2. Watershed Modeling using HSPF

Transport models, whether for rivers, lakes or estuaries, generally require a prediction of the amount of rain water runoff that occurs during storms. Models that make these predictions are called watershed models. There are two major types. The first of these, called event models, simulates single storms using a variety of methods, but generally solves dynamic flow equations requiring a short time step. The other model type, continuous simulation models, simulates longer periods of time and keeps track of the watershed water balance between storms. The advantage of the continuous simulation models is that they continuously predict the soil moisture conditions, a parameter very important to rainfall runoff prediction. The disadvantage of continuous simulation models is that they require a large volume of data and use large time steps. The implication of the large model time step is that they do not solve dynamic flow equations and generally rely on physically-based, parameterized models. The model HSPF is an example of such a continuous simulation watershed model.

This chapter introduces the hydrologic and water quality components of the HSPF model. The first section gives a generalized overview of the model without supplying details about the algorithms used to solve for the predictive quantities. The second section repeats some of the description and adds more details about the actual algorithms implemented in HSPF. The material for this chapter was taken from Socolofsky (1997).

2.1 HSPF Description

Because of its relatively recent development out of earlier models, HSPF utilizes several advanced programming techniques to provide an organized and efficient model package. HSPF was developed in the late 1970’s as a union between the Stanford Watershed Model, an advanced, process-oriented hydrologic model, and several water quality models developed by the EPA, including the Agricultural Runoff Model (ARM) and the NonPoint Source model (NPS) (Bicknell et al. 1993). Because it was developed out of existing models, further research during HSPF’s creation focused on modularity in the program code and flexibility in the user interface. An IBM pseudo-code compiler was used to test the logic of each of the subroutines before the model was finally programmed in FORTRAN. The end result was a uniform, logical, and efficient program code.

Because of its modular design and organized development, watershed simulations in HSPF can range from the simple to the complex and utilize a variety of methods, processes,
and functions without ever changing the code of the program. Figure 2.1 shows a schematic diagram of how HSPF fits within the system of support models developed for watershed analysis by the EPA and the USGS. All of the input meteorological data as well as the output from HSPF are stored in ANNIE, a watershed database program. Data are input to ANNIE either by running HSPF or by using the application program IOWDM. When HSPF is run, the User Control Input (UCI) file controls the flow of data between ANNIE and HSPF (depicted as the loop structure in Figure 2.1) and instructs HSPF what to do for a given simulation. An expert system, HSPEXP, is currently in development that will guide hydrologic calibration of HSPF as well as perform automated error analysis of simulation results. Combining these programs, the HSPF system provides a flexible tool for watershed data management and analysis.

As background to the model, the following paragraphs describe the important physical processes that are modeled within HSPF. This description demonstrates the physical basis of HSPF which allows it to function as a predictive model.

2.1.1 Hydrologic Cycle

In order to model the continuous response of the watershed to input meteorologic forcing, the land-side components of the hydrologic cycle must be modeled in detail (the atmospheric-side of the hydrologic cycle is incorporated in the input meteorologic time series). To do this, HSPF has routines that model snow accumulation and melt and the com-
2.1 HSPF Description

Infiltration Function

Precipitation

Excess Precipitation

Interception

Root Zone Storage

Surface Runoff

Soil Infiltration

Interflow

Baseflow

Stormflow

Surface Storage

Baseflow Storage

Fig. 2.2. Flow diagram for the surface hydrologic cycle as modeled in HSPF.

Complete land-side water budget, including interception, evapotranspiration, surface runoff, interflow, groundwater baseflow, surface and subsurface detention storages, the root-zone soil moisture balance, and overland and river routing of storm water runoff (Bicknell et al. 1993, Donigian et al. 1984). Most of these land-side hydrologic routines were originally part of the Stanford Watershed Model (Bicknell et al. 1993).

