Confirmation of the LSPC Model using selected HSPF Modules

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Background

The Loading Simulation Module, in C++ (LSPC) is a watershed modeling system that includes streamlined Hydrologic Simulation Program FORTRAN (HSPF) algorithms for simulating hydrology, sediment, and general water quality on land as well as a simplified stream transport model. A key advantage of LSPC is that it has no inherent limitations in terms of modeling size or model operations. In addition, the Microsoft Visual C++ programming architecture allows for seamless integration with modern-day, widely available software such as Microsoft Access and Excel.

A benchmark testing methodology was developed to compare the underlying computational algorithms of the LSPC model to known HSPF solutions. Identical HSPF and LSPC configuration and parameterization of the same watershed were run in parallel, and the results were compared and evaluated for similarities and differences. Figure 1 shows the schematic representations of the test watershed as they appear in the LSPC and BASINS-WinHSPF interface windows.

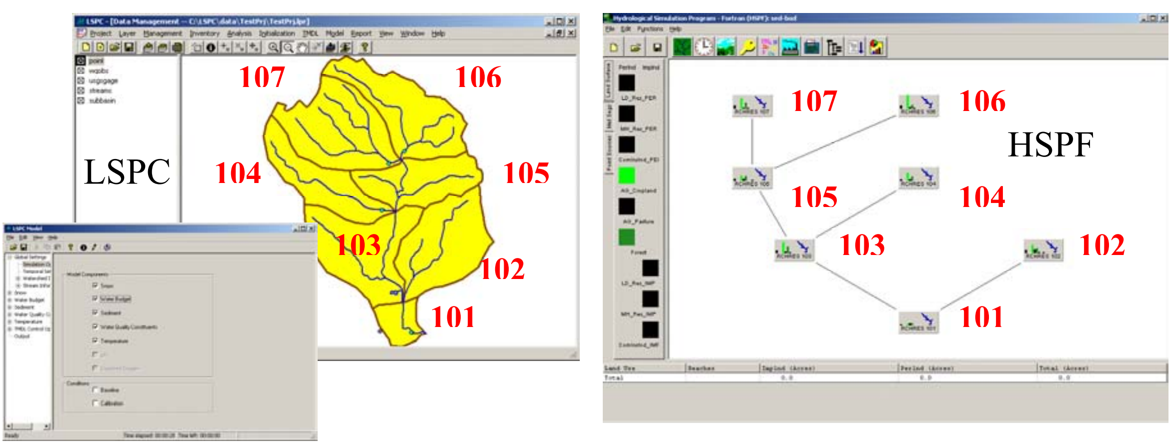


Figure 1. Schematic representations of the test watersheds in LSPC and WinHSPF.

Testing scenarios were constructed for: 1) land hydrology – with and without snow simulation, 2) instream hydraulics, 3) sediment, and 4) general water quality. The second level of permutations for these scenarios included 1) 100% pervious land, 2) 100% impervious land, 3) mixed landuse. The third level of permutations involved checking the computational scheme for instream routing (HSPF parameter name *ks*): 1) *ks* = 0 explicit formulation, and 2) *ks* = 0.5 implicit formulation. LSPC introduces a separate parameter, *af*, which applies to the instream routing scheme for hydraulics, and is independent of *ks*, which is still maintained for load/concentration routing. LSPC currently supports *af* = 0, but *ks* may vary.

The total number of unique LSPC and HSPF modeling scenarios was 12 (2 x 3 x 2). There were 2 at level 1 (with and without snow), 3 level 2 (pervious, impervious, and mixed landuse), and 2 at level 3 (*af*=0 / *ks*=0 and *af* =0 / *ks* =0.5). Two points were selected for evaluating model results: a headwater stream outlet (107), representing one immediate upland drainage, and the most downstream outlet (101), representing flow routed through 6 upstream reaches plus the immediate upland subwatershed area.

Selected results are highlighted below. The discussion follows the logical hydrologic progression of the processes in the models. The first section compares the underlying land hydrology simulations and the instream reach hydraulics. The second section shows differences in sediment simulation. The paper concludes with a look at general water quality comparisons.

Hydrology and Hydraulics

Land Hydrology

Some of the results are presented below. Figure 2 shows surface runoff, interflow outflow, and groundwater outflow from the completely pervious example. LSPC output is plotted on the vertical axis against HSPF output on the horizontal axis.

