JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION
VOL. 38, NO. 5 AMERICAN WATER RESOURCES ASSOCIATION OCTOBER 2002

CALIBRATION OF STORM LOADS IN THE SOUTH PRONG WATERSHED, FLORIDA, USING BASINS/HSPF[1]

M. J. Bergman, W. Green, and L. J. Donnangelo[2]

ABSTRACT: The South Prong watershed is a major tributary system of the Sebastian River and adjacent Indian River Lagoon. Continued urbanization of the Sebastian River drainage basin and other watersheds of the Indian River Lagoon is expected to increase runoff and nonpoint source pollutant loads. The St. Johns River Water Management District developed watershed simulation models to estimate potential impacts on the ecological systems of receiving waters and to assist planners in devising strategies to prevent further degradation of water resources. In the South Prong system, a storm water sampling program was carried out to calibrate the water quality components of the watershed model for total suspended solids (TSS), total phosphorous (TP), and total nitrogen (TN). During the period of May to November 1999, water quality and flow data were collected at three locations within the watershed. Two of the sampling stations were located at the downstream end of major watercourses. The third station was located at the watershed outlet. Five storm events were sampled and measured at each station. Sampling was conducted at appropriate intervals to represent the rising limb, peak, and recession limb of each storm event. The simulations were handled by HSPF (Hydrologic Simulation Program-Fortran). Results include calibration of the hydrology and calibration of the individual storm loads. The hydrologic calibration was continuous over the period 1994 through 1999. Simulated storm runoff, storm loads, and event mean concentrations were compared with their corresponding observed values. The hydrologic calibration showed good results. The outcome of the individual storm calibrations was mixed. Overall, however, the simulated storm loads agreed reasonably well with measured loads for a majority of the storms.

(KEY TERMS: pollution modeling; storm loads; Total Suspended Solids (TSS); Total Phosphorus (TP); Total Nitrogen (TN); HSPF; BASINS; watershed modeling.)

INTRODUCTION

The South Prong watershed is located along the central Atlantic Coast of Florida. With a drainage area of 36,000 acres, it is a major tributary system of the Sebastian River (Figure 1). On an annual basis, the South Prong delivers approximately 40 percent of the total volume discharged by the Sebastian River. In turn, the Sebastian River system is the second largest source of fresh water discharge to the Indian River Lagoon (IRL). Consequently, it and the South Prong are major contributors of the pollutants that attenuate light within the water column and limit the extent and diversity of sea grasses, the keystone ecological community of the IRL.

Future development in this basin and throughout the IRL is expected to increase runoff and nonpoint source pollutant loads, exacerbating an adverse impact to the estuarine ecosystem. To address this growing concern, the St. Johns River Water Management District (District) is developing Pollutant Load Reduction Goals (PLRGs). An important tool to be used in this task is a hydrodynamic/water quality model devised for the IRL that goes by the acronym CH3D (Sheng *et al.*, 2001). However, this model requires input data on runoff and nonpoint source pollutant loads from contributing watersheds.

In order to predict possible impacts on the Sebastian River and to provide the needed input for the CH3D model, the District developed watershed simulation models of the area. These models enable the simulation of different development/management scenarios on runoff volumes and loads within the basin. The South Prong model can be used as a regional planning tool in the Sebastian River area. By expanding the use of these models to other similar basins within the IRL, the lagoon wide effect of such scenarios can be simulated and the results conveyed to the CH3D model for PLRG development.

[1]Paper No. 01184 of the *Journal of the American Water Resources Association*. **Discussions are open until April 1, 2003.**
[2]Respectively, Senior Professional Engineer and Environmental Scientist, St. Johns River Water Management District, P.O. Box 1429, Palatka, Florida 32178-1429; and Engineer III, St. Johns River Water Management District, 7775 Baymeadows Way, Suite 102, Jacksonville, Florida 32256 (E-Mail/Bergman: mbergman@sjrwmd.com).

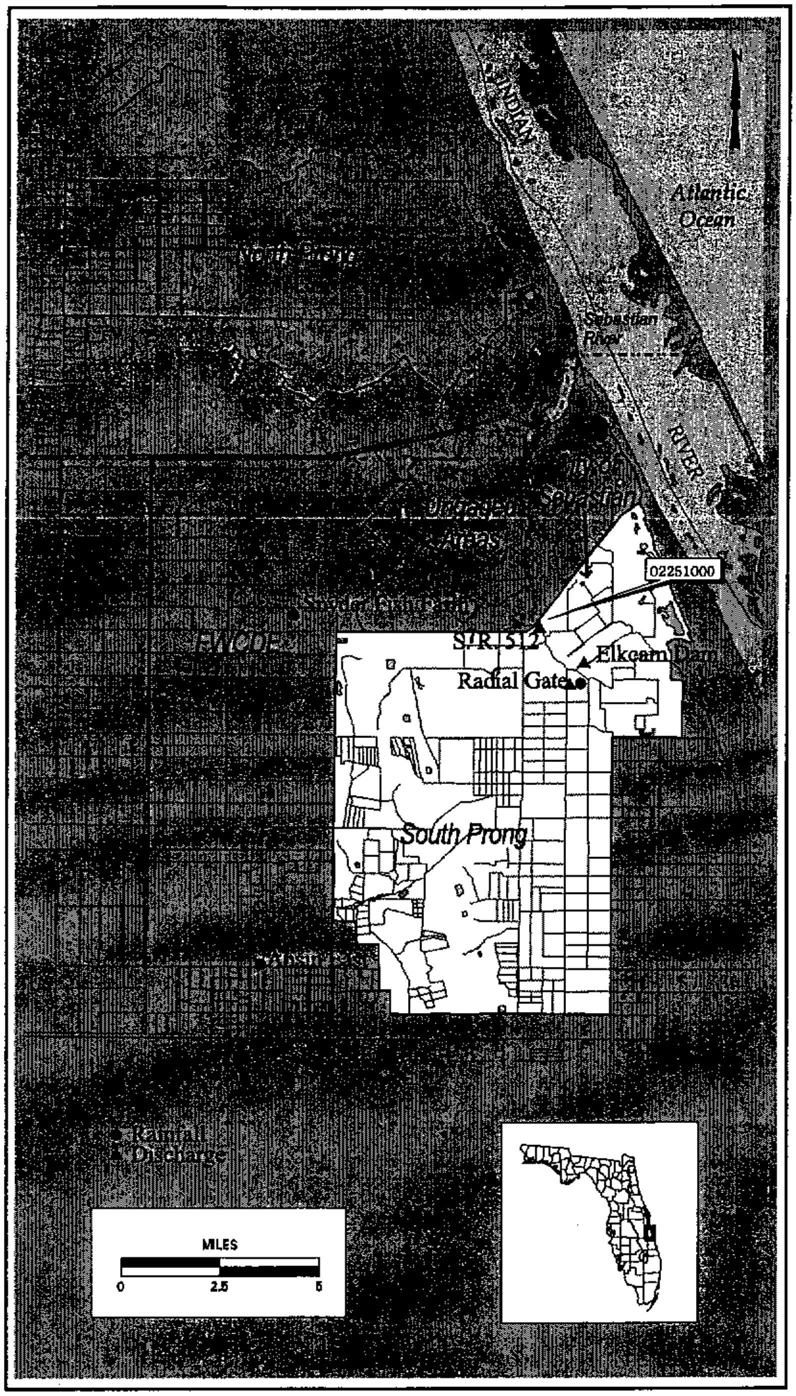

Figure 1. South Prong Watershed.