The pathway of precipitation from the land surface to the watershed outlet is first through canopy interception and then to infiltration or runoff. (See Figure 2.2 for a guide to this section on the hydrologic cycle.) Interception storage is modeled as a finite storage volume that must be filled before excess precipitation can reach the land surface; intercepted water is subsequently evaporated. The method of infiltration excess runoff is applied to the remaining precipitation with an infiltration rate of the soil that is assumed to have spatial and temporal variability. This infiltration function effectively divides the precipitation into surface runoff and soil infiltration. Once the surface/subsurface partitioning of precipitation has occurred, water is either routed over the land surface to the channel or through the subsurface system of storages.

Water that does not infiltrate becomes surface runoff which either flows into surface storage, where it eventually evaporates, or becomes storm flow, which is routed by a
modified Chezy-Manning equation over the land surface and to the river network. The Chezy-Manning equation accounts for the runoff delayed response of the watershed due to friction and watershed shape (Bicknell et al. 1993). The infiltrated water, however, follows a more complicated path.

There are basically three possible fates in the subsurface: interflow, baseflow, or root-zone storage. The infiltrated water is first partitioned between interflow and active groundwater recharge in a similar way to how surface water is partitioned between surface runoff and infiltration. Interflow storage is subsequently routed to the stream through a simple linear reservoir. Active groundwater recharge is further partitioned between baseflow storage and root-zone storage and is a function of the index to soil moisture in the model. Root-zone storage terminates in evapotranspiration; baseflow storage is routed to the stream through another simple linear reservoir with a longer residence time than for interflow.

Evaporation is modeled in response to the Potential EvapoTranspiration (PET) rate. Water evaporates first from the interception storage. Further evaporation potential is satisfied sequentially by baseflow, surface detention storage, active groundwater storage, and root-zone storage where each storage has a different resistance to evaporation. In this way the maximum potential of each storage is depleted either until all the storages have contributed their maximum amount to evapotranspiration or until the PET has been fully satisfied.

Snow melt is modeled by a complete energy balance between the snow pack and the environment. This energy balance considers wind, solar radiation, snow pack reflectivity, ground temperature (conduction), and air temperature (convection). Below a threshold temperature, precipitation falls as snow where the density of new snow is derived from the density of dry snow and the temperature. Snow disappears through melt or sublimation based on the energy balance already described.

### 2.1.2 Flow Routing

Water that reaches the river network either from surface runoff, interflow, or baseflow continues downstream through a tanks-in-series model of the river network. The river is divided into several tanks, where the outflow characteristics of each tank reflect the physical flow in a given reach of the Charles River. The dimensions of each tank are controlled by the river flow and by the importance of mixing in the chemical transport portion of the model.

### 2.1.3 Pollutant Routing

HSPF provides advanced land-side loading functions and standard instream routing algorithms to simulate the occurrence and transport of generalized contaminants from the watershed. Transformation processes are not assumed to occur on the watershed, but rather land-side functions determine the pure loading of the contaminant to the river.
Watershed surface loading functions use the familiar build-up and wash-off equations developed for other nonpoint source loading models. Loading from the subsurface is limited to constant concentrations for interflow and baseflow runoff. In all cases, the contaminant is modeled as a conservative tracer on the land side of the watershed model.

Once the pollutant reaches the river, however, it advects, diffuses, transforms, and dies off through processes including hydrolysis, oxidation by free radical oxygen, photolysis, volatilization, biodegradation, and temperature-dependent, first-order decay. Advection and diffusion are modeled by considering each of the tanks in the river network to be fully mixed, making the dispersion coefficient a function of the number and size of tanks. These techniques allow the concentration and load of a contaminant to be determined at any point in the watershed (Bicknell et al. 1993, EPA 1992, Donigian et al. 1984).

Through watershed loading and river routing of chemicals, a wide range of water quality questions can be addressed. From the simple bacterial contaminants discussed here to complex nutrient interactions, HSPF provides a general framework in which many questions in environmental chemistry can be studied. If additional complexity in these functions becomes necessary, the modular design of HSPF encourages the development and incorporation of new models to replace weaknesses.