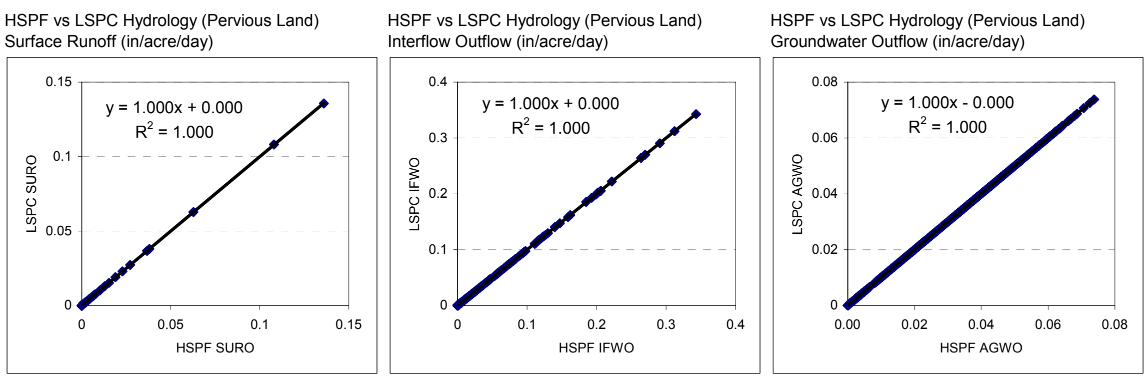


Figure 2. Surface runoff, interflow outflow, and groundwater outflow using 100% pervious land units in all watersheds.

Unlike HSPF, LSPC does not have an IMPLND module. Whenever a land segment is designated as impervious, infiltration and all subsurface processes are automatically disabled in the formulation. To confirm the accuracy of this assumption, an LSPC land segment was designated as pervious and the INFILT parameter was set to zero in the parameter list. The results of both methods exactly equal to HSPF (Figure 3). HSPF does not permit the user to set INFILT equal to zero in the PERLND module.

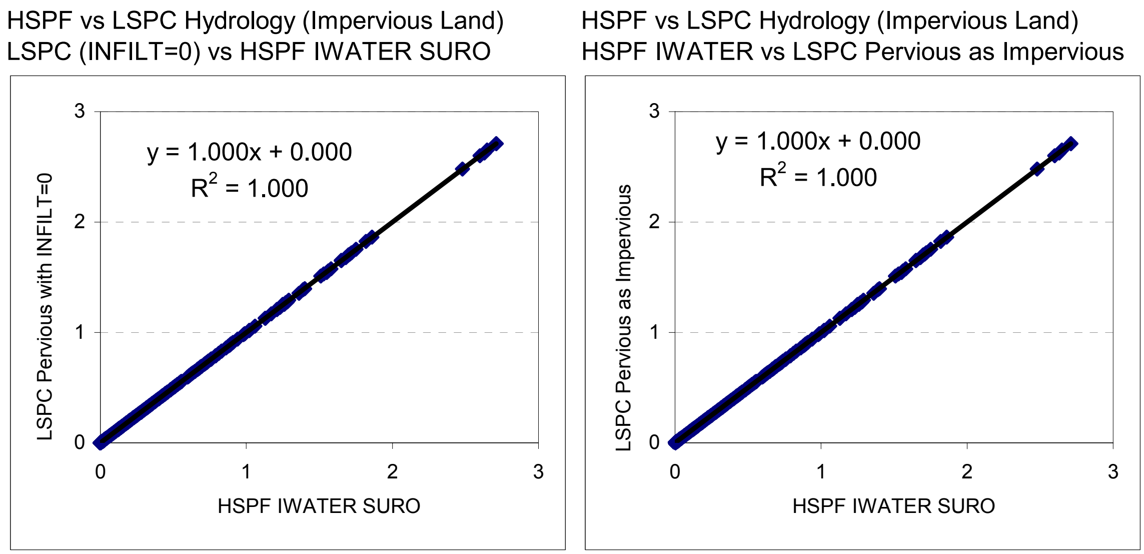


Figure 3. Surface runoff using 100% impervious land units in all watersheds and verification of IMPLND INFILT parameter.