As a step toward this final goal, a storm water sampling program was carried out within the South Prong watershed to calibrate the water quality components of the watershed model. Discussion of the calibration process is provided in logical sequence, addressing the three major components of the model: hydrology, then sediments, and lastly water quality. The calibrations were tested with predefined criteria (statistical and physical) and the results tabulated for quick but comprehensive overview by the reader.

The modeling framework selected for this application was BASINS (Better Assessment Science Integrating Point and Nonpoint Sources) (EPA, 1998). Through GIS (Geographic Information System), BASINS provides an integrating framework in which data preprocessing, model building, simulation, and post-processing are combined. The actual simulation of the hydrologic and water quality processes was handled by HSPF (Hydrologic Simulation Program Fortran). Details can be found in the HSPF users manual (Bicknell *et al.*, 1993).

Conceptually, HSPF simulates the hydrology of a watershed by a network of linear/nonlinear storages that represent the components of the natural system. Inflow and outflow of these storages are controlled by parameters that describe the physical characteristics of each component. The user has to associate parameter values with characteristics of the physical system or obtain values through calibration. Through GIS, the model has access to a wide range of information such as land use, soils, topography, point source discharges, data collection networks, hydrography, and water supply.

Despite a growing use of HSPF in water quality assessment studies, there is an apparent scarcity of literature reporting on its application, particularly within the BASINS framework. Additionally, model simulation results that are presented in the literature often lack criteria of accuracy (Martinec and Rango, 1989). It is within this context that the authors hope that this paper will make a contribution in providing the readers with useful concepts on approaches and limitations.

Project Area

Land use within the South Prong watershed is a mixture of residential development, agriculture (citrus groves), and undeveloped land. The watershed includes the Sebastian River Water Control District, where citrus farming is the major land use. Residential development in the watershed includes the City of Sebastian in the northeast.

Rainfall follows the typical Florida pattern. Annual rainfall measured at Vero Beach, southeast of the watershed, averaged 53.5 inches over the period 1943 through 1995. Most rainfall occurs during the summer months, from June through September. During this period, rainfall occurs mostly in association with local thunderstorm activity, averaging about 26 inches and accounting for about half of the average annual rainfall. During the winter, from December through March, rainfall is generally associated with frontal activity as the result of large scale weather systems. As a consequence, winter rainfall may persist for days and usually affects larger areas than the local summer thunderstorms. Tropical storms affect the region usually during the late summer and early fall at irregular intervals. These storms may cover areas as large as 300 miles across and move relatively slowly. An example is tropical storm Gordon, which occurred in November 1994 and was part of the calibration record used in this study.

Model Description

The three major components of HSPF used in this study are the PERLND, IMPLND, and RCHRES blocks. Specialized submodules in PERLND and IMPLND simulate the processes of pervious and impervious land segments. The RCHRES module handles the channel hydraulics and instream flow processes.

Production of sediments and pollutants at the land surface is handled in HSPF/BASINS by the PERLND and IMPLND modules. Sediment is produced in PERLND by kinetic energy from rain falling on the soil. The detached particles are then available for transport by overland flow. If the overland flow has sufficient energy, scour may also occur. Factors affecting the quantity of detached sediment are rainfall intensity, soil management practices, and the fraction of land surface area under vegetative coverage. These factors are expressed in HSPF by the parameters KRER, SMPF, and CR, respectively. KRER is the detachment coefficient dependent on soil properties and is the primary calibration factor for the sediment detachment process. HSPF allows detached sediment to be reattached to the soil matrix, mimicking processes like compaction, for example. This process is expressed by the parameter AFFIX, which is the fraction by which detached sediment storage decreases each day as a result of soil compaction. The removal of detached sediment from the land surface is determined by the transport capacity of the overland flow. KSER is the coefficient for the transport of detached sediment and is the major calibration parameter. In the simulations, transport capacity is expressed in tons per acre per interval. The quantity of detached sediment is compared with the transport capacity of the overland flow. If the transport capacity is inadequate to carry all the detached sediment, only a fraction of the detached sediment is carried with the overland flow. In such cases the sediment load is transport limited. On the other hand, if the transport capacity exceeds the amount of detached sediment, the load is sediment limited. Impervious areas, represented by IMPLND, yield sediments on impervious areas and are referred to as solids in HSPF. Important parameters here are ACCSDP and KEIM, which are user supplied parameters. ACCSDP is the accumulation rate of solids storage on the impervious surface and is a major calibration parameter for production of sediment on impervious areas. KEIM is the coefficient of transport of solids in the sediment transport equation.

In PERLND, nutrients are simulated as sediment-attached, dissolved in overland flow, and as concentrations in the interflow and ground water. The sediment attached fractions are simulated through user specified potency factors, expressed in pounds of the specific nutrient per ton of sediment. For each nutrient, two potency factors can be supplied: one simulates the sediment-attached nutrients transported by overland flow (POTFW), and the other handles nutrients that are attached to scoured sediments (POTS). Monthly or seasonal variations are possible, but such variations were not performed in this study.

The transport of dissolved nutrients via overland flow is simulated in the model by a process described as buildup and washoff. The general methodology is based on the concept that during dry periods dust, dirt, and pollutants are accumulated on the land surface (buildup). During periods of rainfall, a portion or the entire accumulated load is carried away with the overland flow (washoff). This cycle repeats itself throughout the year. Although the concept was initially developed for impervious areas in urban settings, simulations are performed in a similar fashion for the pervious areas. In HSPF, the function that simulates the buildup process is linear, with parameters for the maximum buildup quantity (SQOLIM) and accumulation rate (ACQOP) to be specified by the user as part of the input data. Washoff is simulated by an exponential decay function, which computes the washoff rate as a function of surface runoff during the simulation interval, storage of pollutant on the land surface at the beginning of the interval, and a user defined parameter representing the depth of surface runoff that results in 90 percent washoff in one hour (WSQOP).

Subsurface flow is the third contributor of pollutant loadings to receiving waters. User specified ground water concentrations, expressed in mg/l, were obtained from well observations in the Florida surficial aquifer. The model allows for monthly variations, though there was insufficient information from the watershed to do so in this study.

The three components are combined in RCHRES for instream transport. RCHRES can simulate a variety of decay processes that may affect the dissolved nutrients. The processes employed in this study were first order decay. The sediment attached fraction of the nutrients is in dynamic equilibrium with the water column. Thus sediment attached nutrients can be released from the sediment and become part of the dissolved fraction in the water column and vise versa. Because this process is relatively slow in comparison with the transport times in the watershed, the exchange of the sediment attached nutrients with the water column was not simulated in this study.

DATA COLLECTION

Three stations to monitor water quality were installed in March and April 1999. The stations were located at the downstream reach of the major watercourses within the project watershed: Elkcam Dam, Radial Gate, and the bridge at State Road 512 (S.R. 512) (Figure 1). The three watercourses monitored in this study have distinct land use characteristics.

The monitoring stations were equipped with tipping bucket rain gauges, continuous surface water level (stage) recording devices, cellular communication systems and automatic samplers.

