in simulation
RTOP	0	None	Flag to select overland flow routing method (see Appendix A)
VRS	0	None	Flag to select constant or monthly-variable retention storage capacity
VNN	0	None	Flag to select constant or monthly-variable Manning's n parameter
RTLI	1	None	Flag to determine if lateral surface inflow to the impervious land segment will be subject to retention storage
LSUR	100	None	Length of assumed overland flow plane. Value provided for generic 1-acre basin. For specific projects, the value should be calculated from the site plan.
SLSUR	0.035	None	Average slope of assumed overland flow path. For specific project sites, the value may be computed drafting or GIS software.
NSUR	0.05	None	Manning's friction coefficient, n, for overland flow plane
RETSC	0.1	Inch	Retention (interception) storage of the impervious surface
PETMAX	40	deg F	Temperature below which ET will be reduced to 50% of that in the input time series
PETMIN	35	deg F	Temperature threshold below which evaporation is set to zero
RETS	1.00E-03	Inch	Retention storage initial value
SURS	1.00E-03	Inch	Surface ponding storage initial value

Linking Land Segments

HSPF includes two general schemes for routing water from land segments (PERLNDs and IMPLNDs) through a watershed. Either all outflows are moved from one land segment to the next land segment or facility at each time step, or a specific routing algorithm is used to weight the distribution of outflows over multiple time steps based on the travel time between model elements in the watershed. Linking separate land segments with routing algorithms becomes more important in larger analysis areas.

As a general rule, if the overland flow timing is similar to or longer than the model time step, then explicit routing algorithms should be considered. Flow routing is managed using RCHRES elements within HSPF. Otherwise flow from adjacent land segments may be routed directly, without weighting algorithms, using either the NETWORK or MASSLINK element.

Representing DMAs That Have IMPs

A special case exists for sites that include a mixture of IMPs and traditional downstream stormwater control facilities that collect both treated and untreated flows. This circumstance was listed in the introduction as an example that requires an HSPF model, particularly if the IMPs have underdrains. In areas with Group D soils, the IMP underdrains will discharge to the local stormwater conveyance system, so downstream hydromodification facilities may need to be sized to manage all flows (if flows from upstream IMPs cannot be segregated). Two methods are proposed for modeling these combination sites:

- One method is to include the IMPs in an HSPF model of the entire project site. The IMP outflows could be routed to the stormwater conveyance system and to any downstream control facilities. In the IMP sizing analysis, the IMPs were modeled with two-layer FTABLEs in HSPF that characterized the geometry and soil moisture holding characteristics of each IMP type. The *Low Impact Design Technical Guidance Manual for Puget Sound*, released in January 2005, provides a survey of various analysis methods used to size IMPs in Western Washington.
- As an alternative, the DMAs that contain IMPs could be modeled as the pre-project soil/cover type. This method is conservative for the range of flows controlled by the IMPs.

Modeling Downstream Hydromodification Facilities

HSPF models storage-based facilities with the FTABLE element, which defines the stage-storage-discharge relationship for a facility. Figure 1 shows an example FTABLE that could be used to model a gravel-filled detention device that allows percolation through the bottom and a flow-control release to the local stormwater conveyance. The first three columns define the stage-area-volume relationship. The final two columns define stage-discharge relationships for this facility.

```
 FTABLE      2
rows cols                                            ***
  11    5
    Depth      Area    Volume    Q Perc  Q Outlet    ***
     (ft)    (acres) (acre-ft)   (cfs)     (cfs)    ***
     0.00      0.03    0.0000    0.0000     0.000
     0.10      0.03    0.0012    0.0001     0.000
     0.20      0.03    0.0025    0.0007     0.001
     0.30      0.03    0.0037    0.0007     0.005
     0.40      0.03    0.0050    0.0007     0.018
     0.50      0.03    0.0062    0.0007     0.047
     0.60      0.03    0.0075    0.0007     0.104
     0.70      0.03    0.0087    0.0007     0.133
     0.80      0.03    0.0100    0.0007     0.142
     0.90      0.03    0.0112    0.0007     0.151
     1.00      0.03    0.0125    0.0007     0.159
 END FTABLE2
```

Figure 1. Sample FTABLE for Stormwater Detention Facility

While the layout of the FTABLE is straightforward, the values in each column and the number of outflow columns depend on the design of the facility. First, the model developer must select the type of facility to model, including its geometry, its detention and infiltration characteristics, and the height and size of any flow control orifices or weirs.

For detention basins, the careful selection of initial orifice sizes and heights can help streamline the process of sizing the facility. The height and diameter of any flow control orifices should be sized to allow the basin outflow to match the requirements of limiting post-project peak flows and durations to pre-project levels from one half the pre-project flow with an average recurrence interval of two years (0.5Q2) to the pre-project flow with an average recurrence interval of 10 years (Q10). For example, a detention basin with two flow control orifices could have its lower orifice sized to pass 0.5Q2 when the water in the basin is just below the height of the *upper orifice*. The upper orifice could pass flows up to Q10 when the water surface reaches the height of an overflow relief weir. If the basin volume is sized to trigger the overflow relief an average of once per 10 years, this setup should come close to approximating the flow and duration control standard, and reduce the number of modeling simulations needed in the iterative facility sizing process.

