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APPLICATION OF SRPM TO PREDICT STORMWATER RUNOFF AND PHOSPHORUS LOADS

by

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Title: Application of SRPM to Predict Stormwater Runoff and Phosphorus Loads

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The stormwater runoff and pollutant model (SRPM), developed by the District, was tested and applied to a catchment located at Wilson Rucks farm in the Lake Okeechobee watershed. The model was validated by comparing the simulated results with the measured data collected during the five-year period of 1990-1994. The first two years' observed data were used to calibrate the model and the calibrated parameter set was then verified by using the last three years' observed data. The performance of the model was also evaluated by comparing the simulated results with results from FHANTM for the same calibration and verification periods. Statistical correlations of the daily, monthly and annual values of observed and simulated phosphorus loads generated from both SRPM and FHANTM were conducted.

Model calibration and verification results indicated that SRPM performed reasonably well in predicting daily, monthly and annual runoff and pollutant loads. Comparisons and statistical analyses results demonstrated that SRPM and FHANTM performed similarly in the estimation of daily, monthly and annual runoff and phosphorus loads. FHANTM is field-scale model for simulating phosphorus loads from agricultural runoff. SRPM is a catchment-scale model, which simulates pollutant loads from catchments containing urban or agricultural fields or both. Because SRPM uses simplified approach for field-scale nutrient simulations, it could not be used to predict load changes subject to land management changes. SRPM can be developed further into a useful tool for watershed planning and management. Modifications may include the incorporation of fertilization practices and cattle manure deposition, which enable the model to evaluate agricultural management strategies for reducing pollutant-enriched runoff in the watershed.

APPLICATION OF SRPM TO PREDICT STORMWATER RUNOFF AND PHOSPHORUS LOADS

Richard Z. Xue[1] and Joyce Zhang[2]

ABSTRACT: Stormwater runoff and the associated pollutant loads have gained great attention in urban planning and agricultural management. Evaluation of alternative scenarios in urban development and agricultural management is needed to assess environmental impacts in existing watersheds. A stormwater runoff and pollutant model (SRPM) was tested to simulate runoff and phosphorus loads on a watershed in south central Florida. The model was validated by comparing simulated results with measured data collected during the five-year period of 1990-1994. The first two years' observed data were used to calibrate the model and the calibrated parameter set was then verified by using the last three years' observed data. The performance of the model also was evaluated by comparing simulated results with results from FHANTM (an agricultural non-point source pollution model) for the same calibration and verification periods. Statistical correlations of the daily, monthly and annual values of observed and simulated phosphorus loads generated from both SRPM and FHANTM were conducted. The modeling results demonstrated that SRPM could provide reasonable estimates of observed daily, monthly and annual pollutant loads and could be developed further into a versatile tool for watershed planning and regulation.
KEY TERMS: Watershed Modeling; Nutrient Management; Water Quality.

INTRODUCTION

Phosphorus enrichment in Lake Okeechobee poses a serious problem to the lake ecosystem. Numerous nutrient management projects had been conducted to reduce the phosphorus loading in the drainage areas north of the lake. In order to evaluate the effectiveness of those nutrient management projects, several models were developed to simulate the phosphorus loadings. These models include CREAMS-WT (a field scale model for Chemicals, Runoff, and Erosion from Agricultural Management Systems-Water Table) (Heatwole et al., 1987, 1988), FHANTM (Field Hydrologic and Nutrient Transport Model) (Tremwel, 1992), and a framework for phosphorus transport modeling in the Lake Okeechobee watershed (Wagner et al., 1996). These models were mainly used for simulating runoff and phosphorus loads from agricultural fields or watersheds. Recently, a Stormwater Runoff and Pollutant Model (SRPM) was developed to simulate surface runoff and the associated pollutant loads in either urban or agricultural areas (Xue, 1995). The model was tested using data collected in a field located north of Lake Okeechobee (Xue and Zhang, 1996).