2.1.4 Land Use Discretization

Land use can be discretized in HSPF through the modeling of multiple pervious land segments (PLSs). A PLS is any land type that exhibits a uniform hydrologic response to input meteorologic forcing (Bicknell et al. 1993, Donigian et al. 1984). PLSs can be differentiated in terms of geology, climate, elevation, and land use, or any combination thereof.

In order to route runoff from the individual PLSs to the channel network, the contributing area from each PLS to each of the channel tanks must be delineated on a watershed map. Figure 2.3 shows a sample section of land comprised of three land uses that drain to one channel tank. HSPF calculates the water balance for each PLS separately through the functions described above assuming a unit area of watershed surface. The actual watershed storages and fluxes are computed by areally-weighted sums of the individual PLS storages and fluxes (Bicknell et al. 1993). Because the water balance on each PLS is calculated independently of the other PLSs, there is no interaction between the storages and fluxes on different land use types.

This aspect of the model classifies it as a lumped-distributed model. The runoff for each land use is calculated by a lumped-parameter model, but the result is distributed over the watershed according to the spatial occurrence of each land use in the watershed. A distributed model would consider the interaction between land uses, and a wholly lumped model would combine all the land uses into a single box model. Since land uses remain discretized in the model, we can simulate current, past, and predicted future development in the watershed by discretizing the Charles River Watershed into an adequate number
Unit runoff and storage for one acre is calculated for each PLS over each timestep.

Fig. 2.3. Schematic of the land use discretization in HSPF showing the independence of the individual PLSs and the calculation of the simulated watershed runoff from the unit runoff of each PLS.

of PLSs. This aspect of the model is crucial to resource management planning in the IM3 study.

An artifact of HSPF’s lumped-distributed formulation is that HSPF was designed to compute the hydrograph and chemical loading function at the outlet of the watershed and not to specifically compute the spatial distribution of flow or loading throughout the watershed. In order for the outlet hydrograph to be correct, however, the spatial distribution must be correct, or errors must exist that are canceled when flow or load are summed at the outlet. Therefore, to predict the longitudinal occurrence of a contaminant along the river, multiple calibration locations for both flow and water quality are required; the simple, classic measurements at the outlet are insufficient.

This brief introduction should provide the background necessary to understand how HSPF is applied.
2.2 Technical Description of Important Processes in HSPF

HSPF is a unique model that draws from standard concepts in hydrology and from a series of other hydrologic models; therefore, a rigorous introduction to the important processes used in this model is required. The remaining sections present this introduction. For detailed documentation of the computer code and the related research behind the logic of each of these algorithms, see the HSPF Version 10 Manual by Bicknell et al. (Bicknell et al. 1993). A step-by-step introduction and case study for how HSPF can be used for a hydrologic study is given in the Application Guide by Donigian et al. (Donigian et al. 1984).

This section assumes a basic knowledge of hydrology, modeling, and the standard algorithms that could be found in introductory hydrology texts such as Bedient and Huber (Bedient & Huber 1992) and Fischer et al. (Fischer et al. 1979). In cases where standard procedures are used, they are merely referenced. When an algorithm is relatively unique to HSPF, a more detailed explanation is given. The goal of this appendix is for the general hydrologist to find all of the information necessary to understand the details of the model algorithms.

2.2.1 Hydrologic Description of HSPF

HSPF is a continuous simulation hydrologic model that grew out of a number of EPA models, including the NPS model, ARM, and the Stanford Watershed Model. The basic feature that sets a continuous simulation model apart from an event-based model is that the inter-storm periods are modeled through a series of soil-moisture and snow-melt routines. Once the model has simulated the hydrologic cycle on the land surface, water and pollutants can be routed through a drainage network. The following sections present the details of the hydrologic cycle and drainage routing for HSPF.