HSPF Modeling Analysis of the Project Site

After compiling the required input dataset, defining model parameters, and specifying the stormwater control scheme for the project area, the next step involves running the HSPF model to determine if the post-project flows are controlled to the pre-project levels. The program requires that projects subject to hydrograph modification control must meet a specific peak flow and duration standard. Partial duration series statistics should be used to (1) parse the HSPF output time series into discrete flow events and (2) compute the recurrence interval and peak flow for each flow event. The peak flow and duration control standard is summarized as follows:

Peak Flow Control

- From 0.5Q2 to Q2 (inclusive), the post-project peak flows should not exceed pre-project peak flows.
- For recurrence intervals from Q2 to Q10, the post-project peak flows may exceed pre-project peak flows by up to 10 percent for a 1-year band within the 2 to 10 year recurrence interval range. For example, the post-project flows could exceed the pre-project flows by up to 10 percent between Q9 and Q10 or from Q5.5 to Q6.5, but not from Q8 to Q10.

Flow Duration Control

- From 0.5Q2 to Q2 (inclusive), the post-project flow durations (i.e., the aggregate time for which the site discharge exceeds a specific flow rate) should not exceed the pre-project flow durations. This recognizes the impact of these relatively frequent events on the stream channel stability.
- For flow rates above Q2, post-project flow durations should not exceed pre-project flow durations by more than 10 percent at any flow rate.
- The post-project durations should not exceed pre-project durations for more than 50 percent of the flow levels from 0.5Q2 to Q10.

Sizing facilities to meet the peak flow and duration control standard is often an iterative process that involves several HSPF simulations and statistical analyses. The following steps outline a general procedure for applying the HSPF model to compute pre-project and post-project flows and assess the performance of hydromodification facilities.

1. Conduct long-term HSPF simulations to compute hourly runoff-hydrographs for the following conditions:
    a. Pre-project site conditions
    b. Proposed post-project site conditions
    c. Mitigated post-project site conditions with hydromodification facilities included
2. Calculate peak flow frequencies using partial duration series statistics, which may be produced using available data analysis software packages.
3. Calculate flow duration statistics using database queries or data analysis software.

4. Produce summary peak flow and flow duration graphics to assess the performance of the hydromodification approach (see Figure 2 and Figure 3). The example shown in the figures meets the peak flow and flow duration standards because the mitigated post-project peak flow and flow duration curves are below the corresponding pre-project curves in the range from 0.5Q2 to Q10. If the post-project flows do not meet the peak flow and flow duration standards, the hydrograph modification management facilities or site design components should be revised and the HSPF modeling process repeated.