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Due to the capability of multi-field simulations in SRPM, this study tested the model using data collected from a watershed containing two fields (i.e. hay and abandoned). Calibration and verification were performed using monitoring data collected from January, 1990 to December, 1994. The simulation results were compared with results from FHANTM simulations for the same calibration and verification periods (Gornak and Zhang, 1996). Statistical correlation analyses between observed and simulated daily, monthly and annual values also were conducted.

WATERSHED DESCRIPTION

The selected watershed is located on Wilson Rucks farm in Okeechobee County, Florida. The farm, originally a dairy, is used to raise heifers and dry cows. Land use in the study watershed is a Pangola hayfield and an abandoned field. Watershed size is approximately 156 acres (about 70% hayfield and 30% abandoned field). Water from the study area drains to Otter Creek, a tributary of Taylor Creek which drains to Lake Okeechobee. The study area is generally flat with a moderate slope to the south and east (six feet per mile). The soil association is Myakka-Immokalee fine sand which is comprised of deep, poorly drained, and nearly level sandy soils. The soils normally have a thick hardpan at a depth of approximately two to two and one-half feet.

Total phosphorus concentration data was collected near Otter Creek, approximately 100 meters downstream of the watershed outlet. Rainfall data was collected at a station located within a half mile of the monitoring site. Daily evapotranspiration data was obtained from FHANTM output and was calculated using measured air temperature data. More descriptions of the watershed were presented by Gornak and Zhang (1996).

MODEL DESCRIPTION

SRPM is a watershed-scale model which simulates stormwater surface runoff and associated pollutant loads generated from urban land uses or agricultural areas with an hourly time step. The model can be applied to an individual storm event or a long-term continuous simulation period such as five or ten years. Up to ten fields/catchments and up to nine user-defined water quality constituents in each application run can be simulated in SRPM (Xue, 1995). The SRPM model requires few hydrology and water quality input parameters and therefore is easy to run. In the hydrology simulation, the SRPM model considers the processes of precipitation, evapotranspiration, infiltration, depression storage, percolation and surface runoff (Xue and Zhang, 1996). The concept of pollutant buildup and washoff was incorporated in SRPM to predict storm-related pollutant loads in the runoff. The model provides hourly, daily, monthly and annual simulation results for surface runoff and associated pollutant concentrations.

FHANTM is a modification of the subsurface drainage model, DRAINMOD (Skaggs, 1980). Modifications include the addition of phosphorus dynamics and transport algorithms and a surface runoff routing time delay relationship. FHANTM operates on a short time interval and provides daily, monthly and annual estimates of runoff, phosphorus loads and concentrations. The model was used to evaluate management alternatives for different landuses in the Lake Okeechobee watershed (Gornak and Zhang, 1996).

MODEL CALIBRATION AND DISCUSSION

Measured daily phosphorus concentration values from January 1, 1990 through December 31, 1991 were used to calibrate the SRPM model. Missing measured daily values of phosphorus concentrations were estimated using linear interpolation when the sampling interval was a week or less. When the sampling interval was two weeks or more, concentration values were assigned to all the estimated daily flows bracketing the day of the sampling date. For example, during a period in which a bi-weekly sample was taken, that concentration was assigned to the daily flows in the week prior to the sampling and the week following the sampling. Due to the lack of measured runoff data, observed daily phosphorus loads used in model calibration and verification were calculated based on the measured daily phosphorus concentrations and daily runoff data generated from FHANTM. Monthly and annual loads were calculated as the sum of the daily loadings.

Simulated monthly runoff and phosphorus loads from SRPM and FHANTM during the calibration period are plotted in Figure 1. The monthly runoff values from SRPM were very close to the results from FHANTM. The simulated monthly phosphorus loads from January 1990 through April 1990 were underpredicted by SRPM and overpredicted by FHANTM, especially in February 1990. During the period of May 1990 through December 1991, the predicted monthly phosphorus loads from SRPM compare favorably with the observed data except for underpredictions in the months of October 1990, July 1991 and August 1991. FHANTM also underpredicted loads in those months and overpredicted loads in the months of July 1990 and April 1991. The variation in predicting monthly phosphorus loads from both models indicates that it is difficult to closely estimate loads without measured runoff data.

