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Project Summary

Application of Hydrologic Simulation Program-FORTRAN (HSPF) in Iowa Agricultural Watersheds

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The Hydrologic Simulation Program-FORTRAN (HSPF) was applied to two watersheds in Iowa to test the model's capability in evaluating the effects of agricultural best management practices (BMPs) on water quality. The project first involved refining HSPF to incorporate a pesticide risk assessment methodology. Before the application of HSPF to the Four Mile Creek Watershed, an evaluation of the sensitivity of model parameters for BMPs was done and a parameter estimation manual was prepared. The model was calibrated and verified in the watershed. The water quality effectiveness of alternative BMP scenarios was then evaluated using the parameter estimation manual. To evaluate the ease of model scale-up and extrapolation to a larger basin, the model was then applied to the Iowa River Basin above Coralville Reservoir.

These applications of HSPF in watersheds of different size in Iowa demonstrated that HSPF is a flexible and realistic means of approximating the impacts of candidate BMPs on water quality in small watersheds and large river basins. Moreover, risk assessment procedures can be used with the simulated chemical concentration time series produced by the model to evaluate the impacts on selected aquatic organisms.

True verification of any model's ability to simulate the effects of BMPs, however, must await the availability of both pre- and post-BMP implementation data. Until such data have been collected, models such as HSPF can still be used to approximate the effects of BMPs on stream water quality, and sensitivity analyses of various model parameters can assist the BMP evaluation and planning process.

These applications provide one of the first systematic attempts to combine a detailed simulation of agricultural runoff and soil processes, which calculate surface and subsurface pollutant transport to receiving waters, with subsequent simulation of instream transport and transformations. The result is a comprehensive simulation of watershed hydrology and water quality.

This Project Summary was developed by EPA's Environmental Research Laboratory, Athens, GA, to announce key findings of the research project that is fully documented in three separate reports (see Project Report ordering information at back).

Background

HSPF is a comprehensive program for modeling sediment, pesticides, nutrients, and other water quality constituents in runoff from urban, agricultural, and other lands. The model allows detailed simulation of stream hydraulics, water quality processes, pesticide and nutrient behavior in soil, and sediment-contaminant transport. Extensive data handling and analysis procedures that support and complement the simulation capabilities are included.

A unique feature of HSPF is the incorporation of runoff models--the Agricultural Runoff Management (ARM) Model and the Nonpoint Source (NPS) Model and stream transport and fate models--in a systematic framework. Simply put, the model uses information on meteorology, land use, and agronomic characteristics to simulate a time history of the quantity and quality of the runoff. Flow rate, sediment load, and nutrient and pesticide concentrations are predicted. The model then takes these results and information about the stream channels in the watershed and simulates the processes that occur in these streams. This produces a time history of water quantity and quality at any point in the watershed. HSPF can be applied to a wide range of water resource problems. The key attribute that makes it widely applicable is its ability to simulate the continuous behavior of time-varying physical processes and to provide statistical summaries of the results.

The work reported here was performed as part of a comprehensive field evaluation program in two Iowa watersheds (Figure 1). The purposes of the program were to test and demonstrate (1) the capability of agricultural BMPs to achieve water quality goals, and (2) the applicability of water quality planning tools (such as HSPF) to the BMP evaluation and selection process. Program results are described in "HSPF Parameter Adjustments to Evaluate the Effects of Best Management Practices," "Modeling Water Quality and the Effects of Agricultural Best Management Practices in Four Mile Creek, Iowa," and "Preliminary Application of HSPF to the Iowa River Basin to Model Water Quality and the Effects of Agricultural Best Management Practices."