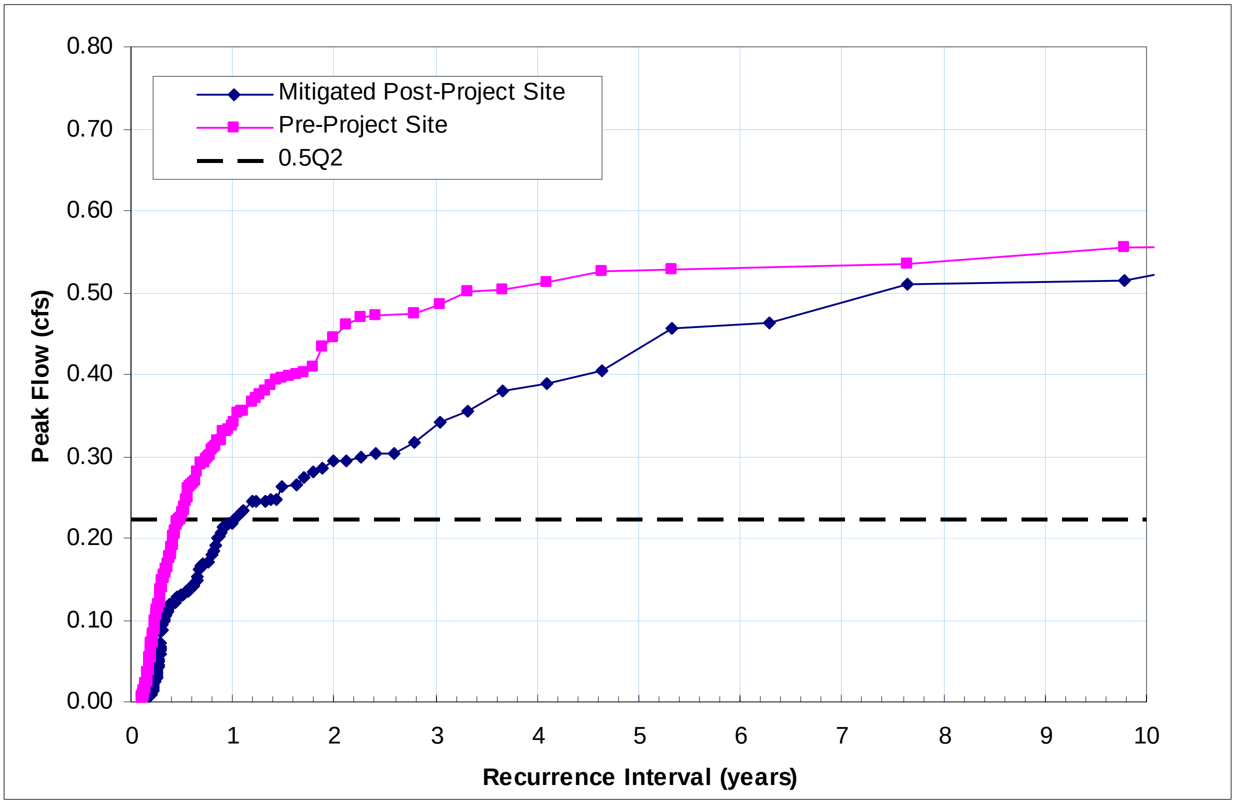

Figure 2. Example Peak Flow Frequency Plot for Post-Project Flows that Meet Control Standard

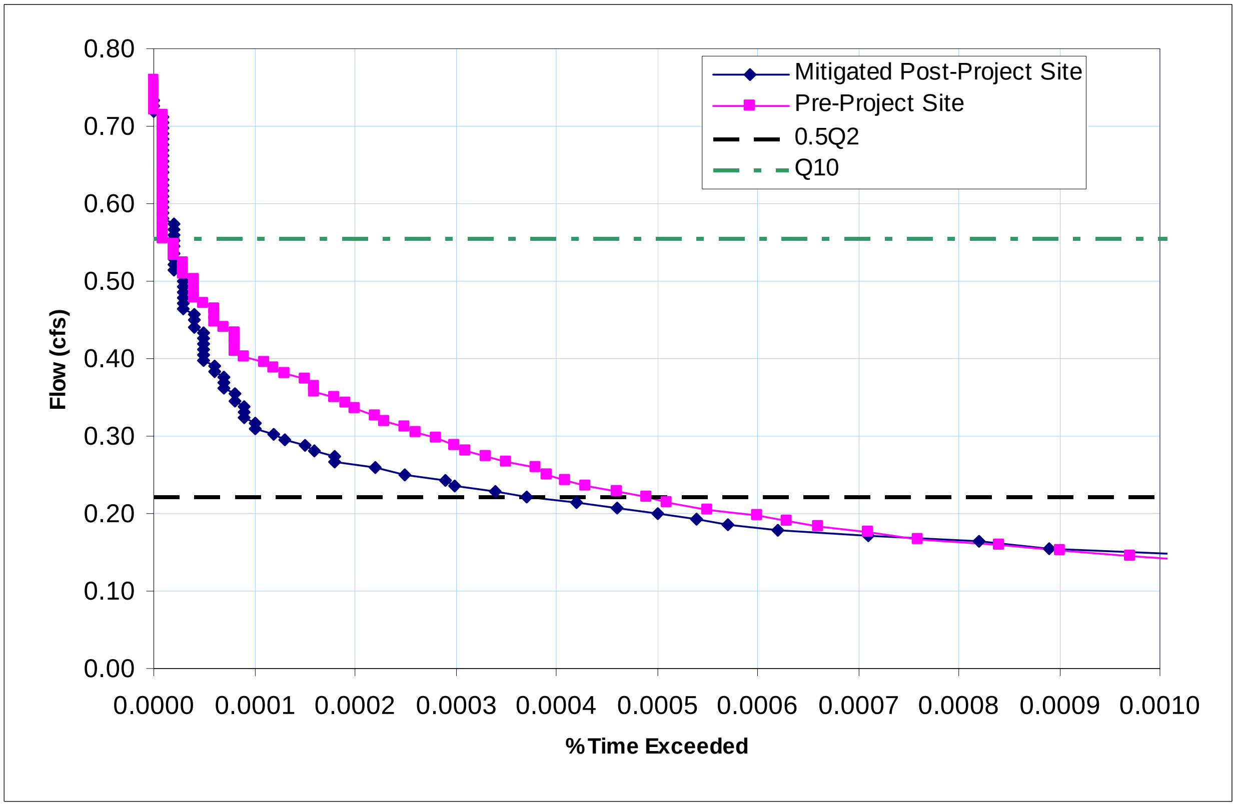

Figure 3. Example Flow Duration Plot for Post-Project Flows that Meet Control Standard

APPENDIX A: HSPF PARAMETER DESCRIPTIONS

This section provides a list of descriptions for the pervious and impervious land surface parameters (PERLND and IMPLND, respectively) used in the HSPF model for Contra Costa. The values for these parameters were derived from numerous sources: the USGS regional calibration on Calabazas Creek in Santa Clara County, the WWHM, and the EPA publication, *EPA Basins Technical Note 6 Estimating Hydrologic and Hydraulic Parameters for HSPF* (July 2000), from which the parameter descriptions below are reproduced.

PERLND Parameters

PWAT-PARM1 Table: Sets PERLND Flags

The PWAT-PARM1 table includes flags to indicate the selected simulation algorithm option, other selection of monthly variability versus constant values for selected parameters. Where flags indicate monthly variability, the corresponding monthly values must be provided in Monthly Input Parameters (see below following the PWAT_PARM4 Table section). That section also provides guidance on which parameters are normally specified as monthly values.

CSNOFG Flag to use snow simulation data; must be checked (CSNOFG=1) if SNOW is simulated.