Instream Hydraulics

Following the land hydrology confirmation, instream routing of flow was evaluated using RCHRES routing in HSPF. The methodology involves developing Functional Tables (F-Tables), which are rating curves relating depth, volume, surface area, and reach outflow. For this example, each watershed had only one outlet. Trapezoidal channel geometry was configured for each reach segment in both HSPF and LSPC. Identical 20-layer F-tables were developed for all the reach segments in both the LSPC and HSPF configuration. When configured with 1 outlet per stream, an HSPF F-table is allowed a maximum of 20 layers, while LSPC allows for 60 layers. For this example, the F-tables for both models were designed so that all possible flows fell within 20 layers.

Figure 4 shows reach outflow from the outlets of headwater stream 107 and downstream segment 101. LSPC output is plotted on the vertical axis against HSPF output on the horizontal axis. Notice the log-scale on the axes. The observed variation in LSPC output, for values between 0.05 and 0.3 cfs, occurs because HSPF rounds F-Table values to two decimal places, while LSPC uses double precision real numbers. The differences are less noticeable as flow accumulates downstream. Figure 5 shows scenario results for when all upland area is completely impervious. The variation is slightly more pronounced (even for the downstream reach) because of the flashy nature of the impervious inflows. Although LSPC provides higher precision in F-table representation, the computational differences are essentially inconsequential; and therefore, should be considered negligible.

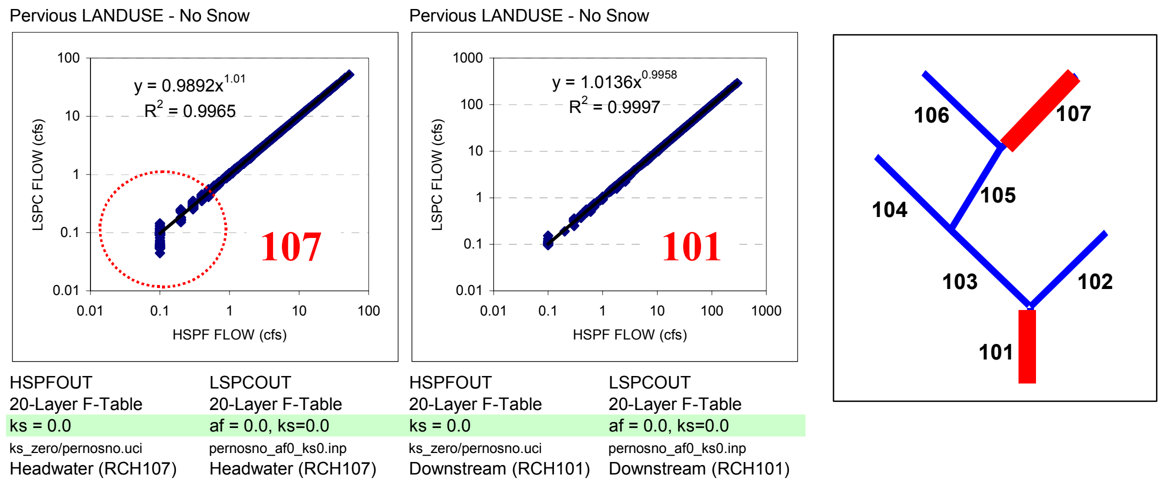


Figure 4. Reach outflow results for LSPC vs. HSPF model output at both a headwater and a downstream reach segment with completely pervious upland area using an explicit flow routing scheme.

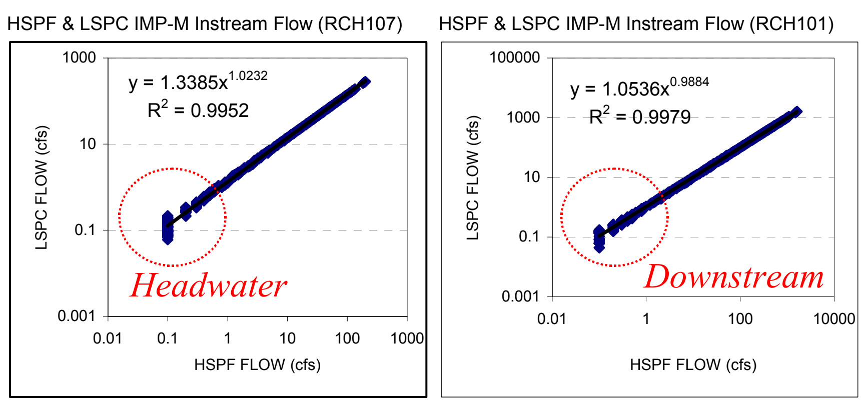


Figure 5. Reach outflow results for LSPC vs. HSPF model output at both a headwater and a downstream reach segment with completely impervious upland area using an explicit flow routing scheme.