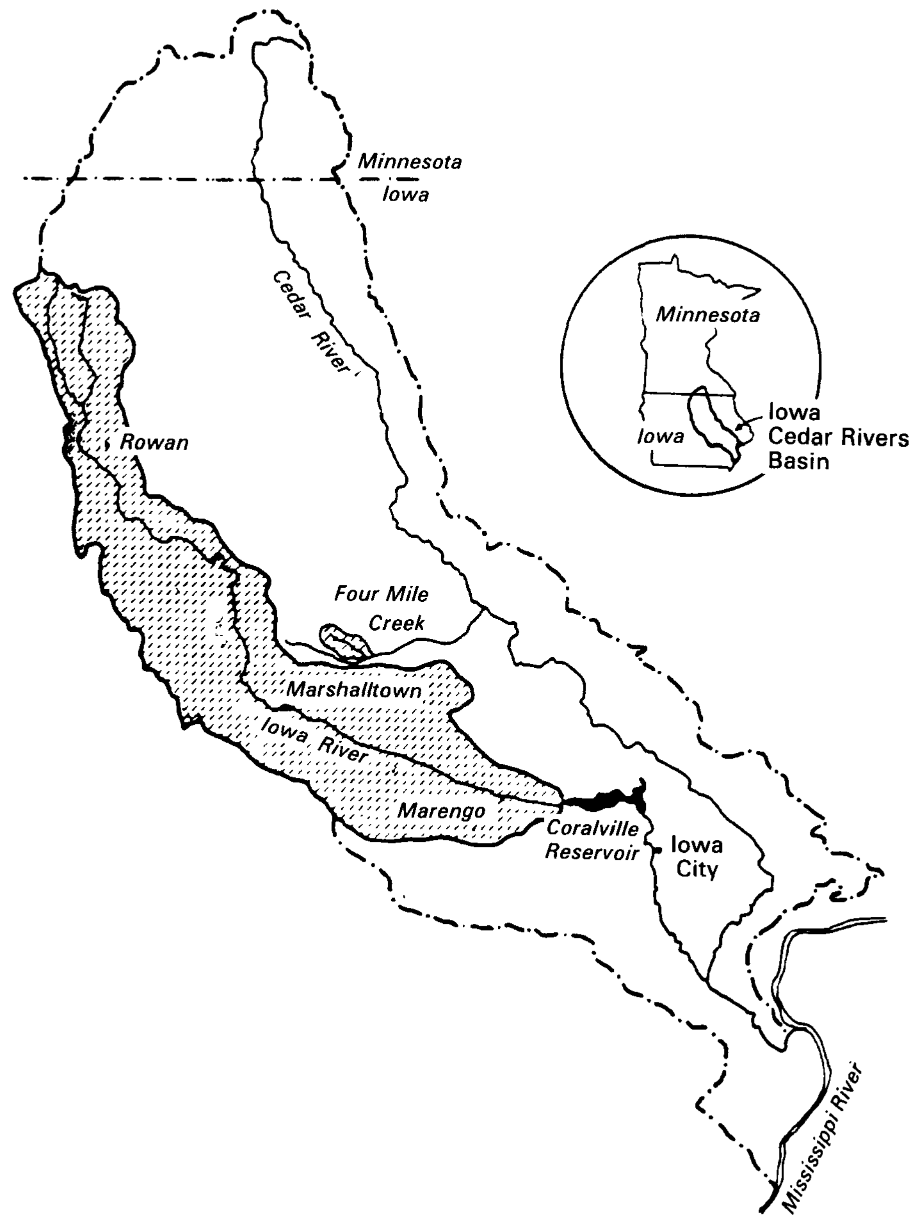

Figure 1. *Location of Four Mile Creek and Iowa-Cedar River Basin Sites for Iowa Field Evaluation Program.*

HSPF Parameter Adjustments for Evaluating BMPs

A key problem in applying most models, especially those with an empirical basis, is how to adjust model parameters to represent the effects of a specific practice, or combination of practices, that comprise a BMP or system of BMPs. "HSPF Parameter Adjustments to Evaluate the Effects of Agricultural Best Management Practices" qualitatively assesses the effects of selected agricultural practices on runoff, erosion, and chemical processes, and quantifies the associated adjustments to model parameters based on the current state of science. Although the specific parameter changes are particular to the HSPF and ARM models, the information presented is generally applicable and should be pertinent to many models having similar representations of the relevant processes.