Simulated annual runoff from SRPM matched very well with the results from FHANTM in the calibration period (Figure 2). The predicted annual phosphorus loads from SRPM were lower than the observed data, whereas the results from FHANTM overpredicted observed data in both 1990 and 1991.

MODEL VERIFICATION AND DISCUSSION

Model verification for SRPM was conducted using measured daily phosphorus concentration values from January 1, 1992 through December 31, 1994. SRPM was run for these three years using the previous set of calibrated parameters, and simulation results were compared with the observed phosphorus loads. Figure 3 presents simulated monthly runoff from SRPM and FHANTM during the verification period and indicates that predicted monthly runoff from both models matched reasonable well.

Predicted monthly phosphorus loads from SRPM matched well with the observed monthly phosphorus data except for a few months in 1993 and in September 1994. The predicted monthly phosphorus loads from FHANTM overpredicted observed data in June 1992 and underpredicted observed data in September 1993 as well as the last four months of the verification period. Predicted annual runoff from SRPM was very close to the simulated annual values from FHANTM in 1993 and 1994 but was higher in 1992 (Figure 4). Compared with the observed annual phosphorus loads, the simulated annual phosphorus values from SRPM indicated that SRPM performed well during the verification period. FHANTM performed well in 1992 and 1993 but underpredicted the observed annual phosphorus load in 1994.