Erosion and Sediment Processes

Land Surface Erosion and Sediment

After establishing consistency in terms of hydrology simulation, a second level of analysis involved comparing erosion and sediment formulations. LSPC uses the formulations in the SOSED1 subroutine from HSPF for simulating detachment and washoff of sediment, as well as scouring of the soil matrix for pervious segments. Model results from pervious segments are essentially identical for both LSPC and HSPF. For impervious land segments, the equations in LSPC are slightly different from those used in SOLIDS block of HSPF. Figure 6 shows LSPC vs. HSPF results, in terms of sediment outflow, for mixed land, 100% impervious land, and 100% pervious land.

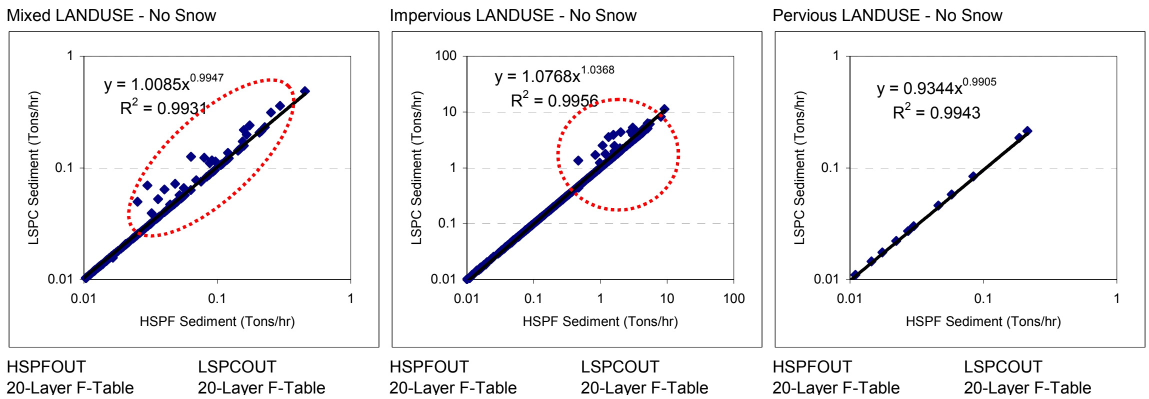


Figure 6.   LSPC vs. HSPF results for mixed land, 100% impervious land, and 100% pervious land.

For impervious SOLIDS simulation in HSPF, the storage of solids on the land surface is updated once a day on days when precipitation did not occur during the previous day, whereas in LSPC, the storage of solids on surface is updated once per *interval* when precipitation did not occur during the previous *interval*. Just as in HSPF, the accumulation parameter itself is specified as a daily value; however, LSPC computes the interval-equivalent and updates solids storage on the land on an interval basis. If HSPF and LSPC are run on a daily timestep interval, the results are essentially identical.

The advantage of the LSPC interval based deposition is that it tends to result in a response curve that tends to be more smooth; however, since *interval* instead of *day* determines when accumulation resumes following a rainfall event, a there are storm events when LSPC will show a slightly higher solids predictions over HSPF, as would be expected with the change in formulation. In areas dominated by imperious land, these slight differences are more noticeable. For long-term total sediment yield, the difference between LSPC and HSPF total predicted load was 7% for mixed landuse, 9% for all-impervious, and -0.3% for all-pervious.

Instream Sediment Routing

In terms of instream sediment transport, LSPC and HSPF use different formulations. LSPC uses the sediment transport formulation from the Environmental Fluid Dynamics Code (EFDC) for instream sediment transport. Although the EFDC formulation differs from subroutine BDEXCH (exchange with bed) from HSPF, it is possible to parameterize them to give the same conceptual results for comparison. Equations 1 and 2 are for sediment deposition in LSPC and HSPF respectively. For equation 1 and 2, both are structurally equivalent when WSEDO = W, SEDN=1 and SEXP=1.