In summary, the report discusses the technical aspects of conventional practices and candidate BMPs as a basis for predicting BMP impacts on relevant agricultural runoff processes in Iowa watersheds. Guidelines and recommendations are included for adjusting all major parameters whose effects can be reasonably quantified. Deficiencies in the current state of knowledge of BMP effects and recommendations for future research and model improvements are presented and discussed.

The approach to assessing the manner in which HSPF parameters should be adjusted to represent the effects of candidate BMPs involved six steps:

- Define conventional agricultural practices for Iowa watersheds.
- Select and define candidate BMPs.
- Evaluate qualitatively the impact of each candidate BMP on agricultural runoff processes (quantity and quality)

relative to conventional practices.

- Identify HSPF model parameters that control or affect specific runoff processes (quantity and quality).
- Evaluate qualitatively the relative effect of each candidate BMP on the HSPF model parameters identified above.
- Quantify the effects of the candidate BMPs on the identified model parameters based on available data, current literature, and, lacking all else, best judgment or experience.

The qualitative assessments provided the basis for quantifying the changes in model parameters.

The qualitative assessment of how the candidate BMPs could be represented by the indicated changes in HSPF parameters relative to those for conventional practices is presented in the report. The candidate BMPs are divided into nonstructural, structural, and input management practices.

Finally, the report provides a discussion of the major HSPF runoff, sediment and chemical parameters in terms of adjustments or changes needed to simulate the effects of the candidate BMPs.

Modeling BMP Effects-Four Mile Creek

"Modeling Water Quality and the Effects of Agricultural Best Management Practices in Four Mile Creek, Iowa" discusses the calibration and verification of HSPF in a relatively small watershed (approximately 20 sq. mi.). Such efforts are needed to evaluate model capabilities and develop sufficient confidence so that the model can be used for BMP analyses.

Hydrologic calibration involves iterative adjustments in selected parameter values based on comparison of observed and simulated runoff volumes and storm hydrographs. The model representation and calibrated parameters are then verified by performing the same comparisons on an independent data set, i.e., runoff volumes and hydrographs that were not used in the calibration. In the Four Mile Creek watershed, observed runoff data for calibration and verification were available for three watershed sites and three small field sites. Approximately 7 years of daily streamflow data (and selected hydrographs) were available for the watershed sites, and 2 1/2 years of runoff data were available from the field sites. A summary of the annual runoff and daily flow statistics for calibration and verification at the Traer gage, a watershed site on Four Mile Creek is given in the report. The calibration and verification results of modeling the watershed hydrology compare reasonably well with the observed values.

The calibration and verification results of modeling alachlor concentrations are shown in Figure 2. The relative timing of applications and the first significant storm event have a major impact on the resulting chemical runoff. Although the alachlor simulations are generally higher than observed values, the concentrations and loads are generally within the range of the observed values. Oftentimes, major discrepancies can be explained by the absence of, or large errors contained in, sampling data during storm events.

The simulations of alachlor edge-of-field loadings and stream concentrations showed that approximately 30% of the alachlor reaching the stream did not reach the watershed outlet at Traer. This is likely due to adsorption onto sediment particles, resulting deposition in the bed, and decay of the compound in the channel bed.