RTOPFG Flag to select overland flow routing method; choose either the method used in predecessor models (HSPX, ARM, and NPS) or the alternative method as described in the HSPF User Manual. Recommendation: Set RTOPFG=1; This method, used in the predecessor models is more commonly used, and has been subjected to more widespread application.

UZFG Flag to select upper zone inflow computation method; choose either the method used in predecessor models (HSPX, ARM, and NPS) or the more exact numerical solution to the integral of inflow to upper zone, i.e the alternative method. Recommendation: Set UZFG=1; This method, used in the predecessor models, is more commonly used, and has been subjected to more widespread application.

VCSFG Flag to select constant or monthly-variable interception storage capacity, CEPSC. Monthly value can be varied to represent seasonal changes in foliage cover; monthly values are commonly used for agricultural, and sometimes deciduous forest land areas.

VUZFG Flag to select constant or monthly-variable upper zone nominal soil moisture storage, UZSN. Monthly values are commonly used for agricultural areas to reflect the timing of cropping and tillage practices.

VMNFG Flag to select constant or monthly-variable Manning=s n for overland flow plane, NSUR. Monthly values are commonly used for agricultural, and sometimes deciduous forest land areas.

VIFWFG Flag to select constant or monthly-variable interflow inflow parameter, INTFW. Monthly values are not often used.

VIRCFG Flag to select constant or monthly varied interflow recession parameter, IRC. Monthly values are not often used.

VLEFG Flag to select constant or monthly varied lower zone ET parameter, LZETP. Monthly values are commonly used for agricultural, and sometimes deciduous forest land areas.

PWAT-PARM2 Table:

FOREST Fraction of land covered by forest (unitless) (measure/estimate). FOREST is the fraction of the land segment which is covered by forest which will continue to transpire in winter (i.e. coniferous). This is only relevant if snow is being considered (i.e., CSNOFG=1 in PWATER-PARM1).

LZSN Lower zone nominal soil moisture storage (inches), (estimate, then calibrate). LZSN is related to both precipitation patterns and soil characteristics in the region. The ARM Model User Manual (Donigian and Davis, 1978, p. 56, LZSN variable) includes a mapping of calibrated LZSN values across the country based on almost 60 applications of earlier models derived from the Stanford-based hydrology algorithms. LaRoche et al (1996) shows values of 5 inches to 14 inches, which is consistent with the 'possible' range of 2 inches to 15 inches shown in the Summary Table. Viessman, et al, 1989, provide initial estimates for LZSN in the Stanford Watershed Model (SWM-IV, predecessor model to HSPF) as one-quarter of the mean annual rainfall plus four inches for arid and semiarid regions, or one-eighth annual mean rainfall plus 4 inches for coastal, humid, or subhumid climates. These formulae tend to give values somewhat higher than are typically seen as final calibrated values; since LZSN will be adjusted through calibration, initial estimates obtained through these formulae may be reasonable starting values.

INFILT Index to mean soil infiltration rate (in/hr); (estimate, then calibrate). In HSPF, INFILT is the parameter that effectively controls the overall division of the available moisture from precipitation (after interception) into surface and subsurface flow and storage components. Thus, high values of INFILT will produce more water in the lower zone and groundwater, and result in higher baseflow to the stream; low values of INFILT will produce more upper zone and interflow storage water, and thus result in greater direct overland flow and interflow. LaRoche et al (1996) shows a range of INFILT values used from 0.004 in/hr to 0.23 in/hr, consistent with the 'typical' range of 0.01 to 0.25 in/hr in the Summary Table. Fontaine and Jacomino (1997) show sediment and sediment associated transport to be sensitive to the INFILT parameter since it controls the amount of direct overland flow transporting the sediment. Since INFILT is not a maximum rate nor an infiltration capacity term, it's values are normally much less than published infiltration rates, percolation rates (from soil percolation tests), or permeability rates from the literature. In any case, initial values are adjusted in the calibration process. INFILT is primarily a function of soil characteristics, and value ranges have been related to SCS hydrologic soil groups (Donigian and Davis, 1978, p.61, variable INFIL) as follows: NRCS Hydrologic INFILT Estimate Soil Group (in/hr) (mm/hr) Runoff Potential

Table A1. Recommended INFILT Parameter Range for Initial Model Setup

NRCS Hydrologic Soil Group	Initial Model Setup: INFILT range (in/hr)	Runoff Potential
A	0.4 to 1.0	Low
B	0.1 to 0.4	Moderate
C	0.05 to 0.1	Moderate to High
D	0.01 to 0.05	High

An alternate estimation method that has not been validated, is derived from the premise that the combination of infiltration and interflow in HSPF represents the infiltration commonly modeled in the literature (e.g. Viessman et al, 1989, Chapter 4). With this assumption, the value of 2.0*INFILT*INTFW should approximate the average measured soil infiltration rate at saturation, or mean permeability.