LSPC Sediment Depostion ($TAU < TAUD$):

$$Deposition\_Flux = WSEDO\left(\frac{sed\_conc}{SEDN}\right)^{SEXP}\left(1-\frac{TAU}{TAUD}\right) \qquad \textit{Equation 1}$$

Where:

WSEDO	= sediment settling velocity
sed_conc	= concentration of suspended sediment fraction
SEDN	= normalizing sediment concentration
SEXP	= exponent for sediment settling
TAU	= simulated instream shear stress
TAUD	= normalizing shear stress

HSPF Sediment Depostion ($TAU < TAUD$):

$$Deposition\_Flux = W \times sed\_conc\left(1-\frac{TAU}{TAUCD}\right) \qquad \textit{Equation 2}$$

Where:

W	= particle settling velocity in still water
sed_conc	= concentration of suspended sediment fraction
TAU	= simulated instream shear stress
TAUCD	= critical shear stress for deposition

Similarly, equations 3 and 4 are for sediment resuspension in LSPC and HSPF respectively. They are structurally equivalent when WRSPO = M, TEX=1, and TAUR=TAUN=TAUCS.

LSPC Sediment Resuspension ($TAU > TAUR$):

$$resuspension\_Flux = WRSPO\left(\frac{TAU - TAUR}{TAUN}\right)^{TEX} \qquad \textit{Equation 3}$$

Where:

WRSPO	= reference sediment resuspension rate
sed_conc	= simulated instream sediment concentration
TAUN	= normalizing stress
TEX	= exponent for sediment resuspension
TAU	= simulated instream shear stress
TAUR	= boundary stress above which resuspension occurs

HSPF Sediment Depostion (*TAU* < *TAUD*):

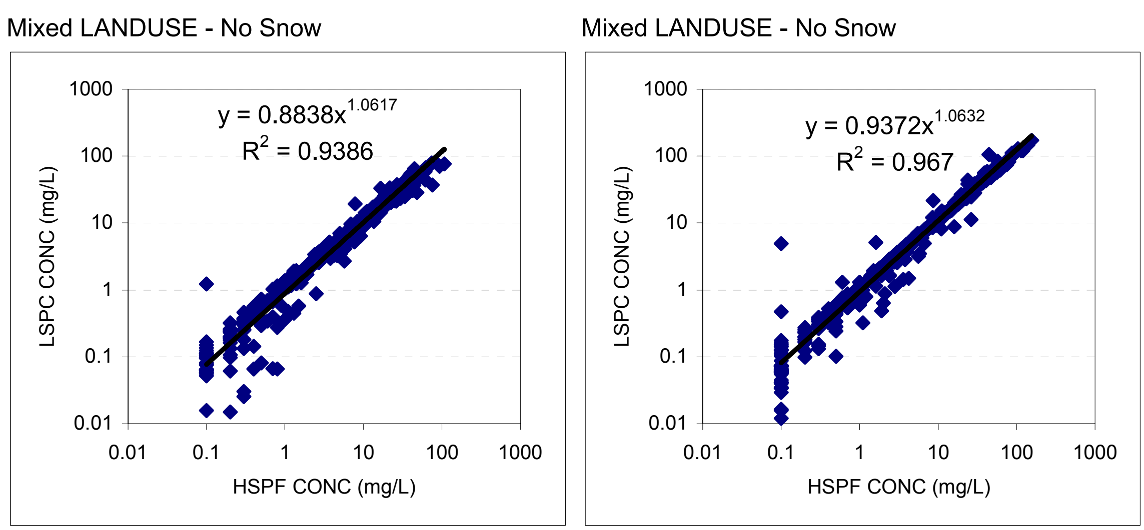
$$resuspension\_Flux = M \times \left(\frac{TAU}{TAUCS} - 1 \right) \qquad \textit{Equation 4}$$

Where:

M	= erodibility coefficient for the sediment fraction
TAU	= simulated instream shear stress
TAUCS	= critical shear stress for scour

Both were parameterized in based on their independent formulations so that the inflowing sediment was divided into the same class breakdown (sands, silt, and clay), and forced to remain in suspension as it flowed through the stream network. Figure 7 below shows the instream sediment response for both the headwater stream 107 and the downstream segment 101 for the mixed landuse scenario. The difference in terms of total sediment load transported through the streams was 4.8% for Reach 107, and 12.5% for Reach 101.