Continuous Hydrologic Cycle. In order to model the continuous response of the watershed to input meteorologic forcing, the land-side components of the hydrologic cycle must be modeled in detail (the atmospheric-side of the hydrologic cycle is incorporated in the input meteorologic time series). To do this, HSPF has routines to model snow accumulation and melt and the land-side water budget, including interception, evaporation, transpiration, surface runoff, interflow, groundwater baseflow, surface and subsurface detention storages, the root-zone soil moisture balance, and overland and river routing of storm water runoff (Bicknell et al. 1993, Donigian et al. 1984). Most of the land-side hydrologic routines in HSPF were part of the Stanford Watershed Model (Bicknell et al. 1993).

The pathway of water from precipitation to the watershed outlet is first through canopy interception, then to infiltration or runoff, where infiltrated water moves through a series of underground storages and surface runoff is routed down the river network. Refer to Figure 2.2 for a flow diagram depicting these processes. The partitioning between surface
and subsurface runoff along with the subsurface storage system is described in detail in the following paragraphs; river routing is covered in Section 2.2.1.

**Infiltration Process.** HSPF attempts to describe both the temporal and spatial variations in infiltration occurring over a pervious land segment (Bicknell et al. 1993). In order to capture the temporal variation in infiltration, a special case solution for cumulative infiltration ($F$) at a point is taken as

$$ F = st^{1/2} + at $$

(2.1)

where $s$ and $a$ are constants related to soil properties (Bicknell et al. 1993, Donigian et al. 1984). By differentiating Equation 2.1 in time, an expression for the infiltration rate ($f$) becomes

$$ f = \frac{dF}{dt} = \frac{1}{2}st^{-1/2} + a. $$

(2.2)

If we take $a$ to be small, then the product $fF$ is a constant. To allow for generality and to match measured data, the general expression used in HSPF is

$$ fF^b = k, $$

(2.3)

where the constant $k$ is related to the soil infiltration rate (Bicknell et al. 1993).

To include the effects of spatial variability, a linear probability density function for infiltration rate over the land segment is assumed (Bicknell et al. 1993). The average infiltration rate as a function of time ($\bar{f}(t)$) can be found from Equation 2.3. Expressing Equation 2.3 for $\bar{f}(t)$ in terms of model parameters, we have

$$ \bar{f}(t) = \frac{I_0}{(\frac{L(t)}{L_N})^b} $$

(2.4)

where $I_0$ is the temporal and spatial average infiltration rate of the soil, $L(t)$ is the lower zone storage, a parameter for the soil moisture storage, and $L_N$ is a nominal storage level for the lower zone storage. The exponent $b$ is usually taken as two. Therefore, $I_0$ replaces $k$ in Equation 2.3, and $F$ is taken to be the ratio of the actual lower zone storage to a nominal storage volume. Figure 2.4 helps to illustrate the infiltration process. The line labeled as the infiltration rate is defined by $\bar{f}(t)$ together with the selection of a linear probability density function and represents the soil’s potential for infiltration across the land segment. The horizontal line represents the actual precipitation reaching the land surface. By induction, the amount of water above the infiltration line does not infiltrate but is available for runoff, and the amount of water below the infiltration line is infiltrated and partitioned among the subsurface storages.

**Subsurface Partitioning.** Water that has infiltrated the land surface is partitioned in the subsurface into interflow, lower zone storage (which represents the root zone storage), and baseflow. Interflow receives the highest priority for water and is determined by drawing a second line in Figure 2.4 below the infiltration line, where the ratio of the ordinates of the infiltration line to the interflow line is given by
2.2 Technical Description of Important Processes in HSPF

% of land surface with infiltration rate less than \( f \)

\[ R = 2I_{if} \frac{L(t)}{L_N} \]  \hspace{1cm} (2.5)

where \( I_{if} \) is a calibration parameter for partitioning of interflow (Bicknell et al. 1993). Any water above the interflow line and below the infiltration line is then put into the interflow storage.