Stage, stream velocity, and rainfall data at these stations were collected from April through October 1999. Rainfall totals were recorded to the nearest 0.01 inches at five-minute intervals, while stage was recorded to the nearest 0.01 feet every 15 minutes. It should be noted that rainfall data collected at the monitoring stations were of limited areal extent, covered a short period of observation, and were not quality controlled. They were, therefore, not considered suitable for application in the model development. Rather, rainfall at the monitoring sites was used as a triggering mechanism for the collection of water quality samples.

Rainfall

Rainfall data used in this study were hourly accumulations collected at long term stations that were operated by the District. The stations included Radial Gate, Snyder Fish Farm, and Ansin East (Figure 1). These stations also were used in earlier studies on the South Prong (Bergman and Donnangelo, 1996). Average annual rainfall in the area totaled 73, 52, 51, 61, 56, and 60 inches for the years 1994 through 1999, respectively. Based on Thiessen areal distribution, the rainfall stations were assigned to the various portions of the watershed. To better capture the localized nature of some of the rainfall events, original rainfall data were replaced by available NEXRAD data from March 1, 1999, through July 31, 1999.

Storm Discharge

Stage data at all three stations were translated into discharge rates by means of stage discharge relationships. Discharge at S.R. 512 was taken directly from published data by the USGS for gage 02251000 located at the bridge. Discharges at Radial Gate were derived from a stage discharge rating table developed by the District.

The outlet structure at the Elkcam Dam consisted of an earthen embankment with three corrugated metal culverts. No stage discharge rating was available. In order to develop a stage discharge relationship for Elkcam Dam, a HEC-RAS (USACE, 1995) model was developed for the Elkcam-Collier-Schumann waterway, including culverts. HEC-RAS is a computer program that simulates water levels in natural streams and channels for selected discharges. Cross sections of the waterway were obtained from the Flood Insurance Study of Indian River County (FEMA, 1989).

Storm Water Quality

From May 1999 to November 1999, samples from five distinct storm events were collected and analyzed. The constituents for this study were total suspended solids (TSS), nitrate plus nitrite (NOx), total Kjeldahl nitrogen (TKN), and total phosphorus (TP). For each storm event, discrete sample sets were collected at each station and analyzed for the above parameters. Nitrogen and phosphorus in the field samples were expressed as total phosphorus and total nitrogen. Total nitrogen was calculated by summing the results of analysis for TKN and total NOx.

Event mean concentrations (EMCs) were calculated as flow weighted averages of the individual samples collected during each storm event. Mass loadings were calculated by correlating constituent concentrations to corresponding flow volumes in the following manner. Concentrations were applied over time to the midpoint between collected samples. The concentration of the initial sample for each event was applied retroactively to the beginning of the respective storm. The concentration of the last collected sample was applied over time to the end of each event. The end of an event occurred in one of three ways: a return to prestorm flow rates, the onset of a new storm event, or termination based upon time (i.e., when the duration following the last sample collected equaled the duration preceding that sample's collection without returning to prestorm flow rates).

Land Use

Land use is a key component in the simulation of water quality. The many different land uses in the watershed were combined into ten basic land use groups: residential (low, medium, and high density), industrial/commercial, upland forest, tree crops, row crops, pasture, open land, and wetlands. Land use groups were derived from quality assured aerial photo interpretation of 1995 digital orthographic quads and stored within the District's GIS database. These were subsequently imported into the BASINS environment. Basic hydrologic units in the model were constructed from combinations of land use groups, soil types, and hydrologic characteristics.

CALIBRATION AND RESULTS

For practical purposes, a good model could be defined as one capable of making consistently reliable predictions of the watershed behavior under different watershed management scenarios and under different meteorological conditions. The first task in achieving this goal is to calibrate the model components in a step-wise progression using field data: hydrology, sediment, and water quality. Emphasis was placed on the dominant processes of the natural system (e.g., rainfall and evapotranspiration; soil properties affecting infiltration, storage, and runoff; generation of pollutant yields on the land surface through buildup and washoff processes; transport of runoff, sediment, and pollutant yields through the channel system) without unnecessary focus on the less well understood complexities of subprocesses.

The calibrations were tested through the application of simple but meaningful criteria. This included visual inspection of plots of simulated versus observed series, comparisons of simulated and observed volumes over different periods of time, and comparisons of simulated and observed storm loads.

Model performance may vary for different applications. For instance, criteria to assess the accuracy of the hydrologic calibration differ from the calibration criteria for sediment yield or the criteria for nonpoint source pollutant yields. Due to the lack of generally agreed upon standards for the evaluation of simulation results, the criteria listed in Table 1 were used as approximate guidelines (Donigian *et al.*, 1984). The differences between the various applications are apparent. It should be noticed that the percentages listed in the table apply to accumulated loads rather than individual events.

TABLE 1. General Guidelines for Evaluation of Simulation Results.*

	Very Good (percent)	Good (percent)	Fair (percent)
Hydrology/Hydraulics	< 10	10-15	15-25
Sediment	< 15	15-25	25-35
Water Quality	< 20	20-30	30-40

*Source: Application Guide for Hydrological Simulation Program-Fortran (HSPF).

Continuous Hydrologic Calibration

Initially, the South Prong hydrologic model was calibrated at S.R. 512 for the period October 1, 1993, through September 30, 1995 (Bergman and Donnangelo, 1996). The model was validated with additional rainfall and discharge data through June 1996; this was done within the context of a regional study of ungaged areas draining to Sebastian River (Bergman and Donnangelo, 2000). In the current study, the record was extended through October 1999, thus providing another opportunity for model validation. A comparison of simulated and observed discharges indicated that the initial calibration was rather robust and no adjustments to parameters had to be made.

Continuous calibrations over a period of several years could only be carried out at S.R. 512 where long term discharge records were available. Such long term records were not available at either Elkcam Dam or Radial Gate. Consequently, separate hydrologic calibrations at these two sites were not possible.

The center graph of Figure 2 plots simulated and observed discharges over the entire period of simulation at S.R. 512. Overall, simulated and observed discharges were relatively close, with simulated low and high flows matching the corresponding observed values. Simulated and observed duration curves are shown in the bottom graph of Figure 2. The curves, which provide information about the flow distribution, match relatively closely, except at the highest flows where simulated discharges exceeded observed ones.

The ASCE Task Committee on Definition of Criteria for Evaluation of Watershed Models (ASCE, 1993) developed a set of statistics to measure the hydrologic performance of watershed models. For continuous hydrologic simulations the following measures were recommended.

The volume error (Equation 1) measures the deviation of simulated volumes from the observed volumes. It is a direct complement to the visual inspection of the calibration, where simulated and observed time-series are compared in plots.

$$VE = \frac{\sum (Vmeas - Vsim}{\sum Vmeas} 100 \tag{1}$$

where VE = volume error, percent, $Vmeas$ = measured volume, and $Vsim$ = simulated volume.