It is important to note also that LSPC does not round or truncate model output, but instead, it maintains double-precision real-number output. This increased numerical precision does not equate to "better" model results. It indicates that during low-flow periods, and between storm events, LSPC shows a gradual sediment decline, sometimes after HSPF has already reached zero.



HSPFOUT	LSPCOUT	HSPFOUT	LSPCOUT
20-Layer F-Table	20-Layer F-Table	20-Layer F-Table	20-Layer F-Table
ks = 0.5	af = 0.0, ks=0.5	ks = 0.5	af = 0.0, ks=0.5
ks_half/mixnosno.uci	mixnosno_af0_ks05.inp	ks_half/mixnosno.uci	mixnosno_af0_ks05.inp
Headwater (RCH107)	Headwater (RCH107)	Downstream (RCH101)	Downstream (RCH101)

Figure 7. LSPC vs. HSPF results for instream sediment concentrations assuming complete suspension during transport (implicit load routing scheme).

General Water Quality

Land Pollutant Outflow

Finally, after establishing consistency in terms of both hydrology and sediment transport simulation, the third level of analysis involved comparing the resultant General Water Quality pollutant production results. For surface pollutants, LSPC applies build-up and washoff by simulation interval. HSPF simulates either on a daily basis or on an interval basis. HSPF was configured so that the formulation was identical to LSPC, and also, the same rates and parameters were used in both configurations. Observed differences in the results are associated with variable precision and rounding. Figure 8 below shows predicted load comparisons for the mixed landuse, 100% impervious, and 100% pervious scenarios. Figure 9 shows timeseries comparisons for a selected period of time. Notice that the load axes in both figures are plotted as log-scale to exaggerate observed low-level variation.

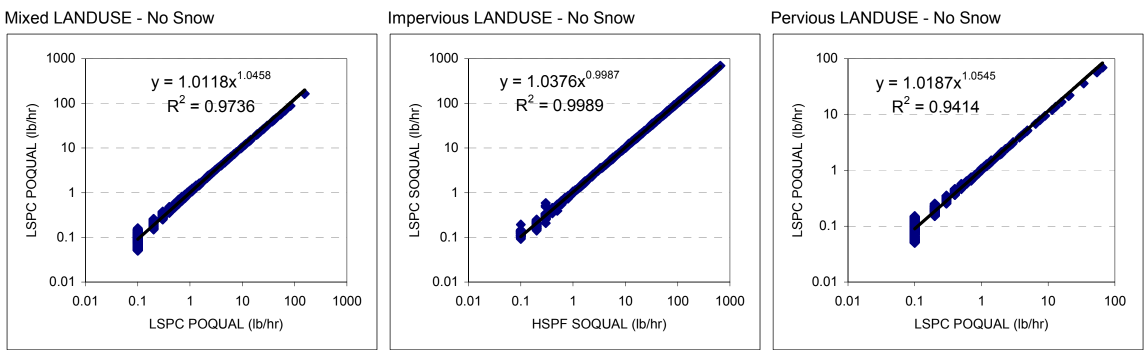


Figure 8. LSPC vs. HSPF general water quality load predictions for the mixed landuse, 100% impervious, and 100% pervious landuse scenarios.