Another method of viewing calibration and verification results is to determine whether decisions on risk or exposure to aquatic organisms would be different if the analyst based his decision on the simulated or the observed chemical information. Figure 3 demonstrates how the frequency (percent of time) of acute, chronic, and sub-lethal conditions might be determined for a particular stream given a time series of chemical concentrations. Using the risk assessment methodology integrated into HSPF, the observed and simulated chemical concentrations were analyzed to determine the percent of time conditions within each region shown in Figure 3 would exist. The results of this analysis using a hypothetical

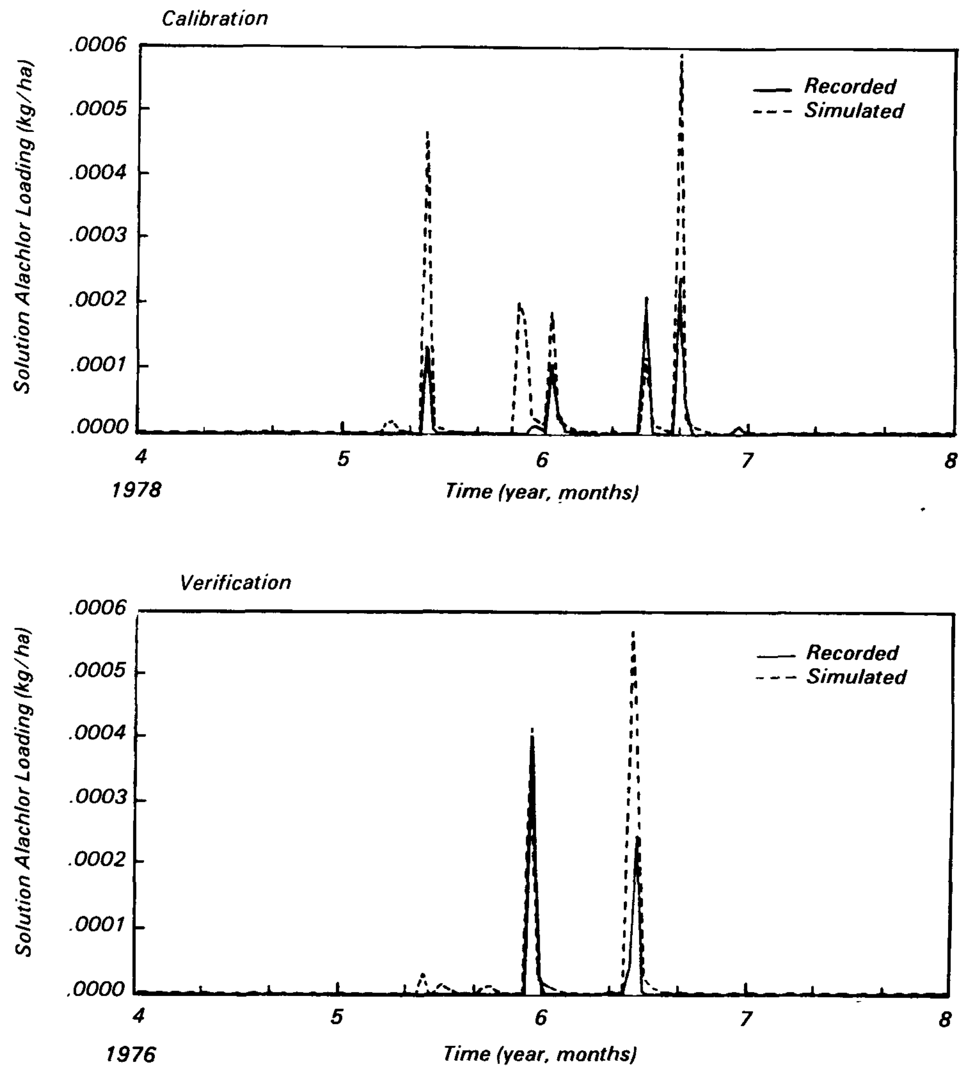

Figure 2. *Calibration and verification results for solution alachlor loading at Traer, IA.*