The lower zone storage is adjusted next from the remaining water according to a smooth function of \( \frac{L(t)}{L_N} \) as depicted in Figure 2.5. The smoothness of Figure 2.5 represents the dynamic nature of the lower zone storage in that the volume of allowable storage is not fixed and recharge does not occur in a step fashion, but rather is dependent on the amount of water already in storage compared to a nominal storage volume. The lower zone storage is most closely linked to soil moisture and represents some of the water stored in the root-zone soil horizon as well as moisture that would effect recharge and interflow in the unsaturated zone.

Infiltrated water that does not go into interflow or lower-zone storage is finally placed in the active groundwater storage.

**Subsurface Flow.** Flow through the subsurface takes the form of interflow or baseflow, where interflow can be thought of as perched groundwater flow during and immediately after storms or flow through the unsaturated zone, and where baseflow is the traditional groundwater contribution to stream flow. Both interflow and baseflow are considered as simple linear reservoirs where the outflow is dependent upon the storage volume and a recession rate.
The general equation for groundwater outflow $G$ over one time step as parameterized in the model is

$$ G = R_G (1 + K_v S_0) S_G $$

(2.6)

where $R_G$ is the groundwater recession constant, $K_v$ is a parameter to make the groundwater storage to outflow nonlinear, $S_0$ is an index to the groundwater slope, and $S_G$ is the groundwater storage at the start of the interval (Bicknell et al. 1993).

Interflow outflow ($I$) has a similar form given by

$$ I = K_1 I_{in} + K_2 S_I $$

(2.7)

where $K_1$ and $K_2$ are variables defined as

$$ K_1 = 1 - \frac{K_2}{-\delta \ln (R_I)} $$

$$ K_2 = 1 - \exp (\delta \ln (R_I)) $$

$I_{in}$ is the interflow inflow during the time step, $S_I$ is the interflow storage, $R_I$ is the interflow recession constant, and $\delta$ is the time step for the simulation (Bicknell et al. 1993).

The effect of interflow and baseflow in the model is to provide two storage mechanisms with different characteristic times that are physically linked to watershed phenomena. The baseflow and interflow recession constants are calibration parameters used to match hydrograph shape at the watershed outlet.
Evapotranspiration Process. The EvapoTranspiration (ET) submodel must consider all of the evaporative fluxes occurring on the watershed. Since the volume of water that leaves a watershed as evapotranspiration exceeds the total volume of stream flow in most hydrologic regimes, evapotranspiration is an important aspect of the water budget (Bicknell et al. 1993). Input time series of Potential EvapoTranspiration (PET) are compared to the available water on the watershed during each time step and the flux of Actual EvapoTranspiration (AET) is calculated as follows (taken from Bicknell, et al. (Bicknell et al. 1993)):

1. **Baseflow.** The first source to satisfy PET comes from active groundwater outflow. This represents losses such as from riparian vegetation and deep-rooted trees. The modeler specifies the percent of total PET that can be met by baseflow; water is withdrawn only from the active groundwater outflow over the time step.

2. **Interception Storage.** There is no limit on the rate of ET from interception storage; therefore, interception storage is depleted until the PET is met or until there is no more water in interception storage.

3. **Upper Zone Storage.** ET from the upper zone is controlled by the ratio of the upper zone storage \((U(t))\) to its nominal storage volume \((U_N)\). If the ratio is greater than two, the ET proceeds at the potential rate, otherwise ET from the upper zone is reduced by an amount dependent on the upper-zone storage deficiency.

4. **Active Groundwater.** ET not satisfied by the above storages can then be sought from the active groundwater storage. Here, again, the modeler specifies the percent of the remaining PET that can be met from active groundwater. That amount of PET is then satisfied unless the groundwater storage is insufficient.

5. **Lower Zone Storage.** ET from the lower zone is the last storage from which PET can be satisfied. Lower zone storage represents soil moisture conditions and is largely dependent on soil properties and the percent and type of vegetative cover. A parameter representing the maximum ET opportunity over the land segment is calculated and then a linear probability density function is assumed for the spatial distribution of evaporation potential, just as for the infiltration rate parameter. The ET potential across the lower zone is then compared to the remaining PET, just as the precipitation is compared to the infiltration rate in Figure 2.4. PET up to the lower zone ET potential is satisfied from the lower zone storage.