LSUR Length of assumed overland flow plane (ft) (estimate/measure). LSUR approximates the average length of travel for water to reach the stream reach, or any drainage path such as small streams, swales, ditches, etc. that quickly deliver the water to the stream or waterbody. LSUR is often assumed to vary with slope such that flat slopes have larger LSUR values and vice versa; typical values range from 200 feet to 500 feet for slopes ranging from 15% to 1 %. It is also often estimated from topographic data by dividing the watershed area by twice the length of all streams, gullies, ditches, etc that move the water to the stream. That is, a representative straight-line reach with length, L, bisecting a representative square areal segment of the watershed, will produce two overland flow planes of width ½ L. However, LSUR values derived from topographic data are often too large (i.e. overestimated) when the data is of insufficient resolution to display the many small streams and drainage ways. Users should make sure that values calculated from GIS or topographic data are consistent with the ranges shown in the Summary Table.

<u>SLSUR</u> Average slope of assumed overland flow path (unitless) (estimate/measure). Average SLSUR values for each land use being simulated can often be estimated directly with GIS capabilities. Graphical techniques include imposing a grid pattern on the watershed and calculating slope values for each grid point for each land use.

<u>KVARY</u> Groundwater recession flow parameter used to describe non-linear groundwater recession rate (/inches) (initialize with reported values, then calibrate as needed) KVARY is usually one of the last PWATER parameters to be adjusted; it is used when the observed groundwater recession demonstrates a seasonal variability with a faster recession (i.e. higher slope and lower AGWRC values) during wet periods, and the opposite during dry periods. LaRoche, et al, 1996 reported an extremely high ‘optimized’ value of 0.66 mm$_{-1}$ or (17 in$_{-1}$) (much higher than any other applications) while Chen, et al, 1995 reported a calibrated value of 0.14 mm$_{-1}$ (or 3.6 in$_{-1}$). Value ranges are shown in the Summary Table. Users should start with a value of 0.0 for KVARY, and then adjust (i.e. increase) if seasonal variations are evident. Plotting daily flows with a logarithmic scale helps to elucidate the slope of the flow recession.

<u>AGWRC</u> Groundwater recession rate, or ratio of current groundwater discharge to that from 24 hours earlier (when KVARY is zero) (/day) (estimate, then calibrate). The overall watershed recession rate is a complex function of watershed conditions, including climate, topography, soils, and land use. Hydrograph separation techniques (see any hydrology or water resources textbook) can be used to estimate the recession rate from observed daily flow data (such as plotting on a logarithmic scale, as noted above); estimated values will likely need to be adjusted through calibration. Value ranges are shown in the Summary Table. LaRoche, et al, 1996 reported an optimized value of 0.99; Chen, et al, 1995 reported values that varied with land use type, ranging from 0.971 for grassland and clearings to 0.996 for high density forest; Fontaine and Jacomino, 1997 reported a calibrated value of 0.99. This experience reflects normal practice of using higher values for forests than open, grassland, cropland and urban areas.

<u>PWAT-PARM3 Table:</u>

<u>PETMAX</u> Temperature below which ET will be reduced to 50% of that in the input time series (deg F), unless it=s been reduced to a lesser value from adjustments made in the SNOW routine (where ET is reduced based on the percent areal snow coverage and fraction of coniferous forest). PETMAX represents a temperature threshold where plant transpiration, which is part of ET, is reduced due to low temperatures (initialize with reported values, then calibrate as needed). It is only used if SNOW is being simulated because it requires air temperature as input (also a requirement of the SNOW module), and the required low temperatures will usually only occur in areas of frequent snowfall. Use the default of 40$_{o}$F as an initial value, which can be adjusted a few degrees if required. PETMIN Temperature at and below which ET will be zero (deg F).

<u>PETMIN</u> represents the temperature threshold where plant transpiration is effectively suspended, i.e. set to zero, due to temperatures approaching freezing (initialize with reported values, then calibrate as needed). Like PETMAX, this parameter is used only if SNOW is being simulated because it requires air temperature as input (also a requirement of the SNOW module), and the required low temperatures will usually only occur in areas of frequent snowfall. Use the default of 35$_{o}$F as an initial value, which can be adjusted a few degrees if required.

<u>INFEXP</u> Exponent that determines how much a deviation from nominal lower zone storage affects the infiltration rate (HSPF Manual, p. 60) (initialize with reported values, then calibrate as needed). Variations of the Stanford approach have used a POWER variable for this parameter; various values of POWER are included in Donigian and Davis (1978, p. 58). However, the vast majority of HSPF applications have used the default value of 2.0 for this exponent. Use the default value of 2.0, and adjust only if supported by local data and conditions.

INFILD Ratio of maximum and mean soil infiltration capacities (initialize with reported value). In the Stanford approach, this parameter has always been set to 2.0, so that the maximum infiltration rate is twice the mean (i.e. input) value; when HSPF was developed, the INFILD parameter was included to allow investigation of this assumption. However, there has been very little research to support using a value other than 2.0. Use the default value of 2.0, and adjust only if supported by local data and conditions.

DEEPFR The fraction of infiltrating water which is lost to deep aquifers (i.e. inactive groundwater), with the remaining fraction (i.e. 1-DEEPFR) assigned to active groundwater storage that contributes baseflow to the stream (estimate, then calibrate). It is also used to represent any other losses that may not be measured at the flow gage used for calibration, such as flow around or under the gage site. This accounts for one of only three major losses from the PWATER water balance (i.e. in addition to ET, and lateral and stream outflows). Watershed areas at high elevations, or in the upland portion of the watershed, are likely to lose more water to deep groundwater (i.e. groundwater that does not discharge within the area of the watershed), than areas at lower elevations or closer to the gage (see discussion and figures in Freeze and Cherry, 1979, section 6.1). DEEPFR should be set to 0.0 initially or estimated based on groundwater studies, and then calibrated, in conjunction with adjustments to ET parameters, to achieve a satisfactory annual water balance.