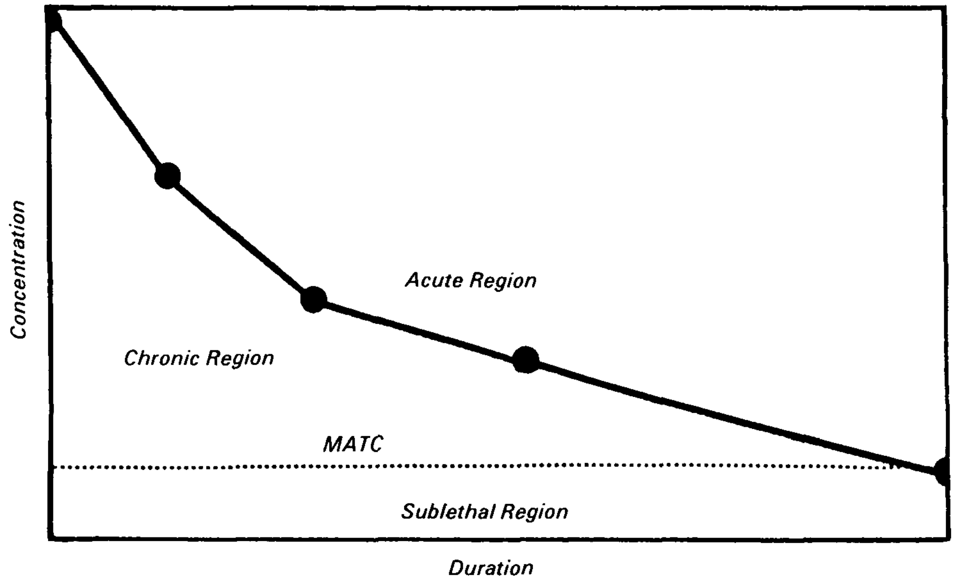

Figure 3. *Lethality analysis of chemical concentration data.*

organism are shown in Table 1. A hypothetical organism was used because all the values observed for alachlor concentrations were considerably lower than any of the maximum acceptable toxicant concentration values for all species of fish found in Four Mile Creek. The table shows that the observed and simulated values agree quite closely indicating that the ultimate decision on aquatic risk and exposure would be the same whether the observed or simulated values were used.

In summary, the instream pesticide simulation results show that reasonably good simulations can be obtained by using small site parameter values for alachlor in conjunction with hydrologic parameters calibrated on the entire watershed and a reasonably good instream hydraulic and sediment transport simulation. In effect, the work has shown that an adequate simulation of the hydrologic transport components on a watershed basis provides a viable means of simulating chemical transport and aquatic risk.

The nutrient simulation followed the same general procedures as the pesticide simulation. The nutrient parameters calibrated on the small sites were extrapolated to the entire watershed and used in conjunction with the watershed hydrology and stream hydraulics to simulate nutrient concentrations and loadings at the watershed outlet. Unlike the pesticide simulation, nutrients are contributed from all land within the watershed whether or not the land received fertilizer applications.

The daily concentrations and loads from nitrate, ammonia, and chloride generally indicate that the loads are simulated considerably better than concentration values, but that the overall simulation is reasonably good. The large differences between the simulated and recorded values for ammonia and phosphate at the watershed outlet are likely due to the lack of simulation data on instream sediment and sediment-nutrient interactions. HSPF did not simulate sediment-nutrient interactions as was done for pesticides.

Although the results were viewed as preliminary, it was concluded that the model is capable of representing the overall watershed system behavior in terms of nutrient simulation. Additional calibration efforts and the suggested model enhancements would likely increase significantly the agreement of simulated and observed values and thus improve the preliminary results presented here.

As a demonstration of the model's utility, a BMP scenario was evaluated using the parameter values reported in the previous study. Using the assumptions and associated changes in parameter values for the BMP scenario described in the report, a comparison can be made of the simulated base condition versus the BMP scenario. Table 2 shows the average percent reductions in runoff (8.3%), sediment (41.7%), alachlor (for solution and sediment, 32.5% and 68.2%, respectively), and nutrients (varies by form) to be expected from the BMP.