The ET algorithms consider each of the above fluxes in series in the order listed above. The parameters that control the flux from each storage then become calibration parameters, and are adjusted until the basin water balance given by

\[
\frac{dS}{dt} = P - E - R
\]

(2.8)

is satisfied, where \(S\) is the watershed storage, \(P\) is the precipitation, \(E\) is the AET and \(R\) is the basin runoff through the outlet. If a long enough sequence is considered and basin
changes are minimal, \( \frac{ds}{dt} \) will be zero, and \( E \) should balance measured \( P \) and \( R \) at a gaging station (Donigian et al. 1984). Further discussion of calibration is given in Chapter 4.

**Flow Routing.** Flow routing takes place in two regimes: on the overland flow plane and in the river channel network. First, the water that did not infiltrate is partitioned between surface runoff and upper zone storage. The upper zone storage has a nominal value less than the lower zone storage, but is partitioned by the same function as shown in Figure 2.5 except that the 50% partition intercept occurs at \( \frac{U(t)}{U_N} \) equal to two and not one (Bicknell et al. 1993). The upper zone storage represents swales, curbs, surface depressions, and numerous other features resulting in ponding.

Surface water not partitioned to the upper zone storage is finally available for runoff and is routed by a modified form of the Chezy-Manning equation for overland flow (Bicknell et al. 1993). Water that is not routed off the watershed to the channel becomes available for infiltration in the next time step.

Water that reaches the channel is routed by a tanks-in-series model where a discharge relationship must be specified at the outlet of each tank. Inflow to a tank over one time step comes from upstream tanks, overland flow (runoff), diversions, and possible return-flows. The volume of the tank is updated, and the downstream discharge is finally computed from the volume-discharge relationship at the downstream end (Bicknell et al. 1993). Tables of volume-discharge relationships for each of the tanks in the network are part of the UCI file and must be specified by the user.

**2.2.2 Transport Description of HSPF**

HSPF provides advanced land-side loading functions and standard instream routing algorithms to simulate the occurrence and transport of generalized contaminants over the watershed. A generalized contaminant is defined by the user in the UCI file by the transformation processes and rate kinetics that govern the contaminant’s interaction with the environment. Transformation processes are not assumed to occur on the watershed, but rather land-side functions determine the pure loading of the contaminant to the river. Once the pollutant reaches the river, however, it advects, diffuses, transforms, and dies-off through processes including hydrolysis, oxidation by free radical oxygen, photolysis, volatilization, biodegradation, and temperature-dependent first-order decay.

The following paragraphs describe how the contaminant is routed through the watershed. Chapter 5 demonstrates how bacteria was defined from these generalized processes.

**Land-side Accumulation and Wash-off.** In general, land-side pollutant pathways are complex and not well known, incorporating flow over the land surface and through complex subsurface lattices in the unsaturated and saturated groundwater zones. Despite the complexity of the problem, much research has gone into representing the loading of watershed contaminants to rivers, and developments in the NPS model, HSP and algorithms specific to HSPF can be used in HSPF simulations that match reasonably well with measured data. Two dominant types of pollutant generation are considered for general
Watershed Loading of a General Contaminant

\[ S_o = A_o + S_o \left( 1 - R_o \right) \]

\[ S_{off} = S_o \left( 1 - \exp \left( \frac{q}{k_w} \right) \right) \]

\[ L_0 = f(t) \]

\[ L_g = k_g \]

\[ L_i = k_i \]

Fig. 2.6. Modeled watershed loading processes for a general quality constituent. \( S_o \) represents build-up due to processes like atmospheric deposition and \( S_{off} \) represents wash-off due to the storm water runoff, \( Q_{storm} \). \( L_0 \), \( L_g \), and \( L_i \) are the dry, groundwater, and interflow loads, respectively.

constituents: sediment associated removal and generalized build-up and wash-off (Bicknell et al. 1993). Sediment removal assumes that the loading of a contaminant from the land surface is proportional to the sediment loading. Build-up and wash-off assumes that there are known deposition rates that load the contaminant to the watershed surface and that the loading is a function of the watershed storage of the contaminant and the surface runoff. Figure 2.6 depicts the build-up and wash-off functions used by HSPF.