BASETP ET by riparian vegetation as active groundwater enters streambed; specified as a fraction of potential ET, which is fulfilled only as outflow exists (estimate, then calibrate). Typical and possible value ranges are shown in the Summary Table. If significant riparian vegetation is present in the watershed then non-zero values of BASETP should be used. Adjustments to BASETP will be visible in changes in the low-flow simulation, and will effect the annual water balance. If riparian vegetation is significant, start with a BASETP value of 0.03 and adjust to obtain a reasonable low-flow simulation in conjunction with a satisfactory annual water balance.

AGWETP Fraction of model segment (i.e. pervious land segment) that is subject to direct evaporation from groundwater storage, e.g. wetlands or marsh areas, where the groundwater surface is at or near the land surface, or in areas with phreatophytic vegetation drawing directly from groundwater. This is represented in the model as the fraction of remaining potential ET (i.e. after base ET, interception ET, and upper zone ET are satisfied), that can be met from active groundwater storage (estimate, then calibrate). If wetlands are represented as a separate PLS (pervious land segment), then AGWETP should be 0.0 for all other land uses, and a high value (0.3 to 0.7) should be used for the wetlands PLS. If wetlands are not separated out as a PLS, identify the fraction of the model segment that meets the conditions of wetlands/marshes or phreatophytic vegetation and use that fraction for an initial value of AGWETP. Like BASETP, adjustments to AGWETP will be visible in changes in the low-flow simulation, and will effect the annual water balance. Follow above guidance for an initial value of AGWETP, and then adjust to obtain a reasonable low-flow simulation in conjunction with a satisfactory annual water balance.

PWAT PARM4 Table:

CEPSC Amount of rainfall, in inches, which is retained by vegetation, never reaches the land surface, and is eventually evaporated (estimate, then calibrate). Typical guidance for CEPSC for selected land surfaces is provided in Donigian and Davis (1978, p. 54, variable EPXM) as follows:

Table A2. Recommended CEPSC Parameter Range for Initial Model Setup

Land Cover	Maximum Interception (in)
Grassland	0.1
Cropland	0.1 to 0.25
Forest Cover, light	0.15
Forest Cover, heavy	0.20

Donigian et al (1983) provide more detail guidance for agricultural conditions, including residue cover for agricultural BMPs. As part of an annual water balance, Viessman, et al. 1989 note that 10-20% of precipitation during growing season is intercepted and as much as 25% of total annual precipitation is intercepted under dense closed forest stands; crops and grasses exhibit a wide range of interception rates - between 7% and 60% of total rainfall. Users should compare the annual interception evaporation (CEPE) with the total rainfall available (PREC in the WDM file), and then adjust the CEPSC values accordingly. (See Monthly Input Values below).

UZSN Nominal upper zone soil moisture storage (inches) (estimate, then calibrate). UZSN is related to land surface characteristics, topography, and LZSN. For agricultural conditions, tillage and other practices, UZSN may change over the course of the growing season. Increasing UZSN value increases the amount of water retained in the upper zone and available for ET, and thereby decreases the dynamic behavior of the surface and reduces direct overland flow; decreasing UZSN has the opposite effect. Donigian and Davis (1978, p. 54) provide initial estimates for UZSN as 0.06 of LZSN, for steep slopes, limited vegetation, low depression storage; 0.08 LZSN for moderate slopes, moderate vegetation, and moderate depression storage; 0.14 LZSN for heavy vegetal or forest cover, soils subject to cracking, high depression storage, very mild slopes. Donigian et al., (1983) include detailed guidance for UZSN for agricultural conditions. LaRoche shows values ranging from 0.016 in to 0.75 in. Fontaine and Jacomino showed average daily stream flow was relatively insensitive to this value but sediment and sediment associated contaminant outflow was sensitive; this is consistent with experience with UZSN having an impact on direct overland flow, but little impact on the annual water balance (except for extremely small watersheds with no baseflow). Typical and possible value ranges are shown in the Summary Table.

NSUR Manning's n for overland flow plane (estimate). Manning's n values for overland flow are considerably higher than the more common published values for flow through a channel, where values range from a low of about 0.011 for smooth concrete, to as high as 0.050-0.1 for flow through unmaintained channels (Hwang and Hita, 1987). Donigian and Davis (1978, p. 61, variable NN) and Donigian et al (1983) have tabulated the following values for different land surface conditions:

Table A3. Recommended NSUR Parameter Range for Initial Model Setup

Overland Flow Surface	Manning's n Value (NSUR)
Smooth packed surface	0.05
Normal roads and parking lots	0.10
Disturbed land surfaces	0.15 to 0.25
Moderate turf/pasture	0.20 to 0.30
Heavy turf, forest litter	0.30 to 0.45
Conventional Tillage	0.15 to 0.25
Smooth fallow	0.15 to 0.20
Rough fallow, cultivated	0.20 to 0.30
Crop residues	0.25 to 0.35
Meadow, heavy turf	0.30 to 0.40

For agricultural conditions, monthly values are often used to reflect the seasonal changes in land surfaces conditions depending on cropping and tillage practices. Additional tabulations of Manning's n values for different types of surface cover can be found in: Weltz, et al, 1992; Engman, 1986; and Mays, 1999. Manning's n values are not often calibrated since they have a relatively small impact on both peak flows and volumes as long as they are within the normal ranges shown above. Also, calibration requires data on just overland flow from very small watersheds, which is not normally available except at research plots and possibly urban sites.