Finally, Table 3 shows the results of the simulation of the BMP scenario in terms of reductions in the fraction of time when acute and lethal conditions exist, following the lethality analysis methodology mentioned previously. The reductions indicate an 8% reduction in the percentage of time when pesticides exceeded the MATC levels in the watershed. Although the values listed here are specific to the conditions under which this BMP scenario was simulated, the overall methodology and analysis indicates how the procedures can be used to evaluate the effects of BMP scenarios on the resulting risk of exposure of aquatic organisms to chemicals.

Although this study demonstrated the overall utility of the HSPF model for evaluating BMPs, numerous weaknesses and difficulties were identified. Needed improvements include a better capability to predict pesticide decay in the field under various environmental conditions; better understanding of nutrient parameters, of tile drainage and snowmelt effects and of field-to-stream sediment delivery; and a better basis for assumptions about agronomic practices.

Table 1. *Lethality Analysis for Alachlor in Four Mile Creek for Hypothetical Organism*

	Global Exceedance (% of time)					
	1978 Calibration		1976 Verification		1976-78	
	OBS	SIM	OBS	SIM	OBS	SIM
Acute Region	0.5	3.3	0.5	1.9	0.2	1.2
Above MATC Value	4.4	6.6	3.3	8.1	1.5	3.2
Sublethal Region (below MATC)	95.6	93.4	96.7	91.9	98.5	96.8

MATC - Maximum Acceptable Toxicant Concentration. (0.003 mg/l used above).
OBS - Observed values.
SIM - Simulated values.

Table 2. *Comparison of Base Conditions with BMP Scenario on Four Mile Creek*

	Base Conditions	*BMP Scenario*	*% Difference*
Runoff (mm)			
76	*69.9*	*60.7*	*-13.2*
77	*48.8*	*43.7*	*-10.4*
78	*161.8*	*152.9*	*- 5.5*
Total	*280.5*	*257.3*	*- 8.3*
Sediment (tonne/ha)			
76	*0.437*	*0.175*	*-60.0*
77	*0.042*	*0.022*	*-47.6*
78	*1.381*	*0.888*	*-35.7*
Total	*1.860*	*1.085*	*-41.7*
Alachlor (kg/ha)			
Solution:			
76	*0.00166*	*0.00084*	*-49.4*
77	*0.00009*	*0.00009*	*0*
78	*0.00212*	*0.00168*	*-20.7*
Total	*0.00387*	*0.00261*	*-32.5*
Sediment:			
76	*0.00012*	*0.00003*	*-69.2*
77	*0*	*0*	*0*
78	*0.00010*	*0.00004*	*-60.0*
Total	*0.00022*	*0.00007*	*-68.2*
Nutrients (kg/ha): 11/77 - 10/78			
NO_3	*26.2*	*20.2*	*-22.9*
Cl	*34.0*	*30.1*	*-11.5*
NH3-Sol	*2.18*	*0.69*	*-68.3*
**NH3-Sed*	*0.00045*	*0.00019*	*-57.8*
**PO4-Sol*	*1.69*	*1.14*	*-32.5*
**PO4-Sed*	*0.00029*	*0.00018*	*-37.9*

** - Edge of Stream Loadings.*

Table 3. *Lethality Analysis of BMP Scenario for Alachlor in Four Mile Creek for Hypothetical Organism*

	Global Exceedance (% of time)					
	Base Conditions		*BMP Scenario*		*% Change*	
	MAX	*AVER*	*MAX*	*AVER*	*MAX*	*AVER*
Acute Region	*1.2*	*0.4*	*1.2*	*0.2*	*0.0*	*-50.*
Above MATC Value	*3.2*	*2.5*	*2.9*	*2.3*	*-9.4*	*-8.0*
Sublethal Region (below MATC)	*96.8*	*97.5*	*97.1*	*97.7*	*+0.3*	*+0.2*

MATC - Maximum Acceptable Toxicant Concentration (0.003 mg/l used above).
MAX - Daily maximum concentrations.
AVER - Daily average concentrations.