The Nash-Sutcliffe coefficient (Equation 2) measures the improved prediction of the discharge due to the model. The Nash-Sutcliffe coefficient varies from 0 to 1, with 1 indicating a perfect fit and 0 indicating that the model does not make any contribution to the prediction. Theoretically, the Nash-Sutcliffe coefficient could become negative, which is meaningless where interpretation of the results is concerned.

$$NS = 1 - \frac{\sum_i (Qi - Q'i)^2}{\sum_i (Qi - Q)^2} \tag{2}$$

where NS = Nash-Sutcliffe coefficient, Qi = measured daily discharge at day i, $Q'i$ = simulated daily discharge at day i, and Q = average measured discharge.

The coefficient of gain from the daily mean, daily gain (DG), has the same numerator as the Nash-Sutcliffe coefficient, but in the denominator the average measured discharge is replaced by daily mean discharges. If daily mean discharges show periodic behavior, then using the long term mean in predictions would not be appropriate. The DG coefficient can vary between 0 and 1, with 1 indicating perfect results.

Table 2 presents a summary of the long term calibration results using the above statistical parameters. Volume errors were less than one percent for the entire simulation period and were below ten percent for individual years except in 1994, when the volume error was 11.94 percent.

Nash-Sutcliffe statistics ranged from 0.63 to 0.85 for all years except 1997 (0.44). For the overall simulation the Nash-Sutcliffe statistic was 0.73. This indicated that the model performed adequately. DG statistics ranged from 0.53 (1997) to 0.74 (1996). No substantial improvements could be obtained by replacing the average discharges by their daily means.

Calibration of Storm Loads

Calibration of sediment, phosphorus, and nitrogen loads focused on individual storm events. The

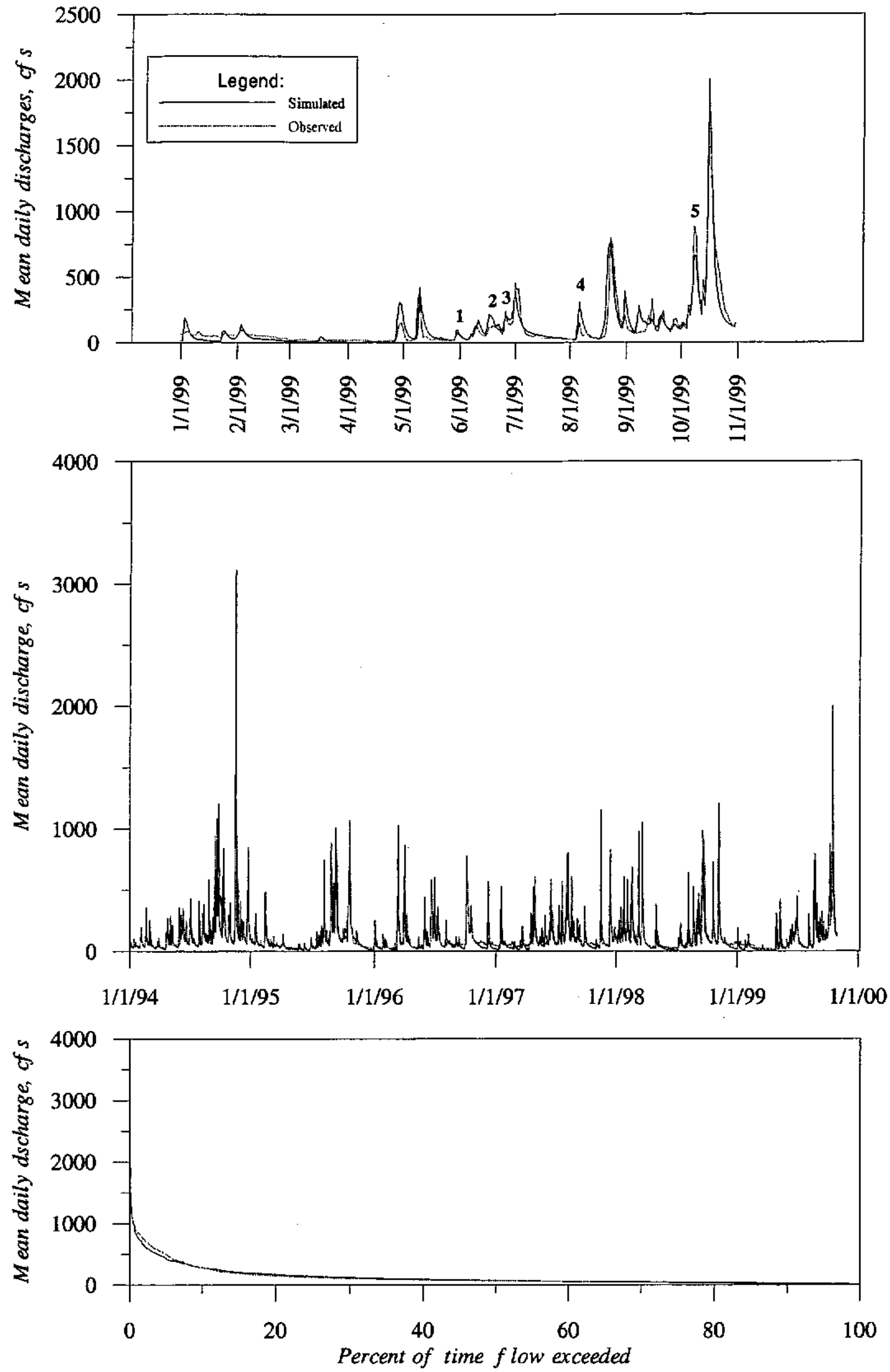

Figure 2. South Prong Discharges at S.R. 512, USGS 02251000, October 1, 1993 to October 31, 1999.

calibrations were carried out over the five observed storm events at the three sample sites: S.R. 512, Radial Gate, and the Elkcam Dam. Simulated and observed storm loads are summarized in Table 3 and simulated and observed event mean concentrations (EMCs) in Table 4. For additional details see Bergman *et al.* (2001).

Storm Volumes. Simulated and observed volumes of the five individual storms at each site were compared. Results are shown in Table 3. The top graph of Figure 2 shows the times of occurrence of each storm as recorded at the S.R. 512 bridge. Rainfall amounts were in the range from one to four inches per storm. Because the storm hydrographs were relatively small and the error percentages were very reasonable, it was not considered necessary to adjust the parameters of the continuous hydrologic calibration described earlier.

TABLE 2. Hydrologic Calibration, South Prong at S.R. 512, USGS 02251000.

Year	Volume Error (percent)	Nash-Sutcliffe (0-1)	Daily Gain (0-1)
1994	11.94	0.73	0.63
1995	7.65	0.80	0.71
1996	-5.60	0.73	0.74
1997	-3.92	0.44	0.53
1998	-10.95	0.63	0.56
1999	-2.33	0.85	0.72
1994-1999	0.58	0.73	0.64

TABLE 3. Summary of Simulated and Observed Storm Loads.