INTFW Coefficient that determines the amount of water which enters the ground from surface detention storage and becomes interflow, as opposed to direct overland flow and upper zone storage (estimate, then calibrate). Interflow can have an important influence on storm hydrographs, particularly when vertical percolation is retarded by a shallow, less permeable soil layer. INTFW affects the timing of runoff by effecting the division of water between interflow and surface processes. Increasing INTFW increases the amount of interflow and decreases direct overland flow, thereby reducing peak flows while maintaining the same volume. Thus it affects the shape of the hydrograph, by shifting and delaying the flow to later in time. Likewise, decreasing INTFW has the opposite effect. Base flow is not affected by INTFW. Rather, once total storm volumes are calibrated, INTFW can be used to raise or lower the peaks to better match the observed hydrograph. Typical and possible value ranges are shown in the Summary Table.

IRC Interflow recession coefficient (estimate, then calibrate). IRC is analogous to the groundwater recession parameter, AGWRC, i.e. it is the ratio of the current daily interflow discharge to the interflow discharge on the previous day. Whereas INTFW affects the volume of interflow, IRC affects the rate at which interflow is discharged from storage. Thus it also affects the hydrograph shape in the 'falling' or recession region of the curve between the peak storm flow and baseflow. The maximum value range is 0.3 – 0.85, with lower values on steeper slopes; values near the high end of the range will make interflow behave more like baseflow, while low values will make interflow behave more like overland flow. IRC should be adjusted based on whether simulated storm peaks recede faster/slower than measured, once AGWRC has been calibrated. Typical and possible value ranges are shown in the Summary Table.

LZETP Index to lower zone evapotranspiration (unitless) (estimate, then calibrate). LZETP is a coefficient to define the ET opportunity; it affects evapotranspiration from the lower zone which represents the primary soil moisture storage and root zone of the soil profile. LZETP behaves much like a 'crop coefficient' with values mostly in the range of 0.2 to 0.7; as such it is primarily a function of vegetation; Typical and possible value ranges are shown in the Summary Table, and the following ranges for different vegetation are expected for the 'maximum' value during the year:

Table A4. Recommended LZETP Parameter Range for Initial Model Setup

Vegetation / Crop Type	Lower Zone ET Potential (LZETP)
Forest	0.6
Grassland	0.4
Row crops	0.5
Barren	0.1
Wetlands	0.6

Monthly Input Parameter Tables:

In general, monthly variation in selected parameters, such as CEPSC and LZETP should be included with the initial parameter estimates. However, adjustments to the monthly values should be addressed only after annual flow volumes are matched well with monitored data. All monthly values can be adjusted to calibrate for seasonal variations.

MON-INTERCEP Table:

Monthly values for interception storage. Monthly values can be developed based on the data presented in the discussion in PWAT-PARM4/CEPSC and the Summary Tables.

MON-UZSN Table:

Monthly values for upper zone storage. For agricultural areas under conventional tillage, lower values are used to reflect seedbed preparation in the spring with values increasing during the growing season until harvest and fall tillage. See PWAT-PARM4/UZSN discussion and Summary Tables for guidance.

MON-MANNING Table:

Monthly values for Manning=s n for the overland flow plane. Monthly values can be used to represent seasonal variability in ground cover including crop and litter residue. See discussion in PWAT-PARM4/NSUR for Manning's n as a function of agricultural conditions.

MON-INTERFLW Table:

Monthly values for interflow parameter (INTFW) are not often used.

MON-IRC Table:

Monthly values for interflow recession parameter are not often used.

MON-LZETPARM Table:

Monthly values for LZETP for evapotranspiration from the lower zone can be developed using an expected maximum value from the PWAT-PARM4/LZETP discussion and the range of values presented in the Summary Tables. Monthly variable values should be used to reflect the seasonality of evapotranspiration, in response to changes in density of vegetation, depth of root zone, and stage of plant growth.

PWAT-STATE1 Table:

CEPS, SURS, IFWS, UZS, LZS, AGWS, are initial values for storage of water in interception, surface ponding, interflow, the upper zone, lower zone, and active groundwater, respectively, and GWVS is the initial index to groundwater slope. All these storages pertain to the first interval of the simulation period. The surface related storages (i.e. CEPS, SURS, IFWS) are highly dynamic, and will reach a dynamic equilibrium within a few days, at most. These state variables can be left blank, or set to 0.0 unless an individual storm is being simulated. The soil storages (i.e. UZS, LZS, and AGWS, and the GWVS) are much less dynamic, so their beginning values can impact the simulation for a period of months to a few years.