Although the surface transport of contaminants is relatively complex in HSPF, the subsurface pathway for general contaminants is greatly simplified. Interflow and baseflow are each assumed to have different constant concentrations of the generalized contaminant, making the assumption that prolonged contact with soils and aquifer material has produced an equilibrium between the water and the contaminant. This is perhaps reasonable for such pollutants as selected metals, dissolved solids, and the calcium carbonate system; however, studies have shown that even these equilibria are governed by complex redox reactions that can change outflow concentrations by orders of magnitude over times as short as days depending on the redox conditions of the soil (Benner et al. 1995, Hornberger...
et al. 1994). As an alternative to a constant concentration, HSPF provides an algorithm (the agri-chemical submodel) that can treat some of the subsurface dynamics, particularly for agricultural organic chemicals, but requires a five-minute time step in all cases and a detailed *a priori* knowledge of subsurface loading conditions.

The bacteria study conducted in this thesis used the simple build-up and wash-off parameterization with constant outflow concentrations for subsurface waters. Possible association with sediment was also investigated, and these algorithms provided enough flexibility to make useful predictions for bacteria. To use the more detailed algorithms, a much greater knowledge of bacterial sources and fate processes would be required which is beyond the scope of this research.

**Channel Routing.** Once the pollutant load to the channel has been determined, there is a much better understanding of the transport processes, and standard routing techniques can be used. HSPF uses a series of continuously stirred mixed reactors (CSTRs) to simulate the advection and diffusion of constituents in the river network. The dispersion coefficient becomes a function of the number and size of each of the reactors. For the advective portion of the process to be stable, a Courant condition also specifies that each tank be long enough that all the water in the tank does not flow out over one time step. These two conditions combine to give criteria for defining the network discretization; Chapter 3 discusses the network development for the Charles River project.

### 2.2.3 Land Use Discretization in HSPF

Land use can be discretized in HSPF through the modeling of multiple pervious land segments (PLSs). A PLS is any land type that exhibits a uniform, hydrologic response to input meteorologic forcing (Bicknell et al. 1993, Donigian et al. 1984). PLSs can be differentiated in terms of geology, climate, elevation, and land use, or any combination thereof. The water balance calculations for each of the PLSs are described in the following sections.

**Spatial Representation.** In order to route runoff from the individual PLSs to the channel network, the contributing area to each of the channel tanks (called reaches) must be delineated on a watershed map. The area of each of the PLSs within the reach area is tabulated in the UCI file. Figure 2.3 shows a sample reach comprised of three land uses. HSPF calculates the water balance for each PLS, as described above, assuming a unit area of watershed surface. The actual watershed storages and fluxes are computed as areally-weighted sums of the individual PLS storages and fluxes (Donigian et al. 1984). Because the water balance on each PLS is calculated independently of the other PLSs, there is no interaction between the storages or fluxes on different land use types.

Impervious area is modeled by a special land segment called an impervious land segment (ILS) which has the same formulation as the PLS but with no infiltration and no subsurface processes. Very little area of a watershed is completely impervious, as assumed by the ILS, so a small fraction of a watershed is given an impervious land use
type (Donigian et al. 1984). ILSs produce very fast response to precipitation due to their parameterization as directly connected impervious area; hence, the actual amount of ILS land becomes a calibration parameter to adjust the fast response of the basin hydrograph. Chapter 4 discusses the calibration of impervious land use for the Charles River Watershed model.
2. Watershed Modeling using HSPF