Storm		S.R. 512 (36,150 acres) Land Use: Residential, Agriculture, Undeveloped			Radial Gate (8,709 acres) Land Use: Agriculture			Elkcam Dam (4,047 acres) Land Use: Residential		
No.	Storm Loads	SIM[1]	OBS[2]	%[3]	SIM[1]	OBS[2]	%[3]	SIM[1]	OBS[2]	%[3]
1	Storm Volume (acre ft)	542	722	-25	206	303	-32	38	21	81
	Sediment TSS (lbs)	10,804	4,978	117	3,702	3,528	5	5,498	542	914
	Total Phosphorus (lbs)	206	351	-41	44	189	-77	45	6	650
	Total Nitrogen (lbs)	1,380	1,197	15	483	837	-42	139	36	286
2	Storm Volume (acre ft)	839	560	50	554	201	176	53	32	66
	Sediment TSS (lbs)	14,608	14,464	1	11,060	3,190	247	2,778	729	281
	Total Phosphorus (lbs)	360	398	-10	230	136	69	30	14	114
	Total Nitrogen (lbs)	2,194	1,930	14	1,588	564	182	102	54	89
3	Storm Volume (acre ft)	1,832	1,589	15	381	428	-11	90	50	80
	Sediment TSS (lbs)	24,191	37,888	-36	11,317	5,280	114	1,343	534	151
	Total Phosphorus (lbs)	727	1,484	-51	189	445	-58	37	20	85
	Total Nitrogen (lbs)	5,028	4,550	11	1,071	1,399	-23	218	77	183
4	Storm Volume (acre ft)	2,005	1,020	97	864	394	119	361	278	30
	Sediment TSS (lbs)	82,281	55,248	49	48,976	6,806	620	22,793	27,816	-18
	Total Phosphorus (lbs)	1,149	904	27	523	216	142	240	279	-14
	Total Nitrogen (lbs)	5,914	2,672	121	2,522	974	159	1,032	926	11
5	Storm Volume (acre ft)	5,148	6,015	-14	1,324	1,528	-13	599	417	44
	Sediment TSS (lbs)	31,584	82,566	-62	14,247	103,599	-86	5,373	7,217	-26
	Total Phosphorus (lbs)	1,998	6,269	-68	559	2,296	-76	211	135	56
	Total Nitrogen (lbs)	18,304	24,795	-26	4,931	8,024	-39	1,714	1,233	39
Total	Storm Volume (acre ft)	**10,358**	**9,907**	**5**	**3,329**	**2,854**	**17**	**1,141**	**798**	**43**
of all	Sediment TSS (lbs)	**163,468**	**195,144**	**-16**	**89,302**	**122,403**	**-27**	**37,782**	**36,838**	**3**
Storms	Total Phosphorus (lbs)	**4,440**	**9,406**	**-53**	**1,545**	**3,282**	**-53**	**563**	**454**	**24**
	Total Nitrogen (lbs)	**32,820**	**35,144**	**-7**	**10,594**	**11,799**	**-10**	**3,205**	**2,326**	**38**

[1]SIM = Simulated.
[2]OBS = Observed.
[3]% = 100* (simulated-observed)/observed.

TABLE 4. Summary of Simulated and Observed Storm EMCs.

Storm No.	Event Mean Concentrations	S.R. 512 (36,150 acres) Land Use: Residential, Agriculture, Undeveloped SIM[1]	OBS[2]	%[3]	Radial Gate (8,709 acres) Land Use: Agriculture SIM[1]	OBS[2]	%[3]	Elkcam Dam (4,047 acres) Land Use: Residential SIM[1]	OBS[2]	%[3]
1	Storm Volume (acre ft)	542	722	-25	206	303	-32	38	21	81
	Sediment TSS (mg/l)	7.34	2.54	189	6.62	4.29	54	53.31	9.51	461
	Total Phosphorus (mg/l)	0.140	0.179	-22	0.079	0.230	-66	0.436	0.105	314
	Total Nitrogen (mg/l)	0.938	0.611	54	0.864	1.018	-15	1.348	0.632	113
2	Storm Volume (acre-ft)	839	560	50	554	201	176	53	32	66
	Sediment TSS (mg/l)	6.42	9.52	-33	7.36	5.85	26	19.31	8.39	130
	Total Phosphorus (mg/l)	0.158	0.262	-40	0.153	0.249	-39	0.209	0.161	29
	Total Nitrogen (mg/l)	0.964	1.270	-24	1.056	1.034	2	0.709	0.622	14
3	Storm Volume (acre ft)	1,832	1,589	15	381	428	-11	90	50	80
	Sediment TSS (mg/l)	4.87	8.79	-45	10.95	4.55	141	5.50	3.94	40
	Total Phosphorus (mg/l)	0.146	0.344	-58	0.183	0.383	-52	0.151	0.147	3
	Total Nitrogen (mg/l)	1.011	1.055	-4	1.036	1.204	-14	0.892	0.567	58
4	Storm Volume (acre ft)	2,005	1,020	97	864	394	119	361	278	30
	Sediment TSS (mg/l)	15.12	19.96	-24	20.89	6.36	228	23.26	36.87	-37
	Total Phosphorus (mg/l)	0.211	0.327	-35	0.223	0.202	10	0.245	0.370	-34
	Total Nitrogen (mg/l)	1.087	0.965	13	1.076	0.911	18	1.053	1.227	-14
5	Storm Volume (acre ft)	5,148	6,015	-14	1,324	1,528	-13	599	417	44
	Sediment TSS (mg/l)	2.26	5.06	-55	3.96	24.98	-84	3.31	6.38	-48
	Total Phosphorus (mg/l)	0.143	0.384	-63	0.156	0.554	-72	0.130	0.119	9
	Total Nitrogen (mg/l)	1.310	1.519	-14	1.372	1.935	-29	1.054	1.089	-3
Total of all Storms	Storm Volume (acre ft)	**10,358**	**9,907**	**5**	**3,329**	**2,854**	**17**	**1,141**	**798**	**43**
	Sediment TSS (mg/l)	**7.20**	**9.17**	**-21**	**9.96**	**9.21**	**8**	**20.94**	**13.02**	**61**
	Total Phosphorus (mg/l)	**0.160**	**0.299**	**-47**	**0.159**	**0.324**	**-51**	**0.234**	**0.181**	**30**
	Total Nitrogen (mg/l)	**1.062**	**1.084**	**-2**	**1.081**	**1.220**	**-11**	**1.011**	**0.828**	**22**

[1]SIM = Simulated.
[2]OBS = Observed.
[3]% = 100* (simulated-observed)/observed.

Total Suspended Solids. In this study, the TSS simulation by HSPF included only inorganic components; however, field data, recorded as TSS, likely included organic material. Overall, results of comparing simulated to observed loads at S. R. 512 varied (Table 3). Error percentages ranged from 1 (Storm 2) to 117 percent (Storm 1). At the Radial Gate site, the error percentages were higher (especially for Storm 2). Simulated loads for Storm Events 4 and 5 at the Elkcam Dam compared very well to those observed, but model results for Storm 1 were highly overpredicted.

When TSS loads for all five events were totaled, underprediction occurred by 16 and 27 percent at S.R. 512 and Radial Gate, respectively. An overprediction of 3 percent occurred at the Elkcam Dam. In comparing simulated and observed event mean concentrations a similar picture emerges (see Table 4.). The percent differences for the accumulated five storm events show an under-prediction by the model at the S.R. 512 bridge of 21 percent, but the model overpredicted TSS by 8 and 61 percent at Radial Gate and Elkcam Dam, respectively. Noticeable are the high TSS loads at Radial Gate, as shown in Table 3. Although the accumulated storm volume at Radial Gate is only 30 percent of the volume at S.R. 512, the accumulated TSS load is more than 60 percent of the load at S.R. 512. The most probable reason for this is the way in which the gate is operated. Between most storms, the gate is kept closed and the structure can function as an overflow weir. During such periods, ample opportunity exists for the sediment to accumulate at the bottom upstream of the gate. During storm events, the gate is opened and the accumulated sediment is flushed out of the channel system.