HSPF Demonstration - Iowa River Basin

"Preliminary Application of HSPF to the Iowa River Basin to Model Water Quality and the Effects of Agricultural Best Management Practices" describes a basin-scale model application that combines the detailed simulation of agricultural runoff and soil processes, surface and subsurface pollutant transport to receiving waters, and subsequent simulation of instream transport and transformations. The result is a comprehensive simulation of river basin water quality. Comparisons of water quality resulting from conventional agronomic practices and BMPs provide a basis for determining the net effects and associated benefits of BMP implementation. Furthermore, using simulated concentrations of pesticides and other toxic pollutants in conjunction with lethality-duration information, the frequency of acute and chronic toxic conditions can be determined to assess the risk to aquatic life of proposed practices.

The investigation of the Iowa River Basin (approximately 7240 sq. km. reported here is an extension or scale-up of the modeling study in the Four Mile Creek watershed (approximately 52 sq. km.) described previously. The objective was to extrapolate the methodology developed on Four Mile Creek to the Iowa River Basin to demonstrate its applicability and functionality on a large river basin. This demonstration must be viewed as preliminary due to the limited data and project resources.

The report documents the procedures and assumptions used in applying HSPF to the Iowa River Basin. The simulation results presented are indicative of the type of information produced by the model. The specific results and comparisons with observed data should not be used as a final determination of the accuracy or reliability of HSPF, however, because of the preliminary nature of this work. Moreover, the model results should not be used as a basis for planning decisions on agricultural nonpoint pollution and BMPs in the study area without additional calibration efforts and reevaluation of the underlying assumptions on which this demonstration rests. This investigation was directed to the assessment of operational problems of modeling chemical fate and transport at the river basin scale.

The development of a simulation plan involved four steps: characterize the area with regard to meteorologic conditions, soils, topography, land use, pollutant sources, etc.; segment the basin to define areas of homogenous hydrologic response; evaluate streamflow and water quality data to devise a modeling and calibration scheme; and ascertain the relative importance of various pollutant sources.

Prior to actual HSPF application to the entire basin, a limited calibration of hydrology and water quality was conducted to demonstrate sufficient agreement between model results and available data so that the model could then be used for BMP analysis and evaluation.

For the actual demonstration of HSPF, a BMP scenario similar to that exercised on the Four Mile Creek watershed, was evaluated on the Iowa River Basin, i.e., *conservation tillage plus contouring.* Table 4 shows a comparison of loadings in the Iowa River at Marengo for the 5-year simulated base conditions and BMP evaluations. Average percentage reduc-

Table 4. *Comparison of Loadings in the Iowa River at Marengo for Base Conditions and BMP Simulations*

	Year	Base	BMP	% Difference
RUNOFF (mm)	1974	183.0	170.0	-7.1
	1975	124.0	116.0	-6.4
	1976	80.0	73.9	-7.6
	1977	47.8	42.4	-11.3
	1978	299.0	280.0	-6.4
	Average	147.0	136.0	-7.5
SEDIMENT (tonnes/ha)	1974	3.91	2.62	-33.0
	1975	0.88	0.47	-47.0
	1976	0.56	0.12	-79.0
	1977	0.019	0.012	-37.0
	1978	5.69	5.49	-3.5
	Average	2.21	1.74	-21.0
SOLN. ALACHLOR (kg/ha)	1974	0.0278	0.0219	-21.0
	1975	0.0026	0.0017	-35.0
	1976	0.0008	0.0004	-50.0
	1977	0.00	0.00	-
	1978	0.0068	0.0048	-29.0
	Average	0.0076	0.0058	-24.0
SED. ALACHLOR (kg/ha)	1974	0.0032	0.0020	-38.0
	1975	0.0002	0.0001	-50.0
	1976	0.00	0.00	-
	1977	0.00	0.00	-
	1978	0.0007	0.0004	-43.0
	Average	0.0008	0.0005	-38.0
NITRATE N (kg/ha)	1974	31.0	29.8	-3.9
	1975	14.9	9.5	-36.0
	1976	9.5	6.2	-35.0
	1977	4.9	3.0	-39.0
	1978	18.5	13.1	-29.0
	Average	15.8	12.3	-22.0
AMMONIA N (kg/ha)	1974	0.48	0.41	-15.0
	1975	0.57	0.30	-47.0
	1976	0.53	0.20	-62.0
	1977	0.37	0.09	-76.0
	1978	0.91	0.46	-49.0
	Average	0.57	0.29	-49.0