If possible, users should allow as long a startup time period as possible (i.e. set the simulation period to begin prior to the period you=ll use for comparison against monitoring data or other use); as noted each of these storages should reach a dynamic equilibrium within a few years of simulation. UZS and LZS should be set equal to UZSN and LZSN respectively, unless it is known that the starting date is during a particularly wet or dry period; starting values can be increased or decreased if wet or dry conditions were evident prior to the simulation period. AGWS is a bit more problematic. If far too high or too low, baseflow will be excessive or skewed low for several months or years, depending on AGWRC and KVARY. Improper values of GWVS can also cause simulation accuracy problems again for lengths of time depending on values of AGWRC and KVARY. However, since when KVARY is set to 0.0 seasonal recession is not represented and GWVS is not calculated. To avoid problems, then, AGWS should be set to 1.0 inch and GWVS to 0.0 for initial simulation runs. If the simulation period is limited in duration, you can check and reset these state variables to values observed for the same period in subsequent years with similar climatic conditions. However, if major calibration changes are made to the parameters controlling these storages (e.g. UZSN, LZSN, INFILT), then the initial conditions should be checked and adjusted during the calibration process. The values for AGWS and GWVS should be checked and adjusted as noted above, which assuming a yearly cycle of groundwater storage, can be compared to values during similar seasons in the simulation period. If the initial simulated baseflow (before the first significant rainfall) is much different from the initial observed streamflow, then further adjustments can be made to raise or lower the flow rates.

IMPLND Parameters

IWAT-PARM1 Table:

The IWAT-PARM1 table includes a number of flag variables to indicate either the selection of a simulation algorithm option, or whether the parameter will be treated as a constant or be varied monthly. As with PWAT-PARM1, where flags indicate monthly variability, corresponding monthly values must be provided in Monthly Input Parameter tables (see below following IWATPARM3 section).

CSNOFG Flag to use snow simulation data; must be checked (CSNOFG=1) if SNOW module is run.

RTOPFG Flag to select overland flow routing method. If RTOPFG=0, a new routing algorithm is used. RTOPFG=1 results in the use of the method used by predecessor models (HSPX, ARM, and NPS). Recommendation: set RTOPFG=1; this method is more commonly used and has been subjected to more widespread application.

VRSFG Flag to select constant or monthly-variable retention storage capacity, RETSC. Monthly values are not often used.

VNNFG Flag to select constant or monthly-variable Manning's n for overland flow plane, NSUR. Monthly values are not often used.

RTLIFG Flag to determine if lateral surface inflow to the impervious land segment will be subject to retention storage (RTLIFG=1). This flag only has an impact if the another land segment drains to the impervious land segment; otherwise lateral surface inflow is nonexistent. This feature is not commonly used in most HSPF applications.

IWAT-PARM2 Table:

LSUR Length of assumed overland flow plane (feet), (measure/estimate). See PWATPARM2/ LSUR discussion. For impervious areas, LSUR reflects the overland flow length on directly connected, or effective impervious area (EIA), and is usually in the range of 50 to 150 feet, although longer lengths may apply in commercial or industrial regions of large metropolitan areas. Impervious surfaces that drain to pervious land, rather than to a reach, are considered part of the pervious land segment and not part of the EIA.

SLSUR Average slope of the assumed overland flow path (unitless), (measure/estimate). See PWAT-PARM2 / SLSUR discussion.

NSUR Manning's n for overland flow plane (estimate). See PWAT-PARM4 / NSUR discussion. Recommendation: set NSUR within the range of 0.05 to 0.10 for paved roads and parking lots.

RETSC Retention (interception) storage of the impervious surface (inches) (estimate). RETSC is the impervious equivalent to the interception storage variable (CEPSC) used for pervious land segments. RETSC is the depth of water that collects on the impervious surface before any runoff occurs. A study of five urban watersheds in the Puget Sound region conducted by the U.S. Geological Survey (Dinicola, 1990) found that a value of 0.10 for RETSC was appropriate. If parking lots and rooftops are designed for detention storage, larger values up to 0.5 inches may be reasonable.

IWAT-PARM3 Table:

The following two parameters are used only if SNOW is being simulated.

PETMAX Temperature below which ET will be reduced by 50% of that in the input time series (degree F), (estimate, then calibrate). See PWAT-PARM3 /PETMAX discussion.

PETMIN Temperature at and below which ET will be set to zero (degree F), (estimate, then calibrate). See PWAT-PARM3 /PETMIN discussion.

Monthly Input Parameter Tables:

MON-RETN Table:

Monthly values for retention storage. Monthly values can be varied to represent seasonal changes in surface retention storage due to litter accumulation or sediment deposition on the impervious surface. Monthly values are not often used.

MON-MANNING Table:

Monthly values for Manning's n for the overland flow plane. As described above for MONRETN, monthly values can be changed to represent seasonal changes on the surface of the impervious area. Monthly values are not often used.

IWAT-STATE1 Table:

RETS and SURS are initial values for storage of water in retention and surface ponding, respectively. Both of these storages pertain to the first day of the simulation period. RETS and SURS are highly dynamic and are only non-zero if the simulation starts during or just following a storm event. They can be left blank or set to zero unless an individual storm is being simulated.