Total Phosphorus. Simulated phosphorus loads at S.R. 512 were mostly underpredicted (Table 3). The model performed relatively well on Events 2 and 4, with a 10 percent underprediction (Event 2), and 27 percent overprediction (Event 4). At the Radial Gate site, both underpredictions and overpredictions occurred. Storm loads totaled over all five events were underpredicted by the model at S.R. 512 and at Radial Gate by about 53 percent. Underpredictions during storm Event 5 accounted for the majority of this difference. When phosphorous loads from only the first four storms were totaled, the differences were reduced to -22 and 0 percent, respectively. At the Elkcam Dam, accumulated loads were overpredicted by 24 percent. This overprediction is attributable in part to lower than expected observed phosphorus concentrations in samples collected during Storm Events 1 and 3. The reason for the lower than expected concentrations is not presently clear but may be attributable to apparent low runoff volumes resulting in longer residence times and higher than expected biological uptake within the Elkcam-Collier-Shumann canal system.

A comparison of EMCs (Table 4) showed similar trends. In general, underpredictions occurred at S.R. 512 and Radial Gate, while overpredictions occurred at the Elkcam Dam. Although the error percentages of simulated and observed concentrations were reasonable, Table 4 shows that the simulated EMCs were underpredicted in 10 out of 15 storm events. One possible explanation for the underpredictions is the possibility that phosphorus is more mobile in the watershed's sandy soils than was assumed in the model. This would be more pronounced in the subwatersheds with significant or dominant agricultural land use (represented by monitoring sites S.R. 512 and Radial Gate) where there has been long term application/accumulation of phosphate.

Total Nitrogen. Predictions of TN loads of individual storms were relatively good. Exceptions were Storms 1 and 3 at the Elkcam Dam, and Storms 2 and 4 at Radial Gate. Loads accumulated over all five storms were underpredicted by 7 and 10 percent at S.R. 512 and Radial Gate, respectively. An overprediction of 38 percent occurred at the Elkcam Dam.

Simulated and observed EMCs are shown in Table 4. The simulations underpredicted TN concentrations in 9 of the 15 events, though the differences were relatively small. Overpredictions by the model largely occurred at the Elkcam Dam for Storm Events 1 through 3.

Total nitrogen was calculated by summing the analytical results of total NOx (nitrate plus nitrite) and Total Kjeldahl Nitrogen (TKN). The largest portion of the TN storm load at each site was due to TKN. Usually, the percentage of ammonia comprising TKN in such systems is insignificant due to rapid uptake by phytoplankton; this is likely the case in this study. Therefore, organic nitrogen is expected to be the main component of the TN load.

Total storm loads receive contributions from both ground and surface water. Nitrogen concentrations in the ground water were reported for a shallow well near Fellsmere. Data were collected at irregular time intervals. From field sampling and laboratory analysis, TKN was determined to be 0.8 mg/l. From this and estimated surface water concentrations (varying about 1 mg/l), probable contributions from ground and surface water to the total storm loads were computed. Using all 15 storms, it was estimated that during storm events, surface water accounted for about 60 to 80 percent of the total TN storm load.

Statistical/Graphical Comparison. The data collected on EMCs did not fall or transform into a normal distribution. Conversely, measured and simulated event loads were lognormally distributed. Even so, nonparametric analyses were first used on the untransformed data to make statistical comparisons between simulated and observed loads. The Wilcoxon Signed Rank Test for Paired Difference was applied to the pooled data (15 events) for all three pollutants (TN, TP, and TSS). The results indicated that no statistical difference existed between the two groups (simulated and observed) for any of the parameters. Parametric analysis (paired t-test) performed on the differences between the transformed samples (observed and simulated) also supported the conclusion of no statistical difference between the groups ($\alpha = 0.05$). The degree to which simulated loads correlated with observed was estimated using Spearman's Rank Coefficient (r_s). The outcome of the analysis indicated there was a relatively strong positive correlation (TN = 0.889, TP = 0.807, TSS = 0.775; p = 0.001). This relationship between loads was further tested using the large sample approximation of Kendall's Tau correlation coefficient (z_s). Here too, a strong linear relationship was indicated ($p \leq 0.001$).

Nonparametric analyses were also applied to simulated and observed EMCs. The results suggested there was a difference between simulated and observed total phosphorous EMCs. It should be remembered that laboratory analysis of field data made no distinction between dissolved and particulate fractions. Had such data been collected and used in the calibration, one might expect to have had greater correlation between model projected and observed EMCs for total phosphorous.

Finally, Figure 3 provides summary plots for all 15 events. Simulated storm runoff volumes, sediment, phosphorous, and nitrogen loads are plotted against