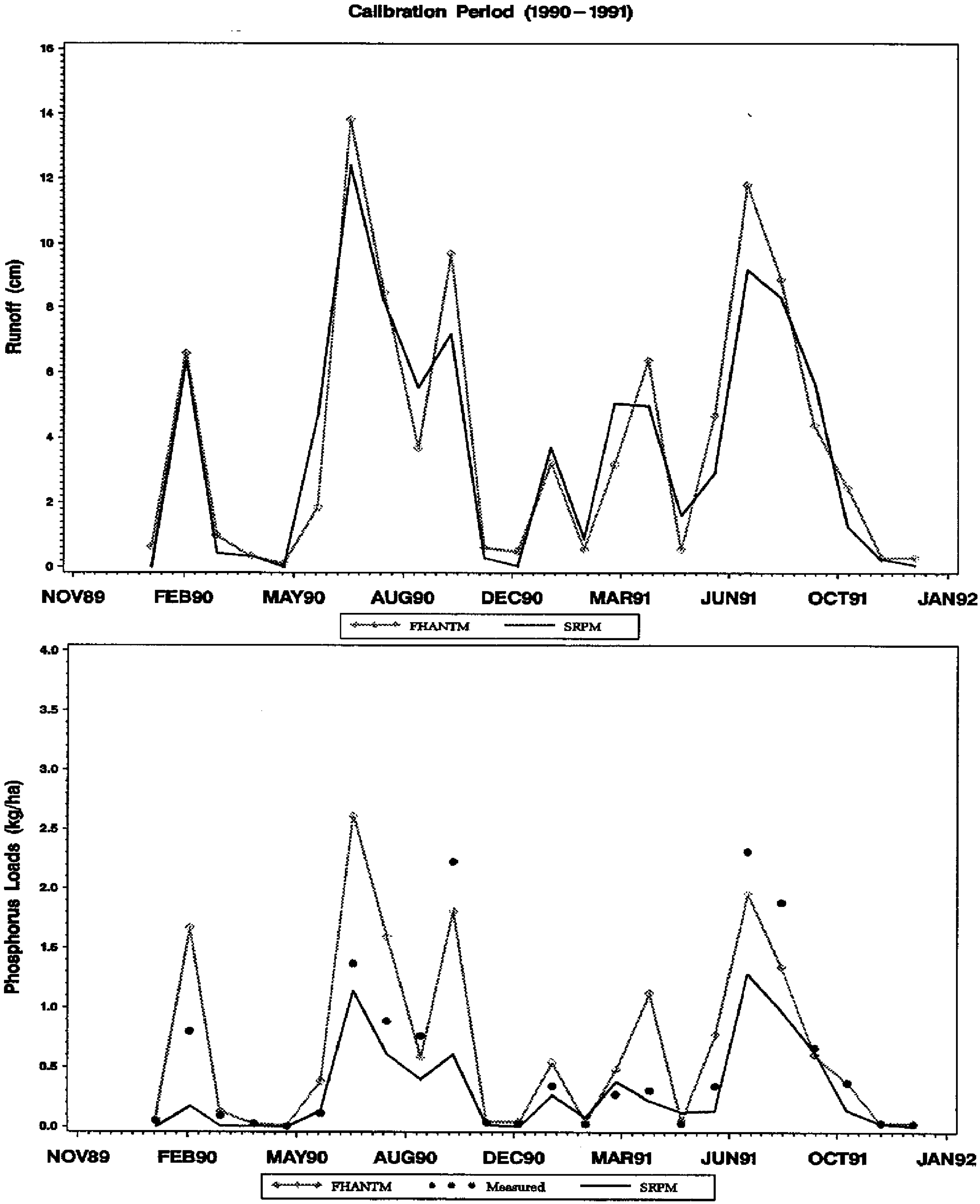

Figure 1. Observed and Predicted Monthly Data in Calibration Period

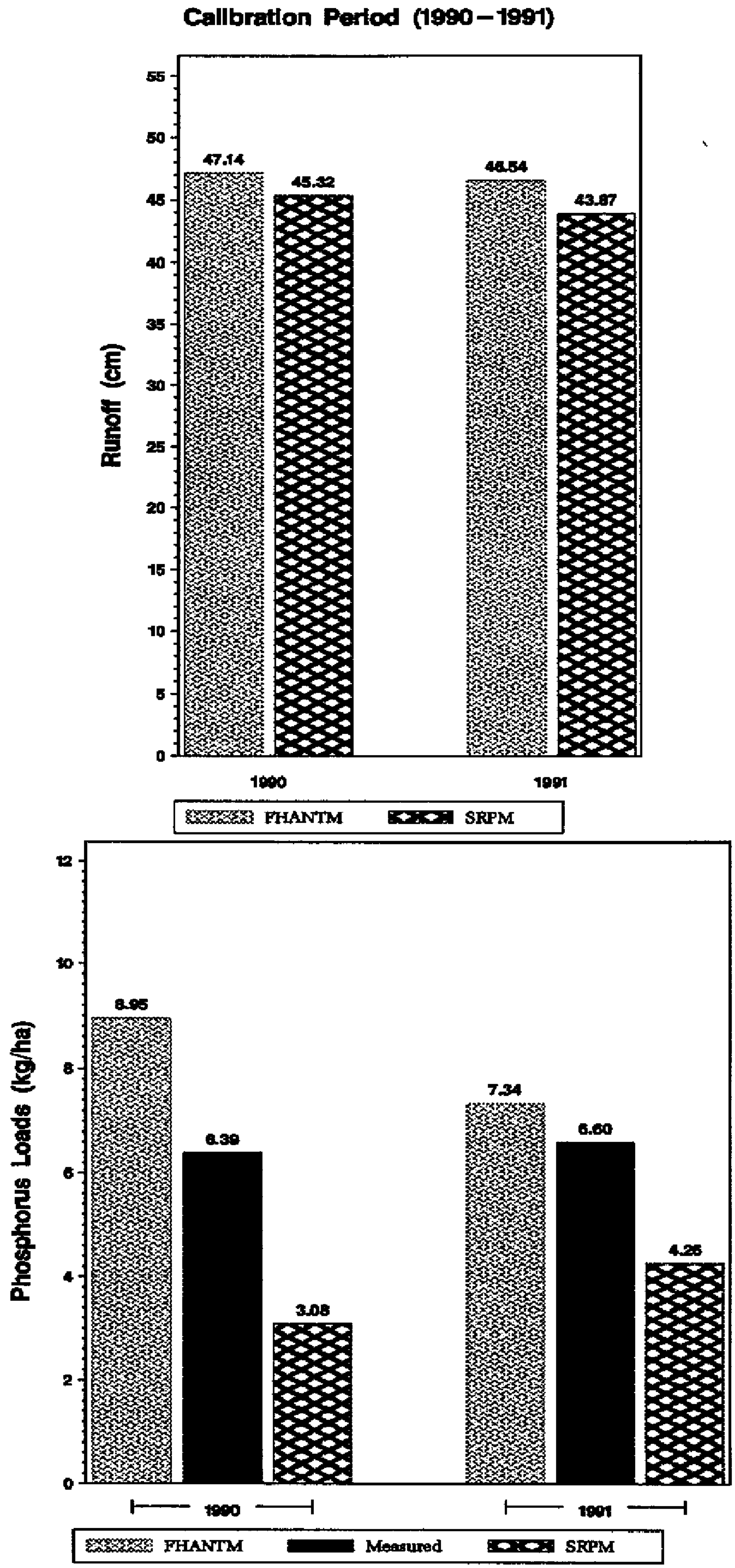

Figure 2. Observed and Predicted Annual Data in Calibration Period

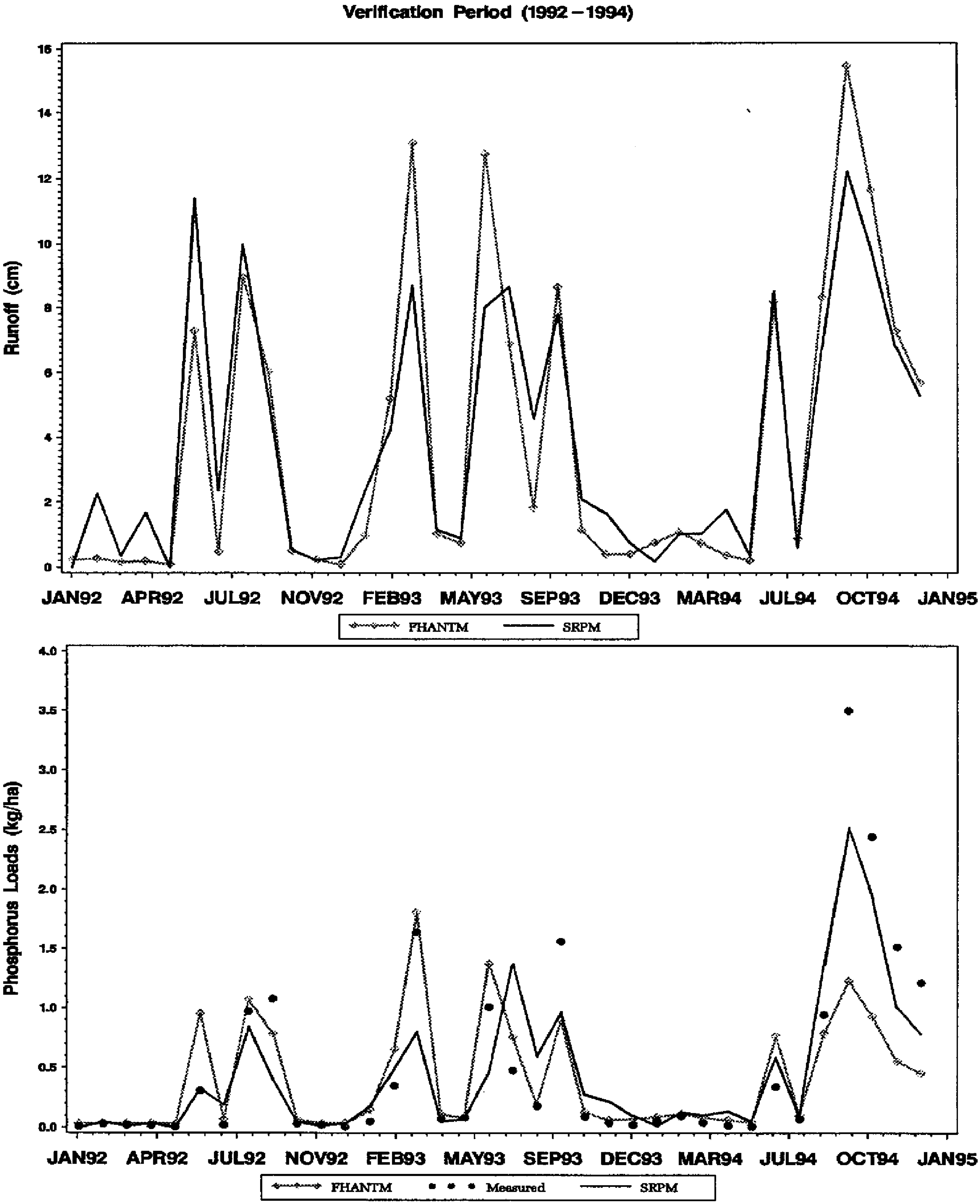

Figure 3. Observed and Predicted Monthly Data in Verification Period

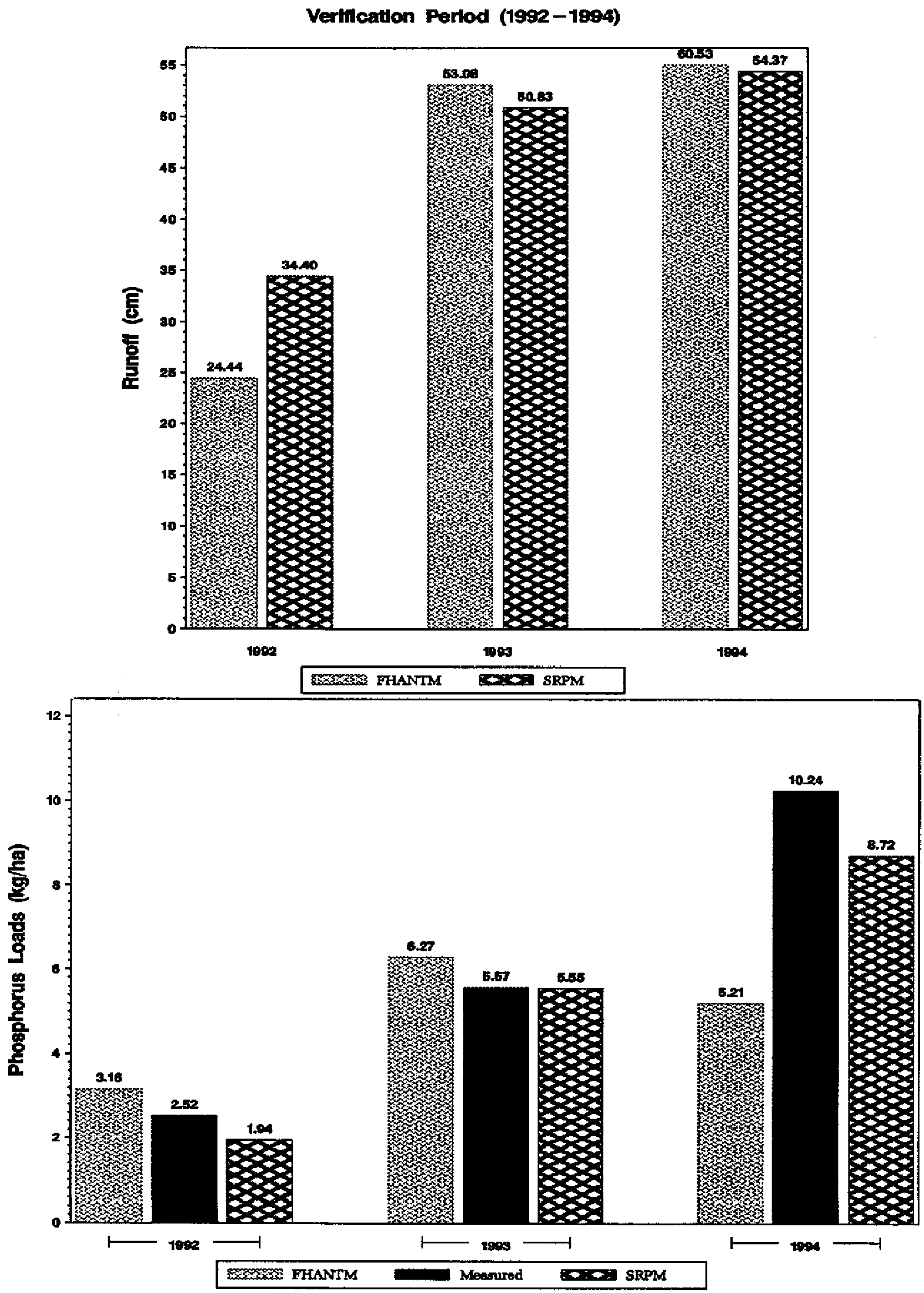

Figure 4. Observed and Predicted Annual Data in Verification Period

STATISTICAL ANALYSES

Statistical analyses were conducted for both SRPM and FHANTM during the calibration and verification periods to evaluate the models' performance. Tables 1 through 3 present the statistical analyses results of the observed and predicted daily, monthly and annual runoff and phosphorus loads generated from SRPM and FHANTM. The statistical results indicate that the FHANTM model performed slightly better than SRPM in predicting daily phosphorus loads by comparing Pearson correlation coefficients (Table 1). High correlation coefficients also were observed between predicted daily runoff from SRPM and FHANTM, with 0.65 for the calibration period and 0.67 for the verification period.