tions are approximated for runoff (7.5%), sediment (21.0%), alachlor (24% and 38% for solution and sediment, respectively), nitrate (22%) and ammonia (49%).

The sediment loss reductions are somewhat less than expected. This is likely due to the fact that a significant portion of the total sediment loss is derived from the channel system itself, which would not be significantly affected by the BMPs. The zero reductions in alachlor occurred during years of extreme drought. The reductions for nitrate and ammonia were lowest in the first year of the simulation period due to the same initial nutrient storages in the soil for both the base conditions and the BMP.

As in the Four Mile Creek application, one of the possible uses of continuous modeling of chemical fate and transport is to evaluate the risk of exposure of aquatic organisms to various magnitudes and durations of chemical concentrations. Table 5 shows the reductions in the fraction of time when acute and lethal conditions exist under the simulated BMP scenario. It is interesting to note that although the BMP scenario provided substantial reductions in the peak concentrations (ranging from 9% to 41%), the absolute reductions in 1974 and 1978 were not sufficient to reduce the concentrations below the 30 ppb threshold assumed in this risk analysis. Overall, the reductions indicate a 23% reduction in the percent of time when lethal conditions occurred in the watershed.

Table 5. *Lethality Analysis of BMP Scenario for Alachlor in the Iowa River at Marengo, Iowa*

	Global Exceedance (% of time)		
	Base Conditions	BMP Scenario	% Change
Acute Region	0.49	0.49	0
Above MATC Value	3.50	2.68	-23.4
Sublethal Region (below MATC)	96.50	97.32	- 0.8

MATC - Maximum Acceptable Toxicant Concentration (0.003 mg/l used above).

Specific conclusions from this study are:

1. HSPF can be used to model the flow, sediment, and water quality from large agricultural river basins.
2. Many model parameters, primarily these related to hydrology and sediment, are calibration dependent.
3. Meteorologic data for different portions of the basin are a critical component.
4. With only minimal calibration effort, simulation of flow frequencies on the main stem of the Iowa River was fair to good in this study.
5. Sediment simulation was judged to be fair to poor due to insufficient calibration, lack of data, and model deficiencies.
6. Simulated pesticide (i.e., alachlor) loadings and concentrations were in the expected range, as generally were the simulated nitrate-nitrogen and ammonia-nitrogen concentrations.

Several needed improvements to HSPF were identified in this study:

1. Accommodation of nutrient and chemical inputs with precipitation.
2. Simulation of both ionized and unionized forms of ammonia and sediment-ammonia interactions.
3. Better definition of bed water quality and sediment processes, possibly with a layered representation.
4. Use of output of nutrient transformations as aids in calibration and analysis of model results.

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This Project Summary covers three reports, entitled:
"HSPF Parameter Adjustments to Evaluate the Effects of Agricultural Best Management Practices," (Order No. PB 83-247 171; Cost: $13.00)
"Modeling Water Quality and the Effects of Agricultural Best Management Practices in Four Mile Creek, Iowa," (Order No. PB 83-250 183; Cost: $13.00)
"Preliminary Application of HSPF to the Iowa River Basin to Model Water Quality and the Effects of Agricultural Best Management Practices," (Order No. PB 83-250 399; Cost: $13.00)
The above reports are available only from: (costs subject to change)
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