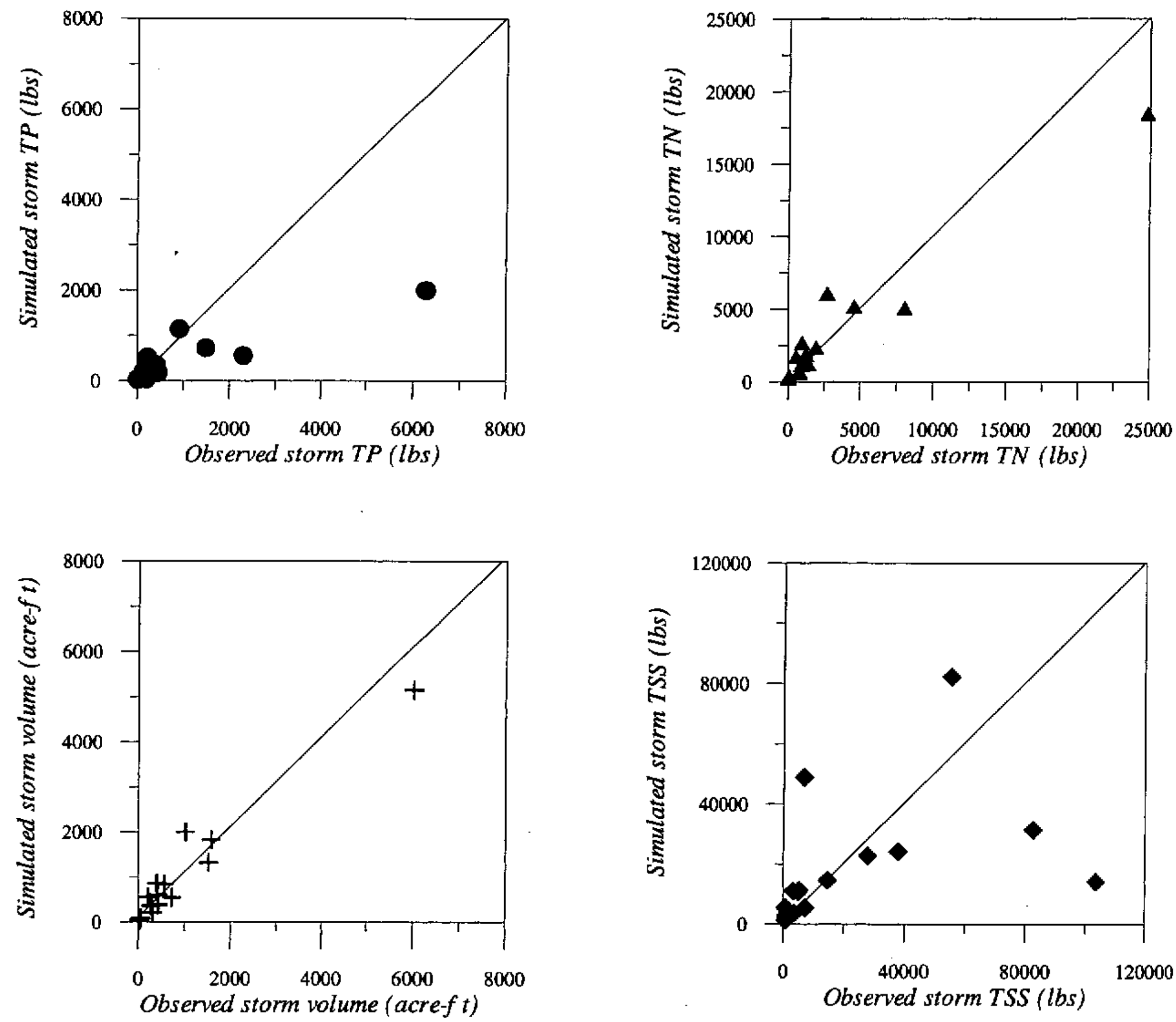

Figure 3. Scatter Plot of Storm Water Loads, South Prong.

their respective observed loads, combining all storms at the three sites. A 45-degree line was added to the plots as a measure of comparison. Storm volumes compared rather well, as did TN. The plots for sediment and phosphorous showed the largest deviation from the 45-degree standard.

SIMULATION OF ANNUAL LOADS

Using the calibrated model, average annual areal loads – expressed in pounds per acre – were predicted from a continuous simulation over the period January 1, 1994, to December 31, 1998. The results are summarized in Table 5. Average TN loads at all three sites were about the same, 7 lbs/acre/year. The average TSS load was the highest at Radial Gate (200 lbs/acre/year), followed by the Elkcam Dam (163 lbs/acre/year), and S.R. 512 (104 lbs/acre/year). The average TP loads at Radial Gate, the Elkcam Dam, and S.R. 512 were 1.65 lbs/acre/year, 1.51 lbs/acre /year, and 1.25 lbs/acre/year, respectively. Because no water quality data were collected over such long period of time, the simulations could not be tested against field observations.

DISCUSSION

The performance accuracy of the model depends on many factors. Of particular importance are the extent and reliability of available data, the capabilities of the

TABLE 5. Simulated Annual Loads in the South Prong Watershed (in lbs/acre/year).

	S.R. 512			Radial Gate			Elkcam Dam		
Year	TSS	TP	TN	TSS	TP	TN	TSS	TP	TN
1994	178	1.80	8.67	402	2.74	9.59	276	2.25	8.90
1995	147	1.36	5.82	350	2.05	5.81	238	1.70	5.85
1996	38	0.80	5.82	67	0.83	5.50	70	0.96	5.61
1997	60	0.98	6.30	106	1.17	6.82	101	1.26	6.70
1998	100	1.29	7.57	175	1.46	7.03	131	1.36	6.79
Average	104	1.25	6.84	220	1.65	6.95	163	1.51	6.77

model to simulate the processes of interest, the physical properties of the watershed, and the spatial and temporal scaling. The following discussion addresses some of the major factors affecting the calibration.

Field Data

All field data contain errors. In hydrology, discharges are rated by the USGS as "excellent" when 95 percent of the mean daily discharges are within 5 percent of their true values, "good" when within 10 percent, and "fair" when within 15 percent. Records that do not meet the above criteria are rated as "poor." The rating of station 02251000 at S.R. 512 was "fair" except for discharges below 100 cfs, which were rated as "poor." Discharges at Radial Gate were obtained from a stage discharge relationship at the structure, and stage discharge relationships at the Elkcam Dam were derived from HEC-RAS runs. However, neither station was used in the hydrologic calibration of the South Prong model; rather they were added in this study as water quality monitoring sites.

Rainfall is another source of errors affecting the calibration. The HSPF model assumes that rainfall is uniformly distributed. Especially in Florida, with its local thunderstorms during the summer, this assumption is often violated. To capture the effects of spatial rainfall distribution, multiple rainfall stations were used in the model. Their area of influence was determined by Thiessen polygons. In addition, at the Elkcam Dam site, NEXRAD data from March 1 through July 31, 1999, replaced the original rainfall data.

Water quality samples were taken at intervals to represent the rising limb, peak, and recession limb of each storm event. Calibration against instantaneous measurements during storm events is difficult because of the large variability in the sample concentrations. Besides, such short temporal scales are not very meaningful because the receiving waters cannot respond to such rapid changes. Therefore, the field samples were used for the computation of total storm loads, against which the model was calibrated.

Model Capabilities and Limitations

Introduction of man-made processes, such as pumping, regulation of discharges, cultivating the land, harvesting the crops, and applying fertilizer complicate the calibration. It would be incorrect to force the parameters of the model to match these special events. Such parameter settings would be biased toward the particular events and would impair the prediction capability of the model. It is possible that data collected at S.R. 512 and Radial Gate display the effects of fertilizer application during Storm Event 5. In early October 1999, both TP and TN showed high concentrations at both sites, but concentrations were not elevated at the Elkcam Dam. The Elkcam Dam site represents mostly residential areas, while Radial Gate and S.R. 512 include large portions of agricultural land. The simulations could not capture this event very well without sacrificing overall model accuracy.

Although the application of fertilizer for early October 1999 could not be positively confirmed, it is known that fertilizer applications occurred at the end of September in 1996, 1997, and 1998 (Boman, 1999). Possibly, fertilizer application also happened in late September 1999. When fertilizer application rates and the time of application are known, HSPF is able to handle the event with the Special Actions Block. This option was not used in this study because man-made events could not be identified positively as to their frequency, time of occurrence, and quantity.

The simulation of sediment includes two separate processes: the generation of sediment at the land surface and instream transport. The first, generation of sediment at the land surface, can be simulated by HSPF only in terms of total sediment. No distinction is made between the different size fractions, and at this stage, sediment simulation is treated as a lumped process. On the other hand, instream transport is based on differentiation between the three inorganic fractions – sand, silt, and clay. The user is expected to supply the proportions that make up the sediment load generated at the land surface. However, the field data provided sediment concentrations as total suspended solids, including both organic and inorganic material. This could account for the underpredictions by the model at S.R. 512.

Calibration of nutrients was restricted to total phosphorus and total nitrogen without addressing their subcomponents. For example, laboratory analysis of the field samples included nitrate plus nitrite (NO_x,) and total Kjeldahl nitrogen (TKN) components. However, these data were not used directly in the calibration process. In general, the calibration of water quality constituents is demanding for two reasons. First, the modeler should have a very good understanding of the processes that take place in the field, make judgments about their relative importance, and have a good understanding of how or whether these processes can be implemented by the model. Especially in water quality, the processes in the field can be very complex due to the large number of factors involved. Water quality parameters may depend on time, temperature, and pH, and therefore are difficult to implement in the model. Secondly, the processes simulated by the model should be supported by data. Often such data are not available or only available from laboratory settings.