Table 2 demonstrated that SRPM performed slightly better than FHANTM in predicting monthly phosphorus loads in both calibration and verification periods. Pearson correlation coefficients of 0.89 in the calibration period and 0.90 in the verification period were calculated for SRPM. FHANTM had the coefficients of 0.84 and 0.76, respectively, in the calibration and verification periods (Table 2). For the prediction of the monthly runoff, Pearson correlation coefficients of 0.95 and 0.93 were observed between the SRPM and FHANTM models for calibration and verification periods, respectively.

With a Pearson correlation coefficient of 0.99, annual predictions of phosphorus loads from SRPM matched very well with the measured annual phosphorus loads in the verification periods (Table 3). A correlation coefficient of 0.55 was calculated between the observed and predicted annual phosphorus loads from FHANTM in the verification period. Underestimation of the phosphorus loads for the extremely wet year of 1994 (Figure 4) is the main cause (Gornak and Zhang, 1996). In contrast, SRPM performed better in predicting annual phosphorus loads for the verification period. A correlation coefficient of 0.999 was calculated between the simulated annual runoff of SRPM and FHANTM, indicating that the two models performed similarly in predicting annual runoff.

CONCLUSIONS AND FUTURE MODEL DEVELOPMENT

The stormwater runoff and pollutant model (SRPM) was tested and applied to a catchment in the Lake Okeechobee watershed. Model calibration and verification results indicated that SRPM performed reasonably well in predicting daily, monthly and annual runoff and phosphorus loads. Comparison of simulated results from SRPM and FHANTM as well as statistical analyses of observed and predicted daily, monthly and annual runoff and phosphorus loads from SRPM and FHANTM were conducted to further evaluate the model performance. Comparisons and statistical analyses results demonstrated that SRPM and FHANTM performed similarly in the estimation of daily and monthly runoff and pollutant loads and SRPM performed better than FHANTM with regards to annual pollutant loads.

The SRPM model was developed to simulate runoff and pollutant loads from either urban catchments or agricultural fields. The current version does not allow changes to be made in land use and related pollutant loading during a simulation. Thus, SRPM cannot currently be used to predict pollutant load changes over a long-term simulation period that involves land use/land management changes. This limitation of SRPM is in the process of being eliminated. The revised version of the model will permit land use/pollutant loading changes to be made on an annual basis. Additional modifications will enable different land management strategies such as changes in crops, changes in fertilization practices or converting dairy cow lots to cattle pasture to be evaluated. The revised SRPM model will be a valuable tool for evaluating specific land changes and resultant runoff quality. The user-