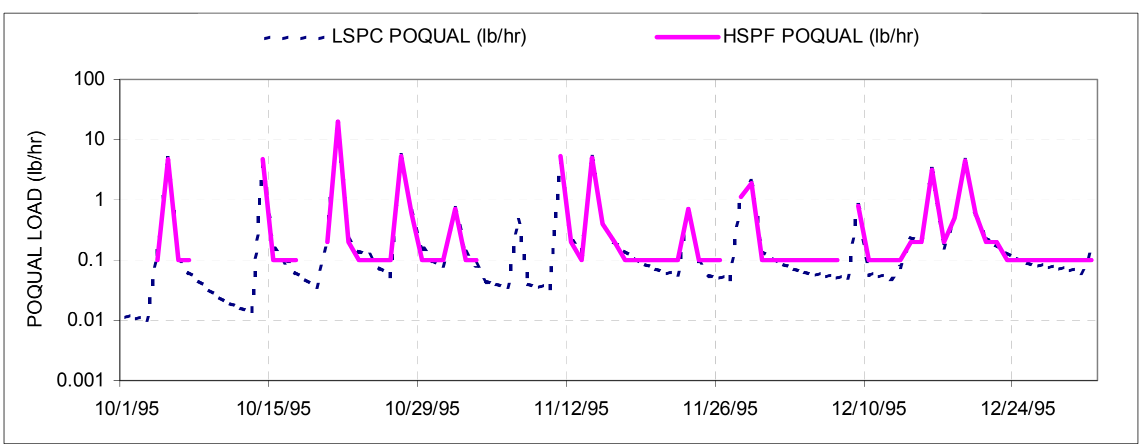
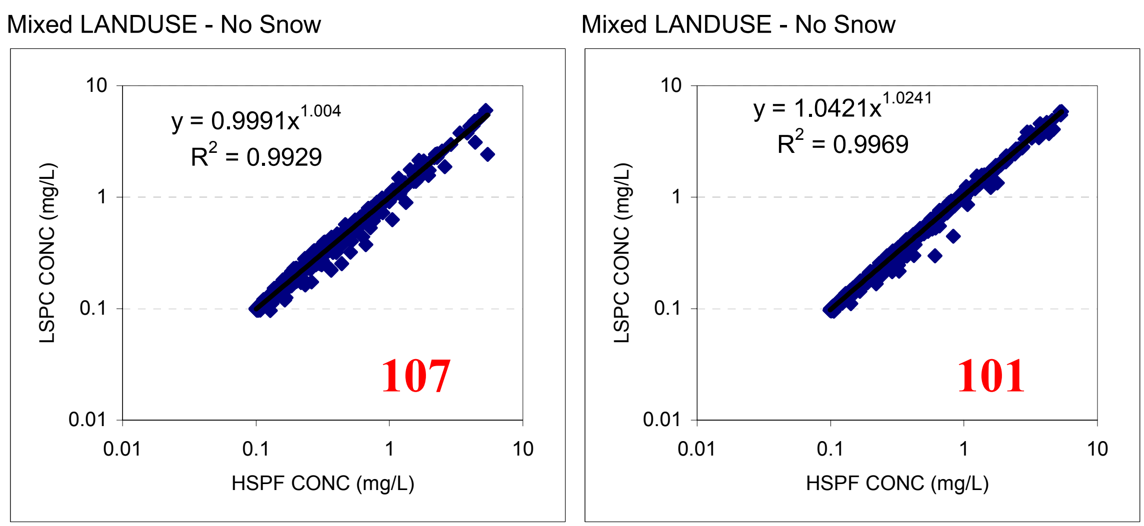


Figure 9. Selected timeseries for LSPC vs. HSPF general water quality load predictions for the mixed landuse.

The total long-term simulated loads for LSPC were slightly higher than for HSPF in all three scenarios (5.3% mixed landuse, 4.0% all-impervious, and 5.7% all-pervious). The total simulated LSPC load for the data shown in figure 9 was 4.7% higher than the same HSPF prediction. This clearly illustrates the differences due to rounding. The fact that LSPC provides greater numerical precision does not mean that it gives better model results; the difference is not significant. However, it does provide smoother transitions in model results between storm events, which is computationally convenient when linking models.

Instream Pollutant Routing

In terms of instream pollutant transport, LSPC and HSPF use the same formulation. A first order decay constant is specified to represent the loss of the general quality constituent as it flows through the reach network. For this example, the instream decay values in both models were set to 0.00001 to keep the pollutant in suspension as much as possible. Figure 10 shows LSPC vs. HSPF instream concentrations from the mixed landuse scenario. In terms of long-term load (sum of instream flows times concentrations) the difference between LPSC and HSPF is 0.8% for the headwater segment 107, and 2.8% for the downstream segment 101. The slight numerical scatter observed in the plots is due to the compounded effects of HSPF rounding.



HSPFOUT	LSPCOUT	HSPFOUT	LSPCOUT
20-Layer F-Table	20-Layer F-Table	20-Layer F-Table	20-Layer F-Table
ks = 0.5	af = 0.0, ks=0.5	ks = 0.5	af = 0.0, ks=0.5
ks_half/mixnosno.uci	mixnosno_af0_ks05.inp	ks_half/mixnosno.uci	mixnosno_af0_ks05.inp

Figure 10. Selected timeseries for LSPC vs. HSPF general water quality load predictions for the mixed landuse (implicit routing scheme).