Once instream, water quality constituents are subject to decay processes. HSPF has various options to mimic these processes, including hydrolysis, oxidation, photolysis, volatilization, biodegradation, and generalized first order decay. The last option is a lumped approach to the individual decay processes and was selected because the individual processes could not be identified or lacked data. In addition, due to the relatively short time of instream transport, from 24 to 48 hours, instream decay did not play a major role with the possible exception of Storm Event 1 within the Elkcam-Collier-Shumann canal system.

Time Scales

In this study, the focus of evaluation was on individual storm volumes and their mass loads of sediment, phosphorus, and nitrogen. Due to the greater variability in simulation results that accompanies these smaller time scales, the error percentages will increase. At the same time, sediment and water quality processes exhibit greater variability than hydrologic processes, which is another reason for greater error percentages. Even so, there was no statistical difference between simulated and observed cumulative loads.

CONCLUSIONS

The model simulates the overall hydrologic characteristics of the South Prong watershed within an acceptable margin of error. Plots showed that simulated discharges and their corresponding observed discharges matched well. Volume errors and the Nash-Sutcliffe statistics were very reasonable, both on an annual and long term (1994 through 1999) basis. Simulated volumes of five storm events at three sites also compared reasonably well with corresponding observed volumes.

Storm loads were calibrated for TSS, TP, and TN at three locations in the watershed. Efforts to calibrate the model against individual storm loads were met with varying degrees of success. Overall, the simulated storm loads agreed reasonably well with measured loads for a majority of the storms. Still, when storm loads were accumulated over all five storms, the simulated and observed loads matched better than was the case for individual storm loads.

Table 6 summarizes the application of evaluation guidelines from Table 1 to the accumulated storm loads at each of the three sites. The large error in prediction of accumulated TP loads at S.R. 512 and Radial Gate could not be explained with available data. However, the possible application of fertilizer during the occurrence of Storm 5, as discussed earlier, could have had some effect. The large error in the prediction of the storm volume at the Elkcam Dam is most likely caused by the method used to calculate observed flows. As was mentioned previously, the flow calculations at this site were imprecise due to the lack of a rating curve from flow measurements.

TABLE 6. Simulation Rating for Accumulated Storm Loads.

Parameter	S.R. 512 Bridge	Radial Gate	Elkcam Dam
TN	Very Good	Very Good	Fair
TP	Poor	Poor	Good
TSS	Good	Fair	Very Good
Volume	Very Good	Good	Poor

The model can be improved in a number of ways. More detail could be added to the assignment of parameters to the various land use groups. The ideal and scientifically correct way is to obtain parameters of unique land use covers from local model calibrations for that specific land use. However, such experiments are lengthy and costly, and resources to carry out such experiments are almost never available. It should also be realized that knowledge about the mechanisms that generate pollutant loads at the land surface is mostly empirical. The mechanisms used by the model (e.g., buildup and washoff algorithms) are not physically based but are, in fact, curve fitting techniques.

From a practical point of view, the various land uses (sometimes hundreds) have to be grouped, since it is impossible to assign unique parameters to each one of them. Thus, land use groups are essentially nonhomogeneous. This also brings up the question of how to group the various land uses and how many land use groups should be used. Considerations such as the purpose of the model, the size of the watershed, and local conditions play an important role in making such decisions. Experience indicates that groupings of more than five to eight land use groups are impractical. This is due to a lack of information enabling one to legitimately assign unique parameters to so many different groups.

Improvements could also be obtained in adding more detail to the simulation of instream flow processes. To account for losses of nutrients (e.g., due to biological uptake) a simple general exponential decay factor was implemented and its value determined by calibration. Specific decay processes were not simulated due to the unavailability of field data. Under such circumstances it is better to apply simple techniques than to speculate at the parameters of the more complex processes.

In our application, the major concern is the increasing urbanization in the area, as stated in the "Introduction." The major expected change in land use will be from "rural" to urban. Consequently, this will increase the amount of impervious area with a resulting increase in runoff and an expected increase in nonpoint source pollutant loads. It is mainly this effect that the model is designed to address. With estimated increases of runoff and loads, measures can be designed to keep the impact on the Sebastian River and Indian River Lagoon systems within desirable levels. We believe that this model can serve as a tool to assist in this task.

LITERATURE CITED

ASCE, 1993. Criteria for Evaluation of Watershed Models. Task Committee on Definition of Criteria for Evaluation of Watershed Models of the Watershed Management Committee, Irrigation and Drainage Division. Journal of Irrigation and Drainage Engineering, Vol. 119, No 3.

Bergman, M. J. and L. J. Donnangelo, 1996. Development of HSPF Hydrologic Simulation Models for the South Prong Drainage Basin of the Sebastian River. Technical Memorandum No. 15. Department of Water Resources, St. Johns River Water Management District, Palatka, Florida.

Bergman, M. J. and L. J. Donnangelo, 2000. Simulation of Freshwater Discharges From Ungaged Areas to the Sebastian River, Florida. Journal of the American Water Resources Association 36(5):1121-1132.

Bergman, M. J., L. J. Donnangelo, and W. Green, 2001. Simulation of Sediment, Phosphorus, and Nitrogen Storm Loads in the South Prong Watershed of the Sebastian River, Florida, Using HSPF/BASINS. Technical Memorandum No. 43. Department of Water Resources, St. Johns River Water Management District, Palatka, Florida.

Bicknell, Brian R., John C. Imhoff, John L. Kittle Jr., Anthony S. Donigian, and Robert C. Johanson, 1993. Hydrologic Simulation Program – Fortran. User's Manual for Release 10. Environmental Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Athens, Georgia.

Boman, Brian, 1999. Nitrate Concentrations and Movement in the Shallow Groundwater of Indian River Citrus Groves. University of Florida, IFAS. Indian River Research and Education Center, Fort Pierce, Florida.

Donigian, Anthony S., John C. Imhoff, Brian R. Bicknell, and Johns L. Kittle, 1984. Application Guide for Hydrological Simulation Program – Fortran (HSPF). Environmental Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Athens, Georgia.

FEMA, 1989. Flood Insurance Study, Indian River County, Florida, and Incorporated Areas. Federal Emergency Management Agency.

Martinec, J. and A. Rango, 1989. Merits of Statistical Criteria for the Performance of Hydrological Models. Water Resources Bulletin 25(2):421-432.

Sheng, Peter Y., Justin R. Davis, K. Park, Y. Zhang, T. Kim, and D. Christian, 2001. Users Manual of a 3-D Integrated Modeling System, CH3D-IMS for the Indian River Lagoon. Civil and Coastal Engineering Department, University of Florida, Gainesville, Florida.

USACE (U.S. Army Corps of Engineers), 1995. HEC-RAS River Analysis System. Hydraulic Reference Manual, Version 1.0, U.S. Army Corps of Engineers, Hydrologic Engineering Center, Davis, California.

USEPA (U.S. Environmental Protection Agency), 1998. Better Assessment Science Integrating Point and Non-Point Sources. BASINS Version 2.0, User's Manual. Exposure Assessment Branch, Standards and Applied Sciences Division, Office of Science and Technology, Office of Water, U.S. Environmental Protection Agency, Washington, D.C.