Table 1. Statistics of Observed/Predicted Daily Runoff and Phosphorus Loads from FHANTM and SRPM

Statistics Analysis	Runoff (cm)				Phosphorus Load (kg/ha)					
	FHANTM		SRPM		Observed		FHANTM		SRPM	
	Calibration	Verification	Calibration	Verification	Calibration	Verification	Calibration	Verification	Calibration	Verification
Mean	0.128	0.126	0.122	0.127	0.018	0.017	0.022	0.013	0.010	0.015
Standard Deviation	0.428	0.443	0.257	0.270	0.070	0.074	0.080	0.042	0.026	0.042
Sum	93.67	138.05	89.19	139.61	12.98	18.33	16.29	14.64	7.34	16.21
Minimum	0	0	0	0	0	0	0	0	0	0
Maximum	4.67	5.17	2.17	2.35	0.92	1.21	0.95	0.47	0.23	0.58
N	730	1096	730	1096	730	1096	730	1096	730	1096
R^2	--	--	0.43	0.45	--	--	0.69	0.62	0.35	0.43
Regression Slope	--	--	0.39	0.41	--	--	0.95	0.44	0.22	0.37
Pearson Correlation Coefficient	--	--	0.65	0.67	--	--	0.83	0.78	0.59	0.66

Table 2. Statistics of Observed/Predicted Monthly Runoff and Phosphorus Loads from FHANTM and SRPM

Statistics Analysis	Runoff (cm)				Phosphorus Load (kg/ha)					
	FHANTM		SRPM		Observed		FHANTM		SRPM	
	Calibration	Verification	Calibration	Verification	Calibration	Verification	Calibration	Verification	Calibration	Verification
Mean	3.903	3.835	3.716	3.878	0.541	0.509	0.679	0.407	0.306	0.450
Standard Deviation	4.050	4.566	3.583	3.795	0.714	0.800	0.762	0.475	0.379	0.587
Sum	93.67	138.05	89.19	139.61	12.98	18.33	16.29	14.64	7.34	16.21
Minimum	0.09	0.08	0	0	0.002	0.007	0.01	0.03	0	0
Maximum	13.81	15.45	12.40	12.22	2.31	3.50	2.61	1.81	1.28	2.52
N	24	36	24	36	24	36	24	36	24	36
R^2	--	--	0.90	0.86	--	--	0.71	0.58	0.78	0.82
Regression Slope	--	--	0.84	0.77	--	--	0.90	0.45	0.47	0.66
Pearson Correlation Coefficient	--	--	0.95	0.93	--	--	0.84	0.76	0.89	0.90

Table 3. Statistics of Observed/Predicted Annual Runoff and Phosphorus Loads from FHANTM and SRPM

Statistics Analysis	Runoff (cm)				Phosphorus Load (kg/ha)					
	FHANTM		SRPM		Observed		FHANTM		SRPM	
	Calibration	Verification	Calibration	Verification	Calibration	Verification	Calibration	Verification	Calibration	Verification
Mean	46.84	46.02	44.60	46.54	6.49	6.11	8.14	4.88	3.67	5.40
Standard Deviation	0.424	19.05	1.02	10.66	0.149	3.89	1.14	1.58	0.83	3.39
Sum	93.67	138.05	89.19	139.61	12.98	18.33	16.29	14.64	7.34	16.21
Minimum	46.54	24.44	43.87	34.40	6.39	2.52	7.34	3.16	3.08	1.94
Maximum	47.14	60.53	45.32	54.37	6.60	10.24	8.95	6.28	4.26	8.72
N	2	3	2	3	2	3	2	3	2	3
R^2	--	--	--	0.999	--	--	--	0.30	--	0.98
Regression Slope	--	--	--	0.56	--	--	--	0.22	--	0.86
Pearson Correlation Coefficient	--	--	--	0.9996	--	--	--	0.55	--	0.99

friendly nature of SRPM will also be appreciated by non-modelers who need to address issues regarding water quality and stormwater runoff.

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